Association science and business center, "WORLD", Kraljevo, Serbia
Institute for Plant Protection and Environment, Belgrade, Serbia

12. JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE, MAK 2025 – KOPAONIK

"CLIMATE CHANGES AND ECOLOGICAL SUSTAINABILITY IN AGRICULTURE AND FOOD PRODUCTION IN SERBIA, THE REGION AND SOUTHEASTERN EUROPE"

PROCEEDINGS

Editors
Dr Danijela Šikuljak
Msci Milan Jovičić

Kopaonik, Serbia
January 30th to February 2nd, 2025.

WORLD
NAUČNO POSLOVNI CENTAR
SCIENTIFIC AND BUSINESS CENTER

ИНСТИТУТ ЗА ЗАШТИТУ БИЉА И ЖИВОТНУ СРЕДИНУ • БЕОГРАД •

Република Србија
МИНИСТАРСТВО НАУКЕ, ТЕХНОЛОШКОГ РАЗВОЈА И ИНОВАЦИЈА

12. МАК 2025

ПРИВРЕДНА КОМОРА СРБИЈЕ
1857

Нама добро а никоме зло

Publishers

Association science and business center, "WORLD", Kraljevo, Serbia
Institute for Plant Protection and Environment, Belgrade, Serbia

In cooperation
City of Kraljevo

For publishers
Dr Nenad Trkulja
Msc Marija Jovičić

Editors
Dr Danijela Šikuljak
MSci Milan Jovičić

Technical editor
Dimitrije Milić

Printing
60 exemplars

Printed by Kvark,
Kraljevo, 2025.

REVIEWERS

HONORARY COMMITTEE

Dr Jelena Begović, Minister of Science, Technological Development and Innovation, Serbia,
Dr Aleksandar Martinović, Minister of Agriculture, Forestry and Water Management, Serbia,
Danilo Golubović, Advisor to the Prime Minister of the Republic of Serbia for agriculture and EU common agricultural policy, Serbia,
Marko Čadež, President of the Serbian Chamber of Commerce, Belgrade, Serbia,
Branko Azeski, North Macedonia Chamber of Commerce, Skopje, N. Macedonia,
Prof. dr Vesna Milić, Dean of Faculty of Agriculture, University of East Sarajevo, Republic of Srpska, Bosnia and Herzegovina,
Prof. dr Božidar Milošević, Dean of Faculty of Agriculture in Lešak, University of Priština temporary settled in Kosovska Mitrovica, Kosovo and Metohija, Serbia,
Prof. dr Saša Orlović, Director of the Institut of Lowland Forestry and Environment, Serbia,
Prof. dr Mile Markoski, Dean, Faculty of Agricultural Sciences and Food, Skopje, N. Macedonia,
Prof. dr Gordana Dimitrovska, Dean, Faculty of Biotechnical Sciences, UKLO, Bitola, N. Macedonia,
Prof. dr Kapllan Sulaj, Dean, Faculty of Biotechnology and Food, Agriculture University of Tirana, Albania,
Prof. dr Muzaffer Denli, Dean, Dicle University Faculty of Agriculture, Turkey,
Prof. dr Boro Krstić, Dean, Faculty of Agriculture in Bijeljina, University of Bijeljina, Republic of Srpska, Bosnia and Herzegovina,
Dr Dejan Sokolivić, Durector, Institute for Forage Crops, Kruševac, Serbia,
Prof. dr Jonel Subotić, Director, Institute of Agricultural Economics, Belgrade, Serbia,
Prof. dr Nenad Đurić, Director, Institute for Vegetable Crops, S. Palanka, Serbia,
Prof. dr Andrea Andrejević, Rector, Educons University, S. Kamenica, Serbia,
Prof. dr Mira Pucarević, Dean, Educons University, Faculty of Environmental Protection, S. Kamenica, Serbia,
Prof. dr Anka Vojvodić, High School of Health and Sanitation of Vocational Studies "Visan", Belgrade, Serbia,
Boban Ilić, General Secretary at Standing Working Group for Regional Rural Development in Southeast Europe - SWGRRD, N. Macedonia,
Rado Savić, Mayor of Lopare Municipality, Republic of Srpska, Bosnia and Herzegovina,
Milan Damjanović, President of the Municipality of Bogatić, Serbia,
Nikola Lončar, President of the Tesla Science Foundation, NYC, USA,
Dr Predrag Terzić, Mayor of Kraljevo City, Kraljevo, Serbia,
Boban Đurović, President of the Municipality of Vrnjačka Banja, Serbia, Mahmud Al Dagistani, Serbian Cinology Association, Belgrade, Serbia,
Dijana Katica, President of the Croatian Association for Tourism and Rural Development, Zagreb, Croatia,
Prof. dr Dragan Damjanović, Serbian Royal Academy of Scientists and Artists, Belgrade, Serbia,
Slobodan Krstić, President of e-Development association, Belgrade, Serbia.

ORGANIZING COMMITTEE

SCIENTIFIC COMMITTEE

F O R E W O R D

Climate change has been recorded across the globe, with changes varying between places and between regions. Climate change impacts natural resources, biodiversity, socio-economic activities, and all sectors of agricultural food production worldwide. The anthropogenic factor additionally affects climate change and contributes to the disruption of the stability of the biosphere, warming of the oceans, melting of glaciers, the occurrence of floods, fires, erosion, degradation and pollution of soils, rivers, lakes, seas, disruption of human health, endangering the survival of plant and animal species, and increasing greenhouse gas emissions. The increase in human population, intensive urbanization and industrialization lead to the reduction of arable land, while soil degradation, high temperatures and drought negatively affect crop productivity.

Climate change and the anthropogenic factor have negative impacts on agricultural production and food security, both for the existing and the projected increase in the human population. Technological cultivation systems that generate increased greenhouse gas emissions, also increasing temperature, CO_2 levels and nitrogen deposition, are employed in order to achieve greater yields in intensive agriculture. This also leads to food contamination and food safety issues (microbial pathogens, toxic biological and toxic chemical pollutants). To ensure the safety of food production, it is necessary to improve food production, adapt to climate change and introduce measures to mitigate the impacts of climate change on agriculture. This requires continuous and joint work by scientists, farmers, politicians, and the public to develop awareness of the impacts of climate change on agriculture and the need for adaptation through the development and introduction of smart agriculture, reducing gas emissions, using water resources and fertilizers rationally, and achieving high yields, ensuring food security in the future.

These proceedings present the results of research on climate change and its impacts on socio-economic development, agricultural production, fertilization, chemical protection, phytocoenological composition, hydrological and pedological changes in agro-ecosystems, variability of genetic, morpho-physiological, biochemical properties and processes in annual and perennial crops, and their adaptive capacity.

The papers present results aimed at addressing the mitigation of the negative effects of climate change and anthropogenic effects on agricultural production on the principles of transformation of agricultural production, which includes breeding and creation of new genotypes highly adaptive to climate change and the development and introduction of smart agriculture. We would like to thank the participants of the 12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE MAK 2025 - Republic Serbia, "Climate changes and ecological sustainability in agriculture and food production in Serbia, the region and Southeastern Europe", who participated in the work and discussions to improve the balance between the negative effects of projected climate change on natural and managed ecosystems.

Prof. dr Desimir Knežević

C O N T E N T

PLENARY ARTICLES

INVITED ARTICLES AND ARTICLES

doi:10.46793/MAK2025.001K

EARLY SORTING FOR HERBICIDE RESISTANCE IN DOUBLED HAPLOIDS OF RAPESEED

Elena V. Kozar*, Elena A. Domblides

Federal State Budgetary Scientific Institution Federal Scientific Vegetable Center (FSBSI FSVC), VNIISSOK, Moscow, Russia, *koz.leno4ek@gmail.com

Abstract: Rapeseed is an herbaceous plant of the cabbage family (Brassicaceae), it is an allotetraploid (2n=38) with two genomes A and C, and it originated from an interspecific cross between *Brassica campestris* L., the donor of genome A, and *Brassica oleracea* L., the donor of genome C. Genome A has ten chromosomes and genome C has nine chromosomes (Tan et al., 2005). Rapeseed is an important oilseed crop worldwide and its production is increasing year by year.

One of the most important parameters determining the profitability of rapeseed cultivation is its yield. The yield of this crop is affected by many facts, including weed infestation of fields by weeds that compete with rapeseed for sunlight, water, soil nutrients, and physical space in the field, which is a serious problem and limits the yield of this crop, reducing it by 23-64% compared to controls without weeds (Bijanzadeh et al., 2010; Guo et al., 2020). On the other hand, the presence of weeds worsens the quality of raw material, because the presence of weed seeds among rapeseed reduces the quality of oil and complicates its processing. Development of herbicide-resistant rapeseed varieties and hybrids is a priority area of breeding as one of the most effective tools for weed control (Tan et al., 2005). Herbicides to which resistant forms of rapeseed have been developed can be divided into six groups: glufosinate, glyphosate, bromoxynil, imidazolino-nones, triazinines and sulfonylureas (Goncharov and Gorlova, 2018). Rapeseed resistant to imidazolinones, triazinines and sulfonylureas has been bred by conventional plant breeding, which is attractive for countries where GMO cultivation is prohibited. The imidazolinone group of herbicides is attractive not only because resistance has been developed without genome editing, but also because of the low toxicity of this group of herbicides to mammals and low application rates. Imidazolinone herbicides were developed in the 1980s, resistant varieties and hybrids to imidazolinones are commercialized under the brand name of the Clearfield® production system (Goncharov and Gorlova, 2018), with the abbreviation "CL" in the names of varieties and hybrids. Imidazolinones belong to one of five chemical families of herbicide inhibiting AHAS. Acetolactate synthase (ALS or AHAS) is a key enzyme for the biosynthesis of branched-chain amino acids. Five AHAS loci have been reported in oilseed rape. Three loci, AHAS2, AHAS3 and AHAS4 originate from the A genome, while two loci, AHAS1 and AHAS5 originate from the C genome (Rutledge et al., 1991). Of these, the AHAS1 and AHAS3 genes are constitutively expressed and encode the major AHAS activities required for B. napus growth and development. Mutations in these genes determine the resistance of oilseed rape to imidazolinones (BnAHAS1R (Ser653Asp), BnAHAS3R(Trp574Leu) (Kozar and Domblides, 2024). The presence of even one mutation already provides some degree of resistance of rapeseed to imidazolinones, but for industrial production it is important that the resistance is very high, so that when varying the herbicide treatment there is full confidence that rapeseed will not be damaged. In addition, forms with both mutations at the same time are preferred for commercial use because they have a synergistic effect on resistance, and it has been shown that these mutations are maximally effective in the homozygous state of the alleles. In view of these aspects, breeding for resistance to imidazolinones without the use of DH-technologies is difficult.

Since markers have been developed for the imidazolinone resistance trait in rapeseed, one obvious technique for early selection of rapeseed for resistance is to use them. However, trait genetics is

usually much more complex and in addition to the major determinant genes, there are many non-target genes that also influence the resistance trait. Because of this, marker-assisted selection has significant limitations, as it is not possible to develop markers for all possible variants of genes that provide a particular trait. Therefore, when using marker-assisted selection, it is possible that a number of resistant genotypes will not be identified, and it will not be possible to determine the degree of resistance of genotypes in comparison with each other at early stages of plant ontogenesis. On the other hand, in marker-assisted breeding there is always the difficulty that the developed markers are not always well reproducible in other laboratories.
All the problems described above can be solved by working with solid selective media under in vitro conditions. By using nutrient media with different addition of herbicides in the nutrient medium, all resistant forms will be identified, and by using several concentrations in one experiment on resistance assessment, it is possible to determine the degree of resistance of genotypes under in vitro conditions in comparison with each other. In our work, we used MS medium (Murashige and Skoog, 1962) with the addition of the following concentrations of imazomox: 2.5 mg L^{-1}, 7.5 mg L^{-1}, 25 mg L^{-1} and 37.5 mg L^{-1}. Microshoots of doubled haploids propagated microclonally so that there were several microshoots per nutrient medium variant were used in the experiment. The experiment was conducted in the presence of susceptibility and resistance controls to imidazolinone group herbicides, and resistance was evaluated two weeks after transplanting plants to imozamox media. The results of the experiment showed that at a concentration of 2.5 mg L^{-1}, the susceptibility control died, while at a concentration of 7.5 mg L^{-1} imazamox in MS solid nutrient medium, the resistance control survived, but the first signs of herbicide damage were visible. Medium supplemented with 25 mg L^{-1} imazamox allowed selection of plants with greater resistance than the resistant control. At a concentration of 37.5 mg L^{-1} plants did not survive. Thus, for the selection of resistant rape genotypes we recommend the medium with the addition of 7.5 mg L^{-1} imazamox. The system of selection of plants for resistance using selective media is very simple in technical execution and gives a great advantage in assessing the degree of resistance of each genotype at early stages, and each genotype due to parallel cultivation on media without the addition of herbicides, if necessary, is always saved for further experiments or breeding work.

Key words: DH-plants, Herbicide, Imidazolinone, Clearfield®, Oilseed rap

ACKNOWLEDGMENT

The work was funded by a grant from the Russian Science Foundation, grant number 23-76-01070, https://rscf.ru/project/23-76-01070/.

REFERENCES

Bijanzadeh, E., Naderi, R., Behpoori, A. (2010). Interrelationships between oilseed rape yield and weeds population under herbicides application. Australian journal of crop science, 4(3), 155-162.
Goncharov, S.V., Gorlova, L.A. (2018). Herbicide tolerance in rapeseed breeding: results and prospects. Oil crops.
Guo, Y., Cheng, L., Long, W., Gao, J., Zhang, J., Chen, S., ... Hu, M. (2020). Synergistic mutations of two rapeseed AHAS genes confer high resistance to sulfonylurea herbicides for weed control. Theoretical and Applied Genetics, 133, 2811-2824.
Kozar, E.V., Domblides, E.A. (2024). Imidazolinone Resistance in Oilseed Rape (*Brassica napus* L.): Current Status, Breeding, Molecular Markers and Prospects for Application in Hybrid Seed Purity Improvement. Horticulturae, 10(6), 553.
Murashige, T., Skoog, F. (1962). A revised medium for rapid growth and bioassays with tobacco tissue cultures. Physiologia plantarum, 15(3).
Rutledge, R.G., Quellet, T., Hattori, J., Miki, B.L. (1991). Molecular characterization and genetic origin of the Brassica napus acetohydroxyacid synthase multigene family. Molecular and General Genetics MGG, 229, 31-40.
Tan, S., Evans, R.R., Dahmer, M.L., Singh, B.K., Shaner, D.L. (2005). Imidazolinone-tolerant crops: history, current status and future. Pest Management Science: Formerly Pesticide Science, 61(3), 246-257.
Thelen, J.J., Ohlrogge, J.B. (2002). Metabolic engineering of fatty acid biosynthesis in plants. Metabolic engineering, 4(1), 12-21.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.003Y

SMART TECHNOLOGIES AND CLIMATE RISKS: INNOVATIONS AND TECHNOLOGIES TO SUPPORT CLIMATE RISK MANAGEMENT ON ECOSYSTEMS AND AGRICULTURE

Neşe Yaman[1*], Isam Mohammed Abdulhameed[2]

[1]Dicle University, Faculty of Agriculture, Dept. of Farm Structures and Irrigation, Diyarbakir Türkiye, *nesheuzen@hotmail.com
[2]Upper Euphrates Basin Developing Centre, University of Anbar, Iraq

Abstract: Climate change is destroying markets by reducing agricultural incomes and increasing risk. It poses a threat to many areas, especially access to food for both rural and urban populations. According to research estimates, climate change problems will affect poor and underdeveloped countries the most, and mass migrations will occur accordingly. is expected to occur. However, these estimates have now gone beyond mere predictions. Because these migrations have been intensely experienced as a reality for the last 10 years. This fact was revealed by the 2012 Report of the Asian Development Bank. According to the report, 20 million people in Asian and Pacific countries were forced to leave their home regions due to climate change between 2009 and 2011. According to this report and research, in the coming years, increasing drought and scarcity of water resources will reduce the number of plant species used in the production of nutrients and medicines necessary for human life. As the tropical climate shifts northward, plant and animal species are expected to shift. Diseases such as malaria, known as tropical diseases, will become widespread. Studies have estimated that due to all these problems, the number of "**climate refugees**" will exceed 20 million by 2050. This article describes the effects of smart agricultural technologies on physical yield losses in agriculture due to climate change and the reduction of indirect negative effects of these losses.

Key words: Agriculture, Smart technologies, Climate change, Ecosystems, Management

1. INTRODUCTION

In order to ensure that agricultural production is minimally damaged by climate change and at least to maintain production at its previous level and prevent its decline, new and smart agricultural technologies must be developed. In addition, existing smart agricultural applications must be put into practice without delay. One of the primary methods in combating the effects of **climate change on agriculture is "emission** and pollutant **reduction practices."** These methods are used to reduce greenhouse gas emissions. Because agriculture, like other industries, is still a source of greenhouse gases due to the use of outdated agricultural management methods.

The annual average of anthropogenic greenhouse gas emissions into the atmosphere due to agricultural activities is between 10% and 12%. For example, according to the Turkish Statistical Institute (TUIK) data, 10.2% of total greenhouse gas emissions in Türkiye in 2014 were caused by agricultural activities. To reduce these emissions, new and smart agricultural practices such as the Internet of Things and the widespread use of connectable individual mobile devices have been introduced.

The Internet of Things (IoT), farmers can monitor and control all processes from planting to harvesting via their smartphones or computers at home. Environmental factors and **energy** Thanks to these technologies that measure and respond to the use of greenhouse gas emissions can be significantly reduced. The benefits obtained through these technologies are as follows:

• Energy efficiency is maximized with smart energy systems compatible with individual mobile phones. Thus, farmers save both energy and money. In this way, input costs are significantly reduced. Using less energy is considered one of the "reduction" methods in the fight against climate change.
• Farmers can efficiently plan the routes of tractors, trucks and transport vehicles they use in agriculture with their smart phones. For example, a transport vehicle is not sent on the road half-full or overloaded, which will increase fuel consumption. Transport vehicles that set off at the right time with the most accurate loading use the shortest distance. In this way, greenhouse gas emissions that are harmful to the environment are reduced. Farmers save both time and expensive diesel and gasoline.
• Farmers can use **Smart Irrigation Systems from their mobile phones.** In this way, they can make better decisions about water usage and do not consume water resources unnecessarily. Since farmers do not use water unnecessarily, they can save on water costs and reduce agricultural inputs.

Smart agricultural applications also increase the energy efficiency of tractors. Today, GPS navigation systems are used in tractors, just like in cars, and this system is made compatible with smart mobile phones. These smart systems help the tractor to be used more effectively and to maintain it regularly. For example, filter cleaning or replacement is done on time, thus preventing additional costs caused by malfunctions. Since remote connection can be established with a smart mobile phone, the tractor is prevented from idling for long periods of time. Moreover, the tractor is operated in accordance with the load required by agricultural work. All these small precautions prevent the release of additional greenhouse gases into the atmosphere.

Spraying machines are also used more efficiently with systems compatible with smart phones. Sensors placed in the fields identify diseased areas and separate areas to be sprayed and those not to be sprayed. After this, a field map is created via GPS and the path to be followed by the tractor with the spraying machine is determined so that precise spraying can be done. The sensor application makes the spraying machine smart by programming it to spray the pesticide when it sees the diseased area. This system also reduces greenhouse gas emissions, saving both pesticide and fuel. As a result, smart agricultural applications that are compatible with individual mobile phones both increase farmer welfare and improve product quality. Moreover, by reducing negative environmental impacts, it ensures that agriculture is transferred to future generations in a sustainable way.

The transfer of environmentally sound technologies (ESTs) is recognized worldwide as one of the most effective ways to combat climate change. These technologies contribute to our fight against climate change by reducing emissions and increasing our resilience to climate change. As Türkiye plans to achieve its recently announced zero carbon target by 2053, this set of analyses aims to raise the necessary awareness on the transfer of ETSs and to provide recommendations on legal regulations and implementation.

Climate change is one of the most pressing problems of the last half century. The main driver of climate change is the high concentration of greenhouse gases in the atmosphere, which is causing temperatures to rise and has serious negative effects on all ecosystems. The key question is how to combat it on a global scale.

2. CLIMATE CHANGE AND URBAN TRANSPORTATION SYSTEMS

The transportation sector accounts for 16.2% of energy-related greenhouse gas emissions in the global climate change impact and is the fastest growing factor (Our World in Data, 2020). EU and OECD countries are the fastest growing contributors to CO_2 it is responsible for approximately 30% of emissions and in some developed countries this rate can reach 40%. In Türkiye, this rate is around 18% (Civelekoğlu and Bıyık, 2018). Climate actions generally consist of two strategies: the implementation of a reduction strategy to reduce or eliminate greenhouse gas emissions in the atmosphere and adaptation strategies to develop societies to withstand the effects of climate change (World Resources Institute, 2020). Intelligent transportation systems are shown as an alternative to reduce the impact of transportation systems on climate change on cities. Intelligent transportation systems make a one-to-one contribution to the smart city model (Jurak et al., 2018) and intelligent transportation systems are, above all, sustainable mobility (Battarra et al., 2018). There are many vehicles and operating systems that define intelligent transportation systems. The most used of these in cities are vehicles using electrical energy. Electric vehicles offer advantages such as energy efficiency, energy recovery, quiet operation and reduction of noise pollution compared to fossil fuel vehicles (Özbay et al., 2020). Electric vehicles emit less greenhouse gases.

Instead of individual vehicles actively used in the city, the use of electric vehicles and public transportation vehicles, and to put it more simply, electric bicycles or shared bicycles should be increased. Examples of studies that increase energy efficiency and reduce carbon emissions in transportation systems are: arranging the rates of highways, railways, airways and sea transportation and choosing efficient transportation types, developing the engine technologies of motor vehicles and increasing efficiency standards, and switching to alternative energy-based vehicles (Ünal and Polat, 2023). One of the most important features of electric trains is that they are environmentally friendly. The amount of carbon emitted into the atmosphere during the production of electricity in electric trains is 20-35% less than trains using diesel fuel (Ünal and Polat, 2023).

Bicycle sharing systems (BPS) are becoming one of the fastest growing transportation types worldwide, and the high rate of use of electric bicycles has been particularly striking in this growth. There are 3 types of car sharing seen in the world: In the first model, individuals share their cars with individuals going in the same direction or individuals accompany individuals who have cars, in the second model, a company car is rented by many individuals and shared, and the third model is peer-to-peer car sharing, which is a newly emerging rental type in Türkiye.

The first Industrial Revolution took place at the beginning of the 18th century. Mechanical looms that used waterpower were discovered, and steam power began to be used more and more. Later, in 1870, the second industrial revolution began with the use of the first production line that operated with electricity and performed mass production (assembly line). The third industrial revolution began in 1969. The first Programmable Logic Controller (PLC) began to be used in electronics and informatics to automate manufacturing (KPGM, 2015). The 4th Industrial Revolution/Industry 4.0 emerged in industry in general when machines began to manage themselves and their production processes without the need for human power. Machines owe their high-level and up-to-date structures to the hybrid technology that emerged by blending computer, communication and internet technologies (EBSO, 2015). According to Boston Consulting Group, one of the world's leading management consulting companies, the (digital) technologies that triggered industry 4.0 are: Internet of Things, big data analytics, artificial intelligence and machine learning, intelligent and human-operable robots, cloud computing, horizontal and vertical software integration, simulation, augmented reality, 3-dimensional software (additive manufacturing), cyber security. Sensors unmanned aerial vehicles, genetic and block chain technologies can also be added to these. (Coşkunoğlu, 2016). These technologies are also described as the most used concepts to define industry 4.0.

3. SMART AGRICULTURE AND ITS FEATURES

It is the result of the process that the agricultural sector has gone through in recent years depending on the general socio-economic and technological developments and their effects on the environmental balance, that the old/traditional agricultural model is under pressure from four main developments that increase the problem of hunger and food scarcity in meeting the demands of the future: demographic characteristics, scarcity of natural resources, climate change and food waste (Wyman, 2018). It is not possible to remove this pressure and increase production with the traditional methods used from the past to the present. Therefore, it is necessary to increase efficiency by utilizing technology. The most up-to-date and modern way to do this is to produce with smart agriculture (Think Tech, 2019). While the adventure of humanity in production, which started with its own power, evolved into the power of the machine with the industrial revolutions, a technological transformation is envisaged in the last series of the industrial revolution that will allow the control and management of production to be transferred to machines. Technological transformation in every field of production has also been experienced in agriculture. In fact, a technological transformation like the stages of the industrial revolution has been experienced in agriculture from the beginning of the 20th century to agriculture 4.0. (ITB, 2019).

Table 1. Technological Transformation in Agriculture (Kaya, 2019)

Before	Traditional Agriculture	Human and Animal Labor
Agriculture 1.0 (early 20th century)	The Beginning of Water and Steam Power	Mechanization
Agriculture 2.0/Green Revolution (1950)	Mass Production, Electricity	Tractor production
Agriculture 3.0/Precision Agriculture (1990)	Computer and Automation	Greenhouse and irrigation automation
Agriculture 4.0/Digital Agriculture (2010)	Information and Communication Technologies	Smart Agriculture

Technology is leading the way in agriculture as it is in every sector. In order to solve problems such as drought due to global warming in agriculture, the use of 70% of the world's fresh water (less than 3% of the world's water) in agriculture and the inadequacy of production that does not meet the demand despite the use of all agricultural lands, and to feed nine billion people in 2050, it will be necessary to increase the yield per unit area approximately two-fold. It will be possible to get rid of this negative situation in agriculture by being inspired by the hope that technology creates in every area of life and by adapting the digital technologies of this age, such as Mass Production, Electricity, Mechanization, Tractor, Computer and Automation, to agriculture (Yıldırım, 2016). In fact, according to the European Agricultural Machinery Association (CEMA), smart agriculture ranks first among the most important factors affecting agricultural practices and structures (smart agriculture, automation, consolidation, professionalism and labor shortage) with 60%. With the fusion of agricultural and information technologies, many new technical terms have begun to be heard in daily life. Examples of these terms include smart agriculture, precision agriculture, digital agriculture, farm management software and driverless (autonomous) vehicles. The most common use is smart agriculture; It includes an advanced system approach that combines control, electronics, computers, database and accounting information. The components of this technology include basic systems such as global positioning systems, geographic information systems, variable rate input application and remote sensing (Demir, 2019). Smart agriculture is information-based agricultural production, the philosophy of which is to produce by managing the heterogeneity of nature. The form of this philosophy is to apply the right amount of input to the right place, at the right time, with the right method. This philosophy is supported by smart agricultural technologies (Tekin, 2018). According to the Smart Agriculture Platform, smart agriculture is a technique that provides soil and product management to increase agricultural productivity, more economical use of resources and minimizes environmental damage. In short, it can be expressed as the application of digital technologies to the agricultural sector or the digital revolution in agriculture. Thanks to the technologies that form smart systems, agricultural vehicles and agricultural fields are equipped with sensors and detectors, and agricultural vehicles are able to communicate with each other. Thanks to the sensors, humidity, vegetation, temperature, steam and air conditions can be measured, plant species can be distinguished with remote sensing, stress conditions, drought, soil and plant conditions are monitored, data is collected and analyzed (Saygılı et al., 2018).

4. USE OF SMART TECHNOLOGIES IN WORLD AGRICULTURE

The benefits of smart agricultural systems, which can be used at every stage of agricultural activities, primarily include creating the conditions for sustainable production, and can be listed as follows (Smart Agriculture Platform, 2019):

✓ Reducing chemical input costs such as fertilizers and medicines,

✓ Providing high quality products in high quantities,

✓ Ensuring a more effective flow of information for business and farming decisions

✓ Establishing a registration system in agriculture can be considered.

In addition, producers will be able to make real-time production performance assessments with these systems and analyze all their products and resources in detail. With the widespread use of the Internet of Things in agriculture, productivity will also increase significantly. In this way, it is aimed to make the work of producers easier and to maximize efficiency compared to traditional methods (Demir, 2019). The difficulties/problems in meeting global food needs with the current agricultural production model have accelerated the establishment and spread of the technology-intensive production model in agriculture. According to the "Smart Agriculture Market Research" conducted by Huawei in 2017, the value of the global smart agriculture market, which was 13.7 billion dollars in 2015, is expected to increase to 26.8 billion dollars in 2020. Accordingly, the smart agriculture market is expected to double in value within 5 years. According to the (CEMA) "Agriculture 4.0: The Future of Agriculture Report", in Europe, Precision Agriculture (PA) and the integration of digital technology are becoming the most influential trends in the sector, as more and more farmers start using digital technologies to run their businesses. For the machinery industry in Europe, 70 to 80% of new farm equipment sold has some form of PA component technology in it. There are 4.500 manufacturers producing 450 different types of machinery with an annual turnover of 26 billion Euros. This sector also employs 135,000 people (ITB, 2019).

The Netherlands and Israel, which are pioneers in the agricultural sector, have adopted Agriculture 4.0 applications more quickly than other countries. In addition to these countries, Taiwan's significant efforts in line with Agriculture 4.0 have brought about significant changes (Kılavuz and Erdem, 2019). The Netherlands, which is considered a model for many countries in the world in agriculture and is shown as a reference in agricultural matters (Tektaş, 2013):

✓ Collaboration models: studies conducted by universities, research institutions, food producers and technology producing companies in the field of agricultural technology.

✓ The world's 4th IT services exporter: 70% of innovations are related to IT technologies,

✓ Production and export of agricultural technologies: With the value of agricultural technology exports being 9 billion Euros in 2015, it has become the most important country in the world in agricultural technologies.

Thanks to these factors (such as planning, education, continuity), the Netherlands, which has the smallest and most densely populated population in Europe, has an agricultural area of one-seventh of Türkiye's surface area, but its agricultural exports are at the level of 90 billion dollars (Boztepe, 2018). Likewise, Israel is another miraculous example. Despite the fact that only 20% of its land is arable due to its high salt content, its natural water resources are below the United Nations' water poverty line, and the agricultural workforce is quite small, it is now able to meet 95% of its food needs with its own production thanks to its successes in the field of agricultural technologies (ITB, 2019).

Smart Agriculture Studies in Türkiye in addition to the changes that agriculture has experienced within itself in this long process, it can be accepted that many issues such as policies, increasing population, urbanization, migration, economic development, technological advancement, etc. affect the functioning of the sector as much as its structure (Kalaycı and Kaya, 2019). Türkiye has a rich agricultural potential in terms of its geographical location, climate structure and product diversity. However, the fact that production is not recorded, producer organizations are not sufficiently active, unstable agricultural policies and unplanned production models cause significant problems in the sector. Failure to adopt a planned production model suitable for domestic and foreign demand creates a surplus in some products and causes producer prices to fall, while a supply deficit in some products causes this deficit to be closed through imports (UİS, 2016). Although there are adaptation difficulties in different countries regarding smart agriculture, it should be known that the way to prevent losses/decline in agriculture will be through this innovation in agriculture.

Because it is obvious that the success of these countries, especially the Netherlands and Israel, is based on technology. When we look at the share of Information and Communication Technologies (ICT) products in their total exports and imports, it is seen that countries that have adapted to the Agriculture 4.0 process have high values in both exports and imports of these products. These countries have been able to increase their productivity with technology (ITB, 2019).
Agricultural technologies are generally produced by non-agricultural sectors. Serious breakthroughs have been made in the world in the production and use of many different mechanical technologies, from soil processing tools to harvesting machines, and the ratio of exports to imports has increased. (UIB, 2017).

Moreover, according to Öğüt (2015), as a result of the interpretation of yield maps, it is possible to save 25% in fertilizer and 20% in herbicide use, and the research results show that a profit of 30 dollars per hectare is important in addition to the profit to be provided in terms of environmental impact with precision agriculture technologies in the world. The economic evaluations show that an area of 160 hectares is sufficient for the return of the costs of variable rate application systems.

On the other hand, the most important factor in the adoption of new technologies in the agricultural sector is the income level of the producers. While the size of the business affects productivity, it also affects the adoption and use of new technologies. Low labor productivity in small-scale family businesses also affects the income level. This situation delays the adoption and use of new technologies. However, the education level of the producer sometimes positively affects the use of new technologies even in small businesses (UIB, 2017).

The steps to be taken for this technological transformation in agriculture can be realized with the cooperation of all stakeholders in a sector consisting of producers (farmers), private sector (manufacturers, technology suppliers), unions and cooperatives, public and universities. As a matter of fact, it is possible to see the cooperation of these stakeholders in some studies on this subject: (ITB, 2019). For example, the Vodafone Smart Village, established in Aydın province with the aim of supporting rural development in partnership with Vodafone Türkiye and TABİT (Agricultural Information and Communication Technologies), is rapidly progressing towards becoming the first smart village in the world and Türkiye equipped with end-to-end digital technologies. The main objectives of the Vodafone Smart Village, where traditional agricultural methods are combined with advanced technology, are to increase the efficiency in agricultural production with information and technologies, to increase young employment in agriculture, and to ensure that technology is spread to other villages. Savings of at least 20% in plant production costs, 22% in animal production costs, and 20% in irrigation are targeted.

Studies in this field have started to increase with national and international collaborations, including Ege University, Boğaziçi University, Ankara University and Konya Food and Agriculture University. The "Global Integration of Turkish Agriculture: Agriculture 4.0" project, carried out in partnership with Ege University Faculty of Economics and Administrative Sciences and Izmir Commodity Exchange, is one of the studies carried out in this field. However, today, the agricultural sector is undergoing a major transformation under the influence of developing technology, and the future of the agricultural sector is now being shaped by technological applications. In fact, the technological transformation of agriculture dates back to the beginning of the 20th century. The most basic feature of the period in which the first transformation, called Agriculture 1.0, took place was that it had a labor-intensive production method with low productivity. During this period, one-third of society actively worked on many small farms and participated in the production of basic agricultural products, and the food needs of the society were met at a sufficient level. By the end of the 1950s, synthetic pesticides, fertilizers and more effective machines reduced production costs, and thus the Agriculture 2.0 period, called the Green Revolution, was entered. Productivity increased thanks to cheap inputs and new vehicles. The Agriculture 3.0 process, which began in the 1990s with the opening of GPS signals to everyone's use, is now more commonly called Precision Agriculture. Manual steering thanks to GPS technology, VRA (Variable Rate Application) systems applied to harvesters, and especially monitoring the fertilization process are the main technologies applied during this period. Precision farming methods, tracking and solutions specific to each parcel of land or each animal in the herd are offered, production costs are reduced, and the process is managed more effectively. In the 2010s, a parallel process like the revolution experienced in the industry with Industry 4.0 began to be experienced in the agricultural sector. This process is given names such as "Agriculture 4.0, Smart Agriculture, Digital Agriculture" and generally refers to the application of smart technologies including sensors, detectors, microprocessors, autonomous decision systems, cloud-based information and communication technologies in the agricultural sector. Thanks to internet-based portals and various algorithms, big data is stored and analyzed, and the entire process from field to table can be monitored, directed, and future projections can be made. Agriculture 4.0 also reveals the cooperation of different actors in the agricultural and food value chain, and therefore the importance of the ecosystem. Agriculture 4.0 applications create important and effective tools to make the agricultural sector more efficient, competitive, environmentally friendly, and sustainable. Technologies used in Agriculture 4.0; It covers the activities of different actors working in the agricultural sector, namely suppliers, producers, growers, intermediaries and technology providers. With the internet of things, big data and smart algorithms, the activities of all these actors can be brought together.

With the adaptation of technology to the agricultural sector, agricultural vehicles and agricultural fields are equipped with sensors and detectors, and agricultural vehicles are enabled to communicate with each other. Thanks to sensors, humidity, vegetation, temperature, steam and air conditions can be measured, plant species can be distinguished with remote sensing, stress conditions, drought, soil and plant conditions are monitored, data is collected and analyzed. Images taken from satellites are processed and combined with data taken from sensors. All agricultural fields can be observed with cloud-connected unmanned aerial vehicles and the information obtained can be followed with smart devices. With the use of GPS technology, a navigation system that allows users to record location information accurately, farmers can find the exact location of field features such as soil type, insect formation, weed presence, borders and obstacles in the agricultural sector. With the accurate determination of these locations, seeds, fertilizers, pesticides and water required for irrigation can be used more effectively according to field features. With this technology, it is possible to create a geographic information system by using digital information in different areas, map the field in terms of yield, soil and quality, and determine the delivery rates of agricultural inputs depending on the soil type. In addition, robots and artificial intelligence are used in the agricultural sector, as in other industries, and more products can be grown faster and healthier. For example, robots used in spraying and weed control reduce chemicals in agricultural production by 90%. Robots also reduce losses in harvesting products, increase speed, and reduce costs.

In addition to these technologies that form the basis of smart systems, all stages of agricultural production can be monitored with information-based farm management systems, from the transportation of resources to the farm to the output of the product (from field to table). There is also a monitoring and sensor system (RFID sensor and tracking) that allows consumers to track the process of the product they buy from the field to the point of purchase. Thanks to this system, the responsibilities of producers to produce safe food are increasing. In this context, Israel is perhaps the most striking example of a successful country. It has managed to turn all disadvantages into advantages thanks to the technologies it has developed and implemented. In addition to exporting approximately 2 billion dollars' worth of vegetables and fruits each year, it also exports the fertilizers and agricultural technologies it produces to many countries. Israel, which has been able to reach self-sufficiency in agricultural production from a disadvantaged position and even exhibit a successful export performance, has prioritized the reclamation of arable lands. In this way, it realizes 66% of its vegetable and fruit exports from seven farms it has established in the desert, 150 meters below sea level. Although it only cultivates in the upper 30 centimeters of soil due to the desert nature of its land, it obtains high yields from its production and exports 90% of its products. In addition, Israel has solved the irrigation problem by purifying and reusing saltwater and industrial wastewater. 86% of the water used in irrigation in the country is provided by recycled water. Each solar panel installed can purify 3.000 liters of salt water with the daily electricity produced. The temperature can also be kept under control for 12 months with pipes laid underground. Many companies that produce fertilizer using various technologies have been established, including the Israel Chemical Company, one of the world's largest fertilizer companies. One of Israel's leading seed companies is trying to increase product efficiency with research and development studies in plant genetics and biotechnology. Another commercial company provides real-time information to producers about both the health status of animals and the quality of milk with the technology it has developed. Another company uses X-rays with the spectral imaging machine it produces to provide information about the nutritional value, maturity, quality of the fruit and even when it will ripen. With this machine, the company can detect in advance a type of mold fungus found in dates, which is the biggest obstacle to the date trade it makes to Arab countries and help prevent exports by intervening. The Israeli government supports agricultural technologies, especially those related to irrigation systems, biotechnology and wastewater reuse. In fact, research and development expenditures in the field of agricultural technologies constitute 17% of Israel's budget. New technological enterprises in the field of agricultural technology have a great impact on the transformation of the difficult conditions of Israel's agricultural sector.

5. CONCLUSION

In the 21st century, rapidly developing technology with robotic devices, remote sensing and remote-control systems; It has started to be used in many sectors such as agriculture and industry. The smart agriculture revolution brought about by developing technology has actually become a necessity, not a choice, today. Thanks to the digital monitoring methods that have entered our lives with Industry 4.0, data collected by systems such as satellites, cameras and sensors can be interpreted using various algorithms, cause and effect relationships can be reported, and appropriate data can be transmitted as instant information from mobile phones. Agricultural equipment such as autonomous tractors or planters saves time and labor. It can work 24 hours a day because no human labor is used. With harvesting machines, human-caused heterogeneous product harvesting is eliminated. In addition, animal damage is prevented by using laser scarecrows in agricultural lands where various animals may be damaged before harvest. By controlling it from mobile phones, excess irrigation water and energy usage in lands irrigated with modern irrigation systems can be prevented. In addition to these benefits, the biggest benefit is to the environment. By reducing emission amounts, easy adaptation can be developed while reducing the effects of climate change.

However, it should not be forgotten that agricultural practices are technical, economic and social activities. Particular emphasis should be placed on training and demonstration studies to adapt traditional producers to new practices. In addition, governments need to provide economic and technical support for these innovative applications to become widespread.

6. REFERENCES

Akıllı Tarım Platformu (2019). Current Status Report of Smart Agriculture in Turkey (Türkiye'de Akıllı Tarımın Mevcut Durum Raporu), Ankara. /in Turkish/

Battarra, R., Gargiulo, C., Tremiterra, M.R., Zucaro, F. (2018). Smart mobility in Italian metropolitan cities: A comparative analysis through indicators and actions. Sustainable Cities and Society, 41, 556-567. doi.org/10.1016/j.scs.2018.06.006

Boztepe, K. (2018). Even Before Lausanne was Signed, the Entire Country Was Like a Construction Site (Daha Lozan İmzalanmadan Koskoca Ülke Şantiye Alanı Gibiydi), www.butundunya.com/pdfs/2018/03/011-016.pdf, 25.12.2024. /in Turkish/

Civelekoğlu, G., Bıyık, Y. (2018). Examining the carbon footprint change caused by the transportation sector (Ulaşım sektöründen kaynaklı karbon ayak izi değişiminin incelenmesi). Bilge International Journal of Science and Technology Research, 2(2), 157-166, Eskişehir, doi: 10.30516/ bilgesci.427359 /in Turkish/

Coşkunoğlu, O. (2016). Industry 4.0: A Techno-Political Assessment (Endüstri 4.0: Bir Tekno-Politik Değerlendirme) Elektrik Mühendisliği, Aralık 459, 8-13. /in Turkish/

Demir, N. (2019). Digitalization in agriculture (Tarımda Dijitalleşme), Anahtar, sayı 371. /in Turkish/

EBSO (2015). Industry 4.0 Those Who Don't Adapt Will Lose Prepare for Beyond the Information Age (Sanayi 4.0 Uyum Sağlamayan Kaybedecek Bilgi Çağının Ötesine Hazırlanın), Eğe Sanayi ve Ticaret Odası Araştırma Müdürlüğü.

İTB (2019). Global Integration of Turkish Agriculture and Agriculture 4.0 (Türk Tarımının Global Entegrasyonu ve Tarım 4.0), İzmir Ticaret Borsası. ISBN 978-605-137-710-0 /in Turkish/

Jurak, J., Brcic, D., Slavulj, M., Šojat, D. (2018). The role of smart mobility in smart cities, 1601-1606. 10.5592/ CO/CETRA.2018.812

Kalaycı, İ., Kaya, M.(2019).Türkiye'de Tarımsal Üretimin Artışı İçin Strateji: Üretim Planlaması, Eds. İsmet Yılmaz, Ekrem Akbulut, Faruk Serin, Uluslararası Bölgesel Kalkınma Konferansı, 26-28 Eylül, Malatya,134-150. /in Turkish/

Kaya, M. (2019). Smart Agriculture (Agriculture 4.0) Proposal for the Development of Ağrı Province (Ağrı'nın Kalkınması için Akıllı Tarım (Tarım 4.0) Önerisi), Akademik bakış Dergisi Sayı: 75, 130-156. /in Turkish/

KPGM (2015). Industry 4.0 The Fourth Industrial Revolution, What Do Tomorrow's Factories Look Like? (Sanayi 4.0 Dördüncü Sanayi Devrimi, Yarının Fabrikaları Neye Benziyor?) https://home.kpmg/content/dam/kpmg/tr/pdf/2016/08/tr-sanayi-4.PDF,12.10.2019 /in Turkish/

Our World in Data (2020). Sector by sector: where do global greenhouse gas emissions come from? https://ourwor ldindata.org/ghg-emissions-by-sector (21.11.2024).

Öğüt, H. (2015). The Meeting Point of Agriculture and Advanced Technology: Precision Agriculture (Tarımın İleri Teknoloji İle Buluşma Noktası: Hassas Tarım), 38-41. /in Turkish/

Özbay, H., Közkurt, C., Dalcalı, A., Tektaş, M. (2020). Transportation Choice of the Future: Electric Vehicles (Geleceğin Ulaşım Tercihi: Elektrikli Araçlar). Akıllı Ulaşım Sistemleri ve Uygulamaları Dergisi, 3(1), 34-50. https://dergipark.org.tr/en/pub/jitsa/ issue/53369/712337 /in Turkish/

Saygılı, F., Kaya, A.A., Çalışkan, E.T., Kozal, E.Ö. (2018). Global Integration of Turkish Agriculture and Agriculture 4.0 (Türk Tarımın Global Entegrasyonu ve Tarım 4.0) İzmir Ticaret Borsası. /in Turkish/

UİB (2017). The Place, Importance, Power, Future of Agriculture and Organic Agriculture in Türkiye's Exports and the Problems Encountered by the Agricultural Sector in Exports. Ways to Improve the Sector (Tarımın Ve Organik Tarımın Türkiye İhracatındaki Yeri, Önemi, Gücü, Geleceği Ve Tarım Sektörünün İhracatta Karşılaştığı Problemler Sektörü Geliştirmenin Yolları), Uludağ İhracatçılar Birliğ Ar- Ge Şubesi. /in Turkish/

UİS (2016). The sector of Agriculture (Tarım Sektörü) - Ulusal İstihdam Stratejisi. /in Turkish/ www.uis.gov.tr/media/ 1430/tar%C4%B1m.docx, 2911.2024

Ünal, E., Polat, E. (2022). Climate Change and Smart Transportation Technologies. 6TH International Congress on Life, Social, and Health Sciences in a Changing World Proceedings Book, 189-195. ISBN: 978-605-71461-9-9. /in Turkish/

Tekin, A.B. (2018). The Future of Agricultural Production: Smart Agriculture (Tarımsal Üretimin Geleceği: Akıllı Tarım), TÜRKTOB Dergisi, 26, 26-27. /in Turkish/

Tektaş, A. (2013). Agriculture and Technology Agriculture 4.0 general trends (Tarım ve Teknoloji Tarım 4.0 genel eğilimler) file:///C:/Users/hp /Downloads/1186, arzu-tektaspdf%20(9).PDF,03.12.2024. /in Turkish/

Think Tech (2019). Smart Agriculture Revolution (Akıllı Tarım Devrimi), https://thinktech.stm.com.tr/detay.aspx ?id=216 ,(05.11.2024). /in Turkish/

World Resources Institute (WRI) (2020). Strategies that achieve climate mitigation and adaptation simultaneously. www.wri.org/insights/5-strategies-achieve-climate-mitigation-and-adaptation-simultaneously (30.10.2024).

Wyman, O. (2018). Agriculture 4.0: The future of farming technology, world government summıt.

Yıldırım, A.E. (2016). Digital transformation in agriculture (Tarımda dijital dönüşüm), www.dunya.com/kose-yazisi/tarimdadijital-donusum/332214 (in Turkish)

doi:10.46793/MAK2025.012T

ECO-INNOVATIVE SOLUTIONS FOR CLIMATE-SMART AGRICULTURE AND FOOD PRODUCTION

Mladen Todorović

CIHEAM - Mediterranean agronomic Instutute of Bari, Italy
mladen@iamb.it

Abstract: The EU Green Deal plan emphasized the relevance of Farm to Fork and Biodiversity Strategies in the agricultural sector. This paper focusses on some important aspects of the above strategies and management solutions to be implemented on the road of adaptation and mitigation of climate change impacts and promotion of resilient and climate-smart agriculture and food production in the Western Balkans. The emphasis is given to the eco-efficiency concept in the valorization of agri-food production's chain, adoption of organic farming practices and climate-smart management solutions.

Key words: Agrifood systems, Climate change, Eco-schemes, Organic farming, Eco-efficiency

1. INTRODUCTION

Every year, the global food system generates revenues between 15 and 19 trillion USD which corresponds to a range of 16-20% of the global Gross Domestic Product (GDP) (Planet Tracker, 2023). It includes the whole food value chain from the input providers (agricultural chemicals and machinery manufacturing), arable producers - farmers, livestock, dairy and seafood producers, through the food and beverages producers, traders and distributors and ending with the retailers, food service and waste companies. The global food system is controlled by very few companies (0.06%) which generates up to 70% of revenues.

Agrifood systems account for about 33% of total anthropogenic greenhouse gas (GHG) emissions (Crippa et al., 2021; Tubiello et al., 2021). They are generated within the farm gate, by crop and livestock production activities; by land-use change (for instance deforestation and peatland drainage); and in pre- and post-production processes, such as food manufacturing, retail, household consumption and food disposal (Tubiello et al., 2022; FAO, 2023). Globally, in 2020, the farm gate emissions represented nearly 50% of total agrifood systems emissions, pre- and post-production processes contributed about 30% and land-use change around 20%.

The World Bank (2023) estimated that the food system generates 2 to 5 times as much value as farm production itself. This (post-farm to farm) ratio varies around the globe, and it is much higher in developed in respect to developing countries. For example, in USA, for every USD spent on food by the consumer, around 11 cents are accounted by economic activity on farms while the rest is gathered through the numerous activities associated with food transformation, conservation, packaging, delivery, and preparation.

The food chain starts from the agricultural activities on the ground and farmers involved in crop cultivation, livestock, dairy and seafood production. This initial part of the system is extremely fragile because it proceeds mainly at the open fields and uncontrolled environment which is strongly affected by climate change. At the global level, over the last 30 years, the losses of agricultural production were estimated be 3.800 trillion USD, with an average of 127 billion USD per year (FAO, 2023). This corresponds to 5% of the global GDP of the agricultural sector (considering 30 years period). Nevertheless, the impact on GDP was much greater (10-20%) in under-developed in respect to developed countries.

Weather- and climate-related extremes caused economic losses of assets estimated at EUR 738 billion during 1980 - 2023 in the European Union, with over EUR 162 billion (22%) between 2021 and 2023 (EEA, online). For example, in Italy, in 2023, the losses of agricultural production due to climate change were estimated to 6 billion Euro. The average EU agricultural losses from the period 2021-2023 (EUR 54 billion per year) corresponds to almost 25% of the agricultural GDP of the EU in the same period (2021-2023). The share of the agricultural sector in the EU's GDP is low (1.3%). However, it is extremely important since it generates the activities of many other sectors (tourism, energy, transport) and affects the health of the environment, landscapes, the state of natural resources (land and water), biodiversity etc.

On average, about 20% of total losses were insured ranging from less than 2% in Romania, Slovenia, Cyprus and Bulgaria to over 35% in Denmark, Luxembourg, Belgium, the Netherlands and France. There were significant differences between the types of events. For meteorological events, over one-third of the losses were insured. It was less than 15% for hydrological events and slightly over 10% for all climatological events, including heatwaves, droughts, and forest fires (EEA, online).

In the European Union (EU) as well as in the countries of Western Balkans, around half of the area is farmed land. The intensity of agricultural activities and the adopted agronomic policies and measures affect the shape landscapes, produce economic and social benefits, and influences biodiversity and ecosystem health. However, agricultural production is affected by climatic events, the overall state of the environment, biodiversity and water and land quality. Hence, in 2021, the EU has released the new Strategy on Adaptation to Climate (EU, 2021) which is based on the EU Green Deal plan where an important section is dedicated to agriculture and implementation of Farm to Fork and Biodiversity Strategies.

This paper focusses on some important aspects of the above strategies and other relevant challenges/issues to be adopted on the road of adaptation and mitigation of climate change impacts and promotion of resilient and climate-smart agriculture and food production. The emphasis is given to the introduction of eco-efficiency concept in the valorization of agri-food product's chain, and adoption of organic farming and precision agriculture technologies.

2. ECO - SCHEMES AND CLIMATE-SMART MANAGEMENT PRACTICES

The EU Green Deal Plan, adopted in 2021, will employ around 1 trillion EUR to fund activities focusing on the reduction of net greenhouse gas emissions by at least 55% by 2030 in respect to 1990 levels. Agricultural sector and rural development are in the center of the EU Green Deal Plan and the Common Agricultural Policy (CAP 2023-2027) represents a key tool to achieve the ambitions of the Farm to Fork Strategy and the Biodiversity Strategy. The objective is managing the transition towards a sustainable food system and in strengthening the efforts of farmers to contribute to the EU's climate objectives and to protect the environment. The targets focusing on the agrifood sector are:

- (i) to reduce by 50% the overall use and risk of chemical pesticides and reduce use by 50% of more hazardous pesticides by 2030,
- (ii) achieve at least 25% of the EU's agricultural land under organic farming and a significant increase in organic aquaculture by 2030,
- (iii) reduce sales of antimicrobials for farmed animals and in aquaculture by 50% by 2030, and
- (iv) reduce nutrient losses by at least 50% while ensuring no deterioration in soil fertility; this will reduce use of fertilizers by at least 20 % by 2030.

The objective is managing the transition towards a sustainable food system and in strengthening the efforts of farmers to contribute to the EU's climate objectives and to protect the environment. Eco-schemes are a new instrument in the CAP to support this transition. EU countries set the eco-schemes in their CAP Strategic Plans. The Commission assessed and approved them as key tools for the CAP to deliver to the Green Deal targets.

Agricultural practices that could be supported by eco-schemes have to meet the following conditions:

- they should cover activities related to climate, environment, animal welfare and antimicrobial resistance,
- they shall be defined based on the needs and priorities identified at national/regional levels,
- their level of ambition has to go beyond the requirements and obligations established under the baseline (including conditionality),
- they shall contribute to reaching the EU Green Deal targets.

EU countries' measures, detailed in the CAP Strategic Plans, cover various areas of environment, climate change and animal welfare actions (Figure 1) including the following:

a. Climate mitigation - including reduction of GHG emissions from agricultural practices, as well as maintenance of existing carbon stores and enhancement of carbon sequestration,
b. Climate change adaption - including reduction of GHG emissions from agricultural practices, as well as maintenance of existing carbon stores and enhancement of carbon sequestration,
c. Protection or improvement of water quality - and reduction of pressure on water resources,
d. Prevention of soil degradation - soil restoration, improvement of soil fertility and of nutrient management,
e. Protection of biodiversity - conservation or restoration of habitats or species, including maintenance and creation of landscape features or non-productive areas,
f. Actions for a sustainable and reduced use of pesticides,
g. Actions to enhance animal welfare - or address antimicrobial resistance.

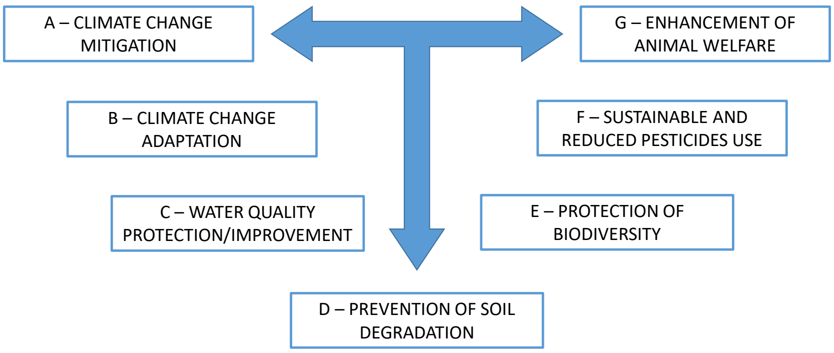


Figure 1. Areas of environment, climate change and animal welfare actions included in the CAP Strategic Plans

A whole set of management practices correspond to actions under the CAP Strategic Plans covering areas of environment, climate change and animal welfare. Some of them are established in the EU policy instruments: organic farming as defined in Regulation (EU) 2018/848 and integrated pest management as defined in Sustainable Use Directive (Table 1). Other practices focused on agroecology (Table 2), husbandry and animal welfare plans (Table 3), agro-forestry and the High Nature Value (HNV) farming (Table 4), carbon farming and precision farming (Table 5), improved nutrient management and water resources protection (Table 6), and other practices beneficial for soil and related to the GHG emissions (Table 7).

Table 1. Climate-smart management practices established in EU policy instruments (adapted from EC, 2021)

Organic farming practices, as defined in Regulation (EU) 2018/848
▪ Conversion to organic farming
▪ Conversion to organic farming
Integrated Pest Management as defined in Sustainable Use Directive
▪ Buffer strips with management practices and without pesticide ▪ Mechanical weed control ▪ Increased use of resilient, pest-resistant crop varieties and species ▪ Land lying fallow with species composition for biodiversity purpose

Table 2. Climate-smart agroecological management practices (adapted from EC, 2021)

Agroecology
▪ Crop rotation with leguminous crops
▪ Mixed cropping - multi cropping
▪ Cover crop between tree rows on permanent crops - orchards, vineyards, olive trees - above conditionality
▪ Winter soil cover and catch crops above conditionality ▪ Low intensity grass-based livestock system ▪ Use of crops/plant varieties more resilient to climate change
▪ Mixed species/diverse sward of permanent grassland for biodiversity purpose (pollination, birds, game feedstocks) ▪ Improved rice cultivation to decrease methane emissions (e.g. alternate wet and dry techniques) ▪ Practices and standards as set under organic farming rules

Table 3. Climate-smart husbandry and animal welfare plans (adapted from EC, 2021)

Husbandry and animal welfare plans
▪ Feeding plans: suitability of and access to feed and water, feed and water quality analyses (e.g. mycotoxins), optimised feed strategies ▪ Friendly housing conditions: increased space allowances per animal, improved flooring (e.g., straw bedding provided on a daily basis), free farrowing, provision of enriched environment (e.g. rooting for pigs, perching, nest-building materials, etc.), shading/sprinklers/ventilation to cope with heat stress ▪ Practices and standards as set under organic farming rules ▪ Practices increasing animal robustness, fertility, longevity and adaptability, e.g. lifespan of dairy cows; breeding lower emission animals, promoting genetic diversity and resilience ▪ Animal health prevention and control plans: overall plan for reducing the risk of infections that require antimicrobials and covering all relevant husbandry practices, e.g. vaccination and treatments, enhanced biosecurity, use of feed additives, etc. ▪ Providing access to pastures and increasing grazing period for grazing animals ▪ Provide and manage regular access to open air areas

Table 4. Climate-smart management practices considering agro-forestry and High Nature Value (HNV) Farming (adapted from EC, 2021)

Agro forestry
▪ Establishment and maintenance of landscape features above conditionality ▪ Management and cutting plan of landscape features ▪ Establishment and maintenance of high-biodiversity silvo-pastoral system
High Nature Value (HNV) Farming
▪ Land lying fallow with species composition for biodiversity purpose (pollination, birds, game feedstocks, etc.) ▪ Shepherding on open spaces and between permanent crops, transhumance and common grazing ▪ Semi-natural habitat creation and enhancement ▪ Reduction of fertiliser use, low intensity management in arable crops

Table 5. Climate-smart management ppractices considering carbon farming and Precision farming (adapted from EC, 2021)

Carbon farming
▪ Conservation agriculture (a, d) ▪ Rewetting wetlands/peatlands, paludiculture ▪ Minimum water table level during winter ▪ Appropriate management of residues, i.e. burying of agricultural residues, seeding on residues ▪ Establishment and maintenance of permanent grassland ▪ Extensive use of permanent grassland
Precision farming
▪ Nutrients management plan, use of innovative approaches to minimise nutrient release, optimal pH for nutrient uptake, circular agriculture ▪ Precision crop farming to reduce inputs (fertilisers, water, plant protection products) ▪ Improving irrigation efficiency

Table 6. Climate-smart practices considering the improvement of nutrient management and protection of water resources (adapted from EC, 2021)

Improvement of nutrient management
▪ Implementation of nitrates-related measures that go beyond the conditionality obligations ▪ Measures to reduce and prevent water, air and soil pollution from excess nutrients such as soil sampling if not already obligatory, creation of nutrient traps
Water resources protection
▪ Managing crop water demand (switching to less water intensive crops, changing planting dates, optimised irrigation schedules)

Table 7. Other climate-smart practices related to soil and GHG emissions (adapted from EC, 2021)

Other practices beneficial for soil
▪ Erosion prevention strips and wind breaks ▪ Establishment or maintenance of terraces and strip cropping
Other practices related to GHG emissions
▪ Feed additives to decrease emissions from enteric fermentation ▪ Improved manure management and storage

3. ORGANIC FARMING PERSPERCTIVES IN THE WESTERN BALKANS

The first quarter of this Century is characterized by a constant promotion and growth of organic farming. Organic agriculture is defined by the International Federation of Organic Agriculture Movements (IFOAM, 2008) as a production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved. Organic farming has an important role in the reduction of GHG emissions of agricultural sector, the improvement of soil carbon sequestration, and overall resilience of crops to droughts, and other extreme events.

Organic agriculture banned the use of fossil-based fertilizers and most synthetic pesticides which reduced the emissions related to both on-farm applications and production of synthetic fertilizers and pesticides. The elimination of synthetic nitrogen fertilizers alone, as is required in organic systems, could lower direct global agricultural greenhouse gas emissions by about 20% (Lal, 2020).

The use of synthetic pesticides has negative effects on the soil invertebrates as they are earthworms, woodlice, spiders, springtails, mites, and some insects which reduces the soil carbon sequestration capacity. Special attention should be fiven to the use of fumigant pesticides which are commonly used on crops like strawberries and injected into soil. They emitted nitrous oxide (N2O), the most potent greenhouse gas.

Organic farming best management practices improve the resiliency of agricultural system by increasing organic matter in soil continuously over time. In this way, the water percolation in the soil might be improved as well as the soil water holding capacity. This affects positively the crops' resistance to extreme weather events like drought and floods.

Muller et al. (2017) reported that a progressive conversion to 50% of EU land under organic farming by 2030 would offer a mitigation potential of 23% of agricultural greenhouse gas emissions through increased soil carbon sequestration and reduced application of mineral fertilizers. It would moreover reduce energy use for the production of synthetic fertilizers, equivalent to a further reduction of 9% of agriculture emissions and would provide many other environmental and animal welfare benefits, as well as successful adaptation strategies to cope with the impacts of climate change.

The last World Organic Agriculture report (FIBL, IFOAM, 2024) indicated that in 2022, organic agricultural land covered about 96.4 million hectares or 2.0% of total agricultural land. The increase of organic agricultural land in 2021-2022 was 20.3 million hectares of +26.6%. The value of organic market in 2022 was about 134.8 billion EUR with the greatest share in USA, Germany and China, whereas the average per capita consumption of organic products is 17 EUR with the greatest consumption in Switzerland (437 EUR), Denmark (365 EUR) and Austria 274 EUR). The organic farming regulation is fully implemented in 75 countries of the world while in other 14 countries it is the process of drafting.

Organic farming in the Western Balkans is still underdeveloped in respect to other neighboring countries. The organic farming land ranges from 733 ha in Albania to 25035 ha in Serbia with the share in respect to total agricultural land from 0.1% (Albania, Bosnia and Herzegovina) to 1.5% (Montenegro) (Figure 2). The organic farming areas are much lower than in the neighboring countries like Bulgaria, Croatia, Slovenia and Greece (Figure 2). The number of certified organic farming producers in the Western Balkans is between 90 in Bosnia and Herzegovina and 890 in North Macedonia. In the EU neighboring countries, the number of organic producers goes from 3718 in Slovenia to 58691 in Greece. However, a contradictory situation is observed considering the organic farming land per organic producers (Figure 3). The greatest organic farming area per producer is observed in Serbia (48.8 ha) and then in Bosnia and Herzegovina (27.7 ha) which indicated the presence of large companies which focused on the export of products to the international markets. In fact, the available data confirmed that both Serbia and Bosnia and Herzegovina exported several times more organic farming products than EU neighboring countries (Bulgaria, Croatia, Greece and Slovenia) which confirmed that the internal organic farming market in the Western Balkans region is not adequately developed.

Therefore, one of the challenges of Western Balkans countries is to focus on the promotion of organic agriculture and extension of organic farming land.

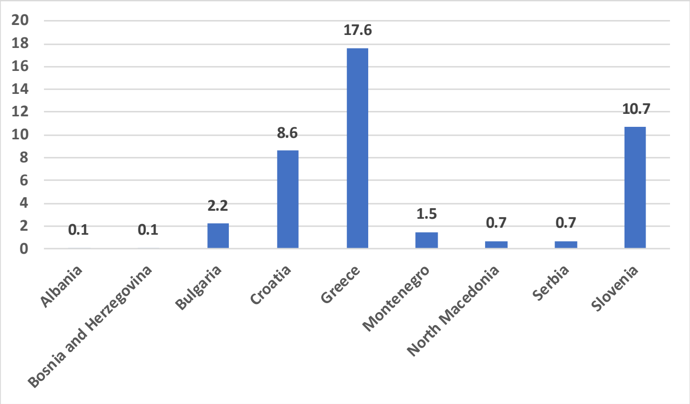


Figure 2. The share of organic farming land in respect to total agricultural land (FIBL, IFOAM, 2024)

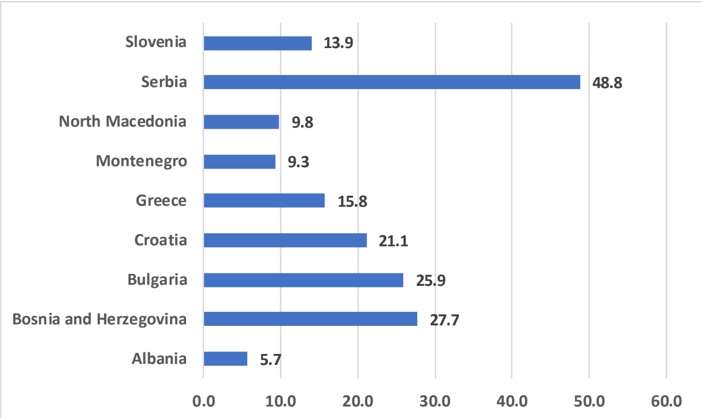


Figure 3. Organic farming area (in ha) per organic producer (FIBL, IFOAM, 2024)

4. ECO-EFFICIENCY CONCEPT

The application of climate-smart management practices should satisfy both economic and environmental criteria. The concept of eco-efficiency represents the combination of a system's economic and environmental performance. It is developed on a system-based approach that interweaves among heterogeneous stakeholders across the entire value chain of a production/service process, as is agri-food production management (Figure 4). Therefore, it includes managers of infrastructures, farmers, agricultural extension staff, environmental authorities, and decision makers.

Eco-efficiency embraces all management activities, on a plot/farm/district level, which contribute to the farming process accomplishment, i.e. including land preparation, sowing, crop growing, harvesting and selling as well as the use of energy, application of nutrients and agro-chemicals and adoption of land management and other farming practices necessary for crop cultivation and harvesting (Figure 4). The eco-efficiency encompasses the actions (processes) related to the creation of the economic value from the commercialization of the final product (yield) and other (any) by-products.

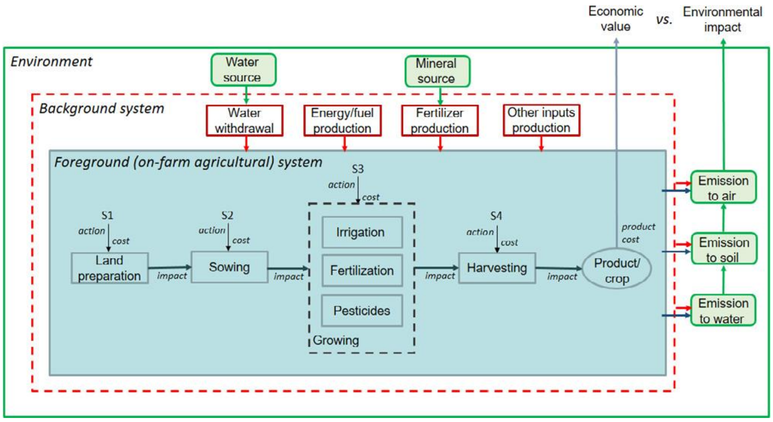


Figure 4. System boundaries and life cycle stages (S) adopted for
the eco-efficiency assessment of on-farm wheat cultivation (Todorovic et al., 2018)

The eco-efficiency (EE) is defined as the ratio between the economic performance (economic value added, EVA) and the corresponding environmental performance (environmental impact score, EIS)

$$EE = \frac{EVA}{EIS} \quad (1)$$

EIS is determined using specific well-consolidated software and databases that permit the adoption of the life cycle impact methodology which provides insightful information on a broad set of environmental impact categories and audiences. The analysis included eighteen midpoint indicators and three endpoint indicators for each specific management action. Global warming, freshwater, and marine eutrophication, terrestrial acidification, ozone formation, stratospheric ozone depletion, ionizing, radiation, water consumption, particulate matter formation, and land use are among the midpoint indicators. The three aggregated endpoint impact categories are damage to human health, ecosystems, and resources.

EVA is expressed in monetary units per year, and it is estimated as the difference between total economic value (TEV) and total financial costs (TFC) related to water use and agricultural production, i.e.

$$TVA = TEV - TFC \quad (2)$$

The agricultural system is divided into "foreground" and "background" subsystems (Figure 4). The former is the system of direct interest for agricultural production and includes all the stages along the wheat cultivation, from land preparation to harvesting. The "background" system includes the environmental impact of the production processes of other inputs (row material) necessary for agricultural production, such as energy (electricity, diesel oil and solar energy), fertilizers (mineral and organic) and any other (agro-chemicals, agricultural machinery, irrigation equipment, etc.).

Eco-efficiency is widely used to highlight differences in fertilization and irrigation management practices (Todorović et al., 2018), conventional and organic cultivation systems (Meisterling et al., 2009), open-field and greenhouse production systems (Shen et al., 2021), etc. Their application is of particular interest in the comparison of the smart agricultural management practices linked with the organic farming conversion process and other low-carbon initiatives.

5. CONCLUSION

Eco-innovative solutions for climate-smart agriculture comprehend a vast set of coordinated activities that should support reorientation of modern society and agricultural systems to a more eco-efficient way of living and production. The adoption of organic farming production methods should be one of priorities since it brings relevant benefits to environment and human health, mitigate the causes of climate change, and support the adaption of agricultural systems to adverse climatic events.

There is a considerable challenge to support the adoption of organic farming production practices in the Western Balkan countries to reach the levels of the neighboring EU countries. Accordingly, the international cooperation initiatives in the region should be promoted to reinforce the on-ground implementation of the climate-smart agrifood management practices in line with the EU Green Deal Plan, Green Agenda for Western Balkans, and climate change response strategies at different levels.

Communication activities should be upgraded to enhance awareness and involvement of society and different stakeholders involved in the agrifood production process. The awareness about climate-smart management practices should be transmitted to the consumers and especially to young generations. Transparency and trust are the keys to success. Modern weather forecasting tools (especially mid and long-term forecasting) and identification of the most suitable proactive management options to adapt to both droughts and floods are needed. Hence, the setup of early warning systems and risk management plans is needed to attenuate the vulnerability of agrifood systems and of the society to climate change and extreme weather events.

The adoption of innovations, based on green technologies, should be guided in a concerted manner. A matrix for the adoption of best management solutions on the ground should be adaptive and inclusive. The priorities for actions and interventions should be agreed jointly among all stakeholders considering the risk of not acting, the overall benefits of specific users and of the society, the costs and attenuation of ecosystem vulnerability. Priority should be given to “no-regret” easily implementable actions which are largely accepted by farmers and consumers who represent the key actors of the whole production chain.

The eco-efficiency should be among the top approaches and indicators for the evaluation of the performances of specific management actions. Eco-efficiency overcomes the specificity of agrifood system production indicators since it includes the overall economic benefits (of all production outputs) and different environmental burdens. Therefore, it makes possible to shift to a comprehensive approach that integrates the appropriateness and interaction of different management practices and inputs (e.g. water, fertilizer, energy, etc.), overall benefits of stakeholders and various environmental impacts.

6. REFERENCES

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A. (2021). Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food, 1-12. doi.org/10.1038/s43016-021-00225-9

EC (2021). List of potential agricultural practices that eco-schemes could support. European Commission, p. 5.

EEA, www.eea.europa.eu/en/analysis/indicators/economic-losses-from-climate-related

EU (2021). Communication from the Commission to the European parliament, the Council, the European economic and social committee and the committee of the regions. Forging a climate-resilient Europe - the new EU Strategy on Adaptation to Climate Change. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:82:FIN

FAO (2023). Greenhouse gas emissions from agrifood systems Global, regional and country trends, 2000-2020, FAOSTAT Analytical Brief 50, Food and Agriculture Organization of United Nations, Rome, Italy.

Lal, R. (2020). Managing soils for negative feedback to climate change and positive impact on food and nutritional security. Soil Science and Plant Nutrition, 66(1), 1-9. doi.org/10.1080/00380768.2020.1718548

Meisterling, K., Samaras, C., Schweizer, V. (2009). Decisions to reduce greenhouse gases from agriculture and product transport: LCA case study of organic and conventional wheat. J. Clean. Prod., doi.org/10.1016/j.jclepro.2008.04.009

Muller, A., Schader, C., El-Hage Scialabba, N., Brüggemann, J., Isensee, A., Erb, K.H., Smith, P., Klocke, P., Leiber, F., Stolze, M., Niggli, U. (2017). Strategies for feeding the world more sustainably with organic agriculture, Nature Communications 8: 1290 doi: 10.1038/s41467-017-01410-w. www.nature.com/naturecommunications

Planet Tracker (2023). Valuing the global food system. https://planet-tracker.org/valuing-the-global-food-system/

Shen, J., Zhang, P., Chang, Y., Zhang, L., Hao, Y., Tang, S., Xiong, X. (2021). The environmental performance of greenhouse versus open-field cherry production systems in China. Sustain. Prod. Consum. doi.org/10.1016/j.spc.2021.07.002

Todorović, M., Mehmeti, A., Cantore, V. (2018). Impact of different water and nitrogen inputs on the ecoefficiency of durum wheat cultivation in Mediterranean environments. J. Clean. Prod., 183, 1276-1288. doi.org/10.1016/j.jclepro.2018.02.200

Tubiello, F.N., Rosenzweig, C., Conchedda, G., Karl, K., Gütschow, J., Xueyao, P. *et al.* (2021). Greenhouse gas emissions from food systems: building the evidence base. Environmental Research Letters, 16(6), 065007

Tubiello, F.N., Karl, K., Flammini, A., Gütschow, J., Obli-Laryea, G., Conchedda, G., Pan, X. *et al*. (2022). Pre- and Post-Production Processes Increasingly Dominate Greenhouse Gas Emissions from Agri-Food Systems. Earth System Science Data 14, 4, 1795-1809. doi.org/10.5194/essd-14-1795-2022

doi:10.46793/MAK2025.022T

SOCIO-ECONOMIC RESPONSES TO CLIMATE CHANGE: NEW POLICIES AND APPROACHES FOR SMART AGRICULTURE

Predrag Terzić

Institute for Political Studies Belgrade, Serbia
predrag.terzic@ips.ac.rs

Abstract: Climate change is a global phenomenon with local manifestations and impacts, which are unequal in terms of its causes and effects. The phenomenon of climate change is likely due to a combination of natural cycles and human activities. The socio-economic response encompasses several integrated activities to mitigate the impacts of climate change that are a challenge for future adaptation. These challenges require identifying effective strategies for the development of new socio-economic scenarios for use resources, safe life, providing foods, protecting environment, creation of integration research and new policy on global level. For food security for human population, agricultural production requires new policies of governments with increasing financial support for development climate-smart agriculture at local, regional and world levels.

1. INTRODUCTION

In recent few decades the scientific studies of human and social dimension of climate changes gain importance for discussion and resolving on global level. The studies are directed to estimate climate changes and their influence on impact on natural resources, human life and health, economic activities, food production, as well as potential and limiting adaptation of urban and rural communities. Studies also, have explored the connection between climate change and human rights (Levi and Patz, 2015). Rural communities in developing countries will be highly vulnerable to climate change with limited capacity to adapt to changes due to various inherent socio-economic, demographic, institutional and political trends (Dasgupta et al., 2014).

The Intergovernmental Panel on Climate Change (IPCC), was set up by the United Nations in 1998 to produce assessments of the state of the Earth's climate system. The current state of scientific knowledge regarding climate change and its impacts was published early in 2007. According to assessment of IPCC climate change is expressed through global warming (Burkett et al., 2014). This assessment is confirmed by increased average global air temperatures, sea level rise, melting of glaciers and snowpack, retreat of Arctic ice, warming of the oceans. Climatic science reported numerous proofs that the phenomenon of global warming is not entirely a part of the natural cycles, but that human activities have impact in most of the warming seen in recent last six decades (IPCC 2014, 2007a).

In recent years the World Health Organization (WHO, 2014) identified climate change as the greatest threat to human health. Global climate change is due to rising atmospheric concentrations of greenhouse gases, primarily due to the burning of fossil fuels, mainly by populations in developed and developing countries. The highest temperatures were recorded in 2022 compared to the previous period so far recorded (Wong, 2024). The estimation of WHO is that 3.6 billion people live in areas highly susceptible to the effects of climate change. In period between 2030 and 2050, estimated that the impact of climate change can lead to approximately 250.000 additional annual deaths, mainly from malnutrition, diarrhea, malaria, and other vector-borne diseases, and the effects of heat stress (WHO, 2024). The costs due to the direct damage to health, excluding costs to agriculture, provision of clean water, and sanitation, are estimated to be between US$ 2-4 billion annually by 2030 (WHO, 2024). The main question facing humankind is whether climate change and these environmental and health consequences are foreseeable and preventable (Parums, 2024).

There is considerable uncertainty surrounding future emissions to climate change, from climate change to possible impacts, and from impacts to adaptation and mitigation measures and policies. In aim to facilitate research and assessment of possibility mitigation climate outcomes and adaptation and respond to the climate change are developed integrated scenarios based on combinations of climate model projections, socioeconomic conditions, and assumptions about climate policies. Socio-economic scenarios represent alternative ‘views’ of the future and are key to understanding potential vulnerability to different levels of climate change. The IPCC has defined a range of socio-economic scenarios in its Special Report on Emission Scenarios (IPCC SRES, 2001).

The IPCC uses global climate models and emission scenarios to estimate future changes in climate patterns. The scenarios cover a wide range of the main driving forces of future greenhouse gas emissions. The climate models, which represent the atmosphere and the oceans, involve conversions of projected emissions into atmospheric greenhouse gas concentrations and then variations in climatic variables. The basic emission scenarios or SRES (A1, A2, B1, B2) represent storylines about possible world developments in economic growth, population increases, global approaches to sustainability and other sociological, technological and economic variables that could influence greenhouse gas emission trends.

Only the models that include both natural and anthropogenic forcing better simulated the past trend of rising land and ocean temperatures, which confirmed a stronger human influence on climate (Hegerl et al. 2007). The fourth assessment report (AR4) of the IPCC established the anthropogenic activities as the major cause of current climate change, what are additionally assessed report (AR5), which states that the impact of anthropogenic causes on climate change have significantly increased than in assesment report AR4 (Myhre et al., 2013).

Modern information technologies have contributed to the development of climate-smart agriculture, which represents a model for the transformation of agriculture and its development in the current climate change in order to increase crop productivity, increase climate adaptability, mitigate the effect of greenhouse gases and ensure food security in regional frameworks.

The aim of this research is (I) review of complex relation and impact among of climate change and biodiversity and society, (II) socioeconomic responses to climatic changes through preventing environment and environmental protection, human health and the role of sustainable agriculture in providing food for the human population.

2. PROJECTION OF CLIMATE CHANGE MODEL

The IPCC created different model scenarios for climate changes which focused on global climate models and emission scenarios to estimate future changes in climate patterns. In scenario family A, economic development is the priority, while in scenario family B, environmental sustainability considerations are important.

The "1" and "2" scenario groups differ in their technological development path: faster and more diverse in "1", and slower and more regionally fragmented in "2". Each scenario is identified as having low (B1), medium-low (B2), medium-high (A1) and high emissions (A2).

Table 1. Overview of main primary driving forces in 2020, 2050 and 2100 for the A1, A2, B1 and B2 scenarios (Adapted from the Special Report on Emission Scenarios)

Scenario group	A1	A2	B1	B2
Population (billion) (1990 = 5.3)				
2020	7.6	8.2	7.6	7.6
2050	8.7	11.3	8.7	9.3
2100	7.0	15.1	7.0	10.4
World GDP (10 12 1990US$/ yr) (1990 = 21)				
2020	57	41	53	51
2050	187	82	136	110
2100	550	243	328	235
Per capita income ratio: developed countries and economies in transition (Kyoto Treaty Annex 1) to developed countries (Kyoto Treaty non-Annex 1) (1990 = 16.1)				
2020	6.2	9.4	8.4	7.7
2050	2.8	6.6	3.6	4.0
2100	1.6	4.2	1.8	3.0

Natural phenomena such as solar variation and volcanoes likely had a small warming effect from preindustrial times to 1950 and a small cooling effect from 1950 onward (IPCC), what have been endorsed by at least 30 scientific societies and academies of science, including all the national academies of science of the major industrialized countries.

The detailed analyses of the simulations that have been conducted with available climate models and socio-economic scenarios, provides clear estimation of global warming of 1.8 ºC to 4 ºC over the next century compared with 1990 levels as well as an increase in annual global precipitation (5 to 25%). This is to be expected, as a warmer atmosphere holds more moisture (IPCC, 2007). The uncertainty in this estimation is based on different estimation of future greenhouse gas emissions and from use of models with differing climate sensitivity, and related changes which will vary from region to region around the globe.

The simulation prediction of changes on the globally:

- the higher warming than the global mean, in zone of high latitudes and high elevations, especially in winter,
- disproportionately increasing of winter and nocturnal temperatures (minimum temperatures) are projected to rise disproportionately,
- more intensity of the hydrological cycle which will bringing more floods and more droughts,
- more winter precipitation as rain, rather than snow, decreasing snowpack and spring runoff, what potentially increase spring and summer droughts.

Warming is expected to continue for more than a thousand years and under conditions if GHG emissions stabilize as a result of the large heat capacity of the oceans, which will affect the melting of glaciers, extinction of species, increase in sea level and change in precipitation regime, expansion of desert areas in the subtropical zone, and will also affect changes in crop yields in arable farming, increase in the range of disease vectors, modification of trade (IPCC, 2007).

In numerous of global climate models (GCMs), contain differences prediction of temperature for the summer period in northern and southern Europe, while all models predict increased annual precipitation in northern Europe, which is likely to cause more frequent and intense flooding, as well as decreased annual precipitation in southern Europe, with the high probability risk of increasing drought (PRUDENCE Project, 2006). This is in agreement with the statement that climate change is a global phenomenon, but its expression and impacts are entirely local.

The scenarios in the frame for 2011-2040 of climate change impact to agricultural production and to the socio-economic scenarios A2 and B2 are very similar or almost identical. In the model forecasts for A2 2080 suggest similar changes in precipitation patterns across Europe, with decreases in southwest and southeast Europe, but increases in the total annual rainfall in the centre and north by the end of the century, while the model the B2 scenario is due to the different consequences for greenhouse gas emissions from this scenario. The two model outputs for the A2 scenario again project a similar pattern of change, with the greatest temperature increases in southern and eastern Europe.

It is important to note that socio-economic conditions have a direct influence on the climate scenarios as they condition the amount of carbon dioxide and other greenhouse gases in the atmosphere. The socio-economic scenarios are also major determinants of possible adaptation options, since economic development is a driver of technological change, population defines demand and consumption, and land use change is influenced by policy.

Nine agro-climatic zones were defined based on the K-mean cluster analysis of temperature and precipitation data from 247 meteorological stations, district crop yield data and irrigation data. The future zones were derived in the same way as the zones in the current climate, but the climate at each station was modified to take account of the changes forecast in the climate scenarios, what agrees (Metzger et al., 2006; Rounsevell et al., 2005). The farming systems are based on specialized field crops, grazing livestock, horticulture and permanent crops in agricultural holdings in the EU.

There is considerable agreement that this warming will be the result of increased releases and atmospheric accumulation, since the industrial revolution, of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and chlorofluorocarbons (CFCs) the primary greenhouse gases (GHGs) (Table 2).

Table 2. Annual greenhouse gas emission by sector (IPCC, 2007)

Sector	GHG gases (%)	CO_2 (%)	Methane (%)
Power Stations	21.3	29.5	-
Industrial Processes	16.8	20.6	-
Transportation fuels	14.4	19.2	-
Agricultural bioproducts	12.5	-	40
Fossil fuel retrieval, processing and distribution	11.3	8.4	29.6
Residential, commercial and other sources	10.3	12.9	4.8
Land use and bio-mass burning	10.0	9.4	6.6
Waste disposal and treatment	3.4	-	18.1

3. SOCIOECONOMIC RESPONSES TO CLIMATE CHANGE

Climate change encompasses changes of Earth on global level which are influenced by the dynamic changes of solar activity, volcanic eruptions, changes of sea water temperature, ice sheet distribution, and atmospheric waves (Scholes and Biggs, 2005). Also, significant influence on climate changes has human activities, which includes deforestation, carbon dioxide emissions from industry and agriculture, which result in acid rain, and ozone depletion by chlorofluorocarbons (CFCs) and greenhouse gases (GHG), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), and sulfur hexafluoride (SF_6) Varshney et al. (2018).

However, the extent and geographical distribution of climate changes is not reliably known. Except that, the scenarios predicting how climate related changes of environment and can influence to human societies and political systems, indicate more uncertainty. The long record of climate change adaptation allows for the proper selection of tools for managing climate risks, especially in rural areas and for low-income households, and that demographic and environmental changes can have a strong impact on the risk of civil conflict and thus peace.

In various scenarios of Representative Concentration Pathways (RCPs) for the period of 2016-2035 in comparison to previous period 1986-2005 there were projected increasing temperature in range 0.3-0.7 °C (Kirtman et al., 2013). The rate of warming will follow the higher rate of GHG emissions. This will have adverse impacts on every sector like water availability, food production, terrestrial ecosystems, marine biodiversity, coastal ecology, health, and livelihoods (Field et al., 2014; IPCC 2007b).

The can adverse influence on the human health, due to dysregulation of thermoregulatory physiological mechanisms, with varied presentation and severity, and can causes the dysregulation of the nervous system and cardiovascular systems, with cardiac arrest being the most common mechanism of death (Leive et al., 2024) and asthma, chronic kidney disease (CKD), and pregnancy increase heat-related mortality (Vaidyanathan et al., 2020). It is now estimated that 30% of the global human population lives where temperatures and humidity are extreme enough to result in excess mortality for at least 20 days of the year and that under continued climate change, 50-75% of all people may live with climate change-associated life-threatening conditions within this century (Mora et al., 2017; Vaidyanathan et al., 2017).

Anthropogenic emission of carbon dioxide (CO_2) from the combustion of fossil fuels and land use change, and methane (CH_4) and nitrous oxide (N_2O) emission from agricultural activities are the major greenhouse gases (GHGs) held responsible for the global warming. Wildfires, the burning of fossil fuels and other human activities contribute to air pollution, which are under climate change, are related to respiratory diseases such as asthma, bronchitis and lung cancer (Hopp et al., 2018). The pollutants such as particulate matter and ozone can worsen cardiovascular health, leading to heart disease and stroke. Air pollution could lead to 6 to 9 million premature deaths per year by 2060 (Haines and Ebi, 2019; Hess et al., 2023; WHO, 2024).

The various approaches to climate change mitigation encompass a wide range of measures including missions on solar energy, improved energy efficiency, sustainable habitat, water conservation, sustainable agriculture i.e. green, eco-friendly and sustainable technology and defining a strategic knowledge platform for climate change.

Agricultural production has an impact on the environment and climate change, resulting in greenhouse gas emissions, which account for approximately 30% of the total amount of GHG, and consumes about 70% of the total freshwater consumption in agricultural production (Wheeler and Von Braun, 2013).

The integrated scenarios provide information, to assess a wide range of individual studies by grouping them on the base of common assumptions about socioeconomic conditions or climate change outcomes. The key determinants for uncertainty in outcomes are different. One of those determinants is climate change, since required mitigation effort and adaptation needs depend strongly on the outcomes to which policy aspires van (Vuuren et al., 2013). The second determinant of uncertainty in outcomes is socioeconomic development, because different development lead to societies which differ according to level of emission, capacity to mitigate emissions or introduce measures for adaptation. The Shared Socioeconomic Pathways (SSPs) are combined with climate change outcomes in integrated scenarios, policy assumptions in order to produce emissions how it could be achieving the desired climate outcomes, as well as to characterize adaptation measures, which is third determinant (Kriegler et al., 2013).

The Global socio-economic scenarios are existing scenarios i.e. the shared socio-economic pathways (SSPs) which are a set of five scenarios that describe expected future events and changes of demographic, economic, technological, social, and environmental factors (O'Neill et al., 2013, 2017). The scenarios are important for both the analysis of generates of emissions and measures of mitigation, and the analysis of societal vulnerability to climate change impacts and adaptation measures.

The capacity of society for the mitigation includes the range of sustain technological factors, national and international institutions for policy making, the availability of financial resources necessary to support mitigation activities, human and social capital, and political strategies for addressing energy security and environmental protection issues (Winkler et al., 2007; Klein et al., 2007). The mitigation capacity, including the capacity for technological change in energy systems, which overlap with determinants of emissions, making these two components closely related in activities for mitigation.

Socioeconomic challenges to adaptation are connected with societal or environmental conditions that, can influence on adaptation to be more difficult, and associated with increased the risks than is projected climate change (sea level rise, changes in temperature and precipitation, and extreme events), i.e. who and what is exposed to hazards, and what is level of risk to their adverse impacts, whether it is geographic, socioeconomic, cultural, etc. (Rothman et al., 2013).

The exposure to climate change hazards, sensitivity to these hazards, and the adaptive capacity to applied measures. These socioeconomic determinants characterize the constraints of autonomous adaptation that are readily accessible to individuals and organizations, and the obstacles and constraints to adaptation policies, in dependance of effectiveness institutions and governance that support/impede policy implementation.

4. POLICY FOR CLIMATE CHANGE

Global climate change in the current era of accelerated industrialization and urbanization is causing changes in the quality of the global environment, which raises concerns about the conservation of natural resources (Zhang and Liu, 2012). According to Environmental Protection Agency-USA, (USEPA), with increasing population, more and more countries are facing the problem of global environmental change originating from large expansion of industrial sector (Rai and Tripathi, 2009).

The growth of human population leads to a rapid increase in the number of industries preparing agro-chemical to sustain agriculture as well as are increase the industrial demand for resources. Economic globalization constitutes integration of national economies into the international economy through trade, direct foreign capital flows, international fluctuation of workers and humanity generally, and links of technology. It is necessary to provide sufficient food for the growing world population. With the human population projected to reach 9 billion by 2050, 70% more food production will be needed. To ensure the stability of a larger quantity of food in the conditions of climate change, it is necessary to modify agricultural production (Sahu et al., 2020). Arable land resources are limited, which requires an increase in the productivity of food plant species, which can be achieved by breeding and creating new highly productive varieties with a high rate of adaptation to changing climate conditions. In addition to creating new genotypes, the answer to increasing productivity lies in the development of new cultivation technologies and smart agriculture (IPCC, 2014; Whitfield et al., 2018; Garnett et al., 2013).

The population has key developing policy for optimal use of land, water resources, agriculture and environmental protection in function of possible adaptation options to climate change. The central objective of the reforms was to develop an agricultural sector that was competitive and responsive to the market, which will be based on high standards environment, the public, animal and plant health, and animal welfare. Also to provide production of key commodities, including sugar, tobacco, olive oil, and fruit and vegetables (Sahu et al., 2020).

Many scientists believe that anthropogenic global warming has either already begun or will become manifest in the very near future, with average global temperatures predicted to rise by 1.5-4.5 °C by the middle of next century (IPCC, 1990). Climate changes can lead to major changes in freshwater availability, the productive capacity of soils, and in patterns of human settlement, and directly or indirectly affect human health. The World Health Organization estimates that the warming and precipitation trends due to anthropogenic climate change of the past 30 years already claim over 150.000 lives annually. Many prevalent human diseases are linked to climate changes, from cardiovascular mortality and respiratory illnesses due to heat waves, to altered transmission of infectious diseases and malnutrition from crop failures (Haines and Ebi, 2019).

There is considerable agreement that this warming will be the result of increased releases and atmospheric accumulation, since the industrial revolution, of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and chlorofluorocarbons (CFCs) the primary greenhouse gases (GHGs). Anticipation of negative consequences of global warming has led to strong public initiation strong to conduct policy actions to curtail GHG emissions (Wirth and Lashof, 1990). Climate-smart agriculture is conceptualized around three fundamental goals: increasing productivity, increasing resilience and adaptation to climate change, and reducing GHG emissions. The indicators of success of smart agriculture are monitoring productivity, resilience, sensitivity, and carbon sequestration in plant species.

Climate change have directly (biophysicaly) affects environmental conditions that are related to the climatic niches of many species, which expressed through species' geographic distributions or even the total extinction of species (Diaz et al., 2019) and indirectly (human-mediated impacts) through socio-economic changes that influence to food commodity production, to the way of land use, land productivity, human health, created to global consumption, production and climate (Roson and Sartori, 2016).

There is interaction between direct and indirect influence of climate change to changes of biodiversity, what require analysis and prediction of socio-economic influence to biophysical effect to disorder biodiversity, and vice versa. This is necessary in the aim to better predict way outcomes for nature and people of any change to policy, regulation, trading conditions or consumption trend at any scale from sub-national to global (Newbold et al., 2019; Struebig et al., 2015). The analyses of these interaction can contribute to better understanding of climate change and improving understanding of synergistic effect direct and indirect in biodiversity modelling and creating the cross-sectoral adaptation and mitigation strategies (Ferrier et al., 2016).

Changes in climate patterns disrupt agricultural systems, leading to decreased crop yields, food shortages and compromised food safety. In Sub-Saharan Africa, southern Asia and Central America, around 80 million people will be at risk of hunger by 2050.

CSA is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate changes, which designed to identify and operationalize sustainable agricultural development within the explicit parameters of climate change (Newell and Taylor, 2018).

5. SMART AGRICULTURE

Climate change, expressed through extreme weather events, such as hurricanes, heatwaves, floods and droughts, is unequal in different regions on the Earth. Forty million people in Africa are living in severe drought conditions. Drought conditions are also increasingly prevalent in more temperate climates. Almost 40% of the lower 48 states in the United States and 17% of the European population are facing drought, which is affecting crop production and food and water security. Agriculture practices are intended to protect the environment, expand the Earth's natural resource base, and maintain and improve soil fertility, bat in past industrial intensified agriculture had significant pressure on natural resources and the environment and sustainable agricultural practices (NIFA, 2024).

In the global climate change policy, and limitation of synergies between adaptation and mitigation the agriculture's key role in providing food security was not clearly established, emerged the concept of climate-smart agriculture. The concept of climate-smart agriculture is relatively new, it was introduced at the 2010 Hague Conference on Agriculture, Food Security and Climate Change (FAO, 2010). The first articulation of the concept was presented in the 2009 FAO report, Food Security and Agricultural Mitigation in Developing Countries: Options for Capturing Synergies, which was launched at the Barcelona Climate Change workshop.

In this concept pointed out that the agricultural sectors are key to climate change response, considering that agriculture vulnerable on climate change, and main generator of greenhouse gases, as well as that the sustainable transformation of the agricultural sector is key to achieving food security, in frame of climate change responses (Lipper and Zilberman, 2017).

Climate-smart agriculture is an approach for transforming agricultural production systems and support sustainable production and can ensure food security under climate change. Climate-smart agriculture has three main objectives: 1) sustainably increase agricultural productivity and incomes; 2) adapt and build resilience to climate change and 3) reduce and/or remove greenhouse gas emissions, where possible. This applied climate-smart agriculture approach can not achieve all thee aims on each location, but can promote synergies of agricultural producers, policy makers and researchers to identify agricultural strategies to resolve climate change suitable to local, regional and global levels. This is in agreement with the FAO vision for sustainable food and agriculture, using principles of ecosystem and sustainable land and water management and landscape analysis, and assessments of the use of resources and energy in agricultural production systems and food systems (Gamage et al., 2024).

Climate-smart agriculture is being developed to increase yields and productivity, increase income in crop and livestock production. The contribution of climate-smart agriculture is significant in the development of an improved model for collecting data on physical, biological and chemical properties of the soil, fertility, crop rotation and planning of sowing and cultivation. It also contributes to the development of new technologies and the introduction of new machines for precise soil cultivation and more efficient application of crop cultivation technology. Optimized application of nutrition and crop protection measures such as nutrition, irrigation and protection from diseases and pests, which leads to achieving increased yields, nutritional value and food safety without adverse impacts on the environment (CIAT, 2017; World Bank; CCAFS and LI-BIRD, 2017).

Increasing food production can be achieved through the improvement of intensive agricultural production and improving the productivity of crop species. Climate-smart agriculture contributes to the reduction and elimination of greenhouse gas emissions or increased carbon sequestration, while the preservation of plant and climatogenic communities, forests, which absorb carbon dioxide (CO_2) from the atmosphere, is important for mitigating the impact of climate warming (Weerakoon et al., 2011).

There are three main interdependent components of climate-smart agriculture, which are used to achieve the main goal of climate-smart agriculture: food production, regional characteristics and institutional social conditions (Luck et al., 2011). Climate-smart agriculture encompasses research in various scientific fields, related to climate, which includes study of morpho-physiological, genetic and biochemical traits of plant species, adaptation for crop production and livestock, climate risk management, as well as research of energy and biofuels in order to remove barriers to the introduction and adoption of climate-smart agriculture principles. Identification of gene locations and mapping of genes in the genome within a species and its relatives are carried out in existing germplasm.

The second component of climate-smart agriculture is the modeling of adaptation and uncertainty, multi-functionality, food systems, biodiversity and ecosystem capacity, and rural population migration due to climate change. Molecular techniques can be used to manipulate gene recombination in offspring to expand genetic diversity, the effect of which can be analyzed, and genome selection can be performed based on the study of the resulting population. Modeling can be applied to genomes, populations, plants, and interactions.

The third component includes planning interdisciplinary research that contributes to the integration of science, research, and management. Climate-smart agriculture has developed numerous strategic programs that are designed to address challenges in agriculture, namely increasing resilience to extreme weather conditions, adapting to climate change, and reducing greenhouse gas emissions that contribute to global warming (Knox et al., 2012), both in small-scale farming systems and transnational companies (Myers et al., 2014).

The development of artificial intelligence (AI) and its introduction to agricultural production is not only a technical advancement but also an opportunity to improve the socioeconomic position of rural communities. These technologies can contribute to creating sustainable agroecosystems capable of responding to global challenges posed by climate change.

Climate-smart agriculture involves the assessment and application of technologies and practices, the creation of a supportive policy and institutional framework and the formulation of investment strategies.

These innovations will only be realized if climate-smart agriculture is integrated into policy-making processes at all levels, and there is cross-sectoral coordination in policy design and implementation.

6. CONCLUSION

Climate change threatens agricultural production and human and animal health, disrupts food markets, posing population-wide risks to food supply. This requires transformation and reorienting agricultural systems to provide food security under condition of the real climate change as well as develop new policies on global and local level to prevent protect environment. Socio-economic conditions have a direct influence on climate changes as they condition the amount of carbon dioxide and other greenhouse gases in the atmosphere.

The policy in context of climate change is directed in solving problem on the base of integrated model for reduction content greenhouse gas (GHG) content in the atmosphere, increasing responsibility on global and regional level for impact in reduction of GHG, development of measures for reduction of GHG, and cooperation with institution to create administrative processes or mechanisms for efficient conduction of control, taxation, voluntary compliance, or some combination these measures. Socio-economic scenarios are also major determinants of possible adaptation options, considering economic development has influence on technological change, population demand and consumption, developing new policies and land use change.

The development of context-specific climate-smart agriculture practices require effective institutional and governance mechanisms to facilitate the dissemination of information and ensure broad participation.

Climate-smart agriculture activities can range over a very broad spectrum, depending on the relative importance of its three objectives - food security, adaptation, and mitigation - in a given country.

Designing a national climate-smart agriculture approach requires the coordination of activities of individual agricultural producers (large-scale and small-scale), who will need to adopt climate-smart agriculture practices, as well as other enterprises involved in the food value chain, the financial sector and possibly governments in the provision of credit for investment in activities that contribute to climate-smart agriculture objectives, as well as Research institutions and rural agricultural extension services in the policy-making process, and generate and disseminate of information on climate variability and its economic and social implications.

7. REFERENCE

Burkett, V.R., Suarez, A.G., Bindi, M., Conde, C., Mukerji, R., Prather, M.J., St. Clair, A.L., Yohe, G.W. (2014). Point of departure. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCraken, S., Mastrandrea, P.R., White, L.L. (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, NY, 169-194.

CIAT; World Bank; CCAFS and LI-BIRD (2017). Climate-Smart Agriculture in Nepal. CSA Country Profiles for Asia Series. Washington, D.C: International Center for Tropical Agriculture (CIAT); the World Bank; CGIAR Research Program on Climate Change, Agriculture and Food Security.

Dasgupta, P., Morton, J.F., Dodman, D., Karapinar, B., Meza, F., Rivera-Ferre, M.G., Toure Sarr, A., Vincent, K.E. (2014). Rural areas. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J, Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, NY, 613-657.

Diaz, S., Settele, J.,Brondízio E.S., Ngo, H.T., Guèze, M., Agard, J., Arneth, A., Balvanera, P.K.A. Brauman, K.A., Butchart, S.H.M., Chan, K.M.A., Garibaldi, L.A., Ichii, K., Liu, J., Subramanian, S.M., Midgley, G.F., Miloslavich,P., Molnár, Z., Obura, D., Pfaff, A., Polasky, S., Purvis, A., Razzaque, J., Reyers, B., Roy Chowdhury, R., Shin, Y.J., Visseren-Hamakers, I.J., Willis, K.J., Zayas,C.N. (Eds.) (2019). IPBES: Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, IPBES secretariat, Bonn.

Ferrier, S. et al. (2016). IPBES. Summary for Policymakers of the Methodological Assessment of Scenarios and Models of Biodiversity and Ecosystem Services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, IPBES secretariat, Bonn.

Field, C.B., Barros, V.R., Mach, K.J., Mastrandrea, M.D., van Aalst, M., Adger, W.N., Arent, D.J., Barnett, J., Betts, R., Bilir, T.E., Birkmann, J., Carmin, J., Chadee, D.D., Challinor, A.J., Chatterjee, M., Cramer, W., Davidson, D.J., Estrada, Y.O., Gattuso, J.P., Hijioka, Y., Hoegh-Guldberg, O., Huang, H.Q., Insarov, G.E., Jones, R.N., Kovats, R.S., Romero-Lankao, P., Larsen, J.N., Losada, I.J., Marengo, J.A., McLean, R.F., Mearns, L.O., Mechler, R., Morton, J.F., Niang, I., Oki, T., Olwoch, J.M., Opondo, M., Ploczanska, E.S., Portner, H.O., Redsteer, M.H., Reisinger, A., Revi, A., Schmidt, D.N., Shaw, M.R., Sokecki, W., Stone, D.A., Stone, J.M.R., Strzepek, K.M., Suarez, A.G., Tschakert, P., Valentini, R., Vicuna, S., Villamizar, A., Vincent, K.E., Warren, R., White, L.L., Wilbanks, T.J., Wong, P.P., Yohe, G.W. (2014). Technical Summary. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.) Climate change 2014: impacts, adaptation, and vulnerability. Part A: global and sectoral aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/NY, 35-94.

Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D. (2013). Sustainable intensification in agriculture: Premises and policies. Science, 341, 33-34.

Haines, A., Ebi, K. (2019). The imperative for climate action to protect health. N. Engl. J. Med., 380(3), 263-73.

Hegerl, G.C., Zwiers, F.W., Braconnot, P., Gillett, N.P., Luo, Y., Marengo Orsini, J.A., Nicholls, N., Penner, J.E., Stott, P.A. (2007). Understanding and attributing climate change. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.) Climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, NY, 663-746.

Hess, J.J., Errett, N.A., McGregor, G., et al. (2023). Public health preparedness for extreme heat events. Annu Rev Public Health., 44(1), 301-321.

Hopp, S., Dominici, F., Bobb, J.F. (2018). Medical diagnoses of heat wave-related hospital admissions in older adults. Prev Med., doi.org/10.1016/j.ypmed.2018.02.001

IPCC (Intergovernmental Panel on Climate Change) (1990). Climate Change: Tile IPCC Scientific Assessment Cambridge University Press, Cambridge, USA.

IPCC (2007a). Climate change 2007: the physical science basis. Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. (Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.)). Cambridge University Press, Cambridge/NY.

IPCC (2007b). Summary for policymakers. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.) Climate change 2007: impacts, adaptation and vulnerability. Contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, 7-22.

IPCC (2007c). Climate change 2007: impacts, adaptation, and vulnerability. Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. (Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.)). Cambridge University Press, Cambridg.

IPCC (2007). Climate Change 2007. www.ipcc.ch. (Accessed 12 December 2008).

IPCC (2014). Climate change 2014: synthesis report. Contribution of Working Groups I, II, and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. (Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.)). Intergovernmental Panel on Climate Change, Geneva.

Kirtman, B., Power, S.B., Adedoyin, J.A., Boer, G.J., Bojariu, R., Camilloni, I., Doblas-Reyes, F.J., Fiore, A.M., Kimoto, M., Meehl, G.A., Prather, M., Sarr, A., Schar, C., Sutton, R., van Oldenborgh, G.J., Vecchi, G., Wang, H.J. (2013). Near-term climate change: projections and predictability. In: Stocker, T.F., Qin, D., Plattner, G-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds,), Climate change 2013: the physical science basis. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, NY, 953-1028.

Klein, R.J.T., Huq, S., Denton, F., Downing, T.E., Richels, R.G., Robinson, J.B., Toth, F.L. (2007). In: Parry ML, Canziani OF, Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Inter-relationships between adaptation and mitigation. Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, 745-777.

Knox, J., Hess, T., Daccache, A., Wheeler, T. (2012). Climate change impacts crop productivity in Africa and South Asia. Environmental Research Letters, 7, 034032

Kriegler, E., Edmonds, J., Hallegatte, S., Ebi, K., Kram, T., Riahi, K., Winkler, H., van Vuuren, D. (2013). A new scenario framework for Climate Change Research: the concept of shared policy assumptions. Climatic Change, Special Issue, Nakicenovic, N., Lempert, R., Janetos, A. (Eds.), A Framework for the Development of New Socioeconomic Scenarios for Climate Change Research.

Lipper, L., Zilberman, D. (2017). A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. In: Lipper, McCarthy, Zilberman, Asfaw and Branca (Eds.). Climate smart agriculture: building resilience to climate change. Springer, USA.

Luck, J., Spackman, M., Freeman, A., Tre bicki, P., Griffiths, W., Finlayac, K., Chakrabortyc, S. (2011). Climate change and diseases of food crops. Plant Pathology, 60, 113-121.

Myers, S.S., Zanobetti, A., Kloog, I., Bloom, A.J., Carlisle, E.A., Dietterich, L.H., Fitzgerald, G., Hasegawa, T., Holbrook, N. M., Nelson, R.L., Ottman, M.J., Raboy, V., Sakai, H., Sartor, K. A., Schwartz, J., Seneweera, S., Tausz, M., Usui, Y. (2014). Increasing CO_2 threatens human nutrition. Nature, 510(7503), 139-142.

Metzger, M.J., Rounsevell, M.D.A., Acosta-Michlik, L., Leemans, R., Schroter, D., (2006). The vulnerability of ecosystems services to land use change. Agriculture Ecosystems and Environment 114, 69- 85.

Mora, C., Dousset, B., Caldwell, I.R., et al. (2017). Global risk of deadly heat. Nat Clim Chan, 7, 501.

Myhre, G., Shindell, D., Breon, F.M., Collins, W., Fuglestdedt, J., Huang, J., Koch, D., Lamarque, J.F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H. (2013). Anthropogenic and natural radiative forcing. In: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate change 2013: the physical science basis. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/N.Y., 659-740.

Newell, P., Taylor, O.G. (2018). Contested landscapes: The global political economy of climate smart agriculture. Journal of Peasant Studies, 45(1),108-129.

Newbold, T. et al. (2019). Climate and land-use change homogenise terrestrial biodiversity, with consequences for ecosystem functioning and human well-being. Emerg. Top. Life Sci., 3, 207-219.

O'Neill, B.C., Kriegler, E., Riahi, K., Ebi, K., Hallegatte, S., Carter, T.R., Mathur, R., van Vuuren, D.P. (2013). A new scenario framework for climate change research: the concept of shared socio-economic pathways. Clim Chang, 122, 387-400. doi.org/10.1007/s10584-013- 0905-2

O'Neill, B.C., Kriegler, E., Ebi, K.L., Kemp-Benedict, E., Riahi, K., Rothman, D.S., Van Ruijven, B., Van Vuuren, D., Birkmann, J., Kok, K., Levy, M., Moss, R., Solecki, W. (2017). The roads ahead: narratives for shared socioeconomic pathways describing world futures in the 21st century. Glob Environ Chang, 42, 169-180. doi.org/10.1016/j.

Parums, D.V. (2024). A Review of the Increasing Global Impact of Climate Change on Human Health and Approaches to Medical Preparedness. Med Sci Monit.

PRUDENCE (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects). http://prudence.dmi.dk

Rai, P.K., Tripathi, B.D. (2009). Comparative assessment of *Azolla pinnata* and *Vallisneria spiralis* in Hg removal from G.B. Pant Sagar of Singrauli Industrial region, India. Environmental Monitoring and Assessment, 148, 75-84.

Roson, R., Sartori, M. (2016). Estimation of climate change damage functions for 140 regions in the GTAP 9 database. J. Glob. Econ. Anal. 1, 78-115.

Rothman, D.S., Romero-Lankao, P., Schweizer, V.J., Bee, B.A. (2013). Challenges to adaptation: A fundamental concept for the Shared Socioeconomic Pathways and beyond. Climatic Change,

Special Issue, Nakicenovic, N., Lempert, R., Janetos, A, (Eds.), A Framework for the Development of New Socio-economic Scenarios for Climate Change Research.
Rounsewell, M.D.A., Ewert, F., Reginster, I., Leemans, R., Carter, T.R. (2005). Future scenarios of European agricultural land use: II. Projecting changes in cropland and grassland. Agriculture Ecosystems & Environment, 107(2-3), 117-135.
Sahu, G., Rout, P.P., Mohapatra, S., Das, S.P., Pradhan, P.P. (2020). Climate Smart Agriculture: A New Approach for Sustainable Intensification. Current Journal of Applied Science and Technology, 39(23), 138-147.
Scholes, R.J., Biggs, R. (2005). A biodiversity in tactness index. Nature, 434, 3, 45-49.
Struebig, M. J., Wilting, A., Gaveau, D.L.A., Meijaard, E., Smith,R.J., Fischer, M., Metcalfe, K., Kramer-Schadt, S. (2015). Targeted conservation to safeguard a biodiversity hotspot from climate and land-cover change. Curr. Biol., 25, 372-378.
Vaidyanathan, A., Malilay, J., Schramm, P., Saha, S. (2020). Heat-related deaths-United States, 2004-2018. MMWR Morb Mortal Wkly Rep., 69,729.
Varshney, R.K., Singh, V.K., Kumar, A., Powell, W., Sorrells, M.E. (2018). Can genomics deliver climate-change ready crops. Curr. Opin. Plant Biol., 45, 205-211.
Vuuren, D.P., Kriegler, E., O'Neill, B.C., Ebi, K.L., Riahi, K., Carter, T.R., Edmonds, J., Hallegatte, S., Kram, T., Mathur, R., Winkler, H. (2013). A new scenario framework for Climate Change Research: scenario matrix architecture. Climatic Change, Special Issue, Nakicenovic, N., Lempert, R., Janetos, A. (Eds.), A Framework for the Development of New Socioeconomic Scenarios for Climate Change Research.
Weerakoon, W.M.W., Mutunayake, M.M.P., Bandara, C., Rao, A.N., Bhandari, D.C., Ladha, J.K. (2011). Direct-seeded rice culture in Sri Lanka: lessons from farmers. Field Crops Research, 121, 53-63.
Wheeler, T., Von Braun, J. (2013). Climate change impacts global food security. Science, 341, 508-513.
Whitfield, S., Challinor, A.J., Rees, R.M. (2018). Frontiers in climate smart food systems: Outlining the research space. Frontiers in Sustainable Food Systems, 2, 1-5.
Winkler, H., Baumert, K., Blanchard, O., Burch, S., Robinson, J. (2007). What factors influence mitigative capacity? Energy Policy, 35(1), 692-703.
Wong, C. (2024). How climate change is hitting Europe: Three graphics reveal health impacts. Nature, 630 (8018), 800-801.
World Health Organization (WHO) (2014). Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s, WHO. Geneva, www.who.int/globalchange/publications/quantitative-risk-assessment/en/
World Health Organization (WHO) (2024). Climate Change. Key Facts. 12 October 2023. Available from: https://www.who.int/news-room/fact-sheets/detail/ climate-change-and-health
Zhang, W.J., Liu, C.H. (2012). Some thoughts on global climate change: will it get warmer and warmer? Environmental Skeptics and Critics, 1(1), 1-7.

doi:10.46793/MAK2025.035P

CHEMICAL WEED CONTROL IN CONDITIONS OF CLIMATE CHANGE

Zvonko Pacanoski

Faculty for Agricultural Sciences and Food, Ss. Cyril and Methodius University, Skopje, R. N. Macedonia
zvonkolav@yahoo.com; zvonkop@zf.ukim.edu.mk

Abstract: Elevate CO_2 levels in the atmosphere might have prominent consequences on weed phenology, subsequently changing herbicide behavior on weeds. Increased atmospheric CO_2 concentration strengthens leaf consistency and minimizes number of stomata and their conductivity potentially reducing the absorption of POST-em applied herbicides. On the other side, higher temperature stimulates stomata conductance, reduce the viscosity of epicuticle waxes, thus increasing the penetration and diffusion of herbicides because of modifications in the structure and the penetrability of the cuticle. However, in some circumstances higher temperatures might cause hastened metabolism, which consequently decreases herbicide activity on target plants. In conditions of higher RH, cuticle hydrating and stomatal conductivity increases, consequently increases the penetrability and translocation particularly of hydrophilic herbicides into the leaf surface. Similarly, under higher irradiance, stomata stay open, photosynthetic rate increases consequently increasing absorption, penetration and subsequent phloem translocation of POST-em systemic herbicides in weed plant tissue. Drought might cause increased cuticle thickness and intensify growth of leaf pubescence, with consequent minimization in herbicide absorption in the leaves. Rainfall after POST-em herbicides application might reduce their efficiency through washing out. Increased occurrence and intensiveness of precipitation will have negative consequences on absorption, translocation, and efficacy of PRE-m herbicides.

Key words: Changing environmental conditions, Weeds, Herbicides

1. INTRODUCTION

Agriculture production in terms of quantity and quality, as well as agronomic practices, including weed management, might be affected significantly in conditions of climate change (Varanasi et al., 2016). Elevating CO_2 levels associated with fluctuations in temperature and rainfall are important issues for upcoming weed control and crop production. Taking into account the greater physiological flexibility (Ziska et al., 2010; Davidson et al., 2011; Billore, 2019) and their greater intra specific genetic variation (Dukes and Mooney, 1999), weeds are expected to demonstrate increased competitiveness and better accommodation regarding increasing temperature and CO_2 concentrations in comparison with crops (Singh et al., 2011; Varanasi et al., 2016). Considering its favorable impact on weed growth, shifting environmental conditions will impact directly or indirectly on the weed control measures by minimizing their efficacy on weeds and making them a considerable issue for sustainable agriculture production as well as costlier in same time (Ziska et al., 1999; Karl et al., 2009). Climatic variation factors are estimated to have substantial consequences on the growth and physiological processes of weedy plants, like growing rate, stomatal conductance, and photosynthetic efficiency (Fuhrer, 2003; Manisankar and Ramesh, 2019). Elevate CO_2 and temperature, sunlight intensity, relative humidity, rainfall, and drought influence the coverage, penetration, translocation, persistence and activity of herbicides (Muzik, 1976; Hatzios and Penner, 1982; Bailey, 2003; Malarkodi et al., 2017). Additionally, mutual actions amongst these ecological factors might have uncertain consequences on efficacy of herbicides (Sutherland et al., 2017). Numerous studies confirmed that shifting environmental conditions might also decrease the susceptibility of weeds to some herbicides (Varanasi et al., 2016; Ziska, 2016; Fernando et al., 2016;

Matzrafi, 2018). For example, in condition of increased CO_2 sensitivity of *Cirsium arvense*, and *Elytrigia repens* to glyphosate and glufosinate was reduced (Ziska and Teasdale, 2000). Similarly, Manea et al. (2011) reported that glyphosate efficacy at increased CO_2 concentrations is diminished in C_4 weeds such as *Eragostis curvula*, *Paspalum dilatatum,* and *Chloris gayana,* because of increased leaf area and total plant biomass. Increased temperatures might worsen the consistency of epicuticle waxes, consequently raising the absorptivity and penetration of herbicides throughout the cuticle (Price, 1983; Patterson et al., 1999). For instance, Sharma and Singh (2001) recorded that absorption and translocation of ^{14}C–glyphosate in *Desmodium tortuosum* was greater at 22 °C than at 16 °C. Although in conditions of elevated temperatures uptake and movement of most POST-em applied herbicides is higher (Patterson et al., 1999), in some circumstances higher temperatures might encourage accelerated metabolism, as well, which consequently decreases herbicide efficacy in control of weeds (Kells et al., 1984; Madafiglio et al., 2000; Medd et al., 2001; Johnson and Young, 2002). Increased CO_2 and temperature might change weed growth phenology, with shortened the period spent in the first growing stages, *i.e.* the stages of highest POST-em herbicide efficacy (Ziska et al., 1999). Also, changes in these factors caused alteration in leaf morphology, leaf surface characteristics or modification in root-to-shoot ratio which change herbicide absorption, distribution and efficacy (Olesen and Bindi, 2002; Poorter and Navas, 2003; Ziska et al., 2004; Dukes et al., 2009). Additionally, enhance in tuber and rhizome growth, joined with enhance in biomass, particular in perennial weeds (Oechel and Strain, 1985), would induce an effect of dilution on some herbicide treatment (Patterson, 1995), making their control more complicated (Patterson et al., 1999). Modifications in environmental factors, like prolonged drought or extended precipitation periods, might restrict the environmental, particular soil conditions required for optimal herbicide applications (Amare, 2016). Generally, dry soil conditions decrease the activityof PRE-em herbicides, affect their application in the soil and the herbicide effectiveness "windows" due to strong herbicide adsorption (Bailey, 2004; Howden et al., 2007), whereas severe or frequent rainfall subsequently the application might cause herbicide leaching (Pacanoski and Mehmeti, 2021; Soukup et al., 2004) and herbicide dilution (Kanampiu et al., 2003).

The aim of research was to contribute to the future of weed control through specific examples of the influence of agro-ecological factors on the action and effectiveness of herbicides in the changed conditions of the external environment, with the single and unique intention of keeping herbicides as the most effective, economical and justified measures in weed control.

2. INTERACTION CO_2 -HERBICIDE EFFICACY

The relevance of interaction CO_2 -herbicide efficacy has occupied research consideration in recent decades due to the constant increase of CO_2 atmospheric concentrations. Elevating CO_2 levels in the atmosphere might have prominent effects on weed phenology (Anwar et al., 2021), consequently altering herbicide effectiveness on weeds (Ziska, et al., 1999; Ziska and Teasdale, 2000; Ziska et al., 2004; Ziska and Runion, 2007). A particular one the most pronounced consequences of increased CO_2 concentrations is the minimizing of stomata conductivity, that might increase as far as 50% in many weed species (Bunce, 1993). Minimized number and stomatal conductance with increasing CO_2 could decrease transpiration resulting in decreased herbicide absorption and efficacy, particularly of PRE-em applied herbicides (Bunce and Ziska, 2000; Ziska and McClung, 2008; Ziska, 2008). Additionally, Nowak et al. (2004) and Ainsworth and Long, (2005) indicated that C_3 and C_4 weeds grown in condition of increased CO_2 concentrations have increased leaf pubescence and thicker cuticle. Apart from increasing leaf thickness, increased CO_2 concentrations might also generate partially stomatal closure (Ziska, 2008; Jackson et al., 2011). These characteristics might minimize uptake and efficacy of POST-em applied herbicides. Manea et al. (2011) found that in three of totally four C_4 grass weeds susceptibility to glyphosate in conditions of raised CO_2 is significantly decreased. Same findings were obtained by Ziska and Goins (2006). The explanations for the minimized effectiveness of the herbicides could be that elevating CO_2 increase leaf consistency and reduce stomatal number and their conductivity potentially reducing the absorption of POST-em applied herbicides. Furthermore, an increase in the apparent photosynthesis rates due to raised CO_2 concentrations, mainly in C_3 weeds, might cause rapid seedling growth, the highest susceptible stage for optimal control of weeds, which could modify the efficacy of POST-em herbicides. For example, *Chenopodium album*, a C_3 weed, demonstrated reduced sensitivity to glyphosate because of enhanced growth and plant biomass at raised CO_2 concentration (Ziska et al., 1999). In addition, perennial weeds might become more troublesome, in case vegetative growth to be encouraged due to increased photosynthesis in relation to increased CO_2. This might be because of a reduced amount of herbicide translocation since the root growth becomes more vigorous. In this context, *Elymus repens* (Ziska and Teasdale, 2000) and *Cirsium arvense* (Ziska et al., 2004) also showed prominent tolerance to glyphosate due to elevated CO_2 levels which caused large stimulation of below-ground growth. Elevate CO_2 levels increase concentration of starch in leaf tissue (Patterson, 1995), particularly in C_3 weeds (Wong, 1990), but reduce protein concentration (Bowes, 1996; Taub et al., 2008; Loladze, 2014). Reduction of protein content results in diminished requirement for branched chain and aromatic amino acids synthesis which might decrease the efficacy of many herbicides, such as ALS and EPSPS inhibitors (Patterson et al., 1999; Varanasi et al., 2016). Changed environmental conditions, particularly rising CO_2 and temperatures, stimulate weed growth through modification of photosynthesis, pigment production, as well as overall metabolic activity. Because of that, photosystem I and II and pigment inhibitors may become more effective. However, the effects of increasing CO_2 concentration on herbicide efficacy is determined by weed species. Namely, at twofold raised atmospheric CO_2 concentrations, effectiveness of metsulfuron in control of *Amaranthus retroflexus* was reduced by 4.6%, efficacy of imazethapyr in control of *Stellaria media* was unchanged, whereas efficacy of imazamethabenz-methyl over *Avena fatua* improved by 15.7% (Archambault et al., 2001). According to same authors, in the same conditions, efficacy of linuron in control of *Polygonum convolvulus* was reduced by 15%, whereas status quo in the efficacy was reported for metribuzin on *Chenopodium album* and bromoxynil on *Kochia scoparia,* respectively. The effects of increasing CO_2 on ACCase inhibitors varied depending on weed species. At double-environment CO_2 concentrations clodinafop efficacy in control of *Avena fatua* improved by 8.6%, while *Avena fatua* control was not affected by sethoxydim. No change in the efficacy was reported for control of *Avena fatua* and *Setaria viridis* by fluazifop (Archambault et al., 2001). Further, decreasing of clopyralid efficacy of 8.9% was noted in control of *Senecio vulgaris*, whereas increasing of efficacy of 2,4–D for 26.9% was obtained in control of *Polygonum convolvulus* (Archambault et al., 2001). Increased frequency of herbicide applications might exceed CO_2-caused declines in efficacy but might bring further hazards for human and animal health due to increase the occurrence of these chemicals in the agroecosystem, and ecosystem as a whole (Ziska et al., 2004).

3.INTERACTION TEMPERATURE-HERBICIDE EFFICACY

Temperature has multiple impacts on weed growth and development as well as herbicide efficacy. Alterations in the apparent photosynthesis rate, respiration, phloem translocation, and protoplasmic flux, as well as rate of water up take and transpiration, leaves formation, cuticle compactness and hydration, number and aperture of stomata will affect up take, diffusion, and herbicides metabolism (Bailey, 2004; Zanatta et al., 2008; Rodenburg et al., 2011). Higher temperature encourages stomata conductivity, reduced the viscosity of cuticle waxes, thus increasing the uptake and diffusion of herbicides due to modifications in the structure and the penetrability of the cuticle (Price, 1983; Chandrasena, 2009). Acifluorfen applied at lower day/night temperature regime (20/15 ºC) caused 70% higher production of cuticle lipids on the leaf surface of *Abutilon theophrasti* than treated plants in condition of higher day/night temperature (32/22 ºC). Decreasing of the cuticle lipids production related to better efficacy of herbicides in condition of increased temperature, corroborating the assumption of higher herbicide efficiency when cuticle structure altered. This investigation also confirmed that when temperature increased from lower to higher day/night temperature regime (20/15 ºC and 32/22 ºC, respectively) absorption of acifluorfen applied alone increased for 25%, but when it was applied with oil-based surfactant absorption increased for 99% (Hatterman-Valenti et al., 2011). Ganie et al. (2017) noted that the efficacy of 2,4-D and glyphosate in control of *Ambrosia artemisiifolia* and *Ambrosia trifida* might be enhanced if applied at higher day/night temperature regime (29/17 ºC), because of improved penetration and translocation in comparison with herbicide applications under lower day/night temperatures (20/11 ºC). Study in greenhouse conditions using various day/night temperatures (10/5, 20/15, and 25/20 °C) demonstrated that glufosinate applied at 1.200 g a.i. ha^{-1} provided poor control of *Raphanus raphanistrum* grown in conditions of lower temperatures (10/5 °C). Contrary, complete control of the weed was provided in condition of higher temperatures15/20 and 20/25 °C, respectively for the same herbicide rate (Kumaratilake and Preston, 2005), indicating increased glufosinate efficacy in condition of increased air temperatures. In study of Fausey and Renner, (2001) flumiclorac exhibited higher activity on *Amaranthus retroflexus* (threefold) and *Chenopodium album* (sevenfold) with increasing of temperatures from 10 °C to 40 °C. Johnson and Young, (2002) reported for threefold increase in mesotrione efficacy in control of *Abutilon theophrasti* and *Xanthium strumarium* with increasing of temperatures from 18 °C to 32 °C. Similarly, at higher temperature, fluthiacet was twice and three times more effective in control of *Amaranthus retroflexus* and *Chenopodium album*, respectively, in comparison with the efficacy recorded at 10 ºC (Fausey and Renner, 2001). Atrazine applied at 3:00 p.m. during the highest air temperature, provided greatest control of *Ambrosia artemisiifolia* and *Abutilon theophrasti* (Stewart et al., 2009). In other similar study, Stopps et al. (2013) confirmed that glyphosate efficacy in control of *Ambrosia artemisiifolia, Abutilon theophrasti*, and *Amaranthus* spp., increased when herbicide application was made between noontime and 18.00 h, which coincides with the highest daily air temperatures. Contrary, in investigation of Stewart et al. (2009), control of *Abutilon theophrasti* was poorly 45% when bromoxynil was applied at midnight, period with lowest air temperature during the day. Irrespective of daily temperature increasing/decreasing, *Chenopodium album Ambrosia artemisiifolia* and *Amaranthus retroflexus* were effectively controlled (>95%) with dicamba + diflufenzopyr. On the other hand, lower temperatures reduced control of *Abutilon theophrasti* by 7% to 15% with same herbicides (Stewart et al., 2009). Similar, in research of Ziska et al. (1999) glyphosate efficacy was reduced in control *Ambrosia trifida* and *Ambrosia artemisiifolia* at low temperatures.

Although the tendency of higher atmospheric temperatures is to enhance penetration and diffusion of many POST-em applied herbicides, in certain circumstances higher temperatures might cause hastened metabolism, which consequently decreases herbicide activity on target weeds (Johnson and Young, 2002). Enhanced metabolism rate was the reason for reduction of pinoxaden efficacy on *Brachypodium hybridum* control and other grasses in conditions of higher temperature (Matzrafi et al., 2019). Ou et al. (2018) tested influence of different temperatures on *Kochia scoparia* growth treated with dicamba and glyphosate under three day/night temperature regimes: 17.5/7.5 °C, 25/15 °C, and 32.5/22.5°C. Noticeable overhead dry plant biomass, injury and mortality symptoms indicated higher sensitivity to one and the other herbicide when *Kochia scoparia* was treated in conditions of the lower (17.5/7.5 °C and 25/15 °C, respectively) day/night temperatures. A similar trend was noted in investigation of Kleinman et al. (2016) when *Conyza bonariensis, Conyza canadensis,* and *Kochia scoparia* were treated with glyphosate. A significant variation in control of *Amaranthus palmeri* with mesotrione was obtained when the weed was grown in conditions of low and high day/night temperature regimes (25/15 °C and 40/30 °C, respectively) in comparison with optimum day/night temperature (32.5/22.5 °C). Related to weed above-ground biomass, injury, and death, *Amaranthus palmeri* was less susceptible at 40/30 °C to mesotrione and more susceptible at 25/15 °C in comparison with 32.5/22.5 °C (Godar et al., 2015). Pyrithiobac provided higher efficacy in control of *Amaranthus palmeri* at 18 ºC (25% dry weight accumulation) than at 40 ºC (70% dry weight accumulation), although the highest efficacy was recorded at 27 ºC (only 2.5% dry weight accumulation) (Mahan et al., 2004). Mesotrione efficacy in control of *Digitaria sanguinalis* and *Amaranthus rudis* decreased by six and seven-fold with temperature increasing from 18 °C to 32 °C (Johnson and Young, 2002). Increased temperatures as well as increased metabolism rate of the weeds nullify enhanced translocation of herbicides, because herbicide metabolisation enhance at higher temperature, as well (Martini et al., 2015; Matzrafi et al., 2019). Higher temperatures also might generate diminishing of herbicide absorption because of quick evaporation of herbicide droplets from the leaf surface (Devine et al., 1993) and volatility of some herbicides, such as growth regulators herbicides causing evaporable drift and potential injury on non-target broadleaved crops (van Rensburg and Breeze, 1990; Strachan et al., 2010).

Further, soil temperature has an effect on the penetration and diffusion of PRE-em applied herbicides within the weed plant, as well as herbicide soil persistence (Rodenburg et al., 2011). Warmer soil temperatures might reduce efficacy of PRE-em herbicides through rising volatility and degradation by soil microorganisms. For example, soil-applied triallate is highly volatile in condition of higher temperatures. According to Atienza et al. (2001) losses of triallate raised from 7% to 41% in loamy soil and 14% to 60% in sandy soil, respectively when temperatures elevate from 5 °C to 25 °C. Opposite, in the controlled trial conditions, efficacy of alachlor and EPTC decreased at low soil temperatures (near 10 °C) (Mulder and Nalewaja, 1978).

4. INTERACTION RELATIVE HUMIDITY-HERBICIDE EFFICACY

Relative humidity (RH) is mainly important for the behavior of POST-em herbicides throughout its acting on herbicide absorption, including contacts among the spray drops, leaves cuticle, and accessibility of the water in or round drops (Devine et al., 1993). In conditions of higher RH, cuticle hydrating and stomatal conductivity increases, consequently increases the penetrability and translocation particularly of hydrophilic herbicides within the leaves (Kudsk et al., 1990; Wichert et al., 1992; Shaw et al., 2000; Hatterman-Valenti et al., 2011). Penetration as well as efficacy of most POST-em herbicides is usually higher if weeds are subjected to higher RH after than before application, concluding that slowly droplets dried might be the reason for greater herbicide efficacy at higher RH conditions instead of cuticle hydrating (Ramsey et al., 2002). Results of Johnson and Young (2002) showed that efficacy of mesotrione in control of *Digitaria sanguinalis* and *Amaranthus rudis* to was two and four-times higher at RH of 85% then at 30%. Similar, glufosinate ammonium efficacy in control of *Avena fatua* significantly increased (>95%) at higher RH compared with its efficacy at lower (40%) RH. Additionally, higher penetration of glufosinate ammonium was recorded when plants of *Avena fatua* were subjected to condition of higher RH half-hour before and after application in comparison with plants exposed to constantly lower RH (Ramsey et al., 2002). According to Ritter and Coble (1981), acifluorfen provided 30% higher efficacy on *Ambrosia artemisiifolia* and *Xanthium strumarium* during its application at 85% RH in comparison with its efficacy at 50% RH. Likewise, Wichert et al. (1992) stated that lactofen, acifluorfen and fomesafen, significantly reduced the amount of *Ipomoea hederaceae* var. *integriuscula, Ipomoea lacunosa*, *Sida spinosa,* and *Xanthium* strumarium in condition of 85% RH, then at 50% RH. Similarly, on trials carried out for two repeated years Shaw et al. (2000) concluded that acifluorfen provided higher control of *Xanthium strumarium* in the second year when RH was higher. Casley and Coupland (1985) stated that higher RH increased glyphosate performance due to slower evaporation from the plant surface, while Mathiassen and Kudsk (1996) claimed that higher RH had no significant influence on glyphosate efficacy.

5. INTERACTION SUNLIGHT INTENSITY-HERBICIDE EFFICACY

Alterations in sunlight intensities influence the plants anatomy, morphology, and physiology, which consequently have an effect on herbicide performance in the plants. Stomatal conductivity and leaf cuticle formation are closely related with intensity of the light (Hull et al., 1975; Raschke et al., 1978). Under conditions of higher irradiation, stomata stay open, photosynthetically rate increases consequently increasing uptake, penetration and subsequent phloem translocation of POST-em applied herbicides in weed plant tissue (Fausey and Renner, 2001; Hwang et al., 2004; Camargo et al., 2012). Efficacy of clethodim, tralkoxydim and bentazon proportionally increased with increasing of sunlight intensity (McMullan, 1996, Hatterman-Valenti et al., 2011). In study of Fausey and Renner, (2001) flumiclorac provided nine times higher control of *Chenopodium album* in condition of higher irradiance intensity (1.000 μmol m^{-2} s^{-2}) compared to lower one (4 μmol m^{-2} s^{-2}). Control of *Amaranthus retroflexus* was 15 times more effective with the same herbicide under higher light intensity than at lower one. In same study, fluthiacet provided higher control of *Chenopodium album* and *Amaranthus retroflexus* at irradiance condition of 1000 μmol m^{-2} s^{-2}, in comparison with efficacy obtained at 4 μmol m^{-2} s^{-2}. Similar, oxadiargyl and oxadiazon applied during the daylight significantly reduced amount of *Echinochloa crus-galli*, but both were completely ineffective applied in the darkness condition (Hwang et al., 2004). UV light reduced the efficacy of tralkoxydim and clethodim, which indicates that application of these graminicides when sunlight intensity is higher during the day might increase their efficacy. Filtering UV light 4 hours after application increased efficacy of these herbicides from 13 to 55% (McMullan, 1996). UV light is obviously significant for efficacy of cyclohexanedione herbicides due to their instability in UV light (Campbell and Penner, 1985; Falb at al., 1990; McInnes et al., 1992). Similar, ^{14}C-paraquat penetration and efficacy in control of *Abutilon theophrasti*, *Chloris virgata* and *Digitaria sanguinalis* was reduced during the UV-B treatment because of increasing leaf epicuticular wax deposition (Wang et al., 2007). Oppositely, in lower irradiance conditions, tendency of plants is to form thinly leaves with smooth leaf structure and heigher plant to catch accessible sunlight required for photochemical synthesis. Such adjustments in weed structure and leaf morphology determinate the herbicide quantity that is received and held by the weed (Upasani and Barla, 2018). For example, surface coverage as well as absorption of POST-em herbicides is enhanced in weed with higher branching, whereas leaves with thicker structure retard herbicides penetration causing decreased herbicide efficacy (Riederer and Schonherr, 1985).

6. INTERACTION DROUGHT AND RAINFALL PATTERN-HERBICIDE EFFICACY

Herbicides might become less effective because of alteration of the outdoor conditions (drying and warming environment) or alterations in morphology, biology, and phenology of the weedy plants (Chauhan et al., 2014; Clements et al., 2014; Ziska and McConnell, 2015). In this context, POST-em herbicides might be significantly influenced by drought. Drought might cause enlarged cuticle thickness and intensify growth of leaf hairiness, with consequent minimization in herbicide penetration within the leaves (Patterson, 1995). For example, the weed cuticle under arid conditions was 50-80% thicker relative to optimal available water situations (Hatterman-Valentiet al., 2011). Increasing aridity and drought might reduce herbicide penetration, intensify herbicide volatilization, and consequently reduce its effectiveness. Drought-influenced weed populations are more challenging for managing with POST-em applied herbicides compared to weeds which actively grow in conditions without environmental stress. For example, for systemic POST-em applied herbicides is necessary active weed growth to be effective. In that context, in conditions of drought spells efficacy of glyphosate in control of *Abuthilon theophrasti* was reduced two and eight–fold when it was applied in two and six leaves weed growth stages, respectively (Zhou et al., 2007). Survival of glyphosate-resistant biotype of *Echinochloa colona* treated with double glyphosate rate (1440 g ha^{-1}) in condition of no water deficiency was only 19%, but under water deficiency this value increased by 62% (Mollaee et al., 2020). Likewise, under dry soil conditions usually activity of PRE-em herbicides is reduced due to strong herbicide soil adsorption (Arıkan et al., 2015). These herbicides depend heavily on accessible water for relocation in the weed seed germination zone (Olson et al., 2000). Herbicide photodecomposition is a common process which takes place on the surface of the soil, and in case that optimal damp is not accessible in period of short period after herbicide applications, control of weed is ususally inadequate. Even for considerably persistent herbicides, inability to penetrate into the soil surface because of the moisture shortage gives weeds the opportunity to germinate without any herbicide injuries. Jursık et al. (2013) claimed a reduced pethoxamid efficacy under dry soil conditions. Contrary, increased soil moisture promotes the efficacy of many, PRE-em applied herbicides, including inhibitors of protoporphyrinogen oxidase (Hatterman-Valenti et al., 2011).

Rainfall after POST-em herbicides application might reduce their efficiency through washing out. Frequent and intensify precipitation would have negative implications on penetration, translocation, and efficacy of herbicides applied PRE-em (Bailey, 2004; Rodenburg et al., 2011). An unusual increase in precipitation might cause leaching of PRE-em herbicides (Soukup et al., 2004; Pacanoski and Mehmeti, 2021), and consequent crop injury (Pacanoski et al., 2020) and under soil water contamination (Froud-Williams, 1996). From the other side, scarce rainfall amounts during the season might cause water-deficit conditions that impact herbicide efficacy (Zanatta et al., 2008; Keikotlhaile, 2011). For example, situations of water deficit reduced the absorption of acifluorfen (Hatterman-Valenti et al., 2011). Pereira et al. (2011) noted that *Eleusine indica* grown in conditions of water-stress was not effectively controlled by sethoxydim. Similarly, control of *Eleusine indica* with fenoxaprop-p-ethyl, topramezone, foramsulfuron, 2,4-D plus dicamba plus MCPP plus carfentrazone, and thiencarbazone-methyl plus foramsulfuron plus halosulfuron-methyl at soil moisture contents < 12% was unsatisfactory (Shekoofa et al., 2020). According to Pereira (2010), *Urochloa plantaginea* grown in conditions of water deficiency was less susceptible to Acetyl CoA Carboxylase (ACCase) inhibitors applied in advance weed growth stages.

7. MULTIPLE INTERACTIONS

Atmospheric CO_2 and air temperature elevate simultaneously. The result could be completely unlike if both environmental factors are considered simultaneously in comparison if separately are taken into account**.** In weeds, alteration in temperatures and CO_2 concentrations might modify net photosynthetically rates resulting with modification in carbohydrate accessibility and stability causing in altered weed physiological and biochemical capabilities. Increased CO_2 and atmospheric temperature might decrease herbicide efficacy by changing herbicide penetration, translocation and metabolism, subsequently increasing herbicide decomposition in weeds and decreasing herbicide availability for the target weed (Matzrafi, 2018). For example, reduced glyphosate susceptibility was observed in *Conyza canadensis* and *Chenopodium album* in response to elevated (32/26 °C) temperature in combination with raised (720 ppm) CO_2. According to obtained results by Matzrafi et al. (2019), 61.1%, 69.0% and 64.0%, of the glyphosate treated plants of *Conyza canadensis* and *Chenopodium album* survived under conditions of mutual effects of higher temperature/elevated CO_2 concentration. Further, the efficacy of cyhalofop-butyl was reduced about 50% in multiple-resistant *Echinochloa colona* plants grown under higher CO_2 concentration (700 ± 50 ppm) and high (35/23 ºC) day/night temperature regime compared to multiple-resistant plants grown at normal atmospheric conditions. Higher CO_2 and temperatures increased the level of resistance to multiple-resistant *E. colona* to cyhalofop-butyl, as well (Refatti et al., 2019). Opposite, mutual effects of CO_2 ambient concentration (400-450 ppm) and day/night temperature (20/10 °C) and increased CO_2 concentrations (400-450 ppm, 800-900 ppm) and day/night temperature regime (25/15 °C), did not reduce efficacy of glyphosate in control of *Lactuca serriola*, *Hordeum murinum*, and *Bromus tectorum* (Jabran and Doğan, 2018). Interaction between CO_2 concentrations and water deficiency was studied by Weller et al. (2019). According to their results, efficacy of glyphosate in control of GR and GS *Chloris truncata* biotypes in condition of moisture stress (50% field capacity) and increased CO_2 level (750 ppm) was significantly reduced. Few studies have examined correlation between temperatures and RH. When higher temperatures are related with higher RH levels, there is increased cuticle hydrating, which consequently increases herbicides penetration and efficacy (Price, 1983). With simultaneous temperature and RH increasing, the efficacy of metribuzin also increased, while at lower temperatures (10 °C and 20 °C) caused no significant decrease in its efficacy (Gealy and Buman, 1989). On the other hand, glufosinate ammonium provided higher efficacy on *Setaria faberi* at higher RH as well as higher temperature (Anderson et al., 1993).

8. CONCLUSION

The successfulness of weed management is predicted to modify together with the changing of climatic conditions. In conditions of rising CO_2 and air temperature, and unpredictable drought spells and prolonged rainfall forecasts, the possibility of herbicides either to generate crop injure or being ineffective is expected, as well. Elevated CO_2 and temperatures might cause morpho-anatomical, physiological and biochemical changes in weeds, their growth and development that could impact on absorption, translocation, and metabolism and on the entire herbicides efficacy. Conditions of soil water deficiency decrease the activity of PRE-em herbicides, affect their persistence in the soil and the "windows" for herbicide effectiveness due to strong herbicide adsorption, while severe or frequent rainfall after the application may cause herbicide leaching and dilution. One-sided and repeated herbicide use is estimated to result in appearance of resistant weed biotypes. Changes in environmental conditions might hasten this. In these circumstances, additional herbicide applications at higher rates might be required to control those weeds, and, at the same time, additional activities increase the expenditure of weed control. Modification strategies exist, but the expenditures of realizing those strategies (for example, herbicide with new active ingredient, higher herbicide rates) are uncertain. Specific national legislation regulated herbicides use. In case of changing environmental conditions, which encourage weed species spreading out of their geographical boundaries, new herbicidal active ingredient might be essential to control them effectively. Commonly it is time consuming to obtain an agreement of state for a new herbicide active ingredient or an active ingredient that previously has not been used.

9. REFERENCES

Ainsworth, E.A., Long, S.P. (2005). What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. New Phytology, 165, 351-371.

Amare, T. (2016). Review of the impact of climate change on weed and their management. J. Agric. Biol. Environ. Stat., 2, 21-27.

Anderson, D.M., Swanton, C.J., Hall, J.C., Mersey, B.G. (1993). The influence of temperature and relative humidity on the efficacy of glufosinate–ammonium. Weed Research, 33, 139-147.

Anwar, M.P., Islam, A.K.M.M., Yeasmin, S., Rashid, M.H., Juraimi, A.S., Ahmed, S., Shrestha, A. (2021). Weeds and their Responses to Management Efforts in a Changing Climate. Agronomy, 11, 1921.

Archambault, D.J., Li, X., Robinson, D., O'Donovan, J.R., Klein, K.K. (2001). The effects of elevated CO_2 and temperature on herbicide efficacy and weed/crop competition. Report to the Prairie Adaptation Res. Coll., No. 29.

Arıkan, N., Burçak, A.A., Türktemel, I., Akbas, A. (2015). Persistence of herbicide in soil. The Turkish Journal of Occupational/Environmental Medicine and Safety, 1, 2(2).

Atienza, J., Tabernero, M.T., A´lvarez-Benedı´, J., Sanz, M. (2001). Volatilisation of triallate as affected by soil texture and air velocity. Chemosphere, 42, 257–261.

Bailey, S.W. (2003). Climate change and decreasing herbicide persistence. Pest Management Science, 60, 158-162.

Billore, S.D. (2019). Weeds in Soybean vis-a-vis other Crops under Climate Change– A Review. Soybean Research, 17(1-2), 1-21.

Bowes, G. (1996). Photosynthetic responses to changing atmospheric carbon dioxide concentration.1n photosynthesis and the Environment, Baker, N.R. (Ed.), Kluwer Publishing, Dordrecht, The Netherlands, 387-407.

Bunce, J.A. (1993). Growth, survival, competition, and canopy carbon dioxide and water vapor exchange of first year alfalfa at an elevated CO_2 concentration. Photosynthetica, 29, 557-565.

Bunce, J.A., Ziska, L.H. (2000). Crop ecosystem responses to climatic change: crop/weed interactions. In: Reddy, K.R., Hodges, F. (Eds.), Climate Change and Global CropProductivity. CABI, New York, 333-348.

Camargo, E.R. Senseman S.A., McCauley G.N., Bowe S., Harden J., Guice J.B. (2012). Interaction between saflufenacil and imazethapyr in red rice (*Oryza* ssp.) and hemp sesbania (*Sesbania exaltata*) as affected by light intensity. Pest Management Science, 68(7), 1010-1018.

Campbell, J.R., Penner, D. (1985). Abiotic transformation of sethoxydim. Weed Science, 33, 435-439.
Chandrasena, N. (2009). How will weed management change under climate change? Some perspectives. Journal of Crop Weed, 5(2), 95-105.
Chauhan, B.S., Prabhjyot-Kaur Mahajan, G., Randhawa, R.J., Singh, H., Kang, M.S. (2014). Global warming and its possible impact on agriculture in India. Adv. Agron., 123, 65-121.
Clements, D.R., DiTommaso, A., Hyvönen, T. (2014). Ecology and management of weeds in a changing climate. In: Chauhan, B.S., Mahajan, G. (Eds.). Recent Advances in Weed Management. Springer, NY, 13-37.
Davidson, A.M., Jennions, M., Nicotra, A.B. (2011). Do invasive species show higher phenotypic plasticity than native species and, if so, is it adaptive? A metaanalysis. Ecol Lett, 14, 419-431.
Devine, M.D., Duke, S.O., Fedtke, C. (1993). Foliar Absorption of Herbicides. Prentice–Hall, Englewood Cliffs, NY, 29-52.
Dukes, J.S., Mooney, H.A. (1999). Does global change increase the success of biological invaders? Trends. Ecol. Evol., 14(4), 135-139.
Dukes, J.S., Pontius, J., Orwig, D., Garnas, J.R., Rodgers, V.L., Brazee, N., Cooke, B., Theoharides, K.A, Stange, E.E., Harrington, R., Ehrenfeld, J., Gurevitch, J., Lerdau, M., Stinson, K., Wick, R., Ayres, M. (2009). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: what can we predict? Can J For Res, 39, 231-248.
Falb, L.N., Bridges, D.C., Smith, A.E.Jr. (1990). Effect of pH and adjuvants on clethodim photodegradation. J. Agric. Food Chem., 38, 875-878.
Fausey, J.C., Renner, K.A. (2001). Environmental effects on CGA–248757 and flumiclorac efficacy/soybean tolerance. Weed Science, 49, 668-674.
Froud-Williams, R.J. (1996). Weeds and climate change: Implications for their ecology and control. Aspects of Applied Biology, 45, 187-196.
Fuhrer, J. (2003). Agroecosystem responses to combinations of elevated CO_2, ozone, and global climate change. Agr. Ecosyst. Environ., 97(1), 1-20.
Ganie, Z.A. Jugulam, M. Jhala A.J. (2017). Temperature Influences Efficacy, Absorption, and Translocation of 2,4–D or Glyphosate in Glyphosate-Resistant and Glyphosate–Susceptible Common Ragweed (*Ambrosia artemisiifolia*) and Giant Ragweed (*Ambrosia trifida*). Weed Science, 65, 588-602.
Gealy, D.R., Buman, R.A. (1989). Response of photosynthesis and growth of jointed goat grass and winter wheat to photosynthetic herbicides and temperature. Proceedings, Western Society of Weed Science, 42, 151-152.
Godar, A.S., Varanasi, V.K., Nakka, S., Prasad, P.V.V., Thompson, C.R., Mithila, J. (2015). Physiological and molecular mechanisms of differential sensitivity of Palmer amaranth (*Amaranthus palmeri*) to mesotrione at varying growth temperatures. PLoSONE, 10:e0126731.
Hatterman-Valenti, H. Pitty, A., Owen M. (2011). Environmental effects on velvetleaf (*Abutilon theophrasti*) epicuticular wax deposition and herbicide absorption. Weed Science, 59(1), 14-21.
Hatzios, K.K., Penner, D. (1982). Metabolism of herbicides in higher plants, CEPCO iv. Burgess Publ., Edina, MN.
Howden, S.M., Soussana, J.F., Tubiello, F.N., Chhetri, N., Dunlop, M., Meinke, H. (2007). Adapting agriculture to climate change. Proc. Natl. Acad. Sci., USA, 104, 19691–19696, doi.org/10.1038/s41598–019–38729–x
Hull, H.H., Morton, H.L., Wharrie, J.R. (1975). Environmental influences on cuticle development and resultant foliar penetration. Bot. Rev., 41, 421-452.
Hwang, I.T., Hong, K.S., Choi, J.S., Kim, H.R., Jeon, D.J., Cho, K.Y. (2004). Protoporphyrinogen IX–oxidizing activities involved in the mode of action of a new compound N–[4–chloro–2–fluoro–5–{3–(2–fluorophenyl)–5–methyl–4.5–dihydroisoxazol–5–yl–methoxyl–phenyl]–3,4,5,6–tetrahydrophthalimide. Pestic. Biochem. Physiol., 80(2), 123-130.

Jabran, K., Doğan, M.N. (2018). High carbon dioxide concentration and elevated temperature impact the growth of weeds, but do not change the efficacy of glyphosate. Pest Management Science, 74(3), 766-771.

Jackson, L., Wheeler, S., Hollander, A., O'Geen, A., Orlove, B., Six, J., Sumner, D.A., Santos-Martin, F., Kramer, J.B., Horwath W.R., Howitt R.E., Tomich T.P. (2011). Case study on potential agricultural responses to climate change in a California landscape. Clim. Change., 109, 407-427.

Johnson, B.C., Young, B.G. (2002). Influence of temperature and relative humidity on the foliar activity of mesotrione. Weed Science, 50, 157-161.

Jursík, M., Kočárek, M., Hamouzová, K., Soukup, J., Venclová, V. (2013). Effect of precipitation on the dissipation, efficacy and selectivity of three chloroacetamide herbicides in sunflower. Plant, Soil and Environment, 59, 175-182.

Kanampiu, F.K., Kabambe, V., Massawe, C., Jasi, L., Friesen, D., Ransom, J.K. Gressel, J. (2003). Multi–site, multi season field tests demonstrate that the herbicide seed-coating herbicide-resistance maize controls *Striga* spp. and increases yields in several African countries. Crop Prot., 22(5), 697-706.

Karl, T.R., Melillo, J.M., Peterson, T.C. (2009). Global climate change impacts in the United States. A state of knowledge report from the U.S. Global Change Research Program. Cambridge University Press, NY, USA, 196.

Keikotlhaile, B.M. (2011). Influence of the processing factors on pesticide residues in fruits and vegetables and its application in consumer risk assessment. PhD Dissertation, Ghent University, Ghent.

Kells, J.J., Meggitt, W.F., Penner, D. (1984). Absorption, translocation, and activity of fluazifop-butyl as influenced by plant growth stage and environment. Weed Science, 32, 143-149.

Kleinman, Z., Ben-Ami, G., Rubin, B. (2016). From sensitivity to resistance –factors affecting the response of *Conyza* spp. to glyphosate. Pest Management Science, 72, 1681-1688.

Kudsk, P., Olesen, T., Thonke, K.E. (1990). The influence of temperature, humidity and simulated rain on the performance of thiameturon–methyl. Weed Research, 30, 261-269.

Kumaratilake, A.R., Preston, C. (2005). Low temperature reduces glufosinate activity and translocation in wild radish (*Raphanus raphanistrum*). Weed Science, 53, 10-16.

Loladze, I. (2014). Hidden shift of the ionome of plants exposed to elevated CO_2 depletes minerals at the base of human nutrition. eLife 3:e02245

Madafiglio, G.P., Medd, R.W., Cornish, P.S., Van de Ven, R. (2000). Temperature mediated responses of flumetsulam and metosulam on *Raphanus raphanistrum*. Weed Research, 40, 387-395.

Mahan, J.R., Dotray, P.A., Light, G.G. (2004). Thermal dependence of enzyme function and inhibition; implications for herbicide efficacy and tolerance. Physiol. Plant., 20, 187-195.

Malarkodi, N., Manikandan, N., Ramaraj, A.P. (2017). Impact of climate change on weeds and weed management. J. Innov. Agric., 4, 1-6.

Manea, A., Leishman, M.R., Downey, P.O. (2011). Exotic C4 grasses have increased tolerance to glyphosate under elevated carbon dioxide. Weed Science, 59, 28-36.

Manisankar, G., Ramesh, T. (2019). Response of weeds under elevated CO_2 and temperature: A review. J. Pharmacogn. Phytochem., SP2, 427-431.

Martini, L.F., Burgos, N.R., Noldin, J.A., Avila, L.A., Salas, R.A. (2015). Absorption, translocation and metabolism of bispyribac–sodium on rice seedlings under cold stress. Pest Management Science, 71, 1021-1029.

Mathiassen, S.K., Kudsk, P. (1996). Influence of climate scenarios on herbicide performance. Second International Weed Control Congress, 3, 905-910.

Matzrafi, M. (2018). Climate change exacerbates pest damage through reduced pesticide efficacy. Pest Management Science, 75, 9-13.

Matzrafi, M. Brunharo, C. Tehranchian, P. Hanson, B.D. Jasieniuk, M. (2019). Increased temperatures and elevated CO_2 levels reduce the sensitivity of *Conyza canadensis* and *Chenopodium album* to glyphosate. Scientific Reports, 9, 2228.

McInnes, D., Marker, K.N., Blackshaw, R.E., Vanden Born, W.H. (1992). The influence of ultraviolet light on the phytotoxicity of sethoxydim tank mixtures with various adjuvants. In Foy, C.L. (Ed.), Adjuvants for Agrichemicals. CRC Press, Boca Raton. FL, 205-213.

McMullan, P.M. (1996). Grass herbicide efficacy is influenced by adjuvant, spray solution pH, and ultraviolet light. Weed Technology, 10, 72-77.

Medd, R.W., Van de Ven, R., Pickering, D.I., Nordblom, T. (2001). Determination of environment specific dose response relationships for clodinafop propargyl on *Avena* spp. Weed Research, 41, 351-368.

Mollaee, M., Mobli, A., Chauhan, B.S. (2020). The response of glyphosate-resistant and glyphosate-susceptible biotypes of Echinochloa colona to carbon dioxide, soil moisture and glyphosate. Scientific Reports, 10, 329. doi.org/10.1038/s41598-019-57307-9

Mulder, C.E.G., Nalewaja, J.D. (1978). Temperature effect of phytotoxicity of soil–applied herbicides. Weed Science, 26, 566-570.

Muzik, T.J. (1976). Influence of environmental factors on toxicity to plants. In Herbicides: Physiology, Biochemistry, Ecology, Audus, L.J. (Ed.), Academic Press, NY, 203-247.

Nowak, R.S., Ellsworth D.S., Smith S.D. (2004). Functional responses of plants to elevated atmospheric CO2: do photosynthetic and productivity data from FACE experiments support early predictions? New Phytol., 162, 253-280.

Oechel, W.C., Strain, B.R. (1985). Native species responses to increased atmospheric carbon dioxide concentration. In: Strain, B.R., Cure, J.D. (Eds.), Direct Effects of Increasing Carbon Diox-ide on Vegetation. University Press of the Pacific, Honolulu, HI.

Olesen, J.E., Bindi, M. (2002). Consequences of climate change for European agricultural productivity, land use and policy. Eur. J. Agron., 16, 239-262.

Olson, B.L., Al-Khatib, K., Stahlman, P., Isakson, P. J. (2000). Efficacy and metabolism of MON 37500 in *Triticum aestivum* and weedy grass species as affected by temperature and soil moisture. Weed Science, 48, 541-548.

Ou, J., Stahlman, P.W., Jugulam, M. (2018). Reduced absorption of glyphosate and decreased translocation of dicamba contribute to poor control of kochia (*Kochia scoparia*) at high temperature. Pest Management Science, 74, 1134-1142.

Pacanoski, Z. Mehmeti, A. (2021). Weed control in sunflower (*Helianthus annuus* L.) with soil–applied herbicides affected by a prolonged and limited rainfall. Agriculture, 27(2), 3-14.

Pacanoski, Z., Kolevska, D.D., Mehmeti, A. (2020). Tolerance of black locust (*Robinia pseudoacacia* L.) seedlings to PRE applied herbicides. Agriculture and Forestry, 66(2), 157-165.

Patterson, D.T. (1995). Weeds in a changing climate. Weed Science, 43, 685-701.

Patterson, D.T., Westbrook, J.K., Joyce, R.J.C., Lingren, P.D., Rogasik, J. (1999). Weeds, insects and diseases. Clim. Change, 43, 711-727.

Pereira, M.R.R. (2010). Effect of herbicides on *Brachiaria plantaginea* plants submitted to water stress. Planta Daninha, 28, 1047-1058.

Pereira, M.R.R., Souza, G.S.F., Martins, D., Melhoranc¸A., Filho, A.L., Klar, A.E. (2011). Responses of *Eleusine indica* plants under different water conditions to ACCase-inhibiting herbicides. Planta Daninha, 29, 397–404.

Poorter, H., Navas, M. (2003). Plant growth and competition at elevated CO_2: on winners, losers and functional groups. New Phytologist, 157, 175-198.

Price, C.E. (1983). The effect of environment on foliage uptake and translocation of herbicides.In: Biologists, A.O.A. (Ed.), Aspects of Applied Biology 4: Influence of Environmental Factors on Herbicide Performance and Crop and Weed Biology, vol. 4. The Association of Applied Biologists, Warwick, 157-169.

Ramsey, R.J.L., Stephenson, G.R., Hall, J.C. (2002). Effect of relative humidity on the uptake, translocation, and efficacy of glufosinate ammonium in wild oat (*Avena fatua*). Pestic. Biochem. Physiol., 73, 1-8.

Raschke, K., Hanebuth, W.F., Farquhar, G.D. (1978). Relationship between stomatal conductance and light intensity in leaves of *Zea mays* L., derived from experiments using the mesophyll as shade. Planta, 139, 73-77.

Refatti, J.P., de Avila, L.A., Camargo, E.R., Ziska, L.H., Oliveira, C., Salas-Perez, R., Rouse, C.E., Roma–Burgos, N. (2019). High (CO_2) and Temperature Increase Resistance to Cyhalofop-Butyl in Multiple-Resistant *Echinochloa colona*. Frontiers in Plant Science, 10, 529.

Riederer, M., Schonherr, J. (1985). Accumulation and transport of (2,4-dichlorophenoxy) acetic acid in plant cuticles: II. Permeability of the cuticular membrane. Ecotoxicol. Environ. Safety, 9, 196-208.
Ritter, R.L., Coble, H.D. (1981). Influence of temperature and relative humidity on the activity of acifluorfen. Weed Science, 29(4), 480-485.
Rodenburg, J., Meinke, H., Johnson, D.E. (2011). Challenges for weed management in African rice systems in a changing climate. J. Agric. Sci., 149, 427-435.
Shekoofa, A., Brosnan, J.T., Vargas, J.J. Tuck, D.P., Elmore, M.T. (2020). Environmental effects on efficacy of herbicides for postemergence goosegrass (*Eleusine indica*) control. Scientific Report, 10, 20579. doi.org/10.1038/s41598-020-77570-5
Sharma, S.D., Singh, M. (2001). Environmental factors affecting absorption and bio–efficacy of glyphosate in Florida beggarweed (*Desmodium tortuosum*). Crop Protection, 20, 511-516.
Shaw, D.R. Morris, W.H., Webster, E.P., Smith, D.B. (2000). Effects of spray volume and droplet size on herbicide deposition and common cocklebur (*Xanthium strumarium*) control. Weed Technology, 14(2), 321-326.
Singh, R.P., Singh, R.K., Singh, M.K. (2011). Impact of climate and carbon dioxide change on weeds and their management a review. Indian Journal of Weed Science, 43(1-2), 1-11.
Soukup, J., Jursı́k, M., Hamouz, P., Holec, J., Krupka, J. (2004). Influence of soil pH, rainfall,dosage, and application timing of herbicide Merlin 750 WG (isoxaflutole) on phytotox–icity level in maize (*Zea mays* L.). Plant Soil Environ, 50, 88-94.
Stewart, C.L., Nurse, R.E., Sikkema, P.H. (2009). Time of day impacts postemergence weed control in corn. Weed Technology, 23, 346-355.
Stopps, G.J., Nurse, R.E., Sikkema, P.H. (2013). The effect of time of day on the activity of post emergence soybean herbicides. Weed Technology, 27, 690-695.
Strachan, S.D., Casini, M.S., Heldreth, K.M., Scocas, J.A., Nissen, S.J., Bukun, B., Lindenmayer, R.B., Shaner, D. L., Westra, P., Brunk, G. (2010). Vapor movement of synthetic auxin herbicides: aminocyclopyrachlor, aminocyclopyrachlor-methyl ester, dicamba, and aminopyralid. Weed Science, 58, 103-108.
Sutherland, W.J., Barnard, P., Broad, S., Clout, M., Connor, B., Côté, I.M., Dicks, L.V., Doran, H., Entwistle, A. C., Fleishman, E., Fox, M., Gaston, K.J., Gibbons, D.W., Jiang, Z., Keim, B., Lickorish, F.A., Markillie, P., Monk, K.A., Pearce–Higgins, J.W., Peck, L.S., Pretty, J., Spalding, M.D., Tonneijck, F.H., Wintle, B.C., Ockendon, N. (2017). A 2017 Horizon Scan of Emerging Issues for GlobalConservation and Biological Diversity. Trends Ecol. Evol., doi.org/10.1016/j.tree.2016.11.005
Taub, D.R., Miller, B. Allen, H. (2008). Effects of elevated CO_2 on the protein concentration of food crops: a meta-analysis. Global Change Biology, 14, 565-575.
Upasani, R.R., Barla, S. (2018). Weed dynamics in changing climate. Int.J.Curr.Microbiol.App.Sci., Special Issue, 7, 2554-2567.
Van Rensburg, E., Breeze, V.G. (1990). Uptake and development of phytotoxicity following exposure to vapour of the herbicide ^{14}C 2,4-d butyl by tomato and lettuce plants. Environ. Exp. Bot., 30, 405-414.
Varanasi, A., Prasad, P.V.V., Jugulam, M. (2016). Impact of climate change factors on weeds and herbicide efficacy, In Advances in Agronomy, Sparks, D.L. (Ed.), 107-146.
Wang, S., Duan, L., Li, J., Tian, X., Li, Z. (2007). UV-B radiation increases paraquat tolerance of two broad-leaved and two grass weeds in relation to changes in herbicide absorption and photosynthesis. Weed Research, 47(2), 122-128.
Weller, S., Florentine, S.K., Mutti, N.K., Jha, P.K., Chauhan, B.S. (2019). Response of Chloris truncata to moisture stress, elevated carbon dioxide and herbicide application. Scientific Reports, 9, 10721. doi.org/10.1038/s41598-019-47237-x
Wichert, R.A., Bozsa, R., Talbert, R.E., Oliver, L.R. (1992). Temperature and relative-humidity effects on diphenylether herbicides. Weed Technology, 6(1), 19-24.
Wong, S.C. (1990). Elevated atmospheric partial pressure of CO_2 and plant growth. II. Non-structural carbohydrate content in cotton plants and its effect on growth parameters. Photosynthesis Research, 23, 171-180.
Zanatta, J.F., Procópio, S.O., Manica, R., Pauletto, E.A., Cargnelutti Filho, A., Vargas, L., Sganzerla, D.C., Rosenthal, M.D.A., Pinto, J.J.O. (2008). Soil water contents and fomesafen efficacy in controlling *Amaranthus hybridus*. Planta Daninha, 26, 143-155.
Zhou, J., Tao, B. Messersmith, C.G., Nalewaja, J.D. (2007). Glyphosate efficacy on velvetleaf (*Abutilon theophrasti*) is affected by stress. Weed Science, 55, 240-244.
Ziska, L.H., Teasdale, J.R., Bunce, J.A. (1999). Future atmospheric carbondioxide may increase tolerance to glyphosate. Weed Science, 47, 608-615.

doi:10.46793/MAK2025.047A

INNOVATIVE INDEX FOR OPTIMIZING USING SALINE WATER IN IRRIGATION

Isam M. Abdulhameed[1*], Nese Yaman[2]

[1]Upper Euphrates Basin Developing Center, University of Anbar. Iraq
*isambayati@uoanbar.edu.iq
[2]Dicle University, Faculty of Agriculture, Dept. of Farm Structures and Irrigation, Diyarbakir, Türkiye, nuzen@dicle.edu.tr

Abstract: According to the climate change in arid and semi-arid regions, saline water will be used in irrigation to mitigate the water gap between available water resources and the water demand. Using saline water to expand the irrigated area was followed by decreasing the crop yield due to osmotic potential, so an optimal indicator must be prepared to optimize the use of saline water.

As climate changes effects water quantity and quality, the aim of this study is to mitigate the climate effects on water by improving the mathematical models and computer programs that are constructed to optimize the use of saline water in irrigation.

This paper proposes an innovative indicator depending on the use of two water resources, river high quality water (1dS/m), and saline drainage water (6dS/m). The relation between Total Dissolved Salts (TDS) and Electrical Conductivity (EC), in saline drainage water is derived from field data of 400 samples taken during 2 years from the Main Outfall Drain (MOD) in Iraq.

This paper proposes an innovative indicator depending on the use of two water resources, river high quality water (1dS/m), and saline drainage water (6dS/m). The relation between Total Dissolved Salts (TDS) and Electrical Conductivity (EC), in saline drainage water is derived from field data of 400 samples taken during 2 years from the Main Outfall Drain (MOD) in Iraq. The study concluded that there is a nonlinear relation between TDS and EC for saline water.

The Crop Productivity Index (CPI) is proposed in this study and defined as a ratio of the volume of fresh water saved according to the use of saline water to the yield losses due to salinity effects. As this ratio is a benefit-cost ratio, its value must be greater than 1, in this study, the CPI critical value is 1.1.

CPI depends on the water salinity and the crop tolerance to salinity, the maximum CPI value for 40 plants selected in this study is 6.43 for barely, (the highest field crop tolerance), while the lowest CPI is 0.4 for bean, (sensitive crop tolerance). The CPI values of many sensitive crops are less than the critical value, that means the irrigation of these crops by saline water is uneconomical financially insufficient.

CPI recommends that the relative yield of any crop irrigated by saline water must be more than 60% to optimize the saline water use.

Key words: Saline water, Crop production, Optimal irrigation, Water gap, Climate change

REFERENCES

Ayers, R.S., Westcot, D.W. (1985). Water quality for agriculture. Rome: Food and Agriculture Organization of the United Nations.

Wilcox, L.V. (1960). Boron injury to plants (No. 211). Agricultural Research Service, US Department of Agriculture.

Rhoades, J.D., Kandiah, A., Mashali, A.M. (1992). The use of saline waters for crop production-FAO irrigation and drainage paper 48. FAO, Rome, 133.

Abdulhameed, I.M. (2017). Maximizing irrigation water productivity by optimizing leaching fraction. Journal of Agricultural Science and Technology A, 7(2017), 73-80. doi.org/10.17265/2161-6256/2017.02.001

Kelly, W.P. (1940). Diagnosis and improvement of saline alkali soils: Agriculture, 160. Handbook 60. US Department of agriculture, Washington DC.

Ning, S., Zhou, B., Wang, Q., Tao, W. (2020). Evaluation of irrigation water salinity and leaching fraction on the water productivity for crops. International Journal of Agricultural and Biological Engineering, 13(1), 170-177. doi.org/10.25165/j.ijabe.20201301.5047

Hasham, G.J., Ramal, M.M. (2022). Water quality assessment of Euphrates River within fallujah city using water quality indices technique. International Journal of Design & Nature and Ecodynamics, 17(4), 563-570. doi.org/10.18280/ijdne.170410

Horneck, D.A., Ellsworth, J.W., Hopkins, B.G., Sullivan, D.M., Stevens, R.G. (2007). Managing salt-affected soils for crop production. Oregon State University. http://hdl.handle.net/1957/20788

Grattan, S. (2002). Irrigation, water salinity and crop production. UCANR Publications.

Malloki, H.N. (2021). Programming the use of main outfall drain water for irrigation. MSc Thesis, Dams and water resources department, college of university of Anbar, Iraq.

Abdulhameed, I.M. (2010). Management of using saline irrigation water under different rainfall conditions. Iraqi Journal for Civil Engineering, 7(1), 1-9.

Corwin, D.L. (2021). Climate change impacts soil salinity in agricultural areas. European Journal of Soil Science, 72(2). doi.org/10.1111/ejss.13010 842-862.

Maas, E. (1993). Testing crops for salinity tolerance. In Proc. workshop on adaptation of plants to soil stresses, 34, 247-247.

Ayers, R.S., Westcot, D.W. (1985). Water Quality for Agriculture. Rome: Food and Agriculture Organization of the United Nations.

FAO (1999). Soil salinity Assessment. Rome. Italy.

Alzubaydi, A. (1990). Soil Salinity, Theoretical and Practical Foundations. University of Baghdad-Iraq, in Arabic.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.049S

THE RELATION BETWEEN THE FOOD EXPENDITURE AND THE RELATIVE POVERTY IN ROMANIA

Cosmin Salasan[1*], Carmen Simona Dumitrescu[2], Cosmina Toader[2], Cristian Gaina[2], Raul Pascalau[3]

[1]Universidad Catolica del Maule/University of Life Sciences "King Mihai I" Timisoara, Romania, *carmendumitrescu@usvt.ro
[2]University of Life Sciences "King Mihai I" Timisoara, Faculty of Management and Rural Tourism, Romania
[3]University of Life Sciences "King Mihai I" Timisoara, Faculty of Agriculture, Romania

Abstract: This research aims to look at how the percentage of money spent on food relates to total household spending as a sign of poverty in Romania. It focuses on the important question of how high food prices affect financial stability and living conditions. To evaluate this connection and its effects on measuring poverty, data on household income, spending habits, and differences in prices across regions is necessary. This paper looks at how food spending relates to total household spending as a way to indicate poverty in Romania. It shows how high food costs can impact financial stability and living standards. The study uses data about household income, spending habits, and different regional prices. It finds that households spending a larger share on food generally have lower overall expenditures, meaning they are more likely to experience poverty. The results suggest that when a big part of a household budget goes to food, it points to financial struggles and may also lead to worse health outcomes. This is because tight budgets limit access to essential healthcare and nutritious food. Furthermore, this research adds to the conversation about how to measure poverty by arguing that food spending ratios can help identify populations at risk, which can help shape public policy and social programs aimed at bettering health equity in Romania. In conclusion, the study highlights the need for policymakers to pay attention to food spending patterns when assessing poverty, pointing out how economic issues and health inequalities are connected. This could help create better strategies for improving the well-being of vulnerable groups in Romania.

Key words: Food expenditure, Household income, Poverty

1. INTRODUCTION

Understanding and addressing poverty is very important in socio-economic development, especially in countries like Romania that are changing economically. Even though Romania has made steps in economic growth since it joined the European Union, the country still deals with issues of poverty and inequality, worsened by high living costs and differences between regions. Food expenses take up a large part of household budgets, raising concerns about how well it serves as an indicator of poverty. Many studies have shown that the amount of income spent on food relates to household welfare, indicating that higher food costs might mean more vulnerability to poverty (Galindo and Nuguer, 2023; OECD, 2019). However, the unique situation in Romania requires more in-depth study, especially regarding how food spending affects assessments of household finances and overall poverty levels (OECD, 2018). The main research question for this paper is to investigate how food expenditure could serve as an effective marker for poverty among Romanian households. The outcomes of this study could influence public policies and social initiatives aimed at reducing poverty, helping to ensure economic stability and better living conditions (Sotiroski et al., 2023; Briciu, 2014). Additionally, food expenditure indicating poverty can lead to more focused and effective support for vulnerable groups, ultimately aiding in the development of comprehensive strategies for poverty reduction in Romania (Dan and Porumbescu, 2012; Torsheim et al., 2015;

Robinson, 2015). Because of the risks tied to food consumption and the large part of household budgets usually spent on food, food spending has become a key area for looking at poverty levels. Studies indicate that a higher amount of food spending often comes with lower total household spending, pointing to a negative link that shows economic struggle (Galindo and Nuguer, 2023; OECD, 2019). This pattern is especially important in Romania, where changing food prices and slow wage growth have worsened the challenges for lower-income families, increasing the need for effective ways to measure poverty (OECD, 2018; Wagstaff et al., 2017a,b). Understanding how food spending relates to the economic well-being of households is crucial for evaluating poverty and creating social policies. In Romania, where the economy has been impacted by historic changes and modern global factors, the proportion of food spending in a household's overall costs is a key factor for poverty evaluation. Research shows that spending a lot of income on food often points to financial stress and highlights issues related to food security, resource access, and general quality of life. The literature review aims to summarize existing research on this topic, drawing connections between food expenditure patterns and poverty indicators in Romania. By examining current findings and identifying key gaps in the literature, the study seeks to enhance understanding of poverty measurement in Romania. Early research revealed that households devoted an unbalanced share of their income to necessities like food, suggesting that food spending could effectively signal poverty levels (Galindo and Nuguer, 2023). Many studies confirmed this trend, underlining the link between high food expenditure and low household income levels (OECD, 2019). Entering the 2000s, Romania's entry into the European Union introduced new economic factors. Scholars noticed that while the overall economy started to improve, disparities continued. Food spending remained high, especially in rural areas, where families often devoted over 50% of their income to nourishment (Wagstaff et al., 2017a,b). This ongoing issue provided policymakers with a clear metric for tackling poverty and developing welfare programs. Recent research has built upon this foundation, using multidimensional poverty indices that underline the need to consider aspects such as health and education alongside food spending (Kashlinsky et al., 2024; Tessore et al., 2024). The proportion of food expenditure within total household expenses is a critical indicator for assessing poverty levels, particularly in Romania. Research shows that higher food spending percentages indicate greater vulnerability to poverty, as families allocate more of their limited resources to basic needs. For example, studies indicate that many Romanian households struggling financially often find their food expenses accounting for over half of their total spending, illustrating economic distress and limited disposable income (Galindo and Nuguer, 2023). Moreover, the connection between income level and food costs points to significant purchasing power differences. Households with lower incomes typically spend a larger share of their budgets on food, leaving less room for other essential needs like health and education (OECD, 2019). In rural areas, this issue is intensified due to limited economic opportunities and high food prices relative to earnings (OECD, 2018). Research focusing on the multifaceted nature of poverty suggests that merely looking at income poverty does not capture the realities faced by people in Romania. Thus, including food expenditure helps offer a broader view of household well-being and economic stability (Wagstaff et al., 2017a,b). The findings suggest that many Romanian households, especially in rural areas, spend a significant portion of their income - sometimes over 50% - on food, highlighting the delicate balance families must strike between meeting basic nutritional requirements and addressing other vital expenses like healthcare and education. Analyzing various methodologies - both quantitative and qualitative - reveals the complexities involved in defining poverty and the need for in-depth evaluations that consider the interconnected nature of food expenses, income levels, and regional differences.

The aim of research is to analyse (i) the relationship between food expenditure and poverty status and Romania, (ii) how food spending affects household well-being, (iii) how changes in food expenses reflect broader economic situations for families, (iv) how these trends might change based on social and demographic factors like income, education, and where they live, and (v) what is the efficient method for estimation food expenditure ratios to measure poverty effectively in Romania.

2. MATERIAL AND METHODS

In recent years, measuring poverty has become more complicated, especially in countries changing their economies like Romania. With living costs going up and income differences growing, it is important to understand how certain household spending can show poverty levels when trying to tackle social inequalities (Galindo and Nuguer, 2023). This research will look at how much food spending relates to total household spending and whether it can indicate poverty among Romanian families. Food spending is relevant as an indicator because it relates closely to a household's economic stability and access to nutrition, which are vital for health and well-being (OECD, 2019). Generally, traditional ways of measuring poverty depend mainly on income data, overlooking how consumption patterns - especially in food - are significant (Wagstaff et al., 2017a,b). This methodology aims to use quantitative methods, like regression analysis and econometric modeling, to show differences in food expenditure ratios among diverse socio-economic groups (Wagstaff et al., 2017a,b). This approach is based on earlier studies that have successfully used these techniques to explore household spending habits and their links to poverty (Kashlinsky et al., 2024). By examining a broad dataset that accounts for regional price differences, this research will add to existing literature, presenting a detailed view of food spending as a lifestyle indicator and a different way to assess economic hardship (Tessore et al., 2024).The importance of this methodology is not just in its contribution to academic research on poverty but also in its practical use. Insights gained can guide public policy and targeted efforts to reduce poverty in Romania (Sotiroski et al., 2023). Understanding how food spending is distributed can help policymakers better identify at-risk groups and create more effective social safety measures (Briciu, 2014). Therefore, this research intends to critically assess the relationship between food spending and poverty, aiming for a comprehensive understanding of economic stability and social fairness (Dan and Porumbescu, 2012). By incorporating household consumption trends into poverty evaluation, this methodology underscores the need for a well-rounded approach to measuring poverty in Romania (Torsheim et al., 2015). The main problem is figuring out the portion of food spending within total household expenses as a trustworthy measure of poverty, working to fix the issues with older, money-based poverty evaluations that miss important consumption details (Galindo and Nuguer, 2023). The numerical part involves looking at existing data from the National Institute of Statistics in Romania, which has thorough details on household income and spending divided into different categories, allowing for detailed econometric analysis (Wagstaff et al., 2017a,b). This approach is backed by earlier studies showing that large surveys can effectively show consumption traits as signs of poverty (Wagstaff et al., 2017a,b). This research plan's importance comes from its ability to help both academic work and practical policy creation, as it brings together factual data to create a richer understanding of poverty in Romania (Tessore et al., 2024). By linking food spending shares to different household features, this study can guide policymakers on the real needs and challenges faced by low-income families, leading to targeted actions that tackle the causes of poverty (Sotiroski et al., 2023). Moreover, the results can contribute to the conversation about how to measure poverty, showing that it's crucial to include consumption data for better evaluations (Briciu, 2014). With this thorough research plan, the study aims to improve the understanding of food spending as a sign of poverty and its usefulness in showing the complex economic struggles faced by Romanian households (Dan and Porumbescu, 2012).

3. RESULTS AND DISCUSSION

Past research emphasizes the complicated link between food expenditure and poverty metrics. For example, many studies show that a high percentage of income spent on food is often associated with limited spending choices, indicating difficult living conditions for many households in Romania. Findings reveal that as disposable income decreases, families tend to focus more on food, which can reduce their ability to participate in productive economic activities. Additionally, existing studies point out regional differences in Romania, showing that rural households, which often depend on subsistence farming, have different spending habits compared to urban families. Knowing how much households spend on food compared to their total spending is important for understanding poverty levels, especially in Romania where economic troubles and high living costs are common. The current study shows that families who spend more of their budget on food usually face tough financial situations and are at risk of poverty and food shortages. The average percentage of spending on food among the households surveyed was around 40%, which is much higher than the EU average of about 15% (Galindo and Nuguer, 2023). This difference highlights the financial difficulties many families in Romania encounter, suggesting that keeping track of food spending is important for measuring poverty. The research also found that higher household income is linked with a lower share of spending on food, meaning that as families earn more, they tend to spend less of their budget on food. This supports the idea that food spending shares can indicate economic struggles (OECD, 2019). These results are consistent with existing studies that have noted a link between high food spending and lower household incomes in different situations (OECD, 2018). Earlier research in Romania found that poor families tend to spend a larger portion of their income on food, which leaves them with less money for important things like health and education (Wagstaff et al., 2017a,b). Importantly, the study shows that food spending varies by region, with rural households spending a higher percentage on food than those in urban areas, showing the impact of economic differences based on location (Wagstaff et al., 2017). These findings are not just theoretical; they provide practical information for policymakers who need to identify and assist at-risk groups. By adding food spending ratios to poverty measurement methods, officials can create focused programs that address the unique challenges faced by families dealing with high food prices. Overall, these insights enhance the academic discussions about poverty indicators, supporting the view that looking at food spending is necessary for understanding socio-economic issues in Romania (Kashlinsky et al., 2024). As the economy in Romania keeps changing, this study highlights the need for continued conversations about the role of food spending in assessing poverty, stressing its importance in developing effective social policies (Tessore et al., 2024). The study shows that the portion of food expenses in total household spending is a key indicator of poverty. This means that families with limited money must spend a bigger part of their budget on basic food needs. About 45% of households surveyed spend more than 50% of their total incomes on food, highlighting a significant vulnerability among these families who are economically disadvantaged (Galindo and Nuguer, 2023). This was especially noticeable in rural areas, where food prices are often higher and income levels are lower, creating a cycle of poverty influenced by rising food prices (OECD, 2019). The analysis shows a clear opposite link between income and the amount spent on food, meaning that as disposable income grows, the percentage spent on food decreases (OECD, 2018). This finding matches previous studies in other developing countries, which also show that higher ratios of food spending reflect a greater risk of poverty (Wagstaff et al., 2017a,b). In Romania, this issue is even clearer when looking at the economic differences between regions, which emphasizes the role of geographic socioeconomic factors in shaping how households spend their money (Wagstaff et al., 2017a,b). Moreover, earlier studies have pointed out the need to include food spending in poverty evaluations. This can help improve policies aimed at helping vulnerable groups, indicating that families who spend more on food may need extra assistance from social safety nets (Kashlinsky et al., 2024; Tessore et al., 2024). The important findings from this study not only add to existing research but also provide useful implications for policymakers. By understanding the relationship between food spending and poverty, targeted actions can be developed to lessen the effects of food insecurity, especially for families hit hardest by increasing food prices (Sotiroski et al., 2023). In summary, the analysis highlights the significance of food expenditure as a crucial factor in assessing poverty in Romania. By examining this relationship in detail, the study supports the integration of consumption habits and food spending into poverty measurement methods, which could make socioeconomic policies addressing food-related poverty more effective (Briciu, 2014; Dan and Porumbescu, 2012). Consequently, the findings lay a groundwork for future studies and policy development that tackle the complex connection between food costs and the economic stability of households. Understanding how food spending relates to poverty in Romania is important, especially because of the noticeable economic differences in the country. This study's results strengthen the idea that high percentages of food costs in household budgets indicate economic weakness. This matches earlier studies that show a strong link between high food expenses and low available income, which puts families at a higher chance of being poor (Galindo and Nuguer, 2023). Specifically, the analysis found that families spending over 50% of their income on food often cannot afford other basic needs, resulting in poor living standards (OECD, 2019). These findings support earlier research that examined similar economic situations, showing that unequal food spending connects with poverty signs, such as limited healthcare access and insufficient educational resources (OECD, 2018). Moreover, there were clear regional differences; for example, rural families spent a lot more on food than urban ones, aligning with findings from (Wagstaff et al., 2017a,b), which emphasized that where people live is crucial in figuring out food costs and economic security. The meanings of these findings are significant, not just for how we measure poverty but also for how policies are created. The results suggest a deeper understanding of food spending as a sign of poverty, possibly leading to better social policies to tackle food insecurity (Wagstaff et al., 2017a,b). Additionally, these insights could guide focused actions aimed at specific groups, especially in rural areas where food spending raises poverty risk (Kashlinsky et al., 2024). In terms of methodology, the study highlights the need for future research to use broader poverty measures that include spending habits along with traditional income measures. Relying only on straightforward poverty metrics might miss the larger economic picture in Romania, as pointed out by (Tessore et al., 2024). Ultimately, including food spending percentages in poverty studies might give a clearer view of household weaknesses, improving both theories and practical steps in efforts to reduce poverty in Romania (Sotiroski et al., 2023). Since food spending shows economic challenges and affects health and nutrition, this study offers important views into the complex nature of poverty, calling for more attention to food costs in future poverty evaluations (Briciu, 2014; Dan and Porumbescu, 2012). Understanding the role of food spending as a sign of poverty is important for creating effective strategies to reduce poverty, particularly in Romania, where economic challenges continue. The results of this study show that when households spend a large part of their income on food, it indicates not just immediate financial hardship but also signals other vulnerabilities, such as poor health and limited access to basic services. By showing that families spending over 50% of their income on food face a greater risk of poverty, this research supports similar findings in existing literature that highlight how spending patterns reveal underlying financial stress (Galindo and Nuguer, 2023). Moreover, the study points out regional differences, noting that rural families deal with more economic challenges than those living in cities, reinforcing previous research that underscores the importance of geographical factors in poverty issues (OECD, 2019). Research has consistently found that high food spending ratios connect to negative social and economic factors, suggesting that families with high food costs often struggle to cover other expenses, which keeps them trapped in poverty (OECD, 2018). Additionally, studies in various settings indicate that food spending reflects not only financial strain but also limited choices in food selection, a situation observed in Romania as well (Wagstaff et al., 2017a,b). The implications of these findings reach into theoretical ideas, practical actions, and research methods. Theoretically, including food spending analysis in poverty assessments provides a fuller view of economic struggles, especially in transitioning economies like Romania where traditional income measurements may not capture the entire situation (Wagstaff et al., 2017a,b). Practically, policymakers can use this information to create targeted programs that meet the needs of households with high food spending, focusing on improving food security and overall health (Kashlinsky et al., 2024). Methodologically, this research emphasizes the need for broader approaches to poverty evaluation that consider spending data in addition to income, suggesting a change in how poverty is defined and understood (Tessore et al., 2024). In conclusion, recognizing food spending as a key indicator of poverty has important implications for developing effective poverty reduction strategies. It highlights the necessity for targeted social policies and enriches discussions on poverty measurement methods within Romania (Sotiroski et al., 2023). By promoting a better understanding of the relationship between consumption and poverty, this study adds to academic literature and guides more informed policy actions to address economic difficulties (Briciu, 2014; Dan and Porumbescu, 2012).

4. CONCLUSION

A detailed look at how much households in Romania spend on food highlights its important role as a measure of poverty. The paper found a clear link between higher food spending and greater risk of poverty in households, especially in rural areas where there are big economic differences. The paper findings have important meanings beyond just academic discussions; they underline the need for policymakers to pay attention to food spending trends when creating economic support programs and social services that help improve food security and assist low-income families. Since food spending can show not only financial stress but also health issues and general living conditions, including these insights in strategies aimed at reducing poverty could make interventions more effective. The study also calls for more research into how food spending and poverty vary by region, with a focus on how social services relate to household spending habits. Future studies could look at how changes in food prices affect household spending, which is crucial for understanding the immediate economic health of vulnerable groups during tough economic times. Additionally, broadening the research to include comparisons with other Eastern European countries may add useful context and help clarify the role of food spending as a poverty indicator. Ultimately, improving knowledge in this field will benefit both academic research and policies that could significantly enhance the lives of families facing financial difficulties. Tackling the complex connections between food spending, poverty, and social policies will be key to building a fairer society in Romania, making sure that no family suffers due to financial challenges related to basic needs. Raising awareness and including food spending factors in poverty evaluations will support ongoing efforts to fight poverty and promote social fairness nationwide. This paper sets the stage for future explorations, concentrating on improving resource distribution based on real data related to household spending habits and their social impact. The results in this paper show that how much households spend on food is an important indicator of poverty in Romania. There are strong links between higher food spending and greater vulnerability among families. The research made clear that food expenses not only show economic struggles but are also key in measuring poverty in the country. The findings have broad implications for academic discussions, as they question current poverty measures that mainly focus on income and suggest a need for a more comprehensive way to assess poverty. Policymakers are encouraged to use these findings to develop programs that meet the specific needs of households with high food expenditure, as these costs may indicate underlying food insecurity that can harm health and well-being. Moreover, these insights call for a review of current social welfare strategies, highlighting the need for integrated support systems that provide both financial aid and nutrition-related services to vulnerable groups. Expanding the research to include comparisons with other countries in the area could offer important insights about using food spending as a poverty indicator beyond Romania, helping to better understand regional poverty issues and their impacts. A stronger emphasis on food spending patterns will help policymakers create informed actions that address both immediate needs and long-term financial stability, fostering a fairer society. The findings establish a base for further research in this vital area, calling for the inclusion of food spending in broader social welfare and economic policy frameworks.

5. ACKNOWLEDGMENT

The research presented in this article is part of project Horizon Europe (HORIZON) 101071300 - Sustainable Horizons - European Universities designing the horizons of sustainability (SHEs) financially supported by the European Union.

6. REFERENCES

Briciu, C. (2014). Poverty in Romania: Dimensions of poverty and landmarks of poverty. www.semanticscholar.org/paper/57ce5154eed3379b5497dd3dd49f4f12d834fde6

Dan, S., Porumbescu, G.A. (2012). Poverty measurement in a transition context: a problem of complexity and accuracy.

www.semanticscholar.org/paper/3e30f315fafedb4b7bfd61e1feb949988a01b5f9
Galindo, A., Nuguer, V. (2023). Latin American and Caribbean Macroeconomic Report: Preparing the Macroeconomic Terrain for Renewed Growth. doi.org/10.18235/0004780
Kashlinsky, E.A., Arendt, R., Ashby, M., Atrio-Barandela, F., Scaramella, R., Strauss, M., Altieri, B. et al. (2024). Euclid preparation XLVI. The Near-IR Background Dipole Experiment with Euclid. www.semanticscholar.org/paper/d5796d4f86717a4d2a686ac0db3d4d569fd12730
OECD (2019). Health for Everyone? OECD health policy studies. doi.org/10.1787/3c8385d0-en
OECD (2018). Stemming the Superbug Tide. OECD health policy studies. doi.org/10.1787/9789264307599-en
Robinson, M. (2015). Encyclopedia of Quality of Life and Well-being Research. Reference Reviews, 29, 22-22. doi.org/10.1108/rr-06-2015-0143
Sotiroski, K., Péter, K., Marcikić, H.O, Sedlak, O., Lakić, V., Radovanov, B. (2023). Assessing sustainable economic development efficiency: A DEA approach. Strategic Management. www.semanticscholar.org/paper/beee7836827366177d240b529e095601689ec1dd
Tessore, E.N., Joachimi, B., Loureiro, A., Hall, A., Cañas-Herrera, G., Tutusaus, I., Jeffrey, N. et al. (2024). Euclid preparation. LIX. Angular power spectra from discrete observations. www.semanticscholar.org/paper/52235ad19d318039515755de78a32bdc67c7e73b
Torsheim, T., Cavallo, F., Levin, K., Schnohr, C., Mazur, J., Niclasen, B., Currie, C. (2015). Psychometric Validation of the Revised Family Affluence Scale: a Latent Variable Approach. Child Indicators Research, 9, 771-784. doi.org/10.1007/s12187-015-9339-x
Wagstaff, A., Flores, G., Smitz, M.F., Hsu, J., Chepynoga, K., Eozenou, P. (2017a). Progress on impoverishing health spending in 122 countries: a retrospective observational study. The Lancet Global Health, 6, e180-e192, e180-e192. doi.org/10.1016/s2214-109x(17)30486-2
Wagstaff, A., Flores, G., Hsu, J., Smitz, M.F., Chepynoga, K., Buisman, L.R., van Wilgenburg, K. et al. (2017b). Progress on catastrophic health spending in 133 countries: a retrospective observational study. The Lancet Global Health, 6, e169-e179. doi.org/10.1016/s2214-109x(17)30429-1

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.056M

SAFETY CONSIDERATIONS FOR CEREALS IN CONNECTION WITH MICROBIAL CONTAMINATION

Mirjana Menkovska[1*], Marija Šarić[2], Desimir Knežević[3]

[1]University Ss. Cyril and Methodius of Skopje, Institute of Animal Science andFishery, Skopje, North Macedonia, *mirjanam06@yahoo.com
[2]University of Novi Sad, Faculty of Technology, Novi Sad, Serbia
[3]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohia, Serbia

Abstract: Food is a necessity for humans and domestic animals, but it can be also a threat to their health and wellbeing. Microbial contamination is the most common cause of foodborne deseases in humans and animals, having also a deleterious effect on the technological quality of grains and food products based on cereals and other field crops. Micro-organisms, such as bacteria and moulds (fungi) may producetoxins. The toxins as secondary metabolites are mycotoxins and most of them are carcinogenic, immunotoxic and haematotoxic, causing many deseases in human and animal population. In this paper is pointed out to the safety and prevention of cereals and their products from mold contamination, including different practices and food processing.

Key words: Mycotoxins, Cereals, Products, Prevention, Practices

1. INTRODUCTION

Cereals and cereal products are of great importance for the population and domestic animals in terms of their nutrition. Their diverse nutritional composition provides them with a significant place in the correct selection of food and feed for the development of the body and maintenanceof health (Menkovska and Cilev, 2000; Menkovska, 2002 a,b). Wheat is the most represented cereal crop and is a strategic crop of many countries in Europe and the world. The most significant and mass application of wheat as food is in the form of bakery products - bread and a wide range of baked goods, as well as confectionery products. The technological quality of wheat is mostly determined by the structural-mechanical and chemical properties of the grain, as well as the products obtained from its processing, including the milling and baking properties, which all together are essential for the production of various baked goods,such as bread, pasta or sweets. The influence on cereal quality besides the cereal kind, genotype, and production region (Menkovska, 2003; Knežević et al., 2022) have also environmental factors (Knežević et al., 2024) and the farming type (Menkovska, 2024).

The quality of raw materials and food products is evaluated based on physical, chemical and microbiological criteria (Menkovska, 2003). Contamination of raw materials and products with microorganisms affects their quality. Wheat as an agricultural crop in rotation, like other cerelas can be attacked by several types of fungal diseases during the growing season, causing various damages, which affect both the total yield and its quality, as well as technological quality of its products for human and animal food and feed endangering their health (Fink-Gremmels et al.,1995; Smith et al.,1995; Šarić et al., 2006, 2008; Menkovska et al., 2007a,b; Microbial food contamination, 2008; Menkovska et al., 2009; Bryden, 2012; Menkovska et al., 2012).

The aim of this research is to present an overview of the developed available methods in the function of maintaining the safety and prevention of cereals and their products from mold contamination, including different practices and food processing.

2. HISTORY AND DISCOVERY OF MYCOTOXICOSIS

The toxic secondary metabolites produced by fungus are mycotoxins. Historically, probably the oldest documented human mycotoxicosis is ergotism. This disease was known in the middle ages as St. Antjony's fire and is by disorders of the central nervous system (convulsion, hallucinations), contraction of the blood vessels (gangrene) and gastrointestinal disorders. It is caused by ingestion of grains contaminated by *Claviceps purpurea* and some other *Claviceps* species, which invade the female portion of the host plant (barley, rye and wheat).

The real descovery of mycotoxins occurred in the 1960's, in the UK because of a severe outbreak of the Turkey 'X' disease, killing about 100.000 turkeys and other farm stock. The cause of this disease was traced to a feed component, peanut meal, which was invested heavily with *Aspergillus flavus*. Analyzing the feed, fluorescent compounds were isolated, which were proven to be responsible for the outbreak, and they were later termed Aflatoxins (Afs).

3. OCCURRENCE OF MYCOTOXINS

The most mycotoxins of concern are produced by five fungus genera of Aspergillus, Penicillium, Fusarium, Claviceps, and Paecilomyces. These five fungus genera and their species infect and contaminate agriculture crops, foods and animal feeds, and under optimum conditions of humidity and temperature proliferate and produce mycotoxins. Mycotoxins produced by these fungus genera species are Aflatoxins, Trichothesenese, Ochratoxins, Ergot alkaloid (Ergolin), Fumonisin, Patulin, and Zearalenone (Richard, 2007; Osama and Menkovska, 2019) (Table 1).

Table 1. The most prevalent mycotoxigenic fungal genera, sources and associated food

Chemical	Source	Associated Food
Aflatoxins	*Asspergillus flavus, A. parasiticus*	Corn, Peanuts, Three nuts, Milk
Trichothecenes	*Mainly Fuzarium*	Cereals and other foods
Ochratoxins	*Penicillium verucosum, A. ochraceus*	Wheat, Barley, Corn
Ergot alkaloids	*Claviceps purpurea*	Rye, Barley, Wheat
Fumononisins	*Fuzarium moniliforme*	Corn
Patulin	*P. expansum*	Apples, Pears
Zearalenon	*Fusarium* spp.	Cereals, Oil, Starch

A. flavus is widely distributed in nature, but *A. paraziticus* is probably less widespread, *A. flavus* was one of the most commonly occurring molds in nuts and oilseeds, soybeans, mung beans, sorghum, and other commodities, while *A. paraziticus* was rarely encountered. *A. nomius* was reported from peanuts and corn. *A. flavus* and *A. paraziticus* have a strong affinity with nuts and oilseeds. Corn, peanuts and cottonseed are the most important crops invaded by these molds, and in many instances, invasion takes place before harvest, not during storage as was once belived. In corn, insect damage to developing kernels allows entry of Aflatoxigenic molds, but invasion can also occur through the silks of developing ears.

Significant amounts of Afs can occur in peanuts, corn and other nuts and oilseeds, particularly in some tropical countries where crops may be grown under marginal conditions and where drying and storage facilities are limited. Peanuts are invaded while still in the ground if the crop suffers drought stress or related factors. Cottonseeds are invaded through the nectarines. Cereals and spices are common substrates for *A. flavus*, but aflatoxin production in these commodities is almost always a result of poor drying, handling, or storage, and aflatoxin is rarely significant. Presently, 18 different Afs have been identified. Especially the most potent AF B1 and G1 occur most frequently (Bui-Klimke and Wu, 2015). The most prominent toxic characteristic of Afs is carcinogenity, but they have also been proven to be immunotoxic and haematotoxic. Diagnosis and treatment of Afs were reported **(**Hope and Hope, 2012).

Fuzarium species are another important group of toxigenic mould. They may also produce a variety of mycotoxins, such as Trichothecenes - deoxynivalenol (DON, vomitoxin), T-2 toxin and HT- 2 toxin), Zearalenon and Fumonisins. They attack cereals, feed and other field fruits, and are a threat to human and animal health (Food microbiology, 2007b; Menkovska et al., 2007, 2010, 2013; Osama and Menkovska, 2019). Co-accurrence of mycotoxin groups in food and feed is also possible (Smith et al., 2016).

3.1. Factors affecting growth and toxin production

Cereal grains are subject to microbiological contamination and proliferation while growing in field. Postharvest microbiological growth is limited by good storage practices, and much of the microflora is removed during the milling process. Microbiological growth in prepared cereal products can lead to spoilage or foodborne illness when well established control measures are used (Kolakowski et al., 2016).

4. SPOILAGE OF CEREALS AND CEREAL PRODUCTS WITH MYCOTOXINS

4.1. Spoilage of Pre- and Postharvest Grains

Cereals grains accumulate a large and varied microflora during growth in the field. Molds, or "field fungi", in the genera Alternaria, Aspergillus, Cladosporium, Fuzarium and Helminthosporium commonly grow on the grain with an a_w of 0.90 or higher, a level that corresponds to a moisture content of about 20% or higher (Food microbiology, 2007a).

Climatic conditions have a major effect on the quality of cereal grain on the amount of mold growth that occurs on cereal grains (Milani, 2013). The combination of below-normal temperatures and above-normal precipitation and relative humidity will foster excessive mold growth, particularly in wheat and barley crops. Under these conditions, field fungi can damage the grain, even to the point of total crop loss. Less invasive mold infections can damage grain quality and sometimes result in the production of mycotoxins (Cotty and Jaime-Garcia, 2007).

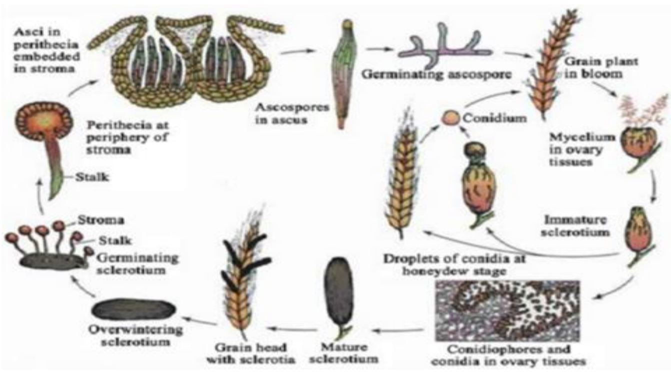


Figure 1. Shematic representation of small grain cereals and grasses contaminationwith *Claviceps ergot* (Schumann and Uppala, 2017).

Figure 1 represents mature sclerotia of claviceps ergot in infected grain crops or grasses germinate in the spring, prior the flowering and give rise to a stroma (stromata plural), where sexual reproduction occurred for the production of ascospores.

4.2. Prevention of mold growth

The first stage of prevention can be achieved by the application of several technologies and practices such as developing fungal resistant crops varieties, control fungal infection or contamination via the application of proper Good Agriculture Practices (GAPs) in the field, lowering moisture content and temperature of post harvested grains during storage, applied fungicides to inhibit fungal proliferation, applied insecticides to control insects infestation, and the proper application of Good Manufacture Practices (GMPs) in foods/animal feeds manufacturing (Menkovska et al., 2007).

Modern grain harvesting and storage practices prevent further mould growth. Crops are cut, threshed, and winnowed by mechanical harvesters in order to separate the grain from chaff. Mechanical dryers are often used to reduce the moisture content of grain before storage.Depending on the size of the global grain reserves, any particular crop could be stored for 1 yearor longer before being processed for consumption.

To protect quality during this period, grain must always be stored in bins and conveyed in vesselsthat exclude water, birds, insects, and rodents. Grains that are dried to 12 to 14% will not moulddurring storage, as long as they are kept dry. Inadequately dried grains will support the growth of“storage fungi” belonging to the genera Penecillium, Rhizopus, Mucor, and Aspergilus. While itis not practical to store grains with a moisture content higher than 15% for long periods, fungistatic agents such as propionic acid, formaldechide, and acetic acid, or combinantions thereof, are used to prevent mold and yeast growth during shorten-term storage of high-moisturegrains to be used as animal feed. Aditionally, crops and stored grains are contaminated by microorganisms from dust, birds, rodents, insects and other environmental sources.

4.3. Effect of Milling on Microbiologal Quality

Before milling, aspiration and screening steps not only clean the grain but also reduce the grain microflora. A significant further reduction of the microflora occurs when the bran is removed. The grain is usually sprayed with water and stored in tempering bins for 6 to 18 h before milling. The amount of water added is just enough to moisten the surface of the grain. Tempering simultaneously, toughens the bran and softens the endosperm crushing in the first milling step. While many millers add up to 300 mg of calcium hypochlorite per ml to the temper water, the utility of this addition is unknown. The hypochlorite has no apparent antimicrobial effect, as it isquickly neutralized by the grain and its dust. In wheat that was temepered for 16 h with and without 200 mg of calcium hypochlorite per ml in the temper water, no reduction in total plate or coliform counts occurred in the hypochlorite- treated samples compared to the untreated samples (Food Microbiology, 2007a).

4.4. Spoilage of Cereal Products - bakery products

The baking of dough products simultaneously reduces the microflora and moisture content, thereby limiting the types of microorganisms that could cause spoilage. Even though mold spores and vegetative microbial cells are casily killed during baking**,** the predominant cause of baked- product spoilage is mold growth. The surfaces of baked products may be contaminated with airborne mold spores during the relatively long product cooling period between baking and packaging (Food Microbiology, 2007a). Many bakery products contain one or more fungistatic agents that retard mold growth. One of the most effective food-grade fungistatic agents is potassium sorbate, typically used at concentrations of 1.000 to 3.000 mg g^{-1}. However, because it inhibits yeast growth and metabolism, the use of potassium is limited to chemically leavened products. Yeast-leavend products are typically protected from mold spoilage using calcium propionate at concentrations of 2.000 to 8.000 mg g^{-1}. Bakery products are relatively easily stabilized against rapid mold spoilage by an interaction of preservative factors: reduced a_w and pH values, residual ethanol content from yeast fermentation, and pasteurization during baking enhance the effectiveness of chemical preservatives. Confectionery components of baked goods, e.g., fruit or cream fillings and icings, are vulnerableto yeast spoilage. This spoilage can be effectively controlled by use of one or more of the following preservative techniques: a_w reduction, pH reduction and addition of a preservative.

Potassium sorbate is particularly effective in this application when used at 1.000 to 2.000 mg g^{-1}. Bakery products with a moist interior have long been known to be vulnerable to "rope" spoilage. Rope is the result of extracellular capsular material production by *Bacillus subtilis.* Endospores that survive baking will grow under favorable conditions to vary high numbers of vegetative cells and produce rope spoilage. Roby products have a melon-like odor and stringy, mucilaginous appearance when pulled apart. Early bakers were encouraged to avoid rope spoilage by adding acetic acid to the dough before baking. The fungistatic agents currently used in bakery products to retard mold spolage have a limited bacteriostatic activity against *B. subtilus*.

4.5. Refrigerated dough products

These products are created by packing unbaked, chemically leavened doughs into containers that become hermetically sealled as the doughs proof. These raw doughs are then baked by the consumer. There are two general types of refrigerated dough products: breadstuffs which have a_w values 0.90 and cookie dough which have an a_w of ca. 0.80. The refrigeration temperature reduced a_w and high carbon dioxide pressure of the breadstuff doughs prevent the growth of almost all microorganisms. Microbial spoilage only occurs after temperature abuse and is almost exclusively caused by *Lactobacillus plantarum* or *Leuconostoc mesenteroides.* The only microorganisms that can grow in refrigerated cookie doughs are osmotolerant yeasts, and then only after abuse at ambient temperature or higher. Bacterial growth is prevented by the low a_w ofcookie dough. Xeterofilic mold growth is prevented by carbon dioxide content in the dough. Mold spoilage of some types of specialty bakery products is retarded using carbon dioxideand/or oxygen scavengers, or by the combined use of head-space carbon dioxide and/or ethyl alcohol.

The use of headspace gases to inhibit mold growth requires the use of packaging materials with very low oxygen transmission rates, and the packages must be well sealed to prevent leakage of the gases. Some bakery products can be protected against mold spoilage by heating them inside a hermetically sealed, moisture-impermeable package.

The internally generated steam originating from moisture in these products is sufficient to kill mold spores on the product surface, thereby preventing mold spores on the product surface, thereby preventing mold growth indefinitely. Conventional microwave ovens and infraredbulbs can be used in this process. Several heat sources generate steam that later equilibrateswith the product. This process is suitable for both refrigerated and shelf-stable baked goods. It ismore effective and less costly than modified-atmosphere packaging.

5. FOOD SAFETY CONSIDERATIONS FOR CEREAL PRODUCTS

The reduced a_w (0.94 or less) of most cereal products prevents the growth of many microorganisms that can cause foodborne illness. *C. botulinum, Clostridium perfingens, E. coli,* and Salmonellae are prevented from growing at this reduced a_w. Even though its minimum a_w forgrowth is 0.94 proteolytic strains of *C. botulinum,* have received special attention, even in bakeryproducts, because of the severity of the illness they cause and because their spores survive the baking process (Denny, 1969).

A major new product category, cooked, refrigerated pasta products, can sometimes present a substantial safety challenge. These products are made both with and without a variety of fillings, and the pasta and filling components sometimes have a_{ws} above 0.95. The products are packed in hermetically sealed containers with very low headspace oxygen in order to prevent mold growth.The resulting anaerobic condition favors the growth of *C. botulinum.*

Cooking eliminates much of the competitive microflora, thereby facilitating *C. botulinum* growthif temperature abuse occurs. It was shown that *C. botulinum* cannot produce toxin in refrigeratedpasta, even when temperature abused at 30 ^{0}C, when the a_w is 0.94 or below. A survey of commercially available refrigerated, filled pasta products revealed that some are capable can support *C. botulinum* growth and toxin production when they are abused at 30 ^{0}C. Some of these commercial products had a_w values as high as 0.983. Refrigerated pasta products such as these need to be formulated to prevent overt food safety hazards should temperature abuse occur.This product design activity must be an integral part of the manufacturer's hazard analysis and critical control point plan. If practical food safety measures, such as the control of pH and a_w limits, cannot be incorporated to protect products from overt food safety hazards during extendedtemperature abuse, the products should not be produced.

Historically, commercially produced dried pasta products were vulnerable to the growth *of S. aureus* and/or *Salmonellae* during dough mixing, extrusion, and drying. Some strains of *S. aureus* have been found to be capable of growth in pasta doughs with a_{ws} as low as 0.86, thoughenterotoxin production is generally inhibited at a_{ws} of 0.90 to 0.94. *Staphylococci* die within several weeks in dried pasta, while *Salmonellae* can persist for more than one year.

However, the potential safety and public health hazards presented by these two pathogens in contaminated dry pasta were found to be exactly the opposite at the time of pasta preparation and consumption. Surviving salmonellae in pasta would be easily killed during cooking, presenting no public health hazard. In contrast, the dead *S. aureus* cells could leave behind their thermostable enterotoxins, which would not be destroyed by cooking pasta, thereby remaining as a potential cause of illness. Commercial pasta production involves continuous dough mixing under vacuum,in which mixers are operated continuosly for days or weeks.

Dough buildup in vacuum mixers is known to create a good environment for growth of and toxin production by *S. aureus*. In one case, *A. flavus* was found to have grown and produced aflatoxin in dough buildups. Once-daily elimination of the dough buildup has been validated to eliminate both of these potential foodborne hazards during continuous production periods of up to 30 days.

Many outbreaks of illnesses caused by *Bacillus cereus* have been associated with consumption of fried rice. In these cases, rice was cooked and then stored at ambient temperature up to 24 h before being prepared and served as fried rice. Under these conditions, *B. cereus* can grow rapidlyand produce a heat-stable emetic toxin. This potential hazard can be eliminated simply by storingthe cooked rice at refrigeration temperatures before frying. In 2005 an outbreak of salmonellisiswas associated with the consumption of cake batter ice cream. Since other ice cream flavours produced by the same manufacturer were not involved in reported cases, it was thought that some component of the cake batter may have been responsible for the illnesses. The cake batter had not been baked or pasteurized before its addition to the ice cream mix. As a result, the US FDA issued a warning against the use of atypical uncooked ingredients in ready-to-eat foods (Food Microbiology, 2007a).

6. REGULATIONS FOR MYCOTOXINS IN GRAINS, FOODS, AND ANIMAL FEEDS

According to the World Food and Nutrition Division in the United Nation Food and Agriculture Organization (FAO), at least 77 countries have been developed specific regulations for mycotoxins in grains, foods, and animal feeds, but the developed specific regulations for each country showed diversity specially in mycotoxins acceptable limits. Food and Agriculture Organization (FAO), and World Health Organization (WHO) carried the responsibility for mycotoxins acceptable limits worldwide harmonization. International regulations of mycotoxinsin grains, foods and animal feeds were published in years from 1980s to 1990s, which covered sampling protocols, standard mycotoxins assay methods, acceptable limits of each mycotoxin ingrains, foods, and animal feed, tolerable daily intake of each mycotoxin for both human and animals (Menkovska, 2011). The nature, sources, detection and regulations of mycotoxins that contaminate foods and feeds are described in detail by Osama and Menkovska (2019).

7. CONCLUSION

The deterioration of the quality of cereals and cereal-based products may occure at anystage of the food chain from the primary production, processing and storage to distribution and consumtion. Therefore, it is necessary to introduce a proper control as a prevention, a preventive quality systems according to the accepted food safety standards, as well as application of the quality managing, including the following measures: Mold contamination and developing in cereals and animal feed to be prevented with a coordinated action by the all participants at the primary production, harvest, drying, storage, distribution, processing and control of their quality.

The frequency data of mould occurrence and concentration to be recorded and to be related to the toxicological data, enabling a risk assessment for humans and animals to be made in order for regulated limits to be established. New technologies and procedures for processed cereals are to be introduced in order negative effects of creation of some new mycotoxin species to be avoid.

The interactive effects of naturally occurring mixtures of mycotoxins, e.g. Aflatoxins and Fuzarium toxins, are poorly understood and may be of much greater significance tohuman and animal health than is yet realized.

New, sophisticated methods for mycotoxin detection, chemical and biolocical methods is necessary to be introduced, as well as fast analytical procedures at the all stages of the food chain.

8. REFERENCES

Bui-Klimke, T.R., Wu, F. (2015). Ochratoxin A and Human Health Risk: A Review of the Evidence. Critical Reviews in Food Science and Nutrition, 55, 1860-1869.

Bryden, W.L. (2012). Mycotoxin Contamination of the Feed Supply Chain: Implications forAnimal Productivity and Feed Security. Animal Feed Science and Technology, 173, 134-158.

Cotty, P.J., Jaime-Garcia, R. (2007). Influences of Climate on Aflatoxin Producing Fungi and Contamination. International Journal of Food Microbiology, 119, 109-115.

Denny, C.B., Goeke, D.J., Steinberg, R. (1969). Inoculation Tests of Clostridium botulinum in Canned Breads with Special Reference to Water Activity. Research Report 4–69, Washington Research Laboratories, National Canners Association, Washington, DC. Available: https://ouci.dntb.gov.ua/en/works/4kV8W607/

Fink-Gremmels, J., Jahn, A., Blom, M.J. (1995). Toxicity and Metabolism of Ochratoxin A. Natural Toxins, 3, 214 - 220.

Food Microbiology: fundamentals and frontiers (2007a). Doyle, M. P., Beuchat, L., (Eds.), 3rd ed., II. Microbial Spoilage and Public Health Concerns, 9, p.171., Copyright 2007 by American Society for Microbiology. Translation from English Hadjieva, M., professional editorial Menkovska, M. (2014), p. 1038. Ars Lamina, Skopje.

Food Microbiology: fundamentals and frontiers (2007b). Doyle, M.P., Beuchat, L. (Eds.), 3rd ed. IV. Mycotoxigenic Molds, 26. Fusaria and toxigenic molds other than Asergili and Penicillia, p.563. Translation from English Hadjieva, M., professional editorial Menkovska, M. (2014), p. 1038. Ars Lamina, Skopje.

Hope, J.H., Hope, B.H. (2012). A Review of the Diagnosis and Treatment of Ochratoxin A Inhalational Exposure Associated with Human Illness and Kidney Disease Including Focal Segmental Glomerulosclerosis. Journal of Environmental and Public Health, 2012, Article ID: 835059.

Knežević, D., Novoselskaya-Dragovich, A.Yu., Kudryavtsev, A.M., Paunović, A., Menkovska,M., Radosavac, A., Matković, S., Roljević. M., Nikolić, S. (2022). Protein quality of bread wheat. Journal of Agricultural, Food and Environmental Sciences, 76(6), 1-10.

Knežević, D., Grčak, M., Grčak, D., Matković Stojšin, M., Ivanović, T., Menkovska, M., Zečević, V. (2024). Variability of seed protein content and gluten content in bread wheat. 6th International Symposium "Modern Trends in Agricultural Production, Rural Developmentand Environmental Protection" (Djukić, D., Zoran Ž., Ilić, Z.Ž., Lutovac, M. (Eds.), Vrnjačka Banja, Republic Serbia: The Balkans Scientific Center of the Russian Academy of Natural Sciences, Belgrade, 79-87.

Kolakowski, B., O'Rourke, S.M., Bietlot, H.P., Kurz, K., Aweryn, B. (2016). Ochratoxin A concentrations in a Variety of Grain-Based and Non-Grain-Based Foods on the Canadian Retail Market from 2009 to 2014. Journal Food Protection, 79, 2143-2159.

Menkovska, M., Cilev, G. (2000). Nutritive value of some kernel feedstuffs produced in Republic of Macedonia, Publishrd in Procedeengs of papers, XXV Meeting "Faculty with Farmers 2000", Faculty of Agriculture, University "Sts. Cyril and Methodius" (Ed.),Skopje, Macedonia, 175-185. /in Macedonian/

Menkovska, M. (2002a). Nutritional survey of cereals grown in the Republic of Macedonia. Published in Proceedings of the sectional oral communication. II Congress of preventivemedicine doctors of Macedonia with international participation, Ohrid, Republic of Macedonia.

Menkovska, M. (2002b). White, integral bread and cereals in the nutrition. Round Table "Food products". Published in the Proceedings of lectures: GTZ, Skopje, Macedonia, 1-7. /in Macedonian/

Menkovska, M. (2003). Technological quality of Macedonian wheat-biochemical approach,recent Instrumental techniques and methods, international standards. Institute of AnimalScience, Ss. Cyril and Methodius University in Skopje, p. 216.

Menkovska, M., Sharic, M., Ivanoski, M., Levkov., V., Djorgovska, N. (2007a). Quality and safety of wheat intended for animal and human nutrition. Published in Proceedings of III Symposium of Livestock Production with international participation, University "Ss. Cyril and Methodius", Ohrid, Macedonia, 351-357.

Menkovska, M., Sharić, M., Ivanoski, M. (2007b). Quality and safety of wheat contaminatedwith *Fusarium spp*. Proceedings of the I International Congress of Food technology, Quality and Safety and XVI Symposium Cereal Bread and Confectionary Products, Novi Sad, Institute for Foodtechnology in Novi Sad (Psodorov, Đ., Ed.), 97-105.

Menkovska, M., Sharic, M., Ivanoski, M. (2007c). Preventive measures for quality and safety supplying of food intended for human and animal nutrition. Proceedings of III Symposium of Livestock production with international participation, University "Ss. Cyril and Methodius", Ohrid, Macedonia, 359-363.

Menkovska, M., Sharic, M., Girazova, E. (2009). Influence of the *Fuzarium* spp. fungus on the quality of wheat kernel and its products. Jubilee Yearly Proceedings of the Agricultural Institute, Book 26-27, University "Ss. Cyril and Methodius", Agricultural Institute, Skopje, Macedonia, 153-162.

Menkovska, M., Levkov, V., Djorgovska, N., Sharic, M., Samardjioski, V., Ushlinovska, I. (2010). Application of rapid technique for screening of mycotoxins in cereals. Proceedings of 2nd Workshop Feed-To-Food and XIV International Feed Technology Symposium, Novi Sad, University of Novi Sad, Institute for Food Technology in N. Sad, 144-147.

Menkovska, M. (2011). Regulations and organs in the field of food and feed safety in Republiblic of Macedonia. Macedonian Journal of Animal Science, 1(2), 355-360.

Menkovska, M., Sharic, M., Mateva, N., Djorgovska, N., Levkov, V., Nikolova, N. (2013). Changes of wheat quality caused by mold contamination. Journal of Hygienic Engineering and Design, 4, 65-68.

Menkovska, M., Gjorgovska, N., Lekov, V., Knežević, D., Pacinovski, N. (2024). The importance of food systems for cereal application in human and animal nutrition. Proceedings of the 11. JEEP International scientific agribusiness conference "MAK 2024 - "Food for the future - vision of Serbia, region and Southeast Europe", Kopaonik, Republic Serbia: The Balkans Scientific Center of the Russian Academy of Natural Sciences, Belgrade, 85-94.

Microbial food contamination (2008). Charls L.W. (Ed.), 2nd Edition, p. 608, Taylor & Francis Group LLC. Translation from English Menkovska, M. (2011), Ars Lamina, Skopje.

Milani, J.M. (2013) Ecological Conditions Affecting Mycotoxin Production in Cereals: A Review Veterinarnia Medicina, 58(8), 405-411.

Osama, O.I., Menkovska, M. (2019). The Nature, Sources, Detections and Regulations of Mycotoxins That Contaminate Foods and Feeds Causing Health Hazards for Both Human and Animals. Journal of Agricultural Chemistry and Environment, 8(1), 33-57.

Richard, J.L. (2007). Some Major Mycotoxins and Their Mycotoxicosis, an Overview. International Journal of Food Microbiology, 119, 3-10.

Šarić, M., Menkovska, M., Guteša, N., Ivanovski, M. (2006). Sprouts from different cereals influence the changes of bread nutritive value. Published in the 5th International Congress of the Chemical Societies of the South-East European Countries, Book of Abstracts, Ohrid, 1,198.

Šarić, D.M., Stojanović, V.T., Škrinjar, M.M., Menkovska, M. (2008). Effects of moulds on the safety and processing quality of *Triticum aestivum*. Proc. Nat. Sci, Matica Srpska, 114, 105-114.

Smith, J.E., Solomons, G., Lewis, C., Anderson, J.G. (1995). Role of Mycotoxins in Human and Animal Nutrition and Health. Natural Toxins, 3, 187-192.

Smith, M.C., Madec, S., Coton, E., Hymery, N. (2016). Natural Co-Occurrence of Mycotoxins in Foods and Feeds and Their in Vitro Combined Toxicological Effects. Toxins (Basel), 8, 94.

Schumann, G.L., Uppala, S.S. (2017). Ergot of rye. The Plant Health Instructor, 17. University of Massachusetts & Texas A & M AgriLife Research Center, Beaumont.

doi:10.46793/MAK2025.065S

AGRI-FOOD IN ALBANIA AND THE QUALITY OF ALBANIAN WINE: AN OVERVIEW OF CHALLENGES, OPPORTUNITIES, AND SUSTAINABLE DEVELOPMENT

Merita Stafasani*, Artiona Laze, Mariola Kodra, Dorina Beli

Agricultural University of Tirana, Faculty of Biotechnology and Food, Department of Chemistry, Tirana, Albania, *mstafasani@ubt.edu.al

Abstract: This paper explores the agri-food sector in Albania, focusing on the country's agricultural potential, the challenges faced by its farmers, and the role of wine production in Albania's economy. Special attention is given to the growing interest in wine quality and the factors influencing its improvement. Challenges such as climate change, limited technological advancements, and insufficient infrastructure are discussed, alongside opportunities for growth through innovation, international market expansion, and improved agricultural practices. Special attention is given to the role of sustainability in promoting eco-friendly practices and ensuring the long-term viability of both viticulture and the broader agri-food sector. The paper concludes with an analysis of the prospects of Albanian agriculture and wine as part of the broader socio-economic and environmental sustainability strategies, including the impact of European Union integration and market expansion. Our study included 11 samples of domestically produced wine, and one imported wine purchased from the market. Eight of them were red wines, while three were white. The basic components, pH, expressed acidity and the content of polyphenols were analyzed using the Folin Ciocalteu's method and total anthocyanins (with the difference in colours at different pH). The results show that their pH ranges from 3.24 to 3.72, acidity from 4.15 to 6.60, and total polyphenols from 0.160 g L^{-1} (white wine) to 2.069 g L^{-1} (Vranac red wine). The concentration of anthocyanins ranged from 24.4 mg L^{-1} for W6 (Cabernet sauvignon) to 86.1 mg L^{-1} for imported wine.

Key words: Total polyphenols, Agri-food, Autochthonous wines, Agriculture, Anthocyanins

1. INTRODUCTION

Albania's viticultural tradition is deeply rooted in its ancient past. The Illyrians, who inhabited the region as early as the 8th century BC, were among the first to cultivate grapes for winemaking. Despite this long-standing heritage, the wine industry faced significant setbacks during the 20th century due to political upheaval and economic challenges. The fall of communism in the early 1990s marked a turning point, allowing for a gradual revival of traditional practices and a shift towards quality production (Decanter, 2023, Wikipedia, 2023).

Today, Albania boasts approximately 8.400 hectares of vineyards, with an annual production of around 3 million Liters of wine (Seven Fifty Daily, 2023; Euronews, 2023). The primary grape varieties cultivated include indigenous types such as Shesh and Zi and Shesh and Bardhë, alongside international varieties like Cabernet Sauvignon and Merlot. The Ministry of Agriculture reports that about 46% of Albanian wine is exported, primarily to European markets (Seven Fifty Daily, 2023; Euronews, 2023). The quality of Albanian wines has gained increasing recognition in recent years, thanks to a blend of modern winemaking techniques and a deep respect for traditional methods. Wine experts and connoisseurs are beginning to take note of Albania's potential as a premier wine destination, with a growing number of wineries gaining international acclaim for the quality and uniqueness of their products. Traditional winemaking in Albania is still largely carried out using artisanal methods, passed down through generations. Many Albanian winemakers emphasize sustainable farming practices, using minimal intervention techniques in the vineyard and the winery.

This focus on tradition, combined with modern winemaking practices, results in wines of exceptional quality, with a unique taste profile that speaks to the land's history and culture.

In regions like Berat, Shkodra, and Fier, local wineries have become famous for producing wines that reflect the character of the local soil and climate. The quality of Albanian wines has steadily gained international recognition, and several wineries have begun to win awards in prestigious wine competitions. These wines are an essential part of the country's agri-food identity and provide a significant contribution to the local economy. Wine consumption in Albania is dominated by domestic production - imports account for less than 1/10 of domestic supply (FAOSTAT, 2018; INSTAT, 2017; UNSTAT, 2018).

In the case of wine, the preference for domestic wine is not dominant compared to imported wine, however, according to a study (Zhllima et al., 2012), there is a potential "niche" market for Albanian wine, and consumer groups that are willing to pay higher prices have been identified. Consumers have declared a preference for wine from several regions such as Përmet, Vlora and Lezha, where there is also a tradition of grape production and processing (Imami et al., 2015).

There are about 80 - 100 wineries in Albania. The highest concentration is in the Durrës region, followed by Vlora. Wineries in Albania can be divided into three groups: (i) medium and large wineries - that produce high-quality wine; (ii) wineries - typically larger - that produce large quantities of standard/table wine and to a small extent selected and aged 12-24 months wine, and (iii) wineries - typically smaller - that produce standard table wine with little or no aging for immediate consumption (Skreli and Imami, 2019).

This paper aims to explore the current state of agri-food in Albania and assess the factors that contribute to the quality of Albanian wines. Additionally, it addresses the challenges and opportunities within the sector and how these may shape Albania's future.

Challenges Facing the Agri-Food Sector

Despite its rich agricultural resources, Albania faces several challenges:

- **Outdated Farming Practices**: Many small farmers still rely on traditional, low-productivity farming methods.
- **Infrastructure Issues**: Poor road networks, limited access to irrigation, and inadequate storage facilities impact the efficiency of agricultural production.
- **Climate Change**: Increased temperatures and unpredictable rainfall patterns affect crop yields.
- **Market Access**: Although there is a growing demand for Albanian agri-food products in international markets, many farmers lack the ability to access these markets due to quality standards and insufficient promotion.
- **Regulatory Framework**: Although recent legislation aims to establish Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) statuses for Albanian wines, implementation remains a challenge (Decanter, 2023; Euronews, 2023).

The characteristic composition of wine originates from the quality of raw materials such as grapes, regimes of alcoholic fermentation, and ageing conditions (Lingua et al., 2016, Gutiérrez et al., 2021). The quality of a wine is determined by various parameters such as alcoholic concentration, polyphenolic composition, density, colour, acidity, aroma, astringency, bitterness, and flavors (Gutiérrez et al., 2021; Wen et al., 2014). To evaluate the quality of Albanian wines, we measured the pH, titratable acidity, and total polyphenols for ten indigenous wines, as well as anthocyanins only for red wines, and compared them to one imported wine.

This paper aims to explore the current state of agri-food in Albania and assess the factors that contribute to the quality of Albanian wines. Additionally, it addresses the challenges and opportunities within the sector and how these may shape Albania's future.

2. MATERIAL AND METHODS

For research is included eleven wine samples were collected, ten of which were indigenous wines aged 1-4 years, and one was an imported wine purchased from the market to compare to our wines. Eight of them were red wines, while three were white. The data of the samples are given in Table 1.

Table 1. General characteristics of the wine samples

Nr. (cod)	Brand	Variety	Packaging
W1	M1	Spätburgunder	0.75L Glass
W2	M2	Kabernet	0.75L Glass
W3	M2	Merlot	0.75L Glass
W4	M3	Shesh and Bardhë	0.75L Glass
W5	M3	Shesh and Zi	0.75L Glass
W6	M4	Vranac	1L Glass
W7	M4	Resling	1L Glass
W8	M5	Shesh and Bardhë	0.75L Glass
W9	M5	Kabernet sauvignon	0.75L
W10	M6	Shesh and Zi (Brusco)	Tetra Pac 3L
W11	Artisanal	Red wine	0.75L Glass

2.1. Determination of pH and titratable acid (TA)

The titratable acidity (TA) and pH for each sample were determined using a Denver pHmeter. Titratable acidity was determined by diluting a 10ml aliquot of each wine with 90ml of distilled water and then titrating the sample with 0.1N NaOH to a pH of 8.1.

2.2. Determination of total polyphenols

Polyphenol determination was performed according to the method presented by Singleton (1999) and the results are presented as mg gallic acid/l by using a SPECORD 40 spectrophotometer. In a 100 ml volumetric flask, 0.5 g of dry gallic acid were dissolved in 10 ml of ethanol and then diluted them to volume with water (Gallic Acid Stock Solution). To prepare a calibration curve, we added 0, 1, 2, 3, 5, and 10 m L^{-1} of the above phenol stock solution into 100 mL volumetric flasks and then diluted them to volume with water. These solutions had phenol concentrations of 0, 50, 100, 150, 250, and 500 mg L^{-1} gallic acid, the effective range of the assay.

2.3. Determination of anthocyanins

The total monomeric anthocyanin content in the wine samples was determined by using the pH-differential method described by Guisti and Wrolstad (2003). Anthocyanins have a maximum absorbance at the wavelength of 520 nm and at the pH of 1.0. The coloured oxonium form predominates at pH 1.0, and the colourless hemiketal form at pH 4.5. The pH-differential method is based on this reaction and permits an accurate and rapid measurement of the total monomeric anthocyanins (Margaret et al., 2006). The spectrophotometric absorbances of the wine at 520 nm and 700 nm for both pH levels, were determined using a 1 mm cuvette and by using a SPECORD 40 spectrophotometer.

3. RESULTS AND DISCUSSION

The results for pH and the titratable acidity (TA) for eleven analyzed wines are presented in Figure 1. The pH values range from 3.17 for W7 to 3.72 obtained for Brusco wine. The changes in the TA values are more visible. The minimum value obtained for W1 (import wine) and the highest value, very different from the other samples, was found for W11, which is an artisanal and unlabeled wine.

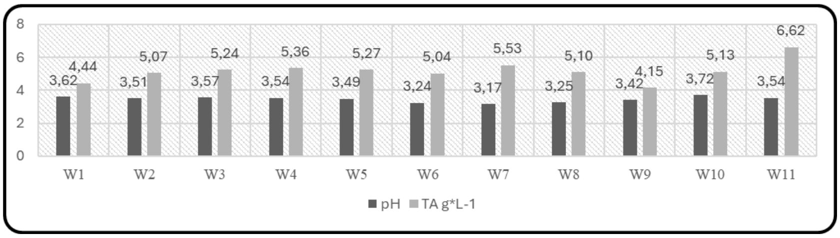


Figure 1. Value for pH and TA (the titratable acidity) for 11 analysed wines

According to the literature, the lower the pH, the higher the acidity in wine. There is no direct correlation between total acidity and pH (it is possible to find wines with a high pH for wine and high acidity) (Beelman and Gallander, 1979).

3.1. Polyphenols

Polyphenols have been reported to have antioxidant, anti-aging, anti-inflammation, anti-obesity, cardioprotective, neuroprotective, antibacterial, antiviral, antifungal, antiproliferative, anti-inflammatory, anti-allergic, anti-hypertensive and antithrombotic properties, and positive effects on human microbiota composition and functionality (Vecchio et al., 2017; Visioli et al., 2020; Fernández-Mar et al., 2012; Poulsen et al., 2013).

Figure 2 presents the polyphenol values obtained from measurements in the 1 L wines studied, expressed in mg AGE L^{-1}. The polyphenol values for white wines range from 159.5 mg L^{-1} to 218.8 mg L^{-1}, while for red wines from 1014.2 mg L^{-1} for artisanal wines to 2069.5 mg L^{-1} for W6 (Vranac).

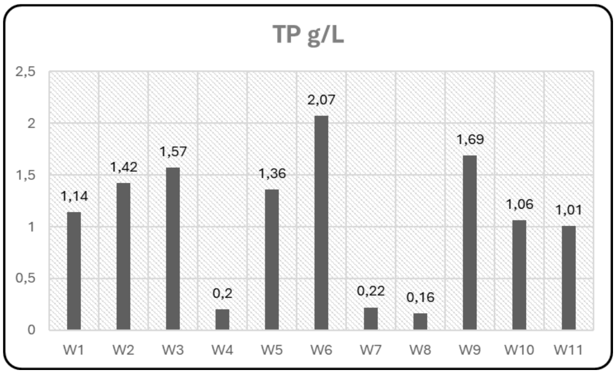


Figure 2. Value of total polyphenols for studied wines

It is important to remember that during the winemaking process, red wines come into contact with every part of the grape. For this reason, their polyphenol concentration is higher (1-5 g L^{-1}) than in white wines (0.2-0.5 g L^{-1}), the contents of which are primarily derived from the pulp, as the types and proportions of polyphenols are different in the pulp, skin, and seeds of grapes (Visioli et al., 2020).

Polyphenolic composition varies among different wines according to the type of grape used, vivification process used, type of yeast that participates in the fermentation, and whether grape solids are present in the maceration process. When the same type of grape is involved, phenolic content may differ depending on the type of soil, weather variations (temperature, rain and humidity) and other biological effects (fungi, insecticides and fertilizers) (Alvarez et al., 2000).

3.2. Anthocyanins

Anthocyanins are responsible for most of the red, blue, and purple colors of fruits, vegetables, flowers, and other plant tissues of the products. In addition to their direct role in the color, anthocyanins also contribute to the taste and chemical characteristics of the wine because of their interactions with other molecules such as colorless phenols, polysaccharides, metals, and anthocyanins themselves (Visioli et al., 2020, Fernández-Mar et al., 2012). The color components of the wine are important parameters that contribute to sensory characteristics (color and astringency) and the antioxidant properties of the wine (Poulsen et al., 2013). With aging, the monomeric anthocyanins are thought to be gradually incorporated into polymeric pigments, and this confers color stability of the wine. The data for monomeric anthocyanin pigment are shown in Figure 3.

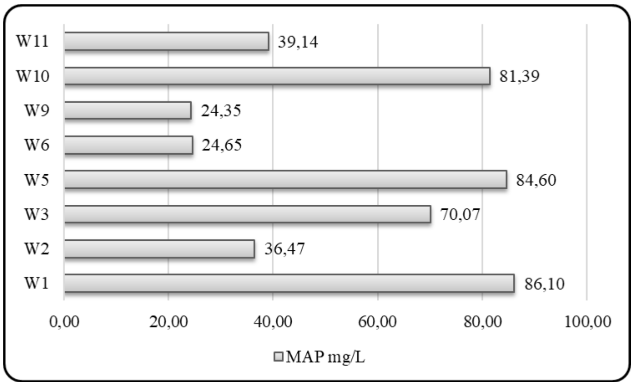


Figure 3. Value of monomeric anthocyanin pigment for 8 red wines

This high concentration of phenolic chemicals helps define the sensory qualities of the grape juices, including color, flavor, and taste. Food additives and nutritional goods made from grapes have become widely available in the global market in recent years, but we must remember that consumers look for both the nutritional products' qualities and their palatability.

3.3. The effect of climate change in chemical properties of wine

Many internal and external factors have proved to significantly affect the concentration of phenolic compounds. It is possible to distinguish three decisive levels in which phenolic compounds may be modulated: (i) vineyard; (ii) winemaking; and (iii) wine storage. A higher concentration of phenolic compounds was exhibited in varieties grown in a climate of long winters with low temperatures and possible snowfall (Gutiérrez et al., 2021). The amount and composition of anthocyanins in red wine grapes vary greatly in species, cultivar, maturity, season, region, and yield (Mazza, 1995). The stability of these anthocyanidins depends on various factors such as the pH, storage temperature, and raw materials used during processing (Nemzer et al., 2022).

Climate change is having profound effects on the chemical properties of wine, influencing everything from grape composition to the final product's sensory characteristics. Warmer temperatures lead to higher sugar accumulation in grapes as photosynthesis rates increase. This results in wines with higher alcohol content, as yeasts convert these sugars into ethanol during fermentation. Studies have shown that potential alcohol levels in grapes have increased by more than 2% by volume over recent decades due to rising temperatures (Leeumen and Darriet, 2020; Knowble Magazine, 2022).

The composition of volatile aroma compounds is significantly influenced by temperature and water stress. Higher temperatures can enhance the production of certain aromatic compounds while inhibiting others. For example, terpenes responsible for floral notes may be reduced at elevated temperatures, while compounds associated with overripe fruit flavours may increase (de Ordun, 2010; Knowble Magazine, 2022). This shift can alter the overall aromatic profile of wines, making them taste more "cooked" or overly ripe rather than fresh and vibrant (Knowble Magazine, 2022; BBC Future, 2022)

As temperatures rise, the acidity of grapes tends to decrease. This is particularly evident with malic acid, which diminishes as grapes ripen in warmer conditions. A reduction in total acidity can lead to wines that taste flabby or less refreshing, as acidity provides balance and longevity to wine (de Ordun 2010; Leeumen and Darriet, 2020; Knowble Magazine, 2022). The pH levels of must (grape juice) have also been observed to rise, sometimes exceeding 4, which can further affect the wine's stability and aging potential (de Ordun, 2010). Water availability plays a crucial role in grape composition. Increased water stress due to changing rainfall patterns can lead to concentrated sugars but may also negatively affect the development of secondary metabolites that contribute to flavour complexity. For instance, some studies indicate that water-stressed vines produce grapes with lower levels of certain aroma precursors, which can diminish the wine's aromatic quality (Leeumen and Darriet, 2020; Knowble Magazine, 2022).

As climate change alters growing seasons, harvest times shift earlier by approximately 10 days to two weeks. This change affects the chemical development of grapes. Early harvesting: While harvesting earlier may prevent grapes from becoming overly sweet due to high sugar concentrations, it risks missing the full development of secondary compounds that contribute to complexity and depth in wine (de Orduña, 2010). This creates a challenge for winemarkers seeking to balance sweetness with acidity and flavor complexity.

4. CONCLUSION

An important part of tourism in Albania are also agritourism experiences that connect visitors with traditions, local cuisine and rural life. The inland areas are characterized by landscapes filled with hills, olive groves and vineyards, making them ideal for agricultural activities; Agriculture serves as a base to present local gastronomy and fresh, seasonal and organic products, such as wine, citrus fruits and olive oil, allowing visitors to experience traditional Albanian cuisine on agritourism farms; Local wineries offer tastings and visits to explore the indigenous grape varieties of Albania.

In line with the ongoing government initiatives, the focus of the "100% Albanian" initiative is the opening for the first time of a physical one-stop service where the best local products of Albania will be exhibited, promoting national heritage and supporting local economies.

Partnerships with local farmers, artisans and producers will guarantee the authenticity and quality of the products offered in these stores. This platform will feature a variety of authentic Albanian products, including exclusive wines and innovative plant-based products. Capitalizing on Albania's rich agricultural and cultural heritage, the "100% Albanian" initiative aims to become a key platform for the promotion and distribution of Albanian products worldwide, thus creating a sustainable and prosperous local economy.

According to our findings, the chemical parameters examined in our wine samples are comparable to those found in the literature. It is observed that significant differences in acidity values were found between certified and artisanal wine.

The chemical properties of wine are intricately linked to climate conditions. As climate change continues to influence temperature patterns, precipitation levels, and atmospheric CO_2 concentrations, winemakers must adapt their practices to maintain wine quality. Understanding these chemical changes is crucial for navigating the challenges posed by a warming world while preserving the unique characteristics that define different wine regions.

Many farms that adapt their agricultural activity to agritourism will need to invest in on-farm processing lines. Potential tourists looking for an agritourism experience expect to taste the traditional food and cuisine that the farm has to offer. Thus, farms will need to invest in on-farm processing plants and machinery. Some of the investments include small wineries and wine tasting rooms. Traditional processed products are highly preferred by foreign tourists seeking agritourism experiences, as processed products can be served in restaurants, as well as sold directly to visitors (AASF and CBS, 2019).

Thanks to its geographical position, number of sunny days, fertile soil and indigenous varieties, Albania has the potential to develop a competitive industry in the region and beyond, if investments are made in quality (including TGJ, EO) and the creation of the Made in Albania brand.

5. REFERENCES

Alvarez-Sala, L., Slowing, K., Gomez-Serranillos, P., Torres, F., Valderrama, M., Millan, J. (2000). Variabilidad del contenido de polifenoles de distintos tipos de vino y su potencial aplicación al conocimiento de sus efectos biologicos. Med Clin (Barc), 114, 331-332.

BBC Future (2022). How climate change is tweaking the taste of wine.

Beelman, R.B., Gallander, J.F. (1979). "Wine Deacidification". In Chichester, C.O., Mrak, E.M., Stewart, Franklin, G. (Eds.). Advances in Food Research, Academic Press, 25, p. 3. ISBN 0-12-016425-6 (Retrieved 2009-08-04)

Van Leeuwen, C., Darriet. P. (2020). The impact of climate change on viticulture and wine quality.

Decanter (2023). Albania: Unique varieties, forward-thinking producers and growing confidence.

Euronews (2023). Albanian government to boost local wine producers with 146 million euros program.

FAOSTAT (2018). www.fao.org/faostat/en

Fernández-Mar, M.I., Mateos, R., García-Parrilla, M.C., Puertas, B., Cantos-Villar, E. (2012). Bioactive compounds in wine: Resveratrol, hydroxytyrosol and melatonin: A review. Food Chem., 13. doi10.1016/j.foodchem.2011.08.023.

Guisti, M.M., Wrolstad, R.E. (2003). Characterization and measurement of anthocyanins by UV-visible spectroscopy. Current protocols in food analytical chemistry. John Wiley & Sons, New York.

Gutiérrez-Escobar, R., Aliaño-González, M.J., Cantos-Villar, E. (2021). Wine Polyphenol Content and Its Influence on Wine Quality and Properties: A Review. Molecules, 26, 718. doi.org/10.3390/ molecules26030718

Imami, D., Skreli, E., Zhllima, E., Cela, A., Sokoli, O. (2015). Consumer preferences for typical local products in Albania. Economia agro-alimentare Economia agro-alimentare / Food Economy, 17(3), 11-29. doi: 10.3280/ECAG2015-003002

INSTAT (2017). www.instat.gov.al

Knowable Magazine (2022). Climate change is altering the chemistry of wine.

Lingua, M.S., Fabani, M.P., Wunderlin, D.A., Baroni, M.V. (2016). From grape to wine: Changes in phenolic composition and its influence on antioxidant activity. Food Chem., 208, 228-238.

Mazza, G. (1995). Anthocyanins in grapes and grape products. Critical Reviews in Food Science and Nutrition, 35, 341-371.

Nemzer, B., Kalita, D., Yashin, A.Y., Yashin, Y.I. (2022). Chemical Composition and Polyphenolic Compounds of Red Wines: Their Antioxidant Activities and Effects on Human Health. A Review. Beverages, 8, 1. doi.org/10.3390/ beverages8010001.

Poulsen, M.M., Jørgensen, J.O.L., Jessen, N., Richelsen, B., Pedersen, S.B. (2013). Resveratrol in metabolic health: An overview of the current evidence and perspectives. Ann. N.Y. Acad. Sci., 1290. doi: 10.1111/nyas.12141.

Programi i Mbështetjes së Agrobiznesit Shqiptar (AASF) (Qershor 2019). Creative Business Solutions (CBS). Sektori i agroturizmit në Shqipëri: Potencialet për zhvillim dhe nevojat financiare.

De Orduña, R.M. (2010). Climate change associated effects on grape and wine quality and production. Food Research International, 43(7), 1844-1855.

Seven Fifty Daily (2023). What You Need to Know About Albanian Wine.

Singleton, V. L., Orthofer, R., Lamuela-Raventos, R.M. (1999). Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu Reagent. Methods in Enzymology, 299, 152-178.

Skreli, E., Imami, D. (2019). Studim për sektorin e verës, AASF. Tiranë, p. 38.

UNSTAT (2018). baza e të dhënave gjendet në https://comtrade.un.org/data/

Vecchio, R., Decordi, G., Grésillon, L., Gugenberger, C., Mahéo, M., Jourjon, F. (2017). European consumers' perception of moderate wine consumption on health. Wine Econ. Policy., 6, 14-22. doi: 10.1016/j.wep.2017.04.001

Visioli, F., Panaite, S.A., Tomé-Carneiro, J. (2020). Wine's phenolic compounds and health: A pythagoean view Molecules. 25, 4105. doi: 10.3390/molecules25184105

Wen, M., Anque, G., Yulin, Z., Hua, W., Ye, L., Hua, L. (2014). A review on astringency and bitterness perception of tannins in wine. Trends Food Sci. Technol., 40, 6-9.

Zhllima, E., Chan-Halbrendt, C., Zhang, Q., Imami, D., Long, R., Leonetti L., Canavari, M. (2012). Latent class analysis of consumer preferences for wine in Tirana, Albania. Journal of international food & agribusiness marketing, 24(4), 321-338.

doi:10.46793/MAK2025.073M

THE IMPACT OF CLIMATE CHANGE ON WHEAT PRODUCTION IN BOSNIA AND HERZEGOVINA

Vesna Milić[1*], Igor Đurđić[1], Branka Govedarica[1], Saša Lalić[2], Tanja Mijatović[1]

[1]University of East Sarajevo, Faculty of Agriculture, Republic of Srpska, Bosnia and Herzegovina
*vesna.milic@pof.ues.rs.ba, igor.djurdjic@pof.ues.rs.ba, branka.govedarica@pof.ues.rs.ba, tanjamijatovic87@yahoo.com
[2]Ministry of Agriculture, Forestry and Water Management, Republic of Srpska, Bosnia and Herzegovina, s.lalic@mps.vladars.rs

Abstract: Agriculture has long been the backbone of the economy of Bosnia and Herzegovina, due to its contribution to overall employment and ensuring food security for a large part of the population. Cereal production, especially wheat, forms the basis for providing food to the population, while corn production is crucial for livestock feed. It is anticipated that the impact of climate change on agricultural production will be largely negative, as water regimes change, and rising temperatures worsen existing challenges to agricultural productivity. In Bosnia and Herzegovina, floods pose the greatest threat to the community, but other natural disasters also cause significant damage to infrastructure, material assets, agriculture, and forests.

Key words: Climate change, Drought, Wheat, Corn

1. INTRODUCTION

Bosnia and Herzegovina's ability to produce various agricultural products is attributed to its favorable agro-climatic conditions and the availability of agricultural land, which covers 46% of the country's territory. It is estimated that about 20.5% of the population is officially employed in this sector, with an average of 56% of those working in agriculture being women. Agricultural land in Bosnia and Herzegovina has not been used in accordance with the general societal interest for a long time, and significant areas of arable land remain uncultivated and abandoned. It is estimated that the total arable land in Bosnia and Herzegovina covers about one million hectares. Generally speaking, agricultural production in Bosnia and Herzegovina is characterized by extensive farming and is highly dependent on weather conditions. The characteristics of the agricultural sector include: low productivity, an unfavorable farm structure, insufficient and poor technological equipment, and a reliance on imports for most inputs needed for production, such as seed material, protective agents, mineral fertilizers, as well as equipment and agricultural machinery. Additionally, the agricultural sector in Bosnia and Herzegovina must focus on improving the quality and production of special (typical and traditional) high-value products, i.e., value-added products, in order to build sustainable competitive advantages. The structure of cultivated areas has not changed for many years. The largest share of total cultivated areas, 58%, is occupied by cereals, followed by forage crops at 26%, vegetables at around 15%, and industrial crops at just 1% (Milić et al., 2019a). The potential of agricultural production in Bosnia and Herzegovina, reflected in favorable agro-climatic conditions, a wide variety of agricultural crops, high-quality agricultural land, good quality and traditional products, a large number of indigenous and original products, and the knowledge and efforts of agricultural producers, has not been anywhere near fully utilized relative to the available opportunities (Milić et al., 2019b).

The projected rise in temperatures, combined with changes in precipitation amounts and evaporation rates, is likely to significantly negatively affect agricultural systems in Bosnia and Herzegovina, especially in the Mediterranean regions and the northern part of the country. Increasing variability in weather patterns has been observed in all seasons, including rapid changes between shorter periods (five to ten days) of extremely cold and warm weather conditions, so-called heat and cold waves, as well as periods with extremely heavy rainfall and droughts. These increased fluctuations in temperature and rainfall lead to a rise in the intensity and frequency of extreme weather events, often accompanied by storms and hail. There is also noticeable variability in weather conditions over short time intervals and small areas, along with worsening biometeorological conditions and clear consequences for agricultural production. The impact of climate change on crop production is reflected in the following indicators: prolonged changes in average air temperatures and precipitation levels; increased development of diseases, weeds, and pests; land degradation (erosion, nutrient leaching, reduced infiltration); extension of the growing season (positive impact); and shortening of the growing season (late spring and early autumn frost). Adaptation strategies to climate change will influence improved management of water resources and irrigation systems, the development of new agricultural systems suited for warmer and drier environments, and various improvements in local crop varieties aimed at maximizing agricultural production under drier conditions.

The aim of the research is to analyze the impact of climate change on wheat production in Bosnia and Herzegovina from 2016 to 2023.

2. MATERIAL AND METHODS

For the analysis of the impact of climate change on field crop production in Bosnia and Herzegovina, we used data from the meteorological institutes of the Republic of Srpska and the Federation of Bosnia and Herzegovina, the Third and Fourth National Reports of Bosnia and Herzegovina in accordance with the United Nations Framework Convention on Climate Change, as well as annual reports from the Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina, the annual reports of the Ministry of Agriculture, Water Management, and Forestry of the Republic of Srpska, and the Statistics Institute of the Republic of Srpska and Bosnia and Herzegovina. The collected data was processed both in tabular and graphical form.

3. RESULTS AND DISCUSSION

3.1. Climate and Climate Change in Bosnia and Herzegovina

In Bosnia and Herzegovina, three dominant climates prevail (mountain and mountain-continental; continental; Mediterranean and modified Mediterranean) conditioned by geographic location, geological substrate, relief, vegetation cover, and proximity to the Adriatic Sea (Trbić et al., 2010; Bajić and Trbić, 2016).

Continental and moderately continental climates dominate the northern regions of Bosnia and the valleys of the middle reaches of the Una, Sana, Vrbas, Bosnia, and Drina rivers. Average annual temperatures are relatively high, ranging from 9.6 °C to 11.4 °C, with pronounced seasons. The highest rainfall (between 1000 and 1500 mm) occurs in the northwestern areas, while the lowest amounts (below 800 mm) are recorded around Bijeljina, Orašje, and Šamac (SNC, 2022).

The mountain and mountain-valley climate covers the hilly-mountain region of Bosnia and Herzegovina, which spreads from the northern border to the southern boundary, represented by a line from Posušje and the southern slopes of Čabulja, Velež, and Bjelašnica to Bileća. This area is under the influence of Central European continental climate from the north and Mediterranean climate from the south. Average annual temperatures range from 1.2 °C to 11.6 °C. The spatial distribution of annual rainfall is uneven due to the complex terrain. High mountain ridges with strong air currents receive large annual rainfall amounts, ranging from 1500 to 2300 mm, while sheltered river valleys and basins have much less, ranging from 700 to 800 mm (SNC, 2022).

The Mediterranean and modified Mediterranean climates are found in the southwest of the country, in the region of Herzegovina. Due to its proximity to the Adriatic Sea and its direct influence on climate characteristics, this area has maritime climate features. Average annual temperatures are relatively high, ranging from 12.8 °C to 15.2 °C. Rainfall in this area is unevenly distributed, both seasonally and spatially. The lowest amount of rainfall is in Čapljina with 1070 mm, while the highest is in Vrbanj (Orjen) with 3347 mm (SNC, 2022).

The thermal regime and climatic characteristics of Bosnia and Herzegovina are influenced by the Azores anticyclone, which causes stable and, in summer, warm weather, and the Icelandic cyclone, which brings precipitation. During winter, the influence of the Siberian anticyclone is sometimes recorded, bringing cold and mostly dry weather, while in summer, there is also the effect of an anticyclone of Saharan or Mediterranean origin, which results in extremely hot and dry conditions (Trbić and Bajić, 2011).

The average annual precipitation in Bosnia and Herzegovina is around 1250 mm, which is about 25% higher than the European average. When water resources are measured per capita, the ratio is even more favorable for Bosnia and Herzegovina: they are 2.5 times greater than the European average. Runoff is 57%, but these water quantities are not evenly distributed, both spatially and temporally. For example, the average annual runoff in the Sava River Basin (Danube sub-basin), which covers 75.7% of Bosnia and Herzegovina's territory, is 62.5%, while runoff to the Adriatic Sea basin, covering 24.3%, is 37.5% (SNC, 2016).

The effect of the greenhouse effect and global warming on the climate of Bosnia and Herzegovina is becoming more evident. The extremity of climate events is increasing to alarming levels. The best example is the period from 2010 to 2020, during which five extremely dry and two extremely rainy years were recorded. In the written meteorological history of Bosnia and Herzegovina, the year 2011 will be remembered as the driest. In contrast, the year 2014 saw enormous amounts of rainfall in May, leading to catastrophic floods in Bosnia and Herzegovina and the region. The highest average annual temperature was recorded in 2014. For the first time in recorded climate data, three consecutive extremely dry years occurred. In 2010, higher-than-average temperatures were recorded compared to the long-term average, but precipitation was significantly above the average, with rainfall distributed evenly during the growing season. The weather during the drought years of 2011, 2012, and 2013 significantly impacted crop yields for most field crops (Vuković, 2016).

The average annual air temperatures in 2016 were significantly above the long-term period average values (1961-1990) throughout Bosnia and Herzegovina, ranging from 10.4 °C to 16.7 °C. In mountain areas, temperatures ranged from 2.2 °C to 8.3 °C. Total rainfall in 2016 ranged from 842.3 mm to 1519.6 mm. Unlike previous years, during 2016, there were no extreme weather events that caused significant material damage or endangered human lives. The winter of 2015/2016 was one of the warmest ever. Early in the year, there were abundant snowfalls, especially in the north and west, where snow depths reached nearly half a meter. Spring was variable with frequent rains, and the late spring frost at the end of April caused significant damage to fruit crops. In the east, there was no strong frost, but snow fell, which also caused damage. Summer was variable with frequent rain, and there were also heavy rainfalls. Unlike previous years, there were no major heatwaves, with temperatures not exceeding 40 degrees Celsius. In the south and east, heavy rainfall occurred, while in other areas, it was slightly below average. December was very dry and cold, one of the driest ever. In many areas, especially in the plains, where fog often lingered, it was the coldest December in the last ten years.

Average annual temperatures in 2017 were significantly above the long-term period average values (1961-1990). Air temperatures ranged from 10.4 °C to 16.0 °C. In mountainous areas, temperatures varied from 1.8 °C to 8.2 °C. Total rainfall in 2017 ranged from 825.4 mm to 1522.6 mm. December and September were the months with the most rainfall during 2017, while August had the least. In the mountainous areas, the highest snow depth was recorded on Bjelašnica at 113 cm. Average annual temperatures in 2018 were significantly above the long-term period average values (1961-1990), ranging from 11.1 °C in the plains to 17.6 °C in Neum, while in the mountains, temperatures ranged from 2.6 °C to 8.8 °C. According to the distribution of percentiles, the temperature conditions in 2018 were classified as extremely warm. Total rainfall in 2018 ranged from 775.1 mm to 1474.9 mm. March and February had the highest rainfall, while September had the lowest. In Mostar, the lowest monthly rainfall in September was 6.7 mm, while in March, it was 305.7 mm, the highest monthly total in 2018. The highest snow depth was recorded in Bihać at 107 cm, and in the mountainous areas on Bjelašnica, the highest snow depth was 219 cm.

Average annual temperatures in 2019 were significantly above the long-term period average values (1961-1990), ranging from 10.9 °C to 17.3 °C, while in the mountains, they ranged from 2.4 °C to 8.8 °C. Total rainfall in 2019 ranged from 843.5 mm to 1557 mm. February and October were the months with the least rainfall. The greatest monthly rainfall in northern and central areas was recorded in May, while in southern areas, it was in November. In lower areas, the highest snow depth ranged from 46 cm, while in the mountains, it reached up to 220 cm.

Average annual temperatures in 2020 were significantly above the long-term period average values (1961-1990), ranging from 10.7 °C to 17.1 °C, while in the mountains, they ranged from 2.6 °C to 8.7 °C. The number of hot days was higher than the average for the period 1961-1990, ranging from 35 at Ivan-sedlo to 130 in Mostar. Total rainfall in 2020 ranged from 776.8 mm to 1448.0 mm. The highest snow depth ranged from 33 cm in lower areas to 74 cm in mountainous regions.

Average annual temperatures in 2021 were slightly above the long-term period average values for the period (1991-2020), ranging from 10.5 °C to 17.1 °C, while in the mountains, they ranged from 1.9 °C to 8.3 °C. Total rainfall in 2021 ranged from 760 mm to 1542 mm. June had the lowest monthly rainfall in most of Bosnia and Herzegovina, while the highest monthly totals were recorded in November. The highest snow depth in lower areas ranged from 39 cm to 243 cm in the mountains (Bjelašnica).

Average annual temperatures in 2022 ranged from 11.2 °C to 17.1 °C, and in the mountains, from 2.6 °C to 9.1 °C. Total rainfall in 2022 ranged from 671 mm to 1205 mm. October had the lowest monthly rainfall in most of Bosnia and Herzegovina, while the highest monthly rainfall was recorded in November. The greatest snow depth ranged from 18 cm in plains areas to 211 cm in the mountains (Bjelašnica).

Average annual temperatures in 2023 were significantly above the long-term period average values for the period (1991-2020), ranging from 11.2 °C to 17.7 °C in lower areas, and from 2.7°C to 9.3°C in the mountains. Total rainfall in 2023 ranged from 885.5 mm to 1851.8 mm. July had the lowest monthly rainfall at most stations, while the greatest monthly rainfall occurred in November. The highest snow depth was 37 cm in lower areas, and in mountainous regions, the greatest snow depth was 187 cm.

3.2. Cereal production in Bosnia and Herzegovina

The average area of arable land used in the Federation of Bosnia and Herzegovina over a ten-year period was 194.000 ha, or 48.6% of the total arable land, while more than half, or 205.000 ha, remained as fallow or uncultivated land. In the Republic of Srpska, the situation was somewhat better, with the average area of cultivated land amounting to around 324.000 ha, or 55.4%, while

44.6%, or 261.000 ha, remained unused (MSTEO Bosnia and Herzegovina, 2023). The average cultivated area in the District is around 30.000 hectares, with about 48% of this land sown, 30% fallow, and 22% uncultivated arable land. The cropping structure on cultivated agricultural land has remained relatively unchanged for many years, with cereals occupying the largest share of sown land. Cereal production is one of the most important segments of agricultural production and essential for the food security of the population. The importance of cereals in Bosnia and Herzegovina's production is evident from the fact that during the observed ten-year period, cereals were sown on an area of about 306.000 hectares on average, which represents 55-60% of the total sown arable land. The cultivation of spring cereals is very important for the hilly-mountainous areas (Bogdanović et al., 2001). An increase in the area planted with spring cereals and buckwheat would contribute to increasing the amount of bread grains for human and livestock consumption (Bogdanović and Milić, 2005, 2007). Domestic cereal production ranges from 1.200.000 to 1.400.000 tons.

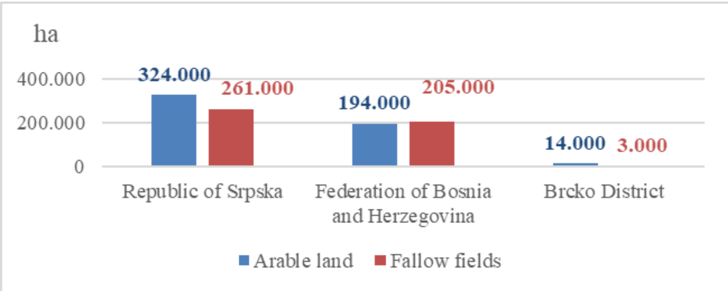


Figure 1. Structure of agricultural land in Bosnia and Herzegovina

The sowing structure on used agricultural land has remained unchanged for a long period, with cereals having the largest share of sown areas, amounting to 58%, followed by forage crops at 26%, vegetables at 14%, and industrial crops at around 2%. Cereal production represents one of the most important segments of agricultural production, as well as in the overall structure of field crop production, since it forms the foundation of food security for the population. In 2016, the harvested area for cereals was around 321.000 hectares, with maize (60%) and wheat (22%) having the largest share of the harvested cereal areas. During the autumn sowing of 2016, 99.307 hectares were sown with cereals, of which 65.181 hectares were winter wheat and 34.048 hectares were other winter cereals. Domestic cereal production ranges between 1.200.000 and 1.400.000 tons. Maize is the number one field crop in Republika Srpska, as over 40% of the sowing area is planted with maize each year, followed by around 44.000 hectares of wheat and between 25.000 and 30.000 hectares of other cereals. In 2016, maize production reached 880.998 tons, which is 57% more than the previous year's production, while wheat production was 194.311 tons, 52% more. Rye increased by 35%, triticale by 34%, barley by 28%, and oats by 15.5%. In the Federation, maize also occupies the largest sown areas, around 50.000 hectares, with a production of about 200.000 tons. Maize production is most widespread in the Federation. In 2016, production reached 243.760 tons, which is 30% more than the previous year. Wheat is in second place with an average of 20.000 hectares sown and an average production of 50 to 70 thousand tons. Wheat production in 2016 was 86.732 tons, a 20.6% increase over 2015. In addition, there was also an increase in the production of other cereals, with rye up by 22.1%, barley by 10.4%, and oats by 15.6% compared to the previous year. In the Brčko District of Bosnia and Herzegovina, maize production was 54.488 tons, wheat 6.210 tons, barley 888 tons, triticale 324 tons, and oats 732 tons.

The stability of agricultural production and the level of cereal yields in Bosnia and Herzegovina largely depend on weather conditions. As a result of climate change over the past 10 years, seven years were marked as drought years, with some years, such as 2008, 2010, and 2012, being extremely dry. In 2014, catastrophic floods occurred, causing significant damage to agricultural production and producers, reducing overall yields and product quality. Maize production contributes the most to the total cereal production. The unfavorable weather conditions during 2008, 2010, 2012, and 2014 negatively impacted maize production and yield, which also affected overall cereal production. In 2016, maize was sown on 193.000 hectares, and thanks to favorable weather conditions and good rainfall distribution, production reached 1.178.423 tons, a 50% increase compared to the previous year. Maize production was also higher compared to the long-term period average values, which is around 814.000 tons. The maize yield was 6.1 tons per hectare, 49% higher than the previous year's yield. In addition to maize, other cereals also recorded higher production, with wheat increasing by 44%, rye by 27%, barley by 22%, oats by 19%, triticale by 31%, and buckwheat by 9%. As for the marketing of the produced cereals and their final use, most of the grain is sold to mills for flour milling and animal feed production or used for livestock feed on the producers' farms.

Climatic conditions such as temperature, precipitation, humidity, insulation, and wind play a key role in the physiological processes of plants and phenophases in the plant life cycle, as well as in determining the limits of plant species distribution and their communities (Popov et al., 2019; Popov et al., 2021), which also reflects in the average yield that varies from year to year. Rapid anthropogenic climate changes affect the plant world and ecosystems through changes in average climatic conditions and variability in climatic extremes (Malhi et al., 2020).

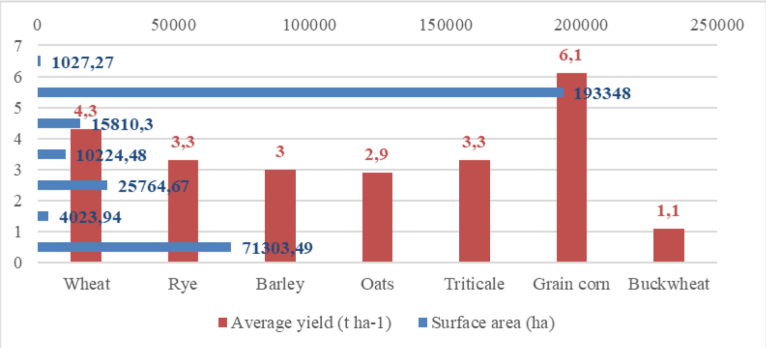


Figure 2. Areas and average grain yields in 2016.

According to statistical data for 2017, in Bosnia and Herzegovina, about 60% of the sown areas were planted with cereals, 24% with forage crops, 13% with vegetables, 2% with industrial crops, around 1% with strawberries and raspberries, and 0.2% with aromatic, spice, and medicinal herbs.

Adverse agro-climatic conditions in 2017 negatively affected plant production. In terms of yields, the year 2017 can be characterized as an extremely bad year, as there was a decrease in yields and overall production of field crops, vegetables, fruits, and grapes. The most significant negative impact of unfavorable weather conditions, particularly drought, was seen in maize crops. The yield of 3.7 tons per hectare was 39% lower than the yield from the previous year. The lower maize yield per hectare also resulted in a 40% decrease in total maize production. In addition to the lack of moisture in the soil, which negatively impacted the formation and filling of the kernels and thus the yield, the drought caused problems with maize pollination and fertilization, leading to incomplete ear formation and poor grain quality.

In the Republika Srpska, maize production in 2017 was 497.500 tons, a decrease of 44%. In the Federation, 157.385 tons of maize were produced, which is 86.375 tons or 35% less compared to the previous year's harvest. According to available data from relevant institutions, a 2% increase in maize production was recorded only in the Brčko District.

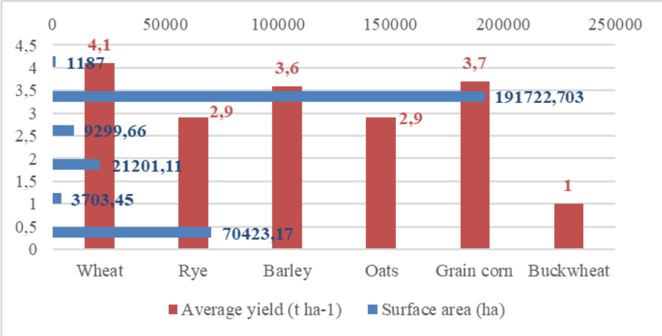


Figure 3. Areas and average grain yields in 2017.

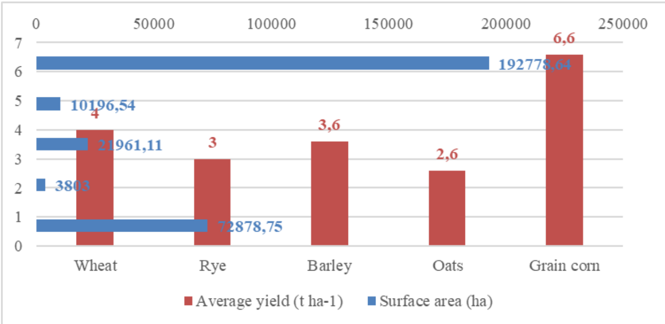


Figure 4. Areas and average grain yields in 2018.

Favorable agro-ecological conditions in 2018 had a positive impact on plant production, making this year a good one, as both yields, and total production of most field crops increased. Extremely favorable conditions, with a good distribution and amount of rainfall, along with timely application of agrotechnical measures, contributed to a good maize yield of 6.6 tons per hectare, which resulted in record production (79% higher compared to 2017). This is the clearest indicator of how dependent agricultural production is on weather conditions. The areas planted with cereals depend on market demand as well as weather conditions during the autumn sowing period. In 2018, in addition to maize, there was an increase in rye production by 6.2% and barley by 3.6%, while oat production decreased by 1.7%.

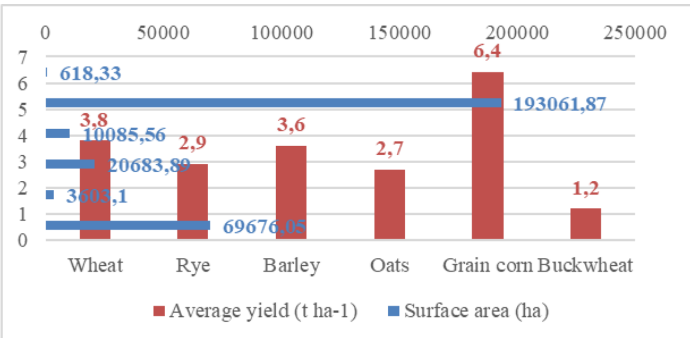


Figure 5. Areas and average grain yields in 2019.

Table 1. Total sown area and average yield of the most important cereals in Bosnia and Herzegovina

Cereals	2016		2017		2018		2019	
	Surface area (ha)	Average yield (t ha^{-1})	Surface area (ha)	Average yield (t ha^{-1})	Surface area (ha)	Average yield (t ha^{-1})	Surface area (ha)	Average yield (t ha^{-1})
Wheat	71.303,49	4.3	70.423,17	4.1	72.878,75	4.0	69.676,05	3.8
Rye	4.023,94	3.3	3.703,45	2.9	3.803	3.0	3.603,10	2.9
Barley	25.764,67	3.0	21.201,11	3.6	21.961,11	3.6	20.683,89	3.6
Oats	10.224,48	2.9	9.299,66	2.9	10.196,54	2.6	10.085,56	2.7
Triticale	15.810,3	3.3	-	-	-	-	-	-
Grain corn	193.348	6.1	191.722,70	3.7	192.778,64	6.6	193.061,87	6.4
Buckwheat	1.027,27	11	1.187	1.0	-	-	618,33	1.2
Total	321.502,15		297.537,09		301.618,04		297.728,8	
Cereals	2020		2021		2022		2023	
	Surface area (ha)	Average yield (t ha^{-1})	Surface area (ha)	Average yield (t ha^{-1})	Surface area (ha)	Average yield (t ha^{-1})	Surface area (ha)	Average yield (t ha^{-1})
Wheat	69.957,39	4.6	63.400,65	4.6	51.092	5.46	62.659	4.4
Rye	3.534,84	3.1	3.359,64	2.8	-	-	3.021	3.3
Barley	21.644,39	4.1	21.500,28	3.6	20.436,8	4.03	15.596	3.4
Oats	10.607,81	3.2	12.126,71	3.22	12.262,08	3.61	37.433	0.5
Triticale	-	-	-	-	4.087,36	5.16	7.770	5.0
Grain corn	200.895,21	7.1	198.472	4.5	116.489,76	8.33	183.950	5.7
Buckwheat	813,12	3.8	815	1.2	-	-	-	-
Total	307.452,76		299.674,28		204.368		310.429	

Ministry of Foreign Trade and Economic Relations of Bosnia and Herzegovina procesed data based on available statistical data and data from the competent entity ministries for agriculture.

Maize is the dominant crop in total cereal production, accounting for 76%. Despite the decline in livestock production and the reduction in the number of animals, maize remains the most widely grown crop on arable land. The maize production for grain in 2020 amounted to 1.426.356 tons, which is 25% higher than the previous year. In 2020, maize was sown on an area of over 200.000 hectares, achieving an average yield of 7.1 tons per hectare, which is 11% higher than the previous year. The increase in sown areas and higher yields per hectare, along with favorable climatic conditions, contributed to a record maize production in the last decade. The wheat crop in Bosnia and Herzegovina in 2020 amounted to 321.804 tons, which is 57.035 tons or 22% higher compared to the previous year. The increase in sown areas and favorable weather conditions that benefited wheat from sowing to grain filling and ripening, as well as adequate treatments, contributed to an increase in the wheat yield to 4.6 tons per hectare. Likewise, in 2020, in addition to wheat and maize, higher production and yields were also recorded for other cereals, including buckwheat (up by 75%), oats (up by 25%), barley (up by 19%), and rye (up by 5%).

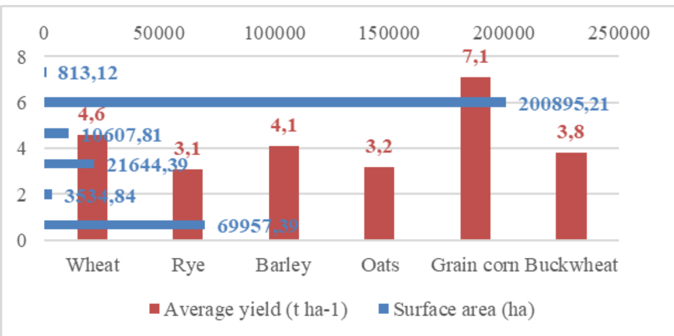


Figure 6. Areas and average grain yields in 2020.

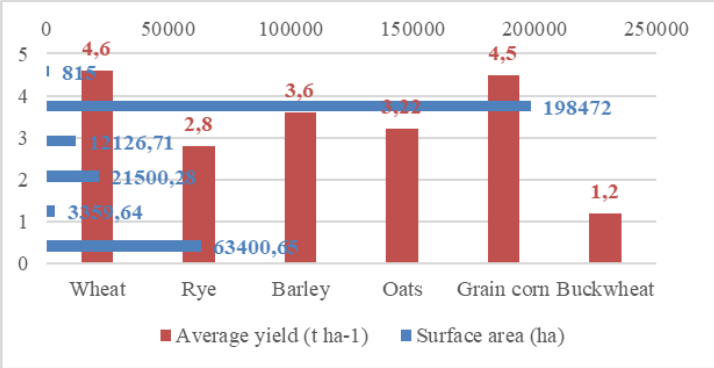


Figure 7. Areas and average grain yields in 2021.

The extremely dry period and high temperatures during the summer months of 2021, especially during the stages of grain formation and filling, negatively impacted the maize yield, which was 4.5 tons per hectare, resulting in a lower overall maize production. The total maize production for grain in 2021 was 37% lower compared to the 2020 harvest. The wheat crop in Bosnia and Herzegovina in 2021 was 9% lower compared to 2020. Unfavorable autumn, low temperatures during spring, and high temperatures during the summer months led to poor yields, which directly affected the wheat harvest. In addition to wheat and maize, the production of other cereals also saw a decrease in yields, with production falling by 25% for buckwheat, 14% for rye, and 13% for barley. The only exception was oats, where production increased by 15%.

In the structure of cereal-planted areas in 2022, approximately 57% was planted with corn, 25% with wheat, 10% with barley, 6% with oats, and 2% with triticale. Regarding the production of major cereal crops, 969.794 tons of corn, 278.711 tons of wheat, 82.279 tons of barley, 44.280 tons of oats, and 21.073 tons of triticale were produced. The production of oats increased by 13%, corn by 9%, barley by 6%, and triticale by 3%, while only the production of wheat decreased by 5% compared to the previous year.

In 2023, in the structure of cereal production, corn for grain accounts for about 73% of total production, followed by wheat with a share of 19%, barley 4%, triticale 3%, and other cereals 2%. According to the Ministry of Agriculture, Forestry, and Water Management of the Republic of Srpska, the total area planted with the most important cereals in the 2022/2023 period is 188.080 hectares, from which 1.073.794 tons of grain were produced. The leading crop is corn for grain with a production of 809.364 tons, followed by wheat with 213.015 tons, triticale ranked third with 38.850 tons, oats with 9.065 tons, and rye with 3,500 tons. In the Federation of Bosnia and Herzegovina in 2023, 215.227 tons of corn for grain, 57.578 tons of wheat, 21.758 tons of barley, 7.619 tons of oats, and 6.497 tons of rye were produced. Production increases were recorded for corn for grain (12%), while decreases were observed in other cereals, with wheat down by 33%, barley by 29%, oats by 27%, and rye by 16%. In the Brčko District of Bosnia and Herzegovina, 21.092 tons of corn, 4.574 tons of wheat, 2.587 tons of barley, 818 tons of oats, and 1.049 tons of other cereals were produced.

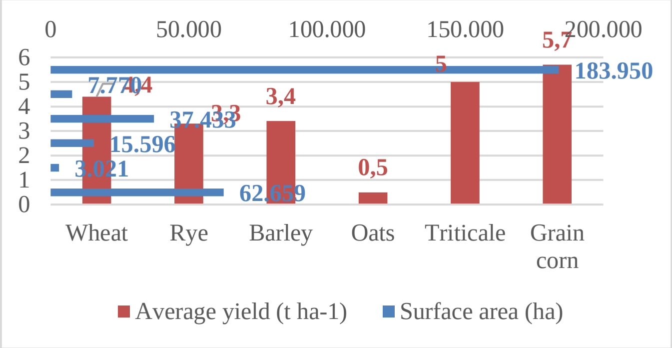


Figure 9. Areas and average grain yields in 2023.

4. CONCLUSION

The negative impact and damage caused by hail, drought, and extreme low and high temperatures cannot be ignored. Measures for climate change have still not been introduced into the agricultural sector because there are no developed or harmonized strategies for agriculture at the national, entity, regional, or local levels, let alone for mitigating the impact of climate change on this sector. Therefore, it can rightly be stated that awareness of climate change is underdeveloped, and the implemented measures and investments in this regard are ad hoc in nature, and likely only at the local level. Around 45% of agricultural land is hilly (300 to 700 meters above sea level), of average quality, and suitable for semi-intensive livestock farming. Mountainous areas (above 700 meters above sea level) make up an additional 35% of agricultural land. However, the high altitude, slope, and infertility of the land limit the use of this land. Less than 20% of agricultural land (half of the total arable land) is suitable for intensive agriculture, and it is mainly found in lowland areas in the northern part of the country, in river valleys. Bosnia and Herzegovina's wealth in water resources has been insufficiently utilized in agricultural production, and only recently, after extreme droughts, has investment in irrigation systems begun.

5. REFERENCES

Bajić, D., Trbić, G. (2016). Climate Atlas of Bosnia and Herzegovina, University of Banja Luka, Faculty of Science, 1-207.

Bogdanović, M., Pržulj, N., Milić, V. (2001). Production of spring cereals and potatoes in the mountainous area. Agroznanje, Banja Luka , R. Srpska, Bosna i Hercegovina. /in Serbian/

Bogdanović, M., Milić, V. (2005). Production of spring cereals and buckwheat in the mountainous area. Agroznanje, Banja Luka, Banja Luka , R. Srpska, Bosna i Hercegovina, 6(2), 15-24. /in Serbian/

Bogdanović, M., Milić, V. (2007). Healthy food production in rural areas – buckwheat cultivation. Proceedings, Jahorina,Bosna i Hercegovina, 372-378. /in Serbian/

Milić, V., Berjan, S., Govedarica, B., Đurđić, I., Jugović, M., Jakišić, T., Perković, G. (2019a). The importance of organic agriculture for the development of rural areas in Bosnia and Herzegovina, Agrotechnologies of the XXI century, Proceedings of All-Russian Scientific and Practical Conference with International Participation Devoted to the Centennial of Higher Agrarian Education in the Ural Region, ИПЦ "Прокростъ" Perm, Russia, 3(3), 36-42.

Milić, V., Drašković, B., Berjan, S., Govedarica, B., Đurđić, I., Jugović, M., Jakišić, T., Perković, G. (2019b). The impact of climate changes on crop production in Bosnia and Herzegovina, Agrotechnologies of the XXI century, Proceedings of All-Russian Scientific and Practical Conference with International Participation Devoted to the Centennial of Higher Agrarian Education in the Ural Region, ИПЦ "Прокростъ" Perm, Russia, 3(3), pp 72.

Popov, T., Gnjato, S., Trbić, G., Ivanišević, M. (2019). Analysis of Extreme Precipitation Indices in the East Herzegovina (Bosnia and Herzegovina). Journal of the Geographical Institute „Jovan Cvijić" SASA, 69(1), 1-16. doi.10.2298/ IJGI1901001P.

Popov, T., Gnjato, S., Trbić, G., Ivanišević, M. (2021). Changes in Air Temperature over East Herzegovina in the 1961-2016 Periods. Гласник/Herald, 25,1-24.

SNC BiH (2016). Third National Communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change (UNFCCC). /in Serbian/

SNC BiH (2022). Fourth National Communication of Bosnia and Herzegovina under the United Nations Framework Convention on Climate Change (UNFCCC). /in Serbian/

Trbić, G., Bajić, D. (2011). Climate changes in the Republic of Srpska and possibilities of adaptation. III Congress of Serbian Geographers, SGD-GDRS-GF UBG, PMF-UNBL, Banja Luka. /in Serbian/

Vuković, A. (2016). The impact of climate change on the occurrence of diseases in wheat for the last time decade in Bosnia and Herzegovina. Papers, Faculty of Agriculture and Food Sarajevo, 9-20. /in Serbian/

doi:10.46793/MAK2025.084N

MEMBER SELECTION FROM A CLIMATE MODEL ENSEMBLE FOR CROP MODEL IMPACT ASSESSMENT IN NORTH GREECE

Melpomeni Nikou[1,2*], Aristeidis K. Georgoulias[1], Vassilis G. Aschonitis[2], Dimitris M. Papamichail[3], Theodoros Mavromatis[1]

[1]Department of Meteorology and Climatology, School of Geology, Aristotle University of Thessaloniki, Greece, *melinanikou@gmail.com
[2]Soil and Water Resources Institute, Hellenic Agricultural Organization (ELGO) - "DEMETER", Thessaloniki, Greece
[3]Department of Hydraulics, Soil Science and Agricultural Engineering, Faculty of Agriculture, Forestry and Natural Environment, Aristotle University of Thessaloniki, Greece

Abstract: Climate change poses significant challenges to crops, including wheat, a crucial crop to Greek agriculture. Rising temperatures, extreme weather, and altered precipitation patterns reduce wheat yield. A region in northern Greece, known for its diverse elevation and climate, was analyzed using data from eight meteorological stations (2006-2023) and 11 EURO-CORDEX models under the RCP4.5 scenario. When the calibrated CERES-Wheat model was driven by the most suitable members, identified using the sRPI index, as compared to the whole ensemble, it improved predictions of wheat anthesis, maturity, and potential yield, thereby supporting adaptation strategies for sustainable wheat production.

Key words: Ensemble model evaluation, Climate change, Wheat production, CERES-Wheat, Simulation scenarios, Greece

1. INTRODUCTION

Greek agriculture faces a significant challenge as a result of the severe impact of climate change on crop productivity and sustainability (IPCC, 2023). Wheat holds particular importance among the various kinds of crops cultivated in Greece. It is mainly grown in Thessaly, Macedonia, Thrace, and central Greece, areas known for their good climate and fertile soil (Koutsika et al., 2010). However, the production of wheat is being increasingly threatened by the effects of climate change (rising temperatures, extreme weather events, and alterations in precipitation patterns, etc.), which leads to reduced yields and compromised seed quality (Farooq et al., 2023).

Climate model ensembles play a crucial role in evaluating climate change impacts with crop models, offering enhanced accuracy and reliability by balancing individual model errors. By integrating diverse scenarios and uncertainties, these ensembles provide a more comprehensive and objective assessment of future climatic conditions, enabling better predictions and informed strategies to mitigate the adverse effects of climate change on wheat production (e.g., Brunner et al., 2020; Merrifield et al., 2020).

Nikou et al. (2024) highlighted the crucial role of selecting and evaluating climate model simulations to improve the accuracy of agronomic impact estimations using calibrated CERES-Wheat model in central Greece. According to standardized Root Mean Square Error index sRPI (Aschonitis et al., 2019), an index that was used to rank climate model realizations of an ensemble based on statistical criteria, measuring deviations of temperature simulations from observations: (a) the top-performing models (these with sRPI $\geq$0.5) predicted anthesis dates within a range of 1.7-2.9 days, on average, earlier than observations, while the low-performing models (these with sRPI <0.5) 10.3-11.9 days later and the full ensemble 4.8-5.2 days, on average, later; (b) for maturity dates, the top simulation runs provided more accurate predictions (within 0.6-1.6, on average, days earlier than observations), whereas low-performing models and the full ensemble predictions resulted in later (12.9 to 13.9 days and 6.7 to 6.9 days, accordingly) predictions; and (c) yield predictions from the top-performing models deviated from observations from +3.1% to +5.7% compared to the low-performing models that showed mean deviations within the range of +20.2% to +23.8% and the full ensemble indicating average errors by +13.6% to 14.4%. In conclusion, when CERES-Wheat model was driven by the most suitable climate models as compared to the whole ensemble, it produced more precise predictions of wheat anthesis, maturity, and potential yield in central Greece.

The aim of this work is to study the value of member selection for assessing the impact of crop models on wheat production, by applying the same methodology in another region in northern Greece, a region also characterized by different altitudes and different climatic conditions.

2. MATERIAL AND METHODS

The study focuses on a region in northern Greece, due to its diverse elevation and climatic conditions, providing a comprehensive landscape for studying the impacts of climate change on wheat production. Data were collected from seven meteorological stations within this region (Figure 1). These stations provided daily observations of precipitation (mm), maximum and minimum air temperature (°C), while solar radiation data were provided from the Copernicus Atmosphere Monitoring Service (CAMS) (Guevara et al., 2021) for the period from December to June (i.e., the growing season) over 17 years (2006-2023). These stations are located at altitudes ranging from 349 to 768 meters above sea level.

Additionally, simulated climate data were obtained from 11 Regional Climate Models (RCMs) of the EURO-CORDEX project, with a spatial resolution of approximately 12.5 km. The RCMs simulated climate conditions under the emission scenario RCP4.5 (Georgoulias et al., 2022). The consistency between the simulated and observed data was guaranteed by utilizing data from the grid cells that contained the meteorological stations (Figure 1).

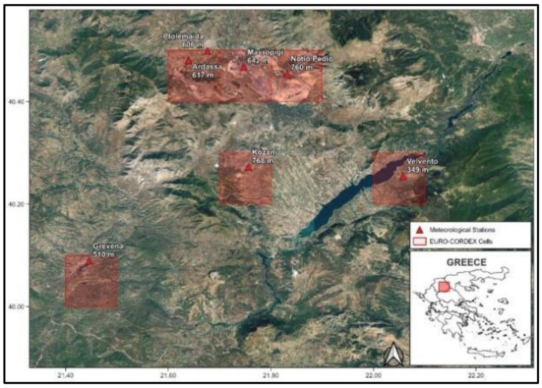


Figure 1. Study area with meteorological stations (red triangles).
Their elevations and the respective EURO-CORDEX cells (red rectangles) are also shown.

To select the most suitable climate model ensemble members, the methodology used by Nikou et al. (2024) was also adopted. Each of the 11 climate models in Table 1 was ranked using the sRPI.

Table 1. Performance of Regional Climate Model Simulations in two regions (in north and central Greece) (Top-performing models are highlighted in bold, while low-performing models are presented in regular fonts)

Model Simulation		sRPI (North Greece)	sRPI (Central Greece)
1	REMO2009__MPI-M-MPI-ESM-LR__r2	1.00	1.00
2	REMO2009__MPI-M-MPI-ESM-LR__r1	0.92	0.98
3	RCA4__MOHC-HadGEM2-ES	0.65	0.62
4	RCA4__MPI-M-MPI-ESM-LR	0.53	0.60
5	RACMO22E__MOHC-HadGEM2-ES	0.40	0.48
6	ALADIN63__CNRM-CERFACS-CNRM-CM5	0.39	0.38
7	CCLM4-8-17__ICHEC-EC-EARTH	0.39	0.55
8	HIRHAM5__ICHEC-EC-EARTH	0.38	0.44
9	RCA4__ICHEC-EC-EARTH	0.22	0.21
10	RACMO22E__CNRM-CERFACS-CNRM-CM5	0.10	0.09
11	RACMO22E__ICHEC-EC-EARTH	0.00	0.00

The sRPI index evaluated model performance based on 12 statistical criteria, quantifying deviation of maximum and minimum air temperature simulations from observations (Table 2). Based on these evaluations, models were ranked and categorized into top (when sRPI ≥ 0.5) and lower (when sRPI < 0.5) performing models (Table 1).

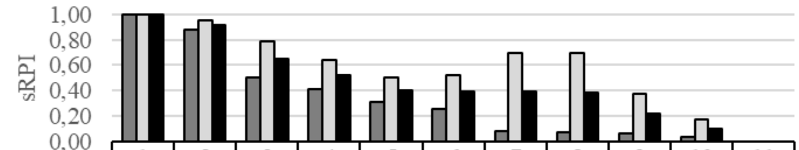
Table 2. Statistical Criteria Used to Evaluate Climate Models

Abbreviation	Statistical Criterion
d	Index of Agreement
NSE	Coefficient of Efficiency (Nash-Sutcliffe efficiency)
KGE	Kling-Gupta efficiency
VE	Volumetric Efficiency
AME	Absolute Maximum Error
MAE	Mean Absolute Error
MBE	Mean Bias Error
RMSE	Root Mean Squared Error
R4MS4E	Fourth Root of the Mean Quadrupled Error
RAE	Relative Absolute Error
RVE	Relative Volume Error
SSE	Sum square error

Regional agronomic data from Greek conditions were used to calibrate the CERES-Wheat model (Nikou and Mavromatis, 2023), a crop simulation model within the Decision Support System for Agrotechnology Transfer (DSSAT v. 4.7.5) (Hoogenboom et al., 2019). Crop simulated flowering and maturity dates, and potential yield were compared across top- and low- performing climate models, and the full ensemble to evaluate the benefits of selective model inclusion using a variety of statistical metrics. Three sowing dates (November 15, December 1, and December 16) were tested to evaluate climate models and determine whether altering sowing dates could mitigate the negative impacts of climate change on wheat production.

3. RESULTS AND DISCUSSION

The effectiveness of 11 climate models across regions showed significant differences in their ability to simulate local temperature conditions, as suggested by the sRPI evaluation (Table 1). Models with sRPI values ≥ 0.5 (top performers) consistently showed lower deviation from observed temperature data, compared with these with sRPI values < 0.5 (low performers), indicating greater accuracy and reliability. Except for CCLM4-8-17__ICHEC-EC-EARTH, the top performers in central Greece performed equally well in the north region (Table 1). Low performing models in one region also performed poorly, according to sRPI, in the second region.



	1	2	3	4	5	6	7	8	9	10	11
	top-performing				low-performing						
■ Tmax	1,00	0,88	0,50	0,41	0,31	0,26	0,08	0,07	0,07	0,03	0,00
□ Tmin	1,00	0,96	0,79	0,64	0,50	0,52	0,70	0,69	0,38	0,17	0,00
■ Total	1,00	0,92	0,65	0,53	0,40	0,39	0,39	0,38	0,22	0,10	0,00

Figure 2. sRPI values in North Greece for Tmax, Tmin and for both (total sRPI = (sRPI $_{Tmax}$+ sRPI $_{Tmin}$)/2)

Figure 2 shows sRPI values in North Greece for Tmax, Tmin and for both temperature extremes (total). sRPI values for Tmax sharply declined (only three climate models scored ≥ 0.5) but also defined final (total) climate model ranking. In contrast, only three climate models scored < 0.5 for Tmin suggesting that climate models simulated better Tmin than Tmax.

Crop simulated results, based on three sowing dates, highlighted several key findings. The top-performing models predicted anthesis dates 2.9-5.6 days, on average (the medians are also shown in Figure 3), earlier than observations, while the low-performing models and the full ensemble 15.1-17.5 and 8.4-9 days later, respectively. The best simulation runs predicted maturity 3-3.9 days earlier, on average, than observations, while the low-performing models and the full ensemble predictions resulted in later predictions (15.3-17.5 days and 8.5- 9.6 days, accordingly). Mean yield predictions from the top-performing models overestimated yields achieved with observed weather from 6.8 to 9.1%, while the low-performing models overestimated by 8.1-10.4% and the full ensemble by 8.1-9.1%. For top performing models, moving of grain filling (GF) period later in the season (by 7.3 days, on average, from moving planting from Nov 15th to Dec 1^{st} and by 4.3 days from Dec 1^{st} to Dec 16^{th}) and not the shorter GF period (it decreased by almost 2 days from Nov 15th to Dec 1^{st} and by an extra day from Dec 1^{st} to Dec 16^{th}) caused average yield decrease by 3.3% from the former planting movement and an additional 2.8% from the latter, illustrating later planting is not an effective adaptation measure for this region.

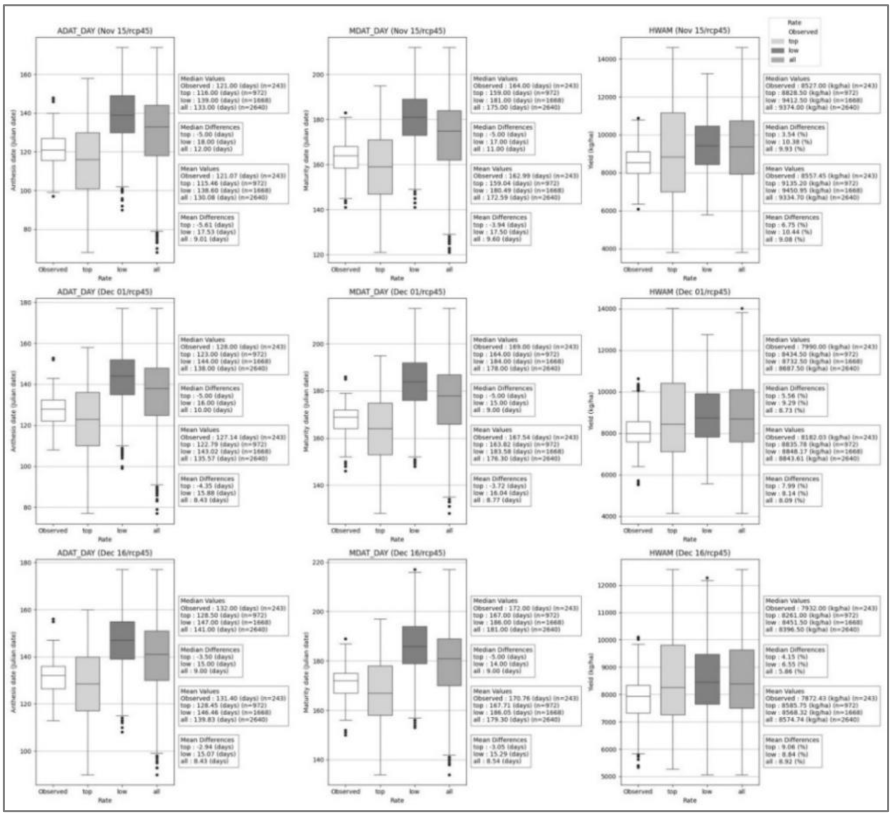


Figure 3. Comparison of anthesis, maturity days (Julian dates), and potential yield (kg/ha), as derived from CERES-Wheat, for three different planting dates (November 15th, December 1st and 16th), for the rcp45 scenario, for the observations (Observed), the total (all), the best (top: sRPI ≥ 0.5) and worst (low: sRPI < 0.5) simulation scenarios. The sample size (total n of growing seasons) for each category is also presented.

4. CONCLUSIONS

This study highlights the role of climate model selection in improving the accuracy of crop model predictions in northern Greece. In comparison to the results found in central Greece, there are some notable differences and similarities in results: (a) except for CCLM4-8-17__ICHEC-EC-EARTH, climate models that performed best in central Greece performed equally well in the north region. Low performing models in one region also performed poorly, according to sRPI, in the second region. This suggests that only a few models are regionally sensitive, but most are not; (b) when the calibrated CERES-Wheat model was driven by the most suitable climate models as compared to the whole ensemble, it produced more precise predictions of wheat anthesis, maturity, and potential yield, thereby supporting better adaptation planning. However, the larger benefits in anthesis (2.8-6.1 days in the north vs 1.9-3.5 in the south) and maturity (4.6-6.6 days in the north vs 5.1-6.3 days in the south) predictions in north region were not translated accordingly in yield benefits (the yield improvement in north region was only 1.0-2.3% vs. 7.9-11.3% in the south). Future research should focus on investigating the role of climate model selection on additional adaptation strategies under historical and future climate conditions to address the ongoing challenges posed by climate change.

5. ACKNOWLEDGMENT

This research was funded by the project "Support for enhancing the operation of the National Network for Climate Change (CLIMPACT)", National Development Program, General Secretariat of Research and Innovation (2023NA11900001 - N. 5201588).

6. REFERENCES

Aschonitis, V.G., Lekakis, E., Tziachris, P., Doulgeris, C., Papadopoulos, F., Papadopoulos, A., Papamichail, D. (2019). A ranking system for comparing models' performance combining multiple statistical criteria and scenarios: The case of reference evapotranspiration models. Environmental Modelling and Software, 114, 98-111. doi.org/10.1016/j.envsoft.2019.01.005

Brunner, L., Pendergrass, A.G., Lehner, F., Merrifield, A.L., Lorenz, R., Knutti, R. (2020). Reduced global warming from CMIP6 projections when weighting models by performance and independence. In Earth System Dynamics, 11(4), 995-1012. doi.org/10.5194/esd-11-995-2020

Farooq, A., Farooq, N., Akbar, H., Hassan, Z.U., Gheewala, S.H. (2023). A Critical Review of Climate Change Impact at a Global Scale on Cereal Crop Production. In Agronomy, 13(1). doi.org/10.3390/agronomy13010162

Georgoulias, A.K., Akritidis, D., Kalisoras, A., Kapsomenakis, J., Melas, D., Zerefos, C.S., Zanis, P. (2022). Climate change projections for Greece in the 21st century from high-resolution EURO-CORDEX RCM simulations. Atmospheric Research, 271. doi.org/10.1016/j.atmosres.2022.106049

Guevara, M., Jorba, O., Tena, C., van der Gon, H., Kuenen, J., Elguindi, N., Darras, S., Granier, C., Pérez Garcia-Pando, C. (2021). Copernicus Atmosphere Monitoring Service TEMPOral profiles (CAMS-TEMPO): global and European emission temporal profile maps for atmospheric chemistry modelling. Earth System Science Data, 13(2), 367–404. doi.org/10.5194/essd-13-367-2021

Hoogenboom, G., Porter, C.H., Boote, K.J., Shelia, V., Wilkens, P.W., Singh, U., White, J.W., Asseng, S., Lizaso, J.I., Moreno, L.P., Pavan, W., Ogoshi, R.M., Hunt, L.A., Tsuji, G.Y., Jones, J.W., Usda-Ars, U. (2019). The DSSAT crop modeling ecosystem (Issue September 2020). doi.org/10.19103/as.2019.0061.10

(IPCC), I.P. on C.C. (2023). Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. doi: 10.1017/9781009325844

Koutsika, M., Gogas, C., Evgenidis, G., Bladenopoulos, K. (2010). Wheat breeding in Greece, 239-273.

Merrifield, A.L., Brunner, L., Lorenz, R., Medhaug, I., Knutti, R. (2020). An investigation of weighting schemes suitable for incorporating large ensembles into multi-model ensembles. Earth System Dynamics, 11(3), 807-834. doi.org/10.5194/esd-11-807-2020.

Nikou, M., Georgoulias, A.K., Aschonitis, V.G., Papamichail, D.M., Mavromatis, T. (2024). Ensemble Evaluation and Member Selection of Regional Climate Models for Crop Model Impact Assessment. Proceedings of the XIV International Scientific Agricultural Symposium "Agrosym 2024," 7.

Nikou, M., Mavromatis, T. (2023). Demonstrating the Use of the Yield-Gap Concept on Crop Model Calibration in Data-Poor Regions: An Application to CERES-Wheat Crop Model in Greece. Land, 12(7). doi.org/10.3390/land12071372

doi:10.46793/MAK2025.090S

RENEWABLE ENERGY AND AI IMPLEMENTATION AS SUSTAINABLE STRATEGY FOR AGRICULTURE RESILIENCE TO CLIMATE CHANGE

Ivan Stevović[1*], Sabahudin Hadrović[2], Bratislav Ćirković[3]

[1]Innovation center of the Faculty of Mechanical engineering, Belgrade, Serbia,
*istevovic@mas.bg.ac.rs
[2]Institute of forestry, Belgrade, Republic of Serbia
[3]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohija, Serbia

Abstract: Climate change has a major impact on all human activities. One of the most important is agriculture from the point of view of food production, as the starting point of survival on the globe. The negative consequences of climate change are reflected in increasingly pronounced droughts and catastrophic floods, and are also reflected in the increase in the frequency of these extremes. Multidisciplinary teams of engineers and scientists are engaged in the development of sustainable strategies, with the aim of increasing the resilience of agriculture to climate change. The application of renewable energy sources and artificial intelligence plays a significant role in the management of sustainable strategies for the protection and improvement of smart agriculture. Wind turbines and photovoltaic panels raised above agricultural land at an appropriate distance form a synergy of agricultural development and renewable energy. Their implementation in itself reduces the emission of greenhouse gases and contributes to mitigating climate change. At the same time, this energy can be used both in the system and locally for pumping water for irrigation. Hydropower and the construction of water acumulations also provide increased opportunities for solving droughts and floods and thereby improving and stabilizing agricultural production and higher resilience of agriculture to climate change. Agricultural residues can be used as a resource for renewable bioenergy. Artificial intelligence, supported by contemporary solutions of sensor technology, helps us in the optimal management of all these complex processes. This research also contains a positive case studies from international practice on the implementation of renewable energy sources and artificial intelligence and their concrete contribution to increasing the resilience of agriculture to climate change.

Key words: Sustainability, Climate Change, Smart Agriculture, Renewable Energy, Artificial Intelligence.

1. INTRODUCTION

Addressing the challenges posed by the climate crisis is one of the most critical issues facing modern society. Agriculture, as one of the most vital economic sectors (Islam et al., 2024), is particularly vulnerable to the impacts of climate change, which manifest through reduced yields, soil degradation, extreme weather conditions, and food supply instability. To enhance the resilience of agriculture to these changes, it is essential to adopt innovative and sustainable strategies that integrate renewable energy sources and advanced technologies such as artificial intelligence (AI).

The concept of "smart agriculture" is based on the integration of modern technologies that enable resource optimization, increased production efficiency, and reduced environmental impact. The use of renewable energy sources, such as solar and wind power (Kassem et al., 2024), contributes to the sustainability of production systems, while the implementation of AI provides real-time precision management of agricultural processes (Elufioye et al., 2024). The incorporation of sensor technology (Morchid et al., 2024) into agricultural practices facilitates the collection of data on soil conditions, weather patterns, and crop needs, enabling informed decision-making and mitigating the risk of losses.

Sustainable agriculture in the era of climate change requires a holistic approach that combines ecological, technological, and social dimensions . The use of renewable energy not only reduces greenhouse gas emissions but also promotes energy independence in rural areas (Wang et al., 2024a,b). On the other hand, AI offers the ability to forecast climate patterns, optimize irrigation, manage pests, and develop resilient crop varieties (Fuentes-Peñailillo et al., 2024). This synergy of technologies has the potential to transform agriculture into a sustainable and adaptive system capable of addressing the challenges of the 21st century.

This paper explores the possibilities of applying renewable energy and artificial intelligence as key components of a strategy to enhance agriculture's resilience to climate change. The focus is on analyzing contemporary technological solutions, their implementation in agricultural practices, and their potential benefits for sustainability and economic development. Additionally, the paper examines the challenges and limitations of adopting these technologies, as well as the prospects for their broader application across diverse agroecological conditions.

By combining scientific insights and practical examples, this study aims to contribute to the development of sustainable agricultural models that ensure food security and the preservation of natural resources in the context of global climate change.

2. METHODOLOGY

This manuscript summarizes the results of the latest research in the field of agriculture resilience to climate change by renewable energy and artificial intelligence implementation. The research in this paper is based on desk research and literature review, with case study methodology of the positive world practice.

The goal is to answer the following questions from the perspective of the sustainable strategy management development and smart agriculture resilience strengthening to climate change:

- What are the main environmental, economic and scientific challenges associated with climate change's impact on agriculture?
- How do changes in energy policies affect the agriculture resilience to climate change?
- What are the newest strategical innovations in agriculture that are sustainable?
- How sensor technology implementation can improve the benefits of smart agriculture?
- How artificial intelligence implementation can support agriculture resilience to climate change
- What are the best representative case sudies in the world relating to renewable energy implementation in agriculture?
- What are the best representative case sudies in the world relating to artificial intelligence implementation in agriculture?

The methodological holistic approach to the research in this manuscript includes a complex and organized procedure, starting from criteria of sustainability and principles according to established questions and phases. For the purpose of finalizing this research, the following general and special scientific methods are used:

- Systematized data collection and analysis of the latest existing, world-recognized scientific results in the field of assessment and management of agriculture resilience to climate change, strategic management, environmental protection, and sustainable development.

- Methods of induction and deduction, analysis and synthesis, as well as the method of analogy.
- The collected data are processed using statistical methods using Microsoft Excel and IBM SPSS Statistics 24 software packages.

This manuscript is organised within four chapters as IMRAD structures of writing. The thirth chapter encompass results and discussion, organized in five subchapters.

3. RESULTS AND DISCUSSION

3.1. Energy and resources policy supporting agriculture resilience to climate change

Energy policies supporting the resilience of agriculture to climate change play a crucial role in ensuring sustainable agricultural production. One innovative approach is the application of **agrivoltaics**, a technology that combines solar panels with agricultural activities. Agrivoltaics enable efficient land use, where solar panels provide shade and reduce evapotranspiration while simultaneously generating electricity. This technology shows significant benefits in arid regions where soil moisture conservation is critical (Luo et al., 2024).

Wind turbines in agriculture represent another example of successful integration of renewable energy sources. Agricultural farms with favorable wind energy potential can utilize wind farms to produce energy needed for irrigation, storage, and product processing. Implementing such solutions reduces dependency on fossil fuels and increases the economic resilience of farms (Borusevich and Pisarek, 2024).

Hydropower and water reservoirs also contribute to the stabilization of agricultural systems. Reservoirs not only supply water for irrigation but also serve as reserves during drought periods and as protection from the floods. Hydropower generated from these systems can support local infrastructure, reducing energy costs for farmers. Water is esencial resource for agriculture (Schmitt and Rosa, 2024). Its cycle is showen in Figure 1.

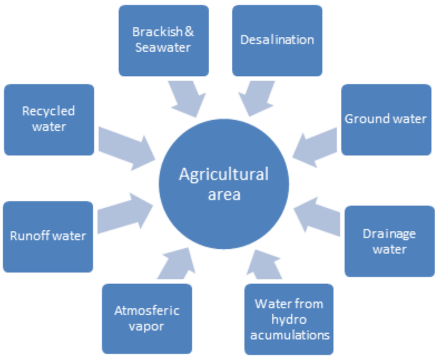


Figure 1. Integration of irrigation cycle into the natural water cycle

Bioenergy, derived from agricultural production residues such as crop leftovers and manure, represents another key component in the energy transition. Biogas plants convert waste into renewable energy while simultaneously reducing methane emissions into the atmosphere. In this way, bioenergy not only helps mitigate climate change but also enhances the circular model of resource management (Toplicean and Datcu, 2024).

Various energy policies support the implementation of these technologies through subsidies, tax incentives, and research programs. For example, the European Union, through its Green Deal, encourages the use of renewable energy sources in agriculture, while national programs worldwide offer additional incentives (Boix-Fayos and de Vente, 2023).

3.2. The newest strategical innovations in agriculture that make agriculture sustainable

The latest strategic innovations in agriculture are aimed at achieving sustainability through the use of advanced technologies and methods. One such innovation is **precision agriculture**, which utilizes sensors, satellite imagery, and IoT technology to monitor crop and soil conditions in real time. This technology allows for the optimization of water, fertilizer, and pesticide usage, contributing to a reduced ecological footprint and increased yields (Wang et al., 2024a,b).

Vertical farms offer a solution for food production in urban areas. These farms use led lighting, hydroponic and aeroponic systems to grow plants without the need for large agricultural areas. Efficient resource utilization, such as water and energy, makes vertical farms an ideal model for future agriculture under resource-limited conditions (Zhou, 2024).

The use of drones for monitoring agricultural areas is becoming increasingly common. Drones can quickly and accurately identify issues such as pests, diseases, and uneven water distribution, enabling timely responses and reducing (Das, 2024).

Genetically improved crops, resistant to drought and pests, play a crucial role in addressing the challenges of climate change. Developing plant varieties that require less water and chemical treatments contributes to both economic and ecological sustainability (Kumar et al., 2024).

Digital platforms that connect farmers with markets enable more efficient production and distribution planning. These platforms provide information on prices, weather conditions, and cultivation techniques, contributing to better resource management and waste reduction (Arun and Mishra, 2024).

3.3. Sensor technology implementation in smart agriculture

Sensor technology is at the heart of smart agriculture, enabling precise and efficient management of resources. Sensors are used to measure various parameters such as soil moisture, temperature, pH levels, and nutrient content, allowing farmers to make data-driven decisions.

Example 1: A vineyard in Chile uses soil moisture sensors connected to an IoT platform (Fuentes-Peñailillo et al., 2023). The sensors provide real-time data, enabling precise irrigation only when the soil moisture drops below a critical threshold. This approach conserves water and enhances grape quality.

Example 2: In Bangladesh, rice paddies equipped with temperature and humidity sensors monitor microclimatic conditions (Islam et al., 2024). Data from these sensors alerts farmers about potential fungal infections, enabling timely intervention and reducing crop losses.

Furthermore, **weather stations** equipped with sensors predict local weather patterns, assisting in the planning of planting and harvesting activities. Combined with GPS-guided machinery, these innovations significantly improve efficiency (Vellingiri et al., 2025).

The integration of sensor technology also supports **automated systems**, such as fertigation units, which dispense fertilizers based on real-time nutrient levels detected by sensors. This reduces over-application and minimizes environmental pollution (Taseer and Han, 2024).

3.4. Artificial intelligence that makes smart agriculture smarter

Artificial intelligence (AI) is revolutionizing smart agriculture, enabling farmers to optimize processes, reduce resource consumption, and enhance productivity. By analyzing vast amounts of data collected from sensors, drones, and satellite imagery, AI provides actionable insights that were previously unattainable. Machine learning algorithms, for example, can predict crop yields, detect diseases at early stages, and recommend precise interventions, thereby minimizing losses and improving quality (Attri et al., 2024).

One transformative application of AI is **predictive analytics**. By integrating historical weather data, soil conditions, and market trends, AI-powered systems enable farmers to make informed decisions about planting, harvesting, and distribution. These insights help mitigate risks associated with climate variability and market fluctuations (Jeffrey and Bommu, 2024).

AI also enhances **robotics in agriculture**, automating labor-intensive tasks such as weeding, pruning, and harvesting. Autonomous machines, guided by AI vision systems, can distinguish between crops and weeds, ensuring precision and reducing the need for herbicides. This approach not only increases efficiency but also promotes environmental sustainability. A study by (Arockia Doss et al., 2024). showcased the financial benefits of robotics in strawberry harvesting. A robotic harvester equipped with advanced AI and vision systems was deployed on a commercial strawberry farm. The system was capable of picking strawberries with 90% accuracy at a rate of 25.000 fruits per day. Compared to manual labor, which typically achieves 15.000 fruits per day per worker, the robot demonstrated a significant productivity increase. Financially, the robotic system reduced labor costs by 40%, saving approximately $ 7.500 per hectare annually while maintaining consistent harvest quality. This example highlights the economic potential of robotics to revolutionize labor-intensive agricultural practices, ensuring both efficiency and profitability.

Moreover, **natural language processing (NLP)** assists in bridging the knowledge gap for farmers. AI-driven chatbots and virtual assistants provide real-time advice in local languages, empowering small-scale farmers to adopt advanced practices (Domínguez et al., 2024).

3.5. Environmental, economical, and scientific challenges in future agriculture

The future of agriculture faces a complex interplay of environmental, economic, and scientific challenges that demand innovative solutions. Environmental issues, primarily driven by climate change, include rising temperatures, irregular rainfall, and increased incidence of extreme weather events. These factors disrupt crop cycles, reduce yields, and threaten global food security. Additionally, soil degradation, loss of biodiversity, and water scarcity exacerbate the environmental crisis, limiting the capacity for sustainable agricultural practices (Saleem et al., 2024).

Economically, farmers worldwide confront fluctuating market conditions, rising production costs, and uncertain profitability. The transition to sustainable practices often requires significant initial investments in advanced technologies, such as precision farming tools, renewable energy systems, and resilient crop varieties. For small-scale farmers, accessing these resources remains a considerable challenge, widening the gap between large industrial farms and smaller operations. Moreover, the globalization of food markets exposes farmers to volatile trade dynamics, with shifts in demand and supply chains posing risks to economic stability (Awokuse et al., 2024).

On the scientific front, advancing agriculture necessitates breakthroughs in several domains, including genetics, climate modeling, and data analytics. Developing crop varieties resistant to pests, diseases, and extreme climatic conditions is critical but requires time-intensive research and rigorous testing. Furthermore, the integration of artificial intelligence and machine learning into farming systems is hindered by a lack of standardized frameworks and uneven technological access across regions. Ethical considerations, such as the use of genetically modified organisms (GMOs), also spark debates, slowing the adoption of potentially transformative technologies

Addressing these challenges requires a coordinated approach that combines policy support, public-private partnerships, and grassroots innovation. Governments must incentivize sustainable farming practices and ensure equitable access to technology and markets. Simultaneously, fostering interdisciplinary collaboration among scientists, economists, and environmentalists will drive the development of resilient agricultural systems capable of withstanding future adversities. Through collective efforts, agriculture can evolve to balance environmental sustainability, economic viability, and scientific advancement (Haloui et al., 2024).

4. CONCLUSION

Climate change poses a comprehensive challenge to agricultural production, but it also offers an opportunity for innovation and transformation of traditional approaches. By applying renewable energy sources and artificial intelligence, agriculture has the potential to become more resilient, efficient, and sustainable, ensuring stable food production and the preservation of natural resources.

Renewable energy sources, such as solar and wind power, provide an opportunity to reduce dependence on fossil fuels, directly impacting the reduction of greenhouse gas emissions. This energy transition is particularly significant for rural areas, where decentralized energy solutions can improve energy accessibility and stimulate local development. At the same time, artificial intelligence offers a wide range of applications, from analyzing data collected by sensors, through automated management of agricultural machinery, to optimizing supply chains. When applied synergistically, these technologies enable better-informed decision-making, cost reductions, and increased profitability.

However, the introduction of these innovations also faces certain challenges. The main obstacles include high initial implementation costs, insufficient technical training for farmers, and limited access to infrastructure in some regions. Addressing these issues requires a multisectoral approach, including government support through subsidies and regulatory frameworks, as well as collaboration between the private sector and academia to develop accessible and scalable solutions.

As demonstrated in this paper, the application of renewable energy sources and artificial intelligence in agriculture is not only a technical advancement but also an opportunity to improve the socioeconomic position of rural communities. These technologies can contribute to creating sustainable agroecosystems capable of responding to global challenges posed by climate change.

The transformation of agriculture through the implementation of renewable energy sources and advanced technologies represents a critical step towards building a resilient and sustainable agri-industrial system. Successful practices from around the world show that it is possible to achieve a balance between economic productivity and the preservation of natural resources. Future efforts should focus on adapting these solutions to local needs and broader education of all stakeholders in the agricultural sector to ensure their long-term impact and sustainability.

5. ACKNOWLEDGMENT

The results presented in this manuscript are supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, Contract 451-03-66/2024-03/200213 dated 05.02.2024.

6. REFERENCES

Arockia Doss, A.S., Jeyabalan, A., Rekha Borah, P., Lingampally, P.K., Schilberg, D. (2024). Advancements in Agricultural Automation: A Comprehensive Review of Artificial Intelligence and Humanoid Robotics in Farming. International Journal of Humanoid Robotics, 21(4), 2350012. doi.org/10.1142/S0219843623500123

Arun, D.P., Mishra, A. (2024). Enabling Digital Platforms: Toward Smart Agriculture. In Artificial Intelligence Techniques in Smart Agriculture. Singapore: Springer Nature Singapore, 237-251.

Attri, I., Awasthi, L.K., Sharma, T.P. (2024). Machine learning in agriculture: a review of crop management applications. Multimedia Tools and Applications, 83(5), 12875-12915

Awokuse, T., Lim, S., Santeramo, F., Steinbach, S. (2024). Robust policy frameworks for strengthening the resilience and sustainability of agri-food global value chains. Food Policy, 127, 102714

Boix-Fayos, C., de Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. Agricultural Systems, 207, 103634

Borusevich, A., Pisarek, L. (2024). Impact of small wind turbines on the surrounding and agricultural environment. Український журнал природничих наук, (9), 140-149.

Das, S. (2024). Transforming Agriculture: Harnessing Robotics and Drones for Sustainable Farming Solution. Journal of Experimental Agriculture International, 46(7), 219-231.

Domínguez, A.G., Roig-Tierno, N., Chaparro-Banegas, N., García-Álvarez-Coque, J.M. (2024). Natural language processing of social network data for the evaluation of agricultural and rural policies. Journal of Rural Studies, 109, 103341

Elufioye, O.A., Ike, C.U., Odeyemi, O., Usman, F.O., Mhlongo, N.Z. (2024). Ai-Driven predictive analytics in agricultural supply chains: a review: assessing the benefits and challenges of ai in forecasting demand and optimizing supply in agriculture. Computer Science & IT Research Journal, 5(2), 473-497.

Fuentes-Peñailillo, F., Gutter, K., Vega, R., Silva, G.C. (2024). Transformative technologies in digital agriculture: Leveraging Internet of Things, remote sensing, and artificial intelligence for smart crop management. Journal of Sensor and Actuator Networks, 13(4), 39.

Fuentes-Peñailillo, F., Ortega-Farías, S., Acevedo-Opazo, C., Rivera, M., Araya-Alman, M. (2023). A Smart Crop Water Stress Index-Based IoT Solution for Precision Irrigation of Wine Grape. Sensors, 24(1), 25.

Haloui, D., Oufaska, K., Oudani, M., El Yassini, K. (2024). Bridging Industry 5.0 and Agriculture 5.0: Historical Perspectives, Opportunities, and Future Perspectives. Sustainability, 16(9), 3507

Islam, M.H., Anam, M.Z., Hoque, M.R., Nishat, M., Bari, A.M. (2024). Agriculture 4.0 adoption challenges in the emerging economies: Implications for smart farming and sustainability. Journal of Economy and Technology, *2*, 278-295.

Jeffrey, L., Bommu, R. (2024). Innovative AI Solutions for Agriculture: Enhancing CropManagement and Yield. International Journal of Advanced Engineering Technologies and Innovations, 1(3), 203-221.

Kassem, Y., Camur, H., Ghoshouni, E.G. (2024). Assessment of a Hybrid (Wind-Solar) System at High-Altitude Agriculture Regions for achieving Sustainable Development Goals. Engineering, Technology & Applied Science Research, 14(1), 12595-12607

Kumar, S., Singh, D., Mohan, S., Shakya, A., Diwakar, S.K., Yadav, V.K. (2024). Genetically Modified Crops: Resistant to Pest and Environmental Stress: A Review. Journal of Advanced Zoology, 45(2).

Luo, J., Luo, Z., Li, W., Shi, W., Sui, X. (2024). The Early Effects of an Agrivoltaic System within a Different Crop Cultivation on Soil Quality in Dry-Hot Valley Eco-Fragile Areas. Agronomy, 14(3), 584.

Morchid, A., El Alami, R., Raezah, A.A., Sabbar, Y. (2024). Applications of internet of things (IoT) and sensors technology to increase food security and agricultural Sustainability: Benefits and challenges. Ain Shams Engineering Journal, 15(3), 102509

Saleem, A., Anwar, S., Nawaz, T., Fahad, S., Saud, S., Ur Rahman, T., Nawaz, T. (2024). Securing a sustainable future: the climate change threat to agriculture, food security, and sustainable development goals. Journal of Umm Al-Qura University for Applied Sciences, 1-17.

Schmitt, R.J.P., Rosa, L. (2024). Dams for hydropower and irrigation: Trends, challenges, and alternatives. Renewable and Sustainable Energy Reviews, 199, 114439.

Taseer, A., Han, X. (2024). Advancements in variable rate spraying for precise spray requirements in precision agriculture using Unmanned aerial spraying Systems: A review. Computers and Electronics in Agriculture, 219, 108841

Toplicean, I.M., Datcu, A.D. (2024). An Overview on Bioeconomy in Agricultural Sector, Biomass Production, Recycling Methods, and Circular Economy Considerations. Agriculture, 14(7), 1143

Vellingiri, A., Kokila, R., Nisha, P., Kumar, M., Chinnusamy, S., Boopathi, S. (2025). Harnessing GPS, Sensors, and Drones to Minimize Environmental Impact: Precision Agriculture. In Designing Sustainable Internet of Things Solutions for Smart Industries (pp. 77-108). IGI Global.

Wang, J., Sun, X., Zhang, S., Zhang, X. (2024a). Does Addressing Rural Energy Poverty Contribute to Achieving Sustainable Agricultural Development? Agriculture, 14(6), p. 795.

Wang, J., Wang, Y., Li, G., Qi, Z. (2024b). Integration of Remote Sensing and Machine Learning for Precision Agriculture: A Comprehensive Perspective on Applications. Agronomy, 14(9), 1975.

Zhou, Y. (2024). Technological Innovation and Significance of Vertical Farming System in High-Density Urban Areas. In E3S Web of Conferences (Vol. 579, p. 03001). EDP Sciences.

doi:10.46793/MAK2025.098S

MANAGERIAL APPROACHES TO SUSTAINABLE CEREAL PRODUCTION IN NORTH MACEDONIA: INTEGRATING CLIMATE-SMART AGRICULTURE, PRECISION FARMING, AND SOIL MANAGEMENT

Viktorija Stojkovski*, Daniela Pelivanoska-Dameska, Katerina Bojkovska

University „St.Kliment Ohridski"- Faculty of Biotechnical Sciences, Bitola
*viktorija.stojkovski@uklo.edu.mk, daniela.pelivanoska@uklo.edu.mk, katerina.bojkovska@uklo.edu.mk

Abstract: This paper presents a comprehensive framework for sustainable cereal production, emphasizing the integration of climate-smart agriculture (CSA), precision farming, and effective soil management strategies. As staple cereals like corn, wheat, and rice constitute over 55% of global calorie intake, enhancing their production while mitigating environmental impact is critical for long-term food security. The study explores the role of CSA in adapting to climate change, reducing greenhouse gas emissions, and boosting productivity through innovative technologies such as renewable energy and soil management practices. Precision farming, leveraging data-driven tools like GIS and GPS, optimizes resource use and crop efficiency, contributing to environmental sustainability and economic viability. Additionally, soil and crop management strategies (SCMS) are essential in preventing land degradation, improving nutrient efficiency, and fostering resilient agricultural systems. The paper also examines the specific agricultural conditions and challenges in North Macedonia, where a strategic focus on modernizing production, promoting climate-friendly practices, and enhancing technological adoption is necessary to ensure sustainable cereal production amidst environmental and market disruptions. This multi-dimensional approach offers valuable insights into balancing productivity with ecological sustainability, addressing global food security concerns.

Key words: Sustainable cereal production, Climate-smart agriculture (CSA), Precision farming, Soil management strategies, Global food security

1. INTRODUCTION

Sustainable cereal production involves a holistic approach that optimizes agricultural practices, minimizes environmental impacts, and ensures long-term food security (Marie, 2023). Staple cereals such as corn, wheat, and rice are grown worldwide and form a significant part of the human diet, accounting for more than 55% of the calories consumed globally (Gutiérrez et al., 2018). Sustainable agriculture not only focuses on efficient and productive farming methods but also emphasizes maintaining ecological balance, improving farmers' well-being, and incorporating social and cultural considerations into agricultural practices (Kamakuala, 2024). Scoones et al. (2020) argue that achieving sustainability requires both systemic and structural approaches.

The systemic approach provides a comprehensive framework for understanding sustainability in business, encompassing environmental, social, and economic dimensions. In contrast, the structural approach establishes the management mechanisms necessary to implement the systemic perspective effectively (Scoones et al., 2020).

This study is directed to analyze potential enhance cereal productivity while minimizing environmental impacts and addressing global food security challenges. It focuses on leveraging innovative technologies, optimizing resource use, and fostering resilience to climate change, with a specific emphasis on the conditions and challenges faced by North Macedonia's agricultural sector.

The aim of work was the research analysis of (i) development a comprehensive framework for sustainable cereal production by integrating climate-smart agriculture (CSA), precision farming, and effective soil and crop management strategies (ii) promoting modernized practices, technological adoption, and sustainable policies, (iii) achieving ecological balance, economic viability, and long-term agricultural sustainability.

2. CLIMATE-SMART AGRICULTURE MANAGEMENT STRATEGY

Climate-Smart Agriculture (CSA) is an approach aimed at strengthening agricultural management for sustainability in the face of climate change. It introduces innovative agricultural technologies and practices to enhance production while promoting adaptation to and mitigation of climate change (Muhie, 2022). The concept encompasses a diverse range of practices, including sustainable soil management, efficient water use, crop diversification, and the adoption of renewable energy sources. CSA represents a comprehensive framework that integrates climate change adaptation and mitigation strategies to ensure food security. For instance, employing renewable energy in agriculture-such as pyrolysis units, solar panels, windmills, and water pumps-is critical for enhancing sustainable food production. These technologies not only reduce greenhouse gas emissions but also improve the resilience and efficiency of agricultural systems. The concept of Climate-Smart Agriculture (CSA) encompasses three main pillars: productivity, adaptation, and mitigation. For poor and developing countries, adaptation and productivity are of primary importance, while mitigation efforts are more prominently addressed in developed countries (Hussain et al., 2022). CSA has proven to be an effective approach for improving soil moisture conservation by 12% and increasing grain yield by 66% in maize crops (Mujeyi and Mudhara, 2020).

According to Muhie (2022), CSA for sustainability is built on three main goals: increasing adaptation to climate change, reducing greenhouse gas emissions below business-as-usual levels, and sustainably increasing production and profitability**.** The broader goals of environmental, social, and economic sustainability are also central to organic farming and play a significant role in determining the acceptability of specific agricultural practices (Taylor et al., 2001). Organic farming systems are characterized by respect for the environment and animals, promotion of sustainable farming methods, use of non-chemical fertilizers and pesticides, production of high-quality food products, and avoidance of genetically modified (GM) crops. Despite its potential benefits, the adoption of CSA practices faces significant challenges. Financial constraints, particularly among smallholder farmers, limit investments in CSA technologies even when government subsidies and schemes are available. Moreover, technological gaps and inadequate infrastructure further exacerbate these difficulties, hindering the adoption of precision farming tools and advanced water management systems essential for building climate resilience.

3. MANAGEMENT STRATEGY OF PRECISION FARMING

The management strategy of precision farming is increasingly being adopted as a decision-support system for planning and managing agricultural activities. It utilizes diverse types of data to guide these processes effectively (Perniola et al., 2015).

The primary goal of precision farming is to tailor inputs and agricultural practices to the specific local variability within a field. This strategy relies on evaluating and interpreting spatial variability to manage it efficiently. By doing so, precision farming enhances crop performance, improves environmental quality, and provides feedback on the efficiency and effectiveness of different practices and resource usage. Through location-specific modeling of inputs and crop responses, precision farming significantly improves crop efficiency, reduces costs, and increases overall agricultural output. The adoption of precision farming technology is significant due to its potential for long-term savings, despite initial costs appearing high. Over time, the financial benefits outweigh those of traditional farming practices, enabling growers to determine the minimum required amount of fertilizer and identify the most effective types for specific regions (Georgia, 2022). Precision farming technologies also play a critical role in improving the long-term planning of agricultural operations. By enabling dynamic adjustments to strategies in response to unforeseen circumstances, these technologies provide farmers with the flexibility needed to optimize outcomes (Georgia, 2022).

The implementation of precision farming demands a fundamental shift in farmers' approaches to agriculture. It requires the integration of technological infrastructure, advanced data analysis capabilities, and a deep understanding of agronomy (Anand et al., 2023). Farmers must embrace this data-driven paradigm to maximize crop yields, minimize resource waste, and reduce environmental impact.

In an era of growing global food demand, resource scarcity, and environmental challenges, precision agriculture technology offers a sustainable solution to meet the world's agricultural needs effectively. Precision agriculture incorporates advanced technologies such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), and Remote Sensing (RS) into agricultural practices. These tools enable farmers to manage field variability more effectively, optimizing profitability by moving away from traditional blanket treatments.

One significant advancement in precision agriculture is Variable Rate Technology (VRT), now integrated into agricultural equipment such as fertilizer and pesticide applicators and yield monitors. The rapid development of VRT has been a key driver of precision agriculture's growth, allowing farmers to tailor management practices to specific field locations. This localized approach reduces input usage while maximizing yields, presenting an attractive proposition for farmers (Anand et al., 2023).

Achieving high yields and efficiency depends on sophisticated management of soil and water resources as well as the precise application of inputs. As an integrated approach to field management based on information and technology, precision agriculture enhances agricultural production, productivity, and efficiency while simultaneously minimizing negative environmental impacts.

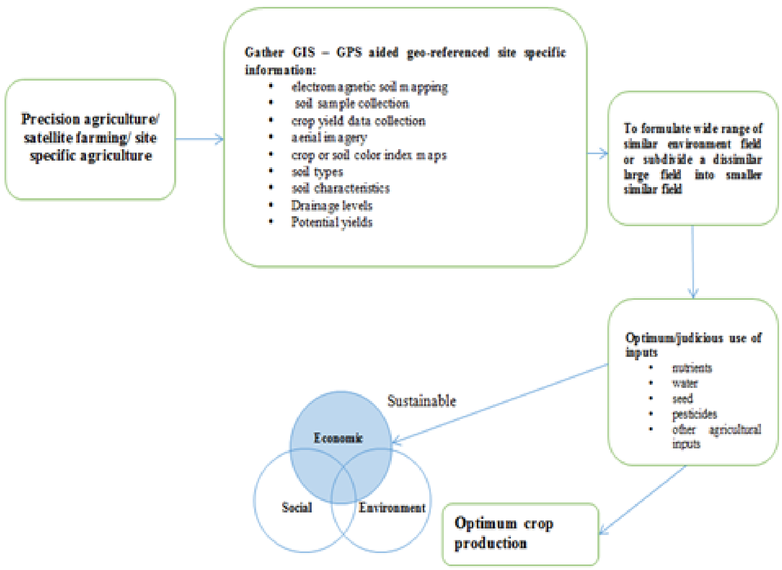


Figure 1. Precision farming for sustainable agriculture (Hossain, 2021)

Achieving high yields and high resource efficiency simultaneously is a widely recognized challenge that requires the integrated application of soil and crop management approaches. Despite the growing global population and escalating food demand, crop yields are stagnating in many regions, and fertilizer use efficiency is declining rapidly (Yokamo et al., 2022). To address these challenges, the Integrated Soil-Crop System Management (ISSM) approach was developed in China. ISSM aims to enhance crop yield and nutrient use efficiency without further increasing chemical fertilizer application, while also mitigating environmental pollution (Zhang et al., 2011). The ISSM paradigm is guided by three core principles: improving soil quality through all feasible and essential measures, ensuring cohesive use of diverse nutrient resources and adequately supplying nutrients to meet crop requirements, and Integrating soil and nutrient management practices with high-yield production systems (Jiao et al., 2018). By aligning soil and nutrient management with sustainable high-yield practices, ISSM offers a pathway to address the dual goals of improving agricultural productivity and protecting the environment.

4. SOIL AND CROP MANAGEMENT STRATEGIES (SCMS)

Agricultural scientists have long recognized that soil management practices are not only vital for maximizing agricultural production but also crucial for mitigating environmental pollution (Shinde and Sirsath, 2020). Soil and Crop Management Strategies (SCMS) aim to enhance crop productivity and prevent land degradation by optimizing various soil properties-biological, physical, chemical, and hydrological-through balanced nutrient management (Esilaba et al., 2005). SCMS are guided by two key principles: **matching input quantity with crop demand** to ensure efficient resource use and **synchronizing nutrient application with crop growth stages** to optimize timing and effectiveness (Shah and Wu, 2019).

These strategies not only improve crop yields but also conserve soil resources and protect the environment (Cui et al., 2014). Effective SCMS focus on preventing soil erosion, a major contributor to land scarcity, while adopting practices that avoid soil contamination and degradation. Soil erosion by water and wind is a primary process that degrades the surface structure of exposed soil, resulting in the loss of nutrient-rich topsoil. This significantly reduces soil fertility and undermines sustainable agricultural practices. By addressing both erosion and contamination, SCMS offers a sustainable approach to improving agricultural productivity while preserving environmental health. Recent research has shown that land degradation is expected to continue due to the significant increase in global GDP by 2050. To ensure future food security, sustainable soil management through efficient nutrient management and appropriate soil conservation practices presents some of the key challenges (Shinde and Sirsath, 2020).

Effective policies are essential for promoting sustainable soil management. By establishing soil quality standards, land use regulations, and incentives for the adoption of sustainable practices, governments can encourage farmers to implement soil conservation measures and mitigate land degradation (Turpin et al., 2017).

Additionally, government subsidies, grants, and tax incentives for sustainable practices-such as cover crops, agroforestry, and organic farming-are crucial for supporting farmers' investment in soil health (Turpin et al., 2017). Furthermore, policies that promote farmer education, extension services, and knowledge exchange platforms significantly enhance awareness and encourage the adoption of sustainable soil management practices (Amundson, 2020).

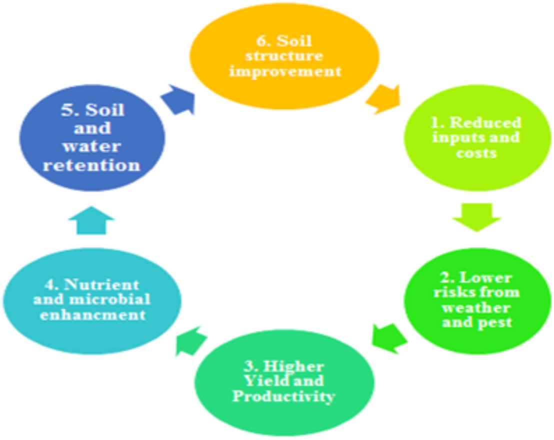


Figure 2. Importance of soil health and management (Srivastava et al., 2024)

5. CEREAL PRODUCTION CONDITIONS IN THE REPUBLIC OF NORTH MACEDONIA

According to data from the State Statistical Office, agricultural land in the Republic of North Macedonia covered 1.256.854 hectares in 2022. In 2023, there was a slight decrease, with the total area falling to 1.250.821 hectares. The sown area in 2022 covered 275.297 hectares, while in 2023, it decreased to 269.834 hectares. The largest share of the area under arable land and gardens is devoted to cereals, with a total of 158.798 hectares sown in 2022. However, in 2023, this area decreased to 156.469 hectares.

Table 1. Cultivated and Sown areas in Republic of North Macedonia (www.stat.gov.mk)

Year	Agricultural area (ha)	Total sown areas (ha)	Cereals (ha)
2022	1.256.854	275.297	158.798
2023	1.250.821	269.834	156.469

In terms of cereal production, wheat and corn account for the largest share of total production. According to an analysis of wheat and corn production over the past five years, the highest production levels were recorded in 2020 for both crops, with each subsequent year showing a continuous decline.

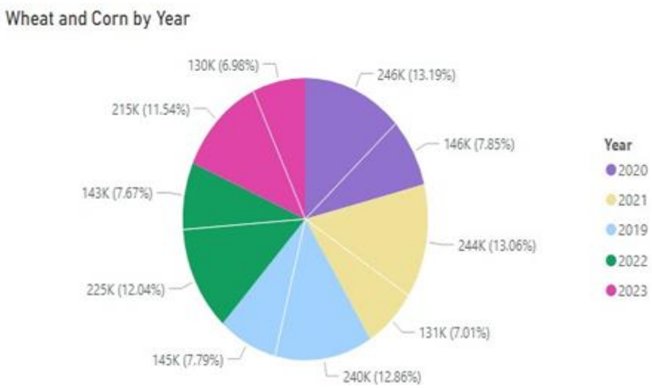


Figure 3. Production of Wheat and Corn in Republic of North Macedonia by Year (www.stat.gov.mk)

When analyzing corn production by region and year, the highest production in the Republic of North Macedonia occurred in 2020, with a total of 146.434 tons. This was followed by a decline in 2021, then an increase in 2022. However, in 2023, corn production reached its lowest point in the entire five-year period. Regarding corn production by region, the Polog region leads in production, followed by Pelagonia, East, Southeast, Skopje, Southwest, Northeast, with the lowest production occurring in the Vardar region.

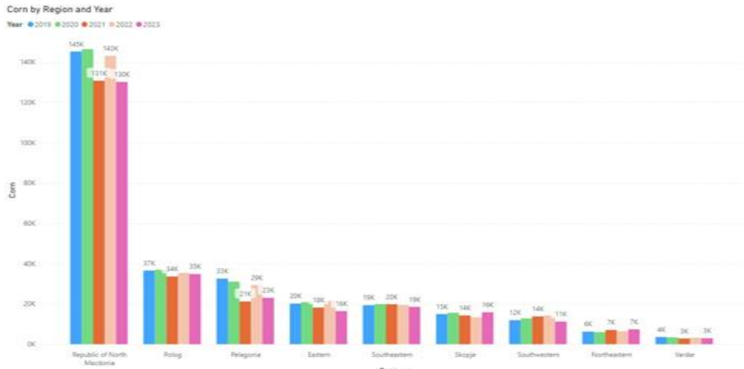


Figure 4. Production of Corn by Region and Year (www.stat.gov.mk)

When analyzing wheat production by region and year, the highest production in the Republic of North Macedonia occurred in 2020, with 246.031 tons. This was followed by a continuous decline, with the lowest production in 2023 compared to the entire five-year period. Regarding wheat production by region, the highest production is in the Pelagonia region, followed by the Northeast, Skopje, Vardar, Southeast, East, Polog, and the lowest production in the Southwest region.

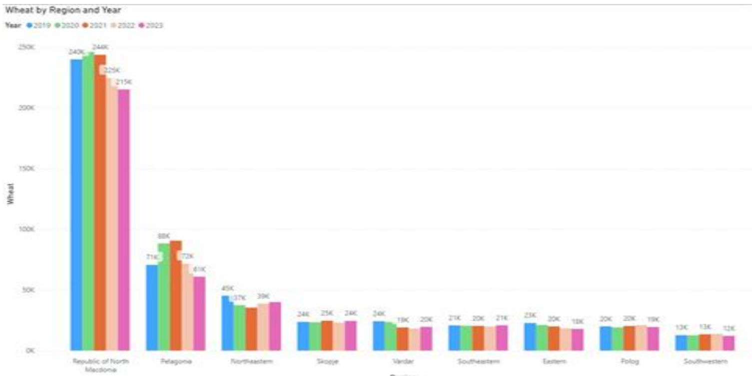


Figure 5. Production of Wheat by Region and Year (www.stat.gov.mk)

6. STRATEGY OF THE REPUBLIC OF NORTH MACEDONIA FOR ADDRESSING AGRICULTURAL CHALLENGES AND INCREASING CEREAL PRODUCTION

The Strategy is the third document in the Republic of North Macedonia of its kind that systematically outlines the policies to be implemented, offering solutions for addressing both current and future challenges. Agriculture is one of the most sensitive sectors to the negative impacts of climate change, and crises caused by new animal and plant diseases are becoming increasingly frequent.

The general goals for the sector include improving the competitiveness and sustainability of agricultural income, applying ecological practices in production to reduce the impact of climate change and adapt to it, and ensuring the sustainable development of rural areas-all supported by the state. Based on the identified weaknesses in wheat production, there is a need to maintain income support that sustains the current level of production, reduce production costs, and increase yields, especially in the face of increased negative climate impacts that primarily affect productivity.

In the event of market disruptions and a drop in purchase prices below the cost of production, intervention measures are legally prescribed in accordance with the law. These measures have thus far been applied only in the form of aid for storage in state warehouses. However, other interventions require simplification of procedures.

Approximately 38 percent of the country is prone to severe soil erosion due to topographic features and heavy rainfall, although in many cases, soil erosion is also caused by unsustainable agricultural practices. The objectives of the strategy include increasing agricultural production through modernization to better meet domestic consumption with local production, improving the quality of Macedonian agricultural products with added value, ensuring food safety and animal welfare, and creating conditions for a competitive and sustainable agriculture sector in both domestic and foreign markets.

Special emphasis is placed on introducing policies that were neglected in the past, particularly those aimed at building human capacity for the adoption of new technologies. The newly established Knowledge and Innovation System will connect all stakeholders in the creation of innovations, knowledge transfer, and digitalization. It also facilitates the exchange of digital technologies, smart agriculture, and production methods based on knowledge and good governance. The negative perception of modern technologies among farmers should be addressed through efficient advisory services, demonstration farms, and training programs designed to encourage the acceptance of new technologies. To mitigate and adapt to climate change, climate-friendly practices will be promoted through their inclusion in cross-compliance requirements and increased co-financing of necessary investments. Farmers will receive support through appropriate advisory packages on best practices and training to reduce the impact of climate change. Policy interventions aimed at protecting soil from degradation will include strict adherence to cross-compliance requirements for soil cover, erosion protection, and support for investments in precision agriculture. This will involve using sensors for the optimal application of agro-technical measures and providing financial support for agro-environmental initiatives.

Precision agriculture, which tailors the use of water and fertilizers to crop needs, will be promoted through operational programs of producer organizations, supported by the Agricultural Knowledge and Innovation System. This will include dedicated advice and training. Income support for grain and fodder crops will help maintain the current level of production, especially in the face of increased negative climate impacts that primarily affect productivity.

Given the importance of wheat for ensuring food security, direct payments will continue in the next period, with higher amounts allocated to producers who achieve higher yields. To increase average yields of crops and meet the needs of existing areas, special support measures, along with an advisory package for the adaptation of advanced technologies, will be introduced. For the restructuring of the agri-food sector, which faces an unfavorable structure and needs modernization, the following interventions are planned: investments in the modernization and diversification of the technological processes of existing agri-food businesses, including support for crop production modernization and the exploitation of production potential in controlled conditions. Special attention will be given to implementing innovative technological solutions and production systems. In addition to investments aimed at improving physical capital, significant attention should be given to enhancing standards, both by adapting the legislative framework and by establishing an effective control system.

Interventions in the technical and technological improvement of the agricultural sector require the mobilization of a wide range of entities, including advisory services, scientific and research institutions, and other stakeholders. A broad array of general measures to support agriculture is needed, along with the establishment of various forms of administrative and technical support to encourage collaboration among these entities. The agricultural advisory system should incorporate the economic, environmental, and social dimensions of managing agricultural holdings and land, enabling the transfer of information on modern technological advancements and innovations from science.

State-supported services should assist farmers and other beneficiaries of national agricultural policy in understanding the relationship between farm management, land management, and the application of specific standards, especially those related to the environment and climate. Due to the benefits for preserving crop growth, yield, and income, it is expected that farmers will more readily accept measures for adapting to negative climate effects. Additionally, the introduction of measures to mitigate climate change impacts will be encouraged through a greater number of instruments in national agricultural policies.

7. CONCLUSION

In conclusion, sustainable cereal production requires a multi-faceted approach that incorporates innovative practices such as Climate-Smart Agriculture (CSA), Precision Farming, and Effective Soil and Crop Management strategies. These practices are crucial for enhancing productivity while minimizing environmental impacts, ensuring long-term food security, and adapting to the challenges posed by climate change. The integration of modern technologies, such as renewable energy and data-driven farming tools, can significantly improve efficiency, reduce resource use, and promote resilience in agricultural systems. However, the successful implementation of these strategies depends on overcoming challenges such as financial constraints, technological gaps, and insufficient infrastructure, especially in developing regions.

In the context of Republic of North Macedonia, the government’s strategic focus on modernizing agricultural practices, fostering technological adoption, and mitigating climate change impacts is vital for enhancing cereal production and achieving sustainability. Continued investment in training, advisory services, and climate-friendly policies will support farmers in adopting sustainable practices and improving yields. Ultimately, fostering collaboration between farmers, government bodies, and research institutions will be key to developing a resilient and sustainable agricultural sector that can meet global food demands while preserving environmental integrity.

8. REFERENCES

Amundson, R. (2020). The policy challenges managing global soil resources. Geoderma, 379, 114639.

Anand, S., Kumar, P., Alok. A., Kumar, R. (2023). Chapter -4 Precision Agriculture, Technology and Implementation. www.researchgate.net/publication/379219789

Cui, Z.L., Wu, L., Ye, Y.L., Ma, W.Q., Chen, X.P., Zhang, F.S. (2014). Trade-off between high yields and greenhouse gas emissions in irrigation wheat cropland in China. Biogeosciences, 11, 2287-2294.

Esilaba, A., Byalebeka, J., Delve, R., Okalebo, J., Ssenyange, D., Mbalule, M., Sali, H. (2005). On farm testing of integrated nutrient management strategies in eastern Uganda. Agric. Syst., 86, 144-165. www.sciencedirect.com/science/article/abs/pii/S0308521X04001738?via%3Dihub

Georgia, S. (2022). Precision farming and their benefits in agriculture, Global Journal of Plant and Soil Science, 6(2), 001-002.

Gutiérrez, S.S.M., Palacios, A.T., Ruiz-Vanoy, J.A., Pérez, S.L. (2018). Sustainable and technological strategies for basic cereal crops in the face of climate change: A literature review. African Journal of Agricultural Research, 13(5), 220-227.

Hossain, M.B. (2021). Soil and Crop Management for Sustainable Agriculture. www.researchgate.net/publication/355909611

Hussain, S. et al. (2022). Climate Smart Agriculture (CSA) Technologies. In: Jatoi, W.N., Mubeen, M., Ahmad, A., Cheema, M.A., Lin, Z., Hashmi, M.Z. (Eds.) Building Climate Resilience in Agriculture. Springer, Cham. doi.org/10.1007/978-3-030-79408-8_20

Jiao, X., Nymadavaa, M., Zhang, F. (2018). The transformation of agriculture in China: Looking back and looking forward. Journal of Integrative Agriculture, 17, 755–764. doi.org/10.1016/S2095-3119(17)61774-X

Kamakuala, Y. (2024). Sustainable Agriculture Practices: Economic, Ecological, and Social Approaches to Enhance Farmer Welfare and Environmental Sustainability, West Science Nature and Technology, 2(2), 47-54.

Marie, A. (2023). Sustainable Cereal Production: Nourishing the Future While Preserving the Planet, Journal of Experimental Food Chemistry, 9, 447.

Muhie, S.H. (2022). Novel approaches and practices to sustainable agriculture, Journal of Agriculture and Food Research, 10. doi.org/10.1016/j.jafr.2022.100446

Mujeyi, M., Mudhara, (2020). Economic analysis of climate-smart agriculture technologies in maize production in smallholder farming systems, African Handbook of Climate Change Adaptation, 1-16.

Perniola, M., Lovelli, S., Arcieri, M., Amato, M. (2015). Sustainability in Cereal Crop Production in Mediterranean Environments. www.researchgate.net/publication/283813082

Scoones, I., Stirling, A., Abrol, D., Atela, J., Charli-Joseph, L., Eakin, H., Ely, A., Olsson, P., Pereira, L., Priya, R., van Zwanenberg, P., Yang, L. (2020). Transformations to sustainability: combining structural, systemic and enabling approaches. Current Opinion in Environmental Sustainability, 42, 65-75. doi.org/10.1016/j.cosust.2019.12.004

Shah, F., Wu, W. (2019). Soil and Crop Management Strategies to Ensure Higher Crop Productivity within Sustainable Environments, Sustainability, 11, 1485

Shinde S.Y., Sirsath D. (2020). Soil Management Strategies to Promote Higher Crop Productivity within Sustainable Environments, International Journal of Science and Research (IJSR), 10(11), 880-883.

Srivastava, R.K., Purohit, S., Alam, E., Islam, M.K. (2024). Advancements in soil management: optimizing crop production through interdisciplinary approaches, Journal of Agriculture and Food Research, 18, 101528. doi.org/10.1016/j.jafr.2024.101528

State Statistical Office, www.stat.gov.mk

Taylor, B.R., Watson, C.A., Stockdale, E.A, Mckinlay, R.G., Younie, D., Cranstoun, D.A.S. (2001). Current Practices and Future Prospects for Organic Cereal production: survey and literature review. www.researchgate.net/publication/238088803

Turpin, N., ten Berge, H., Grignani, C., Guzmán, G., Vanderlinden, K., Steinmann, H.H., Siebielec, G., Spiegel, A., Perret, E., Ruysschaert, G., Laguna, A., Giráldez, J.V., Werner, M., Raschke, I., Zavattaro, L., Costamagna, C., Schlatter, N., Berthold, H., Sandén, T., Baumgarten, A. (2017). An assessment of policies affecting Sustainable Soil Management in Europe and selected member states. Land Use Policy, 66, 241-249. doi.org/10.1016/j.landusepol.2017.04.001

Yokamo, S., Xiaoqiang, J., Gurmu, F., Tettey, K., Jiang, R. (2022). Cereal production trends, nutrient use efficiency and its management practices in agriculture: A review, Archives of Agriculture and Environmental Science, 7(1), 114-120.

Zhang, F., Cui, Z., Fan, M., Zhang, W., Chen, X., Jiang, R. (2011). Integrated Soil-Crop System Management: Reducing Environmental Risk while Increasing Crop Productivity and Improving Nutrient Use Efficiency in China. Journal of Environmental Quality, 40, 1051-1057.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.107L

STABILITY OF GRAIN WEIGHT PER SPIKE IN DIFFERENT WHEAT GENOTYPES IN YEARS WITH PRONOUNCED CLIMATE CHANGE

Kristina Luković[1*], Kamenko Bratković[2], Veselinka Zečević[1], Aleksandra Rakonjac[1], Ivan Tupajić[1], Mirela Matković Stojšin[3], Vladimir Perišić[1]

[1]Institute for Vegetable Crops Smederevska Palanka, S. Palanka, Serbia
*klukovic@institut-palanka.rs
[2]Center for Small Grains and Rural Development, Kragujevac, Serbia
[3]Tamiš Research and Development Institute, Pančevo, Serbia

Abstract: Grain weight per spike is an important yield component, greatly influenced by environmental factors. The aim of this research was to examine the stability of different wheat genotypes in terms of grain weight per spike under different agroecological conditions. The research was conducted during 2013/2014 at three locations (Kragujevac, Sombor, and Kruševac). The AMMI model was used to assess the genotype × environment interaction. The results of the analysis of the variance of the AMMI model for grain weight per spike showed statistically significant differences between the studied genotypes, locations, and their interactions. Both genotype and environment contributed 33% to the total variation of the experiment, while the contribution of the G × E interaction was 9.78%. The most stable genotypes were KG-244/4, KG-1/6, KG-52/23, and KG-307/4, with the KG-244/4 genotype achieving an average value of grain weight per spike at the average level of the experiment. The KG-1/6, KG-52/23, and KG-307/4 genotypes had above-average values of the observed traits. Kragujevac emerged as the most productive locality, achieving the highest average grain weight per spike, though with a significant interaction value. The smallest interaction effect was acquired in Kruševac but with the lowest average value of the studied trait. The genotype KG-52/23 achieved the highest average value of grain weight per spike and exhibited the highest stability of all analyzed genotypes. This indicates that the genotype KG-52/23 retains good productive characteristics of the spike even in less favorable environmental conditions, which makes it suitable for growing in different agroecological conditions. In breeding programs, wheat genotypes like this can be the basis for the future improvement of productive traits, primarily grain yield.

Key words: Wheat, Grain weight per spike, Stability, AMMI model, Climate change

1. INTRODUCTION

Progress in wheat breeding during the second half of the 20th century is characterized by a substantial increase in grain yield, which helped enhance production to meet the growing global population (Araus et al., 2008; Mariem et al., 2020). However, this increase in yield is not accompanied by improvements in yield stability (Martínez-Peña et al., 2023). This lack of stability can be attributed to grain yield being a complex trait influenced by multiple components that affect its expression, height, and stability (Šućur et al., 2024). One of the key quantitative traits positively impacting wheat grain yield is the grain weight per spike (Prodanović et al., 1999; Desheva and Deshev, 2021; Neykov et al., 2022). Although this trait is genetically determined and influenced by numerous minor genes, environmental factors play a significant role in its expression (Quintero et al., 2018). Ferrio et al. (2006) point out that the amount of assimilates (carbohydrates) available during the grain-filling phase and the duration of this period are the primary factors determining grain mass. In plants that experience stress due to high temperatures, drought, or heavy rainfall during grain filling, stress can lead to a reduced filling period and a decrease in the availability of assimilates, which will result in the development of smaller, poorly filled grains with lower mass (Luković et al., 2020; Frantová et al., 2022).

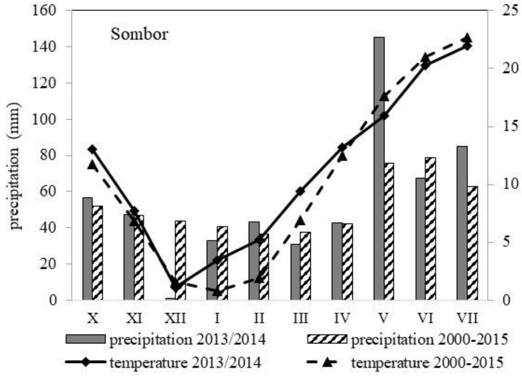
Therefore, research focusing on the stability of yield components is essential for enhancing the yield potential of wheat and for selecting new varieties that can withstand climate challenges. This research aimed to examine the variability and stability of grain weight per spike under different agroecological conditions in Serbia during a year with excessive rainfall.

2. MATERIAL AND METHODS

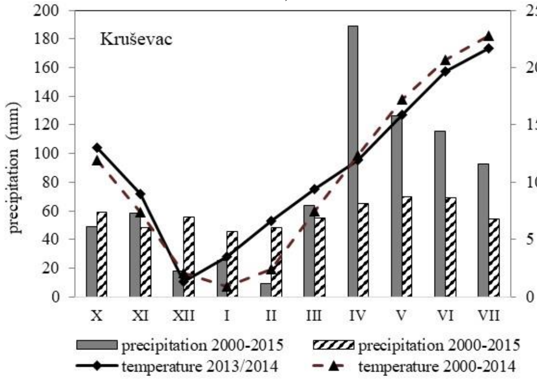
We used 14 winter wheat genotypes as research material, of which 13 were promising lines selected at the Center for Small Grains and Rural Development Kragujevac, and one standard variety - Pobeda. The experimental part of the research was performed during 2013/2014 at three locations: the Institute for Forage Plants in Kruševac, the Agroinstitute in Sombor, and the Center for Small Grains and Rural Development in Kragujevac. The experiment was set up in field conditions in a completely randomized block design, in three replications on a basic plot size of 5 m^2 (5×1 m). Within the plot, 10 rows were sown, with a row spacing of 0.10 m. Sowing was done mechanically, using 600-650 germinated grains per m^2 depending on the genotype characteristics. From each location, at the full maturity stage, 15 representative plants in three replications (45 plants) per tested genotypes were selected to analyze grain weight per spike (g). The assessment of genotype stability under different environmental conditions was examined using the AMMI model (Gauch and Zobel, 1996). The data was illustrated through AMMI 1 and AMMI 2 biplots, facilitating a thorough analysis of the genotype × environment (G×E) interaction, i.e. provided clear insights into the behaviors of genotypes under diverse agroecological conditions. Statistical analysis of the data was performed using the computer statistical program SPSS software version and 22 GenStat 12^{th} (IBM Corporation, New York, NY, USA; GenStat, 2009).

2.1. Climatic conditions during the experiment period

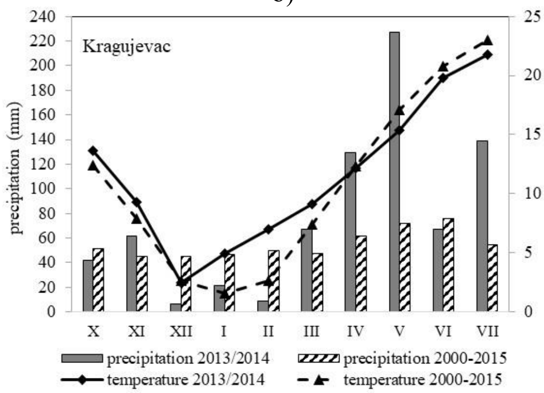
The average values of air temperature and precipitation sums by month, during the research period, are shown in Figure 1 in 2013/2014, October and November experienced slightly increased air temperatures across all three sites. The winter was mild with lower precipitation compared to the multi-year average. During the wheat growing season, 550.9 mm of precipitation was recorded in the area of Sombor, 745.9 mm in Kruševac, and even 768 mm in Kragujevac, which is significantly higher than the multi-year average (35.9 mm, 175.5 mm, and 219 mm, respectively). In addition to the large amount, the distribution of precipitation during the most important phenophases of wheat development was extremely unfavorable. Thus, during April, Kragujevac received 129.1 mm of precipitation and Kruševac 188.8 mm, which is three times the amount of precipitation compared to the multi-year average. Sombor recorded about 42.8 mm of precipitation for the same period. During May, Sombor, and Kruševac recorded twice the amount of precipitation compared to the multi-year average (145 mm and 126.6 mm), and in Kragujevac even three times the amount (227 mm). The year 2014 was characterized by exceptionally high rainfall in the Republic of Serbia, which caused catastrophic floods in some parts of Serbia (Prohaska et al., 2014).



a)



b)



c)

Figure 1. Average values of air temperature and precipitation during the wheat growing season in a) Sombor, b) Kruševac and c) Kragujevac

3. RESULTS AND DISCUSSION

The grain weight per spike is a very important quantitative trait that directly influences grain yield (Matković Stojšin et al., 2022). This observation alignes with the findings of Desheva and Deshev (2021) and Neykov et al. (2022) who indicate that grain yield is more closely related to the grain weight per spike than to the length of spikes or the number of grains per spike. The results from these studies show that the grain weight per spike ranges from 1.29 g (KG-28/6) to 1.86 g (KG-52/23), as illustrated in Figure 2.

Similar findings were reported by Jocković et al. (2014) and Šućur et al. (2024), who analyzed winter wheat genotypes of different geographical origins. Banjac et al. (2015) noted that, depending on the soil type, the average values of the primary spike grain weight can vary widely, ranging from 0.66 g to 2.77 g. In the agroecological conditions of Sombor and Kruševac, the genotype KG-52/23 achieved the highest average primary spike grain weight (1.85 g and 1.68 g, respectively), while in Kragujevac this genotype had a value 2.04 g, which is at the level of the standard variety Pobeda (2.15 g). The studied wheat genotypes had the lowest average primary spike grain weight in Kruševac and the highest in Kragujevac (Figure 2).

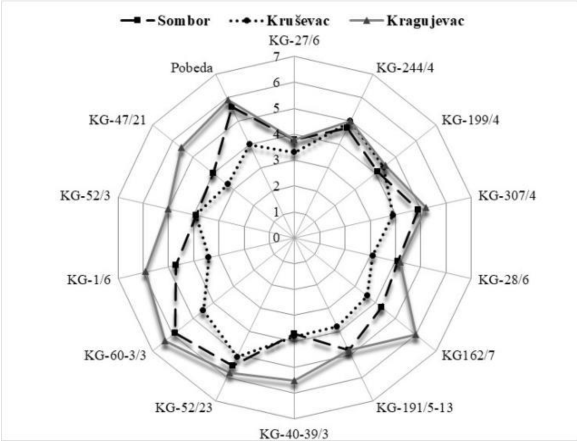


Figure 2. Average values for grain weight per spike (g) by genotype and location

The stability of different genotypes under various environmental conditions was further analyzed using the AMMI model. The analysis of variance for the AMMI model revealed that all sources of variation, both additive (genotype and location) and non-additive (genotype × environment), had highly significant effects on the expression of grain weight per spike. Within the main effects of the analysis of variance, an equal contribution of the sum of squares (33%) belongs to the genotype factor and the environment factor, while the contribution of the interaction was significantly smaller (9.78%) (Figure 3).

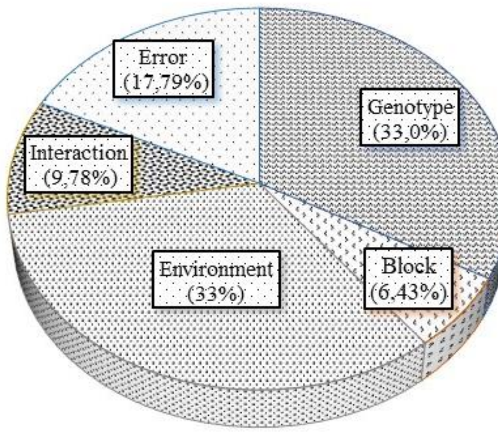


Figure 3. The percentage share of genotype, environment and interaction genotype/ environment in the total sum of squares, for the observed trait

The results of this study align with the results of Petrović et al. (2015) and Kondić et al. (2017), who stated that both genotype and environment significantly influence the variability of grain weight per spike. On the other hand, Urošević et al. (2023) emphasize that the genotype has the most substantial impact on this trait, accounting for 66.7% of the variability, while the environment contributes only 6.5%, and the G×E interaction accounts for 12.2%. The analysis of the interaction identified two main components. The first main component had a statistically significant effect, explaining 85.6% of the variation, whereas the second main component, which accounted for 14.4% of the variation, was not statistically significant (Table 1).

Table 1. Analysis of variance of the AMMI model for grain weight per spike

Source of variation	df	SS	MS	F
Genotype (G)	13	3.34	0.26	11.1322**
Block	6	0.65	0.11	4.7035**
Environment (E)	2	3.34	1.67	15.4168**
G × E	26	0.99	0.04	1.6564*
IPCA1 (85.6%)	14	0.85	0.06	2.63**
IPCA2 (14.4%)	12	0.14	0.01	0.52^{ns}
Error	78	1.80	0.02	-
Total	125	10.12	-	-

**Significant at $p < 0.01$ level, *Significant at $p < 0.05$ level, ^{ns}Non significant

The AMMI 1 biplot illustrates the relationship between the first principal component (IPCA1) and the average grain weight per spike across all studied locations. Among the genotypes, G-52/3, KG-52/23, and KG-1/6 demonstrated the greatest stability related to the first principal component. They were followed by genotypes KG-244/4 and KG-307/4. Notably, the KG-52/3 genotype had values of grain weight per spike lower than average, KG-244/4 genotype achieved around average values, while genotypes KG-1/6, KG-52/23, and KG-307/4 exhibited above-average values for the observed traits. In contrast, genotypes KG-40-39/3, KG-191/5-13, and KG-162/7 displayed the highest interaction values, indicating significant instability across all three locations. At the Kruševac locality, moderate stability was achieved, but the average grain weight per spike was the lowest among all locations.

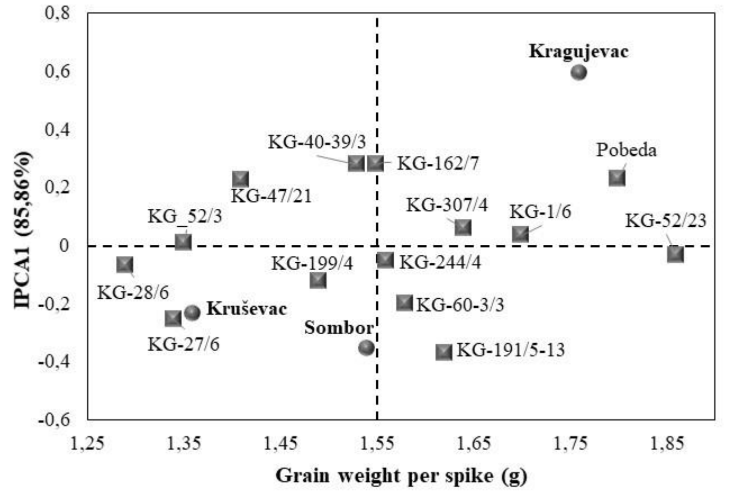


Figure 4. AMMI 1 biplot analysis of stability of grain weight per spike in 14 wheat genotypes in 3 localities

The greatest levels of interaction and, consequently, the least stability was observed in Kragujevac, where the highest average grain weight per spike was recorded (Figure 4). Studying the variability and stability of genotypes in different agro-ecological environments, Dimitrijević et al. (2011) noted that Kragujevac exhibited the highest average values of grain components as a result of a better ratio of generative to vegetative parts of the plant, as the plants tended to be shorter in this area. Additionally, research by Đurić et al. (2016) indicated that genotypes with the highest value of grain weight per spike are characterized by high instability. Zečević et al. (2016) also pointed out the difficulties in reaching stability in genotypes characterized by high values of certain traits.

Figure 5 shows an AMMI 2 biplot which provides a detailed explanation of the G×E interaction, highlighting how genotypes behave in different environments. The ordinate represents the first principal component, accounting for 85.6% of the interaction, while the abscissa represents the second principal component, which explains 14.4% of the interaction. Genotypes that are closest to the coordinate origin (i.e., the point where both axes intersect) are considered the most stable. In this analysis, the genotypes KG-52/23, KG-244/4, KG-199/4, and KG-307/4 was identified as the most stable. The environments, i.e. localities, exhibited a similar effect regarding stability. The distance of the observed locations from the point where both axes intersect indicates that genotypes did not achieve stability at any of the three analyzed locations for the trait being studied.

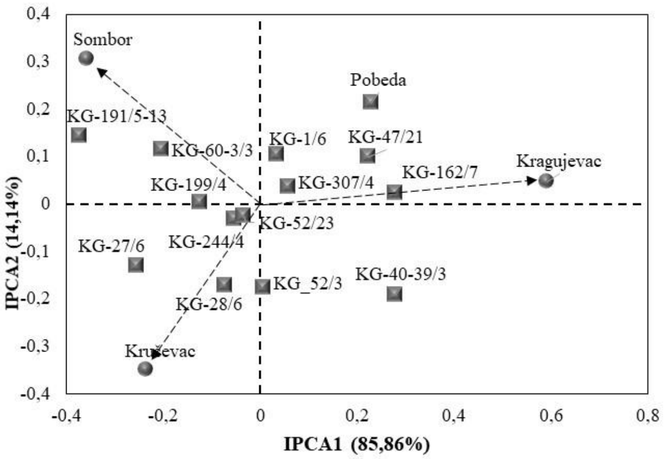


Figure 5. AMMI 1 biplot analysis of stability of grain weight per spike in 14 wheat genotypes in 3 localities

The period of experimental research is characterized by extremely unfavorable climatic conditions during the phenophases of heading, fertilization, and filling of grains. Lower air temperatures and excessive rainfall recorded in April and May across all three localities negatively affected the grain-filling process, resulting in the formation of smaller, poorly filled grains. Matković Stojšin et al. (2023) indicate that adverse climatic conditions during flowering and grain filling can reduce the value of yield components, particularly the weight of grains per spike, which may decrease by as much as 31.8%. The results of this study indicate that the Center for Small Grains and Rural Development has successfully selected stable wheat genotypes that are adapted to a variety of environmental conditions. These genotypes are characterized by improved quantitative traits and the ability to achieve high and stable values of grain weight per spike, which is one of the most important yield components, even in years pronounced by significant climate changes.

4. CONCLUSION

The analysis of variance for the AMMI model established a statistically significant contribution from genotype, environment, and the G×E interaction in the total sum of squares in the experiment concerning grain weight per spike. Within the main effects, both the genotype and environment made equal contributions to the sum of squares, while the interaction's contribution was significantly smaller. This limited interaction effect on the expression of grain yield represents an excellent basis for the selection of stable grain yield varieties. Among the genotypes studied, KG-52/23 demonstrated the highest average yield and greatest stability across all environments. Therefore, it can be considered a highly desirable genotype that is well-adapted to various agroecological conditions.

5. ACKNOWLEDGMENT

The research presented in this article is a part of a scientific project (Contract numbers: 451-03-66/2024-03/200216, 451-03-66/2024-03/200054) and is supported by the Ministry of Science, Technological and Development.

6. REFERENCES

Araus, J.L., Slafer, G.A., Royo, C., Serret, M.D. (2008). Breeding for Yield Potential and Stress Adaptation in Cereals. Critical Reviews in Plant Science, 27, 377-412.

Banjac, B., Dimitrijević, M., Petrović, S., Mladenov, V. (2015). Stabilnost komponenti prinosa hlebne pšenice gajene na različitim tipovima zemljišta. Selekcija i semenarstvo. XXI (2), 81-92.

Desheva, G.N., Deshev, M.G. (2021). Correlation and path coefficient analyses of grain yield and its related components for some common winter wheat genotypes. Agricultural Sciences 13(31), 26-36. doi: 10.22620/agrisci.2021.31.005

Dimitrijević, M., Knežević, D., Petrović, S., Zečević, V., Bošković, J., Belić, M., Pejić, B., Banjac, B. (2011). Stability of yield components in wheat (*Triticum aestivum* L). Genetika, 43(1), 29-39.

Đurić, N., Matković, M., Cvijanović, G., Dozet, G. (2016). Analysis of main additive effects and multiplicative interactions of components of yield of certain genotypes. Ratarstvo i povrtarstvo, 53(2), 61-68.

Ferrio, J.P., Alonso, N., Voltas, J., Araus, J.L. (2006). Grain weight changes over time in ancient cereal crops: Potential roles of climate and genetic improvement. Journal of Cereal Science, 44, 323-332.

Frantová, N., Rábek, M., Elzner, P., Středa, T., Jovanović, I., Holková, L., Martinek, P., Smutná, P., Prášil, I.T. (2022). Different Drought Tolerance Strategy of Wheat Varieties in Spike Architecture. Agronomy,12, 2328. doi: 10.3390/ agronomy12102328

Gauch, H., Zobel, W. (1996). AMMI Analysis of yield trials. Published in Genotype-by-environment interaction, Kang, M.S., Gauch, H.G. (Eds.), CRC Press, Boca Raton, 85-122.

Jocković, B., Mladenov, N., Hristov, N., Aćin, V., Djalović, I. (2014). Interrelationship of grain filling rate and other traits that affect the yield of wheat *(Triticum aestivum* L.). Romanian Agricultural Research, 31, 81-87.

Kondić, D., Bajić, M., Hajder, Đ., Knežević, D., Bosančić, B. (2017). The Spike Characteristics of Winter Wheat (*Triticum aestivum* L.) Varieties in Agro-Ecological Conditions of Banja Luka Region. Agro-knowledge Journal, 18(4), 263-274.

Luković, K., Prodanović, S., Perišić, V., Milovanović, M., Perišić, V., Rajičić, V., Zečević, V. (2020). Multivariate analysis of morphological traits and the most important productive traits of wheat in extreme rainfall conditions. Applied Ecology and Environmental Research, 18(4), 5857-5871. doi: 10.15666/aeer/1804_58575871

Mariem, S.B., Gámez, A.L., Larraya, L., Fuertes-Mendizabal, T., Cañameras, N., Araus, J.L., McGrath, S.P., Hawkesford, M.J., Murua, C.G., Gaudeuls, M., Medina, L., Paton, A., Cattivelli, L., Fangmeier, A., Bunce, J., Tausz-Posch, S., Macdonald, A.J., Aranjuelo, I. (2020). Assessing

the evolution of wheat grain traits during the last 166 years using archived samples. Scientific Reports, 10, 21828. doi: 10.1038/s41598-020-78504-x
Martínez-Peña, R., Rezzouk, F.Z., Díez-Fraile, M.d.C., Nieto-Taladriz, M.T., Araus, J.L., Aparicio, N., Vicente, R. (2023). Genotype-by-environment interaction for grain yield and quality traits in durum wheat: Identification of ideotypes adapted to the Spanish region of Castile and León. European Journal of Agronomy, 151, 126951. doi: 10.1016/j.eja.2023.126951
Matković Stojšin, M., Zečević, V., Bošković, J., Perišić, V., Urošević, D., Roljević Nikolić, S., Knežević, D. (2023). Uticaj faktora spoljašnje sredine na komponente prinosa ozime i jare tvrde pšenice. Zbornik radova Nacionalno naučnog skupa sa međunarodnim učešćem "Biotehnologija i savremeni pristup u gajenju i oplemenjivanju bilja". Institut za povrtarstvo Smederevska Palanka, Smederevska Palanka, Srbija, 106-115.
Matković Stojšin, M., Petrović, S., Banjac, B., Roljević Nikolić, S., Zečević, V., Bačić, J., Đorđević, R., Knežević, D. (2022). Development of selection criteria for improving grain yield in wheat grown in different agro-ecological environments. Acta Agriculturae Serbica, 27(53), 79-87.
Neykov, N., Doneva, M., Chavdarov, P., Alexiev, I. (2022). Correlation, path-coefficient and principal component analysis of yield and some traits related to the productivity of winter barley accessions with Bulgarian origin. Bulgarian Journal of Agricultural Science, 28(4), 658-661.
Petrović, S., Dimitrijević, M., Banjac, B. (2015). Spike traits variability in wheat grown on solonetz and humogley. Book of proceedings, IV International Symposium „Agrosym 2013", Jahorina, Bosnia and Herzegovina, 178-183.
Prodanović, S., Šurlan-Momirović, G., Perović, D., Stančić, I., Nikolić, Z., Veselinović, Z. (1999). Promena strukture populacija pšenice pod uticajem bulk selekcije I. Srednje vrednosti i odnosi svojstava. Zbornik abstrakta, Drugi Kongres Genetičara Srbije, Sokobanja, Srbija.
Prohaska, S., Đukić, D., Bartoš Divac, V., Todorović, N., Božović, N. (2014). Karakteristike jakih kiša koje su prouzrokovale čestu pojavu poplava na teritoriji Srbije u periodu april-septembar 2014. godine. Vodoprivreda, 0350-0519, 46 (267-272), 15-26.
Quintero, A., Molero, G., Reynolds, M.P., Calderini, D.F. (2018). Trade-off between grain weight and grain number in wheat depends on G×E interaction: A case study of an elite CIMMYT panel (CIMCOG). European Journal of Agronomy, 92, 17-29. doi: 10.1016/j.eja.2017.09.07
Šućur, R., Mladenov, V., Banjac, B., Trkulja, D., Mikić, S., Šumaruna, M., Börneo, A. (2024). Phenotypic marker study of worldwide wheat germplasm. Italian Journal of Agronomy, 19, 100002. doi: 10.4081/ija.2023.2194
Urošević, D., Knežević, D., Đurić, N., Matković Stojšin, M., Kandić, V., Mićanović, D., Stojiljković, J., Zečević, V. (2023). Assessing the potential of old and modern Serbian wheat genotypes: yield components and nutritional profiles in a comprehensive study. Agronomy, 13, 2426.
VSN International (2009). GenStat for Windows (12th ed.). VSN International.
Zečević, V., Matković, M., Petrović, S., Dimitrijević, M., Knežević, D. (2016). Stability of spike weight and grain weight per spike of different wheat genotypes. Book of Proceedings, VII International Scientific Agriculture Symposium, Jahorina, Bosnia and Herzegovina, 578-593.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.115L

STATUS AND PROSPECTS OF LIVESTOCK BREEDING AND ANIMAL FEED PRODUCTION IN THE REPUBLIC OF SERBIA IN THE CONTEXT OF CLIMATE CHANGE

Zoran Lugić[1*], Vladimir Zornić[1], Mirjana Petrović[1], Đorđe Lazarević[1], Nedeljko Racić[1], Violeta Mandić[2], Snežana Babić[1]

[1]Institute for Forage Crops, Kruševac, Globoder, Serbia
*zoran.lugic@ikbks.com, vladimir.zornic@ikbks.com, mirjana.petrovic@ikbks.com, djordje.lazarevic@ikbks.com, nedeljko.racic@ikbks.com, snezana.babic@ikbks.com
[2]Institute for Animal Husbandry Belgrade-Zemun, Serbia, violeta_randjelovic@yahoo.com

Abstract: Animal husbandry is the most important branch of agriculture because it produces the most important food for people. Forage plants, grasslands and pastures are a cheap and high-quality source of food for animals. They create a large vegetative mass and are rich in proteins, carbohydrates and other nutrients. The climatic condition in Serbia is favorable for forage production of most important forage crops. The crop structure on arable land is very unfavorable, primarily from the aspect of animal feed production and sustainable land use. The trend of decreasing areas under arable forage plants, meadows and pastures coincides with the trend of decreasing numbers of all types of domestic animals, especially cattle, sheep and pigs. One of the main reasons for the decline in livestock production is the low competitiveness and accumulative nature of this production.

Key words: Animal husbandry, Forage production, Soil, Climate

1. INTRODUCTION

Animal husbandry is the most important branch of agriculture and, in addition to providing important food for people, it reflects the level of its development and the level of living standards in a country. The importance of livestock farming stems from the fact that meat and milk are an indispensable component of the population's diet. On the other hand, livestock production enables balanced exploitation of natural resources and employs a significant number of people, especially in the sparsely populated hilly/mountainous regions of Serbia. Natural conditions in Serbia, and above all the geographical configuration of the terrain, soil quality, agro-ecological conditions are very favorable, both for primary arable agricultural production and for the development of livestock, especially cattle and sheep production. In addition to the existence of a high genetic potential of domestic animals for a certain production, the basic condition for the development of sustainable and competitive animal husbandry is the provision of cheap and high-quality animal feed, especially bulky animal feed as the dominant in the diet of ruminants (Đorđević and Dinić, 2007). As a result of decades of work by scientific institutions in Serbia, there is a high genetic potential for the most economically important traits, both of domestic animals and cultivated forage plants for the production of animal feed (Đukić et al., 2007; Tomić and Sokolović, 2007). Despite all the above, looking at statistical data and trends, the state of livestock production in our country can be characterized as unsatisfactory. Although livestock production is influenced by a large number of factors, the results indicate that one of the causes of the poor state is the insufficient application of scientific results, and especially technological solutions in the sphere of production and preservation of animal feed. As a result of the insufficient application of production technologies, the genetic potential of forage plants for the most important agronomic traits is insufficiently utilized in practice.

If we add to this the high losses in yield and quality during conservation and storage of animal feed, it is clear that these data should be used to find a way to improve the situation in the livestock sector.

The aim of these research was to present the favorable natural resources of the Republic of Serbia (climatic and soil conditions) for the production of animal feed in plain and hilly-mountainous conditions, as well as the negative trends in the number of heads in the last few decades. Also, the goals and the presentation of the recent results of the scientific research in the field of preparation and conservation of animal feed as a basic condition of competitive animal husbandry.

2. CLIMATIC CONDITIONS FOR ANIMAL FEED PRODUCTION IN SERBIA

Serbia extends between 42°15′ and 46°11′ north latitude and 18°49′ and 23°01′ east longitude, and 80% of the territory belongs to the Southeast European region, while 20% is located in the Pannonian Plain and belongs to the Central European region. It is characterized by a continental climate in the north of the country and moderately continental climate conditions in the central and southern parts. The level of water deposits and temperatures are largely determined by both the relief and altitude, as well as latitude and longitude.

Average annual temperatures depend largely on altitude, so that in Vojvodina and central Serbia up to an altitude of 300 m they range from 10.5 °C in Palić to over 11 °C in Niš and Belgrade. With increasing altitude, average annual temperatures decrease, so that in mountains higher than 1000 m they range from 6 °C on the Pešter plateau to 2.7 °C on Mount Kopaonik. Multi-year averages indicate that in the plain and hilly regions of Serbia, average temperatures above 5 °C are in March, while they are already above 11 °C in April. In mountainous areas at an altitude of around 1000 m, average monthly temperatures above 10 °C occur only in May, while at higher altitudes above 1500 m in June and July. The highest average monthly temperatures on the entire territory of Serbia are recorded in July and August, and they range from 20 °C to 22 °C up to an altitude of 400 m, while at higher altitudes they range from 11 °C to 16 °C. Spring temperatures in March and April are similar to the average monthly temperatures in the autumn months, November and October.

The average annual precipitation level, considering the long-term average in Serbia, ranges between 540 and 970 mm. The northern, northeastern and southeastern parts of the country record the lowest multi-year average precipitation, ranging from 539.2 mm in the far north (Palić) to 610.5 mm, as recorded in the east (Zaječar). In these regions, the highest precipitation is in May, June and November, and the lowest in February, September and October. In the central parts of Serbia (Šumadija and Pomoravlje), the precipitation level is slightly higher, ranging from 630 to 700 mm, and is characterized by slightly higher precipitation during the summer months.

The western parts of Serbia are characterized by higher average annual precipitation, ranging from 700 to over 800 mm, while in mountainous areas at altitudes above 1000 m, an average of 800 to 1000 mm of water precipitation falls during the year. The above results show that the amount of precipitation in our country is not small, however, its distribution throughout the year is irregular, so that very often during the summer months (July and August) dry periods occur, which have an adverse effect on the production of animal feed (Figure 1).

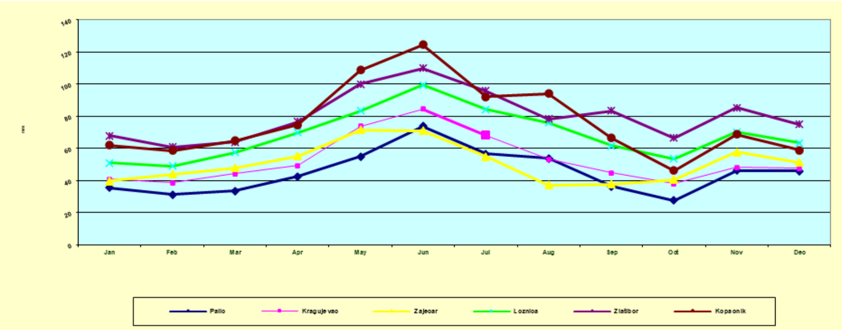


Figure 1. Average precipitation distribution by the months by the location in Serbia (www.hidmet.gov.rs)

Climate change is today's reality with the acceleration of the global warming trend and the occurrence of extreme climate phenomena (droughts, floods, tornadoes, typhoons, etc). It should also be noted that extremely dry years with annual precipitation of 400 to 500 mm, pronounced dry periods and extremely high temperatures exceeding 40 °C in July are not uncommon in Serbia (Figure 2). Such agro-ecological conditions occasionally cause significant oscillations in the production of animal feed, which has an adverse effect on livestock production. Taking into account the fact that very little arable land is irrigated in Serbia, it is necessary to find solutions that will contribute to more stable animal feed production. Solutions must have a multidisciplinary approach and must go in multiple directions, so that their synergy can yield results. First of all, irrigation as a direct measure to prevent the water shortage should be implemented wherever conditions exist. Then, the issue of more efficient use of existing precipitation and soil moisture conservation is related to crop structure, production system and soil cultivation methods. Finally, the creation of genotypes that better withstand stress conditions caused by water shortages and high temperatures, the introduction and cultivation of species from warm regions and other measures could significantly contribute to reducing the risks caused by unstable climatic conditions. The results of monitoring global climate factors in the last two decades indicate an increase in temperatures and temperature instabilities in all parts of the world. However, the largest oscillations and increases in temperatures occur on the European continent and especially in the Pannonian Basin and the Balkan Peninsula (Figure 3). In our country, in the last 20 years, the average temperature has increased by about 1.2 degrees and in the summer period by 1.8 degrees with a tendency for an accelerated increase in temperatures (Figure 4).

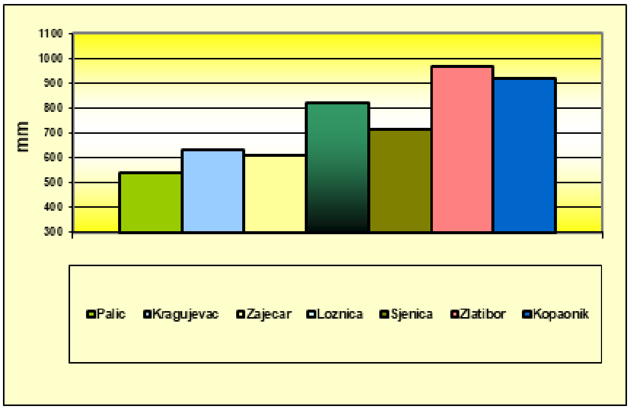


Figure 2. The average level of precipitation by the location in Serbia (www.hidmet.gov.rs)

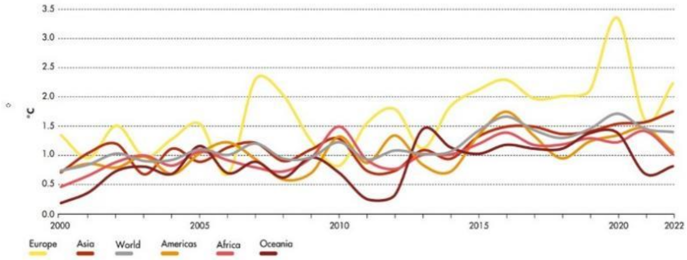


Figure 3. Temperature changes by the region and year (Eurostat, 2023)

Figure 4. Middle global and temperature (°C) for the Republic of Serbia, with comparation to the average 1961-1990 (Vuković Vimić, 2024)

3. LAND, THE BASIC CONDITION OF AGRICULTURAL PRODUCTION

Agricultural, or plant production, provides food for people and animals and has a great impact on soil properties. Intensive agricultural production has long achieved incredible successes and leaps in the production of all agricultural products. The use of large amounts of mineral fertilizers, pesticides and soil cultivation systems has caused great damage, not only to the soil, but also to watercourses, biodiversity and even the health of ecosystems and people. For all the above reasons, it is necessary to adjust the level of land use as a natural resource to the production of sufficient quantities of food, but also to implement measures for its protection and sustainable use. Economically important forage plants (annual and perennial grasses and legumes), thanks to their morphological and biological properties, provide the possibility of efficient land use, production of quality animal feed, but also soil protection from negative processes that modern agriculture entails. The areas under agricultural land as the main resource for plant production in the Republic of Serbia are constantly decreasing. According to data from the Republic Statistical Office (www.stat.gov.rs), there are slightly more than 4 million ha of available land on the territory of the Republic of Serbia (www.stat.gov.rs), of which about 3.25 million ha are used as agricultural land. With about 0.5 ha of arable land per capita, Serbia is among the countries well-provided with this main resource for food production. In the structure of crop production, cereals dominate the area, with an increase in the area under industrial crops and fruits, while there is insufficient area under fodder and other legumes, which makes it impossible to implement crop rotation, as one of the most important agrotechnical measures (Figure 5).

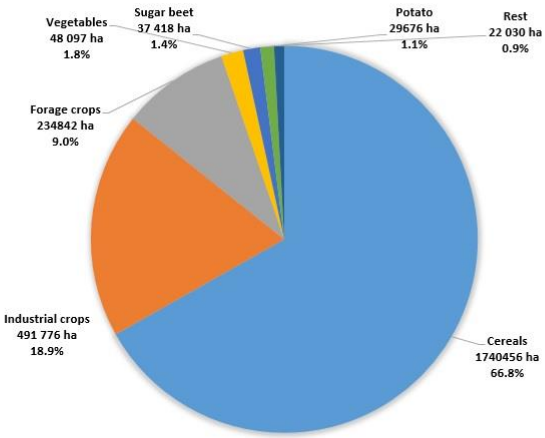


Figure 5. Structure of plant cultures (Statistical Yearbook of Serbia for 2020)
https://publikacije.stat.gov.rs/G2021/Pdf/G20212054.pdf

This crop structure allows for the production of corn and stubble grains, but it is absolutely unfavorable from the aspect of producing high-quality protein animal feed, preserving and sustainable use of soil over a long period of time. Soil, as a natural component of the terrestrial part of the Earth's climate system, participates in a series of reactions with human infrastructure and settlements. In addition to exploitation and disruption of soil functionality caused by anthropogenic factors, climate change represents additional stress for soil health, through reduced precipitation and irregular distribution during the growing season (Stričević et al., 2021). Climate can affect soil directly by changing thermal and moisture conditions that are crucial for the formation and maintenance of soil quality and the services it provides to the environment, and indirectly, by degrading vegetation, which is one of the pedogenetic factors and the main source of organic matter for the soil. Climate change has recently had a profound impact on soils in the Republic of Serbia and the wider region of Southeastern Europe. Given the rise in global temperatures, changes in precipitation patterns and increasingly frequent weather extremes, soil health and productivity are under increasing pressure, and climate change is considered the greatest global threat to sustainable development (Hou, 2021).

The impact of climate change on soil is reflected in one of the most direct consequences, which is degradation. Rising temperatures and changing precipitation accelerate the loss of organic matter, which is especially pronounced in the northern parts of Serbia, which directly affects the fertility and water retention of the soil itself. Due to the highly variable amounts and distribution of precipitation in space and time, the basic rule is to economize with soil moisture (Malešević et al., 2021). Degraded soil is devoid of structure and nutrients, which is reflected in reduced yields and makes it difficult to sustain agricultural production. Irregular and intense rainfall, often accompanied by long-term droughts, leads to various forms of erosion and makes the soil more susceptible to compaction and cracking.

Limited soil fertility is caused by high concentrations of H^+ and Al^{3+} ions, as well as some other heavy metals, organic acids, but also by limited nutrient availability and weak microbiological activity (Gudžić et al., 2017). Most of the soil in central Serbia has acidic chemical reactions and is often deficient in phosphorus. Climate change also affects nutrient availability. Higher temperatures lead to an increase in carbon dioxide concentration in the soil, which leads to changes in nutrient cycling, a decrease in soil pH, and the availability of nitrogen, phosphorus, and potassium. These changes often require increased use of chemical fertilizers, which can further contribute to degradation and pollution.

Climate change and unsustainable land use lead to a decrease in soil as a resource and its permanent loss (Dželetović and Simić, 2024). In areas of southeastern Europe, climate change will have a negative effect on crop production and soil, primarily due to possible water deficits and the occurrence of extreme weather events (prolonged heat waves, hail, storms) that will increase the variability of annual production and lead to a reduction in areas suitable for growing plant species (Cosentino et al., 2012).

4. FORAGE PRODUCTION ON ARABLE LAND

The dominant characteristic of forage production in the lowland areas is the high prevalence of maize on over 1.200.000 ha and grain production of around 4.500.000 tons per year. The largest part of maize grain (80%) and a significant part of products, semi-products and by-products of soybeans and sunflowers are used for feeding domestic animals. In addition, the largest part of barley produced and even a part of wheat and triticale grains are used as forage.

Coarse fodder production takes place on 235.000 ha, which makes up 9% of arable agricultural land, which is absolutely insufficient. According to estimates, in order to provide sufficient quantities of coarse fodder, the area under arable forage plants should amount to 20% of arable land. However, this unfavorable situation is mitigated by the fact that of the total area under arable forage plants, as much as 67% is occupied by the two most important and productive perennial forage plants, alfalfa and red clover (Stošić and Lazarević, 2007). In addition to these species, economically important perennial leguminous forage species in Serbia are birdsfoot trefoil and white clover in clover-grass mixtures (CGM), as well as annual forage plants: fodder peas, fodder vetch, fodder sorghum, Sudan grass and fodder rape.

Alfalfa (*Medicago sativa* L.) is the most important perennial forage legume and it is grown on 106.000 ha. Depending on soil type and climatic conditions, alfalfa without irrigation can yield from 6 t ha^{-1} to 9 t ha^{-1} in the year of establishment, and in the second year 14-19 t ha^{-1} of hay with an average crude protein content for four cuts of 217 g kg^{-1} and an annual crude protein yield of 3.12 t ha^{-1} (Radović et al., 2007).

Alfalfa is most often grown as a pure crop, although it can also be a component of grass-legume mixtures for hay production (Lazarević et al., 1999). It is used for feeding domestic animals in various forms, most often as hay, but also dehydrated in the form of briquettes, as silage and less often as green forage or for grazing.

Red clover (*Trifolium pratense* L.) is grown as a pure crop in Serbia on about 60.000 ha and it successfully replaces alfalfa on soils of increased acidity in lowland and hilly areas. Thanks to its developed root and intensive biological nitrogen fixation and favorable effect on the soil, it is very important in crop rotation. Due to its poor tolerance to drought conditions, its period of use is short, only 2-3 years, and it is mostly grown in the more humid hilly areas of western Serbia. In conditions without irrigation in the second year it gives high hay yields (14-18 t ha^{-1}), with a high protein content (18-22%) and minerals (Lugić et al., 2001, 2006).

On poorer quality soils, birdsfoot trefoil (*Lotus corniculatus* L.) plays an important role in providing the protein component in animal feed. Although there is no economic justification for this, in some areas on soils with increased acidity this species is traditionally grown in pure culture. Due to its high adaptability, it is grown in various agro-ecological conditions, even at high altitudes (Steiner, 1999).

Annual forage plants have a long tradition of cultivation in Serbia and represent an important source of bulky and concentrated animal feed. The most important annual forage legumes are field pea (*Pisum sativum* L.) and common vetch (*Vicia sativa* L.), which are grown on nearly 30.000 ha and are used in various ways. In the agro-ecological conditions of our country, these species provide high yields of biomass of excellent quality (Mihailović et al., 2004). Also, rapid growth and high yields of green forage recommend them as very good green manure (Ćupina et al., 2004). However, the reduction of livestock, the dominance of corn in the lowland area, the simplification of the production process, the reduction to a smaller number of crops and the increase in energy prices have led to a decrease in the distribution of these species. However, in recent years, with the introduction of adequate agricultural mechanization and the adoption of conservation technologies, these species are increasingly grown with small grain cereals as support crops and are used for the production of hay, silage and haylage. Together with reduction of livestock number during the last four decades there was a significant reduction in the area under forage crops in Serbia (Figure 6).

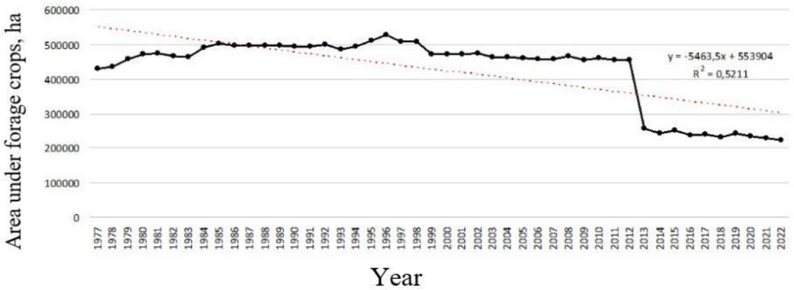


Figure 6. The area under forage crops in last four decades
in Serbia (data used from Statistical Yearbook)

5. GRASSLAND FORAGE PRODUCTION

Grasslands are communities of primarily herbaceous annual, biennial and perennial plant species that cover 30% of the planet's land as permanent cover. Their importance as a spontaneous, natural ecosystem is enormous: they represent a habitat for animals, fungi and microorganisms; they participate in pedogenesis and prevent erosion processes; they store carbon in the deeper layers of the soil, making it inert, which contributes to mitigating the "greenhouse" effect. From the perspective of (human) agricultural practice, grasslands are a resource that is the basis for the supply of bulky animal feed, i.e. they ensure the stability of the market supply of dairy and meat products (Mara, 2012). They are a habitat for pollinators, a source of raw materials for the pharmaceutical industry, and an inexhaustible source of genetic material for wild relatives of cultivated plant species (Cousins and Lindborg, 2008). Grasslands in the Republic of Serbia covered an area of 556.446 ha in 2023, which is a significant decrease compared to 2022, when it was 661.578 ha (SORS, 2024).

A large part of the area under grasslands is in the stage of degradation, as a result of depopulation, reduction in livestock, inaccessibility of terrain, low-profitable production of animal feed, lack of infrastructure, as well as inadequate subsidy policy. In addition to these anthropogenic factors of grassland degradation that are associated with local activities, grasslands also respond to global changes in temperature and precipitation (Gobiet et al., 2014). In Serbia, grasslands are most common in the hilly-mountainous area, and it is precisely this altitude zone that is sensitive to changes in abiotic factors. On the one hand, the existing diversity of autochthonous species is decreasing, while on the other hand, the floristic composition is changing towards the presence of thermophilic species whose range is expanding due to changing environmental conditions (Dibari et al., 2021). Grassland degradation is visible throughout Serbia south of the Sava and Danube rivers, and this conclusion was made as a result of the analysis of over 1000 samples of bulky fodder in the past 10 years in the laboratory of the Institute of Forage Crops in Kruševac. Biomass from sown and semi-natural grasslands was analyzed and most often, regardless of whether they are established or natural communities, the attitude of the owner is inappropriate. Mowing grasslands is carried out in the phenological stages of seed maturation or even its complete rejection has occurred. The rest of the plant - stems and leaves that actually make up the bulky meal have also been modified to the extent that the proportion of unusable components such as lignin has increased and the resulting fodder is in that case not a suitable source of nutrients (Babić et al., 2019).

Due to inadequate fertilization, untimely mowing and other measures, the yield of grasslands is also low and amounts to 2,7 t ha^{-1} in meadows and 2,4 t ha^{-1} in pastures, which indicates that they are lowly productive (SORS, 2024). Some research also indicates that grasslands are generally very responsive to fertilization, and that with adequate fertilization, the yield of grasslands can increase several times, thus significantly increasing the usability of this resource (Lazarević et al., 2009).

Grasslands generally have the potential to resist climate change through the local expansion of species that are tolerant to newly emerging conditions. The key to their adaptability lies in their diversity, so the more diverse the communities, the greater their adaptability to changing conditions (Baca Cabrera et al., 2021). Grasslands in the Republic of Serbia are characterized by high diversity (Stošić et al., 2007) but low production, and as such they represent a sustainable but not economical source of animal feed. In contrast, grasslands in Western European countries are low in diversity due to intensive fertilization and exploitation and are mostly dominated by highly productive species. According to research by Zornić et al. (2024), intensively fertilized nitrogen treatments are dominated by species that have increased requirements for water and nutrients and are suitable for lower temperatures. Such characteristics indicate poor adaptability and if fertilization stops, or dry conditions with increased temperatures occur, there is a drastic drop in yield, and as some say, even a complete loss (Piseddu et al., 2021). This fact is supported by the fact that fertilization is necessary to stimulate the natural diversity of lawns, and the best results are achieved by applying phosphorus and potassium fertilizers at lower doses (up to 80 kg per ha) or without nitrogen, and that with higher amounts of nitrogen, there is a drastic decrease in the natural diversity of lawns (Figure 7).

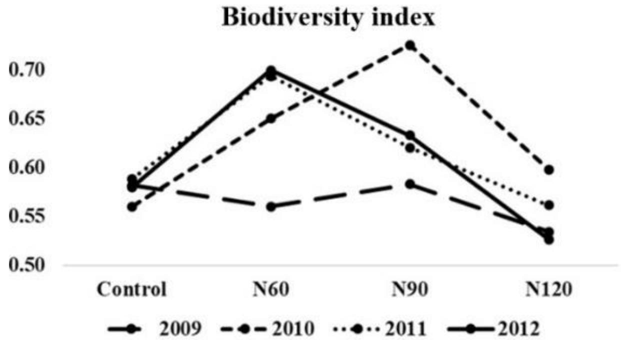


Figure 7. The influence of fertilizaton on biodiversity index in Danthonietum calycinae grassland type (Zornić et al., 2022)

6. SILAGE PRODUCTION

Modern livestock nutrition, especially when it comes to feeding dairy cows, also includes the use of silage. In addition to ensuring cost-effective production in this way, ensiling is also important from the perspective of sustainability and adaptation to climate change. Corn silage is the most widely used silage, both in our country and in the world. Today, 27.340 ha are under silage corn in the Republic of Serbia, which represents 2.96% of the total area under corn (SGS, 2024). These areas are too small to provide sufficient quantities of silage even for the existing number of ruminants, so it is necessary to increase them, especially in a future concept of strengthening livestock production. Silage of green biomass of fodder plants enables their earlier removal from production areas and more intensive use of land (Rakaščan et al., 2019). Ensiling corn provides a significantly higher yield of energy and nutrients per hectare, compared to the production of corn for grain. Corn silage is also important in terms of crop rotation, because by sowing silage corn late, it is possible to ensure two harvests per year, which is important from the perspective of sustainability. In addition, it is known that dry matter losses during ensiling (5-15%) are significantly lower than losses during hay production (20-40%). So, efficient use of energy sources in agricultural production will prevent destruction of natural resources, minimize environmental problems, and improve sustainable agriculture (Pervanchon et al., 2002). In addition, the production of greenhouse gasses, such as methane (CH_4) could be significantly reduced by decreasing the fibre content of the diet. One of the acceptable ways to do this is the increase in the proportion of high starch components, such as corn silage (Hopkins and Prado, 2007).

Due to the very sporadic production of grass and legume silage, statistical data on their production in our country are mainly presented through hay production. The main reason for this is insufficient knowledge of ensiling technology, especially when it comes to legumes. Considering climate change, the negative side of which is particularly reflected in frequent droughts and floods, the introduction of grass and legume silage has significant potential in reducing the risk of total yield losses, as well as in increasing the quality and yield of coarse biomass. In addition, proper ensiling of grass and legumes contributes to the preservation of nutrients, especially in terms of protein content as the most expensive component of the diet. To this end, a cheap and effective measure for ensiling grasses and legumes is wilting, or short-term drying. In addition, modern research has confirmed that ensiling alfalfa in a mixture with red clover achieves significant protein preservation in alfalfa, which is prone to protein degradation (proteolysis) during ensiling (Li et al., 2018, Lazarević et al., 2023). It is important to emphasize that protein production from natural and sown grasslands significantly contributes to sustainability in terms of soil conservation, compared to protein production on arable land.

Recently, there has been a lot of research related to the production of bacterial inoculants that enable an optimal balance between the values of the basic quality parameters of silage fermentation. Special attention has been paid to the production of new strains of lactic acid bacteria. The advantage of bacterial inoculants over other silage additives is that they do not leave residues and do not negatively affect animal health and the quality of their products. Therefore, they are also allowed in organic agricultural production in Serbia (Đorđević et al., 2024), which is significant in terms of sustainable livestock production.

7. THE STATE OF LIVESTOCK PRODUCTION IN SERBIA

Looking at statistical data for the period from 1977 to 2022, one can see a drastic decline in the number of ruminants for the mentioned period (Figures 8 and 9).

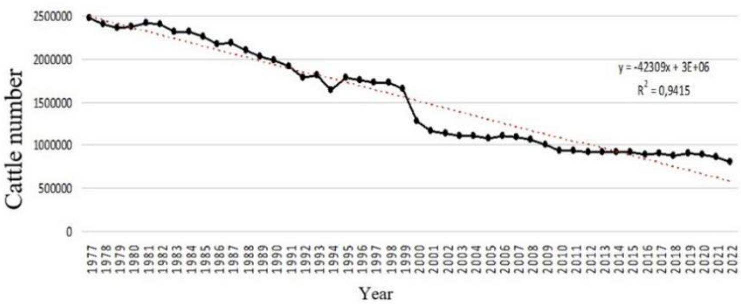


Figure 8. Number of cattle since 1977-2022 in Serbia

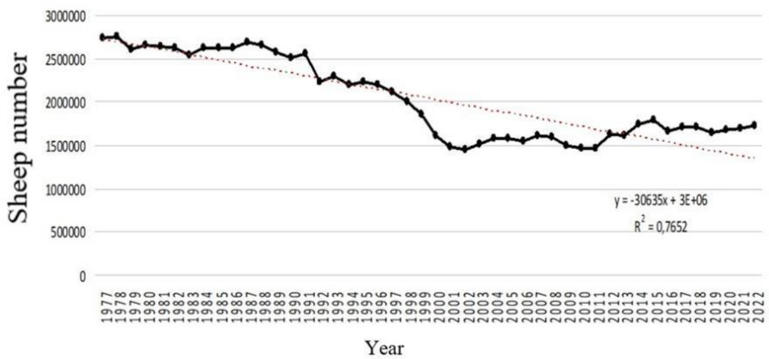


Figure 9. Number of sheep since 1977-2022 in Serbia

This decline was especially pronounced in cows and sheep in the 1990s, when the number of breeding animals was dramatically reduced. This state of affairs was caused by socio-political and social turmoil and economic sanctions that the international community declared against our country. During that period, due to the impossibility of exports and the economic crisis, Serbia lost the markets to which it had exported significant quantities of meat, especially beef, in the 1980s. As an illustration of the situation, we cite the data that in 1990, 165.000 tons of veal and beef were produced in Serbia, while in 2005 this production amounted to only 90.000 tons (FAOSTAT, 2007), while today it is significantly lower. Such data related to the number of cattle are very worrying, especially since these are species in which, unlike the decline, the increase in the number of cattle cannot follow a rapid upward trajectory. The situation is similar with the number of sheep, which after a significant decline in the last few years is slightly increasing. With the rapid decrease in the number of cows, due to the increase in milk production per cow, there was no decrease in milk production for a long period, but a further decline in the number of dairy cattle would certainly cause a deficit in production. The increase in milk production per cow is primarily a result of improved genetic potential of dairy cattle, but also better health care and nutrition. Despite the increase in cow milk production, the situation is not even close to satisfactory and is far behind Western European countries.

Despite negative trends in livestock production, Serbia has a positive balance in foreign trade of agricultural products and is incomparably better than almost all countries in the region that are candidates for joining the European Union (Figure 10). The worrying state of livestock production in Serbia is also indicated by the share of livestock in the value of total agricultural production of only 32%, which places us among agriculturally underdeveloped countries. However, many agricultural economists believe that the situation in domestic livestock production could improve relatively quickly because there is still a significant number of high-quality breeding animals, quality human resources and satisfactory natural resources. When observing the state of livestock farming in the European Union in the period 2002-2022, it can be concluded that the trends are similar and that there is a decline in the number of livestock, especially pigs, sheep and goats (Figure 11). Despite the decline in the number of livestock in the EU, there has been no significant decline in meat and milk production.

Figure 10. The trade of agriculture products in Serbia 2011-2021 (Eurostat, 2023)

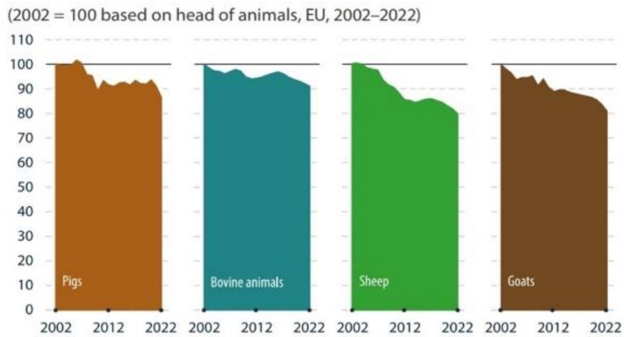


Figure 11. Development of different livestock in Europe 2002-2022 (Eurostat, 2023)

8. CONCLUSION

Serbia has significant areas of agricultural land suitable for crop production, animal feed production and livestock production. Soil and climatic conditions are conducive to the production of fodder plants and high-quality, healthy animal feed.

The crop structure in Serbia is generally unfavourable. Corn and cereals are grown on nearly 68% of arable land, while fodder plants are grown on only 8-9% of arable land with an insufficient share of leguminous plants. This results in overproduction of corn and cereal grains, the inability to respect crop rotation, inefficient land use and questionable quality of animal feed. The situation in livestock production, especially in cattle breeding, is very unfavourable with a multi-decade trend of decreasing headcount. In parallel, the areas under forage plants are decreasing, especially under perennial legumes.

Climate change, i.e. the trend of increasing temperatures and decreasing precipitation during the vegetation period, is increasingly negatively affecting the stability of bulky fodder production and threatens to endanger livestock production.

In such conditions, it is necessary to create and implement agricultural policies that will contribute to increasing the competitiveness of domestic agriculture, and especially livestock breeding. This includes the regionalization of agricultural production, better use and protection of natural resources, the introduction of targeted-linked support measures, increasing the level of knowledge in all segments and other measures that would contribute to the development of livestock breeding as the most important agricultural branch.

9. ACKNOWLEDGMENT

This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (contract No 451-03-66/2024-03/200217).

10. REFERENCES

Babić, S., Lugić, Z., Sokolović, D., Petrović, M., Zornić, V., Anđelković, S., Lazarević, Đ. (2019). Botanical composition and forage quality of natural grasslands of Pešter highlands. Proceedings of X International Scientific Agriculturae Symposium »Agrosym 2019«, Jahorina, 542-547.

Baca Cabrera, J.C., Hirl, R.T., Schaufele, R., Macdonald, A., Schnyder, H. (2021). Stomatal conductance limited the CO_2 response of grassland in the last century. BMC Biology, 19(1), 50.

Cosentino, S.L., Testa, G., Scordia, D., Alexopoulou, E. (2012). Future yields assessment of bioenergy crops in relation to climate change and technological development in Europe. Italian Journal of Agronomy, 7(2), 154-166.

Cousins, O., Lindborg, R. (2008). Remnant grassland habitats as source communities for plant diversification in agricultural landscapes. Biological conservation, 141, 233-240.

Ćupina, B., Erić, P., Krstić, Đ. (2004). Forage catches crop in sustainable agriculture and organing farming. Acta Agriculture Serbica IX, 17, 451-457.

Dibari, C., Pulina, A., Argenti, G., Aglietti, C., Bindi, M., Moriondo, M., Mula, L., Pasqui, M., Seddaiu, G., Roggero, P.P. (2021). Climate change impacts on the Alpine, Continental and Mediterranean grassland systems of Italy: A review. Italian Journal of Agronomy, 16(3).

Dželetović, Ž., Simić, A. (2024). A critical review of the current state of climate change impact research on sustainable use of land. Ecologica, 31(114), 119-128.

Đorđević, N., Božičković, A., Cekić, B. (2024). Inoculants and silage-nutritional value and product quality. Book of abstracts of the 15th Symposium on Forage Plants of the Republic of Serbia "Forage Plant Production: Challenges and Perspectives in the 21st Century", Zemun, 9-10. /in Serbian/

Đorđević, N., Dinić, B. (2007). Food for animals. Arandjelovac, Serbia.

Đukić, D., Lugić, Z., Vasiljević, S., Radović, J., Katić, S., Stajanović, I. (2007). Domestic cultivars of perennial legumes-development and quantitative traits. A periodical of scientific research on field and vegetable crops, 44(1), 7–19.

FAOSTAT (2007). FAO Statistical databases, Food and Agriculture Organization (FAO) of the United Nations Rome, www.fao.org

Gobiet, A., Kotlarski, S., Beniston, M., Heinrich, G., Rajczak, J., Stoffe, M. (2014). 21st century climate change in the European Alps -- a review. The Science of the Total Environment, 493, 1138-1151.

Gudžić, N., Aksić, M., Gudžić, S., Jelić, M., Vuković, A. (2017). Effect of three levels of calcification on mobile Al content and acidity in district brown soil. XXII Conference on biotechnology with international participation, Faculty of Agriculture in Čačak, Proceedings, Book 1, 93-98. /in Serbia/

Hopkins, A., Prado, A.D. (2007). Implications of climate change for grassland in Europe: Impacts, adaptations and mitigation options: A review. Grass Forage Science, 62, 118-126.

Hou, D. (2021). Sustainable soil management and climate change mitigation. Soil Use and Management, 37(2), 220-223.

Lazarević, D., Stošić, M., Dinić, B., Terzić, D. (1999). Dynamics of grass-legume mixture production under continuous grazing by sheep. Biotechnology in livestock farming. 15(3-4), 77-87. /in Serbian/

Lazarević, D., Stošić, M., Dajić, Z., Terzić, D., Cvetković, M. (2009). Productivity and quality of plant mass of meadow ass. *Danthonietum calucinae* depends on the fertilization and utilization time. Biotechnology in animal husbandry, Belgrade-Zemun, 25(1-2), 133-142.

Lazarević, Đ., Stevović, V., Lugić, Z., Tomić, D., Marković, J., Zornić, V., Prijović, M. (2023). The quality of alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.) mixture silages depending on the share in the mixture and additives. Notulae botanicae horti agrobotanici Cluj-Napoca, 51(1), 12954

Li, X., Tian, J., Zhang, Q., Jiang, Y., Wu, Z., Yu, Z. (2018). Effects of mixing red clover with alfalfa at different ratios on dynamics of proteolysis and protease activities during ensiling. Journal of Dairy Science, 101, 1-11.

Lugić, Z., Radović, J., Sokolović, D., Jevtić, G. (2006). Forage yield and quality of some new cultivar of red clover (*Trifolium pratense* L.) in Serbia. Proceedings of 26th EUCARPIA Fodder Crops and Amenity Grasses Section Meeting and 16th EUCARPIA Medicago spp. Group Meeting, Perugia, Italy, 179-181.

Lugić, Z., Ignjatović, S., Lazarević, D., Radović, J. (2001). Investigation of some important characteristics of different genotypes of white clover (*Trifolium repens* L.) under the agroecological conditions of Serbia. Journal of mountain agriculture on the Balkans, 4(1), 53-62.

Malešević, M., Vladimir, A., Jevtić, R. (2021). Prilog poznavanju odnosa biljka-zemljište-klima i primena savremenih tehnologija u poljoprivredi. Racionalno korišćenje zemljišta i voda u Srbiji, 63-70.

Mara, F.P.O. (2012). The Role of Grasslands in Food Security and Climate Change. Annals of botany, 210, 1263–1270.

Mihailović, V., Erić, P., Karagić, Đ., Milić, D., Mikić, A. (2004). Grain yield and grain yield components of fodder pea depending on leaf type. Acta Agriculture Serbica IX, 17, 67-71.

Pervanchon, F., Bockstaller, C., Girardin, P. (2002). Assessment of energy use in arable farming systems by means of an agro-ecological indicator: the energy indicator. Agricultural Systems, 72, 149-72.

Piseddu, F., Bellocchi, G., Picon-Cochard, C. (2021). Mowing and warming effects on grassland species richness and harvested biomass: meta-analyses. Agronomy for Sustainable Development, 41, 74.

Radović, J., Lugić, Z., Sokolović, D., Štrbanović, R., Marković, J. (2007). Variability of productive traits and forage quality of selected genotypes of yellow bird's-foot trefoil. Proceedings, Institute for Agriculture and Vegetables, Novi Sad, 44, 1, 45-50. /in Serbian/

Rakaščan, N., Dražić, G., Živanović, Lj., Ikanović, J., Jovović, Z., Lončar, M., Bojović, R., Popović, V. (2019). Effect of genotypes and locations on wheat yield components. Agriculture and Forestry, 65(1), 233-242.

SGS (2024). Statistical Yearbook of Serbia. Statistical Office of the Republic of Serbia.

SORS (2024). Statistical office of the Republic of Serbia. https://publikacije.stat.gov.rs/G2024/Pdf/G20242057.pdf

Steiner, J.J. (1999). Birdsfoot Trefoil Origins and Germplasm Diversity. In: Trefoil: The Science and Technology of *Lotus*. Published by American Society of Agronomy, 81-96.

Stošić, M., Lazarević, D. (2007). Previous results of research on grasslands in Serbia. Proceedings of the XI symposium on forage plants "Sustainable systems of production and utilization of forage plants", Novi Sad, 44(1), 333-345. /in Serbian/

Stričević, R.J., Simić, A.S.,Vujadinović Mandić, M.P., Sokolović, D.R. (2021). The impact of climate change on the water needs of natural grasslands in Serbia. Journal of Agricultural Sciences (Belgrade), 66(3), 291-307.

Tomić, Z., Sokolović, D. (2007). Breeding of perennial grasses - methods, criteria and results in Serbia. Zbornik Radova Instituta za Ratarstvo i Povrtarstvo, 44(1), 51-69.

Vukovic-Vimic, A. (2024). Critical issues of the Republic of Serbia in the conditions of climate change. SANU Round Table, November 14, 2024. http://vukosavic.etf.rs/desant/skupovisanu.html

Zornić, V., Petrović, M., Anđelković, S., Babić, S., Sokolović, D., Lugić, Z., Marković, J. (2022). The influence of mineral fertilizers on the floristic composition and yield of the *Festuco-nardetum strictae subalpinum* grass community. Proceedings of the XXVII Biotechnology Conference, Čačak, 137-142.

Zornić, V., Petrović, M., Babić, S., Lazarević, Đ., Tomić, D., Racić, N., Radović J. (2024). Landolt indicator values changes as result of fertilization in *Danthonia alpina* grassland. Grassland Science in Europe, 29, 753-755.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.128MS

IMPACT OF FOLIAR FERTILIZATION ON GRAIN WEIGHT PER SPIKE IN DURUM WHEAT GROWN UNDER ORGANIC FARMING

Mirela Matković Stojšin[1*], Veselinka Zečević[2], Slobodan Milenković[3], Kristina Luković[2], Milan Stojšin[4], Dragana Stevanović[1], Desimir Knežević[5]

[1]Tamiš Research and Development Institute, Pančevo, Serbia
*matkovic.stojsin@institut-tamis.rs
[2]Institute for Vegetable Crops, S. Palanka, Serbia
[3]Educons University, Faculty of Ecological Agriculture, Sremska Kamenica, Serbia
[4]University of Novi Sad, Faculty of Agriculture, N. Sad, Serbia
[5]University of Priština temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Serbia

Abstract: The treatment with two foliar N applications (T3), was most effective in improving grain weight per spike in durum wheat genotypes. Genotype KG-3405-03 showed the highest grain weight under T3 in favorable 2013 conditions (1.91 g) but experienced the greatest decrease in 2014. In contrast, genotype KG-43-33/1 achieved the best results under T3 in the less favorable 2014 season (1.61 g), indicating its adaptability to adverse conditions, with foliar N fertilization. KG-28-6 and KG-44-3/1 are more stable and recommended for growing in various agroecological conditions.

Key words: Durum wheat, N treatment, Organic production, Genotypic variation

1. INTRODUCTION

Durum wheat (*Triticum turgidum* L. var. *durum* Desf.) ranks as the second most widely cultivated wheat species globally (Martínez-Moreno et al., 2022). According to International Grains Council (IGC, 2023), durum wheat is grown on approximately 13.7 million hectares worldwide, producing an average of 34.3 million tons of grain between 2018 and 2022. Although its global cultivation area is relatively small, durum wheat is a crucial crop and staple food in many Mediterranean regions, serving as the primary raw material for various traditional end-products such as pasta, couscous, bulgur, and different types of bread (Kabbaj et al., 2017).

Durum wheat is best suited to semi-arid, warm climatic conditions, so it is grown as a winter crop in Mediterranean regions. In colder areas with long winters, it is typically sown in spring and harvested in early autumn (Bassu et al., 2009; Sieber et al., 2014; Martínez-Moreno et al., 2022). In Central and Eastern Europe, particularly in the Pannonian region, most durum wheat varieties are winter types and are sown in the autumn (Vida et al., 2022).

Despite its good adaptability to dry and arid regions, durum wheat production is highly influenced by abiotic and biotic factors, especially drought and high temperatures (Pour-Aboughadareh et al., 2022; Grosse-Heilmann et al., 2024). Considering these challenges and the ongoing climate changes in recent years, the use of various agronomic practices has become increasingly important. These practices include adjusting tillage methods, implementing appropriate crop rotation, modifying sowing dates, and applying nitrogen fertilizers, which can increase yield and grain quality, but also pose environmental risks (Bassu et al., 2009; Knezevic et al., 2014; Morari et al., 2017; Bozek et al., 2021; Grosse-Heilmann et al., 2024). Therefore, organic fertilizers offer a more sustainable alternative and have been shown to improve soil quality and nutrient availability (Mancinelli et al., 2023). However, a limitation of organic fertilizers is the potential reduction in crop yield and quality (Di Mola et al., 2021). The aforementioned authors suggest that the impact of organic fertilizers on the yield and quality of durum wheat is site-specific, with a less pronounced effect on less fertile soils with high clay content.

Given the growing consumer demand for reliable products, especially those from organic production (Mie et al., 2017; Wang et al., 2019), organic durum wheat production has become a key focus due to the increasing interest in organic food (Zečević et al., 2022). Therefore, it is essential to select durum wheat varieties capable of producing high and stable yields, even in marginal envrionment conditions, for both organic wheat growers and breeders (Cséplő et al., 2024). Consequently, it is important to investigate diverse durum wheat genotypes within organic farming systems. Considering that optimizing nitrogen fertilization is a primary objective of applied agricultural research (Ercoli et al., 2013), further studies are needed to determine the optimal fertilizer combinations to improve durum wheat production (Zečević et al., 2022).

The aim of this study is to determine the impact of genotype, nitrogen fertilization treatments, season, and their interactions on the variability of grain weight per spike in durum wheat within an organic farming system.

2. MATERIAL AND METHODS

2.1. Plant material and experimental design

A field experiment was conducted using a randomized block design with three replications on a certified organic farm in Čačak, Serbia, during the 2012/2013 and 2013/2014 growing seasons. The plant material consisted of seven durum wheat genotypes, including three varieties: Windur (Germany), Žitka, and KG Olimpik (Serbia), along with four breeding lines: KG-28-6, KG-3405-03, KG-43-33-1, and KG-44-3-1 (Serbia). Each experimental plot was 5 m², and the soil type was classified as clay loam. The soil on which the experiments were conducted is acidic and classified as a carbonless soil type, with a low pH value and low free $CaCO_3$ content. The soil had a moderate level of organic matter and falls under the class of poorly humus soils. It has medium levels of readily available phosphorus and potassium. All soil analyses were performed at the Laboratory for Soil and Agroecology of the Institute of Field and Vegetable Crops in Novi Sad, Serbia, which is accredited according to the ISO/IEC 17025:2017 standard.

The experiment was conducted following the principles of organic wheat production. According to the Ordinance on Control and Certification in Organic Production in Serbia, maximum intake of 170 kg N ha^{-1} per year is allowed in organic farming. In the first season (2012/2013), potato was the preceding crop, and in the second season (2013/2014), processing crop was beans. In autumn, a starter fertilization was applied using 2 tons of organic fertilizer Italpollina (4:4:4) at a rate of 80 kg of pure nitrogen per hectare. Sowing was performed on November 2nd in the first season and October 25th in the second season, with a seeding rate of 600 seeds per square meter. During the tillering phase in February 2013, 500 kg per hectare of organic fertilizer Dix 10 (10:3:3) was applied, providing 50 kg of pure nitrogen per hectare. These fertilizers, produced by Hello Nature (formerly Italpollina, Italy), were used in the study. Three foliar nitrogen treatments were applied at different stages of plant development: T1 (no nitrogen application), T2 (one foliar spray of 0.3% organic fertilizer Trainer at the beginning of heading on April 10, 2013, and April 14, 2014), and T3 (two foliar sprays of 0.3% organic fertilizer Trainer at heading and anthesis stages, on May 8, 2013, and May 12, 2014), according to the recommended commercial rate. Grain weight per spike was analyzed in 10 randomly selected plants per main plot at full maturity, determined on the primary spikes.

2.2. Agro-meteorological conditions

Meteorological data were obtained from the Meteorological Station of the Fruit Research Institute in Čačak (Figure 1). In the first season (2012/2013), higher temperatures in April and May (13.2 °C and 18.2 °C) played a crucial role in significantly accelerating plant growth. In contrast, the 2013/2014 season was marked by lower average temperatures in November and December (7.3 and 0.5°C), which were below the long-term average, resulting in a delay in plant development. In the 2012/2013 season, the total amount of precipitation was 503 mm, which was higher than in the 2013/2014 season (413.8 mm). Precipitation in 2012/2013 was more evenly distributed throughout the year, with the highest rainfall in December (87.6 mm) and February (68 mm), which provided optimal conditions for early crop development. Although rainfall in April and May 2013 was lower (37 and 78.5 mm), it was still sufficient to support plant growth. In contrast, vegetation in the 2013/2014 season was affected by uneven precipitation distribution, with extremely high rainfall in May (167.8 mm) and June (149.8 mm), which negatively impacted plant health and crop maturity. In the same season, December, January, and February were characterized by very little precipitation or complete lack of it, which slowed down plant growth and development.

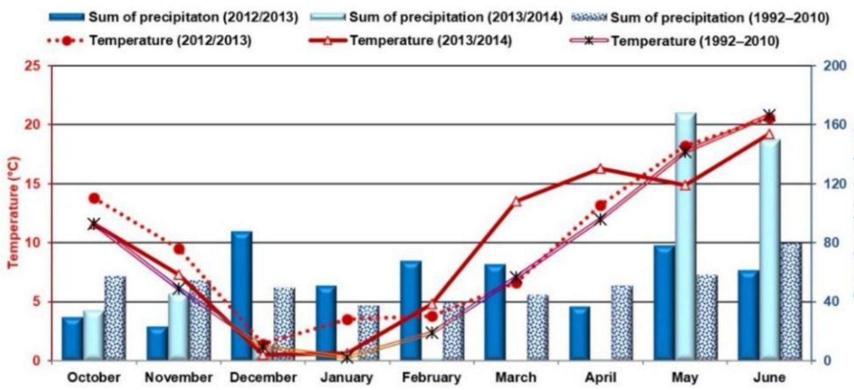


Figure 1. Meteorological conditions during the experiment

2.3. Statistical analysis

To analyze the effect of genotype, foliar fertilization treatments, and year, as well as their interactions on the expression of grain weight per spike, an analysis of variance (ANOVA) was conducted using the MSTAT-C program (Michigan State University, 1990). Multiple comparisons of the variants of the investigated factors were performed using the Least Significant Difference (LSD) test at two significance levels, 1% and 5%.

3. RESULTS AND DISCUSSION

The selection of suitable varieties and balanced fertilizer application are key agronomic practices for enhancing wheat productivity and quality (Panayotova et al., 2017). Therefore, it was important to conduct research on divergent durum wheat genotypes grown under various foliar nitrogen treatments and in different seasons. This study presents the impact of these factors and their interactions on grain weight per spike. Grain weight per spike is an essential yield component that, along with the number of spikes per square meter and the number of spikelets per spike, directly affects durum wheat yield (Kendal, 2019). Furthermore, grain weight per spike serves as a useful phenotypic marker for selecting suitable wheat genotypes, particularly under drought stress conditions (Xu et al., 2023).

The analysis of variance shows a highly significant ($p < 0.01$) effect of the main factors (genotype, year, and foliar nitrogen fertilization treatment) on the phenotypic expression of grain weight per spike (Table 1). The largest proportion of variation in this yield component was attributed to genotype (25.25%), followed by year (15.57%) and foliar nitrogen fertilization treatment (13.65%).

Table 1. Analysis of variance for grain weight per spike in different durum wheat genotypes under three foliar fertilization treatments grown in two vegetation seasons

Source of variation	df	Sum of Squares	Mean Square	F-value	p-value	% sum of squares[1]
Genotype (G)	6	1.948	0.325	15.688^{**}	0.000	25.25
Year (Y)	1	1.201	1.201	58.034^{**}	0.000	15.57
Treatment (T)	2	1.053	0.526	25.445^{**}	0.000	13.65
G × Y	6	1.314	0.219	10.582^{**}	0.000	17.03
G × T	12	0.171	0.014	0.688^{ns}	0.758	2.21
Y × T	2	0.069	0.035	1.674^{ns}	0.194	0.89
G × Y × T	12	0.221	0.018	0.892^{ns}	0.558	2.86
Error	84	1.738	0.021	–	–	–
Total	125	7.714	–	–	–	–

$^{**}p \leq 0.01$: statistically significant effect at the 1% significance level; ^{ns}Non-significant ($p>0.05$)
[1]The share of the sum of squares (%) of the analyzed factors and their interactions is expressed in relation to the sum of squares of the total (100%).

The largest contribution of the genotype factor indicates the presence of divergence in the studied genetic material. Additionally, Zečević et al. (2010), Knežević et al. (2008, 2015), and Kondić et al. (2017) have found that genotype and the external environment significantly affect the variability of grain weight per spike in wheat. The G × Y interaction was statistically significant ($p < 0.01$), while the G × T, T × Y, and G × Y × T interactions were not statistically significant ($p > 0.05$).

Table 2 presents the values of grain weight per spike for all genotypes under the analyzed treatments and seasons. A comparison of the genotypes, regardless of the treatments applied and the years, showed that the genotype KG-3405-03 had the highest average grain weight per spike (1.59 g) and was significantly different ($p < 0.05$) from the other genotypes, except from the KG-44-3/1 line (1.49 g). The lowest value of this trait in the trial was observed in the genotype KG Olimpik (1.22 g) which was significantly different from the other genotypes, except for Windur (1.23 g). An increase in grain weight per spike was observed under the fertilization treatments compared to the control (1.27 g), with values of 1.39 g for one foliar spray (T2) and 1.49 g for two foliar sprays (T3), with significant differences observed between the treatments. The application of the same foliar fertilization treatments had a positive effect on the number of spikes per square meter, number of grains per spike, 1000-grain weight, and grain yield for the same durum wheat genotypes (Zečević et al., 2022). Lopez-Bellido et al. (2012) and Pampana et al. (2013) highlight that split nitrogen fertilizer applications improve nitrogen use efficiency, but the crop response significantly depends on climate and agronomic practices, such as fertilizer quantity, type, splitting ratios, and application timing. Although durum wheat is known for its drought tolerance, it can be negatively affected by water stress (De Vita and Taranto, 2019). On average, for all genotypes and treatments, a significantly higher grain weight per spike was observed in the 2012/2013 season (1.49 g) compared to the 2013/2014 season (1.29 g), which was characterized by considerably lower amount of precipitation. Xu et al. (2023) found that grain weight per spike decreased by 31.7% in wheat under drought conditions. Saghouri el Idrissi et al. (2023) found that grain yield per plant in durum wheat genotypes decreases as water stress increases.

Table 2. Influence of interaction of genotype, treatment and season on the variation of grain weight per spike

Genotype	Foliar fertilization						Average
	T1		T2		T3		
	2013	2014	2013	2014	2013	2014	
Windur	1.19	1.05	1.23	1.13	1.57	1.18	1.22[d]
KG Olimpik	1.12	1.09	1.37	1.09	1.56	1.18	1.23[cd]
Žitka	1.36	1.12	1.64	1.16	1.68	1.20	1.36[bc]
KG-28-6	1.35	1.27	1.51	1.42	1.60	1.54	1.45[b]
KG-44-3/1	1.47	1.44	1.54	1.47	1.56	1.47	1.49[ab]
KG-43-33/1	1.09	1.29	1.38	1.40	1.42	1.61	1.37[b]
KG-3405-03	1.79	1.21	1.86	1.28	1.91	1.50	1.59[a]
Average	1.33	1.21	1.50	1.28	1.61	1.38	1.38
	1.27[C]		1.39[B]		1.49[A]		
LSD	G	Y	G × Y	T	G × T	Y × T	G × Y × T
0.05	0.135	-	0.191	0.088	NS	NS	NS
0.01	0.179	-	0.253	0.117	NS	NS	NS

Means followed by different lowercase letter(s) differ significantly between genotypes, while means followed by different uppercase letter(s) differ significantly between treatments at 5% level of significance: NS- nonsignificant.

The highest average value of grain weight per spike was recorded with the T3 treatment in 2012/2013 (1.61 g), while the lowest average value was found under the T1 treatment in 2013/2014 (1.21 g). In 2013, the grain weight per spike under the control treatment (T1) was lower than under the other treatments for that season (1.31 g). However, this value was higher compared to the T2 treatment (one foliar spray) in the less favorable 2013/2014 season (1.28 g), suggesting that the season plays a key role in the variation of grain weight per spike among the analyzed durum wheat genotypes. Considering only the 2014 season, the T3 treatment also resulted in the highest grain weight per spike (1.38 g) on average for all genotypes, compared to the other treatments in that season. Therefore, it can be concluded that the application of the T3 treatment improved grain weight per spike in both the favorable (2012/2013) and less favorable (2013/2014) growing seasons.

The highest value of grain weight per spike at the experimental level was observed for the genotype KG-3405-03 with the application of the T3 treatment in the 2013 season (1.91 g). In the 2013/2014 season, the highest grain weight per spike was observed in genotype KG-43-33/1 with the T3 treatment (1.61 g). This genotype has the lowest value in the 2012/2013 season under the control treatment (1.09 g). The lowest average grain weight per spike at the trial level was recorded for the genotype Windur (1.05 g), followed by the genotype KG Olimpik (1.09 g), under the treatment without foliar fertilization during the 2013/2014 season (Table 2).

The G × Y interaction was statistically significant ($p < 0.01$) and was therefore analyzed in detail and presented in Figure 2. This significance indicates that different genotypes exhibit varying responses to climatic conditions across the studied years. It suggests that the ranking of genotypes in terms of grain weight per spike changes from year to year.

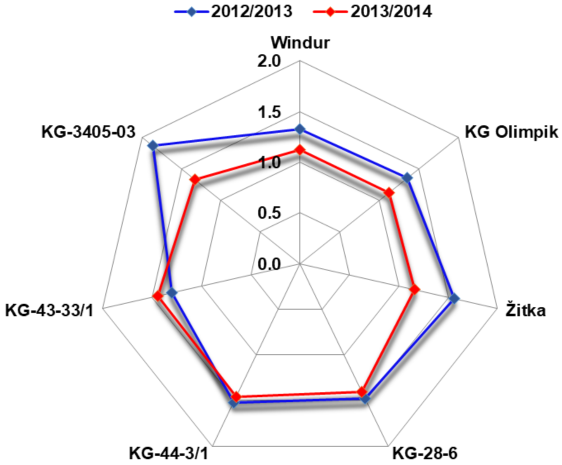


Figure 2. Grain weight per spike for durum wheat genotypes across the analysed seasons

The genotype KG-3405-03 shows high variation in grain weight per spike, with the highest value of 1.86 g in the 2012/2013 season, which decreases by 28.5% to 1.33 g in the 2013/2014 season, indicating its potential in favorable conditions and significant sensitivity to unfavorable environmental factors. In contrast, the genotypes KG-28-6 and KG-44-3/1 showed the least variation between years, making them suitable for cultivation in diverse agroecological conditions. The genotypes Windur and KG Olimpik demonstrated satisfactory stability, but they do not exhibit high potential for achieving elevated grain weight per spike in favorable conditions. The genotype Žitka showed high variation across vegetation seasons, with above-average grain weight per spike in favorable conditions and below-average grain weight in unfavorable conditions. The genotype KG-43-33/1 showed an opposite trend to the other genotypes, with a higher grain weight per spike in the less favorable 2013/2014 season (1.44 g) compared to the 2012/2013 season (1.30 g), which had more evenly distributed rainfall (Figure 2). This suggests that this genotype responds very well to the application of treatment T3 in the 2013/2014 season and may have advantages in specific ecosystems.

4. CONCLUSION

Both foliar fertilization treatments increased grain weight per spike in the analyzed durum wheat genotypes compared to the control (no treatment). The treatment with two foliar sprays (T3) proved to be the most effective in improving grain weight per spike, both under favorable and unfavorable environmental conditions. The genotype KG-3405-03 showed the best response to the T3 treatment in favorable conditions in 2013, with the highest average value of grain weight per spike (1.91 g). However, this genotype also showed the greatest reduction (28.5%) in the less favorable 2013/2014 season. On average, across all treatments, the genotype KG-43-33/1 achieved significantly higher values in the less favorable season compared to the favorable growing season, indicating its exceptional adaptability to adverse climatic conditions when foliar fertilization is applied. The reason for the higher values in the unfavorable season is that this genotype had the best response to the T3 treatment under unfavorable conditions, achieving the highest grain weight per spike (1.61 g). On the other hand, genotypes KG-28-6 and KG-44-3/1 demonstrated good stability, with above-average values on the treatment without nitrogen application (control) in both seasons, making them suitable for cultivation in diverse agroecological conditions.

5. ACKNOWLEDGMENT

This research is part of the project funded by the Ministry of Education, Science, and Technological Development of the Republic of Serbia, titled "Study of the Genetic Basis of Improving Yield and Quality of Small Grains in Different Environmental Conditions" (TR31092). Additionally, this research is financially supported by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia, under grant numbers: 451-03-66/2024-03/200054 and 451-03-66/2024-03/200216.

6. REFERENCES

Bassu, S., Asseng, S., Motzo, R., Giunta, F. (2009). Optimising sowing date of durum wheat in a variable mediterranean environment. Field Crops Research, 111, 109-118. doi.org/10.1016/j.fcr.2008.11.002

Bozek, K.S., Zuk-Golaszewska, K., Bochenek, A., Golaszewski, J., Kalaji, H.M. (2021). Modelling the growth, development and yield of *Triticum durum* desf under the changes of climatic conditions in north-eastern Europe. Scientific Reports, 11, 21753. doi.org/10.1038/s41598-021-01273-8

Cséplő, M., Puskás, K., Vida, G., Ambrózy, Z., Grausgruber, H., Urbanavičiūtė, I., Mikó, P., Bányai, J. (2024). Performance of a durum wheat diversity panel under different management systems. Cereal Research Communications, doi.org/10.1007/s42976-024-00517-3

De Vita, P., Taranto, F. (2019). Durum wheat (*Triticum turgidum* ssp. *durum*) breeding to meet the challenge of climate change. Published in Advances in Plant Breeding Strategies: Cereals, Al-Khayri, J., Jain, S., Johnson, D. (Eds.), Cham, *Switzerland*: Springer. doi.org/10.1007/978-3-030-23108-8_13

Di Mola, I., Ottaiano, L., Sacco, A., Senatore, M., Mori, M. (2021). Organic versus mineral fertilization: Assessing of yield and quality of durum wheat in marginal lands. Italian Journal of Agronomy, 16, 1855. doi.org/10.4081/ija.2021.1855

Ercoli, L., Masoni, A., Pampana, S., Mariotti, M., Arduini, I. (2013). As durum wheat productivity is affected by nitrogen fertilisation management in Central Italy. European Journal of Agronomy, 44, 38-45. dx.doi.org/10.1016/j.eja.2012.08.005

Grosse-Heilmann, M., Cristiano, E., Deidda, R., Viola, F. (2024). Durum wheat productivity today and tomorrow: A review of influencing factors and climate change effects. Resources, Environment and Sustainability, 17, 100170. doi.org/10.1016/j.resenv.2024.100170

International Grains Council (IGC). Available online: https://www.igc.int/en/default.aspx (Accessed on 15 June 2023).

Kabbaj, H., Sall, A.T., Al-Abdallat, A., Geleta, M., Amri, A., Filali-Maltouf, A., Belkadi, B., Ortiz, R., Bassi, F.M. (2017). Genetic diversity within a global panel of durum wheat (*Triticum durum*) landraces and modern germplasm reveals the history of allele exchange. Frontiers in Plant Science, 8, 1277. doi.org/10.3389/fpls201701277

Kendal, E. (2019). Comparing durum wheat cultivars by genotype × yield × trait and genotype × trait biplot method. Chilean Journal of Agricultural Research, 79(4), 512-522. doi.org/10.4067/S0718-58392019000400512

Knežević, D., Zečević, V., Djukić, N., Dodig, D. (2008). Genetic and phenotypic variability of grain mass per spike of winter wheat genotypes (*Triticum aestivum* L.). Kragujevac Journal of Science, 30(1), 131-136.

Knezevic, D., Kondic, D., Markovic, S., Markovic, D., Atanasijevic, S. (2014). Genetic and phenotypic variability, of grain mass and length of spike in wheat (*Triticum aestivum* L.) effected by nitrogen nutrition. Növénytermelés, Supplement, 63, 47-50.

Knežević, D., Radosavac, A., Zelenika, M. (2015). Variability of grain weight per spike in wheat grown in different ecological conditions. Acta Agriculturae Serbica, 20(39), 85-95.

Kondić, D., Bajić, M., Hajder, Đ., Knežević, D., Bosančić, B. (2017). The spike characteristics of winter wheat (*Triticum aestivum* L.) varieties in agro-ecological conditions of Banja Luka region. Agro-knowledge Journal, 18(4) 263-274. doi.org/10.7251/AGREN1704263K

Lopez-Bellido, L., Munoz-Romero, V., Benítez-Vega, J., Fernández-García, P., Redondo, R., López-Bellido, R.J. (2012). Wheat response to nitrogen splitting applied to Vertisols in different tillage systems and cropping rotations under typical Mediterranean climatic conditions. European Journal of Agronomy, 43, 24-32. doi.org/10.1016/j.eja.2012.05.002

Mancinelli, R., Marinari, S., Atait, M., Petroselli, V., Chilosi, G., Jasarevic, M., Catalani, A., Abideen, Z., Mirzaei, M., Allam, M., Radicetti, E. (2023). Durum wheat potato crop rotation, soil tillage, and fertilization source affect soil CO_2 emission and C storage in the Mediterranean environment. Land, 12(2), 326. doi.org/10.3390/land12020326

Martínez-Moreno, F., Ammar, K., Solís, I. (2022). Global changes in cultivated area and breeding activities of durum wheat from 1800 to date: A historical review. Agronomy, 12(5), 1135. doi.org/10.3390/agronomy12051135

Michigan State University (1990). User's Guide to MSTAT-C. Michigan State University, Michigan.

Mie, A., Andersen, H.R., Gunnarsson, S., Kahl, J., Kesse-Guyot, E., Rembiałkowska, E., Quaglio, G., Grandjean, P. (2017). Human health implications of organic food and organic agriculture: a compre hensive review. Environment Health, 16, 111. doi.org/10.1186/s12940-017-0315-4

Morari, F., Zanella, V., Sartori, L., Visioli, G., Berzaghi, P., Mosca, G. (2017). Optimising durum wheat cultivation in north Italy: understanding the effects of site-specific fertilization on yield and protein content. Precision Agriculture, 19, 257-277. doi.org/10.1007/s11119-017-9515-8

Pampana, S., Masoni, A., Ercoli, L., Mariotti, M., Arduini, I. (2013). Effects of nitrogen splitting and source on durum wheat. Cereal Research Communications, 41, 338-347. doi.org/10.1556/CRC.2013.0003

Panayotova, G., Kostadinova, S., Valkova, N. (2017). Grain quality of durum wheat as affected by phosphorus and combined nitrogen phosphorus fertilization. Scientific Papers Series A. Agronomy, 60, 356-363.

Pour-Aboughadareh, A., Mohammadi, R., Etminan, A., Shooshtari, L., Maleki Tabrizi, N., Poczai, P. (2020). Effects of drought stress on some agronomic and morpho-physiological traits in durum wheat genotypes. Sustainability, 12(14), 5610. doi.org/10.3390/su12145610

Saghouri el idissi, I., Kettani, R., Ferrahi, M., Nabloussi, A., Ziri, R., Brhadda, N. (2023). Water stress effect on durum wheat (*Triticum durum Desf.*) advanced lines at flowering stage under controlled conditions. Journal of Agriculture and Food Research, 14, 100696. doi.org/10.1016/j.jafr.2023.100696

Sieber, A.-N., Würschum, T., Longin, C.F.H., Tuberosa, R. (2014). Evaluation of a semi-controlled test as a selection tool for frost tolerance in durum wheat (*Triticum durum*). Plant Breeding, 133, 465–469. doi.org/10.1111/pbr.12181

Vida, G., Cséplő, M., Rakszegi, M., Bányai, J. (2022). Effect of multi-year environmental and meteorological factors on the quality traits of winter durum wheat. Plants, 11, 113. doi.org/10.3390/plants11010113

Wang, X., Pacho, F., Liu, J., Kajungiro, R. (2019). Factors influencing organic food purchase intention in developing countries and the moderating role of knowledge. Sustainability, 11(1), 209. doi.org/10.3390/su11010209

Xu, Z., Lai, X., Ren, Y., Yang, H., Wang, H., Wang, C., Xia, J., Wang, Z., Yang, Z., Geng, H., Shi, X., Zhang, Y. (2023). Impact of drought stress on yield-related agronomic traits of different genotypes in spring wheat. Agronomy*,* 13(12)*,* 2968. doi.org/10.3390/agronomy13122968

Zečević, V., Bošković, J., Dimitrijević, M., Petrović, S. (2010). Genetic and phenotypic variability of yield components in wheat (*Triticum aestivum* L.). Bulgarian Journal of Agricultural Science, 16 (4), 422–428.

Zečević, V., Milenković, S., Bošković, J., Roljević Nikolić, S., Luković, K., Đorđević, R., Knеđević, D. (2022). Influence of foliar nutrition on yield and yield components of durum wheat (*Triticum durum* Desf.) grown in system of organic production. Applied Ecology and Environmental Research, 20(1), 171-187. dx.doi.org/10.15666/aeer/2001_171187

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.136K

VARIABILITY OF NON-PRODUCTIVE TILLERING IN WINTER WHEAT (*Triticum aestivum* L.)

Desimir Knežević[1*], Dušan Urošević[2], Mirjana Menkovska[3], Mirela Matković Stojšin[4], Artiona Laze[5], Danica Mićanović[6], Danijela Kondić[7], Veselinka Zečević[8]

[1]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohija, Serbia
[2]Maize Research Institute Zemun Polje, Belgrade, Serbia
[3]University Ss. Cyril and Methodius of Skopje, Institute of Animal Science and Fishery, Skopje, North Macedonia
[4] Tamiš Research and Development Institute, Pančevo, Serbia
[5]Agricultural University of Tirana, Faculty of Biotechnology and Food, Department of Chemistry, Tirana, Albania
[6]Serbian Chamber of Commerce and Industry, Belgrade, Serbia
[7]Faculty of Agriculture, University of Banja Luka, Banja Luka, Bosnia and Herzegovina
[8]Institute for Vegetable Crops Smederevska Palanka, Smederevska Palanka, Serbia

Abstract: Number of tillers varying depends on genotype capacity, crop density, nutrition, ecoclimatic condition and interaction of all named factors. The aim of this study was estimation variability of non-productive tillering of genetically divergent wheat cultivars grown under different environmental conditions. The ten genetically divergent winter wheat varieties were tested in two years with different climatic conditions. Experiment carried out on field conditions, design in randomized block and three replications. The seeds of varieties were sown at the distance of 0.10 m in rows of 1.0 m length among which was the distance of 0.2 m. For analysis of tillering were used 60 plants in full maturity stage (20 plants per replication). The obtained data processing for analysis of variance by using MSTAT C (5.0 version). The significant differences between values were estimated by F-test and LSD (0.01; 0.05). Similarity among wheat was analyzed by hierarchical method of Euclidean distance. The results showed differences among genotypes for non-productive tillering. The number of non-productive shoots was the least 0.67 in Kosmajka and the highest 4.67 in Somborka with average value 2.52, while in second year the least 1.03 Fortuna and the highest 2.83 in Kremna with average value 1.80 shoots. In each cultivar the more productive tillers associated with more total initiated tillers. The differences between cultivars for tillering are affected by genetic and environmental factors.

Key words: Wheat, Genotype, Variability, Non-productive tillers, Environment

1. INTRODUCTION

Since the limited resources of arable land, there is intensive work on the creation of genotypes with higher genetic potential for yield. There are a number of wheat genotypes that can be used as a parent variety in crosses in the process of developing new varieties with high yields, improved quality and greater adaptability in the variable environmental conditions (Branković et al., 2015; Knežević et al., 2015a, 2020; Thapa et al., 2024).

The improvement in yield in the breeding program includes work on engineering, architecture vegetative organs of plants (root, stem, leaf) and generative (ear, seed) which will have the higher capacity to increase seed yield, greater adaptive ability on the changed climatic factors and better quality (Knežević et al., 2018; De Oliveira Silva et al., 2020). To achieve this, it is necessary to understanding the genetic control of traits, components of yield and quality, thereof on interconnection in order to obtain a desirable combination of the newly created genotype (Knežević et al., 2006, 2015b; Shang et al., 2021).

Climatic changes make it difficult to yield predictions of wheat and other plant species, which is in addition to generating new genotypes necessary to improve the growing system and thus reduce the negative effects of the limiting factors in the production. The increasing of genetic potential for yield of varieties contributes to increasing of total yield, which can be accomplished in a different environmental conditions (Slafer, 2014; Knežević et al., 2021a; Russell et al., 2017), including drought and water deficit (Dodig et al., 2008; Sadras and Slafer, 2012; Lollato et al., 2019), high temperatures (Reynolds and Ortiz, 2010; Fioreze et al., 2019), soil salinity (Matković Stojšin et al., 2022a; 2022b). Increasing genetic potential for yield allows production of larger quantities of wheat seed per unit area and thus the total seed yield. This allows planing reduction of sowing area, which would reduce the production costs and enhance the degree of protection of natural and agro-ecosystems (Spink et al., 2000; Valerio et al., 2009; Knežević et al., 2016).

Tillering in plants is determined with genetic and environmental factors, and in interaction of genotype and environemnt. Wheat which carries of reduced tillering (e.g. *tin*) genes have shown that inhibition of tillering stimulates the development of deeper roots, increases the tiller number, and increases the formation of large spikes under drought environments (Houshmandfar et al., 2019, 2020). Tillering is an underground branching of stem and formation of shoots in the early stages of plant development (Assuero and Tognetti, 2010) and has a significant influence on the final yield of wheat (Russell et al., 2017). Among tillers appear several productive shoots with developed ear and grain, and nonproductive shoots without formed ear or with formed ear without grains (non-fertilized spike). The density of wheat crops is directly influenced by the growth and development of individual plants. The proportion of productive and nonproductive tillers have affects on structure of the population in crop (Knežević et al., 2009; Xu et al., 2015). The total number of shoots plants (productive and nonproductive) depends on environmental conditions: vegetation area for plants, sowing density and mineral nutrition of crops, moisture, light, temperature (Elhani et al., 2007; Kondić et al., 2016; Tilley et al., 2019). In terms of the larger vegetation area, optimal mineral nutrition and soil moisture plants have higher total tillering (productive and nonproductive tillering). Abiotic stress factors at the time of shoot growth may inhibit their formation and at a later stage may cause mortify tillers (Xie et al., 2016). Lack of nutrition can have a direct impact on the development and emergence of shoots, as well as the balance of auxin and cytokinin but which may also affect the interruption of dormancy of lateral buds (Valerio et al., 2009). Depending on these factors, the plant may have a significant number of shoots. In terms of water deficit and drought, tillering is reduced, which can be used as a criterion for selection, especially in the breeding program for drought (Mitchell et al., 2006; 2013).

The aim is to determine the number of non-productive tillers of plants in genetically divergent winter wheat varieties in rare sowing systems which grow in formed low density crop in different environmental conditions.

3. MATRIAL I METHODS

The 10 geneticaly divergent winter wheat varieties were used for analysis variability of number of nonproductive tillers. These wheat varieties were sown which was set up as a randomized block design in three replications, on plots size 1 m^2 on the field in Kraljevo, Serbia in two growing seasons (2015/16 and 2016/17). The seeds of varieties were sown at the distance of 0.05 m in rows of 1 m length among which was the distance of 0.2 m. The mode of rare sowing system used to allow plants to express their potential for tillering. In full maturity stage, the 60 plants (20 per replication) were harvested and used for analysis of tillering. By using MSTAT C version 5.0 were done analysis of variance for monofactorial trials in each year. The significant differences between the average values were estimated by F-test values. The analysis of variance was performed according to a random block system with one factor and significant differences were tested by means of test value of LSD $_{0.05}$ and LSD $_{0.01}$. Similarity among wheat analyzed by hierarchical method of Euclidean distance.

3.1. Weather conditions

The two years of experiment were differed according to measured air temperature and amount of precipitation. Obtained values of temperature and precipitation in first 2015/16 and second year 2015/16 of experiment were compared with average values of previous ten years period (2000-2010). In the first year of experiment 2015/2016, the average temperature was 9.9 °C which was higher than average value of temperature in second year (8.7 °C) as well higher than average temperature of ten years period (8.5 °C). In the first year of experiment 2015/2016, the total amount of precipitation was 651.00 mm and higher than in second year (523.1 mm) as well higher than in average total amount of precipitation for ten years period (417.8 mm). In both years average air temperature and total amount of precipitation were higher than in long-term period (2000-2010). For developing of plant, the regime of temperature and precipitation in second year were more favorable for wheat plant development. For wheat plants emegence in period October - November of second year of experiment were more favorable condition than in first year of experiment. During this period in the second year the amount of precipitation was 161.7 mm, while in the first amount of precipitation was 120.8 mm and average temperature was higher by 0.8 °C in the first year than in second year. In period februar - april the higher precipitation was in first year (250.5 mm) than and second year (174.0mm) while distribution of precipitation was more favorable in the second year. The averrage values of temperature for this period were similar in both years (Table 1).

Table 1. Average monthly temperature and total monthly precipitation in Kraljevo

Temperature and precipitation	Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Xm	Total
^{0}C	2015/16	11.6	7.3	3.3	-0.1	8.8	7.8	14.1	15.5	21.3	9.96	89.64
^{0}C	2016/17	10.6	6.8	0.0	-4.7	5.2	10.8	11.1	16.8	22.1	8.74	78.66
2000-2010		11.8	6.4	1.7	-0.1	2.6	5.9	11.6	16.4	20.4	8.5	76.5
mm	2015/16	56.8	64.0	9.0	86.2	52.7	157.9	39.9	135.9	48.6	72.3	651
mm	2016/17	84.1	77.6	9.4	22.0	35.0	57.0	82.0	100	56.0	41.1	523.1
2000-2010		61.0	44.3	44.6	30.0	29.9	33.2	52.9	52.6	69.3	46.4	417.8

4. RESULTS

In the first year of experiment was established variation for nonproductive tillering, wherein the smallest number of non-productive tillers was 0.67 in the variety Kosmajka, and the highest 4.67 shoots in Somborka wheat variety. In the second year, nonproductive tillering varied between 1.03 shoots in Fortuna and 2.83 shoots in Kremna variety. The average value for both year of tillering was the lowest 1.23 in Kosmajka and the highest 3.07 shoots in Kremna wheat variety.

The average value of unproductive tillering, in the first year, for all varieties was 2.5 shoots, which is higher than in the second year in which the average value was 1.8 nonproductive tillers for all wheat varieties (Table 2).

By analysis of variance were established significant ans high significant differences among cwheat varieties within same year and between years of exsamination of unproductive tillering.

Table 2. Variability of number of nonproductive tillering in winter wheat varieties

Variety	Year		Average
	I year	II year	
Fortuna	2.767bcde	1.033fg	1.900bcde
Sasanka	4.033ab	1.303efg	2.668abc
Danica	3.100bcd	1.667defg	2.383abcd
Somborka	4.667a	1.300efg	2.983ab
Kremna	3.300abc	2.833bcde	3.067a
Kosmajka	0.667g	1.800cdefg	1.233e
Šumadija	2.067cdefg	2.433cdef	2.250abcde
Morava	1.467efg	2.633bcde	2.050 abcde
KG-56S	1.467efg	1.833cdefg	1.650cde
Ljubičevka	1.333efg	1.367efg	1.350de
Average	2.5	1.8	2.2
LSD	Variety	Year	Variety x year
(0,05)	1.096	0.310	1.550
(0,01)	1.574	0.414	2.226

Analysis of components variance showed that the interaction genotype / year had the greatest impact (49.98%) on the expression of non-productive tillering, while the impact of genotype was 10.7% and the impact of the environment (year conditions) was the lowest 4.76% (Table 3)

Table 3. Components of phenotypic variance for nonproductive tillering of wheat - in both years

Source of variance	Degree of freedom (DF)	Sum of squares (SS)	Mean of Sum of squares (MS)	F -test	Proba bility	Component of variance	
						σ^2	Impact (%)
Repetitions (R)	2	0.644	0.322	0.4576	-	-	-
Genotypes (G)	9	22.023	2.447	3.4771**	0.0032	0.218	10.70
Year (E)	1	6.660	6.660	9.4638**	0.0039	0.097	4.76
Cultivar x Year (G xE)	9	33.809	3.757	5.3381**	0.0001	1.018	49.98
Error	38	26.742	0.704	-	-	0.704	34.56
Total	59	89.878	-		-	2.037	100

For the non-productive tillering was found similarity for the four pairs of varieties and the remain two varieties differed wherein one (KG 56) are joined to third pair varieties (Fortuna and Morava) and a variety Sasanka associated to the fourth pair (Sumadia and Danica). These two clusters of three varieties (Morava and KG 56) and (Šumadija, Danica and Sasanka) were mutually similar but with a lesser degree of similarity than varieties within them. The pair of varieties Ljubičevka and Kosmajka have similarity to tje cluster of six varieties, but on the lower level of similarity. The minimum similarity is expressed between the pair Creamna and Somborka and the formed clusters of etight varieties (Figure 1).

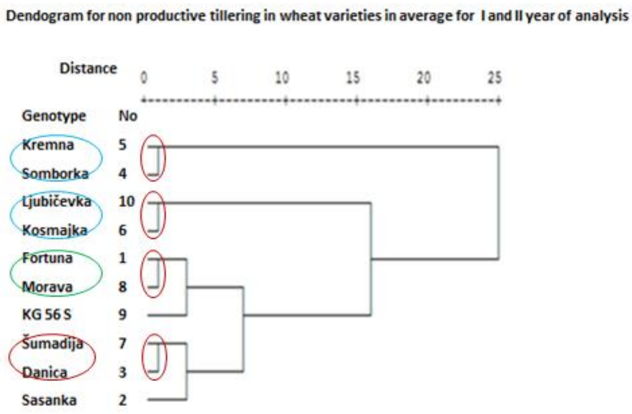


Figure 1. The similarity of wheat variaties for non-productive tillering

5. DISCUSSION

Tillering of wheat is manifested through underground branching of stem and shoot emerging in the early stages of plant development. The number of tillers affects the crop density. The number of non-productive shoots affects crop density. Shoots that form a spike during development and form seeds after pollination and fertilization are productive shoots. Productive shoots play a role in the formation of seed yield (Knežević et al., 2009). Shoots that do not form a spike during development or that form a spike without seeds are non-productive shoots. Non-productive shoots contribute to an increase in the total biological yield, and during the growing season they contribute to the vigor of the plant, increased green area, and thus increased photosynthesis capacity and production of dry mass (Djokić et al., 1992).

In unfavorable conditions (deficit of water, drought) unproductive shoots are more sensitive and dry out faster, die out faster. The non surviving shoots could be beneficial if the amount of carbon they fix exceeds the carbon retained in these tillers, i.e. the amount the carbon which is not re-distributed after their death. In the study of barley was found between the surviving and non-surviving shoots whilst they are still healthy (Chafai et al., 1992). The latter study showed that movement of current photo-assimilate accounted for most of the carbon exported from non-surviving shoots (Assuero et al., 2012). The production of a large number of non-surviving shoots generally appears to be detrimental for remobilization dry matter to seed and value of harvest index, but these shoots may be advantageous for suppressing weeds (Berry et al., 2003; Knežević et al., 2008, 2021b). The non-surviving shoots will reduce the yield potential in the majority of situations by competing for assimilation with the developing spike in fertile shoots, what is more expressed in drought conditions. This is important for producers to find balance of seed rate and optimal economic yield (Spink et al., 2000).

Environmental factors such as soil fertility, soil moisture, nitrogen nutrition, soil and air temperatures have an impact on the manifestation of the potential for tillering. There are differences in the response of different wheat varieties of the same environmental conditions, which indicates the specificity of the genotype. This indicates that is necessary for each wheat variety to determine the optimal density of seeding (Petrović et al., 2008) and the optimum dose of mineral nutrition (Knežević et al., 2016). The determining of optimal density of crops allows appearance of a large number of stems with a productive spike and high productivity of wheat plant what is important to achieve a high yield (Valerio et al., 2009).

The number of productive tillers and infertile tillers are influenced by agricultural conditions including soil moisture, mineral nutrition and accessibility of mineral elements for the absorption, the temperature, the brightness and efficiency of the process of photosynthesis and reutilization and translocation of organic material (Elhani et al., 2007). The comparison among varieties with different tillering studied under different conditions such as sowing dates and densities, plant nutrition and environmental stresses, found that the mobilization of substances in the interaction between the main stem and other tillers is not fully understood (Guo and Schnurbusch, 2015; Hendriks et al., 2016; Houshmandfar et al. 2019).

In other research found that the high number of tillers reduces the performance of wheat plants under drought stress. Nonproductive late tillers do not improve the performance of primary tillers of wheat plants under drought stress, mainly in high-tillering cultivars. Assimilates remobilization from late tillers to primary tillers can be a function of tillering potential (Fioreze et al., 2020). Tillering of wheat plants was expressed under favorable regime mineral nutrition and rainfall. The crop was provided with nitrogen and phosphorus nutrition through mineral fertilizers. Nutrition phosphorus fertilizer has a high impact on wheat yields (Takahashi and Anwar, 2007; Jelić et al., 2017), while the deficit phosphorus results in a lower number of tillers (Valle and Calderini, 2010; Fioreze et al., 2012).

6. CONCLUSION

Based on the results it was established variation the number of nonproductive shoots in wheat varieties examined in experiment conducted in two years which characterized different weather conditions. The varying of tillering in the same variety in two different years shows that genotype response to changing environmental conditions. The average value of nonproductive tillering for all varieties in the second year was 2.5 tillers, which was higher than the average value for all varieties in the first year which is 1.8 shoots. Wheat variety Kremna had the highest number of nonproductive tillers in average for both years 3.07 shoots and in second year 2.98 shoots, although in the first year the variety Somborka had the highest value of tillering 4.67 shoots. Differences between varieties were significant and highly significant for nonproductive tillering. On the expression of tillering were established influence of genetic factors, environmental factors and the interaction of genotype/environment. The interaction of genotype/environment had the highest share, 49.98% on nonproductive tillering, genotype has share 10.70% while environmental factors had the lowest impact 4.76% on expression of nonproductive tillering. The non-productive tillering contributes to a high yield of biomass - mass of the above-ground parts of the plant.

7. ACKNOWLEDGEMENTS

This investigation supported by Ministry of Education, Science and Technology Development of Republic of Serbia, Project TR 31092.

8. REFERENCES

Assuero, S.G., Tognetti, J.A. (2010). Tillering regulation by endogenous and environmental factors and its agricultural management. Am. J. Plant Sci. Biotechnol., (Special Issue 1), 4, 35-48.

Assuero, S.G., Lorenzo, M., Pérez Ramírez, N.M., Velázquez, L.M., Tognetti, J.A. (2012). Tillering promotion by paclobutrazol in wheat and its relationship with plant carbohydrate status, New Zeal. Agric. Res., 55, 347-358.

Berry, P., Spink, J., Foulkes, M., Wade, A. (2003). Quantifying the contributions and losses of dry matter from non-surviving shoots in four cultivars of winter wheat. Field Crops Research, 80(2), 111-121.

Branković, G., Dodig, D., Knežević, D., Kandić, V., Pavlov, J. (2015). Heritability, genetic advance and correlations of plant height, spike length and productive tillering in bread wheat and durum wheat. Contemporary Agriculture, 64(3-4), 150-157.
Chafai, A., Simmons, S.R., Crookston, R.K. (1992). Allocation of photoassimilate by main shoots and nonsurviving tillers in barley. Crop Sci., 32, 1233-1237.
De Oliveira Silva, A., Slafer, G.A., Fritz, A.K., Lollato, R.P. (2020). Physiological Basis of Genotypic Response to Management in Dryland Wheat. Frontiers in Plant Science, 10. doi:10.3389/fpls.2019.01644
Djokić, D., Knežević, D., Kostić, M. (1992). Parametars of accumulation and distribution of dry matter and nitrogen in F_1 and F_2 generation in wheat. Arh. za polj. nauke, 53, 189-192, 75-85.
Dodig, D., Zoric, M., Knezevic, D., King, S.R., Surlan-Momirovic, G. (2008). Genotype x environment interaction for wheat yield in different drought stress conditions and agronomic traits suitable for selection. Australian Journal of Agricultural Research, 59, 536-545.
Elhani, S., Martos, V., Rharrabti, Y., Royo, C., Moral, L.F.G. (2007). Contribution of main stem and tillers to durum wheat (*Triticum turgidum* L. var. *durum*) grain yield and its components grown in Mediterranean environments. Field Crops Research, 103(1), 25-35.
Fioreze, L.S., Castoldi, G., Pivetta, A.L., Pivetta, G.L., Fernandes, M.D., Büll, T.L. (2012). Tillering of two wheat genotypes as affected by phosphorus levels. Acta Scientiarum. Agronomy, 34(3), 331-338.
Fioreze, S.L., Vacari, J., Turek, T.L., Michelon, L.H., Drun, R.P. (2019). Componentes produtivos do trigo em função da temperatura no período de diferenciação de espiguetas. Revista de Ciências Agroveterinárias, 18, 24-32.
Fioreze, S.L., Michelon, L.H., Turek,T.L., Drun, R.P., Julio César Sbardella Dalorsaleta, J.C.S. (2020). Role of nonproductive tillers as transient sinks of assimilates in wheat. Bragantia, 79(2) doi.org/10.1590/1678-4499.20190365
Guo, Z., Schnurbusch, T. (2015). Variation of floret fertility in hexaploid wheat revealed by tiller removal. Journal of Experimental Botany, 66, 5945-5958.
Hendriks, P.W., Kirkegaard, J.A., Lilley, J.M., Gregory, P.J., and Rebetzke, G.J. (2016). A tillering inhibition gene influences root-shoot carbon partitioning and pattern of water use to improve wheat productivity in rainfed environments. Journal of Experimental Botany, 67, 327-340.
Houshmandfar, A., Rebetzke, G.J., Lawes, R., Tausz, M. (2019). Grain yield responsiveness to water supply in near-isogenic reduced-tillering wheat lines-an engineered crop trait near its upper limit, Eur. J. Agron., 102, 33-38.
Houshmandfar, A., Ota, N., O'Leary, G.J., Zheng, B., Chen, Y., Tausz-Posch, S., Fitzgerald, G.J., Richards, R., Rebetzke, G.J., Tausz, M. (2020). A reduced-tillering trait shows small but important yield gains in dryland wheat production, Glob. Change Biol., 26, 4056-4067.
Jelić, M., Maklenović, V., Kovačević, V., Knežević, D., Paunović, A. (2017). Status of plant available phosphorus in Nisava area of the South and Eastern Serbia. Columella-Journal of Agricultural and Environmental Sciences, 4(1), 271-274.
Knežević, D., Zečević, V., Mićanović, D., Djukić, N., Milinković, J. (2006). Yield and quality parameters of winter wheat lines (*Triticum aestivum* L.). Proc. of 2nd Int. Symp. of ecologist of Montenegro, Kotor, 423-429.
Knežević, D., Djukic, N., Paunovic, A., Madic, M. (2008). Variability of harvest index and yield components in wheat (*Triticum aestivum* L.). Cereal Res. Commun., 36, 1151-1154.
Knežević, D., Madić, M., Zečević, V., Paunović, A., Dodig, D., Đukić, N. (2009). Variability of tillering in wheat (*Triticum aestivum* L.). Proceedings of the XIV Conference on Biotechnology. University of Kragujevac, Faculty of Agriculture Čačak, Čačak, 14 (15), 31-37. /in Serbian/
Knežević, D., Radosavac, A., Zelenika, M., (2015b). Variability of grain weight per spike of wheat grown in different ecological conditions**.** Acta Agriculturae Serbica, XX (39), 85-95.
Knežević, D., Kondić, D., Srdić, S., Paunović, A., Madić, M. (2015a). Harvest index and components of yield in winter wheat cultivars (*Triticum aestivum* L.). Proceeding of Sixth

International Scientific Symposium "Agrosym Jahorina 2015". (Ed. Kovacevic, D.), Jahorina Bosnia and Herzegovina, 368-372.

Knežević D., Maklenović, V., Kolarić, Lj., Mićanović, D., Šekularac, A., Knežević, J. (2016). Variation and inheritance of nitrogen content in seed of wheat genotypes (*Triticum aestivum* L.). Genetika, 48(2), 579-586.

Knežević, D., Mićanović, D., Matković, M., Zečević, V., Cvijanović, G. (2018). Limitations and potentials of wheat breeding (*Triticum aestivum* L.). The first domestic scientific expert meeting, Sustainable primary agricultural production in Serbia - state, possibilities, limitations and chances, Megatrend University Belgrade, Faculty of Biofarming, Bačka Topola, Proceedings, 100-107. /in Serbian/

Knežević, D., Laze, A., Paunović, A., Djurović, V., Đukić, N., Valjarević, D., Kondić, D., Mićanović, D., Živić, J., Zečević, V. (2020). Approaches in cereal breeding. Acta Agriculturae Serbica, 25(50), 179-186.

Knežević, D., Zečević, V., Mićanović, D., Roljević Nikolić, S., Branković, G., Paunović, A., Brzaković, T., Matković Stojšin, M., Radosavac, A. (2021a). Plant breeding and adaptation to climate change. National Scientific-professional conference with international participants “Biotechnology and modern approach in cultivating and breeding plants“, Smederevska Palanka, Serbia, Proceedings, 17-29. /in Serbian/

Knežević, D., Urošević, D., Mićanović, D., Paunović, A., Kondić, D., Đurović, V., Radosavac, A., Živić, J., Matković, M., Madić, M., Zečević, V. (2021b). Variability of spike harvest index in wheat (*Triticum aestivum* L.). Book of proceedings of the XII International Scientific Agriculture Symposium “Agrosym 2021”, Jahorina, 420-426.

Kondić, D., Bajić, M., Hajder, Đ., Bosančić, B. (2016). The rate of productive tillers per plant of winter wheat (*Triticum aestivum* L.) cultivars under different sowing densities. Agro-knowledge Journal, 17(4), 345-357.

Lollato, R.P., Figueiredo, B.M., Dhillon, J.S., Arnall, D.B., Raun, W.R. (2019). Wheat grain yield and grain-nitrogen relationships as affected by N, P, and K fertilization: a synthesis of long-term experiments. Field Crops Res., 236, 42-57.

Matković Stojšin, M., Petrović, S., Sućur Elez, J., Malenčić, Dj., Zečević, V., Banjac, B., Knežević, D. (2022a). Effect of Salinity Stress on Antioxidant Activity and Grain Yield of Different Wheat Genotypes. Turkish J. Field Crops, 27(1),33-40.

Matković Stojšin, M., Petrović, S., Banjac, B., Zečević, V., Roljević Nikolić, S., Majstorović, H., Đordević, R., Knežević, D. (2022b). Assessment of Genotype Stress Tolerance as an Effective Way to Sustain Wheat Production under Salinity Stress Conditions. Sustainability 2022, 14, 6973.

Mitchell, J.H., Chapman, S.C., Rebetzke, G.J., Fukai, S. (2006). Reduced Tillering wheat lines mantain kernell weight in dry environments. Austr. Journ. of Agr. Res., 55(7), 797-809.

Mitchell, J.H., Rebetzke, G.J., Chapman, S.C., Fukai, S. (2013). Evaluation of reduced-tillering (*tin*) wheat lines in managed, terminal water deficit environment. Journal of Experimental Botany, 64, 3439-3451.

Petrović, S., Marić, S., Guberac, V., Drezner, G., Eđed, A. (2008). Influence of environmental conditions and sowing rates on winter wheat yield. Cer. Res. Comm., 36, 1307-1310.

Reynolds, M., Ortiz, R. (2010). Adapting crops to climate change: a summary. In Climate Change and Crop Production. Ed. M.P. Reynolds (Cambridge, USA: CABI), p. 292.

Russell, K., Lee, C., Van Sanford, D. (2017). Interaction of genetics, environment, and management in determining soft red winter wheat yields. Agron. J., 109, 2463-2473. doi:10.2134/agronj2017.02.0126

Sadras, V.O., Slafer, G.A. (2012). Environmental modulation of yield components in cereals: heritabilities reveal a hierarchy of phenotypic plasticities. Field Crops Res., 127, 215-224.

Shang, Q., Wang, Y., Tang, H., Sui, N., Zhang, X., Wang, F. (2021). Genetic, hormonal, and environmental control of tillering in wheat. The Crop Journal. doi:10.1016/j.cj.2021.03.00

Slafer, G.A., Savin, R., Sadras, V.O. (2014). Coarse and fine regulation of wheat yield components in response to genotype and environment. Field Crops Res., 157, 71-83. doi: 10.1016/j.fcr.2013.12.004

Spink, J.H., Semere, T., Sparkes, D.L., Whaley, J.M., Foulkes, M.J., Clare, R.W., Scott, R.K. (2000). Effect of sowing date on the optimum plant density of winter wheat. Ann. Appl. Biol., 137, 179-188.

Thapa, D.B., Subedi, M., Sapkota, M., Bohara, S., Pokhrel, K.R., Aryal, L., Acharya, B., Tripathi, S., Chaudhary, C., Mahato, B., Timsina, K., Govindan, V., Joshi, A.K. (2024). The first assessment of grain yield and associated traits in durum wheat across a decade in Nepal. Front. Plant Sci., 15, 1456062

Takahashi, S., Anwar, M.R. (2007). Wheat grain yield, phosphorus uptake and soil phosphorus fraction after 23 years of annual fertilizer application to Andosol. Field Crops Research, 101(1),160-171.

Tilley, M.S., Heiniger, R.W., Crozier, C.R. (2019). Tiller Initiation and its Effects on Yield and Yield Components in Winter Wheat. Agronomy Journal, 111(3), 1-10. doi:10.2134/agronj2018.07.0469

Valle, S.R.; Calderini, D.F. (2010). Phyllochron and tillering of wheat in response to soil aluminum toxicity and phosphorus deficiency. Crop and Pasture Science, 61(11), 863-872.

Valerio, I.P., Carvalho, F.I.F., Oliveira, A.C., Benin, G., Souza, V.Q., Machado, A.A., Bertan, I., Busato, C.C., Silveira, G. and Fonseca, D.A.R. (2009). Seeding density in wheat genotypes as a function of tillering potential. Scientia Agricola, 66(1), 28-39.

Xie, Q., Mayes, S., Sparkes, L.D. (2016). Optimizing tiller production and survival for grain yield improvement in a bread wheat spelt mapping population, Annals of Botany, 117, 51-66.

Xu, C.H., Cai, T., Wang, L.Z., He, R.M. (2015). Physiological basis for the differences of productive capacity among tillers in winter wheat. Journal of Integrative Agriculture, 14(10),1958-1970.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.
doi:10.46793/MAK2025.145U

VARIATION OF SPIKE HARVEST INDEX IN WHEAT (*Triticum aestivum* L.)

Dušan Urošević[1*], Desimir Knežević[2], Mirela Matković Stojšin[3], Gordana Branković[4], Vesna Đurović[5], Vladimir Zornić[6], Veselinka Zečević[7]

[1]Maize Research Institute Zemun Polje, Belgrade, Serbia, *dusan.urosevic@gmail.com
[2]University of Pristina, Faculty of Agriculture, Lešak, Kosovska Mitrovica, Kosovo and Metohija, Serbia
[3]Tamiš Research and Development Institute, Pančevo, Serbia
[4]University of Belgrade, Faculty of Agriculture, Zemun-Belgrade, Serbia
[5]University of Kragujevac, Faculty of Agronomy, Čačak, Serbia
[6]Institute for Forage Crops, Kruševac, Globoder, Serbia, vladimir.zornic@ikbks.com
[7]Institute for Vegetable Crops, Smederevska Palanka, Serbia

Abstract: Spike harvest index (SHI) can be an indicator of partitioning assimilation into seeds vegetative biomass and wheat productivity. The aim of this study is estimation of spike harvest index variation in wheat varieties grown under different environmental conditions. Twenty genetically divergent winter wheat cultivars were included in two years which characterized different weather conditions. On the field experiment in randomized block design in three replications, the seeds of varieties were sown at the distance of 0.10 m in rows of 1.0 m length with the distance of 0.2 m. For analysis of spike harvest index determined in proportion of seed mass spike^{-1}/mass of spike, 60 plants in full maturity stage (20 plants per replication) were used. The results showed differences of spike harvest index among varieties and between years of experiment. In the first year the variety Pobeda had the highest value of spike harvest index (80.93%) and the Evropa 90 had the lowest SHI (75.67%), while in second year of experiment, the variety Zadruga had the highest value of spike harvest index (85.00%) and the Šumadinka had the lowest SHI (75.50%). Differences of SHI in wheat varieties are due to response of genotypes to environmental factors as well as interaction of genotype/environment.

Key words: Wheat, Variety, Variability, Spike Harvest index

1. INTRODUCTION

Wheat represents staple plant species for food consumption which grown on more than 218 million hectares and over 720 billion tons seed yield (FAOSTAT, 2016). Wheat production is compromised by limited arable land resources, genetic potential of varieties for yield, breeding technology, environmental factors, and will become a greater problem given the global warming trend, predicted to increase by up to 2 °C by 2050, which could lead to greater yield losses if it continues in the future, increasing temperature by up to 2 °C by 2050, which could lead to further yield losses (IPCC, 2013; Asseng et al., 2015). This is indicated by data on a decrease in the period 1980-2010 by 5.5% of world wheat production due to global temperature increase (Lobell et al., 2011). The environmental influence, especially high temperature, water deficit and drought stress are seriously limiting yield of wheat (Dodig et al., 2008; Pradhan et al., 2019). Wheat breeding and the creation of varieties with increased capacity of productivity components and adaptive capacity for future climate change conditions play a significant role in maintaining high wheat production. In wheat plants the large number of spikes, number of spikelets and seeds spike^{-1}, seed mass spike^{-1}, thousand mass spike^{-1}, are important roles in forming yield. Also, the spike length has a strong indirect influence on yield through number of spikelets spike^{-1} and further on number of seeds, size and mass of seeds (Zečević et al., 2004). There are differences in determining the impact number of spike per plant and mass of spike per plant based on negative correlation of size of spike and number of spikes.

In breeding program in the aim of creating variety with high yield, the concept of plants contains more productive tillers, more spikes, spikelets spike^{-1}, seed spike^{-1}, mass of seed spike^{-1} (Knežević et al., 2014, 2020). The genetic improvement of is expressed through increase distribution of photosynthetic products into seed than in vegetative biomass which results in increasing harvest index (HI) and yield potential (Knežević et al., 2015a). The genetic improvement of HI and yield potential can be achieved through the increasing seed number per unit area, which is an indicator of spike fertility (Abbate et al., 2013). In addition to seed number per unit area, an increase in potential seed mass is also significant (Calderini et al., 2013). This indicates that model plants need to have large spike, spikelets spike^{-1}, and high mass (Knežević et al., 2011, 2019), especially high mass of seed spike^{-1} (Knežević et al., 2015b). The ratio of seed mass spike^{-1} and mass of spike variate due to number of fertile florets as well number of seeds spike^{-1}. This indicates efficiency of transport and translocation of dry matter through vessel bundles (phloem and xylem) to spike and seed of spike, as well as indicate index of receptive capacity of seed spike^{-1} and post-anthesis photosynthetic capacity of stem. One of the potential traits to increase seed mass is spike harvest index (SHI), of which genetic base is not clearly known yet (Pradhan et al., 2019).

The aim of this investigation is study of variability of seed spike index in wheat vatieties grown under different environmental conditions.

2. MATERIALS AND METHODS

In this study included 20 divergent winter wheat varieties, selected in Institute of field and vegetable crops Novi Sad and in Centre for Small grains in Kragujevac. These varieties grown on experimental field in Kraljevo in two vegetative season 2015/16 and 2016/17. The experiment set up in randomized block design in three replications. The seeds of varieties were sown at the distance of 0.10 m in rows of 1.0 m length with the distance of 0.2 m. For analysis of spike harvest index determined in proportion of seed mass spike^{-1}/mass of spike, 60 plants in full maturity stage (20 plants per replication) were used. Based on the obtained average values of the mass of the seed and mass of spike, the spike harvest index is calculated according to the formula:

$$\text{Spike index (\%)} = \frac{\text{mass of seeds}^{-\text{spike}}}{\text{mass of spike}} \text{ x } 100$$

Obtained data were processed by using the MSTAT C 5.0 version for analysis of variance by the mono factorial system for each year. The significant differences between the average values were estimated by F-test values. The analysis of variance was performed according to a random block system with one factor and significant differences among cultivars according to spike harvest index were tested by means of test value of $LSD_{0.05}$ and $LSD_{0.01}$.

2.1. Weather conditions in the vegetation period

The mean values of temperature and amount of precipitation were different in two years of experiment (2015/16 and 2016/17) and in the long-term period (2000-2010). In the first year during vegetative season, the average temperature was 9.9 ^{0}C and the total rainfall was 651 mm, which is significantly higher than in the second year as well than in the ten years period. The average temperature in the second year during the growing season was 8.7 ^{0}C and similar to the ten years period, while the total precipitation 523.1 mm was significantly higher than in the ten years period. During the seed filling phase of plants in the first year in April the average temperature was higher and in May the average precipitation was higher and favorable than in second year of experiment and then in ten year period (Table 1).

Table 1. Average monthly temperatures and total monthly precipitation in Kraljevo (www.hidmet.gov.rs)

Parameter	Period	Oct	Nov	Dec	Jan	Feb	March	April	May	June	Xm	Total
Temperature ^{0}C	2015/16	11.6	7.3	3.3	-0.1	8.8	7.8	14.1	15.5	21.3	9.96	89.64
Temperature ^{0}C	2016/17	10.6	6.8	0.0	-4.7	5.2	10.8	11.1	16.8	22.1	8.74	78.66
Temperature ^{0}C	2000-2010	11.8	6.4	1.7	-0.1	2.6	5.9	11.6	16.4	20.4	8.5	76.5
Precipitation (mm)	2015/16	56.8	64.0	9.0	86.2	52.7	157.9	39.9	135.9	48.6	72.3	651.0
Precipitation (mm)	2016/17	84.1	77.6	9.4	22.0	35.0	57.0	82.0	100	56.0	41.1	523.1
Precipitation (mm)	2000-2010	61.0	44.3	44.6	30.0	29.9	33.2	52.9	52.6	69.3	46.4	417.8

3. RESULTS AND DISCUSSION

The spike harvest index varied from 75.67% in Evropa to 80.93% in Pobeda variety with average value of 78.45% in the growing season of first year of experiment. The values of spike harvest index in second year of experiment varied from 75.5% in Šumadinka to 81.67% in Evropa and Dična variety with average value 78.94% of all varieties (Table 2). Wheat varieties with higher spike harvest index (SHI) should be characterized by high number of seed spike^{-1} and a high seed mass spike^{-1}, on which values have influence of genotypes and their plasticity and response to environmental conditions.

In previous research of ten wheat cultivars the spike harvest index varied depend on genotypes and environmental condition in vegetation season from the 75.9% to 81.9% in first year and from 76.6% to 83.1% in second year with average value 79.9% of all varieties. The study of spike harvest index in 22 wheat genotypes showed its variation in range from 0.68 to 0.91 Petrović et al. (2002). The spike harvest index varied in dependence of system of wheat growing. So, in study spike harvest index in wheat (Grčak et al., 2019a) found in average 75%, in sole crop of winter wheat and 71.2% in intercrop (wheat/pea), while in spring wheat varieties spike harvest index was 71.9% in sole crop and 70.8% in intercrop wheat/pea (Grčak et al., 2019b).

The spike harvest index is the value of ratio seed mass spike^{-1} and mass of spike. In this study the seed mass spike^{-1} varied in the range from 2.63 g in Zadraga to 3.53 g in Milica cultivar with average value 3.15 g in first year of experiment. The values of seed mass spike^{-1} in the second year of experiment varied from 2.48 g in Agrounija to 3.14 g in KG-75 variety and average value was 2.87 g. The mass of spike varied in the range from 3.3 g in Zadruga to 4.49 g in Milica variety with average value 3.97 g in first year of experiment. The values of mass of spike in vegetation season of the second year of experiment varied from 3.20 g in Alfa to 3.92 g in Oplenka and 3.90 g in KG-75 variety and average value was 3.61 g.

In comparison wheat varieties which have high value of seed mass spike^{-1} (Milica 3.53 g, in first year and 3.06 g in second year) and mass of spike (Milica 4.49 g in first year and 3.88 g in second year), and other group of varieties with low value of seed mass spike^{-1} (Zadruga 2.63 g in first year and 3.12 g in second year) and mass of spike (Zadruga 3.30 g in first year and 3.67 g in second year), the spike harvest index was similar i.e. in Milica SHI was 78.7% and in Zadruga 9.8% in first year while in second year in Milica spike harvest index was 79.07% and in Zadruga 85%. The similar or higher spike harvest index inn varieties with lower value of seed mass spike^{-1} and mas of spike in comparison with varieties with high value of seed mass spike^{-1} and mas of spike value of seed mass spike^{-1} and mas of spike, indicated that the mass of chaff and rachis was higher in the cultivar Danica, i.e. that a larger amount of assimilate deposited in the chaff and rachis and was not fully translocated into seed (Knežević et al., 2021).

Table 2. Analisys of variance for spike harvest index

Variety	Year		Average
	2015/16	2016/17	
Evropa 90	75.67^{f}	81.67^{a}	78.67
Dejana	77.33^{bcdef}	76.43^{gh}	76.88
Sila	77.37^{bcdef}	80.27^{bcd}	78.82
Omega	80.40^{ab}	80.83^{bcd}	80.61
Lasta	79.60^{abcd}	81.53^{bc}	80.56
Milica	78.73^{abcdef}	79.07^{cdef}	78.90
Partizanka	79.00^{abcde}	77.33^{efgh}	78.16
Pobeda	80.93^{a}	77.00^{fgh}	78.96
Dična	79.43^{abcde}	81.67^{b}	80.55
NSR-5	76.37^{ef}	79.00^{cdef}	77.68
Alfa	79.33^{abcde}	78.33^{defg}	78.83
Rodna	78.33^{abcdef}	77.33^{efgh}	77.83
Agrounija	77.67^{bcdef}	75.53^{h}	76.60
Zadruga	79.83^{abc}	85.00^{a}	82.41
KG -75	76.96^{cdef}	80.23^{bcd}	78.59
Šumadinka	79.47^{abcde}	75.50^{h}	77.48
Levčanka	79.23^{abcde}	79.87^{bcde}	79.55
Oplenka	78.77^{abcdef}	76.97^{fgh}	77.87
Gruža	78.00^{abcdef}	76.33^{gh}	77.16
KG-56	76.57^{def}	78.87^{defg}	77.72
Average	78.45	78.94	-

Generally, in average all studied wheat varieties in second year expressed higher values of seed mass spike^{-1} as well mass of spike than in the second year. However, spike harvest index was higher in the second year in 11 variety (Evropa 81.67%, Sila-80.27%, Omega-80.83%, Lasta-81,53%, Milica-79.07%, Dična-81.67%%, NS Rana5-79.0%, Zadruga-85.0%, KG 75-80.23%, Levčanka-79.87%, KG 56-78.87%) than in the first year (Evropa 75.67%, Sila -77.37%, Omega-80.40%, Lasta-79,60%, Milica-78.73%, Dična-79.43%%, NS Rana5-76.37%, Zadruga-79.83 %, KG 75-76.96%, Levčanka-79.23%, KG 56-76.57%).

Variation of the spike harvest index in one variety under different conditions shows the manifestation of a different response to eco-climatic conditions as an expression of the interaction of genotype and external environment. This adaptation of genotypes to different environmental conditions indicates the ability of a variety to express its genetic potential in specific environmental conditions (Thungo et al., 2019; Subira et al., 2015). The variation of spike harvest index depends on environmental conditions indicate genotype capacity for adaptability to change environmental condition, i.e. indicate different efficiency for adsorption, utilization of water and minerals and different efficiency of photosynthesis and translocation and partitioning of assimilates into seed and vegetative part (Rivera-Amado et al., 2019). The identification genetic loci (at the 1B, 2B, 3B, 3D, 4A, 5A, 6A, 6D, 7A, 7D) associated with spike harvest index as well spike fertility contribute to detect markers that are functionally linked to seed yield and harvest index (Pradhan et al., 2019). In early studies showed that correlation between spike HI, estimated on the basis 10 spike sample and plot harvest index, was low and statistically nonsignificant. Based on this study, one could not recommend using spike HI as a predictor of plot harvest index (Hucl and Graf, 1992). Moreover, Pradhan et al. (2019) in study found significant genotypic variation for SHI across all environments and that SHI was positively correlated with spike fertility (0.32 to 0.41) and seed yield (0.24 to 0.49) and harvest index. Also, they reported that SHI have the potential to increase the efficiency of breeding programs aimed at optimizing yield of seeds and its major components in wheat upon validation.

In this study were found significant genotypic variation for spike harvest index in second year environments. The analysis of variance established that the differences between the varieties for the spike harvest index were significant and highly significant. Differences between vegetation seasons for spike harvest index in varieties, indicate that there is an influence of environmental factors on the expression spike harvest index. They established significant differences in the average values of spike harvest index, indicating genetic divergence of varieties (Table 3).

Table 3. Analisys of components of variance for spike harvest index in two vegetation seasons

Source of variance		First year- Vegetation season 2015/16					Second year-Vegetation season 2016/17				
	df	*SS*	*MS*	*F*	$Lsd_{0,05}$	$Lsd_{0,01}$	*SS*	*MS*	*F*	$Lsd_{0,05}$	$Lsd_{0,01}$
Genotypes	2	5.102	2.551	0.7238^{ns}	-	-	24.864	12.432	5.5227**	-	-
Repetitions	19	114.803	6.042	1.7142^{ns}	3.209	4.386	347.775	18.304	8.1311**	2.564	3.505
Error	38	133.944	3.525	-	-	-	85.542	2.251	-	-	-
Total	59	253.850	-	-	-	-	458.182	-	-	-	-

ns-nonsignificant differences; p<0.05*, p<0.01**

In study Knežević et al. (2021) found that variation of spike harvest index determined by greatest influence of genotype (25.63%) while Petrović et al. (2002) found higher impact of environment. The environment conditions had the highest impact on seed mass spike^{-1} (38.35%) and also on the mass of spike (48.63%). Also, variation of values of temperature, precipitation, nutrition has influence on increasing of capacity of spike (Petrović et al., 2008; Knežević et al., 2016) and seed yield (Marijanović et al., 2010).

On the base of obtained values for spike harvest index the five clusters of similar varieties were differentiated in the first year (2015/16) and one variety (Evroppa) that was the most distant in similarity from other varieties in all five clusters. The first cluster contains 6 varieties, in which the greatest similarity is shown by Dejana and Sila, with which Agrounija is most similar at the highest hierarchical level, followed by Rodna and Gruža, and at an even greater distance by the KG 75 variety. The second cluster represents a pair of varieties NS rana 5 and Kragujevčanka 5. The third cluster contains 5 varieties, within which the greatest similarity was shown by Dična and Šumadinka, with which the pair of varieties Alfa and Levčanka showed a higher hierarchical level, and with these four varieties the variety Lasta showed similarity at a greater distance. The fourth cluster contains four varieties, among which the varieties Milica and Oplenka had a high level of similarity, and which were like the varieties Partizanka and Zadruga. The fifth cluster represents a pair of mutually similar varieties Omega and Pobeda. Among those five clusters the third and fourth cluster varieties showed the greatest similarity, then the first and second clusters, and at the next hierarchical level, the third and fourth showed similarity with the first and second, with which the fifth cluster showed similarity at a greater distance and the lowest similarity with all varieties showed the variety Europa (Figure 1).

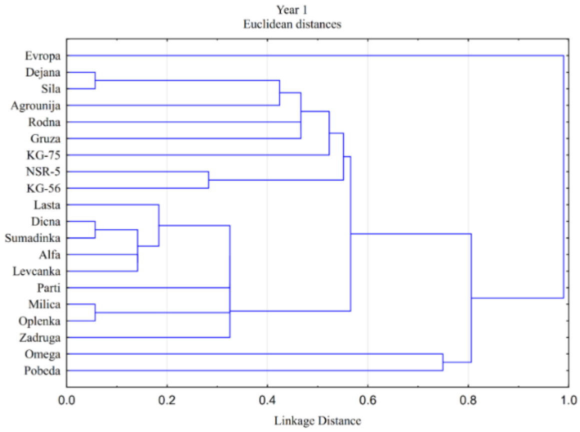


Figure 1. Similarity of wheat genotypes according to the spike harvest index in the vegetation 2015/16 season

In second year (2016/17) the six cluster mutually sim ilar varieties were established and one variety (Zadruga) that was the most distant in similarity from other varieties in all five clusters. The first cluster contains two varieties Evropa and Dična, the second cluster contains four varieties of which the greatest similarity was between the varieties Sila and Kragujevacka 75 with which the varieties Levčanka and then Omega was with a lower degree of similarity. The third cluster has four varieties of which Milica and NS rana 5 showed a high degree of similarity, and with them the varieties Kragujevčanka 56 showed similarity and then Alfa with a lower degree of similarity. The fourth cluster contains two varieties Dejana and Gruža. The fifth cluster contains four varieties of two mutually similar varieties and Partizanka and Rodna and Pobeda and Oplenka. The sixth cluster has two mutually similar varieties Agrounija and Šumadinka. Among those six clusters, the highest similarity was between the fourth and fifth clusters showed the greatest similarity, then the first and second. The same level of similarity was shown by the third cluster with formed cluster from the first and second, and the sixth cluster with the formed cluster from fourth and fifth clusters, and these two groups of three clusters are like each other at a greater distance. The least similarity with all varieties was shown by the variety Zadruga (Figure 2).

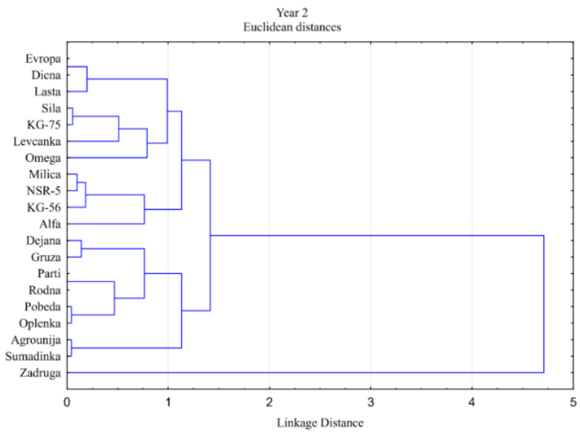


Figure 2. Similarity of wheat genotypes according to the spike harvest index in the vegetation 2016/17 season

In these studies, the examined wheat genotypes showed a high spike harvest index, which on average varies between 76,60% and 82.41% in two vegetation season. In other study of wheat varieties, similar values of variation in spike harvest index were found (Knežević et al., 2021). The high values of spike harvest index indicate high number of seeds spike^{-1}, harvest index what lead high yield of seeds. The significant positive association of spike harvest index found with mass of spike 0.57*, number of seeds spike^{-1} 0.62**, thousand seed mass 0.63** and stem harvest index 0.68** found in study of 61 advanced lines and five Iranian varieties (Moosavi et al., 2020), which is in agriment with previous results reported in reseach (Rahman et al., 2016). For increasing the spike harvest index as well other component of yield, the greatest contribution has soil moisture, mineral nutrition and accessibility of mineral elements for absorption, temperature, light and photosynthetic process and reutilization and translocation of organic matter (Dodig et al., 2008; Rivera-Amado et al., 2019).

4. CONCLUSIONS

In this study were determined significant differences between wheat varieties and between the years of experiment according to spike harvest index in both vegetative season. The variation of spike harvest index in the same variety in two vegetation season indicate genotype's response to different environmental conditions. The highest values of spike harvest index (85.1%) in Zadruga variety expressed in the second experimental investigation, while the least (75.50%) in wheat Levčanka in the second year of experimental investigation. The differences between genotypes were significant and highly significant for spike harvest index. Genetic factors, environmental factors and genotype/environment interaction had an influence on the manifestation spike harvest index.

5. ACKNOWLEDGEMENTS

The research was funded by the Ministry of Education, Science and Technological Development of Republic of Serbia (TR 31092).

6. REFERENCES

Asseng, S., Ewert, F., Martre, P., Rötter, R.P., Lobell, D.B., Cammarano, D., Kimball, B.A., Ottman, M.J., Wall, G.W., White, J.W., Reynolds, M.P., Alderman, P.D., Prasad, P.V.V., Aggarwal, P.K., Anothai, J., Basso, B., Biernath, C., Challinor, A.J., De Sanctis, G., Doltra, J., Fereres, E., Garcia-Vila, M., Gayler, S., Hoogenboom, G., Hunt, L.A., Izaurralde, R.C., Jabloun, M., Jones, C.D., Kersebaum, K.C., Koehler, A.K., Müller, C., Naresh Kumar, S., Nendel, C., O'Leary, G., Olesen, J.E., Palosuo, T., Priesack, E., Eyshi Rezaei, E., Ruane, A.C., Semenov, M.A., Shcherbak, I., Stöckle, C., Stratonovitch, P., Streck, T., Supit, I., Tao, F., Thorburn, P.J., Waha, K., Wang, E., Wallach, D., Wolf, J., Zhao, Z., Zhu, Y. (2014). Rising temperatures reduce global wheat production. Nature Climate Change, 5(2), 143–147. doi:10.1038/nclimate2470

Calderini, D., Quintero, A., Hasan, A., Wingen, L., Griffiths, S., Girousse, C., et al. (2013). "Improving Grain Filling and Potential Grain Size". In. International Workshop of the Wheat Yield Consortium, 3. Proceedings (CENEB, CIMMYT. Cd. Obregon, Sonora (Mexico) CIMMYT), 39.

Dodig, D., Zoric, M., Knezevic, D., King, S.R., Surlan-Momirovic, G. (2008). Genotype x environment interaction for wheat yield in different drought stress conditions and agronomic traits suitable for selection. Australian J.of Agric.Res., 59, 536-545.

FAOSTAT (2016). "Food and Agriculture Organization of the United Nations" in Statistical Database

Grčak, M., Grčak, D., Jevtić, R., Lalošević, M., Kondić, D., Živić, J., Knežević, D. (2019a). Variation of spike index of cereal and index pea pods in monocrops and intercrops system of cultivation. Genetika, 51(3), 1185-1196.

Grčak, M., Grčak, D., Župunski, V., Jevtić, R., Lalošević, M., Radosavac, A., Kondić, D., Živić, J., Paunović, A., Zećević, V., Mićanović, D., Knežević, D. (2019b). Effect of cereals +pea intercropping on spike index of spring wheat, triticale, oat and pods index of pea. Acta Agriculturae Serbica, XXIV,48,167-180.

Hucl, P., Graf, R.J. (1992). Variation in spike harvest index among diverse genotypes of spring wheat and triticale. Can. J. Plant Sci., 72, 257 -261.

IPCC (2013). Climate Change 2001: the Scientific Basis. UK: Cambridge University Press Cambridge.
Knežević, D., Kovačević, V., Paunović, A., Madić, M., Đukić, N., Tanasković, S., Jelić, M. (2011). Varijabilnost mase klasa pšenice *Triticum aestivum* L. Zbornik radova sa 16. savetovanja o biotehnologiji, 16(18), 47-53.
Knežević, D., Zečević, V., Kondic, D., Markovic, S., Šekularac, A. (2014). Genetic and phenotypic variability of grain mass per spike in wheat under different dose of nitrogen nutrition. Turkish journal of agricultural and natural sciences, 805-810.
Knežević, D., Kondic, D., Srdić, S., Paunović, A., Madić, M. (2015a). Harvest index and components of yield in winter wheat cultivars (*Triticum aestivum* L.). Proceeding of *Sixth International Scientific Symposium* "Agrosym Jahorina 2015", Kovacevic, D. (Ed.), Jahorina, Bosnia and Herzegovina, 368-372.
Knežević, D., Radosavac, A., Zelenika, M. (2015b). Variability of grain weight per spike of wheat grown in different ecological conditions. Acta Agriculturae Serbica, 39, 85-95.
Knežević, D., Paunović, A., Zečević, V., Urošević, D., Kondić, D., Mićanović, D., Živić, J., Madić, M., Djurović, V., Srdić, S., Kovačević, V. (2019). Mass variability of winter wheat (*Triticum aestivum* L.) cultivars. Proceedings, XXIV Conference on Biotechnology 24(26), 37-44 with international participation, University of Kragujevac, Faculty of Agriculture, Čačak /in Serbian/
Knežević, D., Laze, A., Paunović, A., Djurović, V., Đukić, N., Valjarević, D., Kondić, D., Mićanović, D., Živić, J., Zečević, V. (2020). Approaches in cereal breeding. Acta Agriculturae Serbica, 25(50), 179-186. https://scindeks.ceon.rs/article.aspx?artid=0354-95422050179K
Knežević, D., Urošević, D., Mićanović, D., Paunović, A., Kondić, D., Đurović, V., Radosavac, A., Živić, J., Matković, M., Madić, M., Zečević, V. (2021). Variability of spike harvest index in wheat (*Triticum aestivum* L.). Kovačević, D. (Ee.), In Book of Proceedings, XII International Scientific Agriculture Symposium "Agrosym 2021", Jahorina, 420-426.
Lobell, D., Schlenker, W., Costa-Roberts, J. (2011). Climate trends and global crop production since 1980. Science, 333, 616-620. doi: 10.1126/ Science.1204531
Marijanović, M., Markulj, A., Tkalec, M., Jozić, A., Kovačević, V. (2010). Impact of precipitation and temperature on wheat (*Triticum aestivum* L.) yields in Eastern Croatia. Acta Agriculturae Serbica, 30, 117-123.
Moosavia, S.S., Nazaria, M., Chaichib, M., Jamshidi Goharrizi, K. (2020). The most effective yield-components associated with increasing yield of wheat (*Triticum aestivum* L.) under terminal drought stress conditions. Desert, 25-2, 139-146.
Petrović S., Dimitrijević M., Kraljević-Balalić M., Mladenov, L. (2002). Stabilnost indeksa klasa divergentnih genotipova pšenice. Zbornik radova, Naučni institute za ratarstvo i povrtarstvo, Novi Sad, 36, 251-261.
Petrović, S., Marić, S., Guberac V., Drezner G., Eđed A. (2008). Influence of environmental conditions and sowing rates on winter wheat yield. Cer.Res.Comm., 36, 1307-1310.
Pradhan, S., Babar, M. A., Robbins, K., Bai, G., Mason, R. E., Khan, J., Shahi, D., Avci, M., Guo, J., Maksud Hossain, M., Bhatta, M., Mergoum, M., Asseng, S., Amand, P., Gezan, S., Baik, B.K., Blount, A., Bernardo, A. (2019). Understanding the Genetic Basis of Spike Fertility to Improve Grain Number, Harvest Index, and Grain Yield in Wheat Under High Temperature Stress Environments. Frontiers in Plant Science, 10, doi:10.3389/fpls.2019.01481
Rahman, M., Barma, N., Biswas, B., Khan, A., Rahman, J. (2016). Study on morpho-physiological traits in spring wheat (*Triticum aestivum* L.) Under rainfed conditions. Bangladesh Journal of Agricultural Research, 41, 235-250.
Rivera-Amado, C., Trujillo-Negrellos, Eliseo., Molero, G., Reynolds, M.P., Sylvester-Bradley, R., Foulkes, M. J. (2019). Optimizing dry-matter partitioning for increased spike growth, grain number and harvest index in spring wheat. Field Crops Research, S037842901831935X. doi:10.1016/j.fcr.2019.04.016
Subira, J., Alvaro, F., Garcíadel Moral, L.F., Royo, C. (2015). Breeding effects on the cultivar × environment interaction of durum wheat yield. Eur. J. Agron., 68, 78-88.
Thungo, Z., Shimelis, H., Odindo, A.O., Mashilo, J. (2019). Genotype-by-environment interaction of elite heat and drought tolerant bread wheat (*Triticum aestivum* L.) genotypes under non-stressed and drought-stressed conditions Acta Agriculturae Scandinavica, Section B-Soil & Plant Science, 69(8), 725-733.
Zečević, V., Knežević, D., Kraljević-Balalić, M., Mićanović, D. (2004). Genetic and phenotypic variability of yield components in wheat (*Triticum aestivum* L.). Genetika, 36(2), 151-159.

doi:10.46793/MAK2025.153P

EFFECT OF INTERCROPPING ON SOME IMPORTANT YIELD COMPONENTS OF SMALL GRAINS

Vladimir Perišić[1*], Dejan Cvikić[1], Vesna Perišić[2], Ivana Živković[1], Vera Rajičić[2], Kamenko Bratković[3], Kristina Luković[1]

[1]Institute for Vegetable Crops Smederevska Palanka, S. Palanka, Serbia
*vperisic@institut-palanka.rs
[2]Faculty of Agriculture Kruševac, University of Niš, Kruševac, Serbia
[3]Center for Small Grains and Rural Development, Kragujevac, Serbia

Abstract: Characteristics of small grains, such as density of plants number per unit area and development in less favorable periods of the year, enable the application of sustainable agriculture principles and the production of healthy food. The trial was set up in the Šumadija District, in four locations, with conventional and intercropping system of winter cereals and peas. The intercropping system had an effect on spike length on some localities and for some species, while no effect on number of grains per spike. Results showed that the main sources of variation had significant effects on examined yield components.

Key words: Small grains, Pea, Intercropping, Yield components

1. INTRODUCTION

Plant production represents the cornerstone of every modern society and has a multiple impact on people's lives, especially from an economic and health perspective. The imperative to produce sufficient amounts of food throughout history was largely fulfilled when the yield of wheat varieties increased by two-three folds and reached its peak of seed production in the second half of the 20th century, during the period of the so-called "Green Revolution" in agricultural production. The main characteristics of this movement were the application of varieties and hybrids selected for highly intensive production, favoring monoculture, the use of large amounts of mineral fertilizers and pesticides, intensive use of mechanization, and the significant consumption of fossil fuels (Leifeld, 2013). One of the main advantages of this production system was the significant increase in average yields of the most important agricultural crops (corn, wheat, rice, etc.), especially in non-developed countries in Asia, Africa, and South America.

During the time, research has indicated the existence of negative consequences of agricultural production based on this approach, primarily the inadequate use of agricultural land as the most important resource, which has resulted in the deterioration of its physical, chemical, biological, and microbiological properties (Tadesse et al., 2016). The devastation of agricultural land has led to groundwater pollution, a decrease in biodiversity, a pronounced dependence of yields on the applied amounts of chemicals (mineral fertilizers and pesticides), while also greatly affecting the healthiness of the final product in the form of the presence of harmful residues.

The development of awareness of the disadvantages of conventional production has led to the formation of a number of different sustainable production systems based on biological principles, which aim to achieve both economic and environmental benefits. The most important goals of sustainable agriculture are efficient management of agricultural land, environmental protection in the agricultural sector, stabilization of incomes of agricultural workers, technological development and modernization of agricultural production, and improvement of product quality and safety (Imadi et al., 2016; Yadav et al., 2020). Unlike conventional agriculture, which is based on high investments, sustainable production systems characterize optimization of investment costs through rationalization (reduction) of the use of mineral fertilizers and pesticides or their total exclusion.

Small grains, primarily wheat, represent one of the strategic agricultural products whose demand has been constantly growing in the first decades of the 21st century. Some of the biological characteristics of winter small grains, such as a great number of plants per unit area and development in less favorable periods of the year (autumn and early winter), when there are no weed species, enable the application of the principles of sustainable agriculture and the production of healthy, safe food. Critical periods in terms of the nutrient requirements of small grains are the initial phenophases of growth after sowing and intensive development during spring.

The formation of a sustainable model of winter cereal cultivation in intercropping with annual legumes (peas, vetches, lupins, etc.) can be one of the ways to overcome the limiting factors that are facing modern agricultural production (Jevtić et al., 2023). Symbiotic fixation of nitrogen from the air is a feature of legumes and the amounts of nitrogen bound in this way depend on the given species, so it ranges from 40-120 kg ha^{-1}a for peas, vetches and lentils, 45-400 kg ha^{-1} per year for clover, and up to 250 kg ha^{-1} for alfalfa (Tadesse et al., 2016; Stevović et al., 2020).

Research has shown that the nitrogen from the process of fixation remains available to the next crop, but also a significant amount is released by the plants into the soil during the growing season. The cultivation of small grains and legumes in intercropping is based on the synergistic relationship between the two cultivated species, through the exchange of nutrients through the soil, with an increased degree of utilization of sunlight during the process of photosynthesis and the suppression of weed species by the optimal density of the intercropping (Bedoussac et al., 2015; Dvořák et al., 2022).

The main goal of the research is the estimation of created models for sustainable agricultural production in comparison of two system of plant growing, solo crops and intercrops of winter cereal and annual legumes (winter pea) and to assess the effect of the cropping system on the variation of the main yield of plant species.

2. MATERIAL AND METHODS

The experiment was set up in the territory of the Šumadija District, in four locations (Jovanovac, Lapovo, Vojkovci, and Oplanić) during 2022/2023. A trial network was formed with a conventional and sustainable production system of winter cereals (barley, wheat and triticale) and winter pea in intercropping. The trial included the winter two-row barley variety Rekord, the winter wheat variety Kruna and the winter triticale variety KG 20, selected at the Center for Small Grains and Rural Development Kragujevac. As a legume within the intercropping with cereals, the first domestic winter protein pea variety for grain NS Mraz was selected, with an aphila leaf type. Within the intercropped part of trial, seed set of small grains was 90% of normal, as well as for 10% for pea.

2.1. Šumadija District soils

During the plot selection, crop rotation, i.e. pre-crops on selected plots (corn, potatoes, alfalfa and other legumes, etc.), was considered. The selected plots are located at different altitudes (from 137 m in Lapovo to 591 m in Vojkovci), which must be considered in later discussion of the achieved results. It should be noted that several soil types are represented in the Šumadija District, which corresponds to the diverse orographic conditions of the terrain. Seven basic soil types were formed: alluvium, smonica, gajnjača, podzol, red, brown and skeletoid soils.

Before the experiment was conducted, soil sampling was carried out for the purposes of agrochemical soil analysis at four selected locations in the Šumadija District. The tested soil fertility parameters were active acidity in H2O and substitution acidity in 1M KCl - potentiometrically, humus content (Tyurin, 1953), total nitrogen content (Kjeldahl, 1883), readily available phosphorus content (mg P2O5/100 g soil) - Al-method (Riehm, 1943), readily available potassium content (mg K2O/100 g soil) - Al-method (Riehm, 1943).

Based on the agrochemical analysis is established that these soils are characterized by a more or less acidic reaction, from 4.47 (Vojkovci) to 5.81 (Jovanovac). A high content of humus (organic matter) and phosphorus was determined for the Oplanić locality, while the potassium content was high on all analyzed plots (Table 1).

Table 1. Agrochemical soil analysis for four localities in the Šumadija District

Locality	Acidity pH	Humus (%)	Nitrogen (%)	Phosphorus P_2O_5 (mg)	Potassium K_2O (mg)
Oplanić	5.56	4.15	0.16	15.58	37.56
Jovanovac	5.81	3.95	0.20	9.67	19.40
Lapovo	5.15	3.80	0.19	3.22	19.40
Vojkovci	4.47	3.64	0.18	5.86	37.56

2.2. Šumadija District climate

The Šumadija District is characterized by a temperate continental climate with pronounced variations, due to the significant difference in altitude between different parts of the region. The average annual temperature ranges from 9-11 °C, in warmer months the average values are above 10 °C and during colder months above - 3 °C. The region is characterized by a lower amount of precipitation, which places it in the "drier" parts of the Republic of Serbia. The total amount of precipitation in the territory of the Šumadija District is in the range of 700 - 900 mm, although it must be noted that in some extreme years this amount can be significantly higher. Based on meteorological data of temperature and precipitation amounts in the territory of the City of Kragujevac (Figure 1), it can be concluded that the average monthly temperatures recorded during the experiment were at the level of the multi-year average (2000-2023). The amount and distribution of precipitation during the experiment indicate that these values were above the multi-year average during November, December, January, April and especially during June (118.8 mm compared to 81.4 mm). There were 24 days with precipitation during June, and the amounts ranged from 50 to even 300 mm. October 2022, as well as February, March and May 2023, stood out as extremely stressful periods in terms of lack of precipitation. The lack of precipitation during October (7.3 mm compared to 50.8 mm for the multi-year average) resulted in slow germination and emergence of the sown species/varieties in the experiments. Smaller amounts of water sediment during February, March and May slowed down the development of crops in conditions of mild winter and spring temperatures.

From the available meteorological data, a significant range between night and day temperatures during May and June 2023 is noticeable. From the data of the Republic Hydrometeorological Institute, it can be observed that a large number of days during May and June (20 days in each month) with difference between the minimum night and maximum daytime temperatures was 10 degrees Celsius or more. This fact can be taken as one of the decisive factors that led to disruptions in flowering and fertilization in small grains, especially triticale, weaker grain filling and hence low values for the 1000 grains mass and hectoliter mass.

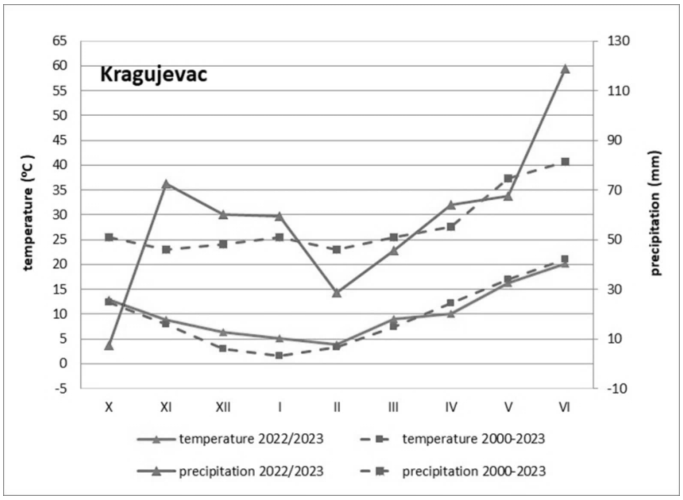


Figure 1. Average temperatures and precipitation amount in the period
October 2022 - June 2023 and multi-year average (2000-2023) in Kragujevac

Soil preparation at the selected locality and the sowing of the plant cultivars included in experiments, was hampered by insufficient rainfall during October (7.3 mm compared to 50.8 mm for the multi-year average). Therefore, sowing was carried out from October 18 to November 10, 2022. Each experiment consisted of a conventional (sowing of small grains) and an intercropped part (sowing of small grains and field peas), with the size of the elementary plot per species/variety of 10 m^2.

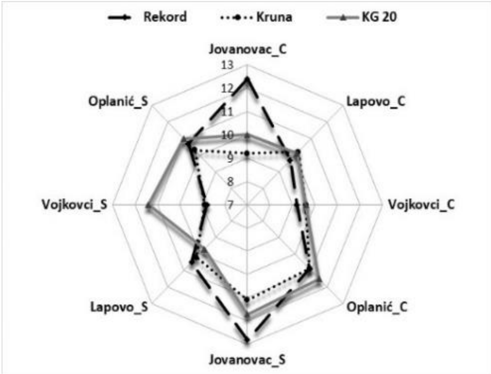
During pre-sowing soil preparation, NPK fertilizer with the formulation 16:16:8 was applied in an amount of 300 kg ha^{-1}, while during the growing season, nitrogen fertilizer KAN (27%) was applied in an amount of 100 kg ha^{-1} (conventional part) and 50 kg ha^{-1} (intercropped part).

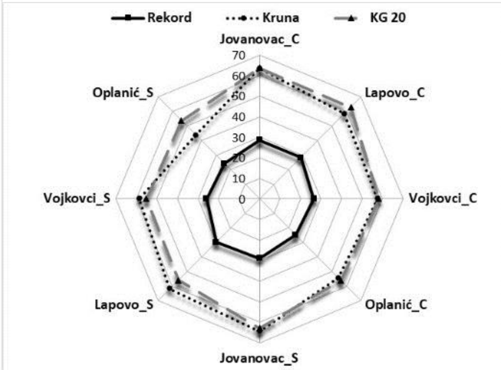
During the growing season, protection of the plant cultivars in trial at all locations was conducted, while the part of the trial with the combined sowing of small grains and field peas was not treated with herbicides. The trial harvest began in late June and ended in mid-July, depending on the tested species/variety.

Biometrical analysis of recorded data for spike length and number of grains per spike of the tested varieties/species of small grains was based on the application of statistical software GenStat 12th (2009) and SPSS 20 (2011). Analysis of variance was conducted according to a completely randomized block design (Johnson and Bhattacharyya, 2010). Also, for all examined wheat genotype principal components of interaction were established, where the stability level was determined by the AMMI1 method.

3. RESULTS AND DISCUSSION

The spike length in the studied cultivars of barley, wheat and triticale varied depending on the location and type of trial (Figures 2 and 3). The highest average value for spike length in barley variety Rekord (12.81 cm), wheat variety Kruna (11.07 cm) and the triticale variety KG 20 (11.73 cm) was recorded at the Jovanovac location in the part of the experiment with intercropped sowing. According to type of trial, cultivar Rekord intercropped with bean expressed higher average value than monocroped in Jovanovac location, as well as cultivar KG 20 in Vojkovci location.





C-conventional, S- sustainable

Figure 2. Average values of spike length by species/varieties at the examined locations

Figure 3. Average values of grain number per spike by species/varieties at the examined locations

The cultivar Rekord achieved the lowest average values for the number of grains per spike compared to the wheat and triticale cultivars, which can be explained by the differences in the morphological characteristics of the spike. The highest value (29.87) was achieved in the Lapovo locality, within the intercropped part of trial survey. The examined wheat and triticale genotypes showed the highest average values at the Jovanovac site in both types of trials (over 60 grains per ear). There were not recorded such obvious differences between different types of trial for examined trait. Examining intercropping of barley and wheat with lupine at different densities, Bitew et al. (2014) found that there was no statistically significant effect on spike length and number of grains per spike.

The AMMI analysis of variance revealed statistically very significant effects of treatments, genotypes, environments and GEI in the expression of spike length (Table 2). The greatest portion in the total variations had the variance for GE interaction (28.38%), while environment and genotype variances were lower (20.85% and 5.94%, respectively).

Table 2. Analysis of variance of AMMI model for spike length

Source	df	SS	MS	F	Fprob
Total	719	1404.9	1.95	*	*
Treatments	23	775	33.7	39.25	0
Genotypes	5	83.4	16.67	19.42	0
Environments	3	292.9	97.63	19.92	0
Block	8	39.2	4.9	5.71	0
Interactions	15	398.7	26.58	30.96	0
IPCA1	7	277.4	39.63	46.16	0
IPCA2	5	104.2	20.83	24.26	0
Residuals	3	17.2	5.72	6.66	0.00019
Error	688	590.7	0.86	*	*

AMMI analysis of principal components, IPCA1 and IPCA2, was conducted since the existence of significant effect of GEI was established. There were recorded highly significant effects of both principal components, wherein IPCA1 covered 69.56% from sum of square of interaction variance, while IPCA2 explained additional 26.13%.

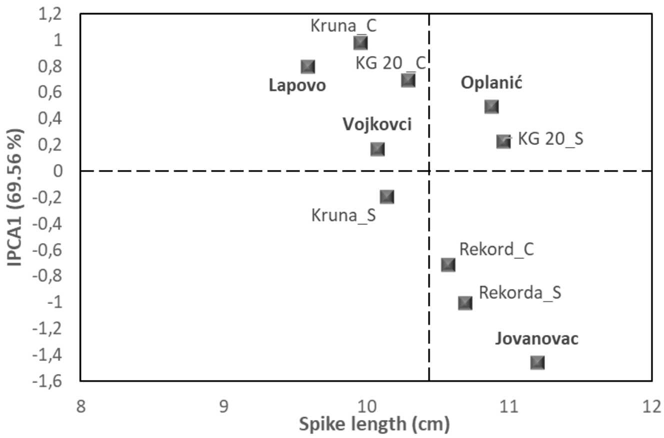


Figure 4. AMMI1 biplot analysis of stability for spike length

According to AMMI1 biplot analysis of stability, the most stable genotype was intercropped triticale KG 20 with the average spike length above mean value of trial. Intercropped genotype Kruna expressed stability, but the average value of examined trait was lower than trial value. Locality Vojkovci represented the most stable locality where genotypes did not express significant values of spike length. A similar locality was Lapovo with less stable performance. Locality Oplanić expressed relatively modest stability while locality Jovanovac is enabling the best conditions for genotypes with narrow stability as barley genotype Rekord.

The AMMI analysis of variance for number of grains per spike (Table 3) pointed out statistically significant effects of treatments, genotypes, environments and GEI in the expression of examined trait. The most important part in the total variations was the variance for genotype effect (74.62%). Similar findings were found by Knežević et al. (2012) and Kondić et al. (2017).

According to AMMI1 biplot analysis of stability, the most stable genotype for number of grains per spike were wheat variety Kruna in the conventional part of trial, as well as intercropped and monocropped triticale cultivar KG 20. Intercropped genotype Kruna expressed narrow stability, esspecially in localities Jovanovac and Vojkovci.

Table 3. Analysis of ariance of AMMI model or umber of grains per spike

Source	Df	SS	MS	F	F prob
Total	719	208150	289	*	*
Treatments	23	167734	7293	128	0
Genotypes	5	155317	31063	545.21	0
Environmenta	3	8121	2707	17.79	0
Block	8	1218	152	2.67	0.0068
Interactions	15	4295	286	5.03	0
IPCA1	7	3490	499	8.75	0
IPCA2	5	716	143	2.51	0.02885
Residuals	3	90	30	0.52	0.66536
Error	688	39199	57	*	*

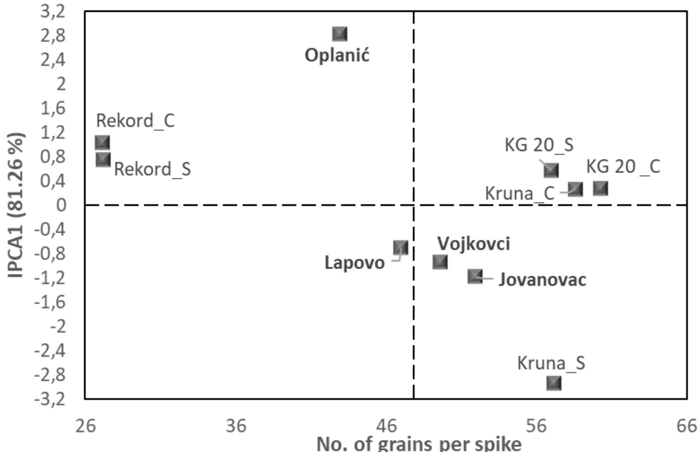


Figure 5. AMMI1 biplot analysis of stability for number of grains per spike

Each winter wheat variety tolerated the presence of winter peas in intercropping to a different extent. Vályi-Nagy et al. (2023) concluded that number and weight of grains in wheat were decisive in terms of yield, which was influenced both by the weather of the given year and the presence of the companion plant. While extreme weather events mostly had a negative effect on crop formation, the presence of winter peas and their natural nitrogen supply alleviated these symptoms.

4. CONCLUSION

Intercropping of winter cereals (barley, wheat and triticale) with winter pea had some effect on spike length on some localities and for some species, while there was no effect on number of grains per spike. The obtained research results showed that the main sources of variation (genotype, environment, and locality) had statistically significant effects on examined yield components, spike length and number of grains per spike. Research on the joint cultivation of small grains and field peas, during one production year, is greatly influenced by the locality and the year, which largely prevents the creation of an optimal production model in order to achieve the best production results. The reintroduction of joint cultivation into agricultural practice must be adapted to each appropriate species/genotype, locality and the capabilities of the agricultural producer. Finally, combining the joint sowing of different agricultural crops with other agrotechnical measures, primarily crop rotation, increases the diversity (diversification) of agricultural production, all with the aim of reducing its negative impact on the natural environment and human health.

5. ACKNOWLEDGMENT

The research presented in this article is a part of a scientific project (Contract number: 451-03-66/2024-03/200216) and is supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, as well as a part of project for improving the system of knowledge creation and transfer through the development of technical-technological, applied, developmental and innovative projects in agriculture and rural development in 2022, (Contract number: 680-00-00101/2/2022-02), supported by the Ministry of Agriculture, Forestry and Water Management.

6. REFERENCES

Bedoussac, L., Journet, E.P., Hauggaard-Nielsen, H., Naudin, C., Corre-Hellou, G., Jensen, E. S., Prieur, L., Justes, E. (2015). Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. Agronomy for Sustainable Development, 911–935. doi :10.1007/s13593-014-0277-7.

Bitew, Y., Abay, F., Dessalegn, T. (2014). Effect of lupine (*Lupinus* spp.) intercropping and seed proportion on the yield and yield component of small cereals in Northwestern Ethiopia. African Journal of Agricultural Research, 9(30), 2287-2297. doi: 10.5897/AJAR2014.8729

Dvořák, P., Capouchová, I., Král, M., Konvalina, P., Janovská, D., Satranský, M. (2022). Grain yield and quality of wheat in wheat-legumes intercropping under organic and conventional growing systems. Plant, Soil and Environment, 68(12), 553-559. doi.org/10.17221/276/2022-PSE

IBM Corp Released (2011). IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY, IBM Corp.

Imadi, S.R., Shazadi, K., Gul, A., Hakeem, K.R. (2016). Sustainable Crop Production System. Published in Plant, Soil and Microbes, Volume 1, Implications in Crop Science, Editors Hakeem, Akhtar, Abdullah, Springer International Publishing, Switzerland, 103-116.

Jevtić, R., Župunski, V., Grčak, M., Živančev, D., Knežević, D. (2023). Cereal-Pea Intercropping Reveals Variability in the Relationships among Yield, Quality Parameters, and Obligate Pathogens Infection in Wheat, Rye, Oat, and Triticale, in a Temperate Environment. Plants, 12, 2067. doi.org/10.3390/ plants12112067

Johnson R., Bhattacharyya, G. (2010). Statistics - Principles and Methods 6th ed, John Wiley & Sons, New Jersey, USA.

Kjeldahl, J. (1883). A New Method for the Determination of Nitrogen in Organic Matter. Zeitschrift für Analytische Chemie, 22, 366-382. dx.doi.org/10.1007/BF01338151

Knežević, D., Zečević, V., Stamenković, S., Atanasijević, S., Milošević B. (2012). Variability of number of kernels per spike in wheat cultivars (*Triticum aestivum* L). Journal of Central European Agriculture, 13(3), 617–623.

Kondić, D., Bajić, M., Hajder, Đ., Knežević, D., Bosančić, B. (2017). The Spike Characteristics of Winter Wheat (*Triticum aestivum* L) Varieties in Agro-Ecological Conditions of Banja Luka Region. Agro-knowledge Journal, 18(4), 263-274. doi: 10.7251/AGREN1704263K

Leifeld, J. (2013). Low-input farming: a way towards climate-friendly agriculture? Carbon Management, 4(1), 31-41. dx.doi.org/10.4155/cmt.12.70

Riehm, H. (1943). Bestimmung der laktatlöslichen Phosphorsäure in karbonathaltigen Böden. Phosphorsäure, 1, 167-178.

Stevović, V., Đurović, D., Tomić, D. (2020). Forage legumes in agricultural production systems. Published in from genetics and the environment to food (Pržulj, N., Trkulja, V., Eds.). ANURS, Banja Luka BIH. /in Serbian/

Tadesse, W., Solh, M., Braun, H.J., Oweis, T., Baum, M. (2016). Approaches and Strategies for sustainable wheat production. Amman, Jordan: International Center for Agricultural Research in the Dry Areas (ICARDA). https://mel.cgiar.org/reporting/downloadmelspace/hash/P9m7yPte/v/961d095bb70caba96ba0ee49b95ad3d2

Tyurin, I.V. (1953). A method of analysis for the comparative study of soil humus composition. Chem. Abstr., 47, 5597.

Vályi-Nagy, M., Rácz, A., Irmes K., Szentpéteri, L., Tar, M., Kassai, K. M., Kristó, I. (2023). Evaluation of the Development Process of Winter Wheat (*Triticum aestivum* L.) and Winter Pea (*Pisum sativum* L.) in Intercropping by Yield Components. Agronomy,13(5), 1323. doi.org/10.3390/agronomy13051323.

VSN International (2009). GenStat for Windows (12th ed.). VSN International.

Yadav, M., Yadav, R., Ahmad, R., Yadav, R., Bharteey, P.K. (2020). Future Trends in Organic Farming and Sustainable Agriculture. Published in Organic Farming Practices and Sustainable Agriculture, Volume 2, Yad Vir Singh (Ed.), AkiNik Publications, Delhi, India.

doi:10.46793/MAK2025.161M

SPIKE LENGTH AND NUMBER OF GRAIN PER SPIKE OF WINTER WHEAT (*Triticum aestivum* L.) GROWN ON TECHNOGENIC SOIL

Nenad Malić[1*], Danijela Kondić[2], Ivana Tošić[3]

[1]Power Plants Stanari, Stanari, Republic of Srpska, Bosnia and Herzegovina
*nenad.malic@e-stanari.net
[2]University of Banja Luka, Faculty of Agriculture, Banja Luka, Republic of Srpska
[3]Agricultural Institute of Republic of Srpska, Banja Luka, Republic of Srpska

Abstract: This paper presents the results of two-year research (2015/16 and 2016/17) on impacts of different agro-technical measures to the yield components of four varieties of winter wheat (Nova Bosanka, Prijedorčanka, Orion and Evropa 90), grown on meliorated Deposol in the process of reclamation in the terchnogenic soil (Stanari lignite mine area). The aim of the research is to determine the impacts of years, different dosages of fertilizers (five treatments: $N_{60+90}P_{60}K_{60}$, $N_{60+40}P_{60}K_{60}$, $N_{60+90}P_{37}K_{37}$, $N_{60+40}P_{37}K_{37}$ and $N_0P_0K_0$) and variety to quantitative properties of the spikes (spike length and grain number per spike). A field experiment was set up following the randomized block design method with four replications. The focus of the research was the effect of three factors: year (A), variety (B) and fertilizer (C). Comparative analyses of the researched wheat varieties for spike length and grain number per spike were performed by analysis of variance 2x4x5. The relevance of the differences was tested using the LSD test. The highest mean spike length was 8.5 cm in the Orion variety, while the smallest mean spike length was 5.0 cm in the Evropa 90 variety. A correlation was found between fertilizer treatments, the largest number of grains per spike (48.75) and the smallest number of grains per spike (13.00) in the Nova Bosanka variety. The lowest mean values of the tested parameters were measured in the control. The applied agro-technical measures impact the production traits of cultivated crops of wheat in the researched agro-ecological conditions.

Key words: Reclamation, Variety, Yield, Mine area Stanari

1. INTRODUCTION

Increasing surface exploitation worldwide, as a means of intense exploitation of mineral ore deposits, particularly coal, results in large degradation and destruction of land. The total quantum of damaged land in Bosnia and Herzegovina at the beginning of the 21st century was over 20.000 ha. The area of land in the Republic of Srpska covered by open pits of minerals on which exploitation has been approved amounts to 8.375 ha (Malić, 2023). Having researched the scope and direction of the biological phase of rehabilitation in the largest three coal basins in the Republic of Srpska (the mines of Gacko, Ugljevik and Stanari), which jointly occupy around 2.000 ha. Malić et al. (2010) found that the reclamation process encompassed around 10% of the technogenic land. The primary goal of restoring damaged areas that are the result of surface exploitation of ore deposits is to establish functionality through managing the newly formed (technogenic) soils.

Out of one billion ha of arable land on Earth, wheat crops account for around 23%, which means that 239.215.000 ha of land yield over 600 million tons a year (Roljević et al., 2011). The largest areas under wheat crops are found in Asia (98 million ha), Europe (60 million ha) and Africa (10 million ha). In recent years, thanks to genetics and agro-technics, and despite climate changes, wheat yields are continually increasing (Denčić et al., 2009). Domestic varieties of small grains have the genetic potential for yields exceeding 7 t ha^{-1} (Mandić et al., 2011). Yield enhancement is most often linked to increasing the ratio of dry matter in the grain. The productiveness of wheat genotypes is a complex characteristic, the realization of which depends on the expression of a number of quantitative properties as its components (Knežević et al., 2020). The primary properties in the definition of productiveness are the number of spikes per unit of area, the number of grains per spike and the mass of the grains per spike (Kraljević Balalić et al., 2001). However, the realization of these quantitative properties results from the activity of minor genes, the degree of their activity being dependent on their mutual interaction and outside influences (Perišić et al., 2011). The most appropriate way to increase total biomass is increasing the efficiency of photosynthesis; however, numerous research shows that spike properties continue to be a limiting factor for wheat yield (Borras et al., 2004; Mirales and Slafer, 2007; Zečević et al., 2008, 2009; Kondić et al., 2020).

In their analysis of the effect of components of wheat yield to grain yield in 100 most productive and 100 least productive wheat genotypes from the Wheat Genetic Collection at the Institute of Field and Vegetable Crops in Novi Sad, Kobiljski and Denčić (1997) stated that an increase in the number of grains per spike, the mass of the grains per spike or the length of the spike in wheat does not always result in increased grain yield, while an increase in spike number per m^2 and a larger spike index are in fact indicative of larger grain yield. Comparably, the research of Hristov et al. (2008) ascertained a highly significant correlation between the height of the plant and the length of the spike, between the number of grains per spike and yield per plant, between the mass of 1000 grains and yield per plant, and between spike index and harvest index, and also a highly significant negative correlation between the harvest index and plant height and spike length. In their two-year research Knežević et al. (2014) determined the differences in mean values of spike length in the tested varieties over two years and under every variation of nitrogen fertilizer. For all genotypes the average spike length increased in correspondence to the dosage of nitrogen for both observed years, which means that the phenotype variability of spike length is dependent on nitrogen fertilization. In their two-year research of 20 wheat varieties from Serbia on very acidic land, Stojković et al. (2010) state that the average grain number per spike was 31 to 41.

So far, the projected directions for Deposol reclamation in the Stanari coal basin, on the existing barren overburden deposit sites, are towards agriculture, afforestation and crops for biomass (Malić et al., 2012l, 2023; Malić, 2023). Deposols are characterized by extremely low fertility. The impact of reclamation measures and agro-technology, which, with the time of reclamation, and the ruling climate impact, act on the technogenic parent substrate, is of crucial importance for the period of formation and formed technological fertility of the reclaimed soil (Malić and Marković, 2021).

The technical reclamation is followed by the agro-technical and the biological phase of reclamation, which is being performed on damaged areas at the Stanari lignite mine through increasing fertility of the surface layer of the overburden, i.e the Deposol type soil, which is characteristic for its low fertility (Malić, 2015), where the need arises for continuous usage of the restored areas. So far, the research on direct reclamation in the Stanari coal basin on the Deposols which are undergoing reclamation or Deposols that have already been meliorated or reclamated (also called Rekultisol) indicates the possibility of cultivating certain agricultural crops (sudangrass, oilseed rape, buckwheat, triticale, wheat etc.). In their three-year research cultivating rye, Malić et al. (2013) measured a maximum mean yield of 5.5 t ha^{-1}. Continuing the research with two years' worth measurements on winter wheat, Malić and Mandić (2014) presented a maximum mean grain yield of the Prijedorčanka variety at 6.28 t ha^{-1}. The task of the research was to select adequate wheat varieties and dosages of mineral fertilizers required for the optimal conduction of the biological phase of the reclamation process, and eventually to utilize (repurpose) the reclaimed areas.

The aim of the study is to determine the impacts of years conditions, different dosages of fertilizers on variation spike length and grain number per spike in four wheat varieties grown on technogenic soil.

2. MATERIAL AND METHODS

The research was conducted on a test plot within the inner deposit site of the Raškovac surface pit at the Stanari lignite mine, as part of the biological phase of reclamation (Elektrane Stanari, municipality of Stanari, Republic of Srpska, Bosnia and Herzegovina). Over two years (2015-2016 and 2016-2017) the focus of the research was on the influence of agro-technical measures on the quantitative properties (spike length and number of grains per spike) the varieties of winter wheat (*Triticum aestivum* L.) which were grown on meliorated Deposol. Prior to sowing the wheat, the agro-technical phase of reclamation was performed using the green manuring method, by growing sudangrass, oilseed rape and rye for two consecutive years, which turns primary Deposol into meliorated Deposol. The wheat was sown in the autumn in 2015 and 2016 according in the 280 kg ha^{-1} sowing rate.

A three-factor field experiment (2x4x5 type) was set up according to the randomized block system method with 4 replications. The size of the base plot was 5 m^2 (5x1 m^2), while the spacing between the blocks and plots was 0.8 m. Factor A represents the two years covered in the research (a_1 and a_2). The second factor, labeled B, is the variety, with four treatments: b_1) Nova Bosanka (N.B), b_2) Prijedorčanka (Prij), b_3) Orion, and b_4) Evropa 90 (Evropa 90). The first three varieties were selected at the Agricultural Institute of the Republic of Srpska (Banja Luka), whereas the fourth (Evropa 90) one was selected at the Institute of Field and Vegetable Crops in Novi Sad.

The third factor (C) represents dosages of mineral fertilizer applied initially and during spring supplementation, with 5 treatments: c_1) $N_{60+90}P_{60}K_{60}$, c_2) $N_{60+40}P_{60}K_{60}$, c_3) $N_{60+90}P_{37}K_{37}$, c_4) $N_{60+40}P_{37}K_{37}$, and c_5) control ($N_0P_0K_0$). The mineral fertilizer used initially was NPK 15:15:15, and during supplementation it was KAN (27% N).

Plant samples for analyses were taken in mature stage, and the measurements conducted on the wheat crops were performed manually. Statistical relevance was determined using the variance analysis method (ANOVA, 2x4x5), while the mean value significant differences were determined using the LSD test.

The experiment was set up on the two-year and three-year meliorated Deposol in the reclamation process, the texture of the soil being sandy loam, predominantly quartz sand and partly clay fractions. Table 1 shows the chemical properties of the meliorated Deposols in the reclamation process.

Table 1. Results of the chemical analysis of the Deposol in the reclamation process

Sample number	pH		Organic matter (%)	Humous (%)	Plant available (mg/100g)	
	H_2O	KCl			P_2O_5	K_2O
1	4.9	4.3	4.8	0.7	3.0	5.0
2	5.7	4.6	5.0	0.1	1.8	2.2
3	5.8	5.1	3.9	0.5	1.2	1.1
4	4.7	3.9	4.2	0.1	0.8	1.5

The average rainfall measured in the three-year period (2015, 2016 and 2017) was 1120 mm. In the winter, spring and early summer period of wheat vegetation (February-June) the rainfall for 2016 was 498 mm, and in the same period of 2017 it was 594 mm. The mean three-year air temperature was 12 °C.

3. RESULTS AND DISCUSSION

The following table presents the measured values of spike length of the wheat plants in the two-year research period. The mean value is 6.71 cm.

Table 2. The average spike length (cm)

Fertilization (factor C)	Research year (factor A)								$\bar{X}$ (C)
	2016 (a_1)				2017 (a_2)				
	Variety (factor B)				Variety (factor B)				
	(b_1) N.B.	(b_2) Prij.	(b_3) Orion	(b_4) Evr.90	(b_1) N.B.	(b_2) Prij.	(b_3) Orion	(b_4) Evr.90	
(c_1) $N_{60+90}P_{60}K_{60}$	7.25	7.25	8.25	7.0	7.37	7.37	8.5	8.0	7.62
(c_2) $N_{60+40}P_{60}K_{60}$	7.0	7.25	7.25	6.75	6.62	5.87	7.87	7.87	7.06
(c_3) $N_{60+90}P_{37}K_{37}$	5.25	6.25	7.25	6.5	6.37	6.62	6.75	6.25	6.4
(c_4) $N_{60+40}P_{37}K_{37}$	7.25	7.75	6.5	6.0	6.87	7.12	6.25	6.0	6.72
(c_5) $N_0P_0K_0$	5.5	6.25	6.5	5.0	5.5	5.75	6.0	5.75	5.78
$\bar{X}$ (B)	6.45	6.95	7.15	6.25	6.54	6.54	7.07	6.77	6.71
$\bar{X}$ (A)	6.7				6.73				

ANOVA	A	B	C	AB	AC	BC	ABC
$F_{exp.}$	0.01--	4.43**	17.37**	1.05--	1.12--	2.49**	1.08--
$Lsd_{0,05}$	-	2.6	2.37	-	-	1.75	-
$Lsd_{0,01}$	-	3.78	3.32	-	-	2.18	-

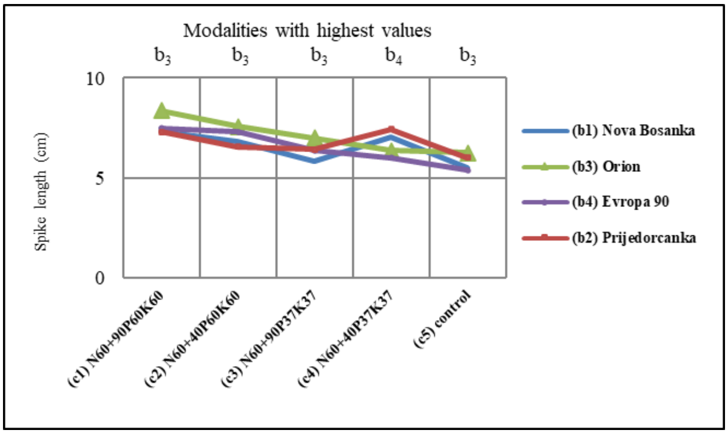


Figure 1. Interaction effect of the varieties (factor B) and fertilizations (factor C) on the spike length of wheat (cm)

Variance analysis shows a statistically highly significant impact of the basic factors of variety and fertilization, and their mutual interaction (BC). The maximum mean spike length in both researched years was measured in the Orion variety combined with fertilizer $N_{60+90}P_{60}K_{60}$. The lowest values were measured in the control for the Evropa 90 variety in the first year, and for the Nova Bosanka variety in the second year. The relations of interaction in Figure 1 show a varying distribution of means for the modality of the B factor (variety) in relation to the treatments of the C factor (fertilization): c_1 ($b_3 > b_4 > b_2 > b_1$), c_2 ($b_3 > b_4 > b_1 > b_2$), c_3 ($b_3 > b_2 > b_3 > b_1$), c_4 ($b_2 > b_1 > b_3 > b_4$), and c_5 ($b_3 > b_2 > b_1 > b_4$).

Table 3. shows the measured results of the grain numbers per wheat spike. The measured values are in the range of 13.00 to 48.75 grains per spike for the researched wheat varieties.

Table 3. The average grain number per spike

Fertilization (factor C)	Research year (factor A)								$\bar{X}$ (K)
	2016 (a_1)				2017 (a_2)				
	Variety (factor M)				Variety (factor M)				
	(b_1) N.B.	(b_2) Prij.	(b_3) Orion	(b_4) Evr. 90	(b_1) N.B.	(b_2) Prij.	(b_3) Orion	(b_4) Evr.90	
(c_1) $N_{60+90}P_{60}K_{60}$	38.25	35.5	36.25	36.5	30.75	33.5	30.0	29.5	33.78
(c_2) $N_{60+40}P_{60}K_{60}$	20.75	42.0	34.5	32.5	28.25	30.75	28.75	33.75	31.4
(c_3) $N_{60+90}P_{37}K_{37}$	32.5	24.75	30.0	25.2	48.75	36.0	35.5	34.0	33.34
(c_4) $N_{60+40}P_{37}K_{37}$	30.75	33.25	30.0	25.0	30.5	34.75	32.25	28.75	30.65
(c_5) $N_0P_0K_0$	13.0	20.35	15.75	16.5	16.75	15.75	16.0	14.5	16.07
$\bar{X}$ (B)	27.05	31.17	29.3	27.1	31.0	30.15	28.5	28.1	29.05
$\bar{X}$ (A)	28.67				29.44				

ANOVA	A	B	C	AB	AC	BC	ABC
$F_{exp.}$	0.53^{--}	1.23^{--}	34.59**	1.02^{--}	5.86**	2.17**	0.84^{--}
$Lsd_{0,05}$	-	-	2.37	-	2.37	1.75	-
$Lsd_{0,01}$	-	-	3.32	-	3.32	2.18	-

Variance analysis shows a statistically highly significant impact of the fertilization factor, as well as of the year×fertilization (AC) and variety×fertilization interactions. The maximum mean number of grains in the first year was determined for the Prijedorčanka variety combined with the c_2 ($N_{60+40}P_{60}K_{60}$) fertilization treatment, and in the second year for the Nova Bosanka variety with the following fertilizer combination: $N_{60+90}P_{37}K_{37}$ (c_3). The lowest values were measured in the control for the Nova Bosanka variety in the first year and for Evropa 90 in the second year. Figures 2 and 3 show the determined interaction effects.

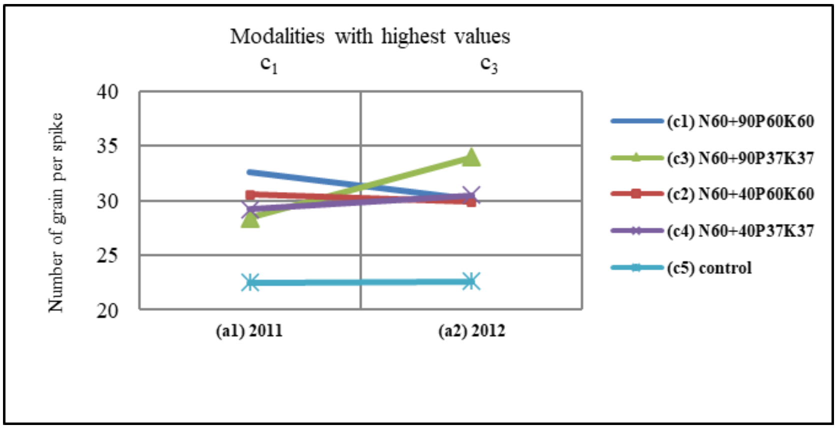


Figure 2. Interaction effect of the years (factor A) and fertilizations (factor C) on the number of grains per spike of wheat

The relations of interaction in Figure 2 show a varying distribution of means for the modality of the C factor (fertilization) over the two years of research (factor A): a_1 ($c_1 > c_2 > c_4 > c_3 > c_5$), and a_2 ($c_3 > c_4 > c_1 > c_2 > c_5$).

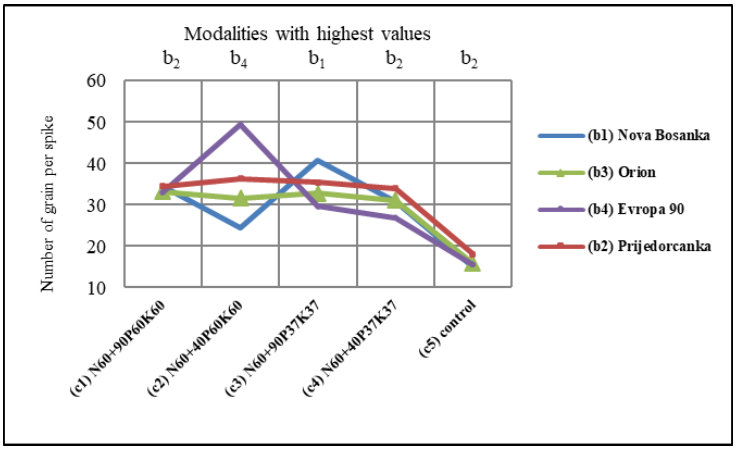


Figure 3. Interaction effect of the varieties (factor B) and fertilizations (factor C) on the number of grains per spike of wheat

The relations of interaction in Figure 3 show the existence of statistical relevance among the individual varieties especially for treatments k_2 and k_3. In addition, the number of grains per spike for the researched varieties for individual fertilization treatments is in the following relation: c_1 ($b_2 > b_1 > b_3 > b_4$), c_2 ($b_4 > b_2 > b_3 > b_1$), c_3 ($b_1 > b_2 > b_3 > b_4$), c_4 ($b_2 > b_3 > b_1 > b_4$), and c_5 ($b_2 > b_3 > b_4 > b_1$).

The measured values for the observed quantitative properties of the researched varieties of winter wheat in treatments with fertilization are in the range of mean values for domestic wheat varieties grown in natural lands. The maximum mean values of spike length for both years (8.25 and 8.5 cm) were measured where the applied dosage of nitrogen fertilizer was highest (90 kg $ha^{-1}N^{-1}$), which is consistent with the findings of Knežević et al. (2014), stating that wheat spike length increases with the increase of nitrogen dosage. As opposed to this property, the maximum mean value of grain numbers per wheat spike (48.75) was measured with the same dosage of nitrogen fertilizer, but with a lower content of the other elements ($N_{60+90}P_{37}K_{37}$). The mean grain number per spike for the Evropa 90 variety in the fertilized treatments was ranging from 29.8 in the first researched year to 31.5 in the second year, which is consistent with the two-year mean value of 35 grains for that variety as found by Stojković et al. (2010).

4. CONCLUSION

The two-year research in growing winter wheat within the biological phase of reclamation of the meliorated Deposol in the process of reclamation in the technogenic soil (Stanari lignite mine area) found the following component variability for the measured quantitative properties:

- the mean spike length was in the range of 5.0 to 8.5 cm, with a mean value of 6.71 cm;
- the measured maximum grain number per spike was 48.75, the minimum was 13.00, with a mean value of 29.05;
- the maximum spike length and grain number were measured when the dosage of nitrogen fertilizer was highest, while the lowest values were in the control;
- the maximum mean wheat spike length was for the Orion variety, and the minimum was for the Evropa 90 variety;
- a correlation was found in the Nova Bosanka variety between fertilization treatment, largest number of grains per spike (48.75) and lowest number of grains per spike (13.00);
- the combination of proper variety selection and appropriate dosages of fertilization has a significant impact on the success of the biological reclamation of degraded land;
- the applied agro-technical measures influence the productive properties of cultivated wheat crops in the observed agro-ecological conditions.

5. ACKNOWLEDGMENT

The research presented in this article is a part of a scientific project (Contract numbers: 451-03-66/2024-03/200216, 451-03-66/2024-03/200054) and is supported by the Ministry of Science, Technological and Development.

6. REFERENCES

Borras, L., Slafer, G.A., Otegui, M.O. (2004). Seed dry weight response to source-sink manipulations in wheat, maize and soybean: a quantitative reappraisal. Field Crop Res., 86, 131-146.

Denčić, S., Kobiljski, B., Mladenov, N., Pržulj., N. (2009). Production, yields and needs for wheat in the world and in our country. Institute for Agriculture and Vegetables, Novi Sad. Proceedings, 46 (II), 367–377. /in Serbian/

Hristov, N., Mladenov, N., Kondić-Šipka A., Štakić, S., Kovačević, N. (2008). Direct and indirect effects of individual properties on wheat grain yield. Institute for Agriculture and Vegetables, Novi Sad. Proceedings, 45, 15–20. /in Serbian/

Kneževic, D., Kondić, D., Marković, S., Marković, D., Kovacević, V. (2014). Genetic and phenotypic variability of length of spike in bread wheat grown under different rate of nitrogen nutrition. Book of Proceedings-Fifth International Scientific Agricultural Symposium "Agrosym 2014". Jahorina, 187-192.

Knežević, D., Laze, A., Paunović, A., Djurović, V., Đukić, N., Valjarević, D., Kondić, D., Mićanović, D., Živić, J., Zečević, V. (2020). Approaches in cereal breeding. Acta Agriculturae Serbica, 25(50), 179-186.

Kobiljski, B., Denčić, S. (1997). Characteristics of spike - selection criteria for wheat yield. Plant Breeders and Seed Producers, IV (3-4), 17–22. /in Serbian/

Kondić, D., Oručević-Žuljević, S., Hajder, Đ., Selimbegović, E. (2020). Evaluation of grain characteristics of domestics wheat (*Triticum aestivum* L.) obsolete cultivars and landraces. Italian Journal of Agronomy 2020, 15, 1345. www.agronomy.it/agro/article/view/1345

Kraljević-Balalić, M., Worland, A.J., Porceddu, E., Kuburović, M. (2001). Variability and gene effect in wheat. In: Monograph Genetic and Breeding of Small Grains. (Quarrie, S. et al., Eds.), 9-49.

Malić, N., Bijelić, V., Kovačević, G. (2010). Reclamation of technogenic soils in the Republic of Srpska. Proceedings of the 1st International Symposium "Modern Technologies in Mining and Environmental Protection-Mining 2010", Tara, 437–444. /in Serbian/

Malić, N., Matko-Stamenković, U., Nožinić, M. (2012). Technogenic Soils of Stanari Coal Basin as Ecological and Agricultural Resource. The First International Congress of Ecologists-Conference Proceedings of the Universitiy of Business Studies Banja Luka, Banja Luka, 651-659.

Malić, N., Mandić, D. (2014). Some quantitative properties of winter wheat (*Triticum aestivum* L.) grown on meliorated deposol. Agro-knowledge, 14(2), 285-295. /in Serbian/

Malić, N. (2015). Reclamation of Stanari Deposol by Agromeliorative Measures and Grass-Leguminous Mixture, PhD thesis. University of Banja Luka, Faculty of Banja Luka. /in Serbian/

Malić, N., Marković, M. (2021). The Dynamics of Chemical Properties in the Mine Technosols After Six Years of Reclamation. 3rd International and 15th National Congress of Soil Science Society of Serbia "Solutions for Future under Global Challenges", Book of Proceedings, Sokobanja, Serbia, 302–312.

Malić, N. (2023). Soil in Terms of Industrialization and Mining-Consequences and Soil Recovery. In: Environment. Ilić, P., Govedar, Z., Pržulj, N. (Eds.), Academy of Sciences and Arts of the Republic of Srpska, Banja Luka, Monograph LV, 327–376. https://doisrpska.nub.rs/index.php/ORUPRS/article/view/10758

Malić, N., Matko U., Trbić, M., Pijunović, R., Marković, M. (2023). Alternative Methods of Rehabilitation (Soil Recovery), Reclamation and Remediation of Mine Technosols. 30th

International Conference Ecological Truth & Environmental Research-Proceedings "Eco-TER’23". Stara Planina, Serbia, 283–288. https://eco.tfbor.bg.ac.rs/download/Zbornici/2023.pdf

Mandić, D., Đurašinović, G., Savić, B., Kikić, S. (2011). Nova Bosanka-New Variety of Winter Wheat. Genetika, 43, 3, 569-574.

Miralles, D.J., Slafer, G.A. (2007). Sink limitations to yield in wheat: how could it be reduced? Journal of Agricultural Science, 145, 139-49.

Perišić, V., Milovanović, V., Đekić, M., Staletić, M. (2011). Inheritance of spike length and number of grains per spike in wheat hybrids. XXV Conference of agronomists, veterinarians and technologists. Belgrade, Proceedings, 17(1–2), 19-26. /in Serbian/

Roljević, S., Cvijanović, D., Sarić, R. (2011). Genetic resources of wheat in the world and in Serbia. XXV Conference of agronomists, veterinarians and technologists, Belgrade. Proceedings, 17(1-2), 27-34. /in Serbian/

Stojković, S., Deletić, N., Biberdžić, M., Aksić, M., Beković, D. (2010). Yield and yield components of wheat genotypes on acidic soil. Agro-knowledge, 11(1), 91-97. /in Serbian/

Zečević, V., Knežević, D., Mićanović, D., Madić, M. (2008). Genetic and phenotypic variability of spike length and plant height in wheat. Kragujevac Journal of Science, 30, 1, 125-130.

Zečević, V., Knežević, D., Bošković, J., Mićanović, D., Dimitrijević, B. (2009). Genetic and phenotypic variability of number of spikelets per spike in winter wheat. Kragujevac Journal of Science, 31, 85-90.

doi:10.46793/MAK2025.169G

EFFICACY OF CERTAIN INSECTICIDES IN CONTROLLING THE CEREAL LEAF BEETLE (*Oulema melanopus* L.) IN WHEAT CROPS IN THE LAPLJE SELO AREA

Dragan Grčak[1], Cecilija Đokić[1], Milosav Grčak[1*], Andrej Sekularac[2], Snežana Gošić Dondo[3], Miroljub Aksić[1], Vera Rajičić[4]

[1]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohia, Serbia, *milosavgrcak@gmail.com, cecilija.djokic2331@gmail.com, miroljub.aksic@pr.ac.rs
[2]Independent researcher, Novi Pazar, Serbia, e-mail: sekularac.andrej@gmail.com
[3]Maize research institute "Zemun Polje", Laboratory of Phytopathology and Entomology, Belgrade, Serbia, sgosic@mrizp.rs
[4]University of Niš, Faculty of Agriculture in Kruševac, Kruševac, Serbia, verarajicic@yahoo.com

Abstract: Agricultural production heavily depends on pest and disease outbreaks, which often act as limiting factors. While the most environmentally friendly solution would be to completely eliminate or limit chemical treatments, such treatments are necessary due to a large number of factors. Therefore, minimizing the number of chemical treatments plays a crucial role in environmental protection. In an effort to find the most effective insecticide treatment against the economically significant pest cereal leaf beetle (*Oulema melanopus* L.), we tested the efficacy of insecticides in the field. The study was conducted in the area of Laplje Selo, Gračanica Municipality, Autonomous Province of Kosovo and Metohija, Serbia. In addition to climate changes that adversely affected the crop itself, the presence of pests was recorded, with the cereal leaf beetle (*Oulema melanopus*) being the most prevalent. The research was carried out during 2023/2024 on the Đokić family farm. Agro-meteorological conditions were favorable for the survival and development of the pest. The experiment examined the presence of the cereal leaf beetle on two wheat varieties, "Zvezdana" and "Sofra," with four variants. The first variant served as a control without chemical protection, while the other three variants were treated with insecticides containing different active ingredients in concentrations recommended by the manufacturers. Two foliar insecticides were used: Decis 2.5 EC (deltamethrin - 25 g L^{-1}) and Laidir 10 CS (lambda-cyhalothrin - 100 g L^{-1}), along with a seed treatment before sowing using the insecticide Coup 200 SL (imidacloprid - 200 g L^{-1}). Based on the research findings and monitoring of this pest, the highest intensity of infestation was observed in the control variant, while both foliar insecticides proved effective in protecting against the cereal leaf beetle. In the variant where seeds were treated before sowing, a lower infestation intensity was also recorded, with no significant damage observed. The insecticide Decis 2.5 EC demonstrated the highest efficacy when analyzing variations in damaged flag leaves. Both foliar insecticides achieved maximum efficacy (100%) 14 days after treatment.

Key words: Pest, Cereal leaf beetle, Insecticides, Pest control

1. INTRODUCTION

Chemical treatment against plant diseases and pests represents one of the most, if not the most important protective measures. However, due to improper or excessive pesticide application, can be harm beneficial flora and fauna and the overall biodiversity, as well as cause long-term environmental damage through various pollution processes (Mahmood et al., 2016). Moreover, the excessive use of chemical agents has negative economic consequences for farmers, as a single timely treatment is often sufficient to keep pests below the damage threshold that would significantly affect agricultural production (Garraway, 2020).

Wheat (*Triticum aestivum* L.) is the most widely used cereal in human nutrition worldwide, serving as a significant source of protein, carbohydrates, fats, vitamins, and micronutrients (Knežević et al., 2022; Philips et al., 2011). Today, cereal crops face numerous diseases and pests that cause substantial damage globally and locally, averaging around 11%. There have even been cases where entire wheat harvests were destroyed. Thus, appropriate protective measures are essential to ensure high and quality production (Staletić et al., 2011). Polyphagous insect species, which constitute approximately 80% of harmful fauna in cereal fields, along with oligophagous species (around 20%), reduce the yield and quality of agricultural products worldwide. This poses a significant limiting factor in crop production (Čamprag, 2007). The cereal leaf beetle (*Oulema melanopus*) is one of the economically most significant pests of cereals in Europe. It primarily attacks wheat, oats, and barley (Ćirić et al., 1993; Philips et al., 2011) but can also be found on other cereals (Kostov, 2001). It is estimated to cause yield reductions of 5-20% in cereal crops (Ihrig et al., 2001; Deutsch et al., 2018; Mazurkiewicz et al., 2021), while in Serbia, research shows it reduces yields by 2-30% (Dimitrijević et al., 2001; Stamenković, 2004; Milovac and Franeta, 2016).

The larvae of the grain beetle (*Oulema melanopus*) feed on meristem tissue cells and use their mouthparts to damage the upper side of the leaves, in the form of longitudinal, white stripes, thereby reducing the photosynthetic surface of the plant leaves, mainly the flag leaf, which has the greatest efficiency in the photosynthesis of organic matter (Dimitrijević et al., 2000). The greatest damage occurs when the flag leaf, essential for seed filling, is affected. Larvae are most prevalent during the latter half of May and the first half of June, while adult insects emerge in late June and early July. The fourth-stage larvae cause the most damage, accounting for approximately 70% of the total harm caused by this species (Milovac and Franeta, 2016). Therefore, it is most effective to control the pest during the early larval stages (I-II), when one or two larvae per plant can be observed (Dimitrijević et al., 2000; Stamenković, 2004; Tanasković et al., 2012).

Modern plant protection involves a variety of control measures, with chemical protection recommended as the last resort in integrated pest management. Due to its effective and rapid action, chemical methods remain the dominant and most commonly used approach for combating harmful organisms. However, excessive use of insecticides leads to environmental contamination, making it crucial to apply treatments at the most appropriate times (Chen et al., 2013). Before applying chemical substances (pesticides) against *Oulema melanopus*, it is necessary to conduct pest monitoring and carry out control measures based on population density and damage levels (Walczak, 2005). There are numerous methods for combating *Oulema melanopus*, with chemical measures being the most widely used. The most commonly used active ingredients in combating this pest include deltamethrin, lambda-cyhalothrin, and imidacloprid. Chemical treatments should be applied with consideration for the specific pest and environmental impact to ensure sustainable agricultural practices (Grčak, 2023).

The aim of this research was study of efficacy of insecticides with different active ingredients in preventing and combating a major pest of cereal crops, the cereal leaf beetle (*Oulema melanopus* L.).

2. MATERIAL AND METHODS

The research was conducted in a field trial at the Đokić family farm, located in Laplje Selo, Gračanica Municipality, during the 2023/24 season, on two wheat varieties: "Zvezdana," and "Sofra". During the study were occured unfavorable weather conditions occurred, a long dry period, uneven germination, and fewer tillers. The winter was with no low temperatures or snow cover, which led to wheat development without winter dormancy, thus favoring pest development.

Wheat crops care was conducted by chemical treatment of weed control and disease prevention, along with the use of growth regulators. The occurrence and intensity of the cereal leaf beetle

(*Oulema melanopus*) attack were monitored on four variants, arranged in a randomized block design, with each variant having three replications on the basic plot 1 m^2 in size. Variant 1- control without chemical insecticide protection. Variant 2 - plants originated from seeds were treated before sowing with the insecticide imidacloprid - 200 g L^{-1}. Variant 3 - plants Foliarly treated with using deltamethrin - 25 g L^{-1}. Variant 4 - Foliarly treated with lambda-cyhalothrin - 100 g L^{-1}. The treatment of the experimental plot was carried out on April 30, 2024, using a backpack sprayer. The efficacy of the insecticides was evaluated using the recommended concentrations: *deltamethrin* at 30 ml ha^{-1} and *lambda-cyhalothrin* at 70 ml ha^{-1}. The efficacy evaluation was conducted 2, 7, and 14 days after foliar treatment by determining the number of larvae m^{-2}. The insecticide efficacy was calculated using Abbott's formula, which is as follows:

$$E = \frac{\mathbf{U-T}}{\mathbf{U}} \mathbf{x\ 100}$$

Where: **E** is the efficacy of the tested insecticide in percentage, **U** is the number of live larvae in the untreated plot,**T** is the number of live larvae in the treated plot.

The damage caused by *Oulema melanopus* larvae to flag leaves was assessed on 10 randomly selected and marked plants before the appearance of the pest. Damage was evaluated using a four-level scale (Ulrich et al., 2004). The damage to the leaves caused by this pest was classified into four categories (Table 1). The damage was monitored only on the flag leaf and was determined by visually estimating the area of the leaf that had been eaten.

Table 1. Wheat leaf damage classes

Class	Damage to Leaf Surface
Class I (Grade 1)	Up to 10% of the leaf surface damaged
Class II (Grade 2)	10 - 20% of the leaf surface damaged
Class III (Grade 3)	20 - 40% of the leaf surface damaged
Class IV (Grade 4)	Over 40% of the leaf surface damaged

3. RESULTS AND DISCUSSION

The efficacy of insecticides calculated according to Abbott's formula is shown in Table 2. The insecticides Deltamethrin and Lambda-cyhalothrin were applied foliarly using a backpack sprayer, while Imidaclopridwas used as a seed treatment before sowing. The protection was carried out once, and the efficacy of the applied insecticides was monitored on days 2, 7 and 14. The assessments were performed visually, by examining each variant and looking for the number of live *Oulema melanopus* larvae.

Table 2. Insecticide efficacy (Foliar and seed treatment)

Variety	Treatment	2 days after treatment		7 days after treatment		14 days after treatment	
		Live larvae	Efficiency (%)	Live larvae	Efficiency (%)	Live larvae	Efficiency (%)
Zvezdana	Deltamethrin	3	78.57	1	94.44	0	100.00
	Lambda-cyhalothrin	4	71.43	1	94.44	0	100.00
	Imidacloprid	7	50.00	8	55.56	8	63.64
	Control	14	-	18	-	22	-
Sofra	Deltamethrin	2	75.00	1	92.31	0	100.00
	Lambda-cyhalothrin	2	75.00	2	84.62	0	100.00
	Imidacloprid	3	62.50	3	76.92	5	68.75
	Control	8	-	13	-	16	-

The insecticide Deltamethrin, even with the first treatment, showed very good efficacy. After the second day, the efficacy was 78.57% for the Zvezdana variety and 75% for the Sofra variety. After five days, or seven days post-treatment, the efficacy increased by nearly 20% (94.44% for Zvezdana and 92.31% for Sofra). Maximum protection was achieved fourteen days after treatment, when the efficacy reached 100%, with no larvae present on the leaves of both wheat varieties.

As for the insecticide Lambda-cyhalothrin, it also showed positive results right after the first efficacy assessment. The number of live larvae on the experimental field treated with this insecticide was 4 for the Zvezdana variety, with an efficacy of 78.6%. The number of live larvae of the grain fluke for the Sofra variety was 2, with an efficacy of 75%. Seven days after treatment, the number of live larvae found in the field for this experimental group decreased to 1 for Zvezdana, and the efficacy increased to 94.44%. For Sofra, 2 larvae of the pest were found, which was the same number as in the first assessment, but due to the increase in the number of larvae in the control group, the efficacy of the Lambda-cyhalothrin treatment increased to 84.62%. The best result was achieved after fourteen days, with 100% efficacy for both varieties.

In the third variant of the experiment, where the seed was treated before sowing with the insecticide Imidacloprid, somewhat different results were observed compared to the previous two foliar insecticides. Characteristic for this part of the experiment are the data showing that after the second day of treatment, the number of live larvae was lower than the number of larvae after fourteen days. For the Zvezdana variety, the assessment after the second day showed that the number of live larvae was 7, with an insecticide efficacy of 50%. Seven days after treatment, the number of live larvae was 8, and the efficacy increased to 55.56% due to the higher number of larvae in the control group. For the same variety (Zvezdana), 14 days after treatment, there was an increase in the number of larvae, which reached 8. The efficacy again increased to 63.64%, but only because the number of larvae in the control group had increased. For the Sofra variety, the assessment after the second day showed that the number of live larvae in the Imidacloprid seed treatment was 3, and the insecticide efficacy was 62.50%. Seven days after treatment, the number of live larvae remained 3, but the efficacy increased to 76.92% due to the increase in larvae in the control group. For the same variety (Sofra), 14 days after treatment with foliar insecticides, the number of larvae on the experimental group whose seed was treated with Imidacloprid increased to 5. The efficacy decreased to 68.75%.

As for the control variant, the number of larvae constantly increased. On the second day after some parts of the experiment were treated foliarly, the number of larvae counted was 14 for the Zvezdana variety and 8 for the Sofra variety. Five days later, that number increased to 18 for the Zvezdana variety and 13 for the Sofra variety. On the final evaluation day, 14 days after treatment, the control variant had 22 larvae for the Zvezdana wheat and 16 for the Sofra wheat.

Looking at the results, we can clearly observe that there was a difference between the two varieties. Such results can be explained by the greater affinity of the pest towards the Zvezdana wheat variety, since previous field results showed that the wheat stem sawfly chooses the plant species on which it will feed. The leaf width in wheat has an impact on reducing oviposition by up to 8 times (Wellso and Hoxie, 1988). The quality of the host plants themselves has a significant impact on the ability of phytophagous insects (Dosdall and Ulmer, 2004; Carcamo et al., 2005; Ishihara and Suzue, 2011). However, another factor that might have influenced the increased number of pests in the Zvezdana variety is that this variety had wheat as the preceding crop, while the Sofra variety had corn as the preceding crop. Regular crop rotation has extremely positive effects in protecting cereal crops from the wheat stem sawfly (Gotlin Čuljak and Juran, 2016). Additional research in this direction is needed to confidently determine what caused the significantly lower number of living larvae on the wheat plants of the Sofra variety compared to the plants of the Zvezdana variety.

The four-grade scale, modified and elaborated by Farook et al. (2018), originally described by Rouag et al. (2012), was used to assess the attack of the cereal leaf beetle. Damage was monitored only on the flag leaf and determined by visually evaluating the chewed area of the leaf. As part of the evaluation, ten randomly selected and marked plants were examined for each experimental group, with three replications, making a total of 30 plants evaluated. The attacked plants were categorized into four groups according to Table 1.

For both studied wheat varieties, a different degree of damage to the flag leaf as a result of the cereal leaf beetle attack was recorded (Table 3).

Table 3. Variation in the number of damaged flag leaves due to the attack of the cereal leaf beetle

Variety	Treatment	Severity of leaf damage									
		7 days					14 days				
		Healthy leaves	Grade 1	Grade 2	Grade 3	Grade 4	Healthy leaves	Grade 1	Grade 2	Grade 3	Grade 4
Zvezdana	Deltamethrin	27	3	0	0	0	27	3	0	0	0
	Lambda-cyhalothrin	25	5	0	0	0	25	4	1	0	0
	Imidacloprid	25	4	1	0	0	22	6	2	0	0
	Control	5	15	6	4	0	3	17	5	3	2
Sofra	Deltamethrin	29	1	0	0	0	29	1	0	0	0
	Lambda-cyhalothrin	27	3	0	0	0	27	3	0	0	0
	Imidacloprid	27	3	0	0	0	24	3	3	0	0
	Control	9	12	6	3	0	8	11	8	3	0

In both wheat varieties, it was found that the majority of plants with leaf damage caused by the larvae of the pest *O. melanopus* had damage to less than 10% of the leaf area (grade 1), a significantly smaller number had damage between 10-20% (grade 2), and fewer plants had damage between 20-40% (grade 3), with the smallest number showing more than 40% damage to the leaf area (grade 4). The intensity of damage greater than 40% of the leaf area was observed only in the Zvezdana variety and only in the control group (without insecticide) after 14 days, while it was not observed in treatments with insecticides or in the Sofra variety.

When observing only the treated plants, the majority exhibited no signs of pest damage, and these leaves were classified as healthy. In the case of the Deltamethrin treatment, plants that were affected showed a damage intensity of 1 (1 in Sofra, 3 in Zvezdana variety) to 10% of the leaf surface on the flag leaves. This level of damage was most prevalent across all treatments, including the control group. Damage intensities 3 and 4 were not observed in plants treated either foliar or through seed treatment before sowing (Figure 1).

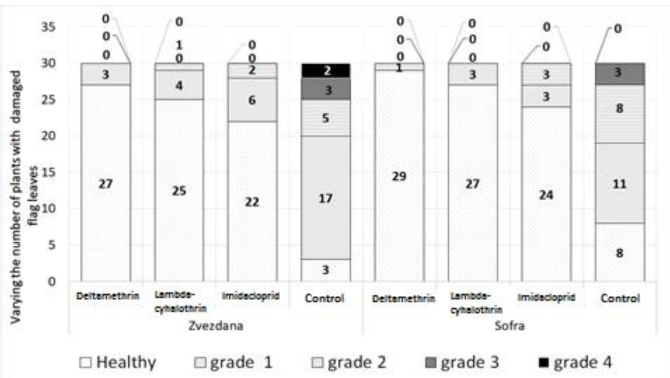


Figure 1. Variation of damaged plant leaves after 14 days with *O. melanopus* in wheat varieties

The damage to wheat plants caused by larval infestations of *Oulema melanopus* L. in open field conditions, with the use of insecticides, varied depending on the genotype and the insecticide applied. As shown in Figrue 1, the control group of the Zvezdana variety exhibited a higher proportion of severe attacks from the cereal leaf beetle (with up to 10 plants rated above 2 for infestation). Additionally, when comparing the number of plants with uninfested flag leaves, the control group of the Zvezdana variety had only 3 healthy flag leaves, while the control group of the Sofra variety had 8 healthy leaves.

The impact of the insecticides in the study yielded expected results, with all treated plants showing significantly fewer leaf damages compared to the control group, and a higher number of leaves showing no signs of pest damage. Once again, the Sofra variety demonstrated slightly better results. In all three treatment groups, Sofra had a higher number of uninfested plants: in the Deltamethrin treatment, 29 healthy plants compared to 27; in the Lambda-cyhalothrin treatment, 27 healthy plants compared to 25; and in the Imidacloprid seed treatment, 24 healthy plants in Sofra compared to 22 in Zvezdana.

Looking at the results, it is clear that the two foliar insecticide treatments differed in terms of the variation in damage to the flag leaves. Additionally, the seed treatment with Imidacloprid resulted in a higher number of infested plants in both varieties (8 for Zvezdana and 6 for Sofra) compared to the foliar treatments.

The differences in the intensity of pest attacks among wheat varieties have been confirmed in various studies. In an experiment conducted in the United States with entomological cages (Buntin et al., 2004), where varying numbers of *O. melanopus* egg masses were introduced into the cages and the effects of pesticides were monitored, variability was observed across five wheat varieties at two different locations. When analyzing plant resistance types against pests, tolerance is undoubtedly the most recognized. This mechanism enables the plant to compensate for pest damage without significant impacts on yield components, particularly when compared to plants with lower (or no) tolerance. In contrast, antixenosis is another form of resistance, where the plant possesses at least one trait that repels pests from attacking (Smith, 2005; Diaz-Montano et al., 2006; Gebretsadik et al., 2022). The results may indicate that certain genotypes in the study exhibit some resistance to *O. melanopus* through undesirable mechanisms (antixenosis), such as oviposition and feeding deterrents. Similar findings were reported in research conducted on Asian and local winter wheat varieties in Canada (El Bouhssini, 2014), where antixenosis was noted in the Asian genotype NN-100. However, the highest intensity of *O. melanopus* attacks was observed in Asian genotypes (NN-41, NN-45, and NN-27). The authors concluded that wheat genotypes developed in Central Asia exhibit certain adverse characteristics for pest feeding and oviposition, which should be further studied for advancing plant resistance to this pest.

The impact of the insecticide in our study yielded expected results, with all treated plants showing significantly less damage to the flag leaves compared to the control. Deltamethrin, used in the experiment and which had the best results, belongs to the pyrethroid chemical group, which are synthetic derivatives of natural pyrethrins extracted from *Chrysanthemum cinerariaefolium* (Metcalf, 2000). Pyrethroids are 2.250 times more toxic to insects than to vertebrates, primarily due to their smaller size, lower body temperature, and greater sensitivity of sodium channels (Bradberry et al., 2005). In controlling *Oulema melanopus*, the best results were achieved using insecticides from the pyrethroid "family" (Philips et al., 2011; Reisig et al., 2012). Furthermore, under the agroecological conditions of our country, pyrethroid insecticides have proven to be the most effective in combating *O. melanopus* (Milovac and Franeta, 2016), although in Croatia (Đopar, 2019), despite their excellent efficiency, a slight resistance of the cereal leaf beetle to pyrethroids was observed.

4. CONCLUSION

Based on the obtained results regarding the larval infestation of the pest *Oulema melanopus*, it can be concluded that the best results were achieved with the insecticide Deltamethrin, containing the active ingredient deltamethrin, for both wheat varieties tested. Additionally, the insecticide Lambda-cyhalothrin also produced very good results, while the seed treatment with the insecticide Imidacloprid showed diminishing efficacy over time.

Differences in the intensity of infestation and insecticide efficacy were also observed between the two wheat varieties. These differences in pest attack can be attributed to the higher resistance of the Sofra variety, but it is also important to consider the role of crop rotation. The wheat variety Zvezdana, following a wheat crop as the preceding crop, had a higher number of live larvae in the control group compared to the Sofra variety, which had corn as the preceding crop. This suggests that crop rotation contributed to the reduction of this pest species. This was reflected in a lower number of live larvae, less damage, and the prevention of resistance development to the applied treatments.

Timely foliar treatment with a highly effective insecticide, combined with proper agronomic practices-particularly crop rotation as one of the fundamental protection measures-can effectively protect against economically significant pests such as the cereal leaf beetle. Reducing the number of treatments helps decrease production costs and, more importantly, minimizes the impact on biodiversity and the environment.

5. ACKNOWLEDGMENT

This work was supported by the Project TR 31092, Ministry of Education, Science and Technological Development of the Republic of Serbia.

6. REFERENCES

Bradberry, S.M., Cage, S.A., Proudfoot, A.T., Vale, J.A. (2005). Poisoning due to pyrethroids. Toxicological reviews, 24, 93-106.

Buntin, G.D., Flanders, K.L., Slaughter, R.W., De Lamar, Z.D. (2004). Damage loss assessment and control of the cereal leaf beetle (Coleoptera: Chrysomelidae) in winter wheat. Journal of Economic Entomology, 97, 374- 382.

Carcamo, H.A., Beres, B.L., Clarke, F., Byers, R.J., Mundel, H.H., May, K., Depauw, R. (2005). Influence of plant host quality on fitness and sex ratio of the wheat stem sawfly (Hymenoptera: Cephidae). Environ Entomol, 34, 1579-1592.

Chen, R.Z., Klein, M.G., Sheng, C.F., Li, Y., Shao, D.X., Li, Q.Y. (2013). Use of pheromone timed insecticide applications integrated with mating disruption or mass trapping against *Ostrinia furnacalis* (Lepidoptera: Pyralidae) in sweet corn. Environmental entomology, 42(6), 1390-1399.

Čamprag, D. (2007). Reproduction of agricultural crop pests in Serbia and neighboring countries during the 20th century. Serbian Academy of Sciences and Arts, branch in Novi Sad, Novi Sad, 1-348. /in Serbian/

Ćirić, D., Knežević, D., Zečević, V., Mićanović, D. (1993). The influence of some agrotechnical measures on the degree of damage to winter wheat by grain leech (*Lema melanopus* L.). Contemporary Agriculture, 41(6), 418-419. /in Serbian/

Deutsch, C.A., Tewksbury, J.J., Tigchelaar, M., Battisti, D.S., Merrill, S.C., Huey, R.B., Naylor, R.L. (2018). Increase in crop losses to insect pests in a warming climate. Science, 361, 916-919.

Diaz-Montano, J., Reese, J.C., Schapaugh, W.T., Campbell, L.R. (2006). Characterization of antibiosis and antixenosis to the soybean aphid (Hemiptera: Aphididae) in several soybean genotypes. Journal of economic entomology, 99(5), 1884-1889.

Dimitrijević, B., Petrić, D., Mićanović, D., Knežević, D. (2000). Establishing of number and location of deposited eggs of cereal leaf beetle (Coleoptera, Chrysomelidae: *Lema melanopus* L.) in small grains. Kragujevac J. Science, 22, 87-92.

Dimitrijević, B., Petrić, D., Ignjatović-Ćupina, A., Knežević, D., Mićanović, D., Zečević V. (2001). Influence of larvae solidity of cereal leaf beetle (Coleoptera, Chrysomelidae: *Lema melanopus* L) on yield decreasing of small grains. Kragujevac J. Science, 23, 99-104.

Dosdall, L.M., Ulmer, B.J. (2004). Feeding, development, and oviposition of bertha armyworm (Lepidoptera: Noctuidae) on different host plant species. Environ Entomol., 33,756-764.

Đopar, K. (2019). Sensitivity of red wheat thrips (*Oulema melanopus* L.) to insecticides, Diploma thesis, 11-17. /in Croation/

El Bouhssini, M. (2014). Antixenosis resistance to *Oulema melanopus* (Coleoptera: Chrysomelidae) in central Asian wheat germplasm. Journal of Economic Entomology, 107, 410-416.

Farook, U.B., Khan, Z.H., Ahad, I., Aafreen, S., Rafieq, I., Yousuf, T., Yousuf, W., Jan, S., Manzoor, A., Wani, R. (2018). Screening for antixenosis resistance of winter wheat genotypes to cereal leaf beetles (*Oulema melanopus* L.). Int. J. Curr. Microbiol. Appl. Sci., 7, 3069-3073.

Garraway, J.L. (2020). Insecticides, Fungicides and Herbicides. In Biotechnology-The Science and the Business, CRC Press, 497-514.

Gebretsadik, K.G., Zhang, Y., Chen, J. (2022). Screening and Evaluation for Antixenosis Resistance in Wheat Accessions and Varieties to Grain Aphid, *Sitobion miscanthi* (Takahashi)(Hemiptera: Aphididae). Plants, 11(8), 1094.

Gotlin Čuljak, T., Juran, I. (2016). Agricultural entomology - systematics of insects. University of Zagreb, Faculty of Agriculture. /in Croation/

Grčak, D. (2023). Insecticidal effect of bifenthrin on the pests *Ostrinia nubialis* (Hbn.), *Oulema melanopus* (L.) and their effect on the yield and quality of corn, wheat and triticale. Doctoral dissertation, Faculty of Agriculture, Lešak, p. 252. /in Serbian/

Ihrig, R.A., Herbert, D.A., Van Duyn, J.W., Bradley, J.R. (2001). Relationship between cereal leaf beetle (Coleoptera: Chrysomelidae) egg and fourth-instar populations and impact of fourth-instar defoliation of winter wheat yields in North Carolina and Virginia. J. Econ. Entomol., 94, 634-639. doi.org/10.1603/0022-0493-94.3.634

Ishihara, M., Suzue, N. (2011). Greater impact of host plant species on oviposition of a willow leaf beetle, *Plagiodera versicolora* Laicharting (Coleoptera: Chrysomelidae) during the adult stage than in developing larval stage. Appl Entomol Zool., 46,125-130.

Knežević, D., Paunović, A., Djurović, V., Roljević Nikolić, S., Mićanović, D., Madić, M., Menkovska, M., Zečević, V. (2022). Improving the quality of wheat for human consumption. XXV Conference on biotechnology with international participation. Čačak, 25-26. March 2022, University of Kragujevac, Faculty of Agriculture, Proceedings, 27(2), 11-20. doi:10.46793/SBT27.011K /in Serbian/

Kostov, K (2001). Breeding wheat lines for host-plant resistance to cereal leaf beetle by using the cross-mutation method. Bulg J Agric. Sci., 7, 7-14.

Mahmood, I., Imadi, S.R., Shazadi, K., Gul, A., Hakeem, K.R. (2016). Effects of pesticides on environment. Plant, soil and microbes, volume 1, Implications in crop science, 253-269.

Mazurkiewicz, A., Jakubowska, M., Tumialis, D., Bocianowski, J., Roik, K. (2021). Foliar application of entomopathogenic nematodes against cereal leaf beetle *Oulema melanopus* L. (Coleoptera: Chrysomelidae) on wheat. Agronomy, 11(8), 1662.

Metcalf, R.L. (2000). Ullmann's Encyclopedia of Industrial Chemistry. Weinheim: Wiley-VCH. (41–43), 273-274. doi:10.1002/14356007.a14_263

Milovac, Ž., Franeta, F. (2016). Biology and control of cereal leaf beetle *Oulema melanopus* (Coleoptera: Chrysomelidae). Biljni lekar, 44(5-6), 517-527.

Philips, C.R., Herbert, D.A., Kuhar, T.P., Reisig, D.D., Thomason, W.E., Malone, S. (2011). Fifty years of cereal leaf beetle in the US: an update on its biology, management, and current research. J. Integral Pest Managment, 2(C1-C5). doi:10.1603/IPM11014

Reisig, D.D., Bacheler, J.S., Herbert, D.A., Kuhar, T., Malone, S., Philips, C., Weisz, R. (2012). Efficacy and value of prophylactic vs. integrated pest management approaches for management of cereal leaf beetle (Coleoptera: Chrysomelidae) in wheat and ramifications for adoption by growers. Journal of economic entomology, 105(5), 1612-1619.

Rouag, N., Mekhlouf, A., Makhlouf, M. (2012). Evaluation of infestation by cereal leaf beetles (*Oulema* spp.) on six varieties of durum wheat (*Triticum dirum* Desf.) seedlings in arid conditions of Setif, Algeria. Agriculture and Biology Journal of North America, 3(12), 525-528.

Smith, C.M. (2005). Plant resistance to arthropods: molecular and conventional approaches. Dordrecht: Springer Netherlands, 101-106.

Staletić, M., Milovanović, M., Perišić, V., Đekić, V. (2011). Značaj integralne zaštite strnih žita u povećanju konkurentnosti proizvodnje. Institut za primenu nauke u poljoprivredi (IPN), Belgrade, 162-171.

Stamenković, S. (2004). Occurrence and harmfulness of grain leech (*Oulema melanopus* L). Biljni lekar, 32(2), 124-131, /in Serbian/

Ulrich, W., Czarnecki, A., Kruszynski, T. (2004). Occurrence of pest species of the genus *Oulema* (Coleoptera: Chrysomelidae) in cereal fields in Northern Poland. Journal of Polish Agricultural Universities, 7(1), 4.

Wellso, S.G., Hoxie, R.P. (1988). Biology of *Oulema*. In Biology of Chrysomelidae.Springer, Dordrecht, 497-511.

doi:10.46793/MAK2025.178G

THE EFFECT OF INTERCROPPING WINTER OATS AND PEAS ON POWDERY MILDEW CONTROL AS A PROTECTIVE STRATEGY IN ORGANIC FARMING

Milosav Grčak[1*], Dragan Grčak[1], Desimir Knežević[1], Radivoje Jevtić[2], Vesna Župunski[2], Branka Orbović[2]

[1]University of Priština, temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohia, Serbia, *milosav.grcak@pr.ac.rs
[2]Institute of Field and Vegetable Crops Novi Sad, National Institute of the Republic of Serbia, Novi Sad, Serbia

Abstract: Intercropping cereals and legumes offers a sustainable and effective strategy for improving the health of organic farming systems. By combining cereal crops with legumes, this practice enhances biodiversity and promotes natural disease control, reducing the reliance on chemical pesticides and disrupts pest and disease cycles, ultimately leading to fewer outbreaks. Furthermore, legumes, such as peas, fix nitrogen in the soil, improving soil fertility and reducing the need for synthetic fertilizers. This study aimed to evaluate the variation in disease indices (DI) of powdery mildew in monocropping and intercropping systems with peas under different environmental conditions across two growing seasons. The field experiment was conducted over two consecutive seasons (2017/2018 and 2018/2019) at the Institute of Field and Vegetable Crops in Novi Sad. The experiment was set up in a randomized complete block design (RCBD) with four replications. A winter oat variety, Jadar, was used, while the intercropping legume was the winter pea variety, Kosmaj. Leaf infection percentages were assessed using the modified Cobb scale, and DI was calculated according to the standard formula. Statistical analyses, including ANOVA, Tukey pairwise comparisons, and two-sample t-tests, were used to determine significant differences in DI between oat plants across seasons and cultivation systems. The results of the Two-Sample T-test revealed a statistically significant difference between oats grown in different cultivation systems (P-Value = 0.000). Disease indices (DI) were significantly lower in oats grown in a mixture with peas (3.21) compared to oats grown as a monocrop (12.79). Tukey Pairwise Comparisons indicated that the DI of the stand-alone crop in the first growing season (14.92) was significantly higher than that of oats in the mixture during both the first (3.91) and second (2.50) growing seasons. Additionally, the DI of oats in the stand-alone crop in the second growing season (10.67) was significantly higher than that of oats in the oat-pea mixture in both growing seasons. No significant difference was found between the DI values of the stand-alone crops in the two seasons. Overall, the results suggest that intercropping winter oats with peas can reduce powdery mildew disease indices under varying climatic conditions.

Key words: Intercropping, Oat, Pea, Monocropping, Diseases

1. INTRODUCTION

Intercropping involves the concurrent cultivation of at least two different crop species grown near each other and typically during the same growing period (Li et al., 2014). The growing interest in cultivating a variety of plants together stemmed initially from the idea that a system featuring two distinct crops could enhance productivity by minimizing their respective limitations. Intercropping, particularly when combining cereals and legumes, provides numerous ecological and agronomic advantages, such as enhanced soil fertility, improved pest management, greater biodiversity, and the possibility of increased yields. However, successful intercropping demands careful planning and management to prevent competition for resources and ensure maximum benefits. Strip, mixed, and relay intercropping are agricultural practices that can significantly enhance crop yields by optimizing resource use and promoting mutual benefits between different crops. Mixed intercropping, where different crops are planted together in the same area, maximizes the use of available space and can lead to complementary interactions between plants, such as nitrogen fixation by legumes benefiting neighboring crops. By choosing compatible crops with complementary growth patterns and resource needs, farmers can maximize the effectiveness of intercropping systems and support more sustainable farming practices (Sobkowicz, 2006; Aziz et al., 2015; Sabolović, 2014).

Oat (*Avena sativa*) is a widely cultivated cereal crop, valued for its nutritional benefits, including high fiber content and essential nutrients. However, like many crops, oats are susceptible to various diseases, with *Blumeria graminis*, commonly known as powdery mildew, being one of the most significant pathogens. Powdery mildew is a fungal disease that primarily affects the leaves of oat plants, leading to the formation of white, powdery fungal growth. Over time, the disease weakens the plant by reducing photosynthesis, stunting growth, and ultimately decreasing yield and grain quality (O'Brien and White, 2016).

Intercropping oats with legumes, such as peas, is a sustainable agricultural practice that offers numerous benefits, particularly in disease management, environmental conservation, and reducing the need for synthetic inputs. The combination of cereals and legumes in intercropping systems promotes biodiversity, which plays a crucial role in reducing disease pressures and managing pests naturally. By fostering a more diverse ecosystem, intercropping can disrupt pest and disease cycles that would otherwise affect monocropped oats (Gecaitė et al., 2021).

The positive effects of intercropping on disease management are particularly evident in the reduction of diseases like powdery mildew. Oats intercropped with peas tend to have lower disease indices compared to monocropped oats, as the mixture encourages healthier plant growth through better nutrient cycling and less stress. This results in a less favorable environment for pathogens, reducing the reliance on fungicides. By minimizing plant disease outbreaks, intercropping also helps maintain the long-term health of crops, enhancing productivity and resilience (Arlauskienė et al., 2011). Intercropping oats with peas presents a promising strategy for managing powdery mildew. By promoting competition for resources, acting as a physical barrier to spore spread, altering the microclimate, and potentially offering allelopathic benefits, peas help reduce the incidence and severity of powdery mildew on oats. This natural approach can serve as an effective complement to traditional disease management practices, reducing the reliance on chemical fungicides and contributing to more sustainable farming systems (Boudreau and Larkin, 2011; Luo et al., 2017; Travadon and McFarland, 2021).

The aim of this study was to determine the variation of disease indices (DI) of powdery mildew in oat in monocropping and intercropping cultivating systems with pea under different environmental conditions in two growing seasons.

2. MATERIAL AND METHODS

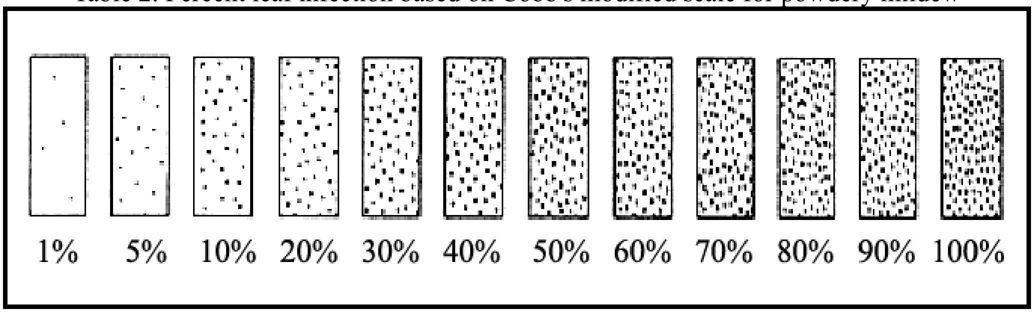
The field experiment was carried out over two consecutive growing seasons, 2017/2018 and 2018/2019, at the experimental field of the Institute of Field and Vegetable Crops in Novi Sad (45° 19′ N 19° 50′ E 80 m). The study was designed using a randomized complete block design (RCBD) with four replications. The winter oat variety Jadar was used for the experiment as well as winter pea variety Kosmaj. Mixed intercropping which involves planting two or more crops together in the same area without a specific row arrangemen was chosen as cultivation system. The sowing density per m^{-2} for monocrop of oat was 157 kg ha^{-1}, whereas the sowing density for the pea monocrop was 140 kg ha^{-1}. In the mixture 70% seeds of pea of recommended density m^{-2} and 30% of seeds of recommended density m^{-2} of small grain was used. The mixture was sown with 30 kg ha^{-1} of pea seeds and 140 kg ha^{-1} of oat seeds. The crops were grown without the use of any fertilizers or pesticides. The winter varieties were sown on October 27 in the first year of the experiment and on October 25 in the second year. The climatic factors are provided in Table 1.

Table 1. Values of weather factors during the 2017/18 and 2018/19 growing seasons

Month	Mean monthly temperature (ºC)		Relative air humidity (%)		Total monthly precipitation (mm)	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
July	24.3	22	56	77	12	81.2
August	24.8	24	55	68	17.4	51.2
September	16.9	18.5	70	70	81.5	27.1
October	12.5	14.9	75	65	38.9	7.4
November	7.1	8	83	78	40.3	24.6
December	3.8	1.7	84	88	48.3	59.2
January	4.3	0	81	87	47.5	45.8
February	1.2	4.2	86	74	81.9	17
March	5	9.8	82	57	60.6	15.9
April	17.2	13.4	60	65	49	54.1
May	20.4	14.7	67	78	64.2	147.6
June	21.5	23.2	74	73	163.2	63.7

From each experimental plot, five plants were sampled per repetition, resulting in a total of 20 plants for each plant type and cultivation system. The percentage of leaf infection was evaluated using the modified Cobb scale, as shown in Table 2 (Peterson et al., 1948; Kiss and Veres, 2017), during the phenophase 71-73 BBCH (grain filling; milk maturity). This phenophase was selected because it has been found to be closely associated with yield (Wegulo et al., 2009).

Table 2. Percent leaf infection based on Cobb's modified scale for powdery mildew



The Disease Index (DI) was calculated using the standard formula, while modified scale with values from 0 to 9, on the basis of which the assessment was made, is presented in Table 3.

Table 3. Leaf infection rating scale used to determine the disease index

Value	0	1	2	3	4	5	6	7	8	9
Degree of leaf infection	Without infection	1-10%	11-20%	21-30%	31-40%	41-50%	51-60%	61-70%	71-80%	≥81%

DI is calculated using the formula where v represents grade of infection (0-9); n - number of plants rated with a given rating; i - the highest grade on the scale and N - total number of evaluated plants.

The formula is expressed as follows: DI (%) = (Σ (v x n) / (i x N)) x 100.

The statistical data analysis was conducted using the Minitab 17 software (trial version). Statistical methods used to determine the significance of differences in DI between rye in different growing seasons and between different cultivation systems were Analysis of Variance (ANOVA), Tukey Pairwise Comparisons and Two-Sample T-Test.

3. RESULTS AND DISCUSSION

The data analysis revealed that the highest DI values were observed in oat as a stand-alone crop during the first growing season (14.92). In contrast, the lowest DI values (2.50) were recorded for oat in the mixture with peas, during the second growing season. Descriptive statistics are provided in Table 4.

Table 4. Disease index of powdery mildew in oat, in different cultivation systems, in two growing seasons

Variable	N	Mean	SE Mean	St Dev
Oat+Pea (2017/18)	20	3.91	0.81	3.64
Oat (2017/18)	20	14.92	1.33	5.96
Oat+Pea (2018/19)	20	2.50	0.74	3.31
Oat (2018/19)	20	10.67	1.96	8.78

The influence of year, cultivation system and joint effect of cultivation system and year (ANOVA) on disease index are shown in Table 5.

Table 5. Analysis of variance for Disease index of powdery mildew on winter oat at different variation sources

Source	DF	Adj SS	Adj MS	F-Value	P-value
Year	1	160.55	160.55	4.70	0.033
Cultivation System	1	1836.77	1836.77	53.72	0.000
C. System * Year	1	40.14	40.14	1.17	0.282
Error	76	2598.42	34.19	-	-
Total	79	4635.88	-	-	-
Model Summary					
S	R-sq		R-sq (adj)		R-sq (pred)
5.8472	43.95%		41.74%		37.89%

Regarding pathogen data, it was confirmed that the climatic conditions of the year had a significant impact on the occurrence of powdery mildew and disease index (P-value = 0.033). Cultivation system had a significant impact on disease index (P-value = 0.000) but the interaction of the cultivation system and the growing seasons did not have significant impact (P-value = 0.282). Looking at the R square it can be concluded that 43.95% of variance in the dependent variable is explained by the model. Values of R square (adj) show us that the model is both explanatory and not overly complex. Visual representation of data such as normal probability plot and histogram for DI of leaf rust residuals is given in Figure 1.

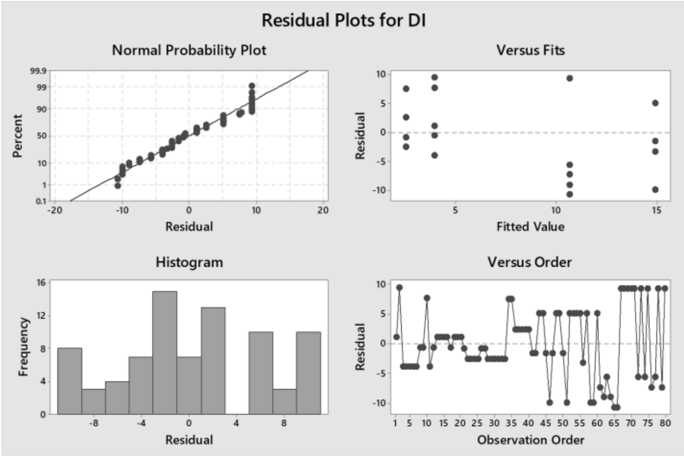


Figure 1. Residual plots for DI of powdery mildew on winter oat in different cultivation systems

Tukey pairwise comparisons (Table 6) revealed significant differences in Disease Index (DI) values across various cropping systems and growing seasons. Means that do not share a letter are significantly different. Specifically, the DI of oat as a stand-alone crop in the first (14.92) and second growing season (10.67) were significantly higher than that of oat grown in mixture with peas in both growing seasons. However, no significant difference was found between the DI of oat as a stand-alone crop in the first growing season (14.92) and oat as stand-alone crop in second season (10.67). There were also no significant differences between oat in mixture from first growing season (3.91) and oat in mixture from second growing season (2.50). These findings highlight the variability in DI across both cropping systems and seasons, with certain treatments showing pronounced differences in disease susceptibility. Differences of means for oat in mixture and oat in monocrop for both growing seasons are presented in Figure 2.

Table 6. Tukey pairwise comparisons - Grouping information using the Tukey method and 95% confidence

Factor	N	Mean	Grouping
Oat+Pea (2017/18)	20	14.92	A
Oat+Pea (2018/19)	20	10.67	A
Oat (2017/18)	20	3.91	B
Oat (2018/19)	20	2.50	B

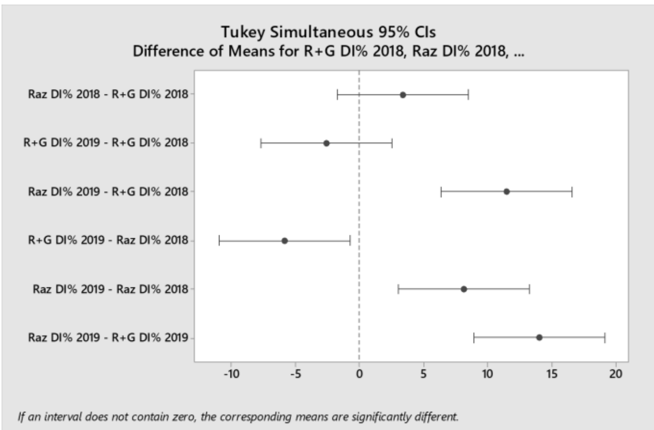


Figure 2. Differences of means for oat in different cultivation systems during both growing seasons

A two-sample t-test (Table 7) was used to compare the means of two independent groups, specifically the differences between different cultivation systems, to determine whether there is a statistically significant difference between them. The results indicate significant statistical difference between oat grown in different cultivation systems (P-value = 0.000). DI was significantly lower in oat grown in a mixture with peas (3.21) then in independent crop (12.79). This highlights the importance of cultivating small grains based on the principles of intercropping for effective pathogen control.

Table 7. Two-sample t-test determining the effect of intercropping on winter oat as a cropping system in terms of DI

	N	Mean	StDev	SE Mean
Oat+Pea DI	40	3.21	3.51	0.55
Oat DI	40	12.79	7.71	1.2
Difference = μ (Oat+Pea DI) - μ (Oat DI)				
Estimate for difference: -9.58				
95% CI for difference: (-12.25, -6.92)				
T-Test of difference = 0 (vs ≠)		T-value = -7.15	P-value = 0.000	DF = 78

Many authors emphasize the significant role of climatic factors in influencing the natural infection dynamics (Lõiveke and Tammaru, 1995; Lõiveke, 1999; Cook et al., 1999; Hardwick et al., 2000; Hovmoller, 2001; Krupinsky et al., 2002; Deacon, 2006; Jevtić et al., 2012). Hardwick et al. (2001) observed notable differences in the susceptibility of varieties to infections and found a positive correlation between the occurrence of foliar diseases and both air temperature and precipitation levels from sowing to yield formation. Our results align with these findings, further supporting this relationship.

Favorable weather conditions conducive to the development of powdery mildew were observed during both growing seasons. In the first growing season, in mid- to late March, an increase in temperature and high relative humidity facilitated the emergence of the first pathogen symptoms on small grain crops at the budding stage, with powdery mildew being the most prominent. These favorable conditions persisted throughout April, supporting the continued development of small grain powdery mildew. The agrometeorological conditions, characterized by higher-than-usual temperatures for this time of year, also contributed to the accelerated growth of winter crops. In the second growing season, April experienced significantly higher precipitation and increased air humidity compared to March, which further promoted the occurrence of the disease, with powdery mildew symptoms detected on small grains. The optimal temperature range for conidia germination of powdery mildew is reported to be between 1 and 30 °C, in the absence of water, while the optimal range for infection spans from 5 to 30 °C (Jevtić et al., 2012).

The reduced intensity of infection in small grains within intercropping systems, compared to those grown independently, aligns with findings from several studies, which suggest that intercropping small grains with peas helps control pathogens like powdery mildew and leaf rust. While intercropping is widely recognized for its potential to enhance biodiversity and reduce disease pressure, the precise mechanisms through which it influences these factors are still not fully understood. Numerous studies have highlighted that the diversity of host plants in intercropping systems can significantly impact pathogen suppression, improving overall disease control. This is in line with the findings of our research, which further supports the idea that increased plant diversity through intercropping can play a key role in managing pathogen populations and optimizing crop health (Mitchell et al., 2003; Garrett et al., 2009; Keesing et al., 2010; Dassou and Tixier, 2016). Intercropping holds considerable promise for managing pathogens in agricultural systems; however, several questions remain regarding the complex relationships between pathogen infection, crop yield, and quality.

4. CONCLUSION

In conclusion, intercropping oat with peas demonstrates potential benefits in pathogen management by reducing disease pressure, particularly for pathogens such as powdery mildew. While our findings support the role of intercropping in improving disease control, further research is needed to fully understand the interactions between crop yield, quality, and pathogen dynamics in such systems. Additionally, investigating the long-term effects of intercropping on soil health, biodiversity, and overall system sustainability will be essential to optimizing intercropping practices. By addressing these uncertainties, we can better harness the potential of intercropping as a sustainable strategy for integrated pest and disease management in diverse agricultural systems.

5. ACKNOWLEDGMENT

This research was supported by the Project TR 31092, Ministry of Education, Science and Technological Development of the Republic of Serbia.

6. REFERENCES

Arlauskienė, A., Maikštėnienė, S., Šarūnaitė, L., Kadžiulienė, Ž., Deveikytė, I., Žėkaitė, V., Česnulevičienė, R. (2011). Competitiveness and productivity of organically grown pea and spring cereal intercrops. Žemdirbystė Agriculture, 98(4), 339.

Aziz, M.A., Mahmood, M., Asif, A., Ali, A. (2015). Wheat-based intercropping: a review. The Journal of Animal & Plant Sciences, 25(4), 896-907.

Boudreau, M.A., Larkin, R.P. (2011). Biological control of plant diseases in intercropping systems. Plant Pathology, 60(6), 1101-1113.

Cook, R.J., Hims, M.J., Vaughan, T.B. (1999). Effects of fungicide spray timing on winter wheat disease control. Plant Pathology, 48, 33–50.

Dassou, A.G., Tixier, P. (2016). Response of pest control by generalist predators to local-scale plant diversity: A meta analysis. Ecology and Evolution, 6(4), 1143-1153.

Deacon, J.W. (2006). Fungi as plant pathogens. Fungal Biology, 4. University of Edinburgh, UK, 142-158.

Garrett, K.A., Zúniga, L.N., Roncal, E., Forbes, G.A., Mundt, C.C., Su, Z., Nelson, R.J. (2009). Intraspecific functional diversity in hosts and its effect on disease risk across a climatic gradient. Ecological Applications, 19(7), 1868-1883.

Gecaitė, V., Arlauskienė, A., Cesevičienė, J. (2021). Competition effects and productivity in oat-forage legume relay intercropping systems under organic farming conditions. Agriculture, 11(2), 99.

Hardwick, N.V., Jones, D.R., Slough, J.E. (2001). Factors affecting diseases of winter wheat in England and Wales 1989-98. Plant Pathology, 50, 453-462.

Hardwick, N.V., Slough, J.E., Jones, D.R. (2000). Cereal disease control – are fungicides the sole answer? In Proceeding of the International Conference on Pests and Diseases. Brighton, England. Pests & Diseases, 1-3, 647–654.

Hovmoller, M.S. (2001). Disease severity and pathotype dynamics of Puccinia striiformis f. sp. tritici in Denmark. Plant Pathology, 50(2), 181-189.

Jevtić, R., Maširević, S., Vajgand, D. (2012). The impact of climate change on diseases and pests of small grains and sunflowers in the Vojvodina region (Serbia). In Mihajlović, D. (Ed.). Essays on fundamental and applied environmental topics. Nova Science Publishers, Inc., 277-305.

Keesing, F., Belden, L.K., Daszak, P., Dobson, A., Harvell, C., Holt, R.D., Hudson, P., Jolles, A., Jones, K.E., Mitchell, C.E., Myers, S.S., Bogich, T., Ostfeld, R.S. (2010). Impacts of biodiversity on the emergence and transmission of infectious diseases. Nature, 468, 647-652.

Kiss, L., Veres, S. (2017). Study of yellow rust infection on various winter wheat genotypes. Columella -Journal of Agricultural and Environmental Sciences, 4(2), 27-32.

Krupinsky, J.M., Bailey, K.L., McMullen, M.P., Gossen, B.D., Turkington, T.K. (2002). Managing Plant Disease Risk in Diversified Cropping Systems. Agronomy Journal, 94, 198-209.
Li, L., Tilman, D., Lambers, H., Zhang, F.S. (2014). Plant diversity and overyielding: insights from belowground facilitation of intercropping in agriculture. New phytologist, 203(1), 63-69.
Lõiveke, H., Tammaru, I. (1995). The diseases and pests of the agricultural plants and their control. In: Lõiveke, H. (ed.). Handbook of plant protection. Tallinn, 82-107.
Lõiveke, H. (1999). The diseases of cereals and their control. In Older, H. (Ed.), Handbook of cereal cultivation. Saku, 135-149.
Luo, L., Zhang, Y., Wang, H. (2017). Effects of intercropping on plant diseases and pest control: A review. Field Crops Research, 202, 58-64.
Mitchell, C.E., Reich, P.B., Tilman, D., Groth, J.V. (2003). Effects of elevated CO_2, nitrogen deposition, and decreased species diversity on foliar fungal plant disease. Global Change Biology, 9, 438-451.
O'Brien, P.A., White, R.G. (2016). Disease Management of Powdery Mildew in Oats. Field Crops Research, 195, 44-53.
Peterson, R.F., Campbell, A.B., Hannah, A.E. (1948). A diagrammatic scale for estimating rust intensity on leaves and stems of cereal. Can. J. Res., 26, 496-500.
Sabolović, V. (2014). Združena setva jednogodišnjih krmnih leguminoza u organskoj poljoprivredi. Master rad. Univerzitet u Novom Sadu, poljoprivredni fakultet. Departman za ratarstvo i povrtarstvo. Novi Sad. /in Serbian/
Sobkowicz, P. (2006). Competition between triticale (*Triticosecale* Witt.) and field beans (*Vicia faba var. minor* L.) in additive intercrops. Plant Soil and Environment, 52(2), 47.
Travadon, R., McFarland, M. (2021). Intercropping legumes with cereals to reduce pathogen load. International Journal of Agricultural Sciences, 5(1), 27-40.
Wegulo, S.N., Breathnach, J.A., Baenziger, P.S. (2009). Effect of growth stage on the relationship between tan spot and spot blotch severity and yield in winter wheat. Crop Prot., 28, 696-702.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.186T

EFFECT OF SOWING TIME AND IRRIGATION REGIMES ON YIELD COMPONENTS OF SWEET CORN

Ivan Tupajić[1], Đorđe Moravčević[2], Marija Ćosić[2], Biljana Šević[1], Vesna Matejić[3], Nenad Đurić[1], Kristina Luković[1], Jelena Stojiljković[1*]

[1]Institute for Vegetable Crops, S. Palanka, Serbia, psssle.jelena@gmail.com
[2]University of Belgrade, Faculty of Agriculture, Belgrade-Zemun, Serbia
[3]University of Kragujevac, Faculty of Agronomy, Čačak, Serbia

Abstract: The objective of this study was to examine the feasibility of cultivating sweet corn in the agroecological conditions of the Šumadija region. During 2022/23, the most widespread hybrid of sweet corn on the Serbian market, 'Enterprise,' was tested. Two irrigation regimes were applied (full and reduced to 50%) along with a control treatment (natural moisture conditions). Harvest and cob analysis were conducted on average 22-25 days after pollination. Statistically significant higher values for the studied parameters were measured in the irrigated treatments across both sowing dates.

Keywords: Sweet corn, Sowing time, Irrigation regime, Yield components

1. INTRODUCTION

Sweet corn (*Zea mays* L. var. *saccharata* Sturt.), belonging to the Poaceae family and Zea genus, is a valuable vegetable crop (Sidahmed et al., 2024). It is grown and consumed fresh, either on the cob or as frozen kernels (Rattin et al., 2018). The kernels of sweet corn are harvested during the milk stage, characterized by a sweet flavour, thin endosperm and pericarp, soft texture, and high nutritional value (Oktem et al., 2004; Kwiatkowski and Clemente, 2007; Ugur and Maden, 2015). Due to its high sugar and nutrient content and extensive use in the food industry (Budak and Aydemir, 2018), sweet corn is among the most significant crops. Optimal productivity and quality of this crop depend greatly on several factors, particularly sowing time and irrigation regime, which influence key production characteristics such as cob length, diameter, weight, kernel weight, and dry matter content. With a short growth period, especially in early hybrids, sweet corn can be cultivated across multiple sowing dates under irrigated conditions (Shibzukhov et al., 2021).

In agricultural practice, the introduction of optimal sowing times and an appropriate irrigation system can significantly impact yield and cob quality, enhancing adaptation to agro-climatic conditions. Sowing time, hybrid selection, soil fertility, and irrigation are the main factors with the greatest influence on sweet corn productivity (Dekhane and Dumbre, 2017). The success of stable production largely depends on the level of applied agronomy, the skilful choice of hybrids, and weather conditions during the growing season (Stojiljković et al., 2023). For successful sweet corn production, irrigation is essential, and its advantage lies in adaptability to various cultivation systems (main, succession, or intercropped) as noted by Revilla et al. (2021).

Previous research suggests that adjusting sowing time can play a critical role in sweet corn's morphological, productive, and chemical characteristics. Optimal use of moisture and nutrients, along with achieving stable yields, relies heavily on adapting the sowing date (Kara, 2011; Banotra et al., 2021; Kılınç et al., 2023). Additionally, selecting an appropriate irrigation method and water amount is vital for improving yield and cob quality. Numerous studies have demonstrated the positive impact of irrigation on cob length, showing that additional watering during flowering and growth stages increases cob length, while reduced irrigation during these periods shortens it (Nemeskeri et al., 2019).

Beyond increasing cob diameter and length, research has also shown the significant impact of optimal irrigation on cob and kernel weight. Given the importance of sweet corn production, it is evident that sowing time and irrigation regime are critical to its productive characteristics. This study aimed to examine the impact of different sowing dates and irrigation regimes on cob length, diameter, total cob weight, kernel weight, and dry matter content in sweet corn.

2. MATERIAL AND METHODS

A two-year study was conducted during 2022 and 2023 in the fields of the village of Bresje, Velika Plana municipality. The experiment was set up using a randomized block design with four replications. Sowing was performed in two planting periods: the first in the regular (spring) season and the second in the successive (summer) season. The row spacing was 70 cm, and the plant spacing was 22 cm. The study focused on the most widely cultivated sweet corn hybrid in Serbia, Enterprise F_1.

Irrigation was applied using a drip system with tapes having a capacity of 10 L m^{-1} h^{-1}. Two irrigation norms were applied: (I) full irrigation norm (100%), (II) 50% of the full irrigation norm, and a control treatment under natural moisture conditions. To maintain soil moisture at 60% field capacity, measurements were made with tensiometers in all treatments at a depth of 0.3 m. The irrigation norm was calculated using the formula:

$$Nz = 10 \cdot D \cdot (FC\%\ vol - \theta z) = mm \cdot m^{-2}$$

Where represents the irrigation norm (mm m^{-2}), is the depth of the soil layer (m), is the field capacity limit in percentage by volume, and is the soil moisture read from the tensiometer curve at the measured water retention force. The field capacity limit was determined in the laboratory at the Faculty of Agriculture in Zemun.

The irrigation duration was calculated from the irrigation norm and the flow rate of the drip tape system (10 L h^{-1} or 10 mm h^{-1}). By halving the irrigation duration, the duration for the reduced irrigation volume (50% of the full norm) was determined. Standard agronomic practices for sweet corn production were applied throughout the growing season.

Morphological and productive traits of the cobs were measured 22-25 days after pollination on 30 cobs per treatment. The dry matter content of sweet corn was estimated using the conventional drying method at 105 °C to a constant mass. The obtained research results were statistically processed using analysis of variance and tested by the LSD test (Least Significant Difference) in IBM SPSS Statistics, version 26.0, and are presented in tables and graphs.

3. RESULTS AND DISCUSSION

Table 1 presents the average values of the investigated yield components of sweet corn, which were influenced by the sowing date and irrigation norms during the two-year study. The sowing date factor did not have a statistically significant impact on the cob length of sweet corn (Table 2). The average cob length was approximately 20 cm for both sowing dates. The irrigation factor, however, had a statistically significant effect on this trait, with the highest value measured in the IR 100% treatment (22.05 cm).

There were no significant differences between the irrigation norms (IR 100% and IR 50%), as shown by the measured approximate values in these treatments. Water deficiency negatively affected the cob diameter and length (Moosavi, 2012). Deng et al. (2009) note that cob length is a highly variable trait, while Kara (2011) suggests that cob length is dependent on the sowing date.

Table 1. Investigated parameters in both sowing dates under different irrigation norms

Date of sowing (A)	Irrigation (B)	Cob length (cm)	Cob diameter (cm)	Total mass cob (g)	Grain weight (g)	Dry matter (%)
I	Control	19.70	4.26	213.4	122.80	32.57
	IR 50%	21.52	4.80	306	188.00	35.61
	IR 100%	22.05	4.88	318.9	207.40	33.56
Average		21.90	4.65	279.4	172.70	33.91
II	Control	19.29	4.69	230.00	146.50	34.44
	IR 50%	21.73	5.16	343.30	242.20	34.16
	IR 100%	21.85	5.27	345.30	236.90	39.18
Average		20.96	5.01	306.20	208.50	35.93
Average/Average		21.43	4.83	292.80	190.60	34.92

Table 2. Impact of sowing date and irrigation on sweet corn yield components

Parameters of sweet corn	Cob length (cm)		Cob diameter (cm)		Total mass cob (g)		Grain weight (g)		Dry matter (%)	
Factors	$A^{nz} B^{**} AB^{**}$		$A^{**} B^{**} AB^{**}$		$A^{**} B^{**} AB^{**}$		$A^{**} B^{**} AB^{**}$		$A^{**} B^{**} AB^{**}$	
LSD	p< 0.05	p< 0.01	p< 0.05	p< 0.01	p< 0.05	p< 0.01	p< 0.05	p< 0.01	p< 0.05	p< 0.01
Date of sowing (A)	0.61	0.80	0.86	0.11	17.22	22.69	14.25	14.25	0.99	1.36
Irrigation (B)	0.61	0.80	0.86	0.11	17.22	22.69	14.25	18.78	1.21	1.66
A x B	1.05	1.38	0.15	0.20	29.82	39.30	24.69	32.54	1.71	2.35

Regarding cob diameter (Figure 1), the average value ranged from 4.88 to 5.01 cm, with sowing date and irrigation norms having a statistically very significant impact on this trait. The highest value was measured on the second sowing date, under the IR 100% treatment (5.27 cm). Water deficiency negatively affects sweet corn development, cob diameter, and mass, as concluded by Nemeskeri et al. (2019). Luchinger and Kamilo (2008) state that cob diameter varies depending on the hybrid and sowing date.

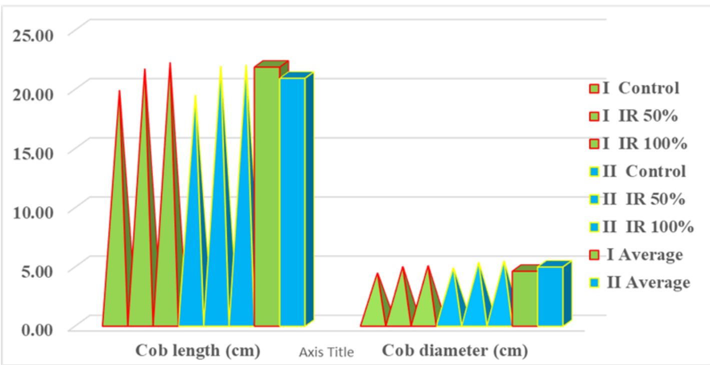


Figure 1. Average values of sweet corn cob length and diameter (cm)

Total cob weight (Figure 2) varied significantly by sowing date, with values ranging from 279.40 g for the first sowing date to 306.20 g for the second sowing date. In the non-irrigated treatment, the total ear weight was 213.40 g on the first sowing date and 230.00 g on the second, which is considerably lower than the values obtained in the irrigated treatments. The highest average value was recorded on the second sowing date under the IR100% treatment, which amounted to 345.30 g. There were no statistically significant differences between the total cob mass in the reduced and full irrigation norms. Kara (2011), in an experiment with five sowing dates, observed significant differences between sowing dates regarding cob length, diameter, and mass. The largest cob diameter, length, mass, and number of grains per cob were achieved with sowing on May 1, while the smallest parameters were obtained with sowing on June 1.

In the non-irrigated treatment, a decrease in grain yield was observed, particularly in terms of the number and mass of grains, which aligns with the results of Illés et al. (2022). In the control treatment, the average grain mass was 122.80 g on the first sowing date and 146.50 g on the second sowing date. The treatments with different irrigation norms resulted in significantly higher values in both sowing dates (207.40 g and 242.20 g). Both investigated factors (sowing date and irrigation) and their interaction had a statistically significant effect on this trait. Irrigation, especially in post-sowing treatments, influences yield components, contributing to higher farm income and maintaining crop rotation practices (Aydinsakir et al., 2013). Water deficit conditions negatively affect the yield and yield components of sweet corn, as noted by Ertek et al. (2013). They also mention that the highest yield is achieved with full irrigation, and any reduction in irrigation norm leads to a direct decrease in yield. In non-irrigated conditions, yield and yield components vary significantly across years and sowing dates (Biberdžić et al., 2018), with the highest yield achieved by sowing in mid-and late April in the first year of research, and early and mid-April in the second year. Stojiljković et al. (2024) also found that late sowing under non-irrigated conditions resulted in a drastic yield reduction for all sweet corn hybrids. Recent years, with significant temperature fluctuations and irregular rainfall distribution during the growing season, have made irrigation crucial for achieving stable yields in sweet corn production. Tupajić et al. (2024) confirmed that in both sowing dates, all three sweet corn hybrids under the non-irrigated condition produced the lowest values for the investigated parameters.

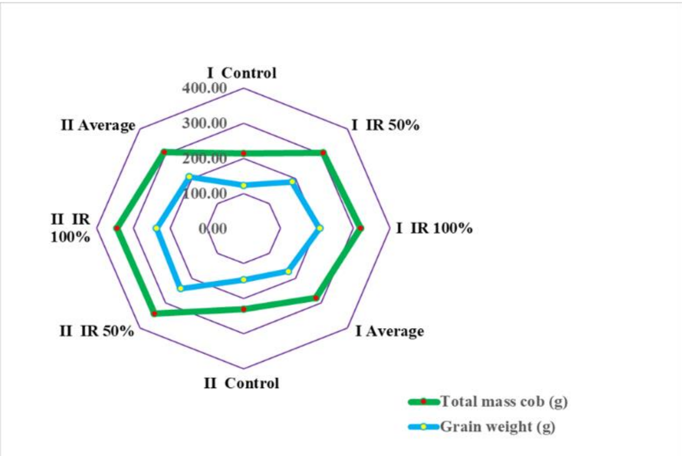


Figure 2. Presents the dry matter content in sweet corn for both sowing dates and all treatments.

Dry matter content in sweet corn kernels (Figure 3) showed a statistically significant effect from both the individual factors and their interaction. The content of dry matter is crucial for evaluating the quality and nutritional value of the grain, because it is the dry matter that affects the energy value and nutritional properties of the product. The highest average values were recorded in the first sowing date under the IR 50% treatment, amounting to 35.61%, while the best result in the second sowing date was achieved in the IR 100% treatment, with a value of 39.18%. Kara et al. (2012)

found that dry matter content decreases with later sowing dates in a two-year study. The highest dry matter content was achieved with sowing on April 1, which contrasts with the results of this study. Water deficiency significantly reduces dry matter content in sweet corn, as noted by Karam et al. (2003), whose findings align with those presented in this study.

Drip irrigation allows efficient water to be used by reducing surface water evaporation (Visvanatha et al., 2002; Oktem et al., 2003). In the study by Kılınç et al. (2023), optimal sowing times were studied in relation to the corn hybrid. They found that later sowing negatively affected ear yield and quality in certain hybrids.

Muslimah et al. (2023) state that drip irrigation is a highly productive and economical agricultural practice in sweet corn production. Dagdelen et al. (2006) determined that water deficiency significantly impacted corn yield, with the highest yield achieved in the irrigated treatments. Pandei et al. (2000) found that non-irrigated conditions led to a yield reduction of 22.6-26.4%.

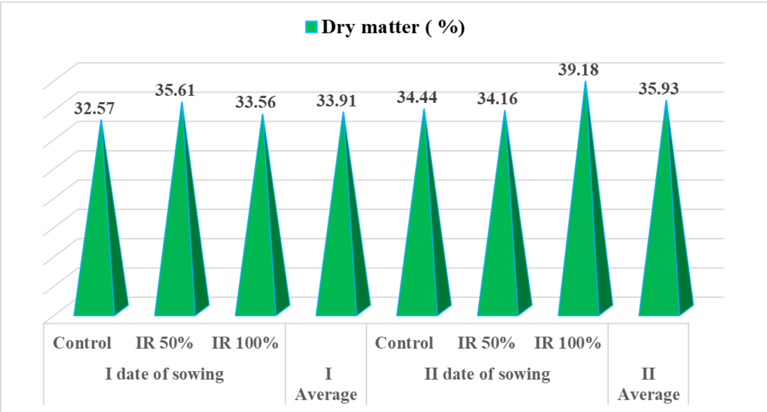


Figure 3. Dry matter content in sweet corn in both sowing dates across all treatments.

4. CONCLUSION

Based on the results of the research, it can be concluded that sweet corn can be successfully grown in the agroecological conditions of the Šumadija region in both sowing periods. The sowing date had a statistically significant impact on the examined parameters, with the best results, on average, achieved in the post-sowing period in both years of the study. In treatments with different irrigation norms (reduced and full norm), statistically significantly higher values for yield components were observed compared to those in the control treatment. Good results were also achieved with the application of drip irrigation, even with a reduced irrigation norm (50% of the full norm). This indicates favourable economic aspects in sweet corn production, ensuring more stable yields in dry years, which are a consequence of the significant climate changes witnessed in recent years.

5. ACKNOWLEDGMENT

The research presented in this article is part of the research project number 451-03-66/2024-03/200216 funded by the Ministry of Science, Technological Development, and Innovation of the Republic of Serbia.

6. REFERENCES

Aydinsakir, K., Erdal, S., Buyuktas, D., Bastug, R., Toker, R. (2013). The influence of regular deficit irrigation applications on water use, yield, and quality components of two corn (*Zea mays* L.) genotypes. Agric. Water Manag., 128, 65-71.

Banotra, M., Sharma, B.C., Kumar, R., Mahajan, A., Nandan, B. (2021). Cultivars and Planting times ffect on growth, yield, quality and economics of sweet corn (*Zea mays* var. *saccharata*) under different conditions. Review, 52 (1), ISSN: 00845841

Biberdžić, M., Stojiljković, J., Barać, S., Đikić, A., Prodanović, D., Lalević, D. (2018). The influence of hybrids and sowing terms on yield and dry down of corn grain. Genetika, 50(3), 959-970. doi.org/10.2298/GENSR1802449B

Budak, F., Aydemir, S.K. (2018). Grain yield and nutritional values of sweet corn (*Zea mays* var. *saccharata*) in produced with good agricultural implementation. Nutrition and Food Science International Journal, 7(2),1-5. doi.org/10.19080/NFSIJ.2018.07.555710

Dagdelen, N., Yılmaz, E., Sezgin, F., Gurbuz, T. (2006). Water-yield relation and water use efficiency of cotton and second crop corn in western Turkey. Agric. Water Management, 82(1-2), 63-85.

Dekhane, S.S., Dumbre, R.B. (2017). Influence of different sowing dates on plant growth and yield of hybrid sweet corns. Adv. Res. J. Crop Improv, 8(2), 191-194.

Deng, R., Wang, Y., Zhen, C., Zhou, Q. (2009). Effect of different sowing date on the growth and development of super sweet corn. http://en.cnki.com. cn/Article_en/CJFDTOTAL-FSDX200903003.htm

Ertek, A., Kara, B. (2013). Yield and quality of sweet corn under deficit irrigation. Agricultural Water Management, 129, 138-144.

Illés, A., Szabó, A., Mohammad, S., Mousavi, N., Bojtor, C., Vad, A., Harsányi, E., Sinka, L. (2022). The influence of precision dripping irrigation system on the phenology and yield indices of sweet maize hybrids. Water, 14, 2480. doi.org/10.3390/w14162480.

Kılınç, S., Atakul, Ş., Kahraman, Ş., Aktaş, H., Erdemci, İ., Gül, İ. (2023). EThe effect of sowing times on some yield and quality characteristics of sweet corn (*Zea mays* sacchararata Sturt.) varieties. Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi, 26(2), 282-292.

Karam, F., Breidy, J., Stephan, C., Rouphael, J. (2003). Evapotranspiration, yield and water use efficiency of drip irrigated corn in the Bekaa Valley of Lebanon. Agric. Water Management, 63(2), 125-137.

Kara, B. (2011). Fresh ear yield and growing degree-days of sweet corn in different sowing dates in southwesern Anatolia region. Turkish Journal of Field Crops, 16(2), 166-171.

Kara, B., Atar, B., Gul, H. (2012). Effects of different sowing dates on protein, sugar and dry matter of sweet corn. Res. on Crops, 13(2), 493-497.

Kwiatkowski, A., Clemente, E. (2007). Características do milho doce (*Zea mays* L.) para industrialização. Revista Brasileira de Tecnologia Agroindustrial, 1, 93-103.

Moosavi, S.G. (2012). The effect of water deficit stress and nitrogen fertilizer levels on morphology traits, yield and leaf area index in maize. Pak. J. Bot., 44, 1351-1355.

Muslimah, Y., Lizman. S.F., Harahap. E.J., Jasmi, R. (2023). Effect drip irrigation and genotypes on the production traits of sweet cprn (*Zea mays* saccharata sturt). SABRAO Journal of Breeding and Genetics, 55(3), 984-991.

Nemeskeri, E., Molnar, K., Racz, C., Dobos, A.C., Helyes, L. (2019). Effect of Water Supply on Spectral Traits and Their Relationship with the Productivity of Sweet Corns. Agronomy, 9, 63. doi.org/10.3390/agronomy9020063

Oktem, A., Simsek, M., Oktem, A.G. (2003). Deficit irrigation effects on sweet corn (*Zea mays* var. *saccharata* Sturt) with drip irrigation system in a semi-arid region: I. Water-yield relationship. Agricultural water management, 61(1), 63-74.

Oktem, A., Oktem, G., Coskun, Y. (2004). Determination of Sowing Dates of Sweet Corn (*Zea mays* L. *saccharata* Sturt.) under fianl›urfa Conditions. Turkish Journal of Agriculture and Forestry, 28, 83-91.

Rattin, J., Molinari, J., Giardina, E., Di Benedetto, A. (2018). Tools for improving sweet corn yield. International Journal of Advances in Agriculture Sciences, 3(10),1-14.
Revilla, P., Anibas, C.M., Tracy, W.F. (2021). Sweet corn research around the world 2015-2020. Agronomy, 11(3), 534.
Shibzukhov, Z., Kishev, A., Shibzukhov, Z., Eziev, M., Akbar, I. (2021). Sowing time influence on the sweet corn productivity in the mountainous ecologically clean zone of Kabardino-Balkaria. E3S Web of Conferences 262, 03024, ITEEA.
Sidahmed, H., Illes, A., Almahi, A., Nagy, J. (2024). Performance of agricultural factors on yield of sweet corn (*Zea mays* L. Saccharata) - A review. Acta Agraria Debreceniensis, doi.org/10.34101/actaagrar/1/12830
Stojiljković, J., Rajičić, V., Đurić, N., Biberčić, M., Trzić, D., Rakonjac, A., Zečević, V. (2023). Uticaj hibrida različitih FAO grupa zrenja i agroekoloških uslova na prinos kukuruza, Zbornik radova: Nacionalni naučni skup sa međunarodnim učešćem Biotehnologija i savremeni pristup u gajenju i oplemenjivanju bilja, Smederevska Palanka, 198-205.
Stojiljković, J., Rajičić, V., Đurić, N., Biberdžić, M., Luković, K., Perišić, V., Zečević, V. (2024). The effect of climate factors on maize yield of late sowing date. 2nd International Symposium on Biotechnology, 47-53.
Tupajić, I., Moravčević, Đ., Ćosić, M., Šević, B., Stojiljković, J., Stevanović, D., Sudimac, M. (2024). Influence of sowing time and irigation on yeld components sweet corn hybrids. Biotehnologija i savremeni pristup gajenju i oplemenjivanju bilja. Smederevska Palanka, Zbornik izvoda, 78-81.
Ugur, A., Maden, H.A. (2015). Sowing and planting period on yield and ear quality of sweet corn (*Zea mays* L. var. *saccharata*). Ciência e Agrotecnologia 39(1), 48-57. doi.org/10.1590/s1413-70542015000100006.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.193N

GRAIN YIELD OF BUCKWHEAT (*Fagopyrum esculentum* Moench) IN DIFFERENT SOW DENSITIES

Olivera Nikolić[1*], Zorana Srećkov[1], Vladimir Sabadoš[2]

[1]University Educons, Faculty of Ecological Agriculture, Sremska Kamenica, Serbia
*olivera.nikolic@educons.edu.rs
[2]Agricultural Advisory and Professional Service, Sombor, Serbia

Abstract: The buckwheat is a current plant due to its compliance with the demands of sustainable agriculture and the high standards of the modern population when it comes to food and dietary regimes. The aim of the work is to explain the influence of sowing densities on grain yield of common buckwheat and the existence of economic reasons for increasing the sowing density. So, 12 genotypes were examined, in 2 years and 3 sowing densities: 160, 120 and 80 kg grains m^{-2}. Results showed there was not a significant difference between average grain yield reached by 120 and 160 kg grains m^{-2}. Such result indicates economic viability of buckwheat growing.

Key words: Buckwheat, Grain yield, Sow density

1. INTRODUCTION

Contemporary, sustainable agriculture faces to very difficult task nowadays: to improve production and provide sufficient amounts of health safe food, for the growing human population, but to reduce use chemical matters and soil degradation and meet all other ecological and socioeconomical requirements. Consequently, it needs changes in practices agriculture, in comparison with conventional, industrialized agriculture, has been done. Beside numerous new and modified agricultural methods, these changes necessarily refer to the sowing structure and the choice of plant species cultivated. Buckwheat (*Fagopyrum* sp.) is a promising environmentally friendly crop that can contribute to the balance between biodiversity benefits and crop yield and meet all above-mentioned requirements and challenges of contemporary agriculture. Its advantages are: high adaptability to organic and sustainable agricultural practices, weed suppressing, allelopathic effects, different uses in agriculture practice (cover crop, fodder, green manure), high valued grain chemical composition and high qualitative products with wide range of benefits in everyday life and healthy diet, important role in food and biotechnology industries and rich source of desirable genes (Zamaratskaia et al., 2023).

Buckwheat is a pseudocereal, alternative minor crop, with long cultivation tradition, for more than 7.000 years. It originated from Asia, but, nowadays, buckwheat is mostly grown in Eurasia, Nordic countries, but in North America, too. Two worldwide most cultivated species are common buckwheat *(Fagopirym esculentum*) and Tartary buckwheat (*F. tartaricum*), although about 4,500 buckwheat varieties are known in the world, adapted to growing in certain climatic and production conditions, used, mainly, as forage and in traditional medicine (Naumović, 2017). In general, the morphological characteristics and growing technology of Tartary buckwheat are like common buckwheat, but there are some differences. Tartary buckwheat has many desirable characteristics such as higher seed yield, self-pollination ability, frost resistance, and overall plant vigor (Gavrić et al., 2018).

Taking into consideration all agronomical and qualitative advantages of buckwheat and the compatibility specific characteristics of its products with the requirements of the contemporary human population, it would be expected its production would continuously grow. Buckwheat production, on the contrary, has shown oscillations, during the last period, in the world. Vieites-Álvarez et al. (2024) analyzed buckwheat production, in period 2013-2023 and registered decreasing from 2.263.764.35 tons in 2013 to 187.506.797 tons, in 2021. At the same time, the growing area decreased from 2.263.608 ha worldwide to, seven years later, to 1.988.534 ha. In the meantime, according to FAO, in 2017, buckwheat was cultivated in 25 countries with the total cultivated acreage of 3.940.526 ha with the total production was 2.056.585 t (www.fao.org/faostat/en/#data/QCL). Pirzadah and Rehman (2021) concluded that such trend is, probably, related to more than one reason, citing, among others, erratic yield, indefinite growing cycle, difficult during harvesting, tendency for abortion of flowers, sensitivity to freezing conditions, the presence of allergy-inducing compounds, economic limitations, consumers habits, etc. The possibility for more mass and stable cultivation of buckwheat is a combination of modern and classical selection methods in breeding buckwheat in order to overcome the difficulties of low yield, difficult harvesting and unstable flour quality, preharvest sprouting resistance, shattering resistance and lodging resistance (Morishita et al., 2020; Nikolić et al., 2024). Such an approach requires a well knowing structure of yield, specific conditions and environmental and agronomic factors influencing grain composition and formatting as well as other physiological processes in plant.

Sowing density, or plant population, plays a crucial role in determining the spatial arrangement of plants, which in turn affects the availability of light, water, and nutrients, as well as intra-plant competition for these resources. The sowing rate, per area unit, depends on the sowing way and differs from 40 to 100 kg ha^{-1}. Consequently, literature data is different when it comes to optimal number of plants per area unit, concluding, however, there is significant sowing density effect on the yield and more of the other traits and qualitative indicators, too (Gavrić et al., 2018). Several studies have shown that optimizing sowing density is vital for achieving maximum grain yield, as both low and high plant populations may lead to suboptimal productivity due to underutilization or excessive competition between plants, respectively (Aozane da Rosa et al., 2022; Wan et al., 2023). Zhou et al. (2023) investigated Tartary buckwheat, concluded that increasing sowing density causes grain to increase, up to one level, while further increasing cause grain yield reduction. As sowing density increases, several factors show a continuous decline, including root characteristics, chlorophyll (a, b), transpiration rate, the number of main stem nodes, branches and leaves, grain number and weight per plant, along with the 1000 - grain weight. On the other hand, plant height and the level of malondialdehyde (MDA) in leaves increase progressively as sowing density rises.

According to Nikolić et al. (2019), average grain yield in buckwheat, grown in condition of stubble growing and irrigation, is obtained in the highest density, but difference, compared to less density variant, was a slight and unprofitable economically. Recent studies emphasize the need to fine-tune sowing densities in different environmental conditions to optimize productivity (Nickhil and Chettry, 2021).

This research aims to review the effects of sowing density on the grain yield of common buckwheat (*Fagopyrum esculentum* Moench), examining the relationship between plant population and yield potential and synthesizing findings from various studies.

2. MATERIAL AND METHODS

2.1. Climate and soil conditions during experiment conducting

Buckwheat is very sensitive to the lack of moisture, especially during the first development phases, in period of rooting, during flowering and yielding period. During the later phases, excess moisture causes a lot of negative effects. Influences of temperatures are rather strong, too. During 2010, 360.4mm precipitation was in May and July, while 125.6 mm precipitation only or almost three times less were in the same period in 2011. It means 2010. was more favorable in terms of soil moisture, necessary for germination. During July and August, almost the same precipitation sums (120 mm, averagely) were in both of investigation years in generative phase (impregnation and grain filling phases). This precipitation sum could be a limiting factor to obtain more yield per unit area because it is a critical period for buckwheat. Air temperatures in vegetative phase of development (intensive growth of trees and branching) were very favorable during both of investigation years. Buckwheat does not tolerate high temperatures. Growth is already slowing down at 28 ºC, as the percentage of impregnation and grain formation (Popović et al., 2013). The optimal temperature for growth and development is 20 °C while temperatures above 30 °C, during flowering phase, followed by low air moisture, cause drying and falling flowers and bad pollination.

2.2. Plant material and experiment method

The trial was set up on carbonate meadow black soil, during 2010 and 2011. The investigation included 12 genotypes: P2, P4, P5 (NS plus), NS buckwheat, P9 and P10, as domestic and P6, P11, Darja, Bamby, Oberon and Bylly, as foreign cultivars. The experiment was designed as a block system, in three replications, with an area of elementary plot 20 m^{-2}. The distance between rows was 25cm. Sowing was in accordance with planned sowing density (80, 120 and 160 grains m^{-2}). These sowing rates are less than literatures recommendations which are up to 300 grains m^{-2}, and up to even 500 grains m^{-2}, sowing handily (Popović et al., 2013). The sowing was done on 15th May in 2010, but on 10th May in 2011. The harvest was done in moment when 2/3 of yield were ripped respectively when grains of the latest genotype were dark brown. The harvest was one - phased, done on 20th August, in 2010. and on 12th August, in 2011. The grain yield was measured per each plot and appropriate sowing density. Based on that, average yield was calculated and expressed as t ha^{-1}, on the base of 14% grain moisture.

2.3. Statistical method

Grain yield (t ha^{-1}) was calculated per year and per sow density as well as average annual value, which includes all sowing densities. Data were analyzed statistically using two factorial models of analysis of variance according to Hadživuković (1973). The differences of means were tested using an LSD test at $p = 0.05$ and $p = 0.01$ probability levels. Coefficient of variation was done, too.

3. RESULTS AND DISCUSSION

3.1. Grain yield

Buckwheat grain yield is unstable and vary, in dependence on year and growing conditions, genotype and applied technology, in range of 1 to 4 t ha^{-1}. Average grain yield, for all tested genotypes, was 2.00 t ha^{-1}, in 2010 (Table 1). Among genotypes, grain yield varied from 1.42 t ha^{-1} (Oberon) to 2.51 t ha^{-1} (P 2). As many as five genotypes (P2, Darja, P5/NS plus, P11 and Bylly) showed highly statistically significant higher grain yield in relation to average experimental value. Coefficient of variation was 4.49%. Average grain yield per sowing density was approximately the same in variants 160 grains m^{-2} and 120 grains m^{-2}while in variant 80 grains per m^{-2} it was significantly lower, even twice as low. Nikolić et al. (2019) determined similar interrelations between sowing densities and grain yield in buckwheat grown in stubble sowing and irrigation conditions. The highest average grain yield is obtained in density of 160 grains m^{-2}, then in density of 120 grains m^{-2}, but difference was a slight, only 80 kg or 3.49% that means both sowing density variant could be applied successfully in buckwheat planting technology. Sowing density of 120 grains m^{-2} has, however, priority due to economic viability. These authors emphasized stronger impact of genotype than environmental factors on grain yield.

Average grain yield, in density variants varied from 1.23 t ha^{-1} (80 grains m^{-2}) to 2.43 t ha^{-1}, in density variant 160 grains m^{-2} (Table 1).

Table 1. Grain yield (t ha^{-1}) buckwheat genotypes in 2010.

Genotype	Grain yield (t ha $^{-1}$) (14% of moisture)			Average grain yield per genotype
	160 grains m^{-2}	120 grains m^{-2}	80 grains m^{-2}	
Oberon	1.44^{--}	1.52^{--}	1.29	1.42^{--}
P2	2.76^{++}	2.58^{++}	2.20^{++}	2.51^{++}
Darja	2.47	2.92^{++}	1.52^{++}	2.30^{++}
P4	2.39	2.22	1.11	1.91^{--}
P5 (NS plus)	2.60^{+}	2.68^{++}	1.14	2.14^{++}
P6	2.48	2.54^{+}	1.03^{-}	2.02
Bamby	2.19^{--}	1.91^{--}	0.82^{--}	1.64^{--}
NS buckwheat	2.47	2.14^{--}	1.08	1.89^{-}
P9	2.43	2.11^{--}	0.89^{--}	1.81^{--}
P10	2.09^{--}	1.87^{--}	0.79^{--}	1.58^{--}
P11	3.07^{++}	2.71^{++}	1.44^{+}	2.41^{++}
Bylly	2. 79	3.03^{++}	1.51^{++}	2.44^{++}
Average	2.43	2.35	1.23	2.00
LSD $_{0,05}$	149	141	164	85
$LSD_{0,01}$	202	191	223	112
Cv	3.64	3.55	7.90	4.49

The difference between grain yield in variant 120 grains per m^{-2} (2.35 t ha^{-1}) in relation to 160 grains per m^{-2} variant was slight. Genotype Oberon showed the least grain yield in both sowing densities: 1.522 t ha^{-1} and 1.44 t ha^{-1} in 120 grains m^{-2} and 160 grains m^{-2}, respectively. Bylly was the highest yielding genotype in variant 120 grains m^{-2} (3.03 t ha^{-1}), but P11 (3.07 t ha^{-1}) in variant 160 grains m^{-2}. As Table 1 shows, statistically significant and statistically highly significant higher yield were achieved by P5 (NS plus) and P2, P11 and Bylly, in sowing density 160 grains per $m^{-2,}$ respectively. Three genotypes obtained statistically highly significant less average grain yield (Oberon, Bamby and P 10) compared to experiment average. In sowing density 120 grains m^{-2}, six genotypes obtained statistically highly significant (P6) or statistically significant higher average grain yield (P2, Darja, NS plus, P11 and Bylly) compared to experiment average. Coefficient of variation was 3.64% (160 grains per m^{-2}), 3.55% (120 grains per m^{-2}) and 7.90 (80 grains per m^{-2}).

The highest variation was registered in the smallest density. In that variant, average grain yield of each genotype varied from 0.79 t ha $^{-1}$ (P 10) to 2.20 t ha $^{-1}$ (P 2). Mainly, the same genotypes as in the rest of variants (P11, P2. Darja and Bylly) expressed statistically significant or statistically highly significant higher grain yield compared to experiment average. In 2011, average grain yield of tested genotypes, for all of sowing densities, was 1.71 t ha^{-1}, significantly less than in 2010 (Table 2). Grain yield, regarding tested genotypes, varied from 1.10 t ha^{-1} (Oberon) to 2.75 t ha^{-1} (Darja). Genotypes: P2, Darja, P4, NS plus and P6 showed highly statistically significant higher grain yield compared to average grain yield while others, except Bylly, were highly significant lower yielding varieties compared to the average value. Coefficient of variation was only 2.41%. In such growing conditions in this year, that were less favorable for growing buckwheat compared to 2010, average yield, according to sowing densities, was uniform: 1.74 t $ha^{-,}$ 1.77 t ha^{-1} and 1.63 t ha^{-1} in sowing density 160 grains m^{-2}, 120 grains m^{-2} and 80 grains m^{-2}, respectively. Many authors (Berdin et al., 2018; Vieites-Alvarez et al., 2024; Knicky et al., 2024) considered sowing rate and pointed out, mainly, dependence on sowing method, cultivars, soil type and soil cultivation methods. Hence, the most recommended sowing rate is 200-500 seeds m^{-2} , although recommendations of 90-160 seeds m^{-2} are also found, confirming the need to know all those specifics in the context of determining the appropriate sowing density.

Table 2. Grain yield (t ha $^{-1}$) buckwheat genotypes in 2011.

Genotype	Grain yield (t ha $^{-1}$) (14% of moisture)			Average
	160 grains m^{-2}	120 grains m^{-2}	80 grains m^{-2}	
Oberon	1.12^{--}	1.10^{--}	1.22^{--}	1.15^{--}
P2	2.41^{++}	2.27^{++}	1.94^{++}	2.21^{++}
Darja	2.75^{++}	2.28^{++}	1.50	2.18^{++}
P4	1.93^{++}	2.36^{++}	1.54	1.94^{++}
P5 (NS plus)	2.12^{++}	2.52^{++}	2.50^{++}	2.39^{++}
P6	2.22^{++}	2.04^{++}	2.09^{++}	2.12^{++}
Bamby	1.27^{--}	1.31^{--}	1.32^{--}	1.30^{--}
NS buckwheat	1.04^{--}	1.57^{--}	1.65	1.42^{--}
P9	1.53	1.46^{--}	1.69	1.56^{--}
P10	1.41^{--}	1.34^{--}	1.36^{--}	1.37^{--}
P11	1.39^{--}	1.30^{--}	1.06^{--}	1.25^{--}
Bylly	1.63	1.70	1.72	1.69
Average	1.74	1.77	1.63	1.71
LSD $_{0,05}$	118	124	199	39
LSD$_{0,01}$	160	168	269	52
Cv	4.03	4.14	7.21	2.41

P2, P5 (NS plus) and P6 obtained highly statistically significant higher yield in all sowing densities variants. Oberon, Bamby, NS buckwheat, P10 and P11, on the contrary, were highly statistically significant lower yielding genotypes, regardless of the density variant. The highest variation of grain yield values was registered in the lowest sowing density (7.21%). Differences among tested genotypes were even up to 2.5 times (from 1.06 t ha^{-1}, P11 to 2.50 t ha^{-1}, NS plus) in variant 80 grains m^{-2}.

Average values of grain yield for both of investigation years, for each sowing density variants, are presented in Table 3. It can be seen that average grain yield for each sowing density, for both of investigation years, was 2.09 t ha $^{-1}$, 2.06 t ha $^{-1}$ and 1.43 t ha $^{-1}$ in variant 160 grains m^{-2}, 120 grains m^{-2} and 80 grains m^{-2}, respectively. Genotypes obtained average grain yield, for both of investigation years and all of densities variants, in range of 1.28 t ha $^{-1}$ (Oberon) - 2.36 t ha $^{-1}$ (P2). Average value of grain yield, finally, was 1.86 t ha $^{-1,}$ but coefficient of variation 4.83.

Ecological factors and expression of investigated genotypes have caused differences and division of genotypes, according to average grain yield, for all sowing densities, into three groups: high – yielding (P2, Darja, P5/NS plus, P6 and Bylly), average yielding (P4 and P11) and lower yielding (Oberon, Bamby, NS buckwheat, P9 and P10). It can be noticed that the average yield of tested genotypes, in 120 grains m^{-2} and 160 grains m^{-2} densities was almost the same, but grain yield in 80 grains m^{-2} variant was significantly lower. That deviation was more pronounced in 2010, when the ecological conditions for growing buckwheat were more favorable. Gavrić et al. (2018), during three study years (2011-2013), used three different sowing densities: 200, 300 and 400 seed m^{-2} and registered increasing of grain yield of Tartary buckwheat align with increasing plant density as well as impact of year of study on this trait. The plant density, however, did not have a significant effect on other traits, like: plant height, 1000-grain weight, hectoliter mass and phenol contents. Zhou et al. (2023) discovered a somewhat different correlation. Namely, increase in sowing density of Tartary buckwheat caused, continuously, a decrease the root morphological indices and activities, chlorophyll a, chlorophyll b and carotenoid contents, many enzymes' activities, net photosynthetic rate, transpiration rate, main stem node, branch and leaf numbers, grain number and weight per plant, whereas plant height increase. The yield of buckwheat first increased and then decreased with the increase in sowing density. Besides that, they observed simultaneous impact of sowing density and application of nitrogen and concluded that sowing at an appropriately high density can promote the increase in the yield of Tartary buckwheat populations under low nitrogen conditions and is recommended for use in production to achieve the high-yielding and nitrogen saving cultivation of Tartary buckwheat. Xiaomei et al. (2018) noticed the same influence of sowing density and nitrogen fertilization on the agronomic traits, grain yield and the leaf photosynthetic characteristics, in common buckwheat.

Table 3. Average grain yield, for both of investigation yield

Genotype	Grain yield (t ha $^{-1}$) (14% of moisture)			Average
	160 grains m^{-2}	120 grains m^{-2}	80 grains m^{-2}	
Oberon	1.28	1.31	1.25	1.28^{--}
P2	2.59	2.43	2.07	2.36^{++}
Darja	2.61	2.60	1.51	2.24^{++}
P4	2.16	2.29	1.32	1.92
P5 (NS plus)	2.37	2.60	1.82	2.26^{++}
P6	2.35	2.29	1.56	2.07^{++}
Bamby	1.73	1.61	1.07	1.47^{--}
NS buckwheat	1.76	1.86	1.37	1.66^{--}
P9	1.98	1.79	1.29	1.69^{--}
P10	1.75	1.60	1.08	1.48^{--}
P11	2.23	2.01	1.25	1.83
Bylly	2.21	2.37	1.61	2.06^{++}
Average	2.09	2.06	1.43	1.86
$LSD_{0,05}$				84
$LSD_{0,01}$				111
Cv				4.83

Wan et al. (2023) studied changes of buckwheat grain yield under different sowing densities and phosphorous rate and recommended 90 plants per m^{-2} and 75 kg ha^{-1} P application rate as the best management. They stressed that high sowing density reduces efficiency of P use and contribution of P to crop yield. Similar trend, as it is described in research Zhou et al. (2023) has been observed in investigation Yang - xiu et al. (2016) and refered to common buckwheat. This study deals with whether conditions in growing season, too, in relation with grain yield. The results showed that in the growth season with more rainfall, with the increase of density, the plant height, the seed number per plant, grain weight per plant, thousand seed weight and seed setting rate showed a trend of decrease, but the yield increased. In the growth season with less rainfall, however, with the increase of density, grain yield increased, at the first, then decreased as well as the number of main stem section, seed number per plant, grain weight per plant and thousand seed weight.

4. CONCLUSION

The buckwheat (*Fagopyrum esculentum* Moench.) is a current plant species due to its specific traits and compliance with demands of sustainable agriculture and contemporary population when it comes to food and dietary regimes. According to obtained results and comparation with average grain yield, regardless of the sowing densities, there were three groups of genotypes: high - yielding (P2, Darja, P5/NS plus, P6 and Bylly), average yielding (P4 and P11) and lower yielding (Oberon, Bamby, NS buckwheat, P9 and P10). Higher grain yield, in relation to average value, in both of experimental years, is results of genetics factors or interaction genotype x environmental factors. Allthough the higher grain yield, in both of experimental years, was reached in variant 160 grain m^{-2}, that difference was not significant and sowing density 120 grain m^{-2} is recommended as the most suitable for the North Bačka region.

As buckwheat production has extremely varied, at global level, it is necessary to register all of obstacles limiting its growing and to work to overcome them, which includes practical research and new breeding approaches, with a combination of modern and classical methods.

5. REFERENCES

Aozana da Rosa, J., Gonzalez da Silva, J.A., Vicenzi, R., Cecatto, A.P., Reolon Costa, A., Peter, C.L., Ferrari Basso, N.F., Ricardo Carvalho, I., Lautenchleger, F., Sgarbossa, J., da Rosa Fraga, D., Adorian Bandeira, W.J. (2022). The density and sowing time of buckwheat in organic and conventional growing system. AJCS, 16(07), 941-948. ISSN:1835-2707. doi: 10.21475/ajcs.22.16.07.

Berdin, S.I., Straholis, I.M., Klitsenko, G.V. (2018). Varietal reaction of buckwheat to methods and norms of seeding. Bulletin of Sumy National Agrarian University, 3(35), 64-67.

Gavrić, T., Gadžo, D., Đikić, M., Bezdrobi, M., Čadro, S., Bašić, F. (2018). Effects of plant density in the yield and toral phenolic contents of Tartary buckwheat. Proceedings of the IX International Agricultural Symposium “Agrosym 2018”, 97-102.

Hadžvuković, S. (1973). Statistical methods (apllied in agricultural and biological investigations) University in Novi Sad, Novi Sad. Radivoj Ćirpanov. P. 491. /in Serbian/

Knicky, M., Zamaratskaia, G., Fogelbe, F. (2024). Yield and protein composition in seeds of four buckwheat (*Fagopyrum* sp.) cultivars cropped in Sweden. Agricultural and Food Science, 33, 261-267.

Morishita, T., Hara, T., Hara, T. (2020). Important agronomic characteristics of yielding ability in common buckwheat; ecotype and ecological differentiation, preharvest sprouting resistance, shattering resistance, and lodging resistance. Breed Sci., 70(1), 39-47. doi: 10.1270/jsbbs.19020. PMID: 32351303; PMCID: PMC7180144.

Naumović, N. (2017). Buckwheat, Publishing and Educational Cooperative, Belgrade /in Serbian/

Nikolić, O., Pavlović, M., Dedić, D., Sabadoš, V. (2019). The influence of sow density on productivity and moisture in buckwheat grain (*Fagopyrum esculentum* Moench.) in condition of stubble sowing and irrigation. Agriculture & Forestry, 65(4), 193-202.

Nikolić, O., Srećkov, Z., Rašić, S., Supić, D. (2024). Agricultural, economic and market indicators of buckwheat (*Fagopyrum esculentum* Moench.) production. Proceedings of 6th International Conference »Modern trneds in agricultural production, rural development and environmental potection«, Vrnjačka Banja, Serbia, 291-299. COBISS. SR-ID 147386889

Pirzadah, T.B., Rehman, R.U. (2021). Reasons for declining buckwheat production, in Buckwheat forgotten crop for the future (CRC Press, Boca Raton, USA), 12, ISBN: ISBN 978100308910

Popović, V., Sikora, V., Glamočlija, Đ., Ikanović, J., Filipović, V., Tabakovic, M. Simić, D. (2013). Influence of agro-ecological conditions and foliar fertilization on yield and yield components of buckwheat in conventional and organic cropping systems. Biotechnology in Animal Husbandry, 29(3), 537-546.

Vieites-Álvarez, Y., Reigosa Manuel, J., Sánchez-Moreiras, A.M. (2024). A decade of advances in the study of buckwheat for organic farming and agroecology (2013-2023). Frontiers in Plant Science, 15,www.frontiersin.org/journals/plantscience/articles/10.3389/fpls.2024.1354672DOI=10.3389/fpls.2024.1354672ISSN=1664-462X

Wan, Ch., Sen, G., Wang, J., Xinhui, L., Jiahao, G., Jincai, T., Wang, Q., Pengfei, D., Wang, M., Yang, P., Jinfeng, G. (2023). Optimal planting density combined with phosphorus input promotes common buckwheat resource use efficiency and productivity to increase grain yield. Agricultural Water Management, 287. 108468, ISSN 0378-3774. doi.org/10.1016/j.agwat.2023.108468

Xiaomei, F., Li, Y., Nie, J., Wang, C., Huang, K., Zhang, Y., Zhang, Y., She, H., Liu, X., Ruan, R., Yuan, X., Yi, Z. (2018). Effects of nitrogen fertilizer and planting density on the leaf photosynthetic characteristics, agronomic traits and grain yield in common buckwheat (*Fagopyrum esculentum* M.), Field Crops Research, 219, 160-168. ISSN 0378-4290, doi.org/10.1016/j.fcr.2018.02.001

Yang-xiu, M.U. , Li-juan, Y., Jiu-pan, Z., Lan-hai, M.U., Yan-ping, D.U., Ke-qin, C. (2018). Effect of Planting Density on Buckwheat Seed Setting Rate and Yield[J]. Hubei Agricultural Sciences, 57(2), 32-34.

Zamaratskaia, G., Gerhardt, K., Knicky, M., Wendin, K. (2023). Buckwheat: an underutilized crop with attractive sensory qualities and health benefits. Critical Reviews in Food Science and Nutrition, 64(33), 12303-12318. doi.org/10.1080/10408398.2023.2249112

Zhou, Q., He, P., Tang, J., Huang, K., Huang, X. (2023). Increasing planting density can improve the yield of Tartary buckwheat. Front Plant Sci., 13, 14:1313181. doi:10.3389/fpls.2023.1313181. PMID: 38155850; PMCID: PMC10753774. www.fao.org/faostat/en/#data/QCL

doi:10.46793/MAK2025.201DJ

FOOD SOVEREIGNTY AND RIGHTS TO SEED

Gordana Đurić[1,2*], Gvozden Mićić[2], Danijela Kondić[1,2], Ivana Radović[3], Nikola Mićić[2,4]

[1] Faculty of Agriculture, University of Banja Luka, Banja Luka, Bosnia and Herzegovina
*gordanadjuric@protonmail.com
[2] Foundation Alica, Banja Luka, Bosnia and Herzegovina
[3] Faculty of Agriculture, University of Belgrade, Belgrade, Serbia
[4] Scientific Fruit Growing Society of Republika Srpska, Banja Luka, Bosnia and Herzegovina

Abstract: Food sovereignty is the human right to healthy and culturally appropriate food produced through ecologically sound and sustainable methods, and the right of people to define their own food and agriculture systems. Food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. In contrast to food security, which focuses on ensuring that enough food is available, food sovereignty emphasizes control over food production and distribution by local communities. Shifting the focus from food security to food sovereignty essentially represents a reconnection between nature, food, and people. The right to seeds is at the basis of each community's food sovereignty, what is possible to achieve only in the system of farmers' seeds. Farmer seed systems are a critical contribution to food sovereignty and farmers' rights. For over 10.000 years, people have freely saved, selected, exchanged, and sold seeds, using and reusing them for sowing and food production. The farmers' seed system is defined by the long-standing continuous renewal and free distribution of seeds and knowledge among people. Seeds are gifted, shared, or traded in informal and formal markets. These seeds are more resilient to climate change, pests, and pathogens, and they also ensure a more diverse food system and a dynamic global ecosystem. Today, farmers' rights to seeds, crucial for their survival, are seriously threatened and are in decline worldwide. These seed systems are undermined by inadequate legislation and insufficient support from governments and public research, primarily as the result of a protected seed market based fundamentally on intellectual property rights and trade agreements. Farmers' seed systems are vital for preservation of plant genetic diversity of all agricultural crops. It is increasingly expected that global climate change, combined with other factors, will significantly alter this agricultural biodiversity. Broad efforts will be needed to help reduce the climate vulnerability of current agricultural production systems and building more resilient and adaptive agroecosystems. The farmers' seed system and the associated traditional agricultural practices are key factors for adaptation.

Keywords: Plant genetic resources, Adaptation, Resilience, Farmers' rights, UNDROP

1. INTRODUCTION

The term food sovereignty was first brought to international attention at the World Food Summit organized by the Food and Agriculture Organization of the United Nations in 1996. It was put forward by La Vía Campesina[1], an international movement that coordinates organizations of small- and medium-sized producers, agricultural workers, rural women and Indigenous communities from

[1] La Vía Campesina, founded in 1993, is an international movement bringing together millions of peasants, landless workers, indigenous people, pastoralists, fishers, migrant farmworkers, small and medium-size farmers, rural women, and peasant youth from around the world. Built on a solid sense of unity and solidarity, it defends peasant agriculture for food sovereignty (https://viacampesina.org/en/international-peasants-voice/)

Asia, the Americas and Europe. During the 1996 World Food Summit, La Vía Campesina presented a set of mutually supportive principles as an alternative to the world trade policies and to realize the human right to food. In their statement, Food sovereignty: a future without hunger (1996), they declared: "Food sovereignty is a precondition to genuine food security" (Pimbert and Claeys, 2024). Food sovereignty is a concept that emphasizes the right of people, especially farmers, to define their own food and agricultural systems. It is closely linked to local control over food production and access to resources, including seeds, land, and water. In contrast to food security, which focuses on ensuring that enough food is available, food sovereignty emphasizes control over food production and distribution by local communities (Patel, 2009; van Willenswaard, 2015). There are six principles of food sovereignty defined by Declaration by Niélény: focuses on food for people; values food providers; localises food systems; puts control locally; builds knowledge and skills; work with nature (Niélény, 2007). Over the past two decades, food sovereignty has been discussed and defended under the leadership of La Vía Campesina. For food sovereignty advocates, ideas about seeds need to be liberated from today's dominant vision of modernity and the corporate enclosure of the commons (Pimbert, 2019).

As it is mentioned by Dokmanović (2020), food sovereignty is a specific concept and, at the same time, an overarching right, an alternative model of development and a political framework, with objective to realize the rights of local food producers and rural people to determine their own food and agriculture systems. About twenty states have already integrated food sovereignty in their constitutions and legislation. Beside, this, the Latin American and Caribbean Parliament and of the Pan-African Parliament develop a model law that would assist states to include food sovereignty in their legislation.

In Bosnia and Herzegovina (BIH) and neighboring countries, there is not much research activities about food sovereignty, if we exclude rare works that deal with this issue from a legal perspective, as a matter of basic human rights (Dokmanović, 2020) or the activities of citizen associations that have raised this issue in BIH in connection with agroecological transition (Mićić et al., 2021, Đurić and Mićić, 2023). Serbia was the only country in the former Yugoslavia that was self-sufficient in food. However, the latest data suggest that it is also losing that self-sufficiency in animal husbandry (Brankov and Matkovski, 2022) but also in the most important part of sovereignty, seed production (Internet link 1).

Rights to seed are an integral part of food sovereignty. They encompass the ability of farmers to save, exchange, and reuse seeds without legal or commercial restrictions. Historically, farmers have maintained biodiversity and adapted crops to local conditions through locally adapted traditional practices. However, modern intellectual property laws, particularly those governing plant breeders' rights and patents, increasingly restrict these traditional practices, threatening both agricultural biodiversity and farmers' rights (Fakhri, 2021). Seed commons, i.e. the collective management of seeds and associated knowledge, is a major aim of food sovereignty, which is crucial alternative and should led to the dead end of industrialized agriculture (Pimbert, 2022b).

Today, broadly there are two different seed systems: farmers' seed system and commodity (industrial) seed system (Fakhri, 2021). In farmers' or traditional seed systems, farmers save seed from each cycle, while farmers in formal (commodity, industrial) seed systems typically purchase seed every cycle. In traditional seed systems, farmers select seed according to local and cultural preferences, making natural and human selection to act together and providing to local adaptation of different landraces (Mastretta-Yanes et al., 2024). By this way, the farmers' seed systems are fundamental for generating of evosystems services, i.e. evolutionary processes as a resuls of the maitaining and use of genetic diversity (Faith et al., 2010).

Farmers' seed systems are defined by the long-standing continuous renewal and free distribution of seeds and knowledge among peoples. Through the hystory of humankind, seeds are gifted, shared, or bought and sold in informal and formal markets. Farmers' seed is more adaptable to local conditions and as such more resilient against climate change, pest and pathogens. It is base for more diverse food system and more dynamic global ecosystem. Today, farmers' right to seeds, vital to their survival, is seriously threatened and is regressing throughout the world. The farmers' seed systems have been endangered by inappropriate legal frame and by insufficient support from governments and public research. This is largely the result of protected seed market, based essentially on intellectual property rights (IPRs) and trade agreements (Fakhri, 2021).

Farmer seed systems and farmers' varieties make a critical contribution to food sovereignty (Pimbert, 2022a). Farmers know that good food comes from good seeds. However, farmers' varieties have become increasingly vulnerable due to many negative circumstances, including climate change, loss of small farms, market pressures, and seed privatization. As a result, farming communities and their local seed systems eroded, with grave repercussions on local food systems (Seed Change, 2019).

Commodity (industrial) seed systems, in contrast, are dedicated to the reproduction of homogeneous material and varieties dependent on chemical inputs. These varieties fall under regimes of property and contract law. The main purpose of such systems is a profit making and production of food as much as possible. However, these systems are unstable and unsustainable by themselves. They are very dependent on farmers' seed systems, and natural biodiversity, who provide them with initial breeding material. However, the farmers' seed system depends on farmers' rights to freely store, use, exchange and sell their seeds. Consequently, when states do not adequately protect and support farmers' seed systems, they in weaken and destabilize ecosystems, but also violate the basic people's human rights. The more the seed system relies on property regimes and contract law, the more institutional mechanisms are needed to ensure the protection of human rights. Certification systems also carry the same risks as property regimes and contract law, albeit to a lesser degree. In systems where a plant and its genetic material (seed) are commodity, there are a small number of people who more easily control the seed by limiting access to the others. Here is not only a question of preserving biodiversity, but a question of its sustainable use through multiplication and selection, which implies always releasing and continuing to maintain the best seeds. The seed must be sown in order to regenerate ("conservation is by use"). Furthermore, seed exchange is essential for the global development and adaptation of new crops and knowledge in response to climate change, pests, diseases and human food security needs (Fakhri, 2021).

Although the western Balkan region is the richest in biodiversity in Europe and it is known for a large number of autochthonous varieties and local populations of all agricultural crops, the issue of conservation and sustainable use of vital genetic resources has not been adequately resolved (Rivera et al., 2018; FAO, 2021). Serbia is a member of The International Treaty on Plant Genetic Resoures for Food and Agriculture (ITPGRFA), while BIH has not joined this agreement, which is the most important mechanism for farmers' rights and the rights of local community seeds[2]. Both countries are parties to the Convention on Biological Diversity (CBD)[3], whereby Serbia is also a party to the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (ABS Nagoya Protocol) until BIH had not ratified this protocol[4]. During the adoption of the United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas (UNDROP), Serbia voted for this document while BIH abstained together[5]. This suggests that farmers' rights in BIH are at a low level and that politicians do not deal with them, while Serbia had made progress and there are stronger movements for food sovereignty, as research suggests (Dokamović, 2020; Brankov, 2022). In

[2] https://www.fao.org/plant-treaty/countries/membership/en/
[3] https://www.cbd.int/information/parties.shtml
[4] https://www.cbd.int/abs/nagoya-protocol/signatories
[5] https://digitallibrary.un.org/record/1656160?ln=en

connection with the conservation of genetic resources, both countries have a program for the conservation of plant genetic resources and established public gene banks (Rivera et al., 2018). There are also civil society organizations in both countries with succesful community seed banks inside the "Frame of Life"[6] (Paštrić, Mionica) and Foundation Alica[7] (Banja Luka) which actively work on advocating for farmers' rights and farmer's varieties as well as agroecology and agrobiodiversity both within their communities and regionally through two networks: Balkan Seed Network Association (Pautrat and Willard, 2023) and BILIM network (Bucini et al., 2024).

The aim of research is to analyze the farmers' rights in connection with food sovereignty with a special emphasis to rights to seed in the light of the EU seed marketing regulation reform.

2. FARMERS' RIGHTS TO SEED

The rights of farmers, local communities and indigenous peoples are guaranteed by a number of international legal instruments. All international agreements dedicated to the conservation and sustainable use of plant genetic resources contain provisions about the right of farmers, indigenous peoples and local communities, above all the right to seeds. Regardless of all these mechanisms, there is a lot of ambiguity regarding the implementation of farmers' rights in national legislations.

The most important international mechanisms regarding the Farmers' Rights today are ITPGRFA[8] and UNDROP[9], but both are interconnected with other ones, such UPOV Covention[10] and CBD[11] and (Golay and Batur, 2021).

Before WTO[12] and its TRIPS[13] Agreement (1995), intelectual property rights (IPRs) over seeds and varieties remained a regional issue, mainly in the US and EU. US developed patents system over plants in mid-twentieth century. EU developed system based on plant varieties protection (PVP) after 1961. TRIPS requires from WTO members to implement an IPRs regime with certain minimum requirements. Art. 27 (3) (b) obliges MS to provide protection for plant varieties either by patents, by an effective *sui generis* system or by any combination there of. But it does not define what is meant by "an effective *sui generis* system". The combination of TRIPS Agreements and UPOV Convention forced farmers to have a relationship with breeders.

The 1978 UPOV Convention (UPOV, 1961; 1972; 1978) implicitly recognizes farmers' right to save, use and exchange seeds, leaving farmers to only seek permission from the IPR holder if they sell the seed. The 1991 UPOV Convention reframes farmers' rights to save, use and exchange seed as an optional privilege that MS can elect to enact. (Since 1998, States can only join the 1991 Convention).

---

[6] https://www.okvirzivota.org.rs/
[7] http://alica-foundation.org/sr/
[8] International Treaty on Plant Genetic Resources for Food and Agriculture (https://www.fao.org/plant-treaty/en/)
[9] United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas (https://digitallibrary.un.org/record/1650694?ln=en&v=pdf)
[10] International Convention for the Protection of New Varieties of Plants (https://upovlex.upov.int/en/convention)
[11] Convention on biological Diversity (https://www.cbd.int/)
[12]World Trade Organization was established in 1994, started from 1 January 1995. Its predecessor organization is the GATT - General Agreement on Tariffs and Trade established in 1948. https://www.wto.org/
[13]The Agreement on Trade-Related Aspects of Intellectual Property Rights is Annex 1C of the Marrakesh Agreement Establishing the World Trade Organization, signed in Marrakesh, Morocco on 15 April 1994. https://www.wto.org/english/tratop_e/trips_e/trips_e.htm

US and EU style IPRs system for plant varieties did not initially concern most countries focused their efforts on supporting farmers' seed system. But with the TRIPS agreement, these countries had to enact some sort of system to protect plant varieties.

The concept of Farmers' Rights obtained international recognition for the first time in 1989 in the context of the International Undertaking on Plant Genetic Resources (IUPGR; IU), originally adopted by the FAO Conference in 1983. In the same year, FAO established the Commission for Plant Genetic Resources (which is transformed in Commission for Genetic Resources for Food and Agriculture in 1995; hereafter: Commission). In that time, genetic resources are seen as common heritage of humankind. In the 10 years since its adoption, the IU has evolved through interpretative resolutions reflecting the growing recognition of the need to reconcile plant breeders' rights with the interests of developed countries. Therefore, the issue of national sovereignty over PGR has become a mechanism through which developing countries have sought to redress the asymmetry in the benefits that developed and developing countries derive from PGR. The first interpretative resolution (4/89) provided a consistent interpretation of the recognition that breeders' rights are not necessarily in conflict with IP. Farmers' rights were also recognized, defined in the second resolution (5/89) as "rights arising from the past, present and future contributions of farmers to the conservation, improvement and provision of access to plant genetic resources, in particular those in centres of origin/diversity" The emergence of the concept of Farmers' Rights was motivated more as part of a political effort to redress the perceived imbalance of the increasing use and expansion of Plant Breeders' Rights than as a legal concept or property right. States agreed that Farmers' Rights should be recognized through an international fund, a fund that had never been operationalized. (Correa, 2017).

The CBD (1992) represented a fundamental change in the way in which genetic resources were exchanged and viewed and no longer were they seen as the common heritage of humankind. They fell under national sovereignty with controlled access, and private breeding arised with IPRs (plant breeders' rights & patents), as countries increasingly asserted sovereign rights over their biological and genetic resources and control over their access (Wynberg et al., 2021). While the concept of Farmers' Rights was known when the negotiation of the Convention on Biological Diversity (CBD) took place, the Convention did not make any reference to it. However, Resolution 3 of the Nairobi Conference for the Adoption of the Agreed Text of the CBD recognized the need to seek solutions to two outstanding matters concerning plant genetic resources, one of which was "the question of farmers' rights" (Correa, 2017). From the mid-1990s, the Commission began the negotiation process for a revision of the IU to bring it into line with the CBD. The negotiations for the revision of the IU started, in November 1994, at first extraordinary session of the Commission. They continued until 3 November 2001, when the Thirty-first FAO Conference adopted the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), by unanimity (IPGRI, 2004).

ITPGRFA, in fact was the first legally binding instrument to formally acknowledge the tremendous contribution made by farmers, local communities and Indigenous Peoples in developing and conserving crop diversity (Moore and Tymowski, 2005). Article 9 of the ITPGRFA advocates for the recognition, realization and promotion of Farmers' Rights relating to plant genetic resources for food and agriculture. National governments are enjoined to promote, protect and implement Farmers' Rights by protecting relevant traditional knowledge, making provision for farmers to participate equitably in sharing benefits, and ensuring that farmers participate in national decision-making related to plant genetic resources. In addition to these provisions, the importance of the right of farmers to save, use, exchange and sell farm-saved seed/propagating material is affirmed (FAO, 2023).

The acceptance of the concept of Farmers' Rights in the ITPGRFA (Treaty) were among the most contentious issues in the seven years of negotiations leading to the adoption of the ITPGRFA. The adopted text has set out a general umbrella to promote a set of policies relevant to farmers' use and conservation of plant genetic resources for food and agriculture, but it has not provided a precise definition of such rights because of objections od lobbyists of private seed companies from developed countries (USA, Canada). Regardless, it has created a platform for initiatives to improve farmers' participation in decision making and to support their activities as both producers and breeders (Correa, 2017). The ITPGRFA recognizes the right relating to seeds as a component of Farmers' Rights in a preambular paragraph and in the text of the Treaty with a non-binding formulation of this rights, although the Treaty has the legally binding nature as such. Such contex of Farmers' Rights is unable to derogate international obligations that the contracting parties may have under other binding international treaties, such as UPOV 1991. While this is the current legal situation, the ITPGRFA indicates the direction in which the national and international law should evolve in order to ensure the effective recognition of farmers' contributions to a sustainable agriculture and food security. The concept of Farmers' Rights recognized the role of farmers as custodians of biodiversity and helped to draw attention to the need to preserve practices that are essential for a sustainable agriculture (Correa, 2017).

To assist Contracting Parties in promoting and implementing Farmers' Rights, the Governing Body of ITPGRFA established the Ad Hoc Technical Expert Group on Farmers' Rights with mandate to develop tools for implemenation of the Artcicle 9. This group developed document with 32 options drawing on the experiences of Contracting Parties and stakeholders after survay (FAO, 2023).

Beside all above mentioned mechanisms, the UN adopted the Declaration on the Rights of Peasants and Other People Working in Rural Areas in which peasants' right to seeds is recognized (UNDROP, 2018). The States shall 'support peasant seed system, and promote the use of peasant seeds and agrobiodiversity' (Article 19(6)). They shall 'ensure that seed policies, plant variety protection and other IP laws, certification schemes and seed marketing laws respect and take into account the rights, needs and realities of peasants' (Article 19(8)). UNDROP aims to strengthen the rights of peasants and rural workers, including their rights to land, seeds, biodiversity and a healthy environment. Relevant aspects of UNDROP that relate to the right to seeds include (Golay and Batur, 2021):

- The right to seeds: UNDROP explicitly recognizes the right of peasants to save, use, exchange and sell seeds saved on farms. It also protects traditional knowledge and agricultural biodiversity.
- Participation in decision-making: Promotes the inclusion of peasants and rural workers in decision-making processes that affect their rights and resources.
- Protection from displacement: The Declaration emphasizes the protection of rural communities from displacement and the imposition of agricultural models that threaten their livelihoods and cultural practices.

3. EUROEPAN UNION SEED MARKETING REGULATION AND RIGHTS TO SEED

The current European Union (EU) rules on the production and marketing of seed originally dating from the 1960s. The aim of the legislation was to increase productivity and create a competitive seed industry. In the current EU seed legislation[14], the exchange and sale of seeds by farmers fall into the definition of seed marketing. This means that all farmers, no matter their size and activity (whether

[14] EU seed marketing regulation reform started in 2019. In July 2023, the European Commission presented a draft for new regulation on the production and marketing of seeds and propagating material (e.g. fruit tree cuttings or seed potatoes). In April 2024, the European Parliament called for improvements to protect agro-biodiversity and farmers' rights. The Agriculture Ministers' discussions are still ongoing. Trialogue negotiations between the Commission, Council, and Parliament could begin in spring 2025 under the Polish Presidency of the Council (Arche Noah, 2024).

they engage in seed or food production), need to comply with the strict rules of the EU Seed Marketing Directives, and consequently with all trade and property mechanisms (WTO, TRIPS, UPOV, IPRs). They can only exchange quality-controlled seeds of registered varieties (Arche Noah, 2024). EU seed marketing legislation has been criticised for contributing to the reduction of crop diversity by imposing strict regulations that favour uniform, commercially grown varieties over traditional and indigenous varieties. This framework has made it challenging for smallholder farmers and seed producers to market diverse and locally adapted seeds, thereby jeopardising agricultural biodiversity and food sovereignty (ARC2020, 2023).

National implementation of EU rules has been unequal at best. Farmer communities are thus affected very differently across the EU, facing outright violation or conditional recognition of their rights to seeds (Golay and Batur, 2021). But, there are sizeable differences between national seed laws across the EU. Regardless of such general seed marketing regulation, the member countries have implemented the ITPGRFA article in their national laws on seeds, which regulates the rights of farmers to seeds. Examples from Austria, France, Denmark, Norway, and Italy and are given below.

Austrian seed laws allow the transmission of seed by farmers, peasants or seed users against payment or in kind for the purpose of conservation if the person does not trade in seed, if the variety is not registered (except conservation and amateur varieties) and if the transmission is done in small quantities. In fact, the exchange of seed for the protection of plant genetic resources between farmers and seed users does not mean „marketing“. Austrian seed savers' and farmers' organizations had successfully fought for a non-exclusive way of registering traditional seeds at the national level (GRAIN, 2015).

In France, seed exchanges between peasants are considered to fall under the regime of mutual assistance, and are not subject to seed marketing legislation (GRAIN, 2015). Danish legislation takes into account the realities of farmer seed systems, and allow for the exchange of seeds amongst farmers, and sale of unregistered varieties under certain conditions for non-commercial use of seeds. By this interpretation, marketing of plant genetic resources that are not intended for commercial production, or "non-commercial seeds", are not regarded as subject to the legislation (Nordplus, 2015; Foreningen Frøsamlerne, 2022).

Norway became a member of UPOV in 1993, based on the 1978 Act of the UPOV Convention. Even though the 1991 Act was adopted by many other countries at that time, Norway chose to adhere to the 1978 Act. In 2004, the government proposed changes to the Plant Breeders' Rights Act and to join the 1991 Act of the UPOV Convention. However, this proposal spurred public debate. After the election in 2005, the new government withdrew the proposed changes in the PVP legislation on the grounds that they limited Farmers' Rights. At the same time, the breeding industry was promised to receive stronger government support for the development of varieties that are suitable to Norwegian conditions and adapted to climate change. Based on this agreement, farmers in Norway could continue to save and use farm-saved seed and propagating material of protected varieties without paying any remuneration to the holder of the plant variety protection right (FAO, 2014).

In accordance with the objectives of the ITPGRFA, Italian regional laws[15] have emerged as one of the most interesting institutional attempts at European level towards enhancing and protecting

[15] Regional Law 64/2004 'The protection and enhancement of local breeds and varieties of interest to agriculture, husbandry and forestry'.
Regional Law 15/2000 'The protection of autochthonous genetic resources of interest to agriculture'.
Regional Law 25/2001 'The protection of autochthonous genetic resources of interest to agriculture'.
Regional Law 11/2002 'The protection of autochthonous genetic resources of interest to agriculture and forestry'.

agricultural biodiversity. The regional laws highlight the importance of supporting farming systems that are close relationship with the territory and local communities, creating sufficient juridical space for the varieties that are not part of the 'formal' seed system. In addition, the Constitutional Law Nr. 3 of 18 October 2001 'Amendments to Title V Part II of the Constitution' amends the legislative area of responsibility between State and Region defining which matters are the exclusive responsibility of the State and which are subject to joint State/Region legislation. Not being expressly earmarked for either State or joint legislation, agriculture is one of the residual matters of Regional responsibility (Bertacchini, 2011).

A new success in fight for farmers' seed in EU is the adoption of Regulation (EU) 2018/848 of the European Parliament and the Council regarding the production and marketing of plant reproductive material from organic heterogeneous material (OHM) of certain genera or species. However, the regime only applies within the boundaries of organic production. It may thus not completely cater to the needs of landraces, or varieties that have been deleted from the national lists due to the loss of mainstream commercial interest, but could still be interesting for conservation purposes, or for the specific qualities they have (Batur et al., 2023).

Seed legislation, while allowing for the informal exchange that characterizes farmers' seed systems and recognizing their role in seed production and the conservation of on-farm agrobiodiversity, should also recognize that farmers develop plant varieties adapted to their local agro-ecological conditions through continuous selection of farmers' varieties. Such an approach would be consistent with the obligations of States not only to conserve but also to ensure the sustainable use of agrobiodiversity, as enshrined in Articles 6, 8 and 10 of the CBD and Articles 5 and 6 of the ITPGRFA, together with the realization of farmers' rights enshrined in Article 9 of the ITPGRFA and Article 19 of the UNDROP (Batur at al., 2021).

The European Union is currently reviewing its legislation on seed marketing, patent rights and the regulation of new genomic techniques (NGTs). These proposed changes have significant implications for seed rights and food sovereignty, in particular for traditional farmers' practices and control over seeds. While the proposal offers avenues for diversifying the seed market, it has been criticized for failing to fully recognize and protect farmers' rights to seeds as enshrined in the UNDROP. Critics argue that the proposal could negatively impact farmers' farming systems and represents a missed opportunity to fulfill international human rights obligations related to the right to food and seeds (Batur et al., 2023).

The proposed legislative changes have several potential implications:

- Farmers' Rights: There are concerns that the new regulations may not adequately protect farmers' traditional rights to save, use, exchange, and sell seeds, especially if NGTs are deregulated and patented varieties become more prevalent.
- Biodiversity: The emphasis on commercially grown, uniform varieties could lead to a reduction in agricultural biodiversity, making food systems more vulnerable to pests, diseases, and climate change.
- Food Sovereignty: By potentially limiting farmers' control over seeds and favoring corporate interests, the proposed law could undermine food sovereignty, which emphasizes the rights of local communities to control their own food systems.

If the proposal is not substantially revised, it will become a missed opportunity to integrate peasants' rights to the EU seed marketing legislation, with dire consequences for food security and agricultural biodiversity in the European Union (Batur et al., 2023). 139 organisations - civil society and farmers'

Regional Law 3/2003 'The protection of animal and plant resources in the Region of the Marches'. Regional Law 1/2008 'The protection of local breeds and varieties of the Region of Emilia Romagna of interest to agriculture'.

initiatives, regional seed companies as well as nature conservation and development organisations from 23 European countries sent a joint letter to the 27 EU Agriculture Ministers in December 2024 calling for urgent improvements to EU seed legislation and they warn: ‘The current legislative proposal is a major threat to the diversity of our crops and the right of our farmers to their own seeds’(Arche Noah, 2024).

4. CONCLUSION

Despite all international instruments, the implementation of Farmers’ Rights remains inconsistent and faces several challenges:

- Legal obstacles: Many countries have adopted intellectual property laws that prioritize the rights of commercial plant breeders over traditional farmers’ practices, limiting their ability to freely use seeds.
- Lack of support: Inadequate government support for traditional seed systems and insufficient investment in public agricultural research undermine farmers’ rights.
- Corporate influence: The dominance of multinational agribusinesses in the seed market poses significant challenges to maintaining seed sovereignty and biodiversity.
- Efforts to implement the ITPGRFA and UNDROP are essential to ensuring food sovereignty and protecting farmers’ rights to seeds. Strengthening these frameworks and supporting local seed systems is vital for sustainable agriculture, biodiversity conservation and the resilience of food systems in the face of climate change and other global challenges.
- While the legislative changes proposed by the EU aim to modernize seed marketing and accommodate new technologies, they have sparked significant debate regarding their impact on farmers’ rights, biodiversity, and food sovereignty. It is crucial that policymakers carefully consider these implications to ensure that the new regulations support sustainable and equitable agricultural practices.

Community seed banks and CSOs are essential in fostering sustainable agricultural systems, protecting farmers’ rights, and ensuring long-term food sovereignty in Serbia, Bosnia and Herzegovina, and beyond. Supporting and scaling up these initiatives can significantly contribute to resilient local food systems and the empowerment of farming communities.

5. ACKNOWLEDGMENT

The research is a part of the project "Strengthening the capacities of CSOs and other local stakeholders for better conservation and use of plant genetic resources in Bosnia and Herzegovina" which is financially supported by FAOREU (2024-2025) and the project "School of Agroecology - a new approach in agriculture and food system" financially supported by the Ministry of Agriculture, Forestry and Water Management of the Republic of Srpska (2023-2024), both implemented by Foundation Alica, Banja Luka (BIH).

6. REFERENCE

ARC2020 (2023). Seeds of Europe – Centering Small Producers’ Voices in Seed Law Reformhttps:www.arc2020.eu/seeds-of-europe-centering-small-producers-voices-in-seed-law-reform

ARCHE NOAH, Society for the Preservation and Promotion of Plant Diversity (2024). Seed Legislation: 139 Organisations and over 140,000 Citizens Appeal to EU Agriculture Ministers and new EU Health Commissioner. Press Release. (Accessed December 2024).

Batur, F., Bocci, R., Bartha, B. (2021). Marketing Farmers’ Varieties in Europe: Encouraging Pathways with Missing Links for the Recognition and Support of Farmer Seed Systems. Agronomy 2021, 11. doi.org/10.3390/agronomy11112159

Batur, F., Peschard, K., Golay, C. (2023). EU Commission Proposal on Seed Marketing (2023/0227). A Commentary From the Perspective of the Right to Food, the Right to Seeds snd UNDROP. Geneva Academy. www.geneva-academy.ch/joomlatools-files/docman-files/GEN%20ACAD.%20UNDROP%20RIGHT%20TO%20FOOD%20SEEDS%20IN%20THE%20EU%20COMMISSION%20PROPOSAL%20ON%20SEED%20MARKETING.pdf (Accessed on January 2025).

Bertacchini, E. (2011). Regional Legislation in Italy for the Protection of Local Varieties. Journal of Agriculture and Environment for International Development (JAEID), 103(1/2), 51-63. doi.org/10.12895/jaeid.20091/2.24

Brankov, T., Matkovski, B. (2022). Is a Food Shortage Coming to the Western Balkans? Foods 2022, 11, 3672. doi.org/10.3390/foods11223672

Bucini, G., Ledant, C., Anisimova, M., Anderson, C., Ferrante A., Gradeci R., Atay, A., Chitadze, T., Devnosadze, M., Balogh, L., Baymakova, G. (2024). A Case Study of the Bilim Community - Organizations and Networks as Engines of Agroecology Transitions in Eastern Europe and West-Central Asia. Perspectives on Agroecology Transitions – No. 6, University of Vermonth, Institute for Agroecology, www.uvm.edu/sites/default/files/Institute-for-Agroecology/Case-Study-Bilim-Community_2.pdf

Correa, M.C. (2017). Implementing Farmers' Rights Relating to Seeds. Research papers 75. South Centre. www.southcentre.int/wp-content/uploads/2017/05/RP75_Implementing-Farmers-Rights-Relating-to-Seeds_EN-1.pdf

Dokmanović, M. (2020). Prehrambena suverenost -food sovereignty- u uporednom pravu. Strani pravni život, LXIV (2). doi:10.5937/spz64-23782

Đurić, G., Mićić, G. (2023). Agroecology - transition to sustainable agricultiral and food systems. 6th International Scientific Conference 'Village and Agriculture', 29-30 September, 2023, Bijeljina-– Republic of Srpska, BIH. Book of Proceedings, 26-43. www.ubn.rs.ba/sites/default/files/download/Book_of_proceedings-2023_E.pdf

Faith, D.P., Magallon, S., Hendry, A.P., Conti, E., Yahara, T., Donoghue, M.J. (2010). Evosystems services: An evlutionyra perspective on the links between biodiversity and human well-being. Current Opinion in Envviromental Sustainablitity, 21(1-2), 66-74. doi.org/10.1016/j.cosust.2010.04.002

Fakhri, M. (2021). A/HRC/49/43: Seeds, Right to Life and Farmers' Rights - Report of the Special Rapporteur on the right to food. www.ohchr.org/en/documents/thematic-reports/ahrc4943-seeds-right-life-and-farmers-rights-report-special-rapporteur

FAO (2014). Note by Secretary: Views, Experiences and Best Practices as an Example of Possible Options for the National Implementation of Article 9 of the International Treaty Submitted by Contracting Parties and Relevant Organizations. Farmers' Rights – Submission from Norway. www.fao.org/fileadmin/user_upload/faoweb/plant-treaty/submissions/FRs_Norway.pdf

FAO (2021). Report on monitoring schemes and data collection on biodiversity for food and agriculture in Eastern Europe and Central Asia. Rome. doi.org/10.4060/cb6959en

FAO (2023). Options for Encouraging, Guiding and Promoting the Realization of Farmers' Rights as set out in Article 9 of the International Treaty. Rome. doi.org/10.4060/cc7864en

Foreningen Frøsamlerne - Danish Seed Savers. (2022).The Danish Seed Savers' contribution to the Open Public Consultation on the Reform of EU Seed Marketing Rules. https://liberatediversity.org/have-your-say-eu-seed-marketing-legislation-impact-assessment-survey/

Golay, C., Batur, F. (2021). Practical Manual on the Right to Seeds in Europe. The United Nations Declaration on the rights of peasants and other people working in rural areas and the right to seeds in Europe. Academy Briefing N. 19, Geneva Academy.

GRAIN (2015). Seed laws that criminalise farmers: resistance and fightback. La Via Campesina. https://grain.org/fr/article/5142-seed-laws-that-criminalise-farmers-resistance-and-fightback#5%20Europe%20strives

IPGRI - International Plant Genetic Resources Institute (2004). Bragdon, S. (Ed.) International law of relevance to plant genetic resources. Issues in genetic resources, 10, p. 124. ISBN: 978-92-9043-614-0, ISBN: 92-9043-614-X

ITPGRFA (2009). International Treaty on Plant Genetic Resources for Food and Agriculture. www.fao.org/plant-treaty/overview/texts-treaty/en/

Mastretta-Yanes, A., Tobin, D., Bellon, M.R., von Wettberg, E.B., Cibrian-Jaramillo, A., Wegier, A., Monroy-Sais, A.S., Gálvez-Reyes, N., Ruiz-Arocho, J., Chen, Y.H. (2024). Human management of ongoing evolutionary processes in agroecosystems. Plants, People, Planet, 1-17.

Mićić, G., Rokvić, G., Đurić, G., Marković, D. (2022). Transition from conventional to agroecological systems, case study of Bosnia and Herzegovina. Economics of Agriculture, 69(1), 269-279. doi.org/10.5937/ekoPolj2201269M

Moore, G., Tymowski, W. (2005). Explanatory Guide to the International Treaty on Plant Genetic Resources for Food and Agriculture. IUCN, Gland, Switzerland and Cambridge, UK. xii + 212. https://iucn.org/sites/default/files/import/downloads/eplp_057__explanatory_guide_to_the_international_treaty_on_plant_genetic_resources_fo.pdf

Niélény, (2007). Declaration of Niélény. Nyéléni Village, Sélingué, Mali. https://viacampesina.org/en/wp-content/uploads/sites/2/2024/04/Nyeleni-Declaration_Food-Sovereignty_EN.pdf

Nordplus (2015). Legal aspects of seed trade and exchange in the Baltic states and Denmark from seed-savers point of view. www.froesamlerne.dk/cgi-bin/uploads/media/Projekter/Legislation_booklet_EN_arbejdskopi.pdf

Patel, R. (2009). Food sovereignty. The Journal of Peasant Studies, 36(3), 663-706. doi.org/10.1080/03066150903143079

Pautrat, A., Willard, M. (2023). The Balkan Seed Network Leading the Way to Agrobiodiversity. www.arc2020.eu/the-balkan-seed-network-leading-the-way-to-agrobiodiversity/

Pimbert, M. P. (2019). Food sovereignty. In Ferranti, P., Berry, E.M., Anderson, J.R. (Eds.), Encyclopedia of food security and sustainability, Elsevier, 3, 181-189.

Pimbert, M., Claeys, P. (2024). Food Sovereignty. Oxford Research Encyclopedia of Anthropology. (Accessed on January 2025), https://oxfordre.com/anthropology/view/10.1093/acrefore/9780190854584.001.0001/acrefore-9780190854584-e-297.

Pimbert, M.P. (2022a). Introduction: Thinking About Seeds. (doi: 10.1007/978-3-030-89405-4_1). In: Seeds for Diversity and Inclusion. (Eds). Nishikawa, Yoshiaki and Pimbert, Michel, 1-19. doi:10.1007/978-3-030-89405-4

Pimbert, M.P. (2022b). Reclaiming Diverse Seed Commons Through Food Sovereignty, Agroecology and Economies of Care (doi:10.1007/978-3-030-89405-4_2). In: Seeds for Diversity and Inclusion. Eds. Nishikawa, Yoshiaki and Pimbert, Michel, 21-40. doi:10.1007/978-3-030-89405-4

Rivera, H., Gaugitsch, H., Bartel, A., Schindler, S. (2018). Agrobiodiversity in Southeast Europe-assessment and policy recommendations. Regional synthesis report agrobiodiversity. (Eds.) Ivanovska, S., Andonov, S., Djimrevska, I., Mohr, B., Jani, S., Kume, K., Duric, G., Golub, D., Drkenda, P., Zecevic, E., Fetahu, S., Hoxha, A., Jovovic, Z., Markovic, B., Dajic Stevanovic, Z., Djordjevic Milosevic, S. (2018). Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Skopje. p. 77. http://seerural.org/wp-ćontent/uploads/2018/09/Agrobiodiversity-Study-Synthesis-report.pdf.

Seed Change (2019). Farmer seed systems: A critical contribution to food sovereignty and farmers' rights. https://weseedchange.org/wp-content/uploads/2020/05/Farmers-seed-systems-EN-a-critical-contribution-to-food-sovereignty-and-farmers-rights.pdf

UNDROP (2018). United Nations Declaration on the Rights of Peasants and Other People Working in Rural Areas : resolution / adopted by the Human Rights Council on 28 September 2018, UN. Human Rights Council (39th sess. : 2018 : Geneva) https://digitallibrary.un.org/record/1650694?ln=en&v=pdf

UPOV (1961; 1972; 1978; 1991). The International Convention for the Protection of New Varieties of Plants. https://upovlex.upov.int/en/convention

van Willenswaard, H. (2015). No Food Security Without Food Sovereignty. In: Hongladarom, S. (eds) Food Security and Food Safety for the Twenty-first Century. Springer, Singapore. doi.org/10.1007/978-981-287-417-7_

Wynberg, R., Andersen, R., Laird, S., Kusena, K., Prip, C., Westengen, O.T. (2021). Farmers' Rights and Digital Sequence Information: Crisis or Opportunity to Reclaim Stewardship Over Agrobiodiversity? Front. Plant Sci. 12:686728. doi: 10.3389/fpls.2021.686728

Internet links (1): twww.google.com/search?q=tatjana+brankov+prehrambena+suvreensopt&client=firefox-b-e&sca_esv=c24ef50bf02c270d&ei=_HyDZ5bNH6K8wPAPsf6WoAM&ved=0ahUKEwiWu5DP4e-KAxUiHhAIHTG_BTQQ4dUDCBA&uact=5&oq=tatjana+brankov+prehrambena+suvreensopt&gs_lp=Egxnd3Mtd2l6LXNlcnAiJ3RhdGphbmEgYnJhbmtvdiBwcmVocmFtYmVuYSBzdXZyZWVuc29wdDIHECEYoAEYCjIHECEYoAEYCkiZKFDzBFiiJnABeACQAQCYAYcBoAHfFKoBBDAuMjS4AQPIAQD4AQGYAhmgAq0VwgIJEAAYsAMYBxgewgIIEC4YgAQYsAPCAgkQABiwAxgIGB7CAg4QABiABBiwAxiGAxiKBcICCxAAGIAEGLADGKIEwgIGEAAYFhgewgILEAAYgAQYhgMYigXCAggQABiABBiiBMICBRAhGKABwgIEECEYFZgDAIgGAZAGB5IHBDEuMjSgB5VS&sclient=gws-wiz-serp#fpstate=ive&vld=cid:12203ee2,vid:CG4sC_zqExc,st:1466

doi:10.46793/MAK2025.213R

ALLELOPATHY AND WEED CONTROL IN CHANGING CLIMATE

Ljiljana Radivojević[1*], Marija Sarić-Krsmanović[1], Jelena Gajić-Umiljendić[1], Ljiljana Šantrić[1], Danijela Šikuljak[2]

[1]Institute of Pesticides and Environmental Protection, Belgrade
*ljiljana.radivojevic@gmail.com
[2]Institute for Plant Protection and Environment, Belgrade

Abstract: Modern agriculture involves dealing with challenges from climate change, environmental pollution, depletion of natural resources, as well as pressure to cope with dependence on agricultural inputs with aim sustainable management of crop production and the environment. Weeds are one of the most challenging problems facing agricultural production, while modern agriculture relies heavily on synthetic herbicides for weed control. The excessive use of synthetic herbicides has contributed significantly to soil degradation, environmental pollution and adverse effects on non-target organisms and human health. Also, long-lasting exploitation of herbicides with one target site in plants has resulted in the evolution of weeds resistant to herbicides. Due to all these problems, there is a need to develop a sustainable, environmentally friendly tool for weed management. One great field for discovering new approaches for weed control is allelopathy and allelochemicals. Allelopathy is a biological phenomenon of chemical interaction between plants and this phenomenon has great potential to be used as an effective and environmentally friendly tool for weed management in agriculture. Previous studies showed that some plant species possess potent allelochemicals that have great potential to be ecofriendly bioherbicides.

Key words: Allelopathy, Allelochemicals, Bioherbicides, Weed control

1. INTRODUCTION

Climate is defined as the sum of the weather conditions of a given area, quantified as long-term statistics of meteorological variables (temperature, wind, precipitation and sunshine hours) that are essential for the growth, development and productivity of vegetation, animals and people (World Meteorological Organization, 1992). In recent decades, changes in climate have caused significant impacts on natural and human ecosystems, on agriculture, and on the growth of all plant species, including crops and weeds (Kang and Banga, 2013; Chauhan, 2013).

Weeds are one of the most challenging problems facing agricultural production all over the world. Weeds compete for light, nutrients, water, and space that reduces crop growth and yield. Additionally, weeds also harbor insect pests, bacterial, fungal and virual pathogens, further reducing the crop yield (Chauhan, 2020). Modern agriculture relies heavily on synthetic herbicides for weed control. The heavy reliance on herbicides has resulted in 533 unique cases of herbicide-resistant weeds globally with 273 species. Weeds have evolved resistance to 21 of the 31 known herbicide sites of action and 168 different herbicides. Herbicide-resistant weeds have been reported in 101 crops in 72 countries. The heavy reliance on herbicides with similar mechanisms of action (MOA) has resulted in 513 unique cases of herbicide-resistant weeds globally across 267 species (Heap, 2024). In addition, there are several other negative consequences related to excessive use of herbicides, such as high chemical costs, potential leaching and runoff into groundwater, or concerns with recycling irrigation water (Poudyal and Cregg, 2019). Public concerns over the impact of herbicides on human health and the environment are also increasing. Due to the evolution of herbicide-resistant weeds, lack of new herbicides with new MOA and public awareness with synthetic herbicides, there is a need to develop a sustainable ecofriendly tool to manage weeds. One great field for discovering such tools is the use of plant based natural compounds called allelochemicals to control weeds. Allelochemicals have the potential to be used as natural herbicides to control certain types of weeds (Khamare et al., 2022).

The focus of this review is to provide an overview of previous research on allelopathic plants, allelochemicals, and the use of allelopathy in crop production and the ways in which allelopathy could be used for weed control in the context of climate change.

2. WEED CONTROL IN MODERN AGRICULTURE

One of the most important elements to sustaining life and promoting good health is ensuring access to enough safe and nutritious food. It is estimated that agricultural production may encounter many difficulties in securing food production for the rapidly growing human population in the coming years. The world's population is expected to increase by 2 billion persons in the next 30 years, from 7.7 billion currently to 9.8 billion in 2050 (Hernandez-Tenorio et al., 2022).

To withstand these harsh challenges induced by abiotic and biotic factors the world needs to adopt novel and improved agricultural practices and strategies for high sustainability and productivity (Khursheed et al., 2023). Among the major biotic constraints, weeds are considered the most harmful to agricultural production (Gharde et al., 2018). Worldwide huge crop losses have been found to result from heavy weed infestations. Crop losses due to weeds continue to reduce the available production of food and cash crops worldwide. It is very difficult to indicate the yield loss due to any single weed species; therefore, the loss is estimated as the collective effects by all weed species. Globally, compared to other biotic factors, weeds produced the highest potential loss at 34%, with animal pests and pathogens being less important-with losses of 18 and 16%, respectively (Głąb et al., 2017). Integrated Weed Management (IWM) is a long-term comprehensive approach to controlling and mitigating infestation in fields incorporating physical, genetic, biological, cultural and chemical weed management techniques (Jabran et al., 2015). Farmers usually rely on quick and effective synthetic herbicides which represent the backbone of the agri-food sector in its endeavor to secure food production and suppress yield losses, but their application is perceived as an obstacle to the achievement of sustainability (Lykogianni et al., 2021). The excessive use of chemical herbicides has contributed significantly to soil degradation, environmental pollution, and adverse effects on non-target organisms and has been proven to have deleterious effects on human health. The consequences of the inappropriate adjustment of herbicides to the weed species occupying the fields, the use of herbicides at the wrong plant developmental stage and under unsuitable weather conditions are the accumulation of active compounds in the soil, the accumulation of weed species, and the acceleration of the evolution of resistant biotypes (Motmainna et al., 2021). Long-lasting exploitation of herbicides with one target site in plants has resulted in the evolution of weeds resistant to herbicides (Soltys et al., 2013).

The complete exclusion of chemical control of weeds is impossible with current agrochemical practices, so it is necessary to develop novel classes of herbicides with new mechanisms of action and target sites. Reducing the large-scale use of herbicides and introducing organic production systems requires the combined efforts of all actors in the food value chain (Mohring and Finger, 2022). In the face of climate change, increasing consumer awareness of crop protection products and fertilization, coupled with unconventional methods to ensure safe and superior agricultural products are in high demand (Głąb et al., 2017). The need for safe food production and eco-friendly trends in weed management forces scientists to develop innovative solutions. There is a growing need for new herbicides with safer toxicological and environmental profiles. Natural compounds provide a wide selection of potential new environmentally safe herbicides, so-called "bioherbicides", which are based on compounds produced by living organisms (Soltys et al., 2013). Bioherbicides are broadly defined as products derived either from living organisms or their secondary metabolites to suppress target weed populations without harming the environment (Scavo and Mauromicale, 2021). Recently, among the proposed approaches, research on allelopathy has become increasingly prevalent in weed management for agroecosystems (Hoang Anh et al., 2021).

3. ALLELOPATHY AND ALLELOCHEMICALS

Allelopathy refers to the direct or indirect effect of plants upon neighboring plants or their associated microflora or microfauna by the production of allelochemicals that interfere with the growth of the plant (IAS, 2018). The word allelopathy is derived from two separate Greek words, allelon meaning of each other or mutual and pathos meaning to suffer or feeling. The chemical interaction between plants has been known for thousands of years but the term 'allelopathy' was first used by Austrian scientist Hans Molisch in 1937 (Willis, 2007).

Allelochemicals can affect vital physiological processes in plants, such as respiration, photosynthesis, cell division and elongation, membrane fluidity, protein biosynthesis, and the activity of many enzymes, and they might also affect tissue water status (Field et al, 2006; Hussain and Reigosa, 2011; Hussain et al., 2020). They belong to many chemical families, such as phenols, flavonoids, terpenoids, glucosinolates, benzoquinones, and cyanogenic compounds (Li et al., 2010; Hussain et al., 2020).

Phenolics are a class of the most important and most common plant allelochemicals that are known to be present in a variety of plant tissues, including stem, leaf, root, flower, pollen, or fruit. Phenolics can be generally classified into phenolic acids, flavonoids, coumarins, lignins, tannins, stilbenes and others and are found in many plant species including weeds (Figure 1) (Puig et al., 2018; Li et al., 2020; Khamare et al., 2022). Nine flavonoid compounds have been isolated and identified from *Abuthilon theophrasti* (Matławska and Sikorska, 2005), while the phenolic composition of *Ambrosia artemisiifolia* includes isorhamnetin, quercetin, and kaempferol (Mihajlović et al., 2015). Chemical constituents of *Xanthium strumarium* include phenolic compounds such as gallic acid, protocatechuic acid, quercetin, chlorogenic acid, caffeic acid, rutin, and feluric acid (Srinivas et al., 2011). The mechanism of allelopathy associated with phenolic compounds includes interfering with hormone activity, membrane permeability, photosynthesis, respiration and synthesis of organic compounds in susceptible plants (Latif et al., 2017).

Terpenoids are classified based on the number of isoprene units in their carbon skeleton, e.g. monoter penes, sesquiterpenes, diterpenes, sesterpenes and triterpenes. *Asteraceae* plants are a natural source of allelopathic sesquiterpenes and sesquiterpene lactones. They can inhibit the enzyme asparagine synthase, thereby preventing growth and can also interfere with mitochondrial cell organelle respiration and the release of proteins into the plasma membrane (Araújo et al., 2021; Nair et al., 2022).

Coumarins are abundant in plants families *Apiaceae*, *Rutaceae*, *Asteraceae* and *Fabaceae* (Bachheti et al., 2020). A C7-hydroxyl group in the coumarin structure seems to contribute significantly to the herbicidal activity of this family of compounds. A7-hydroxycoumarins, such as umbelliferone, esculetin, and scopoletin, have received interest as eco-friendly herbicides and are known for their allelopathic effect (Galan-Pérez et al., 2022).

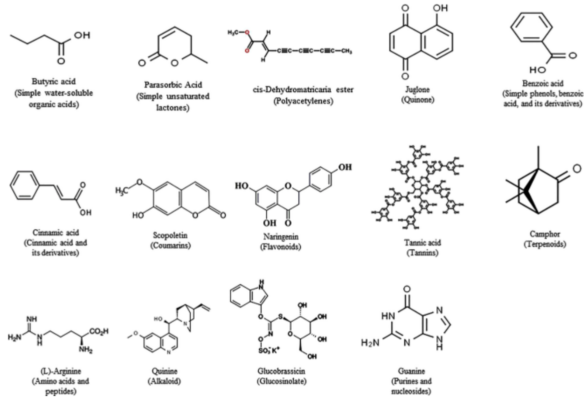


Figure 1. Representative allelochemicals from the classified
14 categories based on their chemical similarities (Khamare et al., 2022)

4. ALLELOCHEMICALS AND WEED CONTROL

Allelopathic interactions play an important role in agricultural ecosystems due to their impact on crop growth. Allelopathy may contribute to integrated weed control by incorporating cover crops as living or dead mulches, and/or crop residues into the soil. There is a viable prospect of using allelopathic mechanisms as an environmentally friendly tool for weed control in cropping systems without relying on synthetic herbicides. The incorporation of allelopathic plants into agricultural strategies will enhance sustainable crop production due to the positive effects of these practices on soil fertility, organic matter content and ecosystem biodiversity (Kostina-Bednarz et al., 2023).

Many allelochemicals are water-soluble and water acts as the carrier and medium for allelopathic activity (Farooq et al., 2011). Water soluble allelochemical extract from different parts of allelopathic species, such as leaves, stems, roots, and seeds have great potential to be used for controlling weeds. It has been reported that there are about 400.000 compounds in plants with allelopathic potential, and only about 3% of these compounds have been identified for their herbicidal activity (Einhellig, 1996). These allelochemicals can control the germination and growth of weeds through various modes of action (Kostina-Bednarz et al., 2023).

Research by Šćepanović et al. (2021) found that aqueous extracts of the cover crop *Camellina sativa* inhibited germination, shoot length, root length, and fresh seedling weight, as well as early growth of the invasive weed species *Ambrosia artemisiifolia*. Sarić-Krsmanović et al. (2021) studied the effects of water extracts produced from fresh leaves of *Xanthium strumarium* and *A. artemisiiflia* on the weeds *Abutilon theophrasti* and *Chenopodium album*. The extracts from *A. artemisiiflolia* leaves caused significant reductions in *A. theophrasti* fresh weight and height, while *X. strumarium* water extracts caused a negligible decrease in both parameters in *A. theophrasti*. In these treatments *C. album* exhibited higher sensitivity than *A. theophrasti.* In a study conducted by Đorđević et al. (2022) the herbicidal potential of walnut leaf extract (*Juglans regia*) against two weeds *Amaranthus retroflexus* and *Ch. album* was investigated. The results obtained from biological tests showed a significant negative effect of walnut leaf extract on germination and seedling growth of the tested weeds. Although it affected the growth of corn seedlings *in vitro* similarly to the tested weeds, corn germination was less sensitive to the treatment, and the extract did not have a significant negative effect on oxidative stress conditions in corn plants. The findings showed that walnut leaf extract may have a promising role in replacing chemical herbicides in corn.

5. BIOHERBICIDES BASED ON ALLELOCHEMICALS

Plant-based allelochemical bioherbicides are becoming increasingly popular with the aim of protecting the environment and human health from the excessive use of synthetic herbicides, as well as overcoming the phenomenon of weed resistance (Scavo and Mauromicale, 2021). Most allelochemicals are totally or partially soluble in water making them easier to apply and safer for use in the environment (Lengai and Muthomi, 2018). Before an allelochemical can be used as an herbicide, it must meet certain criteria. It is necessary to identify its chemical structure, know its mechanism of action, determine its persistence in the soil, its effect on the environment, non-target organisms and human health (Soltys et al., 2013; Khursheed et al., 2023).

Allelochemicals could be used as tem plates to synthesize novel herbicides. For example, several studies have been performed to develop new herbicides using coumarins because of their bioactivity and the results showed that some of the novel compounds had the same inhibitory effect on weeds as the commercial herbicide acetochlor. In their study Zhao et al. (2021), designed and synthesized a series of new phenoxypyridine derivatives containing the natural product coumarin. These compounds showed excellent herbicidal activity under greenhouse conditions, like the commercial herbicide oxyfluorfen. The herbicidal activity of these compounds was significantly affected by the types of substituents introduced at the phenoxypyridine and coumarin rings. The visual injury and growth status of the test crops were observed at regular intervals and the crop selectivity tests showed that maize, cotton, and soybean had excellent tolerance to the new compound, but rice and wheat were damaged.

Bioherbicides are prepared from plant parts or modeled after natural substances when it is necessary to prepare the plant material and then extract it using solvents or distillit to obtain the corresponding extracts or essential oils. The quality of the obtained extracts is influenced by the type of solvent used and the extraction method. Dried plant parts are generally preferred due to the higher yield of the active ingredient. Solvents with low toxicity, high capacity to dissolve large amounts of compounds, easy evaporation and preservatives should be used for extraction (Lengai and Muthomi, 2018).

The challenge of the widespread use of bioherbicides is to optimize formulation and application methods that will allow the active agent to be evenly introduced to the targeted area without excessive use of the product. Precise application of the substance at the site of the weed to be controlled without exposing the crop significantly increases the effectiveness of the bioherbicide One should bear in mind that the cost of bioherbicides must be competitive to become realistic alter natives to conventional herbicides (Głąb et al., 2017; Kremer, 2019).

Therefore, it is imperative to find an optimal solution that would simplify the procedures and enable the development of new bioherbicides with a competitive price acceptable to agricultural producers and thus increase their application (Šunjka and Mechora, 2022).

However, widely developed bioinformatics and cheminformatics support the discovery of new bioherbicidal compounds. The basis for the design of new compounds using specialized computer programs is the precisely identified and characterized chemical structure of allelochemicals. Chemoinformatic tools can propose structures of similar compounds and after several alterations, lead to improvements in their activity and stability. An example of this was the modification of leptospermone (Soltys et al., 2013). Owing to its herbicidal properties leptospermone-a triketone identified in 1977. has been used to create numerous highly active chemical analogs such as Sulcotrione® and Mesotrione® (Kostina-Bednarz et al., 2023). Other products that are not herbicides perse but have been synthesized and produced based on natural molecules are phosphinothricin (a biosynthetic version of glufosinate) and bialophos (a microbial phytotoxic product) (Cordeau et al., 2016).

However, there are also some factors that limit the full adoption of bioherbicides in weed control. The biodegradation, type, and concentration of allelochemicals released into the environment depend on the combined effects of the plant itself and environmental factors which are sometimes difficult to control. The relatively short environmental half-life of allelochemicals is good from an environmental toxicology standpoint. However, an herbicide must persist sufficiently long to have the desired effect and to be effective (Motmainna et al., 2021). It should be noted that, compared to synthetic herbicide, botanical herbicide releases into the environment a mixture of allelochemicals, with a qualitative and quantitative composition that is difficult to precisely predict. A single allelopathic compound may not show allelopathic activity individually in a certain situation but might increase allelopathy in association with other allelochemicals. It is therefore important to evaluate interactions such as synergy, antagonism and incremental effects, between different allelochemicals (Motmainna et al., 2021). Allelochemicals have multi-site action in plants without the high specificity which is achieved in the case of synthetic herbicides and are also highly dose dependent. Under field conditions, high doses of allelochemicals are necessary to achieve the desired efficacy, and the concentration of these bioactive components is dictated by the environment under which they grow (Scavo and Mauromicale, 2021).

6. CONCLUSION

In recent decades, changes in climate have caused significant impacts on agriculture, on the growth of all plant species, including crops and weeds. Modern agiculture usually rely on quick and effective synthetic herbicides for weed control which represent the backbone of the agri-food sector in its endeavor to secure food production and suppress yield losses. Soil degradation, environmental pollution and adverse effects on human health and non-target organisms are a consequence of the excessive use of synthetic herbicides. Currently, it is difficult to replace chemical weed management entirely, but an integrated weed management approach may lead to success. The concept of allelopathy can be employed in integrated weed management and reduced use of synthetic herbicides. Studies showed that allelochemicals can be integrated with other weed management practices to get better weed control, reduce herbicide use, reduce production costs and avoid any herbicide resistance. However, there are also some factors that limit the full adoption of allelochemicals in weed control. The use new and modern methods of bioinformatics and cheminformatics to identify the chemical structures and mechanisms of action of allelochemicals can be a starting point for designing formulations and the synthesis of novel agrochemicals based on allelochemicals as a natural product.

7. ACKNOWLEDGMENT

The research presented in this article is part of Contracts No. 451-03-66/2024-03/200010, 451-03-65/2024-03/200216 and 451-03-65/2024-03/200114 financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

8. REFERENCES

Araújo, C.A., Sant, C., Morgado, A. et al. (2021). *Asteraceae* family: a review of its allelopathic potential and the case of *Acmella oleracea* and *Sphagneticola trilobata*. Rodriguesia. doi. org/ 10. 1590/ 2175- 78602 02172 137

Bachheti, A., Sharma, A., Bachheti, R.K. et al. (2020). Plant allelochemicals and their various applications. In: Co-evolution of secondary metabolites, Merillon J.M. and Ramawat K. (Eds.), Springer, Switzerland, 441-465.

Chauhan, B.S. (2013). Strategies to manage weedy rice in Asia. Crop Prot., 48, 51-56.

Chauhan, B.S. (2020). Grand challenges in weed management. Front. Agron. 1. doi: 10.3389/fagro.2019.00003

Cordeau, S., Triolet, M., Wayman, S. et al. (2016). Bioherbicides: Dead in the water? A review of the existing products for integrated weed management. Crop. Prot., 87,44-49.

Đorđević, T., Đurović-Pejčev, R., Stevanović, M., Sarić-Krsmanović, M., Radivojević, Lj., Šantrić, Lj., Gajić-Umiljendić, J. (2022). Phytotoxicity and allelopathic potential of *Juglans regia* L. leaf extract. Front. Plant Sci., 13:986740

Galan-Perez, J.A., Gamiz, B., Celis, R. (2022). Soil modification with organic amendments and organo-clays: effects on sorption, degradation, and bioactivity of the allelochemical scopoletin. J. Enviro. Manag., 302, 114102

Gharde, Y., Singh, P.K., Dubey, .RP., Gupta, P.K. (2018). Assessment of yield and economic losses in agriculture due to weeds in India. Crop. Prot., 107,12-18.

Głąb, L., Sowiński, J., Bough, R., Dayan, F.E. (2017). Allelopathic potential of sorghum (*Sorghum bicolor* (L.) Moench) in weed control: a comprehensive review. In: Advances in agronomy, Sparks D.L. (Ed.), Academic Press, Cambridge, 145,43-95.

Einhellig, F.A. (1996). Interactions involving allelopathy in cropping systems. Agron. J., 88, 886-893.

Farooq, M., Jabran, K, Cheema, Z.A., Hm, K. (2011). The role of allelopathy in agricultural pest management. Pest. Manag. Sci., 67, 493-506.

Field, B., Jordan, F., Osbourn, A. (2006). First encounters-deployment of defense-related natural products by plants. New Phytol., 172, 193-207.

Heap, I. (2024). International survey of herbicide resistant weeds. Available at: www.weedscience.org (Accessed December 25, 2024).

Hernandez-Tenorio, F., Miranda, A.M., Rodriguez, C.A. et al. (2022). Potential strategies in biopesticide formulations: a bibliometric analysis. Agronomy, 12, 2665.

Hoang Anh, L., Van Quan, N., Tuan Nghia, L., Dang Xuan, T. (2021). Phenolic allelochemicals: achievements, limitations, and prospective approaches in weed management. Weed Biol. Manag., 21,37-67.

Hussain, M.I., El-Sheikh, M.A., Reigosa, M.J. (2020). Allelopathic potential of aqueous extract from *Acacia melanoxylon* R. Br. on *Lactuca sativa*. Plants, 9, 1228.

Hussain, M.I. Reigosa, M.J. (2011). Allelochemical stress inhibits growth, leaf water relations, PSII photochemistry, non-photochemical fluorescence quenching, and heat energy dissipation in three C3 perennial species. J. Exp. Bot., 62, 4533-4545.

Jabran, K., Mahajan, G., Sardana, V., Chauhan, B.S. (2015). Allelopathy for weed control in agricultural systems. Crop. Prot., 72, 57-65.

Kang, M.S., Banga, S.S. (2013). Global agriculture and climate change: a perspective. In Combating climate change: cn agricultural perspective, Kang, M.S., Banga, S.S. (Eds.), FL: CRC Press, Boca Raton, FL, 11-25.

Khamare, Y., Chen, J., Marble, S.C. (2022). Allelopathy and its application as a weed management tool: A review. Front. Plant Sci., 13, 1034649

Khursheed, A., Rather, M.A., Jain, V. et al (2022). Plant based natural products as potential ecofriendly and safer biopesticides: a comprehensive overview of their advantages over conventional pesticides, limitations and regulatory aspects. Microb. Pathog., 173:105854

Kostina-Bednarz, M., Płonka, J., Barchanska, H. (2023). Allelopathy as a source of bioherbicides: challenges and prospects for sustainable agriculture. Rev. Environ. Sci. Biotechnol., 22, 471-504.

Kremer, R.J. (2019). Bioherbicides and nanotechnology: current status and future trends. In: Nano-biopesticides today and future perspectives, Koul, O. (Ed.), Academic Press, Cambridge, 353-366.

Latif, S., Chiapusio, G., Weston, L.A. (2017). Allelopathy and the role of allelochemicals in plant defence. In: Advances in botanical research, Becard G. (Ed.), Academic Press, Cambridge, 82, 19-54.

Lengai, G.M.W., Muthomi, J.W. (2018). Biopesticides and their role in sustainable agricultural production. J. Biosci. Med., 6, 7-41.

Li, M., Ma, L., Song, Y., Yan, X., Lei, Q., Zhang, X. (2020). Allelopathic effects of phenolic acids on germination of watermelon (*Citrullus lanatus* Thunb): Dose-effect relationship and quantitative structure-activity relationship. Allelopath J., 51, 165-176.
Li, Z.H., Wang, Q., Ruan, X., Pan, C.D., Jiang, D.A. (2010). Phenolics and plant allelopathy. Molecules 15, 8933-8952.
Lykogianni, M., Bempelou, E., Karamaouna, F., Aliferis, K.A. (2021). Do pesticides promote or hinder sustainability in agriculture? The challenge of sustainable use of pesticides in modern agriculture. Sci. Total Environ. 795:148625
Matławska, I., Sikorska, M. (2005). Flavonoids from *Abutilon theophrasti* flowers. Acta Poloniae Pharmaceutica, 62, 135-139.
Mihajlović, L., Radosavljević, J., Burazer, L., Smiljanić, K., Ćirković Veličković, T. (2015). Composition of polyphenol and polyamide compounds in common ragweed (*Ambrosia artemisiifolia* L.) pollen and sub-pollen particles. Phytochem., 109, 125-132.
Mohring, N., Finger, R. (2022). Pesticide-free but not organic: Adoption of a large-scale wheat production standard in Switzerland. Food Policy, 106, 102188.
Motmainna, M., Shukor, B.A., Md. Kamal Uddin, J. et al (2021). Assessment of allelopathic compounds to develop new natural herbicides: a review. Allelopath J., 52, 21-40.
Nair, G., Raja, S.S.S., Vijayakumar, R. (2022). Secondary metabolites - an overview. In: Secondary metabolites-trends and reviews applied, Vijayakumar, R., Raja, S. (Eds.). IntechOpen, London, p. 8. doi. org/ 10. 5772/ intechopen. 9812
Poudyal, S., Cregg, B.M. (2019). Irrigation of nursery crops with recycled runoff: a review of potential impact of pesticides on plant growth and physiology. Hort Tech., 29, 716-729.
Puig, C.G., Reigosa, M.J., Valentão, P., Andrade, P.B., Pedrol, N. (2018). Unraveling the bioherbicide potential of *Eucalyptus globulus* Labill: biochemistry and effects of its aqueous extract. PLoS ONE 13: e0192872
Sarić-Krsmanović, M., Radivojević, Lj., Šantrić, Lj., Đorđević, T., Gajić Umiljendić, J. (2021). Effects of mixtures of allelopathic plant water extracts and an herbicide on weed suppression. J. Environ. Sci. Health, Part B, 56,16-22.
Scavo, A., Mauromicale, G. (2021). Crop allelopathy for sustainable weed management in agroecosystems: knowing the present with a view to the future. Agronomy, 11, 2104.
Soltys, D., Krasuska, U., Bogatek, R., Gniazdowska, A. (2013). Allelochemicals as bioherbicides-present and perspectives. In: Herbicides-current research and case studies in use, Price, A., Kelton, J. (Eds.), InTech, London, 517-542.
Srinivas, P.V., Rao, R.U., Venkateshwarulu, E.L., Kumar, A.C. (2011). Phytochemical screening and *in vitro* antimicrobial investigation of the methanolic extract of *Xanthium strumarium* leaf. International Journal of Drug Development & Research, 3, 286-293.
Šćepanović, M., Sarić-Krsmanović, M., Šoštarčić, V., Brijačak, E., Lakić, J., Špirović Trifunović, B., Gajić Umiljendić, J., Radivojević, Lj. (2021). Inhibitory effects of Brassicaceae cover crop on *Ambrosia artemisiifolia* germination and early Growth. Plants, 10, 794.
Šunjka, D., Mechora, Š. (2022). An alternative source of biopesticides and improvement in their formulation-recent advances. Plants 11, 1-13.
Willis, R.J. (2007). The history of allelopathy. Springer, Dordrecht.
World Meteorological Organization (1992). International Meteorological Vocabulary, 2nd Edn. Geneva: World Meteorological Organization.
Zhao, M., Cheng, J., Guo, B. et al (2018). Momilactone and related diterpenoids as potential agricultural chemicals. J. Agric. Food Chem., 66, 7859-7872.

doi:10.46793/MAK2025.221S

IMPACT OF ENVIRONMENTAL CHANGES ON SOYBEAN WEED FLORA

Markola Saulić[1*], Uroš Mladenović[2], Miroslav Matejić[2], Marko Kovačević[2], Aleksandar Stevanović[1]

[1]The Academy of Applied Studies Polytechnic, Belgrade, Serbia
*msaulic@politehnika.edu.rs
[2]University of Belgrade, Faculty of Agriculture, Zemun-Belgrade, Serbia

Abstract: Over the past decades, climate change has induced transformations in the weed flora of arable ecosystems. In soybean production, weeds can have a very negative impact on yield and grain quality and can complicate the harvest of the crop. Phytocenological assessments in soya before and POST-EM application showed 14 weed species were present: *Abuthilon theophrasti* L., *Amaranthus retroflexus* L., *Ambrosia artemisiifolia* L., *Bilderdykia convolvulus* L., *Chenopodium album* L., *Cirsium arvense* L., *Convolvulus arvensis* L., *Echinochloa crus-galli* L., *Hibiscus trionum* L., *Lamium purpureum* L., *Portulaca oleracea* L, *Sorghum halepense* (L.) Pers., *Stellaria media* L. and *Trifolium repens* L. Out of 14 species, as many as 4 belonged to invasive weed. It indicates that invasive weeds provide good models for the rapid changes, partly because invasive weeds exhibit unique evolutionary mechanisms integral to their success hanging temperatures, moisture regimes and extreme climate events operate universally, but invasive plant species are generally better equipped than native plants to adapt.

Key words: Soya, Environmental changes, Weed species

1. INTRODUCTION

Climate change on a global scale was noticed and presented several decades ago (National Science Board U.S. 1974), However, awareness of the problems and consequences of climate change is still insufficiently developed, and investments in solving these problems are disproportionate. Climate change is one of the greatest global challenges. The world is already facing many problems brought about by climate change, and predictions indicate that there will certainly be more of them in the coming decades. It is believed that climate change causes a chain of problems that require an integrated approach to identifying factors that limit yield, which will likely have a significant impact on overall agricultural production in the future (IPCC, 2014). It is uncertain to expect an increase in air temperature, changes in the amount and distribution of precipitation, an increase in the variability of climatic factors, and the occurrence of extreme climatic events in the future (Bekavac et al., 2010). Climate change impacts many activities, but its effects on agricultural production could be acute. Climate change, in combination with an increasing world population, is predicted to escalate the global need for farmland, a resource that is already in high demand (Barrow et al., 2008) and dwindling rapidly. Estimates of annual damages in agriculture due to temperature increase or extended periods of drought will be more costly than damages in other activities. Yield losses are caused both by direct effects of climate change on crops and by indirect effects such as increased inputs in crop production for weed control (Korres et al., 2016). In recent years, there has been a massive expansion and change of weed species on the territory of Serbia because of the trend of climate warming, increased concentration of CO_2 and other gases. This affects the spread of already existing weeds, as well as the appearance of new, even more aggressive non-native invasive weed species (Radičević et al., 2008). Invasive plant species represent a major problem and a hindrance to the preservation of biodiversity (McNeely et al., 2001) and a hindrance to the preservation of biodiversity, causing significant and irreversible changes in the environment, primarily changes in the floristic structure. Invasive weed can define as a plant that is either native or non-native and may have negative effects on either natural ecosystems or agroecosystems but must clearly be invasive in that it exhibits a tendency to rapidly colonize and spread to occupy new niches (Clements, 2017) than we can understand. Invasive weeds provide many examples of more rapid evolutionary modes and are designed to respond rapidly to environmental stressors associated with disturbance (Clements et al., 2004). This is particularly evident in soybean crops, as in recent years there has been a fluctuation in soybean yields, indicating challenges and potential for growing this crop in Serbia. In soybean production, weeds can have a very negative impact on yield and grain quality and can complicate the harvest. The application of herbicides is the most common measure, which, in combination with other practices, ensures effective weed control, facilitates production, and contributes to economic profitability and stability (Mladenović et al., 2024). However, excessive pesticide use can significantly disrupt the microbiological balance in the soil and negatively affect the quality of agricultural products, the environment, and production costs. The issue of climate change can be approached from various perspectives, and this paper presents how global climate change affects the composition of weed flora and the increasing occurrence of invasive weed species.

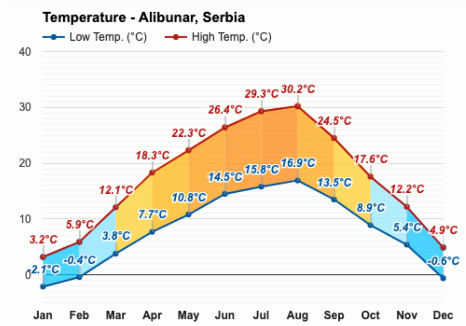
The aim of the research is to determine the weediness of soybean crops after herbicides application and to examine whether changes in the environment (long periods of drought and high temperatures) affect the intensification of certain weed species.

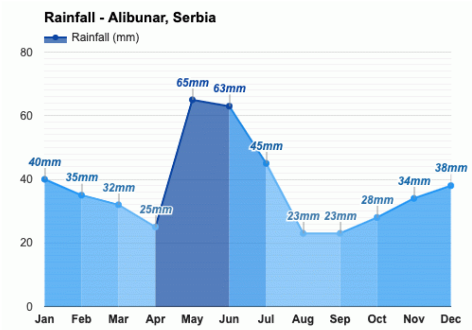
2. MATERIAL AND METHODS

A field trial was conducted at the Marko Kovačević agricultural estate in Velika Greda in Banat (Figure 1). During the spring of 2024 the trial design were a randomized block system with four replications and a basic plot area of 25 m^{-2} in soybean and the weed density was determined by counting the individuals using a frame with dimensions of 1×1 m. Pre-sowing soil preparation was done at the last week of March and sowing of soybeans on April 23. Weediness of the plot was noticed immediately before sowing, so for that reason pre-emergence herbicides: Max 51 (a.i. flumioksazin 510 g kg^{-1}, WG) in amount 120 g ha^{-1}, Glifomark (a.i. glifosate 480 g L^{-1}, SL) in amount 3 L ha^{-1} and Mont 960 EC (a.i. S-metolachlor 960 g L^{-1}, EC) in amount 1.2 L ha^{-1} were applied immediately after
soybean sowling.

Figure 1. Marko Kovačević agricultural estate in Velika Greda (Alibunar)

Post-emergence herbicide Corum (a.i. bentazon 480 g L^{-1} + imazamox 22,4 g L^{-1}, SL) in amount 1.2 L ha^{-1}, Bentamark 480 SL (a.i. bentazon 480 g L^{-1}, SL) in amount 0.5 L ha^{-1} and Kloman (a.i. klomazon 480 g L^{-1}, EC) in amount 0.15 L ha^{-1} were applied when the soybeans were at the first true leaf stage. Although the same combination of herbicides was planned for the second treatment, due to the favorable results of the phytocenological assessment, the planned split application was omitted, and it was decided to use Kletox extra (a.i. Kletodim 240 g L^{-1}, EC) in amount 1 L ha^{-1} with the addition of Dash EC in amount 0.5 L ha^{-1}, which gave effective control results to control *Sorghum halepense* (L.) Pers. Phytocoenological assessments were performed after sowing, 7 and 14 days after the first and second post emergence applications. At the same time, weed infestation of control plots without application of pesticides (NT) was also monitored. In Figures 2 and 3 the average minimum and maximum monthly temperatures and average rainfall for the municipality Alibunar are shown.





Figures 2 and 3. Average minimum and maximum monthly temperatures and average rainfall for the municipality Alibunar

3. RESULTS AND DISCUSSION

During the first phytocenological assessment immediately after sowling in the treatments (T) and control (K) 3 weed species (*Ambrosia artemisiifolia* L., *Chenopodium album* L., *Stellaria media* L. were observed. Phytocenological assessments 7 and 14 days after first post emergence application in treatman (T) showed only *Sorghum* halepense, while in the control, 14 weed species were present: *Abuthilon theophrasti* L., *Amaranthus retroflexus* L., *Ambrosia artemisiifolia* L., *Bilderdykia convolvulus* L., *Chenopodium album* L., *Cirsium arvense* L., *Convolvulus arvensis* L., *Echinochloa crus-galli* L., *Hibiscus trionum* L., *Lamium purpureum* L., *Portulaca oleracea* L., *Sorghum halepense* (L.) Pers., *Stellaria media* L. and *Trifolium repens* L. After 7 days of the second post emergence application, 100% herbicide efficacy was observed on *S. halepense* in T, while in the NT without pesticide, 14 species were detected.

In the research of two soybean crop locations, the effective of herbicides was tested, and 8 and 7 weed species were identified, respectively (Samardžić et al., 2024), while in our case, it was recorded 14 weeds from 10 familias, 12 belong to broadleaf weeds, and only two are narrow-leaved species (*Sorghum halepense* (L.) Pers and *Echinochloa crus-galli* L.) (Figure 4). In a year like this one, with extremely high temperatures and a long summer drought period, it is confirmed that the fact is that *Echinochloa* spp. is a weed of warm regions that requires high temperatures for dry matter production and growth (Maun and Bennett, 1986). Although *Sorghum halepense* (L.) Pers was successfully controlled in the herbicide trial, it should not be forgotten that this species is one of the most economically significant weeds in field crops (Vrbničanin et al., 2009). Perennial weeds like *S. halepense* may become more difficult to control, if increased photosynthesis stimulates greater production of rhizomes and other storage organs (Patterson, 2017).

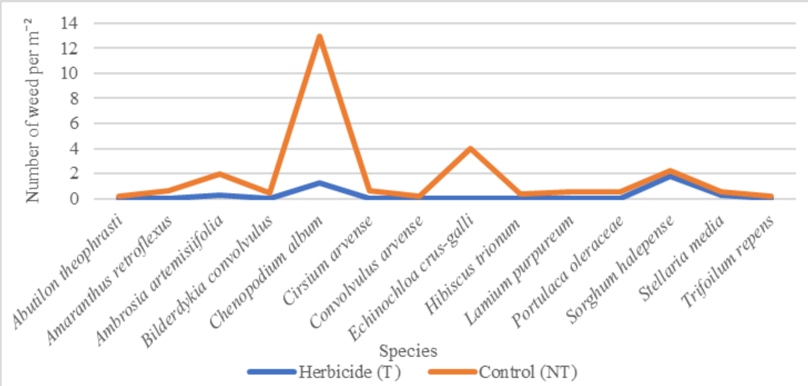


Figure 4. The presentation of weed species in treatments with herbicides application (T) and in the control plots (NT)

15-20 years ago, the most common and dangerous weeds were *Amaranthus retroflexus* L., *Chenopodium album* L., *Sinapis arvensis* L., *Cirsium arvense* L., *Datura* stramonium L. *Sorghum halepense* (L.) Pers., while in the last 4-5 years, in addition to the above, they are considered the most important weeds which belong to invasive species: *Ambrosia artemisiifolia* L., *Iva xantifolia* L., *Abutilon theophrasti* L., *Xanthium strumarium* etc. (Radičević et al., 2008). In our study, our research out of the 14 species, as many as 4 invasive species were observed. It is known that invasive weeds provide good models for the rapid changes, partly because invasive weeds exhibit unique evolutionary mechanisms integral to their success hanging temperatures, moisture regimes and extreme climate events operate universally, but invasive plant species are generally better equipped than native plants to adapt (Clements and Jones, 2022).

Soya as a crop typically grown during the spring season and it is particularly susceptible to weed competition in the early growth stages. This competition can result in losses of approximately 40-60% of the potential yield (Samardžić et al., 2024) and the critical period for weed control in soybean is between 30 and 45 days after the sowing (Pacanoski, 2014). The soybean crop has a lower habitus than corn, and it often happens that weeds that sprout later (avoid control measures) outgrow the crop, shade it, flower and bear fruit. The biggest problem in soybean crops is caused by the following species *Chenopodium album* L. because its cosmopolitan distribution and its ability to cause damage and *Ambrosia artemisiifoila* L. Ragweed is a neophyte which inhabits various crops and ruderal habitats. Considering that it is an invasive and aggressive species, sometimes 100% eradication is necessary to reduce the frequency of allergic reactions in individuals sensitive to pollen and to prevent seed formation (Janjić et al., 2011), as the seed retains its viability in the soil for over 40 years, making its reproductive potential extremely high with permanent presence in the soil seed bank (Levente et al., 2003). Also, *Abutilon theophrasti* L. is a very strong competitor for life support and natural resources, especially for light (Vrbničanin, 2015). The results of the phytocenological assessment in a year like this one with extremely high temperatures and a dry summer period confirmed that compared with crops, weeds have more variable characteristics as they have not been subjected to the same degree of selection for specific favorable traits (e.g., lack of seed dormancy, uniform growth, high yields). Weeds tend to exhibit greater potential capability to adapt to stress than crop plants (Korres et al., 2016) (Figures 5 and 6).

Figures 5 and 6. Phytocenological assessments after post emergence application (T) and in the control plots (NT)

4. CONCLUSION

In recent decades, we have observed global climate change, fluctuations in soybean yields, increased weed infestations, the rise of invasive weed species, and the uncontrolled use of herbicides. Clearly, research on weed evolution in response to climate change has advanced considerably over the last several decades, but there are still many questions to be explored more fully if we are to approach the goal of devising more proactive management strategies. This is one of the reasons why, in addition to monitoring yields, scientists increasingly for phytocenological assessments of weeds in crops. During 2024, a year of extremely high temperatures and a long dry period, we estimated that the soybean crop has 14 weed species, of which 4 are invasive which confirmed that weeds adapt more easily and quickly to extreme conditions.

5. REFERENCES

Barrow, J.R., Lucero, M.E., Reyes-Vera, I., Havstad, K.M. (2008). Do symbiotic microbes have a role in plant evolution, performance and response to stress? Commun Integr Biol., 1, 69-73. doi:10.4161/cib.1.1.6238

Bekavac, G., Purar, B., Jocković, Đ., Stojaković, M., Ivanović, M., Malidža, G., Đalović, I. (2010). Proizvodnja kukuruza u uslovima globalnih klimatskih promena. Ratarstvo i povrtarstvo, 47, 2, 443-450. /in Serbian/

Clements, D.R., Jones, V.L. (2021). Rapid Evolution of Invasive Weeds Under Climate Change: Present Evidence and Future Research Needs. Frontiers in Agronomy, 3, 1-16.

Clements, D.R., DiTommaso, A., Jordan, N., Booth, B., Murphy, S.D., Cardina, J., et al. (2004). Adaptability of plants invading North American cropland. Agriculture Ecosystems & Environment, 104, 379-398. doi: 10.1016/j.agee.2004.03.003

Clements, D.R. (2017). Invasive weed species and their effects. In Integrated Weed Management for Sustainable Agriculture, Zimdahl, R. (Ed.), Cambridge, UK, Burleigh Dodds Science Publishing, 65-88.

IPCC (2014). Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Billir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Geniova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea and L.L. White (eds.). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1132.

Janjić, V., Vrbničanin, S., Malidža, G. (2011). Mogućnost suzbijanja ambrozije (*Ambrosia artemisiifoila* L.). Biljni lekar, XXXIX,1, 44-54.

Korres, N.E., Norsworthy, J.K., Tehranchian, P., Gitsopoulos, T.K., Loka, D.A., Oosterhuis, D.M., David, R., Gealy, D.R., Moss, S.R., Burgos, N.R., Miller, R.M., Palhano, M. (2016). Cultivars to face climate change effects on crops and weeds: a review. Agron. Sustain. Dev., 36.

Levente, K., Laszlo, V., Gyula, B. (2003). A parlagfu (*Ambrosia artemisiifolia* L.) elleni biologiai vedekezes lehetosegi. Novenyvedelem, 39, 319-331.

Maun, M.A., Bennett, S.C.H. (1986). The biology of Canadian weeds. 77. *Echinochloa crus-galli* (L.). Canadian Journal of Plant Science, 66, 739-759.

McNeely, J.A., Mooney, H.A., Neville, L.E., Schei P.J., Waage J.K. (2001). Global Strategy on Invasive Alien Species, Gland, IUCN, 2001.

Mladenović, U., Balog, A., Saulić, M., Stojićević, D. (2024). Efikasnost različitih herbicida u suzbijanju korova u usevu soje. XII Kongres o korovima i savetovanje o herbicidima i regulatorima rasta. Weed Science Congress and Symposium on herbicides and growth regulators, Srebrno Jezero, 23-26.

National Science Board (1974). Science and the Challenges ahead: report of the National Science Board Washington D.C. National Science Foundation.

Patterson, D. (2017). Weeds in a Changing Climate. Weed Science, 43, 4, 685-700.

Pacanoski, Z. (2014). Sinergizam kompeticije, agrotehničkih mera i primene herbicida za efikasno suzbijanje korova u biljnoj proizvodnji. Acta herbologica, 23(2), 129-142.

Samardžić, N., Popov, M., Stojanović, T., Ugrinov, S., Paroški, D. (2024). Effects of two different herbicides on weed flora in soybean. Acta herbologica, 33(1), 43-51.

Radičević, Z., Radenković, T., Bojović, J. (2008). Uticaj klimatskih faktora na promenu sastava korovske flore u Srbiji. Acta herbologica, 17(1) 31-36.

Vrbničanin, S., Malidža, G., Stefanović, L., Elezović, I., Stanković-Kalezić, R., Marisavljević, D., Radovanov Jovanović, K., Pavlović, D., Gavrić, M. (2009). Distribucija nekih ekonomski štetnih, invazivnih i karantinskih korovskih vrsta na području Srbije, III deo - prostorna distribucija i zastupljenost osam korovskih vrsta. Biljni lekar, 37(1), 21-30.

Vrbničanin, S. (2015). Invazivni korovi. Invazivni procesi, ekološko-genetički potencijal, unošenje, predviđanje, rizici, širenje, štete i kartiranje. Kriterijumi, metode i rezultatoi kartiranja alohtonih invazivnih korova na području Srbije. Herbološko društvo Srbije, Beograd. /in Serbian/

doi:10.46793/MAK2025.227M

CLIMATE CHANGE IMPACT ON SUGAR BEET PRODUCTION IN SERBIA

Anja Milosavljević[1*], Zlatko Miličević[1], Saša Rajačić[1], Nenad Trkulja[2]

[1]Research and Development Center, Sunoko, Indjija, Serbia
*anja.milosavljevic@sunoko.rs
[2]Institute for Plant Protection and Environment, Department of Plant Diseases, Belgrade, Serbia

Abstract: Climate change has been one of the biggest problems in agriculture production worldwide. High temperatures and low precipitation had led to devastating losses and have been one of the biggest contributors in appearance of some of plant diseases and pests that transmit some of pathogens. Temperatures rise in last year has been in great disproportion in comparison with multiyear average temperatures for each region where sugar beet has been grown with deviations of almost 5 °C in some months. Precipitation was very low, during months when sugar beet needed it the most it was the lowest. Following high temperatures and low precipitation we had some shift in plant pathogens and pest appearances which led to development of certain diseases caused by Aphids and Cixiids. Impact on sugar beet production is extreme not only in yield losses but in sugar content and quality. This led to big problems in factories since more complex processes had to be used in order to get sugar. Those factors have a huge impact but are very unpredictable, varying from year to year, and need to be addressed in order to stabilize sugar beet production.

Key words: Sugar beet, Climate change, Plant disease, Plant pests, Serbia

1.INTRODUCTION

Climate change caused by global warming is the main cause of changes in the world with enormous impact on agricultural production (Nordhaus, 1991; Pearce et al., 1996; Cline, 2007). One of main symptoms of climate change is the increase in average temperatures (Christensen and Hewitson, 2007). This occurrence is influenced by natural and artificial factors, mostly by increase of greenhouse gases and aerosol concentration which lead to changes in our climate system in general. Carbon dioxide was recognized as main cause of global warming in 1985 by World Meteorological Organization (WMO) and United Nations Environment Programme (UNEP) and was followed by Intergovernmental Panel on Climate Change (IPCC), organized in 1988 for purpose of research and studies of climate change. Those researchers found that global warming caused by human activities has been started since middle of 20th century and if continue with fossil fuel consumption by rate it will cause increase of average temperatures by 6.4 °C by the end of 21st century (IPCC, 2007, 2022). High temperatures lead to decrease in yield and quality of product especially when combined with long periods of low precipitation or even droughts (Schlenker and Roberts, 2008).

One of the important factors of climate change is short, mild winters and early springs, without or with low snowfall during winter. This affects overwintering of pathogens and pests, or their earlier emergence in vegetation. Missed assessment of application timing, higher probability for earlier disease development, appearance of new pathogens and pests are some of consequences. Agriculture is highly dependable on climate, so climate changes affect it the most (Gupta et al., 2020). The vulnerability of agriculture is even more significant since it is production directly connected to climate conditions, production under the open sky.

Climate in Serbia is diverse, depending on region. Report on observed climate change impacts on agriculture in Serbia (2019) showed that temperatures will probably rise to 4.3 °C by the end of the century and stated significant climate change in Serbia, especially during summers and falls. Study showed that precipitation changes were not stable but rather wary from year to year, but are always present in summer months, with higher number of heath waves. Božanić and Mitrović (2019) estimated that during period from 2000 to 2015 Serbia had losses of over 5 billion EUR caused by climate changes events. This has an enormous impact on countries economy and development of society in general. This year (2024) in Serbia we had heat waves and long periods without precipitation, in some parts of country up to 60 days without rainfall. Those sites were mostly in regions where sugar beet is grown, which affected production severely. Sugar beet grooving region is based in Autonomous Province of Vojvodina, that occupies the northernmost part of Serbia (Trkulja et al., 2015, 2017). Different problems caused by shifts in temperature and humidity were noticed in different regions of Vojvodina province during seasons 2023 and 2024, like sugar beet Aphid *Pemphigus betae* Doane and '*Candidatus* Phytoplasma solani', a novel problem in sugar beet production (Ćurćić et al., 2021). Considering that agriculture is a vital part of humankind's survival it is of outmost importance to deal with issues accordingly in each country of the world.

The aim of research was to determine the impact of high temperatures and low precipitation in shift of problems present in fields and finding best solutions for those newly developed diseases and pest.

2. CLIMATE CHANGE INFLUENCE ON SUGAR BEET CROPS, DETECTION OF NEGATIVE EFFECTS AND PROPOSAL SOLUTION

Both high temperatures and low precipitation are some of the greatest consequences of climate change affecting agriculture on a large scale. Those parameters are followed trough years on multiple locations in Serbia. Republic Hydrometeorological Service of Serbia and Forecasting-reporting service officially collect data from multiple weather stations. Along with them, Sunoko company has its own weather stations on several locations in Vojvodina region for its own data collection and information regarding trial localities. Combined, those stations give us information about large set of parameters, but most importantly regarding temperatures and precipitation. That information gives us insight about changes in weather conditions, but also about conditions for disease development or pests activation in field, through Daily Infection Values (DIVs). Those data are of most importance in quick and timely application of pesticides in fields for plant protection. The importance of this is multilayered, from economics to ecologic. Producers need to reduce usage of pesticides and any delay in treatment means more problems with pathogens and pests and multiple treatments applied. If done on time, this is ecologically important because we use less products during plant protection, thus pesticides residues are downgraded in fields. During years of research, we followed the connection of weather changes and disease and pest development in fields. We collected samples from all over Vojvodina region to determine disease and pest development in sugar beet fields caused by climate change. Together with infected plants, we also collected different pests present in sugar beet production. Pests were collected in traps in multiple fields trough Vojvodina region.

Data collected from weather stations showed us that big change regarding temperatures in Serbia had happened in last few years. Higher temperatures were measured than average when compared with representative period (Figures 1 and 2). What is also noticed is the difference in temperature deviation from average temperatures when compared years 2023 and 2024 with each other. During 2024 there were many more days with extremely high temperatures and heath waves. In the spring, the difference in average temperatures was recorded of 4.4 °C at the beginning compared to representative period, with little less deviation during May. Extremely big differences are recorded during summer months when sugar beet is in the stages of intensive growing. During 2023 those differences were also higher than representative period, but not in scale like during 2024, with even lower temperatures than representative period during months of April and May.

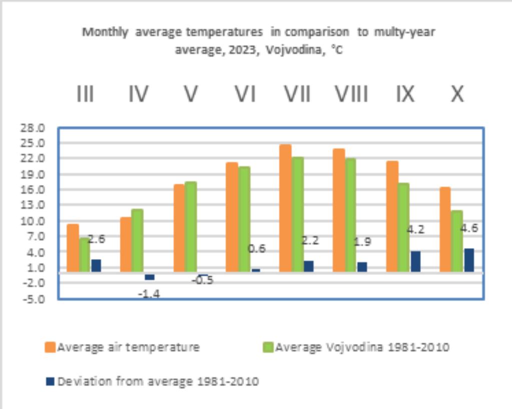


Figure 1. Monthly average temperatures in comparison to multy-year average, Vojvodina, 2023.

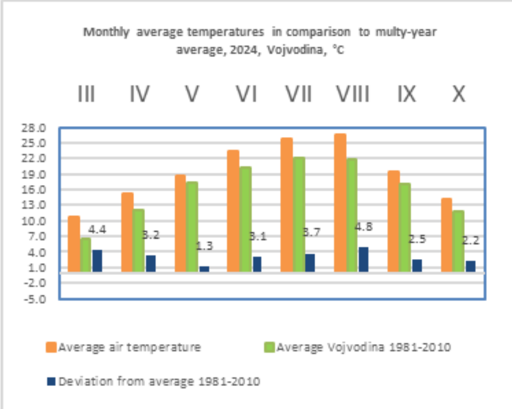


Figure 2. Monthly average temperatures in comparison to multy-year average, Vojvodina, 2024.

Looking at data regarding precipitation it is determined that balance is damaged, and that soil does not have sufficient water supplies (Figures 3 and 4). Like with temperatures, precipitation is also different when comparing years 2023 and 2024 directly. At the beginning of 2023 conditions were little more favorable than in 2024 year. 2024 expressed deficit in water from the beginning of the season to May in which had some rainfall. In most places in the region of Vojvodina was a period of 60 days without rainfall, or with local rainfall of no significance during the 2024 season.

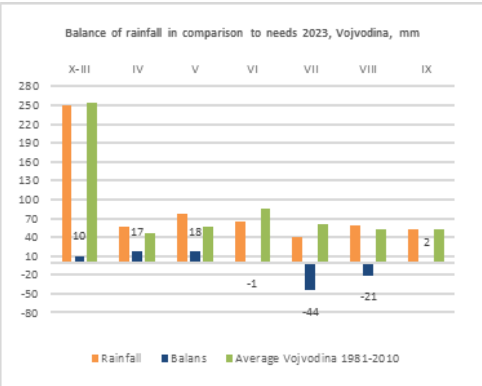


Figure 3. Balance of rainfall in comparison to needs 2023, Vojvodina (mm)

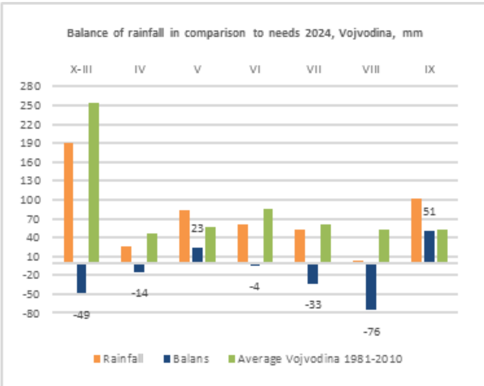


Figure 4. Balance of rainfall in comparison to needs 2024, Vojvodina (mm)

Year 2023 was one of the hottest years in history but was followed by even hotter 2024 and according to Copernicus - the European Union's Earth Observation Programme, 2024 was a second record-breaking year, following the exceptional 2023 (The 2024 Annual Climate Summary). High temperatures and low precipitation brought a lot of problems in plant production and different phenomena were noticed. Plants drying was detected, with different percentage trough Vojvodina region. During 2024 we had a higher percentage of dead plants from drought than we had during 2023. Root rot and rubbery roots were significant phenomena detected during monitoring period, but origin of those is not the same in all production regions.

Monitoring Bačka region (part of Vojvodina Province) in 2023, almost no root rot was detected, even when we appeared it was at random, low incidence and frequency. During 2024 an increase in root rot was detected in this region. Following this problem, we detected presence of sugar beet root Aphids in every checked field (Figure 5). The phenomenon was in abundance and made great impact on sugar beet production with effect of lover yield and sugar content but also ecological impact trough needs of application of insecticides in order to save production. Root Aphids made sugar beet plants more susceptible to plant pathogenic soil fungi that cause root rots subsequently. Among the most important there were *Macrophomina phaseolina* and *Fusarium* species. Also, we had a lot of saprophytic pathogens present in those roots.

Figure 5. Sugar beet roots infested with root lice

During summer months rubbery roots were detected followed by root rot and finally plants death. Difference between years 2023 and 2024 was observed. Also, significant differences are recorded in appearance in different parts of Vojvodina province. '*Candidatus* phytoplasma solani' is considered to be the main reason of this phenomena. Another name, trivial one is "stolbur" phytoplasma. Vectors that transmit this disease are Cixiid planthopers, mainly *Reptalus panzeri*, *Reptalus artemisiae* (*R. quinquecostatus*) and *Hyalesthes obsoletus*. During 2023, with lover average temperatures than in 2024 almost 98% of rubbery roots were infected with phytoplasmas, followed by root rot and finally death of plants. Each year monitoring of their flight in fields has been done, especially in Banat region since their appearance is on highest level in this part of Vojvodina. During 2024 when temperatures were even higher than in 2023, with mild winter and hot spring, cixiid emerged earlier and we had less share of phytoplasma in total root rot, at rate of almost 60% rubbery roots that end up being infected with phytoplasmas. This is still a high number, but less than in 2023. The emergence of cixiids in 2024 was 4 weeks before it was expected. The peak of flight was in the first two weeks of June, after which appearance in fields drastically downgraded. This is all due to climate change and changes in temperatures. Usually, peak of cixiidas flight was between 1 and 15 July, but warm winter and spring made adults to emerge earlier. Srem region had biggest difference in percentage of root rot caused by phytoplasmas, with differences from more than 97% in 2023 to about 29% in 2024. Bačka region had appearance of symptoms only on border zone with Banat region and it was random in fields, with no epidemic phenomena.

The main problems caused by climate change are hard to control, since agriculture production depends on weather. Nevertheless, there are some steps that we can do in order to manage production better and give sugar beet help to grow healthier, readier to face all challenges during vegetation. To better control appearance of phytoplasma disease in fields we recommend sets of mitigation measures. We separated those mitigation options into 4 different categories, of which every is of outmost importance in order for this production to be productive even in extreme years like 2024 was. The first group represents good agrotechnical practices which include: soil undermining, soil processing done in optimal terminus and humidity, intermediate cultivation, crop rotation, minimum number of passes and reducing tire pressure. Soil undermining gives a better environment for sugar beet to grow, to keep humidity, to disperse more equally and take more from soil during vegetation. If processing is done at the optimal time, we do eliminate clumping that can appear if it is done in period with more humid soil. Reducing the number of passes keeps soil from damage, together with reducing tire pressure we keep soil compaction in order to have looser arable and soil that retains humidity better. The second mitigation part is varieties choice for each region, and it should be done in accordance with analyses done. The third part is monitoring of pests and disease infection in field, which is one of the most important parts of controlling problems in production of sugar beet. Depending on precise pest flights determination and disease infection, we can give timely recommendations for pesticide use. If this is missed, we can have a problem that can be doubled. If we miss control of pests and disease, there after we need to use more pesticides to protect sugar beet. Other ways are ecological, from reason of overuse of products in field to control problems, which lead to more residues in soil. Finally, if the situation with sugar beet health in fields is not satisfactory and can decrease with pass of time, earlier start of campaign is something that is recommended in order to save as much sugar beet as possible.

3. DISCUSSION

Agriculture is the branch of production the most connected and dependable to the environment. Every step of production is susceptible but mostly production of plants because of its specific organization, duration and dependence on weather conditions. Climate change has and will have a great impact on agricultural production (Gautam, 2009). IPCC imply that it is particularly important for agriculture to adopt measures to minimize damages and work on reduction of greenhouse gases emission because even when those decrease, climate warming will continue for several decades, so were problems caused by this (IPCC and Kyoto Protocol). Anupama (2004) stated that variations in temperature and precipitation cause epidemic of diseases and pests which affect food production system through food security and lower harvests. Any and every problem in agriculture production is directly connected to food chain supply (Fan, 2012) and therefore impacts economics (Kohler and Maseli, 2012; Fahad and Wang, 2017). In Serbia, sugar beet production is one of the vital food productions and climate changes had impacted it greatly by levering yield and sugar quality and also making processing in factories difficult. There are predictions of IMF (2017) that temperature rise and decrease in rainfall will decrease production by 1,7% and 0,35%, respectively. Zhai and Zhuang (2012) determined that pattern variation of pests and diseases decrease production, which was one of the highest problems detected in sugar beet fields in Serbia trough years, making sugar beet production more complicated and shifting approach in terms of production technology. Warmer winters are followed by increase in diseases and pests during vegetation (Mendelsohn et al., 1994), and even in Serbia brought new problem in some regions that were not as important before, like sugar beet root Aphid in Bačka region. Very dry seasons with mild winters are favorable for sugar beet root Aphid development, and during drought in Minnesota in 1980s there was infestation detected in some parts of the state (Campbell and Hutchison, 1991). Connection is determined in more use of pesticides because of bigger populations of certain pests to harmful effect on ecosystems in general (Malla, 2008), even more so if monitoring is not done properly and timing in control of diseases and pests is missed and more products need to be used in order to save production. New treatments became obligatory in order to control cixiids that transmit phytoplasma disease in fields and without proper monitoring of pest flight it is impossible to do it in timely manner. Soil is of outmost importance for plant growing and its fertility is endangered (Sinha et al., 1998) so it is very important to maintain water, air and root movement in soil and its compaction. Only this way plants can grow healthier which leads to easier protection and better plant defense system. Water deficiency is eminent during vegetation when rainfall is low, and temperatures are high, so plant production is reduced in yield and quality (Imhen Institute, 2010). In Serbia's sugar beet production, we manage to determine some crucial problems developed because climate changes, primarily because reduced rainfall and high temperatures. The direct influence of those changes is on cycles of development and epidemiology of pests that transmit those diseases or damage plants directly. One of the most important shifts is in root roots where we have different origins of problem depending on weather conditions during each season. In this paper we emphasize significance of root Aphids and cixiids causing root rot and transmitting phytoplasmas that subsequently cause rubbery root and root rot.

To minimize damage caused by those diseases, we determined steps that showed us significant positive impact on sugar beet production. Climate changes are very complicated for production, but individual measures can mitigate their effect on production.

4. CONCLUSION

On the base of research established changes of temperature and precipitation in area of cultivation sugar beet in Serbia and intensive phenomenon of root Aphids and cixiids causing root rot and transmitting phytoplasmas which further cause rubbery root and root rot. In Serbia in warm winters are increase in diseases and pests during vegetation, particularly appearance sugar beet root Aphid in Bačka region. The variation of pests and diseases due to climate change have impact to decrease sugar beet production, in Serbia what require mitigation measure and adapting technology of production. To minimize damage caused by those diseases, we determined steps that showed us significant positive impact on sugar beet production. The control cixiids that transmit phytoplasma disease in fields can conduct through proper monitoring of pest flight, soil fertility by maintain water, air and root movement in soil and its compaction

5. ACKNOWLEDGMENT

The research presented in this article is part of Contracts No. 451-03-66/2024-03/200010 financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

6. REFERENCES

Anupama, M. (2004). Climate change and its impact on agriculture International Journal of Scientific and Research Publications, 4(4), ISSN 2250-3153.

Božanić, D., Mitrović, Đ. (2019). Study on the Socio-economic Aspects of Climate Change in the Republic of Serbia. United Nations Development Programme, Belgrade. www.klimatskepromene.rs/wp-content/uploads/2020/07/engl-screen-_06-04-2020_DRAFT_-Study-on-the-Socio-economic-Aspects-of-Climate-Change-on-the-Republic-of-Serbia_UNDP.pdf

Campbell, C.D., Hutchison, W.D. (1991). Sugarbeet root aphid control in southern Minnesota. Insect. & Acaracide Tests., 16, 231-232.

Cline, W. (2007). Global Warming and Agriculture. Washington, DC, Peterson Institute for International Economics.

Fahad, S., Wang, J. (2017). Evaluation of Pakistani farmers' willingness to pay for crop insurance using contingent valuation method: the case of Khyber Pakhtunkhwa province. Land Use Policy.

Zhai, F., Zhuang, J. (2012). Agricultural impact of climate change: A general equilibrium analysis with special references to southeast Asia. doi:10.4135/9788132114000.n3

Malla, G. (2008). Climate Change and Its Impact on Nepalese agriculture. The Journal of Agriculture and Environment. https://doi.org/10.3126/AEJ.V9I0.2119

Gautam, H.R. (2009) Preserving the future. In: Joy of Life-The Mighty Aqua. Bennett, Coleman & Co. Ltd., The Times of India, Chandigarh.

Gupta, K.A., Yadav, D., Gupta, P., Gupta, V., Ranjan, S., Badhai, S. (2020). Effects of Climate Change on Agriculture. Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005, U.P., India.

IMF (2017). The Effects of Weather Shocks on Economic Activity. How Can Low-Income Countries Cope? IMF Publication. Chapter 3.

IPCC (2007). Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Work Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate. Cambridge University Press: Cambridge, UK.

IPCC (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (Pörtner, H.O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Møller, V., Okem, A., Rama, B. (Eds.). Cambridge University Press. doi.org/10.1017/9781009325844

Imhen Institute (2010). Climate change and its impact in Vietnam. Science and Technics Publishing House, HaNoi.

Kohler, T., Maseli, D. (2012). Mountains and Climate Change-From Understanding to Action, third ed. Published by Geographica Bernensia with support of the Swiss Agency for Development and Cooperation (SDC) and an International Team of Contributors. Bern, Switzerland.

Mendelsohn, R., Nordhaus, W.D., Shaw, D. (1994). The impact of global warming on agriculture: a Ricardian analysis. Am. Econ. Rev., 84(4), 753-771.

Nordhaus, W.D. (1991). To slow or not to slow: The economics of the greenhouse effect. The Economic Journal. 101, 920-937.

Pearce, D., Cline, W., Achanta, A., Fankhauser, S., Pachauri, R., Tol, R., Vellinga, P. (1996). The social costs of climate change: Greenhouse damage and benefits of control, in: Bruce, J., Lee, H., Haites, E. (Eds.), Climate Change 1995 Economic and Social Dimensions of Climate, Cambridge: Cambridge University Press, 179-224.

Schlenker, W., Roberts, M. (2008). Estimating the impact of climate change on crop yields: the importance of nonlinear temperature effects. NBER Working Paper, 13799.

Sinha, S.K., Singh, G.B., Rai, M. (1998). In: Decline in crop productivity in Haryana and Punjab: myth or reality? Indian Council of Agricultural Research, New Delhi, p.89.

Trkulja, N., Milosavljević, A., Stanisavljević, R., Mitrović, M., Jović, J., Toševski, I., Bošković, J. (2015). Occurrence of Cercospora beticola populations resistant to benzimidazoles and demethylation-inhibiting fungicides in Serbia and their impact on disease management. Crop Protection, 75, 80-87. doi.org/10.1016/j.cropro.2015.05.017

Trkulja, N., Milosavljević, A., Mitrović, M., Jović, J., Toševski, I., Khan, M., Secor, G. (2017). Molecular and experimental evidence of multi-resistance of *Cercospora beticola* field populations to MBC, DMI and QoI fungicides. Eur. J. Plant Pathol., 149, 895-910.

World Meteorological Organization https://wmo.int

United Nations Environment Programee, www.unep.org

Republic Hydrometeorological Service of Serbia, www.hidmet.gov.rs

Forecasting-reporting service, Vojvodina, Serbia, www.pisvojvodina.com/default.aspx

Copernicus Programee - the European Union's Earth Observation Programme https://climate.copernicus.eu/global-climate-highlights-2024

doi:10.46793/MAK2025.234M

ADAPTATION OF SUGAR BEET PRODUCTION IN TIMES OF CLIMATE CHANGE

Zlatko Miličević[1*], Anja Milosavljević[1], Ana Anđelković[2], Danijela Šikuljak[2], Nenad Trkulja[2]

[1]Research and Development Center, Sunoko, Inđija, Serbia, *zlatko.milicevic@sunoko.rs
[2]Institute for plant protection and environment, Belgrade, Serbia

Abstract: Climate change is increasingly exerting a negative impact on the sustainability of agricultural production. The application of numerous plant protection agents and crop fertilizers contributes to soil, food, and water pollution, as well as increased greenhouse gas emissions, thus influencing climatic parameters. Conversely, climate change, through altered precipitation patterns, rising air temperatures, hailstorms during summer, and spring frosts, increases the intensity of plant diseases, insect outbreaks (including resistant strains), and vegetation changes, all of which disrupt sugar beet production. These interrelations between climate and sugar beet production technology necessitate the modification of existing production methods. In response, the Research Center of Sunoko is investigating and implementing various methods, such as soil and plant tissue analyses, weed control machinery, biopreparations, and non-chemical disease and weed control measures. These efforts aim to preserve the environment, mitigate climate impacts, and achieve high yields. The goal of Sunoko's sustainable sugar beet production is to develop new cultivation technologies that responsibly manage natural resources, soil, surface and groundwater, biodiversity, and the safety and health of humans and animals.

Key words: Sugar beet, Climate change, Sustainable production

1. INTRODUCTION

The concept of sustainable agriculture entails a continuous link between a healthy environment and good yields. The growing demand for food drives the development of new agricultural technologies and methods. However, the pursuit of higher profits has often overshadowed environmental preservation, resulting in climate changes that increasingly threaten agricultural sustainability.

The excessive use of plant protection agents and fertilizers contributes to soil, water, and food contamination and accounts for 10-12% of greenhouse gas emissions (Müller et al., 2016). As human activities exacerbate environmental degradation, climate changes are altering precipitation patterns, air temperatures, and seasonal occurrences such as hailstorms and frosts, intensifying plant diseases, insect proliferation, and resistant weed strains (Piao et al., 2019).

Climate change is among the greatest challenges society faces today, with predominantly negative effects on agriculture (IPCC, 2014). Olesen et al. (2011) noted years ago that regions such as the Pannonian Plain are particularly susceptible to climate change, with summer heatwaves and droughts severely impacting crop cultivation.

Sugar beet cultivation in these conditions faces significant stress, transitioning from dry winters to hot summers. Yield projections suggest climate change may increase sugar beet yields in northern Europe but decrease them in central regions like northern France, Belgium, and Poland between 2021-2050 (Jones et al., 2003). These challenges necessitate the adaptation of sugar beet cultivation technologies to address climate-induced stress while safeguarding environmental resources.

The aim of the research is to present the technology of sugar beet production at Sunoco, and the principles of developing a new cultivation technology with a responsible impact on natural resources, soil, underground and above-ground water, biodiversity, safety and health of people and animals.

2. SUGAR BEET PRODUCTION IN SERBIA AND WORLDWIDE

The largest sugar beet producers globally include China, Russia, France, the United States, and Germany (FAOSTAT, 2024). Annually, approximately 40 million tons of sugar are produced worldwide, with 80% originating in Europe (Draycott, 2006). In Serbia, sugar beet cultivation increased by 12.4% in 2024 compared to the previous year, covering 46.839 hectares. However, compared to the 10-year average (2014-2023), the increase was only 3.3% (www.stat.gov.rs). Statistical analyses indicate that while global sugar beet production has stagnated since 2006, Serbia has experienced a significant decline, from 3.19 million tons in 2006 to 1.67 million tons in 2022 (Figures 1 and 2).

Figure 1. Production sugar beet in Europe and World

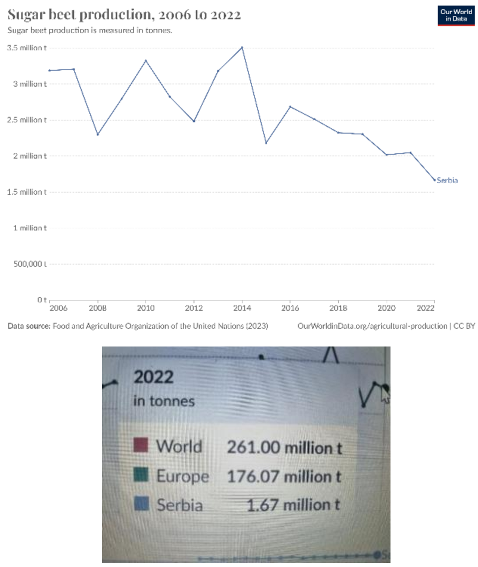


Figure 2. Production sugar beet in Serbia

3. CLIMATIC FACTORS AND SUGAR BEET PRODUCTION

Sugar beet has been cultivated since the 18th century, with consistent advancements in varieties and farming technologies. Modern varieties boast sugar content exceeding 18%, compared to 4% in the past (McGrath et al., 2018). Numerous abiotic factors, especially climatic factors, are important factors in achieving high yields. As they change, sugar beet production also fluctuates (Figures 1 and 2). In general, climate change is one of the biggest challenges of today. Prolonged waves of high temperatures causing dry periods, stormy weather, heavy rainfall in short time intervals, etc. are parameters for organizing sustainable agriculture.

In the territory of the largest sugar beet production in Serbia (Vojvodina) long-term analyses showed reduction in precipitation and a temperature increase of 2.9 °C by 2024, directly impacting sugar beet production. A more detailed monthly analysis showed that the temperature in March/April was on average 3.8 °C higher, and in the period when the biggest problem with precipitation was 3.9 °C compared to the same period for the ten-year average. On the other hand, the analysis of precipitation showed that the winter period (October-March) did not provide enough moisture (50 mm less than for the same period in the ten-year average). Also, a large lack of moisture is noted in the July-August period, 55 mm less (Table 1). Both factors are closely related and together affect the sugar beet yield: directly on the development of roots and leaves and indirectly on the development of pathogens and insects that damage young beet plants.

Table 1. The ratio of precipitation and temperature in 2024 compared to the ten-year average

	October-March	April	May	Jun	July	August	September
Lack of precipitation	-50	-15	+ 22	-5	-34	-76	+50
Temperature rise	-	+ 4,4	+ 1,3	+ 3,1	+ 3,7	+ 2,5	0

The occurrence of drought affects yield reduction (> 50%), determines root quality and especially white sugar yield (Fasahat et al., 2018). Sucrose accumulation (decreases 15-20% of fresh mass) of sugar beet is affected by drought stress by restricting leaf development and root growth (Hoffmann, 2010). The content of sucrose affects the content of white sugar, and the content is greatly influenced by biotic factors: physical properties of the soil, climate, moisture reserves in the soil, plant nutrition, duration of stress, etc. (Mohammadian et al., 2001). On the other hand, drought and high temperatures disrupt the structure and quality of the soil, which hinders the development of the sugar beet root system. Due to all of the above, Sunoko adapts its production to all the challenges that agricultural production faces due to climate change. At the same time, the company and its Research Center take care to adapt the production technology in accordance with the requirements and care for the environment. Analysis of the quality of sugar beet roots showed that soil compaction due to drought affects poor root development, the appearance of rot and reduced sugar content. In the fields of Sunokos, after analyzing the volume of the soil (compaction), it was found that one of the causes of the occurrence of root rot was found. Due to the drought, the soil was too compacted (1.4-1.5 g cm^{-3}) and the sugar beet root had no space to develop. Soil samples were colected with a probe at several localities (A1, A2, A3 and A4) (Table 2). After the statistical analysis, it was found that at a depth of 50 cm in samples A1 and A2, the volume of the soil improved and thus the percentage of root rot was lower (A1 = 42% and A2 = 0%, Table 2). Contrary to this, in the other two samples, the percentage of rot increases because the volume of the soil was well above 1.4 g cm^{-3}.

Table 2. Volumetric mass of soil and percentage of rotten roots

Soil Depth (cm)	Sample A1	Sample A2	Sample A3	Sample A4
	Volumetric mass of soil (g cm^{-3})			
10	1.22	1.14	1.10	1.21
20	1.04	1.26	1.26	1.49
30	1.43	1.17	1.52	1.39
40	1.48	1.50	1.52	1.44
50	1.37	1.33	1.46	1.40
% root rot	42%	0%	75%	57%

The wetness of the soil and the appearance of the crust (Figure 3) that occurs after heavy rainfall greatly affects young plants. turnips. Because of this phenomenon, machines are introduced that break up the crust but at the same time mix the applied fertilizer into the deeper layers of the soil. However, inter-row cultivation mixes weed seeds (Posner et al., 2008) and increases their abundance in the crop. Improperly performed inter-row cultivation (the time when crop rows are closed) damages the leaves and opens the way for pathogens to enter.

Figure 3. Cultivation of the sugar beet crop

The problem of the presence of a large number of weeds and a developed resistant population of weeds is solved by the introduction of machines for the mechanical destruction of weeds, all with the aim of reducing the use of pesticides and preserving the environment (Figures 4 and 5).

Figure 4. Harrow with spring tines

Figure 5. Harrow with rotating star

One of the ways to take care of the environment is to perform a soil analysis before applying crop fertilizers. The company Sunoko conducts soil and leaf analysis on its arable land and the producers it cooperates with due to proper crop feeding and reduced application of fertilizers containing various metal elements (Figure 6). Achieving high yields, i.e. good root development and a higher percentage of sugar, depends on the presence of macro and micro elements: N, P, K, Mg, Na, Ca, Cu, Fe, Mn, Zn, Mo, Ni and B (Amin et al ., 2013; Rassam et al., 2015; Li et al., 2023).

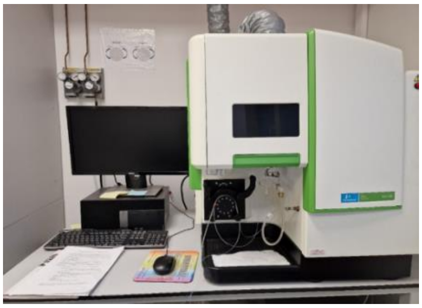


Figure 6. ICP-OES, Perkin Elmer Avio 200

Another measure of the Sunoko company to alleviate the stress of young sugar beet plants and increase yields while protecting the environment is the application of biological preparations (eg. based on *Bacillus* spp.). The preparation is an effective tool for controlling pathogens that attack the root, leaf, flower and stem. Bacteria produce plant hormones that stimulate cell division and plant growth and enhance resistance to stress conditions. Experiments with the application of biological preparations have shown that after application there is a greater leaf mass (73.74% vs control

26.26%), a lower level of infection with phytopathogenic fungi (eg. *Cercospora beticola*, Figure 7), an increase in yield (Figure 8) and better digestion (Figure 9).

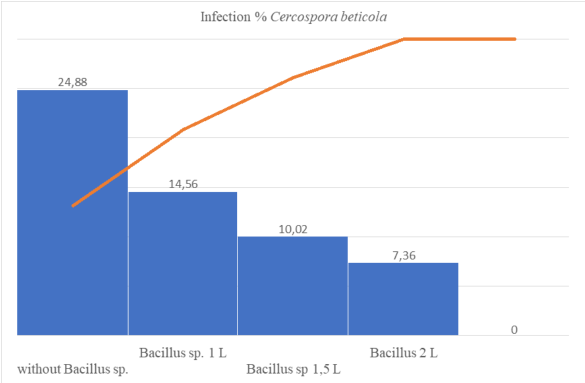


Figure 7. Influence of *Bacillus* spp. on appearance *Cercospora beticola*

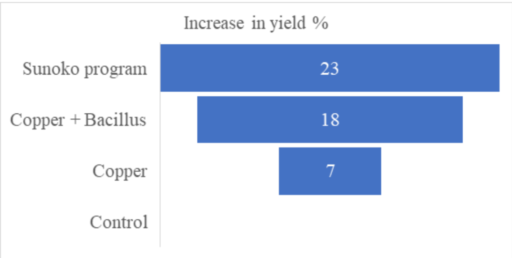


Figure 8. Influence of *Bacillus* spp. on yield

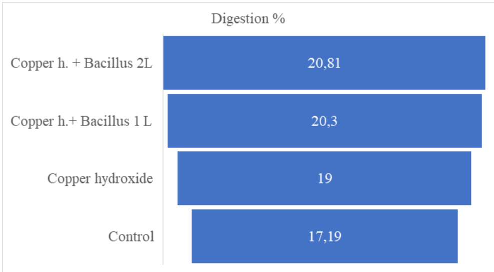


Figure 9. Influence of *Bacillus* spp. on digestion

3. CONCLUSION

Climate change presents a pervasive limiting factor for sustainable sugar beet production. Achieving high yields, sustainable agriculture, and environmental preservation requires the adoption of innovative and adaptive farming technologies, along with rational pesticide and fertilizer use. These measures are critical to meeting the challenges of agricultural production under fluctuating climate conditions.

- To adapt sugar beet production to the impact of climate change, Sunoco is implementing innovative measures in production technology, including.
- Monitoring soil and plant material fertility and, based on this, programming the optimal application of mineral substances and metal-based fertilizers.
- Introduction and application of biopreparations, i.e. biological agents based on *Bacillus* spp. in order to improve plant resistance to stress, reduce pathogen attacks and increase sugar content and yield.
- Use of weed control machinery: Mechanical weed control reduces pesticide reliance, preserving soil health and biodiversity.

4. ACKNOWLEDGMENT

The research presented in this article is part of Contracts No. 451-03-66/2024-03/200010 financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

5. REFERENCES

Amin, G.A., Badr, E.A., Afifi, M.H.M. (2013). Root yield and quality of sugar beet (*Beta vulgaris* L.) in response to biofertilizer and foliar application with micronutrients. World Appl. Sci. J., 27, 1385-1389.

Draycott, A.P. (2006). Sugar Beet. doi:10.1002/9780470751114

Fasahat, P., Aghaeezadeh, M., Jabbari, L., Sadeghzadeh Hemayati, S., Townson, P. (2018). Sucrose accumulation in sugar beet: from fodder beet selection to genomic selection. Sugar Tech., 20, 635-644.

Hoffmann, C. (2010). Sucrose accumulation in sugar beet under drought stress. J Agron Crop Sci., 196, 243-252.

IPCC- Intergovernmental Panel on Climate Change (2014). Climate change: synthesis report. Contribution of Working Groups I, II, and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.). Intergovernmental Panel on Climate Change, Geneva.

McGrath, J.M., Lee, P. (2018). Sugar beet breeding. Plant breeding reviews, 42, 167-218. doi.org/10.1002/9781119521358.ch5

Jones, P.D., Lister, D.H., Jaggard, K.W. *et al.* Future Climate Impact on the Productivity of Sugar Beet (*Beta vulgaris* L.) in Europe. Climatic Change, 58, 93-108. doi.org/10.1023/A:1023420102432

Li, J.J., Liu, X.Y., Xu, L.Q., Li, W.S., Yao, Q., Yin, X.L., Wang, Q.H., Tan, W.B., Xing, W., Liu, D.L. (2023). Nitrogen stress-induced transcriptome changes revealed the molecular response and tolerance characteristics in maintaining the C/N balance of sugar beet (*Beta vulgaris* L.) Frontiers in Plant Science, 14:1164151. doi: 10.3389/fpls.2023.1164151

Mohammadian, R., Khoyi, F., Rahimian, H., Moghaddam, M., Ghassemi-Golezani, K., Sadeghian, S. (2001). The effects of early season drought on stomatal conduc-tance, leaf-air temperature difference and proline accumulation in sugar beet genotypes. J. Agric. Sci., 3, 181-192.

Müller, A., Bautze, L., Meier, M., Gattinger, A., Gall, E., Chatzinikolaou, E., ... Ullmann, L. (2016). Organic farming, climate change mitigation and beyond. Reducing the environmental impacts of EU agriculture. www.ifoam-eu.org/sites/default/files/ifoameu_advocacy_climate_change_report_2016.pdf

Olesen, J.E., Trnka, M., Kersebaum, K., Skjelvåg, A., Seguin, B., Peltonen-Sainio, P. et al. (2011). Impacts and adaptation of European crop production systems to climate change. Eur. J. Agron., 34, 96-112. doi: 10.1016/j.eja.2010.11.003

Piao, S., Liu, Q., Chen, A., Janssens, I.A., Fu, Y., Dai, J., Liu, L., Lian, X., Shen, M., Zhu, X. (2019). Plant phenology and global climate change: Current progresses and challenges. Glob. Chang. Biol., 25, 1922-1940.

Posner, J.L., Baldock, J.O., Hedtcke, J.L. (2008). Organic and conventional production systems in the Wisconsin integrated cropping systems trials: I. Productivity 1990-2002. Agronomy J., 100(2), 253-260.

Rassam, G., Dashti, M., Dadkhah, A., Yazdi, A.K. (2015). Root yield and quality of sugar beet in relation to foliar application of micronutrients. Ann. West Univ. Timisoara: Series Biol., 18, 87-94.

www.ginniemae.gov

www.stat.gov.rs

doi:10.46793/MAK2025.240S

EXAMINING THE IMPORTANCE OF BIODIVERSITY CONSERVATION FACTORS

Vojislav Stojanović[1*], Bojana Ristanović[2], Gordana Petrović[3], Zoran Jovanović[4]

[1]Academy of Applied Technical and Preschool Studies, Serbia
*svojislav221@gmail.com
[2]Faculty of Agriculture Kruševac, University of Niš, Kruševac, Serbia
[3]Independent researcher, Kragujevac, Serbia
[4]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohia, Serbia

Abstract: The paper examines the importance of biodiversity protection factors in the Republic of Serbia. The research was conducted during 2024, using the structural equation model. Research findings show that habitat preservation has the greatest impact on increasing the value of biodiversity in the Republic of Serbia, that is, that education and involvement of members of local communities has the least impact on increasing the value of biodiversity in the Republic of Serbia. The findings suggest that an integrated approach to biodiversity protection is needed in the Republic of Serbia

Key words: Biodiversity, Serbia, Structural equation model, Biodiversity protection factors

1. INTRODUCTION

Biodiversity, or biological diversity, is defined as the variability of living organisms, including species diversity, genetic diversity within species, and ecosystem diversity (Taylor et al., 2020). This definition implies that the biodiversity of a particular region encompasses the collection of all genes, species, and ecosystems found within that area. The diversity of genes and their combinations in a given region leads to morphological variations among individuals and populations within species, as well as taxonomic diversity of species within communities or ecosystems. These differences result in functional differentiation within specific species (Bartkowski, 2017), ultimately affecting the diversity of ecosystems themselves. The preservation of this biological diversity is of paramount importance for maintaining the health of our planet and the well-being of all organisms, including humans. Biodiversity contributes to ecosystem stability, provides resources for food, medicine, and materials, and plays a critical role in regulating climate, water quality, and soil health. Unfortunately, human activities such as urbanization, industrialization, overfishing, deforestation, and pollution pose significant threats to biodiversity. These activities lead to habitat loss, species extinction, and ecosystem fragmentation. Estimates suggest that over one million species are currently threatened, which has far-reaching consequences for ecosystems and human society. Thus, the protection of biodiversity has become an urgent global obligation. This protection not only involves the conservation of endangered species but also the establishment and maintenance of ecosystems, support for sustainable practices, and the promotion of awareness regarding the importance of biodiversity. International efforts, such as the Convention on Biological Diversity (CBD), aim to unite countries in a collective fight against biodiversity loss through various strategies and action plans (Halkos and Matsiori, 2022).

Biodiversity conservation is a complex process that requires the integration of various strategies and approaches while considering numerous factors. Despite the fact that there is no general consensus in scientific and academic circles regarding the number and significance of the factors influencing biodiversity, there is agreement that the following are essential: habitat conservation involves the establishment of protected areas, such as national parks and nature reserves, aimed at minimizing human activities that lead to environmental degradation. Sustainable resource management refers to the use of natural resources in a manner that meets the needs of present generations without compromising the ability of future generations to meet their own needs. Pollution reduction encompasses a range of strategies and measures aimed at decreasing or eliminating contaminants in air, water, and soil to preserve ecosystem health and human welfare, as well as to improve environmental quality. Education and the involvement of local communities in addressing critical issues related to biodiversity conservation involve activities aimed at developing and implementing projects, promoting traditional knowledge, and engaging community members in decision-making processes regarding biodiversity protection (Halkos and Jones, 2012).

The impact of these factors can best be understood through their influence on the value of biodiversity. It is well established that biodiversity possesses intrinsic value, which is reflected through the utility that humans derive from the use of natural resources or the elements of biodiversity. This value can be both direct and indirect (Nguyen, 2023). While direct benefits of biodiversity have market value (price) and can be quantifiably estimated to some extent, greater challenges arise when addressing indirect values (Paul et al., 2020). Consequently, expressing the value of biodiversity is a complex task. Currently, the widely accepted method for measuring biodiversity value is through seven sub-dimensions defined by Alho (2008): intrinsic, market, political, aesthetic, anthropocentric, and compensation value.

In light of the aforementioned, the purpose of this study is to examine the significance of key factors in biodiversity conservation. The aim is to (i) quantify the impacts of these key factors to determine which of them has the greatest influence on environmental protection in the Republic of Serbia (ii) ranking these factors to ensure that limited resources are allocated effectively to achieve maximum benefits for increasing biodiversity value with minimal investment of finite resources.

2. MATERIAL AND METHODS

The analysis of theoretical concepts of biodiversity value, the study adopts the following research model, as depicted in Figure 1. The model indicates that the total value of biodiversity depends on four factors of biodiversity conservation. Furthermore, based on the presented model, the following three hypotheses can be defined, which facilitate the achievement of the main objective of the study.

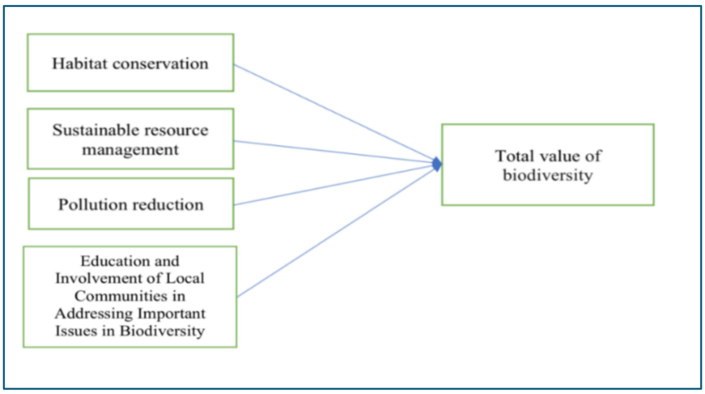


Figure 1. Research model

• **H1**: All factors of biodiversity conservation have a statistically significant and positive impact on the total value of biodiversity in the Republic of Serbia.

• **H2**: In the Republic of Serbia, habitat conservation has the greatest significance on the total value of biodiversity.
• **H3**: Sustainable resource management and pollution reduction have an equal impact on the value of biodiversity in the Republic of Serbia.

Table 1. Questionnaire

Varijable	Item	Factor loadings				
		TV	HC	SM	PL	EI
Total value (TV)	Biodiversity in the Republic of Serbia is diverse	0.743				
	Biodiversity is beneficial for social well-being in the Republic of Serbia	0.713				
	The Republic of Serbia is characterized by untouched nature	0.784				
	Natural landscapes are aesthetically pleasing.	0.773				
	Human activities do not threaten biodiversity in the Republic of Serbia	0.801				
	Humans depend on biodiversity.	0.832				
	Scientific research based on the study of biodiversity in the Republic of Serbia has great potential	0.725				
	Preventive expenditures for the protection of biodiversity in the Republic of Serbia are sufficient	0.713				
Habitat conservation (HC)	The current state of habitats in my area is satisfactory.		0.717			
	Awareness of habitat protection is high in my local community.		0.498			
	I often participate in habitat restoration and cleaning activities.		0.576			
	Habitat conservation is essential for the preservation of biodiversity.		0.689			
Sustainable resource management (SM)	Local authorities effectively manage natural resources.			0.811		
	All community members are aware of the importance of sustainable resource management.			0.645		
	Practices such as recycling are important for my community.			0.725		
	I am taking personal steps towards the sustainable use of resources			0.711		
Pollution reduction (PR)	Local authorities are taking adequate measures to reduce pollution in our community.				0.698	
	Citizens are aware of the ways in which their behavior can contribute to reducing pollution.				0.348	
	Pollution education programs are available and useful for my community.				0.451	
	Reducing pollution is a priority for our local community.				0.973	
Education and Involvement of Local Communities in Addressing Important Issues in Biodiversity Conservation (EI)	I participated in educational programs on environmental protection.					0.739
	Educational initiatives on biodiversity conservation are important to my community.					0.673
	Citizens are sufficiently informed about the problems of biodiversity protection.					0.742
	I often look for information about biodiversity protection from different sources.					0.591

Note: All items with a factor loading of less than 0.5 were omitted from further analysis. There was no cross-loading between items, all with values higher than 0.3. So we can talk about good convergent and divergent validity of the questionnaire Respondents rated the items from the questionnaire using a five-point Likert scale, ranging from (1) "strongly disagree" to (5) "strongly agree." The adequacy of the sample was tested using the KMO (Kaiser-Meyer-Olkin) test of sampling adequacy (KMO value = 0.891). The results of the validity test conducted on the questionnaire are presented in Table 1. The results of the factor analysis reveal that the questions are organized according to the anticipated patterns, thereby ensuring the reliability of the questionnaire for future analysis. The data collected for this study were analyzed using the JASP statistical software for structural equation modeling.

The research was conducted on a sample of 52 experts in the field of environmental protection in the Republic of Serbia, all of whom possess substantial work experience in this area. Data were collected using a structured questionnaire, which was constructed based on an analysis of the expert literature. Since this is a new questionnaire, it was tested through exploratory factor analysis. The questionnaire is presented in Table 1. The study was carried out during the year 2024. To confirm or refute the established hypotheses, structural equation modeling was employed.

3. RESULTS AND DISCUSSION

Before the estimation of model parameters, a detailed correlation analysis was conducted. A key requirement for the appropriate application of factor and structural analysis is that the variables exhibit strong correlations. The correlation matrix, presented in Table 2, illustrates the interrelationships among the variables measured within the model. Additionally, it includes the average extracted variance, which measures the reliability of the multi-item sections, as well as Cronbach's alpha. Furthermore, the fit indices for the structural equation model are also displayed in Table 2.

Table 2. Correlation matrix, AVE, reliability and goodness of fit indices

	TV	HC	SM	PR	EI
TV	1				
HC	0.434	1			
SM	0.236	0.438	1		
PR	0.321	0.286	0.348	1	
EI	0.261	0.367	0.557	0.256	1
AVE	0.748	0.767	0.685	0.699	
Cronbach alfa	0.811	0.888	0.756	0.759	
RMSEA (*root mean square error of approximation*)				0.023	
RMSR (*root mean square residual*)				0.052	
NNFI (*non-normed fit index*)				0.926	
AGFI (*adjusted GFI*)				0.899	

As can be seen from Table 2, the variables are correlated with each other. The AVE for each construct is greater than the squared correlation coefficient for the corresponding interconstructs, which confirms the discriminant validity of the model. Cronbach's alpha values in all cases are above 0.7, which indicates an acceptable level of reliability for each construct. Additionally, construct reliability was further supported by the fact that all AVEs exceeded 0.6. The fit indices indicate that the proposed JASP structural model fits the data well. The results of the confirmatory factor analysis are presented in Table 3.

The results presented in Table 3 show that the hypothesis H1, which states that all factors of biodiversity protection have a statistically significant and positive impact on the total value of biodiversity in the Republic of Serbia, is proven and that H1 can be accepted as valid. This finding emphasizes the need for an integrated approach to nature protection. Through a combination of education, active community engagement, sustainable resource management, habitat conservation and pollution reduction, it is possible to significantly improve the state of biodiversity in the Republic of Serbia. These results indicate the importance of continuing and strengthening these practices in order to ensure the long-term survival and prosperity of biological diversity in the country. The finding that habitat conservation is key to maintaining healthy ecosystems. The finding shows that this factor has the greatest impact on biodiversity protection in the Republic of Serbia. Obtaining such a result, hypothesis H2, is proven and can be accepted as valid. In other words, the finding indicates that in the Republic of Serbia, protected areas represent the best way to preserve biodiversity, which positively affects the overall biological diversity and its value.

Table 3. Results of hypothesis testing

Variable	Coefficient	Stand. Error	Critical value	p value	Results
HC ←TV	0.237	0.011	21.545	0.000	H1 accept
SM ←TV	0.192	0.027	7.111	0.000	
PR←TV	0.098	0.002	49.000	0.000	
EI ←TV	0.076	0.007	10.857	0.000	
The coefficient for HC has the highest positive value and is statistically significant					H2 accept
The value of the coefficient for SM is significantly higher than the value of the coefficient for PR					H3 not accept

The finding that sustainable resource management has the greatest impact, after habitat conservation, on biodiversity protection indicates that the adoption of sustainable practices can lead to a reduction in pressure on resources and an increase in biodiversity in the Republic of Serbia. The result of this is an increase in its value. However, the finding that sustainable resource management has a significantly higher coefficient than pollution reduction clearly indicates the greater importance of the former compared to the latter. This finding indicates that hypothesis H3, which states that these two factors have the same impact, cannot be accepted as valid and that hypothesis H3 must be rejected. This finding indicates that pollution is a very big problem in the Republic of Serbia. Illegal landfills are a particularly big problem.

Although education plays an important role in increasing awareness of the importance of biodiversity, awareness alone is not always sufficient to motivate individuals to actively engage. Many people may be informed about the issues, but the lack of practical tools or opportunities to get involved can reduce the effect of educational ones. In some cases, access to education can be problematic. If educational programs are not adapted to the specific needs of the community or culture, their impact may be limited. Also, the lack of resources or support for implementing educational activities can significantly reduce their effectiveness. For this reason, the Republic of Serbia should work on improving educational programs and encouraging local communities to become more actively involved in making decisions regarding the preservation of their environment.

4. CONCLUSION

Based on the analysis of the impact of various biodiversity protection factors in the Republic of Serbia, we can conclude that habitat preservation, sustainable resource management, pollution reduction and the involvement of local communities are key elements that significantly contribute to the preservation of biological diversity. These factors not only directly improve ecosystem health, but also promote community awareness and engagement, which is essential for the long-term conservation of natural resources.

However, the findings indicate that education, although important, has a limited impact on protecting biodiversity. This may be due to a number of reasons, including a lack of practical application of new knowledge, a weak connection between awareness and action, as well as challenges in accessing appropriate training. Therefore, future biodiversity protection strategies should focus on an integrated approach that will include not only education, but also practical initiatives, support for local communities, and active management of natural resources.

By combining these elements, it is possible to create a sustainable framework for the preservation of biodiversity in Serbia. Given the importance of biological diversity for ecosystem services and the general well-being of society, it is essential to develop and implement policies that effectively address all aspects of nature conservation, in order to ensure a healthier and more sustainable environment for future generations.

5. REFERENCES

Alho, C.J.R. (2008). The value of biodiversity. Brazilian Journal of Biology, 68, 1115-1118.

Bartkowski, B. (2017). Are diverse ecosystems more valuable? Economic value of biodiversity as result of uncertainty and spatial interactions in ecosystem service provision. Ecosystem Services, 24, 50-57.

Halkos, G., Matsiori, S. (2022). Understanding the public's perceptions of the importance, management, and conservation of biodiversity. Economic Analysis and Policy, 75, 262-270.

Halkos, G.E., Jones, N. (2012). Modeling the effect of social factors on improving biodiversity protection. Ecological Economics, 78, 90-99.

Nguyen, M.H. (2023). Investigating urban residents' involvement in biodiversity conservation in protected areas: Empirical evidence from Vietnam, Ritsumeikan Asia Pacific University.

Paul, C., Hanley, N., Meyer, S.T., Fürst, C., Weisser, W.W., Knoke, T. (2020). On the functional relationship between biodiversity and economic value. Science Advances, 6(5), eaax7712.

Taylor, B., Chapron, G., Kopnina, H., Orlikowska, E., Gray, J., Piccolo, J.J. (2020). The need for ecocentrism in biodiversity conservation. Conservation Biology, 34(5), 1089-1096.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.246S

ASSESSMENT OF ENERGY SAVINGS IN PUBLIC BUILDINGS IN THE CITY OF NOVI SAD

Vojislav Stojanović[1*], Nataša Perović[2], Tatjana Ivanović[3]

[1]Academy of Applied Technical and Preschool Studies, Serbia
*svojislav221@gmail.com
[2]Faculty of Business Economics and Law Bar, University of Adriatik, Bar, Montenegro
[3]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohia, Serbia

Abstract: Climate change poses a significant global threat, prompting increased focus on energy efficiency and savings, which play a crucial role in reducing greenhouse gas emissions. In Serbia, energy efficiency is two to three times lower than in EU countries, with the housing sector being the largest consumer. Between 2014 and 2016, energy efficiency measures in public buildings in Novi Sad yielded substantial savings 1.812.998 kWh/year and € 77.718 annually. For every € 0.48 invested, 1 kWh/year of energy savings was achieved, along with a reduction of 439 tons of CO_2 emissions annually.

Key words: Climate change, Energy savings, Public buildings, Novi Sad

1. INTRODUCTION

The City of Novi Sad is a vital urban center in Serbia, recognized as the second largest city in the country. It serves not only as the largest local self-government unit but also holds the distinguished status of being the capital of the Autonomous Province of Vojvodina (Ašonja and Rajković, 2017). This significant role within the region underscores Novi Sad's cultural, economic, and political importance. Novi Sad is a city's with the most notable attributes is its strategic geographical position, situated on crucial transport corridors that enhance its connectivity both regionally and internationally. The city is well-served by an international highway that runs through it, establishing a critical link between Southeastern Europe and Western Europe. In addition, the Danube River flows through Novi Sad, providing vital waterway access that connects Western European countries to the Black Sea, further elevating the city's logistical significance.

Novi Sad's urban area encompasses 15 suburban settlements, together covering a total expanse of 702.7 km², while the city center itself occupies 129.4 km² (Official Gazette of the City of Novi Sad, 2016). This extensive area not only highlights the city's growth and development but also reflects its capacity to accommodate a diverse population and various economic activities.

In terms of climate, Novi Sad exhibits characteristics of both moderate continental and fully continental climates, allowing residents to experience all four seasons. The average annual temperature in the city is 10.9 °C, with January temperatures typically hovering around -1 °C, while July brings warmer weather, averaging 21.6 °C. This climatic diversity contributes to the vibrant lifestyle and array of outdoor activities available to inhabitants and visitors like Ašonja (2017).

The main research addressed to analyze energy savings in public buildings in the City of Novi Sad after the implementation of EE measures. The study analyzed the level of energy efficiency (EE) measures implemented in public buildings, based on which energy savings and savings on reduced annual CO_2 emissions were calculated.

The aim of the study is to determine the impact of the implemented measures primarily on energy savings, financial savings and environmental conservation. The aim of the research in the study is to recognize the savings of environmental CO_2 (tCO_2/year) and energy-final energy (kWh/year), through the implementation of EE measures and the construction of RES plants.

2. MATERIAL AND METHODS

The research is focused on assessing the energy savings achieved in public buildings within the City of Novi Sad. The EE measures to which the research problem relates are reconstruction of the heating system, replacement of worn-out joinery, replacement of energy-inefficient lighting, insulation of buildings, etc.) (Vukasović and Todić, 2024).

In this research is included 200 public buildings in the City of Novi Sad, among them is included facilities of institutions in: education, culture healthcare, and administrative buildings, which are located in the City of Novi Sad. Among them the examination specifically focused on 27 distinct public buildings (Table 1).

Table 1. Public buildings that are the subject of research (Ašonja, 2024)

Groups of public buildings by function	Types of public buildings	Number of buildings
CULTURAL INSTITUTIONS	Cultural centers	2
	Theaters	2
	Museums	2
	Other	8
HEALTH INSTITUTIONS	Health centers	6
	Medical centers	28
EDUCATIONAL INSTITUTIONS	Preschools	73
	Elementary schools	40
	High schools	16
COLLECTIVE ACCOMMODATION FACILITIES	Nursing homes	1
	Other	2
ADMINISTRATIVE BUILDINGS	Urban buildings	30

Based on the identified problem and the focus of the research, two hypotheses were established:

- The implementation of energy efficiency (EE) measures in public facilities can result in average total annual final energy savings of 500.000 kWh per year for the period from 2020 to 2022.
- The implementation of EE measures in public facilities can lead to average total annual reductions in CO_2 emissions of at least 150 t CO_2 per year for the same period (2020-2022).

3. RESULTS AND DISCUSSION

It is unofficially estimated that there are over 16.000 public buildings in the Republic of Serbia that need energy renovation (Ašonja et al., 2017; Vasić, 2018). This requires the repair of insufficient insulation, outdated heating systems, poor carpentry, etc., or the renovation or replacement of all the aforementioned deficiencies in these buildings. After completing the calculations, the data regarding energy savings estimates for public buildings in the City of Novi Sad were analyzed. The comprehensive data summarizing the total energy savings resulting from the implementation of EE measures in public buildings within the City of Novi Sad are presented in Table 2.

Table 2 presents key parameters related to investments in energy efficiency (EE) measures implemented in public buildings over the period from 2014 to 2016. Total investments for the applied EE measures significantly increased during the observed period, rising from € 132.747 in 2020, to € 197.062 in 2021, and reaching an impressive € 540.801 in 2022. This trend indicates a comprehensive approach to energy renovation and the willingness of local authorities to invest in enhancing energy efficiency.

Table 2. Total energy savings after the implementation of EE measures in public buildings in the territory of the City of Novi Sad (Ašonja, 2024)

Parameters observed	2020	2021	2022	Total
Total investments for EE measures applied - (€)	132.747	197.062	540.801	870.610
Total annual final energy savings - FES (kWh/year)	343.662	373.625	1.104.711	1.812.998
Savings – (€/year)	13.385	12.226	52.107	77.718
CO_2 savings - (tCO_2/year)	67	83	289	439

Total annual final energy savings (FES) also experienced a significant rise, from 343.662 kWh in 2020 to 1.104.711 kWh in 2022. This increased energy saving reflects the success of the implemented measures and their effectiveness in reducing energy consumption in public facilities.

In terms of financial savings, a decrease was observed in 2021 (€ 12.226) compared to 2020 (€ 13.385), but savings increased again in 2016 to € 52.107. This fluctuation may be attributed to higher investments made in 2023, resulting in considerable reductions in energy consumption and, consequently, greater savings.

CO_2 emissions reductions also demonstrate a positive trend, with a total reduction of 439 tCO_2 across the entire observed period. These estimates highlight that the energy efficiency measures applied significantly contributed to the decrease in harmful gas emissions, which is crucial for environmental preservation and combating climate change.

Novi Sad’s is strategic location and substantial urban area, and diverse climate makes it a notable city in Serbia, with a bright future ahead as it continues to develop and enhance its role within the region. Considering the aforementioned, an important question for Novi Sad is how to become a leader in energy saving in public buildings. Therefore, the purpose of the paper is to assessment of energy savings in public buildings in the city of Novi Sad after the implementation of energy efficiency measures. the city of Novi Sad was among the first cities in the Republic of Serbia to implement energy efficiency measures, which, among other things, emphasize increasing the use of energy from renewable sources (Vukasović and Todić, 2024).

The City of Novi Sad covers the energy and water expenses for these observed facilities. However, this number does not include buildings under the jurisdiction of public utility companies, which are responsible for their own energy and water costs.

Overall, the results from the table indicate that investments in energy efficiency measures in public buildings in Novi Sad yielded positive outcomes in terms of energy savings and CO_2 emissions reductions. This further emphasizes the importance of such investments for a sustainable future.

4. CONCLUSION

Based on the conducted research on the topic "Assessment of energy savings in public buildings in the City of Novi Sad after the implementation of energy efficiency measures," two hypotheses have been confirmed. The analysis of the research findings, focusing on the applied energy efficiency (EE) measures from 2020 to 2022, shows that total final energy savings exceeded 500.000 kWh/year, reaching a total of 1.812.998 kWh/year. This result validates the first hypothesis. Additionally, it was determined that the overall reductions in CO_2 emissions surpassed 150 tCO_2/year, with a total reduction of 439 tCO_2/year, thus confirming the second hypothesis as well.

Based on the benefits analysis of the implemented EE measures, several additional initiatives are recommended for public buildings, including the management of heating, cooling, and ventilation systems, the reconstruction of lighting systems, and the improvement of thermal insulation. Furthermore, the construction of solar power plants and systems with solar collectors for hot water preparation is advised.

To further enhance energy efficiency at the local level, it is essential to provide incentive pricing for future thermal energy producers utilizing renewable energy sources (RES), maximize the use of locally available resources such as agricultural biomass, and significantly implement cogeneration systems for simultaneous heat and power generation. These recommendations have the potential to lead to substantial improvements in energy efficiency, emission reductions, and environmental preservation in the City of Novi Sad.

5. REFERENCE

Ašonja, A.N., Rajković, J.Z. (2017). An Energy Consumption Analysis on Public Applications in the City of Novi Sad. Applied Engineering Letters, 2(3), 115-120.

Ašonja, A.N. (2017). Energy balances of public buildings in the city of Novi Sad. Annals of the Faculty of Engineering Hunedoara, 15(2), 81.

Ašonja, A., Desnica, E., Radovanovic, L. (2017). Energy efficiency analysis of corn cob used as a fuel. Energy Sources, Part B: Economics, Planning, and Policy, 12(1), 1-7.

Ašonja, A.N. (2024). Energy efficiency analysis. Internal materials.

Vasić, G. (2018). Application of multi criteria analysis in the design of energy policy: Space and water heating in households-City Novi Sad, Serbia. Energy Policy, 113, 410-419.

Vukasović, V., Todić, D. (2024). Environmental law in Serbia. Kluwer Law International BV.

doi:10.46793/MAK2025.250N

EVALUATION OF SUSTAINABLE AGRICULTURAL TOURISM CRITERIA

Miroslav Nedeljković[1*], Slađana Vujičić[2]

[1]Institute of Agricultural Economics, Belgrade, Serbia
*miroslavnedeljkovic2015@gmail.com
[2]Faculty of Health Studies, University of Bijeljina, Bijeljina, Bosnia and Herzegovina

Abstract: In this paper, a group of selected factors of importance for the sustainable development of agritourism in Serbia was assessed using the fuzzy logic of expert decision-making, i.e. the objective multi-criteria decision-making method SiWeC (Simple Weight Calculation). The aim of the research was to determine the significance of the criteria that influence the potential further development of this branch of tourism in our country. The results show the successful application of the selected method, where the criterion "Active participation in tourism activities" together with the criterion "Environmental quality" received the highest rating from the experts. Given the results obtained, it is necessary to improve the criteria that were rated the worst in the future, i.e. work on greater cooperation with the local community through expanded and improved marketing activities of hosts, i.e. service providers. The method used for assessing the criteria thus gains greater transparency in research in this area, and as such needs to be further developed.

Key words: Agrotourism, Sustainability, Multi-criteria decision-making, SiWeC method

1. INTRODUCTION

Nowadays, there is an increasing emphasis on improving rural areas, and the way to achieve this is to develop tourism, or tourism activities in them. In addition to the development of tourism activities, attention should also be paid to their sustainability. Therefore, it is necessary to develop the principles on which sustainability is based. Thus, Tseng et al. (2019) believes that the emphasis of sustainability is on the application of values and principles that aim to direct human activities in a responsible and coordinated manner with environmental and social consequences. Also, as Prevolšek et al. (2020) concludes, the concept of sustainability in tourism implies the presence of economic, environmental and social dimensions as the primary criterion of sustainability. Jeločnik et al. (2013) believe that sustainability related to tourism is usually framed by its large share in the GDP of a country, and that it exerts an impact on a balanced regional and contributes to the further increase in foreign direct investment in a country.

Agritourism represents a diverse offer of agricultural activities, most often on small and medium-sized farms. (Giaccio et al., 2018) Agritourism as such has its roots at the beginning of the last century. It represents an unusual combination of tourism and agriculture and, as Puška et al. (2020) notes, is not the only form of tourism that can occur in rural areas of a country. The existing interaction between agriculture and tourism is crucial for the socio-economic stability of rural areas, thus enabling farmers to maintain their agricultural practices while engaging visitors (Baby and Kim, 2024). Palmi and Lezzi (2020) believe that agritourism is a form of multifunctionality in agriculture, which presupposes the preservation of rural landscapes and biodiversity, thereby strengthening employment and providing sustainability to rural areas. Thus, farmers use this multifunctionality to achieve full integration of farm income on the one hand and raise tourist awareness about the role of agriculture in preserving the environment, natural resources, cultural heritage, as well as traditions and customs (Giaccio et al., 2018; Puška et al., 2020). Kousar and Kausar (2024) believe that the practice of agritourism varies greatly across regions, emphasizing their cultural, economic and ecological characteristics, thereby promoting their sustainable development and unique rural experiences.

Based on the previous statement, the subject of this paper will be the sustainability of agritourism in the Republic of Serbia, or rather, determining the importance of the characteristics that influence its development. The need for research lies in the fact that Serbia is a rural country with a well-rooted tradition and historical and cultural heritage, preserved nature, which can best demonstrate its financial valorization through the development of this type of tourism. For this purpose, it is necessary to investigate the factors that influence sustainability, or rather, to show their individual importance.

For the purpose of evaluation, multi-criteria analysis methods play a major role, which have taken their place in a large number of works by the author in the previous period. Mahaptra et al. (2023) using the AHP method identifies key indicators of impact on rural tourism (agritourism) in India. In his study, the cultural factor plays the greatest role in the development of rural tourism, followed by criteria such as heritage and local quality factors. Wu et al. (2022) using a hybrid fuzzy multi-criteria decision-making model selects the most suitable agritourism location in Vietnam, while Vazin et al. (2024) also using a fuzzy decision-making model identifies certain villages suitable for agritourism. Using the Delphi method and the AHP multi-criteria decision-making method. Park et al. (2017) assess the quality of accommodation in rural tourism, and ways to improve and expand them. Many other authors also use multi-criteria analysis methods for the purpose of selecting factors of influence for the development of sustainable agrotourism potential (Muhacir and Tazebay, 2017; Anabestani, 2016; Puška et al., 2022; Adamov et al., 2020; Nedeljković et al., 2022).

The aim of the research was to determine the significance of the criteria that influence the potential further development of this branch of tourism in our country.

2. MATERIAL AND METHODOLOGY

The research process is presented in the following flowchart (Figure 1), in the elaboration of which the available scientific and professional material was used as a source of information, as well as a questionnaire sent to the engaged experts to fill in. The first step was to determine (define) the criteria that will be used in the research. The selection was narrowed down to ten criteria that are presented in the following Table 1. After that, a framework research model was formed, and the selection of experts in the subject area was initiated. Given that this is an expert decision-making process, it was necessary to obtain as precise an assessment as possible of the criteria that were forwarded to the selected experts via questionnaire. The research involved 6 experts whose structure was such that it consisted of employees in tourism organizations who have many years of experience in this field. After that, the selected selection method was applied, and the final ranking was made. The results are given in the continuation of the paper, as well as a description of the applied method. Finally, the necessary conclusions were drawn.

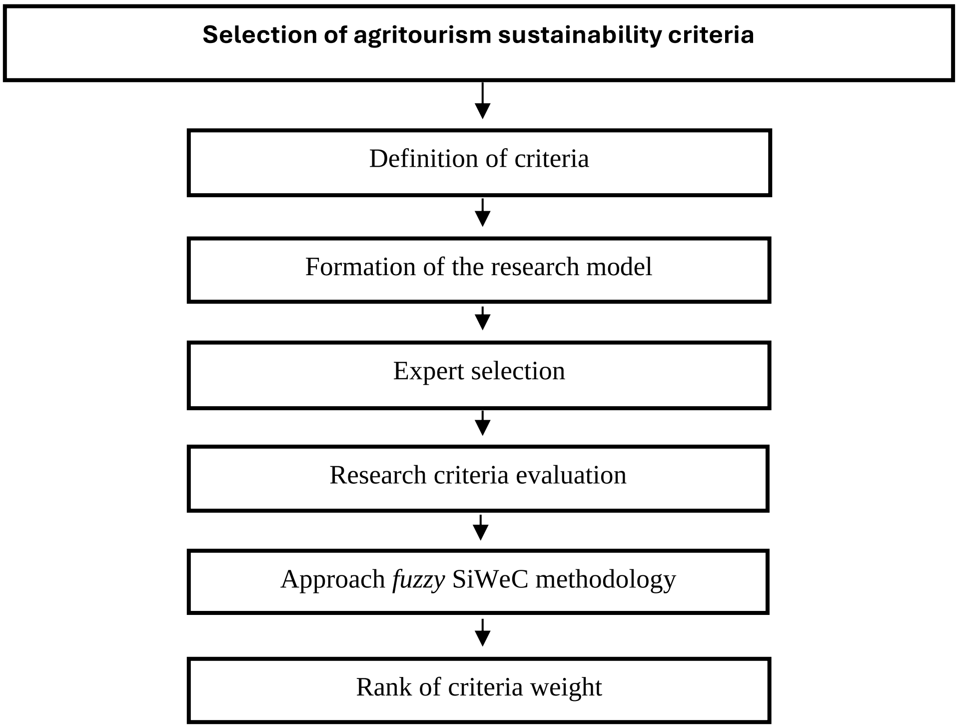


Figure 1. Research methodology

Table 1. Evaluation criteria

ID	Criterion	Explanation
1	Price	Examination of monetary rewards for the use of agrotourism facilities.
2	Location	Examination of the spatial accommodation of agrotourism capacity.
3	Marketing	Examining whether the promotion of sustainable tourism offers is necessary.
4	Quality of service provided	Examination of the quality of the provided sustainable agritourism offer.
5	Helping the local community	Examining whether the use of agritourism offers contributes to improving the standards of the local community.
6	Collaboration with the local community	Examining the possibility of helping the local community by users of agritourism offers.
7	Active participation in tourism activities	Survey of the participation of users of sustainable agritourism in all the content offered.
8	Availability of natural resources	Examining the availability of natural resources.
9	Environmental quality	Examining the quality of the environment in the agritourism offer.
10	Diversity of resources	Examining the diversity of sustainable resources in the agritourism offer.

The classical logic of decision-making and evaluation of given criteria finds its place in research where the information is complete and accurate. For this purpose, it is particularly desirable to use objective methods for calculating weighting coefficients. In the case of incomplete and inaccurate information of a subjective nature, it is important to apply *fuzzy* logic in research. In this case, the research uses *fuzzy* logic and thus converts linguistic values into a fuzzy number system. For the purposes of this paper, the *fuzzy* scale shown in the following Table 2 was used.

Table 2. Linguistic evaluations and *fuzzy* membership functions (Puška et al., 2024)

Linguistic Values	Fuzzy numbers
Very low (VL)	1, 1, 2
Low (L)	1, 2, 4
Medium low (ML)	2, 4, 6
Medium (M)	3, 5, 7
Medium good (MG)	5, 7, 9
Good (G)	7, 9, 10
Very good (VG)	9, 10, 10

For the evaluation of the criteria, i.e. obtaining the necessary weight coefficients, we used the innovative fuzzy subjective method of multi-criteria decision-making SiWeC (Simple Weight Calculation). The method was developed by Puška et al. (2024) and is characterized by simplicity both for decision-makers and for the calculation itself. The method was developed in two directions, namely as a regular SiWeC method (crips numbers) and a fuzzy SiWeC method that we will use further in the work. By using it, we popularize the method and set the basis for its further development and application in the subject area. The steps of the fuzzy SiWeC method are given below:

Step 1. Experts determine the importance of each criterion.
Step 2. Linguistic values are transformed into fuzzy numbers, represented as:

$$\tilde{x}_{ij} = \left(x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u}\right)$$

where x_{ij}^{l} represents first, x_{ij}^{m} second, and x_{ij}^{u} third fuzzy number.
Step 3. The fuzzy numbers are normalized as:

$$\tilde{n}_{ij} = \frac{x_{ij}^{l}}{max\ x_{ij}^{u}}, \frac{x_{ij}^{m}}{max\ x_{ij}^{u}}, \frac{x_{ij}^{u}}{max\ x_{ij}^{u}}$$

where $max\ x_{ij}^{u}$ is the maximum value across all criteria.
Step 4. Calculation of standard deviation ($st.dev_j$).
Step 5. The normalized ratings are weighted using the standard deviation values:

$$\tilde{v}_{ij} = \tilde{n}_{ij} \times st.dev_j$$

Step 6. The sum of the weighted values for each criterion is calculated:

$$\tilde{s}_{ij} = \sum_{j=1}^{n} \tilde{v}_j$$

Step 7. The fuzzy values of the criteria weights are computed as:

$$\widetilde{w}_{ij} = \frac{s_{ij}^{l}}{\sum_{j=1}^{n} s_{ij}^{u}}, \frac{s_{ij}^{m}}{\sum_{j=1}^{n} s_{ij}^{m}}, \frac{s_{ij}^{u}}{\sum_{j=1}^{n} s_{ij}^{l}}$$

Step 8. Defuzzification of the weights criteria

$$w_{j_{def}} = \frac{w_{ij}^{l} + 4 \times w_{ij}^{m} + w_{ij}^{l}}{6}$$

3. RESULTS AND DISCUSSION

Table 3 presents the linguistic values obtained, or scores, using the fuzzy number scale presented in the previous Table 2. Previously, the expert assessment was given by the experts via a questionnaire using scores from 1 (worst) to 7 (best). The next step is to form a fuzzy decision matrix (Table 4).

Table 3. Experts evaluations of the criteria importance

Expert	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
E1	G	MG	M	VG	G	G	VG	G	VG	MG
E2	MG	MG	ML	G	MG	MG	VG	VG	G	VG
E3	VG	VG	G	VG	G	G	MG	MG	G	MG
E4	MG	VG	MG	G	G	MG	VG	G	VG	MG
E5	G	VG	MG	MG	G	MG	VG	VG	G	G
E6	G	G	M	VG	M	M	VG	G	VG	MG

Table 4. Fuzzy decision matrix

Expert	C1	C2	C3	C4	C5	C10
E1	(7,9,10)	(5,7,9)	(3,5,7)	(9,10,10)	(7,9,10)	(5,7,9)
E2	(5,7,9)	(5,7,9)	(2,4,6)	(7,9,10)	(5,7,9)	(9,10,10)
E3	(9,10,10)	(9,10,10)	(7,9,10)	(9,10,10)	(7,9,10)	(5,7,9)
E4	(5,7,9)	(9,10,10)	(5,7,9)	(7,9,10)	(7,9,10)	(5,7,9)
E5	(7,9,10)	(9,10,10)	(5,7,9)	(5,7,9)	(7,9,10)	(7,9,10)
E6	(7,9,10)	(7,9,10)	(3,5,7)	(9,10,10)	(3,5,7)	(5,7,9)

After forming the fuzzy decision matrix, we perform the intended calculation steps using the given method. Through the following graph 1, we see that criterion 7, or "active participation in tourist facilities", received the highest score (Figure 2). Immediately following is the criterion "environmental quality". The worst rated criterion was "marketing", as well as the criterion "cooperation with the local community". The assessment results show an increasing interest in active participation and a healthy and clean environment, thus escaping from the urban areas in which they live every day.

Although active participation in tourist activities was rated the best, cooperation with the local community itself was not rated the best, which indicates that tourist facilities are still used sporadically or randomly, without any pre-arranged organization, which is also confirmed by the assessment of marketing activities obtained through expert opinion. The research somewhat coincides with the results of the research by Nedeljković et al. (2022) and the study by Puška et al. (2022), where priority is given to criteria that promote sustainable development and environmental protection. It is also interesting to note that the "price" criterion did not receive the highest rating.

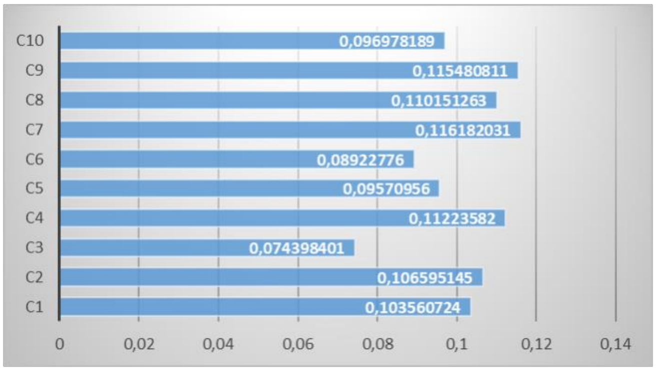


Figure 2. Ranking of criteria

4. CONCLUSION

Agrotourism today represents an important niche of a country's tourist offer. As a complex activity with diverse content that it can afford to its users, many factors influence its sustainable development. For this reason, the paper attempted to determine the significance of the selected factors and select the most important ones using an adequate innovative method. Active participation in tourist content and the quality of the environment represent the most important factors for users. In the continuation of the development of this form of tourism, it is necessary to animate the local population more, as well as to establish greater cooperation with potential tourists through additional marketing activities. Also, the paper successfully applied the fuzzy innovative method of multi-criteria decision-making, which can be successfully used in future similar research.

5. ACKNOWLEDGEMENTS

Paper is a part of research financed by the MSTDI RS, agreed in decision no. 451-03-66/2024-03/200009.

6. REFERENCE

Adamov, T., Ciolac, R., Iancu, T., Brad, I., Pet, E., Popescu, G., et al. (2020). Sustainability of agritourism activity: Initiatives and challenges in Romanian mountain rural regions. Sustainability, 12(6), 2502. doi:10.3390/su12062502

Anabestani, A. (2016). An Analysis of Factors Affecting Tourism Brands in Rural Settlements ff Iran (Case Study: Binaloud County). The Turkish Online Journal of Design, Art and Communication, Special Edition, 2061-2075. doi:10.7456/1060AGSE/084

Baby, J. Kim, D.Y. (2024). Sustainable agritourism for farm profitability: Comprehensive evaluation of visitors' intrinsic motivation, environmental behavior, and satisfaction. Land, 13(9), 1466.

Giaccio, V., Giannelli, A., Mastronardi, L. (2018). Explaining determinants of agri-tourism income: Evidence from Italy. Tour. Rev., 73(2), 216-229. doi:10.1108/tr-05-2017-0089

Jeločnik, M., Zubović, J., Subić, J. (2013). State of tourism in Republic of Serbia during the period of economic slowdown. In Sustainable development of tourism market: International practice and Russian experience, V. Trukhachev, Ed.; Stavropol State Agrarian University - Sequoia: Stavropol, Russian Federation, 15-27.

Kousar, S., Kausar, N. (2024). Multi-Criteria Decision-Making for Sustainable Agritourism: An Integrated Fuzzy-Rough Approach. Spectrum of Operational Research, 2(1), 134-150.

Mahaptra, P., Bandaru, R., Nanda, D., Tripathy, S. (2023). Determining key influential factors of rural tourism an ahp model. Optimization Techniques in Engineering: Advances and Applications, 323–343.

Muhacir, E.S.A., Tazebay, I. (2017). A tool in determination of rural tourism alternatives: the ecosystem services approach. Turkish Journal of Forestry, 18(1), 74-81. doi: 10.18182/tjf.308633

Nedeljković, M., Puška, A., Krstić, S. (2022). Multicriteria approach to rural tourism development in Republic of Srpska. Economics of Agriculture, 69(1), 13-26.

Palmi, P., Lezzi, G.E. (2020). How authenticity and tradition shift into sustainability and innovation: Evidence from Italian agritourism. Int. J. Environ. Res. Public Health, 17(15), 5389. doi:10.3390/ijerph17155389

Park, D.B., Kim, K.H., Choo, H. (2017). The Development of Quality Standards for Rural Farm Accommodations: A Case Study in South Korea. Journal of Hospitality & Tourism Research, 41(6), 673-695. doi: 10.1177/1096348014550871

Prevolšek, B., Maksimović, A., Puška, A., Pažek, K., Žibert, M., Rozman, Č. (2020). Sustainable development of ethno-villages in Bosnia and Herzegovina: A multi criteria assessment. Sustainability, 12(4), 1399. doi:10.3390/su12041399

Puška, A., Maksimović, A., Grgić, Z., Šakić Bobić, B. (2020). Improving competitiveness of agritourism in Bosnia and Herzegovina by using the decision support model. Econ. Thought Pract., 49(1), 227-246.

Puška, A., Nedeljković, M., Jeločnik, M., Subić, J., Nancu, D., Andrei, J.V. (2022). An assessment of improving the sustainable agro-touristic offer in an emerging country using the integrative approach based on fuzzy logic. Frontiers in environmental science, 10, 894811

Puška, A., Nedeljković, M., Pamučar, D., Božanić, D., Simić, V. (2024). Application of the new simple weight calculation (SIWEC) method in the case study in the sales channels of agricultural products, Methods X, 13.

Tseng, M.L., Chang, C.H., Wu, K.J., Lin, C.W.R., Kalnaovkul, B., Tan, R.R. (2019). Sustainable agritourism in Thailand: Modeling business performance and environmental sustainability under uncertainty. Sustainability, 11, 4087. doi:10.3390/su11154087

Vazin, N., Sadeghi, A., Barati, Z. (2024). Identification of suitable villages for agritourism development (a case study of semirom county). Spatial Planning, 14(3), 1-30.

Wu, C.K., Wang, C.N., Le, T.K.T. (2022). Fuzzy multi criteria decision making model for agritourism location selection: A case study in Vietnam. Axioms, 11(4), 176.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.257V

FOOD PRESERVATION-THERMAL PRESERVATION OF FOOD

Darko Veljanovski*, Blagojce Najdovski, Dzulijana Tomovska, Borche Makarijoski, Daniel Simakoski

Faculty of biotechnical sciences Bitola, UKLO North Macedonia
*darko.veljanovski@uklo.edu.mk

Abstract: Food preservation is determined by a group of processes whose goal is to maintain the quality of food for as long as possible, i.e., to prevent its spoilage or decay altogether. Preserved food remains usable for a long time, even in areas far from the place of production (farms, meat industries, processing industries, etc.). The preservation of food and the simultaneous achievement of a longer shelf life, while not changing its production performance, have always been and will continue to be fundamental goals for humans, as food is the basis for the life of every organism, including humans. A long time ago, humans began using different methods to preserve food, and because of this, there is a variety of experiences with some of the techniques and principles upon which modern food preservation processes are based, such as salting, drying, smoking, freezing, storing in oil, etc.

Key words: Food preservation, Termal preservation, Sterilization

1. INTRODUCTION

Preservation of food is a method of preserving its beneficial and high-quality characteristics for a longer period, allowing it to remain unchanged both qualitatively and quantitatively. There are many methods and different approaches to food preservation, as different types of food require different treatments. Practically all people are using many methods but, the most used method is thermal preservation of food method because it allows the longest shelf life for processed products. Something important about preservation food is that method of food preservation guarantees 100% sterility and an unlimited shelf life, as a small portion of microorganisms remain active in even the most minimally processed food. Therefore, every food, especially canned food, must always have an expiration date.

The aim of the paper is to analyze food preservation methods with a focus on thermal food preservation methods

2. DEVELOPMENT OF FOOD PRESERVATION

Food preservation is a crucial aspect of modern food production and distribution, aimed at maintaining food quality and maximizing nutritional benefits. This process involves a variety of techniques, including growing, harvesting, processing, packaging, and distribution, all of which contribute to extending the shelf life of food items (Tuward, 2024).

2.1. The foundation of the canning industry

The foundations of the canning industry were laid in the early 19th century, when certain cooks of the time started using thermal sterilization as a means of preserving food. This led to the establishment of the food canning industry, which developed rapidly and significantly. The accelerated development of food preservation technologies and the extension of shelf life were further aided by the discoveries of

Louis Pasteur and later advancements in process techniques. Such achievements and improvements in the methods and techniques for the food canning industry are very important and have become increasingly important for the modern way of life and the organization of society as a whole. The food canning industry not only enables the supply of food that is less dependent on the time and place of its production, but it also stimulates production and reduces the risk of spoilage. (Kishor, 2024).

In practice, as well as in literature, it is acknowledged that food spoilage is primarily caused by the activity of insects and rodents, but most often and easily by microorganisms and other pests, as well as by enzymes present in the food, and other reactions leading to the degradation of individual components of the food. This is often due to the influence of external temperatures, oxygen in the air, light, water, and even aging. These factors in nature rarely act alone, most often acting simultaneously. In practice, when food is exposed to certain temperatures, and in a humid environment, it naturally comes into contact with air and oxygen, which makes it unstable in terms of its safety. In such conditions, the activity of microorganisms or indigenous enzymes increases. Due to these reasons, the type and intensity of the changes that affect the reduction of quality depend on the type of food and the environmental conditions. The quality of food with living tissue (for example, fruits and vegetables), i.e., fresh food, can be diminished by metabolic processes. After the cessation of metabolism, atrophy and death of the tissue occur, leading to a decrease in the food's quality, influenced by enzymatic activity in the food itself (for example, autolysis, oxidation, and other changes in fish and meat) or due to attacks by microorganisms.

Every food is exposed to the action of microorganisms, which directly attack and spoil it. Microorganisms break down food and, with the help of enzymes, decompose complex nutrients into simpler compounds that they use for nutrition, releasing waste products in the process. The environmental conditions that affect the activity of microorganisms include temperature, acidity, and the presence of oxygen. Food preservation, as a science, introduces methods based on understanding and eliminating, or at least reducing, the conditions for the activity of individual types of microorganisms.

There are numerous methods for preserving food, but traditional food preservation almost exclusively involves preventing spoilage caused by microbial activity. Once the organism dies, the balance characteristic of every living tissue is disrupted, and under the influence of its own enzymatic systems, changes occur in the color, texture, taste, and smell of the food. These same changes and disruptions can also occur when the temperature and oxygen from the air are not properly controlled and regulated. The higher temperatures applied during food preservation can negatively affect the quality of the product, so it is essential to carefully select the conditions for food processing. The combined effect of increased temperature, oxygen, and light particularly negatively impacts certain key components of nutrients (such as vitamins, lipids, colorants, and aroma substances). The activity of water in various biological, chemical, and physical processes such as microbial activity and development, enzymatic and non-enzymatic reactions, crystallization, and other less influential processes is an important factor in the stability and longevity of food.

The term "water activity" (aw) refers to the ratio of the partial pressure of water vapor present in the food (pw) to the partial pressure of pure water vapor (p°w). It is a measure of the proportion of "free water," i.e., water that is not permanently bound to the components of the food, and on which microbiological, biochemical, and chemical processes (i.e., processes of food spoilage) depend. The water activity (aw) in relation to the minimum values (awmin) differs significantly for specific biological processes of microflora and the chemical changes in the food itself.

Pests such as rodents, parasites and others are more active and frequent in unhygienic environmental conditions, where food is not stored properly or under expected conditions. Thus, even though they directly contaminate food with eggs, fibers, and excrement, pests also make it easier for microorganisms to penetrate food by damaging it.

Food that is stored for long periods becomes more susceptible to spoilage, except for food that undergoes long biochemical processes or is stored in appropriate, pre-determined conditions that contribute to its longevity. Such products include meat products, cheeses (such as feta and kashkaval), preserves, wines, and similar items.

The principles and methods of preservation are usually classified into two groups: principles and methods of abiotic (without life) and anabiotic (revival) preservation. These are applied mainly for the long-term storage of food intended for use or processing at times when fresh food is unavailable or in places where it is not produced.

3. TERMAL PRESERVATION OF FOOD

3.1. Food preservation through thermal process

Thermal treatment is one of the oldest methods of food preservation practiced extensively all over the world. These processing applications can be practiced at home and in industries. This paper aims to provide a short description of these heat treatments. It will make clear the basic concept of Blanching, Pasteurization, Sterilization, and Hot Filling. (Dewan, 2020). Food preservation from this perspective cannot only be considered as a process to prevent spoilage due to microbial activity. In practice, multiple basic principles and methods of preservation are often combined. In literature, besides this classification, there is also a classification of preservation into physical, chemical, biological, and combined methods, based on the nature of the process.

3.2. Thermal sterilization - thermal preservation process

Thermal sterilization as a preservation process is based on an established theory and includes various steps, such as the preparation of raw materials and packaging of products in the thermal sterilization process. The process involves both general and specific operations of food preservation. Additionally, specific phenomena related to the spoilage of products preserved through thermal sterilization occur.

3.3. Thermal sterilization - basis of preservation

To destroy microorganisms and inactivate enzymes, food is packaged in hermetically sealed containers, most commonly cans, and then undergoes thermal sterilization. Depending on the method, the food is sterilized either after it is sealed in the packaging or beforehand. Achieving the expected durability and quality of the product is the primary issue of sterilization, and it requires selecting the appropriate thermal process conditions to achieve an optimum balance of preservation, while simultaneously preserving the organoleptic and nutritional properties of the food subjected to the preservation process. Thermal sterilization has been used to achieve long-term shelf stability for canned foods and is now used for a broad range of products. The majority of shelf-stable foods are thermally processed after being placed in the final containers (Farid et al., 2006).

To achieve the desired outcome during preservation, it is necessary to determine the parameters of the thermal treatment during processing and then choose the technological conditions for sterilization with minimal degradation and production costs. First and foremost, it is important to know which microorganisms can be responsible for food contamination, as well as which ones can be considered as reference or key microorganisms for assessing the effectiveness of sterilization. For the contaminants, it is essential to understand the properties of the food, particularly water activity (aw) and acidity (pH), as these influence the potential for microbial growth and thermal resistance, as well as the hygiene conditions during production and storage. The appropriate microorganism is selected based on its thermal resistance and its ability to be pathogenic. Thermal treatment during sterilization will effectively destroy all other microorganisms that could develop in the food if it destroys the reference microorganism.

4. SPECIFICITY TERMAL PRESERVATION OF FOOD

4.1. Thermal resistance of microorganisms

The term "thermal resistance" refers to the ability of microorganisms to survive thermal treatment. It was initially determined through lethal time or, in English terminology, the "time-to-death," which referred to the amount of time required for thermal treatment to destroy all microorganisms at a specific temperature. Recently, the term "time-to-death" has been replaced with "thermal reduction time," indicating the time required to reduce the population of a microorganism.

There are other appropriate principles for short-term food preservation, one of which is to keep the organism from which the food is derived alive for as long as possible, ideally until just before the food is used. Another principle applies when the time between the death of the organism from which the food is obtained and the time of use is longer. In such cases, the food must be cleaned, cooled, and protected from spoilage as quickly as possible.

4.2. Principles of food preservation through abiotic and anabiotic states

The principles of food preservation through abiotic (without life) and anabiotic (revival) states stem from the understanding that microorganisms are the cause of spoilage, and the key to preservation is controlling their activity. In this regard, the principles of abiotic preservation include the removal or complete destruction of microorganisms from food, with simultaneous protection from any contamination, while the principles of anabiotic preservation focus on suppressing or limiting microbial activity by creating unfavorable conditions for their development, without entirely destroying them.

The principles of abiotic preservation are based on sterilization methods, such as: thermal sterilization, ionizing radiation, ultrasound, well-known chemical sterilization, and ultrafiltration. In contrast, the principles of anabiotic preservation are based on methods such as cooling (psychroanabiotic), freezing (cryoanabiotic), biological preparation (cenoanabiotic), chemical preparation (chemoanabiotic), and other suitable methods such as modern preservation in controlled or modified gas atmospheres.

D is an exponential function of temperature, which can be represented by the expression:

$$\log\frac{D1}{D2} = \frac{T1-T2}{z}$$

In this case, D1 and D2 are the times for a tenfold reduction in temperatures T1 and T2, and z is the temperature change that causes a tenfold decrease in D (tenfold destruction rate of microorganisms), so that z = T1-T2 when D1/D2 = 0.10. Under the same conditions, each type of microorganism is characterized by a specific value of z. These values typically range from 5 to around 14 °C. It is generally considered that D decreases tenfold when the temperature increases by 10 °C. For example, for Clostridium botulinum, z is 10 °C.

An increase in temperature accelerates chemical reactions that lead to the degradation of important components in food, and these reactions become two to three times faster. With the same sterilization effect, the natural properties of the food degrade much less when the effect is achieved through short-term thermal treatment at a higher temperature, as opposed to when the thermal process takes longer at a lower temperature. This is why some sterilization methods, such as high temperature short time (HTST), high short sterilization (HSS), and ultra-high temperature (UHT), rely on brief thermal treatment at high temperatures. However, because these processes require rapid heat exchange with the environment, their application is usually limited to food sterilization where such exchange can occur, such as with convection in liquid or semi-liquid foods. The advantages of rapid heat exchange are especially well utilized in sterilization before packaging, most commonly in products like long-life milk, juices, etc.

4.3. Microbiological aspect of a sterilized product and its microbiological stability

The microbiological aspect of a sterilized product, or its microbiological stability, is assessed based on the probability and possibility of microorganism survival before thermal treatment. According to the accepted theoretical model, it is not possible to achieve absolute sterility of food through thermal treatment for a specific time, since the rate of microorganism destruction follows certain laws. Thus, the number of microorganisms or spores before thermal treatment is observed, then the number of surviving microorganisms after thermal treatment at a constant temperature T for a certain time is determined, and for all this, the time for a tenfold reduction at that temperature must also be established. In practice, the so-called commercial sterility is most often calculated, and it is achieved through sterilization based on established operational parameters, whereby thermal treatment reduces the microbial population and the activity of the remaining microflora to a level where the risk of spoilage of the canned product is minimized. In everyday practice, the possibility of spoilage of a canned food is not assessed individually but for the entire production batch by product type and production conditions.

4.3.1. The thermal treatment for the sterilization of food

In which pathogenic microorganisms can develop must be such that the probability of their survival is very low. The risk of spoilage of canned food due to non-pathogenic microorganisms can be significantly higher if no excessive commercial damage is risked. In such cases, sterilization may be sufficient if one microbial cell or spore survives in a thousand cans, for which a shorter thermal treatment is adequate. The regime required for sterilization can be determined experimentally and calculated and graphically or analytically displayed, based on the values of heat penetration into the product obtained experimentally. In such cases, it should be considered that the thermal resistance of microorganisms is greatest when the pH of the food to be sterilized is around 7, but the lower the pH, the higher the rate of microorganism destruction. Accordingly, food is classified as weakly acidic (with pH more than 5) and acidic (with pH lower than 5).

For the sterilization of acidic foods (for example, fruit products, so-called pickled products), which spoil under the activity of yeasts and non-spore-forming bacteria, thermal treatment up to 100 °C (pasteurization) is sufficient. In contrast, the temperature for sterilizing weakly acidic foods must be greater than 100 °C. The plants and processes for thermal sterilization differ primarily depending on whether the sterilization occurs before or after packaging or if these methods are combined.
Before packaging, food in liquid, semi-liquid, and paste-like form is sterilized. In such cases, the packaging is sterilized by filling it with boiling sterilized food, but if this packaging sterilization is not sufficient, the sealed product is additionally subjected to thermal treatment.

Today, with more advanced methods, techniques, and technologies in the food industry, so-called aseptic processes are increasingly used, which involve sterilization, cooling, and then packaging. In such cases, the packaging must be sterile, and the food is cooled after sterilization, followed by filling and sealing (of the packaging) under aseptic conditions. Under these conditions, the slow cooling of canned food, which leads to its degradation, is avoided. Aseptic conditions for the filling and sealing of packaging in these processes are created by an atmosphere of dry saturated or superheated steam. Food in solid form, such as fruit, vegetables, meat, etc., is generally sterilized after packaging in sealed containers, most often cans.

4.4. Selection plants as a part of the system for canning with sterilization before packaging

The choice of plants for canning with sterilization before packaging depends on the properties of the food, the type of packaging, and its capacity. In such plants, various heat exchangers are used for the sterilization of food enclosed in packaging, which are structurally designed for rapid heat transfer and achieving fast thermal treatment (Jildeh et al., 2021).

For the sterilization of food enclosed in different types of packaging, both continuous and batch processes under atmospheric and elevated pressure are used. The simplest device is a water bath heated by steam, either directly or indirectly. For larger capacities, there are continuous plants for sterilization in a water bath and cooling in a single flow, including tunnel pasteurizers. In these devices, cans usually move on conveyors and are sterilized by heating through jets of hot water or saturated steam directed directly at the packaging of the product.

Sterilization under high pressure, higher than atmospheric pressure, is carried out in autoclaves. Due to the increasing use of continuous lines, older batch-type vertical and horizontal autoclaves are being gradually phased out, and continuous or automated batch autoclaves are being introduced. These better meet the requirements of modern packaging and enable much better results and greater cost-effectiveness in sterilization.

5. CONCLUSION

Food preservation involves a series of processes through which microorganisms in food are destroyed or their growth and reproduction are halted. Regardless of the applied preservation method, the nutritional and biological value of the food must be preserved. Thanks to preservation, food can be stored for extended periods (from several months to several years) and can be used outside of its season and outside the place of production. In exceptional conditions (war, poor harvests), preservation can ensure food reserves. When preserving food, it is never completely sterilized. One reason for this is to preserve the quality of the food, and another is that such food provides an excellent medium for the reproduction of microorganisms, which could potentially contaminate it. Preserved foods that can be stored for a longer time are called canned goods. These are products preserved by heat in hermetically sealed metal cans. Semi-canned goods are preserved foods with a limited shelf life (5-6 months), which are stored at temperatures of 0-5 °C and require specific storage conditions. Preservation methods that act on microorganisms can be: Physical-chemical, chemical and biological.

6. REFERENCES

Dewan, F. (2020). Thermal Treatment of Food Preservation. BangabandhuSheikh Mujibur Rahman Agric. Univ., 1-15. doi: 10.13140/RG.2.2.16633.49761/1

Farid, A.G., Abdul-Ghani Al-Baali, Mohammed M. (2006). Thermal Sterilization of Food. Food Engineering Series, FSES, 1-16.

Tuward, J. (2024). Food storage and preservation. Futuristic Trends in Agriculture Engineering & Food Sciences, Volume 3, Book 24, 102-115.

Kishor, B. (2024). Canning of Fruits and Vegetables. Current Trends in Post Harvest Management. www.researchgate.net/publication/380465426_canning#fullTextFileContent

Jildeh, Z.B., Wagner, P.H.Schöning, M.J. (2021). Sterilization of Objects, Products, and Packaging Surfaces and Their Characterization in Different Fields of Industry: The status in 2020. Special Issue: Engineering of Functional Interfaces. doi.org/10.1002/pssa.202170039

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.263M

WEED FLORA COMPOSITION IN EXCEPTIONALLY HOT AND DRY YEARS

Maja Meseldžija[1*], Milica Dudić[1], Radovan Begović[2], Milica Vranešević[1]

[1]Faculty of Agriculture, University of Novi Sad, Novi Sad, Serbia
*maja.meseldzija@polj.edu.rs; milica.dudic@polj.edu.rs; milica.vranesevic@polj.edu.rs
[2]Kite doo Novi Sad, Čenej, Serbia, radovan.begovic@kitedoo.rs

Abstract: Maize crops are affected by weeds which can reduce yield and by climate change which can positively or negatively affect both crops and weeds. The aim of study was analysis of weed species (biological and ecological characteristics) in maize weed community under extreme climate conditions. The investigation was performed during the maize vegetation season in 2017 and 2024, as exceptionally dry and hot years. The weed flora in maize consisted of 12 species in 2017 and 10 species in 2024, with dominance of broadleaf weeds. The most represented life forms were therophytes (75% and 80% through the years), with a significant dominance of weed ruderal species. Ecological analysis indicated that the maize agroecosystems were moderately dry ($F_{\bar{x}} = 2.31$), neutral in pH value ($R_{\bar{x}} = 3.30$), eutrophic ($N_{\bar{x}} = 3.81$), moderately rich in humus ($H_{\bar{x}} = 2.87$), well-aerated ($D_{\bar{x}} = 3.37$), warm ($T_{\bar{x}} = 4.31$), lighted ($L_{\bar{x}} =3.93$) and unsalted ($S_- =75\%$; $S_+ = 25\%$). These species are adapted to the moderate continental climate conditions ($K_{\bar{x}} = 3.12$). The variations in weed population observed between two years in the studied areas can be attributed to climate conditions, which play a crucial role on life cycle duration, weed spread and population dynamics. In 2017 most common weeds were *Ambrosia artemisiifolia* (14.25 weeds m^{-2}) and *Chenopodium album* (32.50 weeds m^{-2}), with a total weeds abundance of 99.75 weeds m^{-2}. In 2024, which was warmer and with less precipitation during the vegetative period, the dominant weed species was *Setaria viridis* (10.50 weeds m^{-2}) with total weeds abundance of 22.50 weeds m^{-2}. Results showed that weeds in maize fields undergo notable shifts over time driven by climate change and site-specific factors in relation to long-term average of temperature and precipitation.

Key words: Maize crop, Weeds, Biological and ecological characteristics, Climate change

1. INTRODUCTION

Maize (*Zea mays* L.) along with wheat and rice is among the world's most important food crops. It is widely used for food production, animal feed and energy purposes (Grzanka et al., 2022). Protecting maize from weeds, pests and diseases is essential in order to avoid the large losses they cause in maize yield and quality (Triveni et al., 2017). Weeds compete with crops for water, light, and nutrients, which can reduce crop yield and quality (Gürbüz et al., 2023) and also can serve as hosts for diseases and pests. According to Oerke and Dehne (2004), weed pressure can reduce maize production by up to 37%, underscoring the importance of effective weed control during the early stages of crop growth. The critical period of weed competition in maize is from 1 to 8 weeks after sowing (Jhala et al., 2014), during which timely weed management becomes necessary in order to realize the maximum yield potential (Triveni et al., 2017). Changes in climate and atmosphere are directly affecting growing conditions for plants. Climate change is predicted to result in rising temperatures and reduced precipitation during spring and summer in Europe, with a consequence, that will affect crops and weeds (Peters and Gerowitt, 2014). The impact of climate change on weeds may manifest as expansions in geographic ranges, changes in species life cycles and shifts in population dynamics. As weeds migrate, the structure and composition of weed communities within natural and managed ecosystems will change (Ramesh et al., 2017). These changes in weed biology, ecology and competitive potential in the wake of climate change will lead to complex crop-weed interactions, requiring adaptive strategies. Certain weeds may go extinct, while others may become more aggressive invaders. Typically, weeds are colonizers, possessing distinctive biological characteristics and ecological adaptability that allow them to dominate crops in a habitat with changed environmental conditions (Anwar et al., 2021). Trends such as increasing average annual temperature, precipitation extremes and greenhouse gas emissions are already visible, which inevitably affect weed composition, leading to changes in the ecological and bio-ecological traits of certain weeds at the population level (Lukačević and Štefanić, 2023). Changes in the composition of weed flora on the territory of Serbia has become evident both in the most important crops and in ruderal habitats during the past decades. A total of 213 types of weeds develops in the maize crop in Serbia, with 192 of dicotyledonous (90%) weeds and 21 species of monocotyledonous weeds (10%) (Simić and Stefanović, 2006). Examining the interactions between climate and weeds, various strategies can be devised to reduce yield losses and economic damage caused by weeds such as integrated weed management, planting resilient crop varieties, adjusting planting dates, adopting site-specific weed control, rotating and mixing herbicides, and employing mulching and tillage practices (Kaur et al., 2024).

The aim of this research was to analyze floristic composition and abundance of weeds in maize crops under the different climate conditions for two, extremely dry and hot years, before herbicide application.

2. MATERIAL AND METHODS

The floristic study of weed species was conducted in a maize crop during 2017 and 2024, as exceptionally hot and dry years, in North-West Bačka district. The maize hybrid in 2017 was AS 72 (FAO maturity group 640) sown on April 6th, and in 2024 hybrid was DKC5685 (FAO maturity group 480) sown on April 10th, at the recommended seed rate. The soil on the survey plots belongs to the chernozem soil type. Species were identified by Flora of SR Serbia I-IX (Josifović, 1992), Flora of Serbia I (Sarić, 1992) and Flora Europeae I-V (Tutin et al., 1964). Life forms were determined by Ujvarosi (1973), flowering time and weed site category by Čanak et al. (1978), and ecological indices by Landolt (1977) and Knežević (1994).

The weed abundance was determined using the method of square meter. Data for monthly temperature and precipitation in the study area for 2017, 2024 and long-term average of temperature and precipitation (1991-2020) were obtained from the Republic Hydrometeorological Service of Serbia (www.hidmet.gov.rs). The average temperature and precipitation during the maize vegetation are displayed in Figures 1 and 2. Statistical analysis of the data was performed using STATISTICA 13 (TIBISCO Software Inc, 2020).

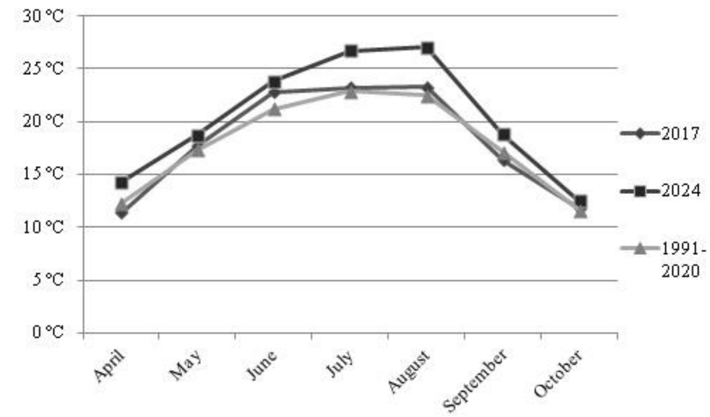


Figure 1. Monthly air temperature (°C) during the vegetative season of maize crop in 2017-2024 and long-term temperatures

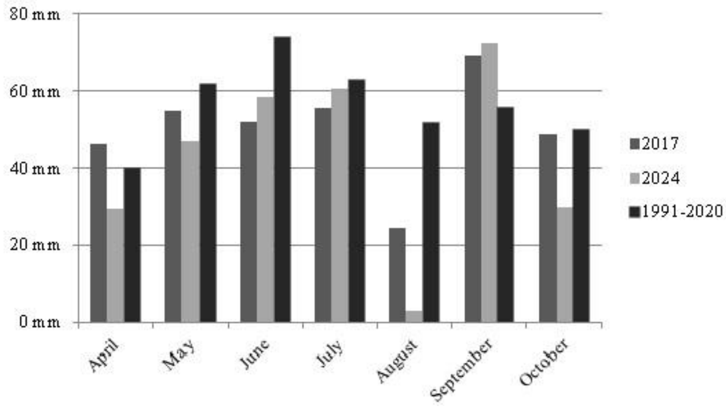


Figure 2. Monthly precipitation (mm) during the vegetative season
of maize crop in 2017-2024 and long-term percipitation

3. RESULTS AND DISCUSSION

The floristic study of weeds observed in maize crop during the experimental period identified 12 species in 2017 and 10 species in 2024 (Table 1), with broadleaf weeds being the most represented group. All species were classified into 9 families and 13 genus. Three grass weed species (class Liliopsida) from Poaceae family were recorded, while the remaining 13 species belonged to class Magnoliopsida, with the family Asteraceae being represent with 3 species, and families Chenopodiaceae, Solanaceae and Amaranthaceae represented by 2 species each. The prevalence of plant life forms is a good indicator of their adaptability to environmental factors. An analysis of the biological spectrum of weeds in the study indicated a therophytic character of weed flora with predominance of therophytes which made up 75% (9 species) in 2017, and 80% (8 species) in 2024, including also the majority of the species which affect weediness the most. Among these, T_4 therophytes which typically develop in spring and their seed matured in late summer were dominant (13 species). In contrast, T_1 therophytes were represented by only one species *Veronica persica* (Table 1). The presence of therophytes is typical for ecosystems which are under strong anthropogenic influence and points the instability of the weed flora (Kovačević, 2008; Brdar-Jokanović et al., 2017). Geophytes were less prevalent, constituting 25% of the weed flora in 2017 and 20% in 2024. Within this group, G_1 geophytes, characteristic for having rhizomes were present with one species (*Sorghum halepense*), while G_3 geophytes characteristic for having adventitious buds on the root were presented with two species (*Cirsium arvense* and *Convolvulus arvensis*). All weed species were categorized as weed ruderal (WR) species, except *Ambrosia artemisiifolia*, *Datura stramonium* and *Xanthium strumarium*, which were classified as ruderal (R) plants, and *V. persica*, which was categorized as a weed species (W).

Table 1. Weeds present in maize crop with their life forms, category according to site, ecological index and years of appearance

Family	Plant species	Life form	Category according to site	Ecological index									Years
				F	R	N	H	D	L	T	K	S	
Amaranthaceae	*Amaranthus blitoides* S. Watson	T4	WR	2	3	4	3	3	4	5	3	-	2024
	Amaranthus retroflexus L.	T4	WR	2	3	4	3	3	4	4	3	-	2017
Asteraceae	*Ambrosia artemisiifolia* L.	T4	R	2	3	4	2	2	4	5	3	+	2017
	Cirsium arvense (L.) Scop.	G3	WR	3	3	4	3	4	3	4	3	+	2017
	Xanthium strumarium L.	T4	R	3	3	5	3	2	4	5	3	+	2017
Chenopodiaceae	*Chenopodium album* L.	T4	WR	2	3	4	3	4	4	3	3	-	2017/2024
	Chenopodium hybridum L.	T4	WR	3	4	4	3	3	4	4	4	-	2017/2024
Convolvulaceae	*Convolvulus arvensis* L.	G3	WR	2	4	3	3	4	4	4	3	-	2017/2024
Solanaceae	*Datura stramonium* L.	T4	R	3	3	4	4	4	4	5	2	+	2017/2024
	Solanum nigrum L.	T4	WR	3	4	4	3	4	4	4	3	-	2017/2024
Boraginaceae	*Heliotropium europaeum* L.	T4	WR	2	4	4	3	3	4	5	4	-	2024
Poaceae	*Setaria glauca* (L.) Beauv.	T4	WR	2	3	4	2	3	4	4	3	-	2017
	Setaria viridis (L.) P. Beauv.	T4	WR	2	3	4	2	4	4	4	3	-	2024
	Sorghum halepense (L.) Pers.	G1	WR	1	2	3	3	3	4	5	3	-	2017/2024
Lamiaceae	*Stachys annua* L.	T4	WR	2	4	2	3	4	4	4	4	-	2024
Plantaginaceae	*Veronica persica* Poir.	T1	W	3	4	4	3	4	4	4	3	-	2017
Total 9	16	average		2.3	3.3	3.8	2.8	3.3	3.9	4.3	3.1		

T – therophyta (T4 – germinate in the spring and produce seeds at the end of summer; T1 – germinate in the autumn and produce seed in early spring); G – geophyta (G1 – geophytes characteristic for having rhizomes, G3 – geophytes characteristic for having adventitious buds on the root); W- weed species; WR – weed ruderal species; R – ruderal species; F – humidity; R – pH; N – nutriments; H – humus content; D – dispersity; L – light; T – temperature factor; K – continentality; s – salinity

The flowering time of weed species is a crucial factor for the timely application of weed control measures to prevent their seed production. Analysis of flowering time revealed that most of them start flowering in June (12 species), with most completing their time of flowering in September. The earliest flower was *V. persica* (starting in March), while the shortest flowering time of only one month (in June) had *Setaria glauca*, *Setaria viridis* and *S. halepense* (Figure 3).

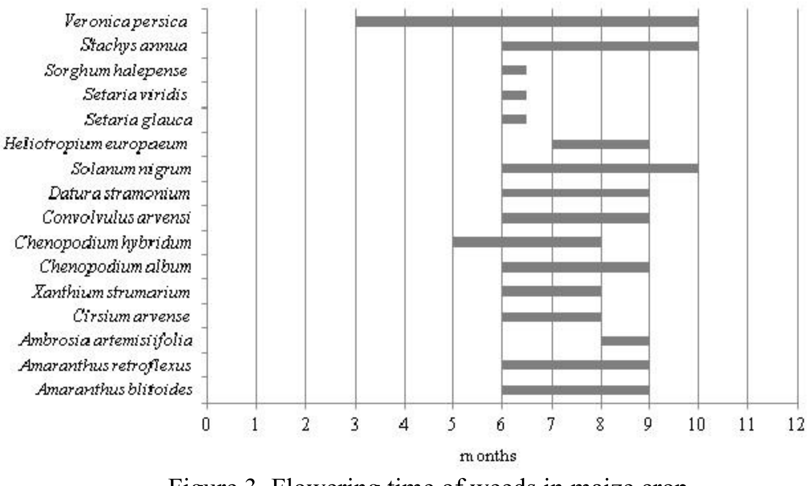


Figure 3. Flowering time of weeds in maize crop

The results of the ecological analysis of weeds in maize crop showed that examined agroecosystems were moderately dry ($F_{\bar{x}}$ = 2.31), slightly acidic to neutral reaction ($R_{\bar{x}}$ = 3.30), relatively rich in nitrogen compounds ($N_{\bar{x}}$ = 3.81), with moderate content of humus ($H_{\bar{x}}$ = 2.87), well aerated ($D_{\bar{x}}$ = 3.37), hight lighted ($L_{\bar{x}}$ =3.93), warm ($T_{\bar{x}}$ = 4.31) and predominantly non-saline (S- =75%; S+ = 25%). The conditions at the studied localities are characteristic of a moderately continental climate ($K_{\bar{x}}$ = 3.12) (Figure 4).

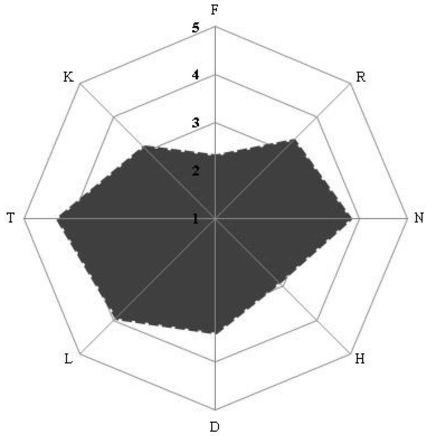


Figure 4. Ecological analysis of all weeds in maize

The differences in weed population observed between 2017 and 2024 in the investigated area can be attributed to climate conditions, which have a significant influence on the weed spread, life cycle duration and population dynamics (Anwar et al., 2021; Begović et al., 2023). In the context of climate change, soil moisture and temperature are the primary factors affecting the composition and distribution of weed species. During sowing (April) and the early growth stage of maize (June), the average temperatures in both years of study were higher than the long-term average (1991-2020). In 2024, the highest temperatures were recorded (Figure 1), exceeding the long-term average ($\bar{x}$=17.84 °C) by 2.42 °C. In the same year, July and August had higher temperatures by 3.8 °C and 4.5 °C, respectively. The period from April to October in 2024 was warmer and featured less levels of precipitation, which were approximately 300 mm, compared to 2017, when the precipitation was 351 mm. The distribution of precipitation differed significantly between the two years. The spring was followed by a warmer summer with less precipitation than the long-term average, suggesting a warmer start of growing season and accelerate the emergence and early growth of weeds. Midway through the growing season (July) 55.60 mm of rain was recorded in 2017, and 60.70 mm in 2024, which was below the long-term average (63 mm) (Figure 2). Favorable distribution of precipitation was noted in 2017, whereas 2024 was characterized by a lower distribution, especially in August when only 2.9 mm of rainfall was recorded. Such reduced precipitation can further decrease crop yields, especially during the grain-filling stages, which are sensitive to drought. Lee (2011) reported that increasing temperature by 4 °C advanced the emergence of *Chenopodium album* and *Setaria viridis* by 26 and 35 days, respectively, and flowering time by 50 and 31.5 days. Similarly, Umkulzhum et al. (2024) observed that high temperatures promote the vigorous growth of *Datura stramonium*, so this plant could serve as a promising candidate in the context of climate change.

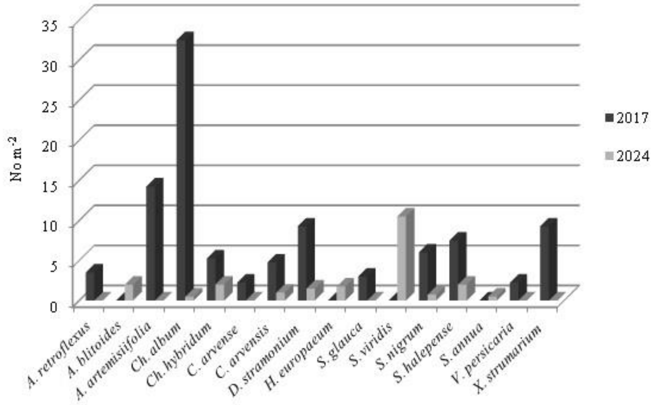


Figure 5. The presence and number of weed flora during the 2017 and 2024

The maize-weed community at the examined localities consisted of 16 species, with an average density of 61.12 individuals m^{-2} over two years. The total number of weed species varied between years. In 2017, 12 species were recorded, with a total weed density of 99.75 m^{-2}. The most prevalent species were *Chenopodium album* (32.50 weeds m^{-2}), *Ambrosia artemisiifolia* (14.25 weeds m^{-2}), *Datura stramonium* and *Xanthium strumarium* (9.25 weeds m^{-2}) (Figure 5). The least represented species during this year were *Cirsium arvense* and *Veronica persica* (2.25 weeds m^{-2}). Generally, weeds do not have an equal distribution or significance in crops across all regions of Serbia. In the broader area of Serbia, the most common species in maize are *Abutilon theophrasti, Amaranthus retroflexus, Ambrosia artemisiifiolia, Bilderdykia convolvulus, Chenopodium album, Cirsium arvense, Convolvulus arvensis, Cynodon dactylon, Datura stramonium, Hibiscus trionum, Panicum crus-galli, Polygonum lapathifolium, Setaria glauca, Setaria viridis, Solanum nigrum, Sonchus arvensis, Sorghum halepense, Symphytum officinale* and *Xanthium strumarium* (Nedeljković, 2021). In contrast, 2024 was characterized by slightly lower precipitation and higher air temperatures especially during the growing season (April-September), and total of 10 weed species were recorded, with an overall density of only 22.50 weeds/m^2, which is significantly lower than in 2017. The floristic composition of weeds this year did not include species such as *Amaranthus retroflexus, Ambrosia artemisiifolia, Cirsium arvense, Setaria glauca, Veronica persica* and *Xanthium strumarium*. The most dominant species in 2024 was grass weed *Setaria viridis* (10.50 weeds m^{-2}; 46.67%), and less represented were *Amaranthus blitoides* (2 weeds m^{-2}), *Chenopodium hybridum* (2 weeds m^{-2}) and *Sorghum halepense* (2 weeds m^{-2}), with a representation of 8.89%. Other species were even less prevalent. Across both years, an increase in the proportion of annual weed species (13 in total) was observed, attributed to the application of agrotechnical and chemical measures. Some study indicated that *Setaria viridis* would be a problematic weed in maize cropping systems due to its synchrony with maize emergence, likely stimulated by increased temperature (Peters and Gerowitt, 2014). Therefore, this species would become a competitor of maize at enhanced temperatures at the time of emergence (Ramesh et al., 2017). The obtained results indicate that the floristic composition of weeds in maize undergoes changes, reflected in the types of species, their number, and overall abundance, which are influenced by climate changes and site-specific conditions over the years.

4. CONCLUSION

Floristic investigation of weed species in maize crops found a total of 12 species in 2017 and 10 species in 2024. The most common species were from the *Asteraceae* and *Poaceae* families. Examined weed flora is dominated by weed ruderal plants, and therophytes constituted the majority of the weed flora (75% in 2017 and 80% in 2024), indicative of their adaptability to the anthropogenic and climatic pressures (exceptionally hot and dry conditions) of the studied agroecosystems. The ecological analysis showed that examined agroecosystems were moderately dry, with neutral pH values, moderately rich in organic compounds, well aerated, well-lit, warm, non-saline, and characterized by conditions of moderately continental climate. In 2017, with higher precipitation and moderate temperatures, total weed density peaked at 99.75 weeds m^{-2}, dominated by annual species *Chenopodium album* (32.50 weeds m^{-2}) and *Ambrosia artemisiifolia* (14.25 weeds m^{-2}). Conversely, 2024, characterized by slightly lower precipitation and higher temperatures during the growing season, saw a significant decline in weed density to 22.5 weeds m^{-2} and a shift in dominance to thermophilic weed *Setaria viridis* (10.5 weeds m^{-2}). The results highlight those climatic variations, particularly temperature and precipitation relation to long-term average (1991-2020), along with locations to weed management strategies, drive a significant shift in weed community in maize crops.

5. ACKNOWLEDGMENT

The research in this paper is part of a project entitled: Determination of excess water in Vojvodina within the framework of climate change and extreme hydrometeorological phenomena (contract no. 002955429 2024 09418 003 000 000 001) funded by the Provincial Secretariat for Higher Education and Scientific Research activity.

6. REFERENCES

Anwar, M.P., Islam, A.K.M.M., Yeasmin, S., Rashid, M.H., Juraimi, A.S., Ahmed, S., Shrestha, A. (2021). Weeds and Their Responses to Management Efforts in A Changing Climate. Agronomy, 11, 1921. doi.org/10.3390/agronomy11101921

Begović, R., Dudić, M., Meseldžija, M., Vranešević, M., Jurišić, A. (2023). Rationalizing Herbicide Use in Maize within the Framework of Climatic Change and Extreme Hydrometeorological Phenomena. Sustainability, 15(19), 14444. doi.org/10.3390/su151914444

Brdar-Jokanović, M., Ljevnaić-Mašić, B., Džigurski, D., Nikolić, Lj., Ćirić, V., Maksimović, L., Adamović, D. (2017). Organically and conventionally grown peppermint (*Mentha* x *piperita* L.) as affected by weeds. Journal on Processing and Energy in Agriculture, 21(2), 111-114.

Čanak, M., Parabućski, S., Kojić M. (1978). Illustrated weed flora of Yugoslavia. Matica srpska, Novi Sad, Srbija, 1-44. /in Serbian/

Grzanka, M., Sobiech, Ł., Idziak, R., Skrzypczak, G. (2022). Effect of the time of herbicide application and the properties of the spray solution on the efficacy of weed control in maize (*Zea mays* L.) cultivation. Agriculture, 12(3), 353. doi.org/10.3390/agriculture12030353

Gürbüz, R., Açıkgöz, Ç., Çoruh, İ. (2023). Examining the weed flora in maize fields and assessing the effectiveness of specific herbicides in suppressing weeds and enhancing maize yield of Igdir province, Türkiye. Turkish Journal of Weed Science, 26(1), 26-37.

Jhala, A.J., Knezevic, S.Z., Ganie, Z.A., Singh, M. (2014). Integrated weed management in maize. In Recent Advances in Weed Management, Springer, New York, NY, 177-196.

Josifović, M. (Ed.) (1992). Flora of SR Serbia I-IX, Serbian Academy of Sciences and Arts (SANU), Beograd, Srbija (1970-1977). /in Serbian/

Kaur, R., Kumar, S., Ali, S.A., Kumar, S., Ezing, U.M., Bana, R.S., Meena, S.L., Dass, A., Singh, T. (2024). Impacts of climate change on crop-weed dynamics: Challenges and strategies for weed management in a changing climate. Open J Environ Biol, 9(1), 015-021. dx.doi.org/10.17352/ojeb.00004

Knežević, A. (1994). Monograph of the flora of vascular plants on salt marshes in the Banat region (Yugoslavia). Matica srpska, Novi Sad, Serbia. /in Serbian/

Kovačević, D. (2008). Field weeds - biology and control. University of Belgrade, Faculty of Agriculture-Zemun, Belgrade-Zemun, Serbia. /in Serbian/

Landolt, E. (1977). Ökologische Zeigerwerte zur Schweizer Flora. Offentlichungen der Geobotanishen Institutes der ETH, Stiftung Rübel, Zürich, 64 Heft.

Lee, J. (2011). The combined effect of elevated CO_2 and temperature on the growth and phenology of two annual C3 and C4 weedy species. Agric. Ecosys. Environ., 140, 484-491. doi: 10.1016/j.agee.2011.01.013

Lukačević, M., Štefanić, E. (2023). Weed species shifts due to climate change: a case study of row crops in the northeastern Croatia. Research Journal of Agricultural Science, 55(2). ISSN: 2668-926X

Nedeljković, D. (2021). Critical timing of weed control in corn crop with standard and double row sowing. Doctoral dissertation. University of Belgrade, Faculty of Agriculture Zemun. Serbia. /in Serbian/

Oerke, E.C., Dehne, H.W. (2004). Safeguarding production losses in major crops and the role of crop protection. Crop protection, 23 (4), 275-285.

Peters, K., Gerowitt, B. (2014). Important maize weeds profit in growth and reproduction from climate change conditions represented by higher temperatures and reduced humidity. Journal of Applied Botany and Food Quality, 87, 234-242. doi:10.5073/JABFQ.2014.087.033

Ramesh, K., Matloob, A., Aslam, F., Florentine, S.K., Chauhan, B.S. (2017). Weeds in a Changing Climate: Vulnerabilities, Consequences, and Implications for Future Weed Management. Front. Plant Sci., 8, 95. doi:10.3389/fpls.2017.00095

Sarić, M. (1992). Flora of Serbia I, Serbian Academy of Sciences and Arts (SANU), p.429. /inSerbian/

Simić, M., Stefanović, L. (2006). Analysis of the corn weed community in Zemun Field. Arch. agricultural sciences, 67, 239 (2006/3), 89-100. /in Serbian/

Triveni, U., Rani, Y.S., Patro, T.S.S.K., Bharathalakshmi, M. (2017). Effect of different pre-and post-emergence herbicides on weed control, productivity and economics of maize. Indian Journal of Weed Science, 49(3), 231. doi.org/10.5958/0974-8164.2017.00061.2

Tutin, G., Heywood, V.H., Burges, N.A., Valentine, D.H., Walters, S.M., Webb, D.A. (Eds.) (1964). Flora Europeae I-V, University Press: Cambrige, UK.

Ujvárosi, M. (1973). Gymnövények. Mezogazdasági Kiado, Budapest, Hungary.

Umkulzhum, F., Ameena, M., Susha, V.S., Renjan, B., Sreelekshm, K., Sethulekshmi, V.S., Shanavas, S. (2024). Weeds and Their Response to Changing Climate: A Review. International Journal of Environment and Climate Change, 14(4), 768-779. doi: 10.9734/ijecc/2024/v14i44157.

Quintero, A., Molero, G., Reynolds, M.P., Calderini, D.F. (2018). Trade-off between grain weight and grain number in wheat depends on G×E interaction: A case study of an elite CIMMYT panel (CIMCOG). European Journal of Agronomy, 92, 17-29. doi: 10.1016/j.eja.2017.09.07

Šućur, R., Mladenov, V., Banjac, B., Trkulja, D., Mikić, S., Šumaruna, M., Börneo, A. (2024). Phenotypic marker study of worldwide wheat germplasm. Italian Journal of Agronomy, 19: 100002. doi: 10.4081/ija.2023.2194

Urošević, D., Knežević, D., Đurić, N., Matković Stojšin, M., Kandić, V., Mićanović, D., Stojiljković, J., Zečević, V. (2023). Assessing the potential of old and modern Serbian wheat genotypes: yield components and nutritional profiles in a comprehensive study. Agronomy, 13(9), 2426.

VSN International (2009). GenStat for Windows (12th ed.), VSN International.

Zečević, V., Matković, M., Petrović, S., Dimitrijević, M., Knežević, D. (2016). Stability of spike weight and grain weight per spike of different wheat genotypes. Book of Proceedings, VII International Scientific Agriculture Symposium, Jahorina, Bosnia and Herzegovina, 578-593.

doi:10.46793/MAK2025.271K

IMPACT OF CLIMATE CHANGE ON *Ambrosia artemisiifolia* L.

Bojan Konstantinović*, Milena Popov, Nataša Samardžić, Tijana Stojanović, Stefan Ugrinov

University of Novi Sad, Faculty of Agriculture, Novi Sad, Serbia
*bojank@polj.uns.ac.rs

Abstract: Climate change is one of the most pressing global challenges of the 21st century, influencing various ecological processes and species distributions. One of the many species affected by these changes is *Ambrosia artemisiifolia*, a plant native to North America that has established itself in various regions and successfully spread to all continents except Antarctica over the last two centuries. Known for its potent allergenic pollen, common ragweed presents a significant threat to public health, agriculture, and ecosystems. As climate change continues to alter environmental conditions, its spread and impact are likely to intensify. Climatic changes have become increasingly evident in Serbia, particularly over the last two decades. In our region, we are witnessing hotter summers and a growing imbalance in rainfall during the growing season. However, these conditions did not limit the spread of ragweed, which has become increasingly common in Serbia, particularly in ruderal habitats.

Key words: Ragweed, Novi Sad, Ruderal habitats

1. INTRODUCTION

Ambrosia artemisiifolia is native to North America but has become widespread in Europe since its introduction in the late 19th century (Essl et al., 2015). The plant has been aptly characterized as a highly successful dominant species thriving in abandoned areas, even under harsh ecophysiological conditions in extreme and unpredictable environment (Singh and Mathur, 2021). This species is inotorious for producing the allergenic pollen, which affects millions of people annually (Lake et al., 2017). In Europe, Ambrosia species have been linked to a significant rise in respiratory allergies in regions where they are found, impacting approximately 13.5 million individuals and incurring annual healthcare costs of up to 7.4 billion euros. (Schaffner et al., 2020). The increase in its distribution and abundance has been attributed to various factors, including land use changes, agricultural practices, and climate variability (Ziska et al., 2011). With global temperatures rising and weather patterns shifting due to climate change, understanding the potential impacts on A. artemisiifolia is crucial for predicting future ecological and public health challenges.

The primary drivers of global climate change are urbanization, agriculture, industrial activities and the greenhouse effect. These climatic changes contribute to the annual rise in carbon dioxide (CO_2) levels and surface temperatures on Earth. In general, climate change pertains to any alteration in climate that can adversely affects living organisms, including humans, plants and animals, ultimately harming the environment. It encompasses a range of environmental changes, including rising temperatures, altered precipitation patterns, and increased atmospheric CO_2 levels (Kabir et al., 2023). These factors can significantly influence the growth, reproduction and distribution of *A. artemisiifolia*.

The Earth's average surface temperature is approximately 14 °C and has risen by nearly 1 °C over the last century. This elevation has altered precipitation patterns, resulting in either decreased or increased rainfall in various regions (Singh and Kumar, 2022). Higher temperatures can extend the growing season for A. artemisiifolia, allowing it to germinate and thrive in previously unsuitable regions. Studies have shown that elevated temperatures significantly enhance the plant height, male inflorescences size, and pollen release duration (Cheng et al., 2023). Warmer autumn temperatures extend the growing season for ragweed.

Additionally, the effect of doubling the CO_2 levels led to a significant increase in the pollen count (Sikoparija et al., 2017). Wayne et al. (2002) found that the doubling of atmospheric CO_2 concentration resulted in a 61% increase in pollen production per ragweed plant. Singer et al. (2005) showed that recent and anticipated rises in CO_2 levels could directly enhance the allergenic properties of ragweed pollen, potentially increasing the prevalence and/or severity of seasonal allergies. Furthermore, Ambrosia pollen collected near busy roadways exhibited greater allergenicity than the pollen from natural vegetative areas (Wayne et al., 2002). This not only intensifies the plant's allergenic effects, but also enhances its competitive edge over native species, further promoting its spread.

Warmer spring temperatures result in earlier flowering and prolonged pollen production. In Europe, *A. artemisiifolia* is less common in the far north and far south due to environmental constraints. In the north, thermal and photoperiod limitations hinder its growth and, even though the populations can reach maturity and produce seeds, low temperatures and cold climate promote extinction. On the other hand, in the southern edge of its habitat, drought is considered a major factor limiting its invasion. However, global warming may render previously unsuitable regions in northern and northeastern Europe favorable for the species, enabling its expansion (Makra et al., 2015).

Changes in precipitation can also affect the distribution of *A. artemisiifolia*, which is sensitive to very low or very high annual precipitation variability, indicating a general sensitivity to precipitation extremes (Case and Stinson, 2018). In Europe, strong summer droughts currently limit the ragweed's spread (Gallien et al., 2016). As climate change alters rainfall patterns, increased precipitation in certain areas may further enhance ragweed growth.

Climatic changes have become increasingly evident in Serbia, particularly over the last two decades. A comparison of mean air temperatures during the summer months from 1981 to 2024 revealed that the summer of 2024 was the warmest, with precipitation levels below the average for this reference period. However, these conditions did not limit the spread of ragweed, which has become increasingly common in Serbia, particularly in ruderal habitats.

The aim of the research is to estimate the effects of temperature and precipitation on the ragweed's appearance, spread in the monitored areas and duration of the pollination.

2. MATERIAL AND METHODS

In this study the included data comprise of the registered micro-localities with the ragweed occurrence during the growing season from May to October in four consecutive years, from 2021 to 2024. The monitoring and determining the numbers, coverage and persistence of ragweed populations, as well as of the other allergenic species, was conducted in 14 suburbs of the municipality of Novi Sad. The weather data for the municipality of Novi Sad was sourced from the Republic Hydrometeorological Institute of Serbia, while the pollination calendar information was obtained from the City Administration for Environmental Protection in Novi Sad.

2.1. Weather conditions

From May to October 2024 was the warmest year, with notable temperature peaks in July (26.9 °C) and August (27.5 °C), while 2021 and 2023 had cooler conditions, particularly in May and June. Precipitation varied significantly, with 2023 being the wettest in May (124.8 mm) and 2022 experiencing extremes, including very dry conditions in May (17.9 mm) and heavy rainfall in September (159.0 mm). August was particularly wet in 2022 and 2024, while 2023 and 2021 had moderate rainfall overall. October was relatively stable, with 2021 being wetter and 2023 the driest. Overall, 2024 was the hottest, and 2022 showed the most dramatic precipitation variability.

The average monthly temperatures and precipitation for Novi Sad and its surrounding areas for the four studied years compared with the reference period 1991-2020 can be seen in Tables 1 and 2.

Table 1. Average monthly temperatures (°C) for Novi Sad and its surrounding areas and their evaluation using the percentile method relative to the reference period 1991-2020.

	March	April	May	June	July	August	September	October	November
2021	6.2	9.6*	16.0**	23.3###	25.5###	22.1	17.9#	10.6**	7.2
2022	5.5**	10.9*	19.1##	23.9###	25.1##	24.6##	16.8	13.7#	7.6
2023	9.0#	10.4*	17.2	21.5	24.7##	23.7	21.4###	16.6###	8.4#
2024	11.5##	15.3##	18.1#	24.3###	26.9###	27.5###	19.5##	13.5#	5.1*

*- very cold, **- cold, #- warm, ##- very warm ###- extremely warm (www.hidmet.gov.rs)

Table 2. Average monthly precipitation (mm) for Novi Sad and its surrounding areas and their evaluation using the percentile method relative to the reference period 1991-2020.

	March	April	May	June	July	August	September	October	November
2021	42.8	55.1	62.9	23.9###	114.4*	46.4	16.4#	88*	114.6**
2022	1.1	54.5	17.9###	43.6#	13.8##	103.9*	159.0***	31.0	44.7
2023	25.3	63.9*	124.8**	35.4#	58.2	39.9	63.5	11.4#	83.8*
2024	/	/	/	57.3#	29.4	1.2##	130.1**	48.3##	59.5

#- dry, ##-very dry, ###- extremely dry, *- rainy, **- very rainy, ***- extremely rainy (www.hidmet.gov.rs)

3. RESULTS AND DISCUSION

This study examines the impact of temperature and precipitation on the occurrence and spread of ragweed in the observed areas, with a focus on their impact on the duration of the ragweed pollination period from 2021 to 2024. The research found a different number of micro-localities with ragweed occurrence during the growing season from June to October in one year. Differences between years during the period 2021-2024, were also found in the number of micro-localities with ragweed occurrence in each month from June to October (Figure 1). According to the analysis of the average monthly air temperatures and precipitation levels for the same timeframe, it is observed that the lower average temperatures in May 2021 led to a deceleration in the development of ragweed, resulting in the issuance of the first orders for its suppression only in mid-June of that year. According to official data from the City Administration for Environmental Protection in Novi Sad, the first ragweed pollen grains were detected in the air on July 1, with the main pollen season starting and ending five days later than the average. In June 2024, the warmest month compared to previous years, there was an intensification in ragweed growth, with as many as 323 micro-localities infested throughout all suburban settlements of the municipality of Novi Sad, surpassing numbers from previous years.

Similarly, in 2022, extreme mean air temperatures in June and July, coupled with an unusually dry May and a very rainy or extremely rainy period in August and September, resulted in the shortest period with elevated pollen values recorded. The mean daily temperatures in September were within average values only in 2022 when a notable number of micro-localities under ragweed were observed and mapped compared to the same month in preceding years. Overall, 2024 stood out as the warmest among the examined years, leading to the mapping of the highest number of microsites and recommendations for early mowing (starting as early as May). During 2024, measuring stations in Novi Sad noted the appearance of ambrosia pollen in the air as early as June 9, the earliest date compared to the three previous years.

Finally, substantial precipitation in May 2023 hindered the emergence and growth of ragweed, resulting in the least number of microsites hosting the plant during June and July compared to the same period in other examined years. This, combined with high average temperatures in September, influenced the pollination calendar, causing the main pollen season to end five days earlier than usual.

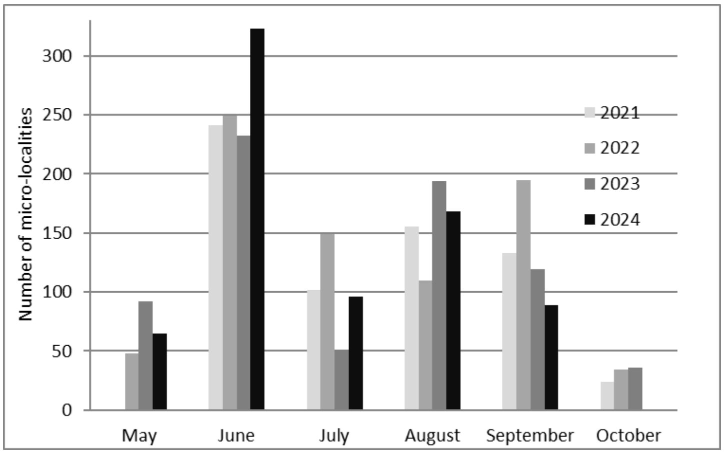


Figure 1. Number of micro-localities with ragweed population in suburban settlements of the municipality of Novi Sad

4. CONCLUSION

The impact of climate change on the spread of *Ambrosia artemisiifolia* in Serbia presents significant ecological, agricultural, and public health challenge. As environmental conditions continue to shift, the potential for this invasive species to expand its range and increase its prevalence is high. From the analysis of the presented data, it can be seen that extreme rainfall, as well as droughts, are not a limiting factor for the spread of ragweed or the emergence of new populations in micro-localities. Precipitation and air temperature somewhat dictate the beginning of the growing season and the length of the pollination period, but the increasingly frequent extremes of these parameters do not seem to restrict ragweed pollination. Constant monitoring is essential to provide the most accurate predictions of ragweed pollen occurrence and to anticipate its further spread. Regular surveillance and suppression efforts will play a critical role in managing the ecological and public health impacts of this invasive species.

Based on the obtained results, precise recommendations can and are being given to the competent institutions regarding the timing and methods of the ragweed control in order to prevent pollination, fruiting and further spread of this invasive species.

5. REFERENCES

Case, M.J., Stinson, K.A. (2018). Climate change impacts on the distribution of the allergenic plant, common ragweed (*Ambrosia artemisiifolia*) in the eastern United States. PLOS ONE, 13(10), e0205677

Essl, F., Biró, K., Brandes, D., Broennimann, O., Bullock, J.M., Chapman, D.S., Chauvel, B., Dullinger, S., Fumanal, B., Guisan, A., Karrer G., Kazinczi G., Kueffer C., Laitung B., Lavoie, C., Leitner, M., Mang, T., Moser, D., Müller-Schärer, H., Petitpierre, B., Richter, R., Schaffner, U., Smith, M., Starfinger, U., Vautard, R., Vogl, G., Lippe, M., Follak, S. (2015). Biological Flora of the British Isles: *Ambrosia artemisiifolia*. Journal of Ecology, 103, 1069-1098.

Gallien, L., Thuiller, W., Fort, N., Boleda, M., Alberto, F.J., Rioux, D., Lainé, J., Lavergne, S. (2016). Is there any evidence for rapid, genetically based, climatic niche expansion in the invasive common ragweed? PLOS ONE, 11(4), e0152867

Lake, I.R., Jones, N.R., Agnew, M., Goodess, C.M., Giorgi, F., Hamaoui-Laguel, L., Semenov, M.A., Solmon, F., Storkey, J., Vautard, R., Epstein, M.M. (2017). Climate Change and Future Pollen Allergy in Europe. Environmental Health Perspectives, 125(3), 385-391.

Makra, L., Matyasovszky, I., Hufnagel, L., Tusnády, G. (2015). The history of ragweed in the world. Applied ecology and environmental research, 13(2), 489-512.

Kabir, M., Habiba, U.E., Khan, W., Shah, A., Rahim, S., De los Rios-Escalante, P.R., Farooqi, Z.U.R., Ali, L., Shafiq, M. (2023). Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review, Journal of King Saud University - Science, 35(5), 102693

Sikoparija, B., Skjøth, C.A., Celenk, S., Testoni, C., Abramidze, T., Alm Kübler, K., Belmonte, J., Berger, U., Bonini, M., Charalampopoulos, A., Damialis, A., Clot, A., Dahl, Å., de Weger, L.A., Gehrig, R., Hendrickx, M., Hoebeke, L., Ianovici, N., Kofol, Seliger, A., Magyar, D., Mányoki, G., Milkovska, S., Myszkowska, D., Páldy, A., Pashley, C.H., Rasmussen, K., Ritenberga, O., Rodinkova, V., Rybníček, O., Shalaboda, V., Šaulienė, I., Ščevková, J., Stjepanović, B., Thibaudon, M., Verstraeten, C., Vokou, D., Yankova, R., Smith, M. (2017). Spatial and temporal variations in airborne Ambrosia pollen in Europe. Aerobiologia, 33(2), 181-189.

Singer, B.D., Ziska, L.H., Frenz, D.A., Gebhard, D.E., Straka, J.G. (2005). Increasing Amb a 1 content in common ragweed (*Ambrosia artemisiifolia*) pollen as a function of rising atmospheric CO_2 concentration. Functional Plant Biology, 32, 667-670.

Singh, A.B., Mathur, C. (2021). Climate change and pollen allergy in India and south Asia. Immunology and Allergy Clinics of North America, 41(1), 33-52.

Singh, A.B., Kumar, P. (2022). Climate change and allergic diseases: An overview. Front Allergy, 13(3), 964987.

Schaffner, U., Steinbach, S., Sun, Y., Skjøth, C. A., de Weger, L.A., Lommen, S.T., Augustinus, B. A., Bonini, M., Karrer, G., Šikoparija, B., Thibaudon, M., Müller-Schärer, H. (2020). Biological weed control to relieve millions from Ambrosia allergies in Europe. Nature Communications, 11(1), 1745.

Wayne, P., Fosters, C.J., Bazzez, F., Epstein, P. (2002). Production of allergenic pollen by ragweed (*Ambrosia artemisiifolia* L.) in increased CO_2 enriched atmosphere. Ann Allergy Asthma Immunol., 88(3), 279-282.

Cheng, X., Frank, U., Zhao, F., Capella, J.R., Winkler, J.B., Schnitzler, J.P., Ghirardo, A., Bertić, M., Estrella, N., Durner, J., Pritsch, K. (2023). Plant growth traits and allergenic potential of *Ambrosia artemisiifolia* pollen as modified by temperature and NO_2. Environmental and Experimental Botany, 206, 105193.

Ziska, L., Knowlton, K., Rogers, C., Dalan, D., Tierney, N., Elder, M.A., Filley, W., Shropshire, J., Ford, L.B., Hedberg, C., Fleetwood, P., Hovanky, K.T., Kavanaugh, T., Fulford, G., Vrtis, R.F., Patz, J.A., Portnoy, J., Coates, F., Bielory, L., Frenz, D. (2011). Recent warming by latitude associated with increased length of ragweed pollen season in central North America. Proceedings of the National Academy of Sciences of the United States of America, 108(10), 4248-51.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.276J

APPLICATION OF THE EPIC MODEL FOR THE PRODUCTION OF KHORASAN WHEAT IN THE CONDITIONS OF CLIMATE CHANGE IN SERBIA AND LIBYA

Snežana Janković[1*], Ayiman Omar Alkhammas[2], Divna Simić[1], Marija Gavrilović[1], Danijela Šikuljak[3], Jela Ikanović[4], Sveto Rakić[4]

[1]Institute for the Application of Science in Agriculture, Belgrade, Serbia
*sjankovic@ipn.bg.ac.rs
[2]Faculty of Applied Ecology Futura, University Metopolitan, Serbia
[3]Institute for Plant Protection and Environment, Belgrade, Serbia
[4]Faculty of Agriculture, University of Belgrade, Serbia

Abstract: Based on the results of a two-year study on the impact of agro-ecological conditions in Serbia in the regions of the Sava River and the Danube River, the possibility of introducing Khorasan wheat in the three most important agricultural regions of Libya was analyzed using the EPIC model (Erosion Productivity Impact Calculator). The EPIC method was used to analyze precipitation and temperature, which have the biggest impact on the growth and development of wheat. It has been found that by choosing the most suitable production technology, Khorasan wheat can be grown as a winter or facultative-winter crop in these areas.

Key words: Khorasan, EPIC model, Climate change, Introduction in Libya

1. INTRODUCTION

The Special Report on Climate Change and Land published in 2019 by the Intergovernmental Panel on Climate Change (IPCC) pointed out that rising temperatures, changing precipitation patterns and more frequent weather extremes were destroying the stability of global food supplies www.ipcc.ch/site/assets/uploads/2019/08/Fullreport.pdf). Zhiqiang et al. (2022) pointed out that the model of climate impact on the environment (EPIC) could simulate crop productivity over hundreds of years under different climate scenarios, as well as environmental conditions and farming systems, thus being widely used to study the impact of climate change on agriculture. Climate change has been affecting the global food supply. Therefore, it is important that every country takes care of the sustainability of the food system that ensures food security for the population. The most important bread grain in the world is wheat (*Triticum* sp.), and wheat bread feeds over 70% of the world's population. According to FAOSTAT data for 2023, the areas under wheat in the world amounted to 219.153.830 ha^{-1}, which implies a great importance of this crop. With an average yield of 3.689 kg ha^{-1}, 808.441.564 tons of grain were produced. The area under wheat has gradually decreased worldwide, in contrast to total production, where grain yields per unit area have been increasing. A similar trend can also be seen in Serbia over the last ten years.

Wheat has relatively lower yields than most other crops. However, with certain agrotechnical measures, yields can increase. This set of measures includes choosing the best preceding crops and avoiding monocultures, having better soil preparation, using optimal seed rates, plant nutrition tailored to natural fertility based on agrochemical testing of the soil, as well as growing varieties more tolerant to pests and pathogens, and implementing weed control, which is also of great importance for subsequent crops (Đurić et al., 2015). In order to improve wheat production further, especially considering a temperature increase caused by climate change, it is necessary to introduce new types and varieties with specific production characteristics and grain qualities that can be used to produce food with a higher nutritional value. This is also important from the aspect of small farms that produce value-added products.

In terms of genetic and morphological characteristics, Khorasan wheat is very similar to durum wheat (genome AABB). Kamut grains are one third as large as soft wheat grains, 20-40% richer in total protein and about 65% richer in essential amino acids, and they contain more oil, vitamins and mineral salts. An increased content of monosaccharides gives the grains a sweet taste, which is why kamut is also called sweet wheat. Its flour can be mixed with wheat flour in various ratios and is used to produce food with increased nutritional and energy value, for example bread, pastries, pasta, cakes or pancakes. This food is very suitable for physically active people. Research by the International Food Allergy Association (IFAA) has shown that Khorasan wheat flour contains significantly less α-gluten. This food in lower amounts can be used in the diet of people who are allergic to these proteins (Wentzel, 2010; Carnevali, 2014). Regarding the total amount gliadins in wheat grains, Colombo and Gregorini (2012) pointed out that some old wheat varieties had even higher content of these proteins.

The newly bred varieties Claudio, Egiptianka and others have a high genetic breeding potential, show greater tolerance to abiotic stress caused by drought and high air temperatures and are more tolerant to pests (grain leeches and birds), also having a higher utilization rate of plant assimilates from the soil than soft wheat (Qiunn, 1999; Guliani et al., 2014; Dinelli et al., 2014). Due to its good productive and biological properties, in some countries this species is cultivated in organic farming, and the growing demand for food has led to an increase in Khorasan wheat acreage, especially in some arid areas of America, Asia and Africa.

The aim of this research was to use the EPIC method in order to determine the possibility of introducing Khorasan wheat species into Libyan agricultural production based on the compliance agroecological conditions and the most suitable production technology.

2. MATERIAL AND METHODS

Based on the results of the previous research on the influence of agro-ecological and soil properties in the Danube region (Surduk village, Stara Pazova municipality) on Chernozem-type soils and the Sava River region (Ušće village, Obrenovac municipality) on Ritska chernica-type soils that was conducted over a period of two years on Khorasan wheat, and with using the EPIC (Erosion Productivity Impact Calculator) model, the researchers analyzed the possibility of introducing Khorasan wheat in agricultural areas of Libya (Ayiman, 2017; Glamočlija et al., 2015 2017; Janković et al., 2020). The Erosion Productivity Impact Calculator (EPIC) was used as a programming model to assess the agro-ecological conditions and the possibility of introducing Khorasan wheat. This crop production estimation model was introduced in the USA (Nicks et al., 1990).

The following form was used to determine the water balance according to growth stages:

$$SWl = \frac{FCl - WPl}{4} + WPl$$

where: SWl - water volume in layer l (mm),
FCl - field water capacity (mm),
WPl - wilting moisture (mm),
4 - the number of layers of the root system.

To determine the optimal thermal regime by growth stages, the following form for calculating daily heat units was used:

$$HUk = \frac{Tmx,k + Tmn,k}{2} - Tb,\ j\,; HUk \geq 0$$

where: *HU* – heat units per day k,
Tmx – maximum temperature on day k,
*Tm*n – minimum temperature on day k,
Tbj – base temperature for crop j (no growth takes place at or below *Tb*).

The decision in favor of this model is the fact that it was tested in several experiments and showed significant to very significant agreement, both in assessing the needs of plants for basic meteorological factors, as well as in predicting the main morphological and production indicators in the agroecological conditions of the Sava River region (Serbia), (Đulaković, 2012). The data obtained on the climatic conditions of the agricultural areas of Libya were used to create the EPIC model to determine the accuracy of this type of simulation of ontogenesis of Khorasan wheat.

3. RESULTS AND DISCUSSION

The research in Serbia investigated the adaptability of Khorasan wheat to the conditions of a temperate continental climate, characterized by higher winter precipitation levels compared to the center of origin of Khorasan wheat and soils with significantly more favorable chemical and physical properties.

To assess the possibility of growing Khorasan wheat in the main agricultural area of Libya (Mediterranean region), only monthly data on basic climate conditions (precipitation amount and distribution, and monthly heat distribution) were used, as this is the main limiting factor for growing winter wheat outside the optimal areas. When assessing the applicability of this model, it should be noted that some species of the genus Triticum are already cultivated in the above-mentioned agricultural areas, but under very heterogeneous soil conditions and with different cropping systems (dry farming or irrigated farming).

For using the Climate Generator sub-model, monthly distribution of precipitation and heat (minimum and maximum air temperatures) were used as the indicators. Based on the data on optimal plant requirements for water and heat according to growth stages (presented in monthly values), meteorological conditions during the trials in the Danube River and the Sava River regions and the climatic conditions of the Mediterranean region in Libya, the researchers compared water and heat regime for the vegetation period of Khorasan wheat. The following form was used to determine the water balance according to growth stages.

3.1. Water regime

The water balance in the experimental fields in Serbia during the two-year research was within the limits of the conditionally optimal needs of the plants with small monthly fluctuations during the vegetation period of the plants (Table 1). Significant differences were observed at the three potential locations for the cultivation of Khorasan wheat in Libya. Total precipitation was 36% lower in Benghazi and up to 40% lower in Tripoli, while it was 22% higher in the Bayda region. An analysis of the monthly distribution of precipitation shows that there was significantly more precipitation in December and January, and within the limits of the conditionally optimal plant requirements in November and February.

Table 1. Monthly distribution of precipitation during the wheat growing season (mm)

Month	Requirements*	Field of study** Danube River region	Tripoli	Bayda	Benghazi
October	66	63	47	38	18
November	48	32	58	55	30
December	41	34	68	121	65
January	48	49	62	121	67
February	40	49	32	105	42
March	50	75	30	58	29
April	55	32	14	25	9
May	70	80	5	9	4
Total	418	414	254	532	264

*Conditional optimal plant requirements for the period October-May (mm); ** Two-year average of precipitation in the experimental fields of the Danube River region and the Sava River Region

The application of the EPIC model to determine water requirements by growth stage shows that Bayda has the most favorable water regime, while the other two areas have a significant deficit in the first growth stage and in the stages of fertilization and floral initiation (Table 2).

Table 2. Analysis of the water balance and conditional optimal requirements of Khorasan wheat (mm)

Month	Requirements*	Tripoli	+/-	Bayda	+/-	Benghazi	+/-
October	66	47	-19	38	-28	18	-48
November	48	58	+3	55	0	30	-35
December	41	68	+18	121	+71	65	+15
January	48	62	+14	121	+73	67	+19
February	40	32	-13	105	+60	42	-3
March	50	30	-25	58	+3	29	-26
April	55	14	-51	25	-40	9	-56
May	70	5	-55	9	-51	4	-56
Total	418	254	-195	532	+83	264	-185

*The values were determined based on the equation of optimal soil moisture and wilting points (EPIC model)

3.2. Thermal conditions

The distribution of heat (average monthly air temperatures) in the experimental fields in Serbia was very favorable, so that the average temperatures of 8.8 °C were at the level of optimal plant requirements (7.5 °C) (Table 3). In all three potential areas for the introduction of Khorasan wheat into production, the thermal regime was above the needs of winter wheat. Since Khorasan wheat originates from warmer regions, with predominate spring forms, a significantly higher monthly heat distribution may have a favorable effect on the speed of certain growth stages, especially in the heat stage. Under conditions of higher air temperatures, the light stage and the formation of generative organs in the plants begin as early as January, which will shorten the growing season as a whole. Wheat sown in the pre-winter period would complete its life cycle in 120-140 days, like most spring varieties in Serbia.

Table 3. Analysis of thermal conditions and conditional optimal requirements of Khorasan wheat (°C)

Month	Requirements*	Field of study** Danube River region	Tripoli	Bayda	Benghazi
October	12	11	23	18	22
November	5	7	18	14	18
December	3	3	15	10	14
January	1	1	13	8	13
February	3	5	14	9	13
March	9	11	16	11	15
April	14	15	19	14	19
May	22	17	22	18	23
Total	7.5	8.8	17.8	13.6	17.3

* Conditional optimal plant requirements for the period October-May (°C); ** Two-year average of precipitation in the experimental fields of the Danube River and the Sava River regions

The analysis of monthly heat distribution and the average heat regime in three areas of Libya by using the Epic model has shown that plants sown in November (with a favorable water regime) can complete the heat stage under very favorable conditions of the external environment and move to the generative development stage earlier (Table 4).

Table 4. Monthly distribution of heat during the wheat growing season (°C)

Month	Requirements*	Tripoli	+/-	Bayda	+/-	Benghazi	+/-
October	12	23	+11	18	+6	22	+10
November	5	18	+15	14	+9	18	+13
December	3	15	+12	10	+7	14	+11
January	1	13	+12	8	+7	13	+12
February	3	14	+11	9	+6	13	+10
March	9	16	+7	11	+2	15	+6
April	14	19	+5	14	0	19	+5
May	22	22	0	18	-4	23	+1
Total	7.5	17.8	+10.3	13.6	+6.1	17.3	+9.8

* The values were determined based on the equation for the conditionally optimal air temperature (EPIC model)

The agricultural areas of Libya are in the southern Mediterranean region, characterized by warm winters, so that the average monthly air temperatures in November and December are at the level of optimal requirements for the development of the vegetative stages of growth. Under these thermal conditions and with a favorable water regime, the stages of germination, emergence, rooting and tillering will be completed in 40-50 days, which is significantly shorter than in areas with a continental climate in Serbia.

Over the last decades, Khorasan wheat (kamut) has played an important role, especially in the system of ecologically sustainable and organic production of recent decades in some countries of Western Europe, and in Serbia, particularly when it comes to functional foods, and nutrition of sensitive groups (Pagliai et al., 2020). According Vavilov (1951), this ancient type of wheat was already cultivated 6,000 years ago in the Great Khorasan area (the area of northeastern Iran and neighboring countries). Its cultivation extended from Central Asia to ancient Egypt, where it was grown during the time of the pharaohs due to its grains that were larger and more nutritious than soft wheat grains

(Qiunn, 1999). In 1990, Bob Qiunn applied for a patent and registered it on the American continent, naming it kamut, after the ancient Egyptian word for wheat, and this commercial name has since become established worldwide (Ikanović et al., 2014). Today, Kamut® is a type of Khorasan wheat whose seeds are always grown in the system of organic agricultural production, so there are no hybrids or genetically modified varieties. According to Lockman (2011), Khorasan wheat with the commercial name Kamut® is grown in more than 40 countries. Its grains are highly valued in the diet due to their high digestibility, sweet taste and texture. They are rich in proteins, amino acids, vitamins, mineral salts, especially selenium, zinc and magnesium. The results reported by Benedetti et al. (2012) indicated a higher nutritional value of Khorasan wheat flour products compared to durum wheat products. The significant utility value of its grains, as well as the possibility of introducing Khorasan wheat in organic farming crop rotations and its influence on sowing density and use of fertilizers are also important for the following crops (Stoyanova et al., 2017), overall increasing biodiversity in the function of biodiversity conservation, as noted by Filipović and Ugrenović (2010), Atanasova and Maneva (2021).

Our previous studies have shown that the investigated varietal material does not exhibit pronounced winter hardiness like soft wheat and can be successfully grown as a winter and spring crop (Glamočlija et al., 2012). Since the species originates from the arid areas of Central Asia, Khorasan wheat has a greater tolerance to abiotic stress caused by drought, which indicates possible directions for its reintroduction in Serbia and cultivation in Libya. At the same time, it is sensitive to increased humidity, especially in early spring, and is more exposed to infestation by pathogenic fungi than newer, tolerant soft wheat varieties.

Given the threat to food security posed by climate change, a study on crop growth model has been progressively developed using the EPIC growth model. Within the EPIC model, there are several sophisticated sub-models. The most important sub-model is the Climate Generator, which includes all the data on climate conditions. Another important sub-model is the Soil Conditions that contains data on the physical and chemical properties (fertility) of the soil. The Agrotechnical Measures sub-model provides a detailed description of the entire production technology, from crop rotation, tillage, plant nutrition, genotype and sowing to plant care and protection. The efficiency of this model was confirmed by the research results of Đulaković et al. (2006) and Đulaković (2012), after it was applied in the estimation of corn production under known climate and soil conditions.

4. CONCLUSION

The basic meteorological elements and their perennial values are within the limits of the conditional optimal needs of plants for water and heat. Khorasan is a new wheat variety for Libya, which, according to the initial research results, can be successfully grown. Due to its specific biological properties and its greater tolerance to unfavorable agro-ecological conditions, it is suitable for introduction into crop rotations in organic farming, as well as for cultivation on poorer soils, where it could be grown in a system of environmental sustainability in agriculture. By applying the EPIC model, it was found that this species can be cultivated in Libya both in the Mediterranean areas and in the central areas where there is organized plant production.

5. ACKNOWLEDGEMENTS

The research was done under the Contract on the implementation and financing of scientific research in 2024 between the Institute for Science Application in Agriculture and the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, No. 451-03-66/2024-03/200045, No. 451-03-66/2024-03/200010.

6. REFERENCES

Ayiman, O.A. (2017). Uticaj agroekoloških i zemljišnih uslova podunavlja i posavine na morfološke i proizvodne osobine korasan pšenice i mogućnost introdukcije u Libiji. Doktorska disertacija.

Atanasova, D., Maneva, V. (2021). Effect of predecessors on the phytosanitary status and productivity of emmer (*Tr. dicoccum*) and kamut (*Tr. turgidum polonicum*) in organic farming.

Benedetti, S., Primiterra, M., Tagliamonte, M.C., Carnevali, A., Gianotti, A., Bordoni, A., Canestrari, F. (2012). Counteraction of oxidative damage in the rat liver by an ancient grain (Kamut brand khorasan wheat). Nutrition, 28(4), 436-441.

Colomba, M.S., Gregorini, A. (2012). Are ancient durum wheats less toxic to celiac patients? A study of α-gliadin from Graziella, Ra and Kamut. The Scientific World Journal. doi.org/10.1100/2012/837416

Carnevali, A. (2014). Role of Kamut® brand khorasan wheat in the counteraction of non-celiac wheat sensitivity and oxidative damage. Food Research International, kamut, (63), 218-226.

Dinelli, G., Di Silvestro, R., Marotti, I., Bosi, S., Bregola, V., Di Loreto, A., Catizone, P. (2014). Agronomic traits and deoxynivalenol contamination of two tetraploid wheat species (*Triticum turgidum* spp. durum, *Triticum turgidum* spp. *turanicum*) grown strictly under low input conditions. Italian Journal of Agronomy, 9(3), 127-135.

Đulaković, V., Glamočlija Đ., Đulaković, G. (2006). Osetljivost matematičkog modela biljne proizvodnje na neke parametre vegetacione sredine. Forum kvaliteta, AGRO-CHEMYCUS II, Tara, Sekcija "Agrohemija i životna sredina", 1-9. /in Serbian/

Đulaković, V. (2012). Korišćenje EPIC modela simulacije biljne proizvodnje u planiranju prinosa kukuruza, doktorska disertacija. Poljoprivredni fakultet, Beograd, p. 73. /in Serbian/

Đurić, N., Kresović, B., Glamočlija, Đ. (2015). Sistemi konvencionalne i organske proizvodnje ratarskih useva, monografija. PKB Agroekonomik, Beograd. /in Serbian/

Filipović, V., Ugrenović, V. (2010). Biološka raznolikost organske proizvodnje u funkciji očuvanja biodiverziteta. Četvrti forum o organskoj proizvodnji. Centar za organsku proizvodnju, Selenča, 44-46. /in Serbian/

FAOSTAT 2023. www.fao.org/statistics/en

Glamočlija, Đ., Ikanović, J., Ugrenović, V., Filipović, V., Pavlović, S., Dončić, D., Milutinović, M. (2012). Proučavanje osobina dve populacije korasan pšenice (*Triticum turgidum*, ssp. *turanicum* Jakubz.) u agroekološkim uslovima istočnog Srema. IX simpozijum o zaštiti bilja u BIH. Zbornik rezimea, p. 113. /in Serbian/

Glamočlija, Đ., Janković, S., Popović, V., Filipović, V., Ugrenović, V., Kuzevski, J. (2015). Alternativne ratarske biljke u konvencionalnomi organskom sistemu gajenja, monografija. Izdavač, IPN, Beograd. /in Serbian/

Glamočlija, Đ., Janković, S., Kuzevski, J., Đurić, N., Ayiman, O.A., Glamočlija, N., Maksimović, J. (2017). Uticaj povećanih količina azota i tipa zemljišta na morfološke i proizvodne osobine korasan pšenice. XXXI Savetovanje agronoma, veterinara, tehnologa i agroekonomista Instituta PKB Agroekonomik, Padinska Skela, Beograd. Zbornik radova, 23(1-2), 61-70. www.ipcc.ch/site/assets/uploads/2019/08/Fullreport.pdf /in Serbian/

Guliani, M.M., Giuzio, I., De Caro, A., Flagella Z. (2014). Relationships between nitrogen utilization and grain technological quality in old wheats: II Grain yield and quality. Agornomy Journal, 103, 1668-1675.

Ikanović, J., Popović, V., Janković, S., Živanović, Lj., Rakić, S., Dončić, D. (2014). Khorasan wheat population researching in the minimum tillage conditions. Genetika, 46(1), 105-115.

Janković, S., Popović, V., Rakić, S., Simić, D., Alkhammas, A.O., Rakić, R., Stanković, S. (2020). Influence of nutrition on productivity and chemical composition of Khorasan wheat - *Triticum turgidum* ssp. *turanicum* Jakubz. Agriculture and Forestry, 66(4), 113-124. doi: 10.17707/ AgricultForest. 66.4.09

Lockman, J.R. (2011). A guide for growing Kamut® Khorasan wheat. Montana Flour & Grains, Fort Benton.

Nicks, A.D., Richardson, C.W., Williams, J.R. (1990). Evaluation of the EPIC model weather generator, In: 1. Model Documentation. USDA-ARS, Technical Bulletin, 1768, 105-124.

Pagliai, G., Colombini, B., Dinu, M., Whittaker, A., Masoni, A., Danza, G., Sofi, F. (2020). Effectiveness of a Khorasan wheat-based replacement on pain symptoms and quality of life in patients with fibromyalgia. Pain Medicine, 21(10), 2366-2372.

Qiunn, R. (1999). Kamut: Ancient grain, new cereal. Perspectives on new crops and new uses. J. Janick (Ed.), ASHS Press, Alexandria, VA.

Stoyanova, V., Maneva, V., Atanasova, D. (2017). Effect of Sowing and Fertilization Rates on The Productivity of Kamut (*Triticum turgidum polonicum*). In CONGRESS BOOK, p. 271.

Wentzel, B.S. (2010). The utilization of gluten fractions as quality parameters in selected South African wheat cultivars, MSc thesis, the Department of Plant Sciences (Plant Breeding), Faculty of Natural and Agricultural Sciences, University of the Free State, Bloemfontein.

doi:10.46793/MAK2025.284J

ENVIRONMENTAL SUSTAINABILITY AND INFLUENCE OF DIGESTATES ON RYE HEIGHT IN BIOGAS PRODUCTION

Snežana Janković[1*], Jela Ikanović[2], Nikola Rakašćan[3], Vera Popović[4], Divna Simić[1], Danijela Šikuljak[5], Slađan Stanković[1], Sveto Rakić[2]

[1]Institute for the Application of Science in Agriculture, Belgrade, Serbia
*sjankovic@ipn.bg.ac.rs
[2]Faculty of Agriculture, University of Belgrade, Serbia, jela@agrif.bg.ac.rs
[3]Biogas Energy, Rit-Ekonomija 1, Ilandža, Alibunar, Serbia, n.rakascan@biogasenergy.rs
[4]Institute of Agriculture and Vegetables, Novi Sad, Serbia, bravera@eunet.rs
[5]Institute for Plant Protection and Environment, Belgrade, Serbia

Abstract: The influence of digestate, a by-product of biogas production, on rye height was investigated. Trials over three years at Ilandža and Dolovo examined rye growth with and without the application of 50 t ha^{-1} of digestate. The tallest plants were found at Dolovo with digestate application. The highest plant height (130.99 cm) was recorded in 2023, while the lowest (126.46 cm) was in 2021. The study contributes to climate change mitigation and CO_2 emission reduction.

Key words: Ecological sustainability, Rye height, Digestate, Biomass, Renewable sources

1. INTRODUCTION

Pressure on the environment and natural resources has increased significantly with the growth of the human population on the planet and changes in lifestyle. One of the reasons is the linear economy by which resources are extracted from the environment, things are produced that are used and finally thrown away. In this way, non-renewable resources are primarily at risk, and when it comes to agriculture, it is primarily land. Today, the world is talking more and more about the circular economy and an approach that is economically and ecologically sustainable. One of the examples for the maximum utilization of resources is the use of energy crops and biomass in order to reduce waste and produce biogas with the simultaneous use of digestate as a by-product in the production process in biogas power plants as a means of improving land with less favorable properties (Janković et al., 2017).

Climatic changes can modify farming, with the simultaneous reduction of yield zones (Gunaseelan, 1997; Amon, 2003; 2007; Stupar et al., 2023; Simić et al., 2023). As an alternative source of nutrients, digestate contributes to the mitigation of climate change through the reduction of greenhouse gas emissions, both directly and indirectly through the production of nitrogen and phosphorus mineral fertilizers (Ikanović et al., 2021). Nitrogen application increases yield and production (Nkoa, 2014; Stupar et al., 2017). A system that integrates the production of biogas and electricity from renewable sources, agro-energy crops with the production of this biomass on marginal land using digestate from the AD process as a soil improver leads to approaching the goals of low-carbon agriculture and circular economy by recycling materials (Dražić et al., 2021; Popović et al., 2011, 2020, 2024; Terzić et al., 2018; Milunović et al., 2022; Rakić et al., 2023).

The use of renewable energy sources from the aspect of climate change and ecological sustainability is very important, which is why an increasing number of researchers, in all sectors, are engaged in their development and improvement of use technologies. The results of these researches are in accordance with the foundations of the 2030 Agenda and the Sustainable Development Goals and the Sustainable Development Goals - COR, especially goal 7 - available renewable energy, but also goals 9 - industry, innovation and infrastructure, 10 - reducing inequality, 13 - actions for the climate and 15 - life on land (https://sdg.indikatori.rs/ http://devinfo.stat.gov.rs/diFiles/diProfili/SDG_Srbija_cir.pdf).

Unlike other renewable sources for which technologies imply reducing the impact on the environment primarily by reducing greenhouse gas emissions during the entire life cycle of the plant, energy crops and biomass are specific because they use CO_2 from the atmosphere in the process of photosynthesis for their development their use makes it easier to achieve carbon neutrality. Growing agro-energy crops increases soil fertility by increasing its carbon content. Also, they can be grown on marginal and contaminated lands, which avoids competition with food production on fertile agricultural lands while simultaneously remediating degraded sites. The EUBCE (European Biomass Conference and Exhibition) community is mobilizing to change regulations so that the contribution of biomass is better taken into account in the European Union's "Fit for 55" roadmap. The cross-sectoral package "Fit for 55" presents the regulatory context for accelerating the EU's commitment to achieve a net emission reduction of at least 55% by 2030. The goal is that between 2021 and 2030, EU member states ensure that greenhouse gas emissions from land use, land use change and/or forestry are in balance with the removal of SO_2 from the atmosphere. This means the inclusion and intensification of carbon farming initiatives, with the intention of increasing carbon storage in the agricultural sector. In December 2021, the European Commission made official the advantages of natural storage and use of SO_2 applied in biogas production. This is a positive step towards fully recognizing the environmental benefits of sustainable biogas and biomethane production (www.etaflorence.it/proceedings/). Biogas production through the process of anaerobic digestion (AD) is a form of renewable energy that has the greatest potential in the circular economy. The process refers to the decomposition of organic matter by the activity of microorganisms. On this occasion, biogas containing 50-75% methane is produced, which is the main product, while all other gases are undesirable and are considered biogas pollutants (Kirubakarana, 2009).

Biomass energy of agro-energy crops through conversion by biochemical processes enables retention of valuable organic structures and their recycling when applied as biological fertilizer or soil amendment (Brown, 2007). The most promising technology for the conversion of biomass energy is anaerobic digestion (AD), which is used for the needs of industry and households for waste disposal (biomass of trees with leaves, grains or tubers), whereby gaseous, liquid and solid fuels are obtained (Janković et al., 2017).

A very important aspect for the expansion of the biogas industry is the use and use of digestate, which is the effluent of biogas plants, the inadequate disposal of which can negatively affect the ecosystem. However, the use of digestate as fertilizer in agricultural production contributes to land improvement and plant nutrition. Due to different substrates, digestion conditions and handling methods, digestates have different characteristics, but the way to choose the most suitable technology and the interactive flow diagram (Sobhi et al., 2022) include different digestate utilization technologies, solid and liquid digestate separation technologies, as well as liquid and solid processing technologies phases. The potential of energy production from different raw materials varies depending on the type, level of processing and concentration of biodegradable material, so that certain types of waste, due to low energy content or limited availability of materials, do not have a high enough potential for sustainable production, which is why the use of agro-energy crops is necessary (Janković et al., 2017, 2019).

The aim of this study was to examine the influence of digestate, genotypes, location and year, a by product of biogas production, on rye height.

2. MATERIAL AND METHODS

Experimental trials were conducted over three years, at two locations in Ilandža and Dolovo, according to a random block system in three repetitions with genotypes Serafino (KWS) and Savo (IFVCNS), without digestate, and with the application of 50 t ha^{-1} of digestate. The soil in Ilandža is of the hydrogen rite type. During many years of use, with intensive agricultural production, lack of crop rotation, excessive fertilization with mineral fertilizers without prior agrochemical analysis, excessive watering with water containing elevated concentrations of salt, partial degradation of these surfaces occurred. For the control location, Dolovo soil of the chernozem type was chosen. Standard technology was used, sowing was done in the optimal autumn period and mowing at wax maturity. Using the random sampling method, 10 plants were selected from each plot and plant height (cm) and biomass yield were measured, and then the yield was recalculated in t ha^{-1}.

Laboratory analyzes of soil and digestate were performed in accredited laboratories using the following methods: SPRS ISO 11465-2002 for determining moisture content; SPRS EN 15934 for determination of dry matter content; the Tyurin method for determining the content of organic matter, and the C-org content was determined using the factor 1.724 according to Nelson and Sommers (1982); the content of total nitrogen was determined by the Kjeldahl method (SPRS ISO 13878-2005), the content of P_2O_5 and K_2O AL by the Egner-Riehm method; pH and electrical conductivity (ES) by conductometry (SRPS ISO 10390:2007), and the $CaCO_3$ content by the SRPS ISO 10693: 2005 method. Experimental data were analyzed with descriptive and analytical statistics using the statistical package Statistica 12. Analysis of variance (ANOVA), F-test and LSD-test were performed for the significance level of 0.05% and 0.01%.

3. RESULTS AND DISCUSSION

3.1. Agroecological conditions

Meteorological data for the growing season 2020-2023, Pančevo and Ilandža, Serbia are presented in Figures 1 and 2. Average temperatures at the Ilandža site varied from 7.4 °C (2021), 8.3 °C (2023) to 9.0 °C (2022), while average multi-year temperatures were 7.6 °C (Figure 1).

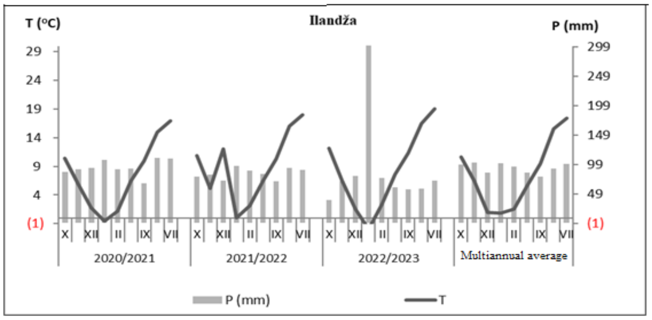


Figure 1. Meteorological data for the growing season 2021-2023, Ilandža, Serbia

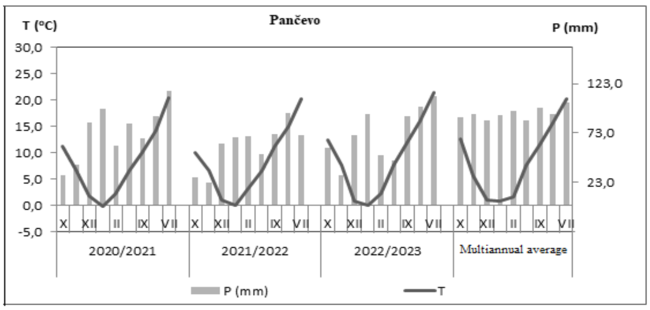


Figure 2. Meteorological data for the growing season 2021-2023, Pančevo, Serbia

Average temperatures in Pančevo varied from 8.0 °C (2021), 8.1 °C (2022) to 8.8 °C (2023), while the average multi-year temperatures were 8.4 °C, (Figure 2). Total rainfall at the Ilandža site varied from 757.2 mm (2022), 847.7 mm (2021) to 895.2 mm (2023), while average annual rainfall was 840.8 mm, Figure 1. Total rainfall in Pančevo varied from 539.1 mm (2022), 646.4 mm (2023) to 667.4 mm (2021), while average annual precipitation was 834.0 mm (Figure 2).

3.2. Soil conditions

Agrochemical analyzes of the soil on which agro-energy crops were grown (Table 1) indicate that the soil in the Ilandža location is of lower performance compared to Dolovo, especially in relation to the content of organic carbon and electrical conductivity, which indicates partial salinity.

Table 1. Basic agrochemical properties of the soil

Locality	pH_{KCl}	C_{org} (%)	N_{tot} (%)	P_2O_5 (g/kg)	K_2O (g/kg)	$CaCO_3$ (%)	EC mS/cm
Ilandža	6.95±0.30	3.62±1.65	0.14±0.04	0.54±0.20	0.38±0.22	2.04±0.46	1.61±0.16
Dolovo	7.00±0.10	4.02±0.55	0.20±0.02	0.43±0.60	0.34±0.08	2.86±0.12	0.72±0.04

The composition of the digestate used is shown in Table 2. The content of dry matter is unchanged during the examined years, because it primarily depends on the type and performance of the digester, while the content of N, P and K is variable, because it depends on the raw material used (silage of corn and sorghum and pork manure in different ratios). By spreading AD digestate, about 27 kg N ha^{-1}, 1.6 kg P ha^{-1} and 9.8 kg K ha^{-1} are applied to the plot.

Table 2. Basic agrochemical properties of digestate

Parameter	Moisture content (%)	Dry matter content (%)	N_{tot} (%)	P_{Egner} (g/kg)	K_{Egner} (g/kg)
2021.	87.32	12.69	0.61	0.46	0.21
2022.	87.21	12.39	0.48	0.27	0,18
2023.	87.61	12.34	0.50	0.32	0,16
Arithmetic mean	87.55	12.45	0.54	0.32	0,20

3.3. Plant height

For the investigated agro-energy crop, the plant height was the highest at the Dolovo location in the variant with the application of AD digestate (133.51 cm) (Table 3). Descriptive statistics established the highest plant height values, on average for both locations, they were in 2023 (130.99 cm), and the lowest values for plant height were in 2021 (126.46 cm). At the Dolovo site (131.90 cm), the plants were statistically significantly larger than at the Ilandža site (125.19 cm). The significant increase in the height of the plants in the third year of the test compared to the first year is a consequence of the favorable effect of temperature and precipitation. Compared to the multi-year average, precipitation in the third year of the study was significantly higher (895.1 mm in Ilandža and 646.4 cm in Dolovo), which, along with favorable temperatures, led to higher values of the tested parameter (Table 3).

By analyzing the obtained results, we can conclude that there is a significant dependence of plant height and the year of research, which is in agreement with the results of Popović et al. (2020, 2024). Rye in the variant with the application of AD digestate had statistically significantly higher values for plant height in all three investigated years (140.36 cm, 142.65 cm and 139.78 cm) and statistically significantly higher values in both locations, in the location of Ilindža (137.97 cm) and at the Dolovo site (143.89 cm), Table 3.

Table 3. Descriptive statistics for the of rye plants height, localities Ilindža and Dolovo

Effect	Level of factors				No	Mean	Std.Dev.	Std. Error	-95.0%	+95.00
Total					72	128,547	15,4418	1,8198	124,918	132,175
Genotip	Savc				36	129,688	13,5618	2,2603	125,100	134,277
Genotip	Serafin				36	127,405	17,2368	2,8728	121,573	133,237
Godina	2021				24	126,462	16,0894	3,2842	119,668	133,256
Godina	2022				24	128,191	17,2534	3,5218	120,906	135,477
Godina	2023				24	130,987	12,9865	2,6508	125,503	136,471
Varijanta	Kontrola				36	116,161	10,7255	1,7875	112,532	119,790
Varijanta	Digestat				36	140,933	7,2854	1,2142	138,468	143,398
Lokalitet	Ilandza				36	125,194	15,2381	2,5397	120,038	130,350
Lokalitet	Dolov				36	131,900	15,1124	2,5187	126,786	137,013
Genotip*Godina	Savc	2021			12	129,716	14,5836	4,2099	120,450	138,982
Genotip*Godina	Savc	2022			12	127,616	17,2894	4,9910	116,631	138,601
Genotip*Godina	Savc	2023			12	131,733	8,0223	2,3158	126,636	136,830
Genotip*Godina	Serafin	2021			12	123,208	17,4781	5,0455	112,103	134,313
Genotip*Godina	Serafin	2022			12	128,766	17,9661	5,1863	117,351	140,181
Genotip*Godina	Serafin	2023			12	130,241	16,9428	4,8909	119,476	141,006
Genotip*Varijanta	Savc	Kontrola			18	118,544	8,8466	2,0851	114,145	122,943
Genotip*Varijanta	Savc	Digestat			18	140,833	6,1150	1,4413	137,792	143,874
Genotip*Varijanta	Serafin	Kontrola			18	113,777	12,1057	2,8533	107,757	119,797
Genotip*Varijanta	Serafin	Digestat			18	141,033	8,4771	1,9980	136,817	145,248
Godina*Varijanta	2021	Kontrola			12	112,558	8,3442	2,4087	107,256	117,860
Godina*Varijanta	2021	Digestat			12	140,366	7,0601	2,0381	135,880	144,852
Godina*Varijanta	2022	Kontrola			12	113,725	11,4534	3,3063	106,447	121,002
Godina*Varijanta	2022	Digestat			12	142,658	5,8842	1,6986	138,919	146,397
Godina*Varijanta	2023	Kontrola			12	122,200	10,2372	2,9552	115,695	128,704
Godina*Varijanta	2023	Digestat			12	139,775	8,9079	2,5715	134,115	145,434
Genotip*Lokalitet	Savc	Ilandza			18	129,088	15,3443	3,6167	121,458	136,719
Genotip*Lokalitet	Savc	Dolov			18	130,288	11,9354	2,8132	124,353	136,224
Genotip*Lokalitet	Serafin	Ilandza			18	121,300	14,5085	3,4196	114,085	128,514
Genotip*Lokalitet	Serafin	Dolov			18	133,511	17,9514	4,2311	124,584	142,438
Godina*Lokalitet	2021	Ilandza			12	126,108	15,2259	4,3953	116,434	135,782
Godina*Lokalitet	2021	Dolov			12	126,816	17,5832	5,0758	115,644	137,988
Godina*Lokalitet	2022	Ilandza			12	124,500	18,4967	5,3395	112,747	136,252
Godina*Lokalitet	2022	Dolov			12	131,883	15,8291	4,5694	121,826	141,940
Godina*Lokalitet	2023	Ilandza			12	124,975	12,7818	3,6897	116,853	133,096
Godina*Lokalitet	2023	Dolov			12	137,000	10,5064	3,0329	130,324	143,675
Varijanta*Lokalitet	Kontrola	Ilandza			18	112,416	8,8187	2,0786	108,031	116,802
Varijanta*Lokalitet	Kontrola	Dolov			18	119,905	11,3745	2,6810	114,249	125,562
Varijanta*Lokalitet	Digestat	Ilandza			18	137,972	7,3851	1,7407	134,299	141,644
Varijanta*Lokalitet	Digestat	Dolov			18	143,894	6,0139	1,4175	140,903	146,885
Genotip*Godina*Varijanta	Savc	2021	Kontrola		6	117,233	7,2890	2,9757	109,583	124,882
Genotip*Godina*Varijanta	Savc	2021	Digestat		6	142,200	6,3853	2,6067	135,499	148,901
Genotip*Godina*Varijanta	Savc	2022	Kontrola		6	112,616	9,0045	3,6760	103,167	122,066
Genotip*Godina*Varijanta	Savc	2022	Digestat		6	142,616	6,0459	2,4682	136,271	148,961
Genotip*Godina*Varijanta	Savc	2023	Kontrola		6	125,783	4,9773	2,0319	120,560	131,006
Genotip*Godina*Varijanta	Savc	2023	Digestat		6	137,683	5,6435	2,3039	131,760	143,605
Genotip*Godina*Varijanta	Serafin	2021	Kontrola		6	107,883	6,8988	2,8164	100,643	115,123
Genotip*Godina*Varijanta	Serafin	2021	Digestat		6	138,533	7,7988	3,1838	130,348	146,717
Genotip*Godina*Varijanta	Serafin	2022	Kontrola		6	114,833	14,3028	5,8391	99,823	129,843
Genotip*Godina*Varijanta	Serafin	2022	Digestat		6	142,700	6,2941	2,5695	136,094	149,305
Genotip*Godina*Varijanta	Serafin	2023	Kontrola		6	118,616	13,2277	5,4002	104,735	132,498
Genotip*Godina*Varijanta	Serafin	2023	Digestat		6	141,866	11,4988	4,6943	129,799	153,933
Genotip*Godina*Lokalitet	Savc	2021	Ilandza		6	131,700	14,2303	5,8095	116,766	146,633
Genotip*Godina*Lokalitet	Savc	2021	Dolov		6	127,733	15,9987	6,5314	110,943	144,522
Genotip*Godina*Lokalitet	Savc	2022	Ilandza		6	125,650	21,5363	8,7921	103,049	148,251
Genotip*Godina*Lokalitet	Savc	2022	Dolov		6	129,583	13,5844	5,5458	115,327	143,839
Genotip*Godina*Lokalitet	Savc	2023	Ilandza		6	129,916	10,5363	4,3014	118,859	140,973
Genotip*Godina*Lokalitet	Savc	2023	Dolov		6	133,550	4,7597	1,9431	128,555	138,545
Genotip*Godina*Lokalitet	Serafin	2021	Ilandza		6	120,516	15,2473	6,2247	104,515	136,517
Genotip*Godina*Lokalitet	Serafin	2021	Dolov		6	125,900	20,5475	8,3884	104,336	147,463
Genotip*Godina*Lokalitet	Serafin	2022	Ilandza		6	123,350	16,9026	6,9004	105,611	141,088
Genotip*Godina*Lokalitet	Serafin	2022	Dolov		6	134,183	18,8149	7,6811	114,438	153,928
Genotip*Godina*Lokalitet	Serafin	2023	Ilandza		6	120,033	13,7768	5,6243	105,575	134,491
Genotip*Godina*Lokalitet	Serafin	2023	Dolov		6	140,450	13,8429	5,6513	125,922	154,977
Genotip*Varijanta*Lokalitet	Savc	Kontrola	Ilandza		9	116,488	9,0363	3,0121	109,542	123,434
Genotip*Varijanta*Lokalitet	Savc	Kontrola	Dolov		9	120,600	8,6687	2,8895	113,936	127,263
Genotip*Varijanta*Lokalitet	Savc	Digestat	Ilandza		9	141,688	7,8398	2,6132	135,662	147,715
Genotip*Varijanta*Lokalitet	Savc	Digestat	Dolov		9	139,977	4,0437	1,3479	136,869	143,086
Genotip*Varijanta*Lokalitet	Serafin	Kontrola	Ilandza		9	108,344	6,8040	2,2680	103,114	113,574
Genotip*Varijanta*Lokalitet	Serafin	Kontrola	Dolov		9	119,211	14,0960	4,6986	108,375	130,046
Genotip*Varijanta*Lokalitet	Serafin	Digestat	Ilandza		9	134,255	4,8327	1,6109	130,540	137,970
Genotip*Varijanta*Lokalitet	Serafin	Digestat	Dolov		9	147,811	5,0979	1,6993	143,892	151,729
Godina*Varijanta*Lokalitet	2021	Kontrola	Ilandza		6	114,383	10,2192	4,1720	103,658	125,107
Godina*Varijanta*Lokalitet	2021	Kontrola	Dolov		6	110,733	6,3836	2,6061	104,034	117,432
Godina*Varijanta*Lokalitet	2021	Digestat	Ilandza		6	137,833	8,6977	3,5508	128,705	146,961
Godina*Varijanta*Lokalitet	2021	Digestat	Dolov		6	142,900	4,3137	1,7610	138,373	147,426
Godina*Varijanta*Lokalitet	2022	Kontrola	Ilandza		6	107,750	6,2272	2,5422	101,214	114,285
Godina*Varijanta*Lokalitet	2022	Kontrola	Dolov		6	119,700	12,8117	5,2303	106,254	133,145
Godina*Varijanta*Lokalitet	2022	Digestat	Ilandza		6	141,250	6,3685	2,5999	134,566	147,933
Godina*Varijanta*Lokalitet	2022	Digestat	Dolov		6	144,066	5,5547	2,2677	138,237	149,896
Godina*Varijanta*Lokalitet	2023	Kontrola	Ilandza		6	115,116	9,0380	3,6897	105,631	124,601
Godina*Varijanta*Lokalitet	2023	Kontrola	Dolov		6	129,283	5,3349	2,1779	123,684	134,882
Godina*Varijanta*Lokalitet	2023	Digestat	Ilandza		6	134,833	6,6701	2,7230	127,833	141,833
Godina*Varijanta*Lokalitet	2023	Digestat	Dolov		6	144,716	8,4542	3,4514	135,844	153,588
Genotip*Godina*Varijanta*Lokalitet	Savc	2021	Kontrola	Ilandza	3	120,766	8,7088	5,0280	99,132	142,400
Genotip*Godina*Varijanta*Lokalitet	Savc	2021	Kontrola	Dolov	3	113,700	4,4192	2,5514	102,721	124,678
Genotip*Godina*Varijanta*Lokalitet	Savc	2021	Digestat	Ilandza	3	142,633	8,4736	4,8922	121,583	163,683
Genotip*Godina*Varijanta*Lokalitet	Savc	2021	Digestat	Dolov	3	141,766	5,4372	3,1391	128,259	155,273
Genotip*Godina*Varijanta*Lokalitet	Savc	2022	Kontrola	Ilandza	3	106,833	5,4848	3,1666	93,208	120,458
Genotip*Godina*Varijanta*Lokalitet	Savc	2022	Kontrola	Dolov	3	118,400	8,5017	4,9085	97,280	139,519
Genotip*Godina*Varijanta*Lokalitet	Savc	2022	Digestat	Ilandza	3	144,466	8,2008	4,7347	124,094	164,838
Genotip*Godina*Varijanta*Lokalitet	Savc	2022	Digestat	Dolov	3	140,766	3,7233	2,1496	131,517	150,016
Genotip*Godina*Varijanta*Lokalitet	Savc	2023	Kontrola	Ilandza	3	121,866	3,1659	1,8278	114,002	129,731
Genotip*Godina*Varijanta*Lokalitet	Savc	2023	Kontrola	Dolov	3	129,700	2,4269	1,4011	123,671	135,728
Genotip*Godina*Varijanta*Lokalitet	Savc	2023	Digestat	Ilandza	3	137,966	8,5500	4,9363	116,727	159,206
Genotip*Godina*Varijanta*Lokalitet	Savc	2023	Digestat	Dolov	3	137,400	2,5059	1,4468	131,174	143,625
Genotip*Godina*Varijanta*Lokalitet	Serafin	2021	Kontrola	Ilandza	3	108,000	7,9372	4,5825	88,282	127,717
Genotip*Godina*Varijanta*Lokalitet	Serafin	2021	Kontrola	Dolov	3	107,766	7,4795	4,3183	89,186	126,346
Genotip*Godina*Varijanta*Lokalitet	Serafin	2021	Digestat	Ilandza	3	133,033	6,9428	4,0084	115,786	150,280
Genotip*Godina*Varijanta*Lokalitet	Serafin	2021	Digestat	Dolov	3	144,033	3,6198	2,0899	135,041	153,025
Genotip*Godina*Varijanta*Lokalitet	Serafin	2022	Kontrola	Ilandza	3	108,666	8,0214	4,6311	88,740	128,593
Genotip*Godina*Varijanta*Lokalitet	Serafin	2022	Kontrola	Dolov	3	121,000	18,2482	10,5356	75,668	166,331
Genotip*Godina*Varijanta*Lokalitet	Serafin	2022	Digestat	Ilandza	3	138,033	1,7616	1,0170	133,657	142,409
Genotip*Godina*Varijanta*Lokalitet	Serafin	2022	Digestat	Dolov	3	147,366	5,5320	3,1939	133,624	161,109
Genotip*Godina*Varijanta*Lokalitet	Serafin	2023	Kontrola	Ilandza	3	108,366	7,5831	4,3781	89,529	127,204
Genotip*Godina*Varijanta*Lokalitet	Serafin	2023	Kontrola	Dolov	3	128,866	8,0463	4,6455	108,878	148,854
Genotip*Godina*Varijanta*Lokalitet	Serafin	2023	Digestat	Ilandza	3	131,700	2,9444	1,7000	124,385	139,014
Genotip*Godina*Varijanta*Lokalitet	Serafin	2023	Digestat	Dolov	3	152,033	3,4356	1,9835	143,498	160,567

The influence of year and genotype, as well as their interaction on the height of rye plants, during three growing seasons is shown in Table 4. Based on the analysis of variance, it can be concluded that the influence of the variant on plant height was statistically significant (Fexp = 215.6**), as well as locality (Fehr = 215.6) and that they had a significant influence on the obtained plant height values. The interaction of year x variant (Fehr = 4.59), year x location (Fexp = 3.79) and genotype x location (Fehr = 10.65) had a statistically significant effect on the obtained plant height values (Table 6, Figure 3).

Table 4. ANOVA for the height of rye plants for 3 years: 2020/21; 2021/2022; 2022/2023

Effect	SS	Degr. of Freedom	MS	F	p
Intercept	118975	1	118975	23223.50	0.00000**
Genotype - G	94	1	94	1.83	ns
Year - Y	250	2	125	2.44	ns
Variant - V	11046	1	11046	215.61	0.00000**
Locality - L	809	1	809	15.80	0.00023**
G x Y	182	2	91	1.77	ns
G x V	111	1	111	2.17	ns
Y x V	470	2	235	4.59	0.01503*
G x L	546	1	546	10.65	0.00203**
G x L	388	2	194	3.79	0.02962*
V x L	11	1	11	0.22	ns
G x Y x V	138	2	69	1.34	ns
G x Y x L	79	2	40	0.78	ns
G x V x L	81	1	81	1.59	ns
Y x V x L	256	2	128	2.49	ns
G x Y x V x L	10	2	5	0.10	ns
Error	2459	48	51		

ns-nonsignificant differences, p<0,01**, p<0,05*

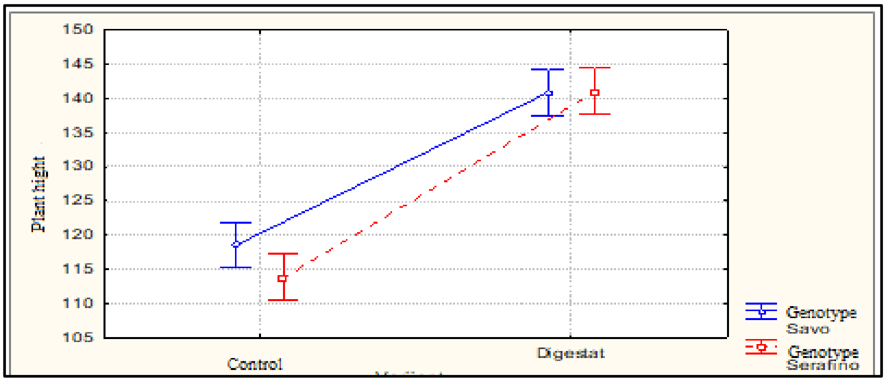


Figure 3. Effect of feeding on the height of rye plants

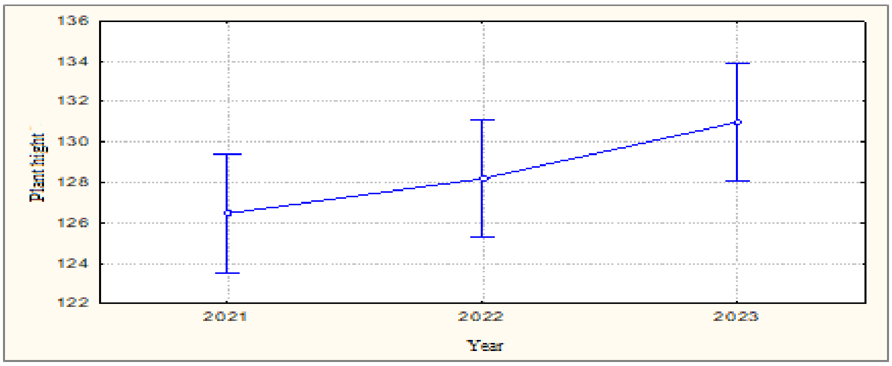


Figure 4. Influence of the year on the height of rye plants

In the variant with digestate, the value for the examined parameter, plant height, was statistically significantly higher than for the control variant (Figure 3). Figure 4 shows the influence of the year on the height of rye plants, from which it can be seen that in 2023, the values for plant height were were higher compared to 2021 and 2022.

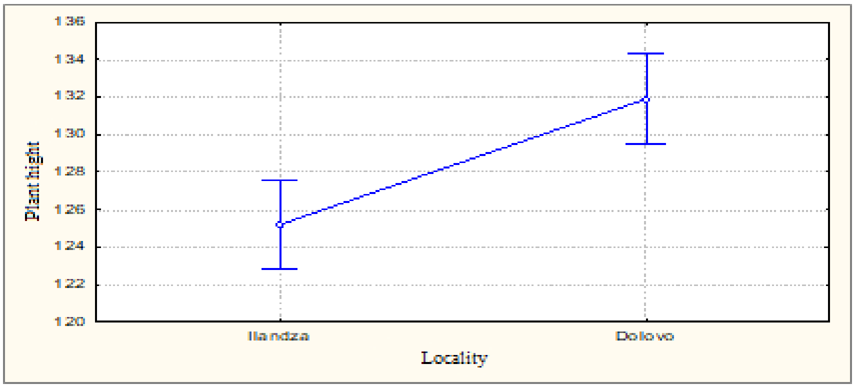


Figure 5. Influence of location on the height of rye plants

At the Dolovo site, the values for plant height were statistically significantly higher than at the Ilandža locality (Figure 5). The rye Savo genotype had higher plant height values than the rye Serafino genotype (Figure 6).

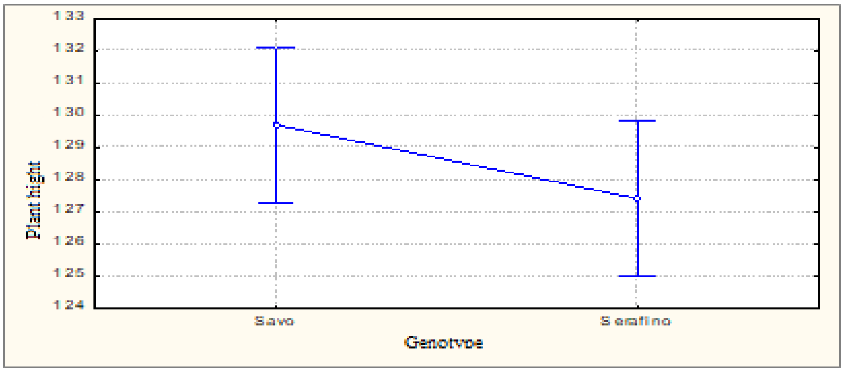


Figure 6. Influence of genotype on the height of rye plants

The interaction Genotype x Year x Variant had a statistically significant effect on the obtained values for plant height, which is presented in (Figure 7).

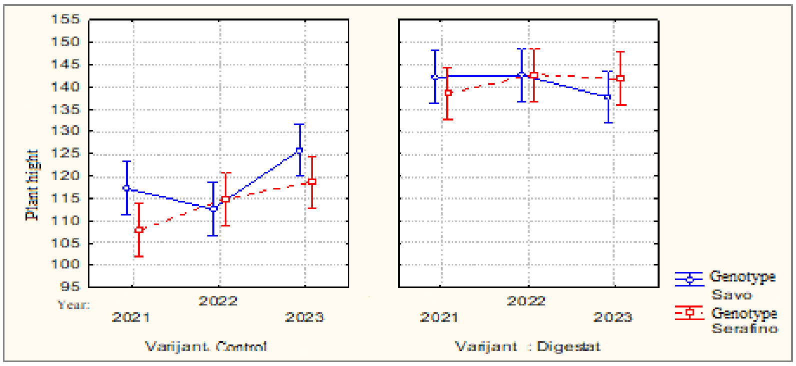


Figure 7. Interaction Genotype x Year x Variant for the height of rye plants

The Genotype x Year x Locality interaction had a statistically significant effect on the obtained values for plant height, (Figure 8) and also the Genotype x Variant x Locality interaction (Figure 9) and the Genotype x Year x Variant x Locality interaction (Figure 10).

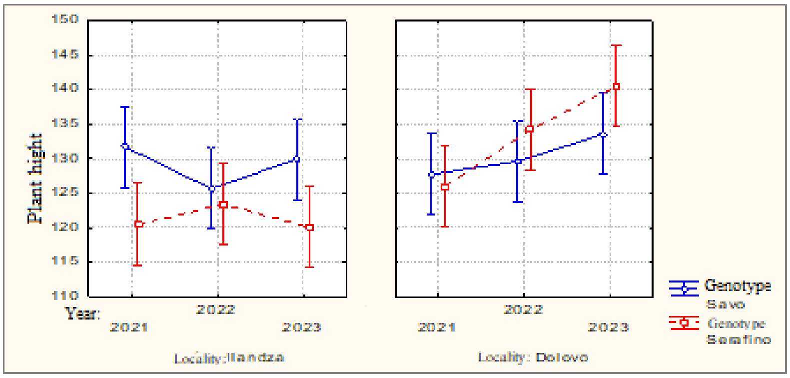


Figure 8. Interaction Genotype x Year x Locality for the height of rye plants

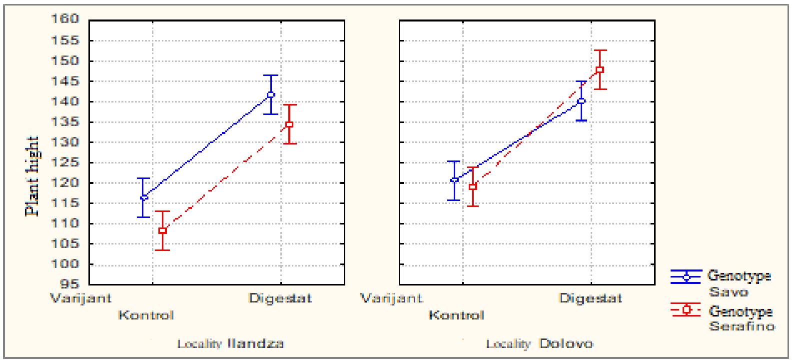


Figure 9. Genotype x Variant x Locality interaction for the height of rye plants

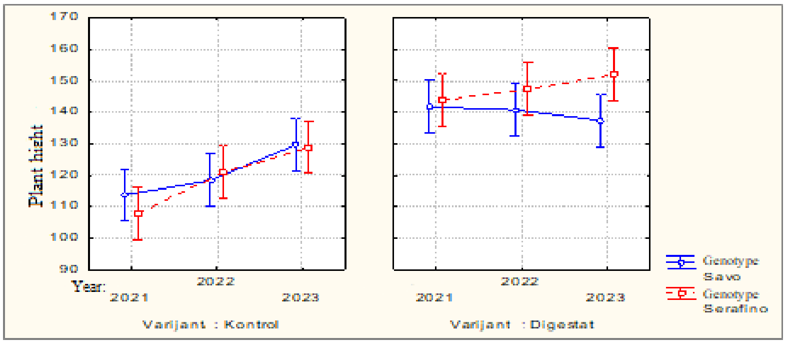


Figure 10. Interaction Genotype x Year x Variant x Locality for the height of rye plants

4. CONCLUSION

Research has shown that the height of the plants is the highest in the Dolovo location in the variant with the application of AD digestate. The highest values of plant height, on average for both localities, were in 2023 (130.99 cm), and the lowest values for plant height were in 2021 (126.46 cm). At the Dolovo site (131.90 cm), the plants were statistically significantly larger than at the Ilandža site (125.19 cm). Rye should be produced on degraded or marginal land in order to avoid competition with food production with the use of solid digestate, as a product of anaerobic digestion, in the production of rye as a component for biogas production, with an adequate yield and at the same time avoiding or reducing the use of mineral fertilizers. The flow model in the biogas power plant contributes to the rational use of less fertile, degraded land for the production of rye as an agro-energy crop with the use of digestate as a soil improver, which achieves ecological sustainability, reduction of greenhouse gas emissions (GHG) and proper farm waste management. Economic and general social sustainability is also increased through reducing the operating costs of the biogas plant and mitigating climate change.

5. ACKNOWLEDGEMENTS

The work was created as a result of research within the contract on the implementation and financing of scientific research work in 2024 between the Institute for the Application of Science in Agriculture and the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, no. 451-03-66/2024-03/200045, 451-03-66/2024-03/200032, 451-03-65/2024-03/200116 and 451-03-66/2024-03/200010.

6. REFERENCES

Amon, T., Amon, B., Kryvoruchko,V., Zollitsch,W., Mayer, K., Gruber, L. (2007). Biogas production from maize and dairy cattle manure-influence of biomass composition on the methane yield. Agriculture, Ecosystems and Environment. 118, 173-182. doi.org/10.1016/j.agee.2006.05.007

Amon, T., Kryvoruchko, V., Amon, B., Moitzi, G., Buga, S., Lyson, D.F., Hackl, E., Jeremic, D., Zollitsch, W., Potsche, E. (2003). Biogas production from the energy crops maize and clover Maize Silage as Substrate for Biogas Production. Grass. Forschungs project Nr. 1249 GZ 24.002/59-IIA1/01, Institut fur Land- und Umveltund Energietechnik. Universitat fur Bodenkultur, Wienna, Austria. dx.doi.org/10.5772/64378 193

Dražić, N., Rakašćan, N., Radojević, V., Popović, V., Ignjatov, M., Ikanović, J., Petković, Z. (2021). Cereals as energy sources in the function of circular economy. Agriculture and Forestry, Podgorica, MNE, 67(3), 7-18. doi.org/10.17707/AgricultForest.67.3.01

Egner, H., Riehm, H., Domingo, W.R. (1960). Investigations of the chemical soil analysis as a basis for the evaluation of nutrient status in soil. II. Chemical retraction methods for phosphorus and potassium determination. K Lantbruks Høgsk Ann, 26, 199-215.

Gunaseelan, V.N. (1997). Anaerobic digestion of biomass for methane production: a review. Biomass and Bioenergy, 13, 83-114. doi.org/10.1016/S0961-9534(97)00020-2

Ikanović, J., Dražić, N., Rakaščan, N., Popović, V., Živanović, Lj., Kolarić, Lj. (2021). Biomass and biogas productivity of wheat and rye on chernozem. X Symposium with international participation - Innovations in field and vegetable production, Faculty of Agriculture, Zemun-Belgrade, 44-45. /In Serbian/ISBN 978-86-7834-383-4

Janković, S., Glamočlija, Đ., Ikanović, J., Rakić, S. (2019). Secondary agricultural products. Institute for the Application of Science in Agriculture, Belgrade, 1-386. ISBN: 978-86-81689-41-7. COBISS.SR-ID: 280644108. /in Serbian/

Janković, S., Glamočlija, Đ., Prodanović, S. (2017). Energy crops Production and processing technology. Institute for the Application of Science in Agriculture, Belgrade, 1-271. ISBN: 978-86-81689-32-6. COBISS.SR-ID: 229916172 /in Serbian/

Kirubakarana, V., Sivaramakrishnanb, V., Nalinic, R., Sekard, T., Premalathae, M., Subramaniane, P. (2009). A review on gasification of biomass. Renewable and Sustainable Energy Reviews, 13, 179.

Milunović, I., Popović, V., Rakaščan, N., Ikanović, J., Trkulja, V., Radojević, V., Dražić, G. (2022). Genotype×year interaction on rye productivity parameters cultivated on sandy chernozem soil. Genetika, Belgrade, 54(2), 887-905. doi.org/10.2298/GENSR2202887M

Nkoa, R. (2014). Agricultural benefits and environmental risks of soil fertilization with anaerobic digestates: a review. Agronomy for Sustainable Development, 34(2), 473-492. doi.org/10.1007/s13593-013-0196-z.

Nelson, D.W., Sommers, L.E. (1982). Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties. Agronomy Monograph, 9, 539-579.
Popović, V., Vučković, S., Jovović, Z., Ljubičić, N., Kostić, M., Rakaščan, N., Glamočlija-Mladenović, M., Ikanović, J. (2020). Genotype by year interaction effects on soybean morpho-productive traits and biogas production. Genetika, Belgrade, 52, 3, 1055-1073. doi.org/10.2298/GENSR2003055P /in Serbian/
Popovic, V., Vasileva, V., Ljubičić, N., Rakaščan, N., Ikanović, J. (2024). Environment, soil and digestate interaction of maize silage and biogas production. Agronomy, 14(11), 2612. doi.org/10.3390/agronomy14112612
Pović, V., Glamoclija, Đ., Malešević, M., Ikanović, J., Dražić, G., Spasić, M., Stanković, S. (2011). Genotype specificity in nitrogen nutrition of malting barley. Gnetika. Belgrade, 43, 1, 197-204. /in Serbian/
doi.org/10.2298/GENSR1101197P
Rakić, R., Ikanović, J., Popović, V., Rakić, S., Janković, S., Ristić, V., Petković, Z. (2023). Environment and digestate affect on the oat quality and yield parameters. Agriculture and Forestry, 69(3), 247–257. doi.org/10.17707/AgricultForest.69.3.18
Simić, D., Janković, S., Stanković, S., Rahović, D., Popović, V., Markoski, M., Predić, T., Ugrenović, V. (2023). Testing of the potassium content in the soil for the purpose of preserving biodiversity. Agriculture and Forestry, 69(1), 31-41. doi.org/10.17707/AgricultForest.69.1.03
Sobhi, M., Guo, J., Gaballah, M.S., Li, B., Zheng, J., Cui, X., Sun, H., Dong, R. (2022). Selecting the optimal nutrients recovery application for a biogas slurry based on its characteristics and the local environmental conditions: A critical review, Science of The Total Environment, 814, 152700. doi.org/10.1016/j.scitotenv.2021.152700
Stupar, V., Paunović, A., Madić, M., Knežević, D. (2017). Influence of genotype and nitrogen nutrition on grain size variability in spring malting barley. Genetika, 49(3),1095-1104.
Stupar, V., Živković, Z., Stevanović, A., Stojićević, D., Sekulić, T., Bošković, J., Popović, V. (2023). The effect of fertility control on soil conservation as a basic resource of sustainable agriculture. Notulae Botanicae Horti Agrobotanici Cluj-Napoca, 52, 1, 13389. doi.org/10.15835/nbha52113389
Terzić, D., Djekić, V., Jevtić, S., Popović, V., Jevtić, A., Mijajlović, J., Jevtić, A. (2018). Effect of long-term fertilization on grain yield and yield components in winter triticale. The Journal of Animal and Plant Sciences, 28(3), 830-836. www.thejaps.org.pk/docs/v-28-03/19.pdf

doi:10.46793/MAK2025.294A

THE TWIN THREATS OF CLIMATE CHANGE AND PLANT INVASIONS IN SERBIA

Ana Anđelković[1*], Maja Novković[2], Dušanka Cvijanović[2], Dragana Marisavljević[1], Danijela Šikuljak[1], Snežana Radulović[2]

[1]Institute for Plant Protection and Environment, Department of Weed Research, Belgrade, Serbia; ana.andjelkovic21@gmail.com
[2]University of Novi Sad, Faculty of Sciences, Department of Biology and Ecology, Novi Sad, Serbia

Abstract: Climate change and invasive species represent two of the five major direct drivers of biodiversity loss globally. These two phenomena are inextricably linked and expected to interact in very complex ways, which are difficult to foresee with certainty. Field studies conducted over the last decade across the territory of Serbia show the spread and dominance of invasive alien plants (IAPs) in this country, particularly in its riparian and roadside habitats. Bearing these results in mind, we provide an illustrative review of perspectives for Serbia regarding the problem of IAPs spread in conditions of climate change. A number of river valleys are expected to experience added invasion pressures, resulting from the spread of IAPs via shared river corridors with our neighboring countries. Additionally, mountain regions in Serbia are predicted to experience increased temperatures, changing precipitation patterns, and anthropogenic activities that worsen ecosystem fragility, making them more susceptible to plant invasions. Although they currently face lower invasion pressures, an increase in both the number and abundance of invasive species in these areas is expected due to climate change and other factors.

Key words: Invasive alien plants, Climate change, Serbia

1. INTRODUCTION

Invasive alien species (IAS) and climate change have been identified as two of the top five direct drivers causing global changes in nature (IPBES, 2019). Records show that human activities have led to the introduction of more than 37.000 established alien species worldwide (Seebens et al., 2023). Moreover, new alien species are nowadays being recorded at a rate of nearly 200 per year, which has never been seen before. To this date 6% of the established alien plants have been categorized as invasive globally (IPBES, 2023).

The highest proportion of negative impacts of IAS have been documented in cultivated areas and temperate and boreal forests (Bacher et al., 2023). Negative impacts of IAS have affected various ecosystem services, resulting in significant economic losses. Estimates made in 2019 put the global annual costs due to biological invasions at over 423 billion US dollars (Bacher et al., 2023). The thematic assessment report conducted by IPBES in 2023 shows that invasive alien species and their impacts are increasing rapidly worldwide. They also highlight that these impacts will most likely continue to rise in the future (IPBES, 2023).

Aim of this review is to provide a brief illustration of the potential effects climate change would have on plant invasions in Serbia

2. THE ROLE OF CLIMATE CHANGE IN ENABLING BIOLOGICAL INVASIONS

Both the global assessment on biodiversity and ecosystem services (IPBES, 2019) and the report of the Intergovernmental Panel on Climate Change (IPPC, 2022) recognize that, over the last few decades, anthropogenic climate change has become one of the leading threats to biodiversity and ecosystems globally. It modifies the range and abundances of species, leads to changes in their communities and food webs, thus also modifying ecosystem functions (IPBES, 2019; IPCC, 2022). The IPBES report (2023) states that the combined impacts of climate change and land- and sea-use change are expected to significantly exacerbate the future risks posed by invasive alien species. Furthermore, these interactions can also modify the patterns of natural disturbance events and increase their intensity, leading to more severe consequences.

Climate change is already impacting both the Serbian economy and society, leading to losses caused by extreme weather events, droughts and high temperatures, estimated at over 5 billion EUR for the 2000-2015 period (Božanić and Mitrović, 2019).

Changes in both temperature and rainfall patterns will further enable biological invasions, by facilitating the introduction and establishment of alien species into new areas, where they were previously unable to survive (Walther et al., 2009). The IPBES report (2023) stresses the fact that although the rise in the number of alien species has been continuous for centuries in all regions, with the global costs of IAS quadrupling every ten years since 1970, global warming will facilitate the establishment of IAS to an even greater extent, leading to their further spread (IPBES, 2023). This will also be true for Serbia, where climate change is also expected to facilitate the emergence of new alien weeds, pests and diseases (Stričević et al., 2019). These authors highlight that the emergence of new invasive diseases represents one of the urgent vulnerabilities of high importance to agriculture in Serbia under climate change conditions.

Numerous indicators point to the fact that global warming has enabled the spread of alien species into areas where previously their survival and production of viable offspring were not possible (Walther et al., 2009). In the era of rapid global change, it is highly likely that current activities in solving this problem will not suffice (Webber and Scott, 2012). Predictions show that global warming will intensify the spread of species into previously uninvaded areas, and lead to the more rapid population growth of invasive species in the already invaded areas (Vilà et al., 2010). Additionally, when predicting the changes in species distributions in climate change conditions, it is necessary to also consider the combined effects of anthropogenic disturbances (Wang et al., 2019). Moreover, Vilà et al. (2021) also show that as climate change alters environmental conditions, this will in turn affect weed growth and competition with crops.

In order to predict the reaction of individual species to climate change, it is necessary to possess data on the genetic structure of their populations, their geographic distribution, pollen characteristics and numerous ecological parameters (Schierenbeck, 2017). Changes in temperature and the dynamics and amount of precipitation will most likely impact the phenological changes (Iler et al., 2019) and the distribution range of a majority of plant and animal species (Vilà et al., 2007). Dukes and Mooney (1999) emphasize that climate change will favor those species with the ability to adapt to a wide range of climate conditions and to expand their distribution range over a short time period, without depending on other groups of organisms for pollination and seed dispersal, which are all known traits of invasive plants. Consequently, the future of food production will also depend critically on the impacts of climate change on the spread of invasive alien species (Ziska et al., 2011).

3. PERSPECTIVES FOR SERBIA

The phenomena of biological invasions and climate change are inextricably linked and present two of the most overarching aspects of environmental change globally (Walther et al., 2009). They are expected to interact in very complex ways (Kolar and Lodge, 2001), which are difficult to foresee with certainty.

A projection of the effects of climate change over a 50-year period shows how the highly invasive species, Japanese knotweed (*Reynoutria japonica*) could significantly expand its distribution in the invaded range, due to changes in winter temperatures and the increase in average yearly temperatures (Beerling et al., 1995). In their study, Jovanović et al. (2018) show that while Japanese knotweed is expected to experience range expansion in riparian habitats of Southeastern Europe, both Japanese and Bohemian knotweed (*Reynoutria* x *bohemica*) are predicted to potentially experience range contractions in garden habitats (30% decrease for Bohemian knotweed). Similar research studying the effects of climate change on the distribution of highly invasive and strongly allergenic plant, common ragweed (*Ambrosia artemisiifolia*), have shown that its expansion could be even more drastic in the conditions of projected climate change (Essl et al., 2009; Richter et al., 2013). In Serbia, where this species is already very widespread (Vrbničanin et al., 2008), invading a range of different habitat types (Figure 18-5 in Anđelković, 2019), this could threaten even those few areas where it hasn't yet spread. Similarly, Follak and Essl (2013) point to the fact that due to climate change, Johnson grass (*Sorghum halepense*) could represent a very significant problem for control in agricultural areas of Central Europe. This would also be expected for the territory of Serbia, where this highly invasive weed species is already very widespread (Vrbničanin et al., 2009) and resistant to certain herbicides (Božić et al., 2024). In a similar manner, global warming and increased nitrogen deposition could interact to increase the invasiveness of goldenrods (*Solidago canadensis* and *Solidago gigantea*), which would be especially alarming for riparian areas of Serbia, where *S. gigantea* is still present in a limited number of field sites (Figure 15-22 in Anđelković, 2019).

Moreover, given that each of the abovementioned invasive plant species forms part of a wider biological system, it is necessary to consider that climate change would influence it not only as an individual population, but the entire ecosystem, in entirely unpredictable ways (Ziska et al., 2011). Nevertheless, studies done across the territory of Serbia over the last ten years, studying the distribution and abundance of invasive alien plants in riparian and roadside habitats of Serbia (Anđelković, 2019; Anđelković et al., 2016, 2021, 2022a, 2022b, 2024) give us an overview of the current situation regarding the spread of these species of concern and a platform for further studies and future predictions.

In Serbia we can expect that river basins of Sava and Velika Morava rivers will fall under a strong pressure of spread and dominance of invasive species. This pressure on the Sava river basin would result from their spread from the west, following the valleys of rivers which are shared between Croatia and Serbia, especially bearing in mind the fact that Bosut and Studva rivers have been shown to be hotspots of plant invasions (Anđelković, 2019). Meanwhile, basin of the Velika Morava river faces strong invasion pressures, with a special emphasis on invasion hotspots observed in the river valleys of the Crnica river and the entire river basin of the Zapadna Morava river (Figure 1).

Estimates show that mountain areas would experience a drastic increase in temperature and changes in the amount and seasonality of precipitation (Mina et al., 2017). Anthropogenic activities represent an added pressure in mountain areas, bearing a significant impact on ecosystem services of forest ecosystems in these high altitudes (Mina et al., 2017). Given that further degradation of these zones is expected in the conditions of climate change (Simpson and Prots, 2013), this can further exacerbate the fragility of these forest ecosystems, and thereby also their susceptibility to plant invasions.

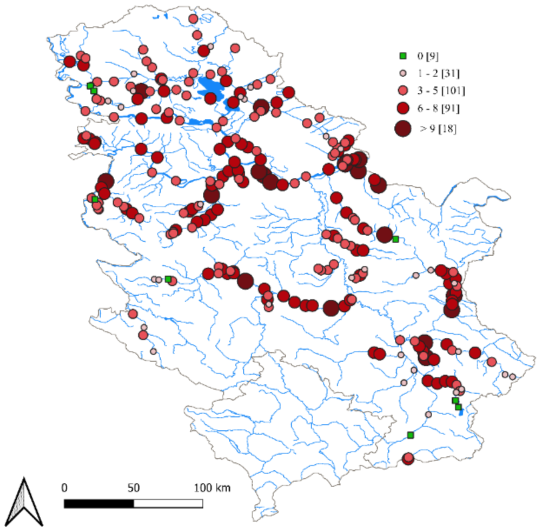


Figure 1. Map of Serbia showing riparian areas with the number of recorded invasive alien plants per field site highlighting the most strongly invaded areas (Anđelković, 2019; Anđelković et al., 2022),

Simpson and Prots (2013) show that Ukrainian Carpathians are one of the mountain areas in the temperate zone which is already facing an increased level of plant invasions. IAPs are now spreading from lowlands, where they have been present for over a century, into the mountains and protected areas situated in their territory. A similar pattern of spread can be expected in other areas of the range of Carpathian Mountains, including its Serbian part. Climate models predict that by 2100 protected areas in the Carpathian Mountains of Ukraine will face a significant increase in areas suitable for the establishment of highly invasive species, such as *Robinia pseudoacacia* and *Helianthus tuberosus*, due to climate change. This study by Simpson and Prots (2013) also predicts that by 2050 their further lateral spread will mostly be concentrated along smaller mountain streams and rivers.

A similar outlook can be expected in riparian areas of rivers and streams located at higher altitudes in Serbia. Although these field sites currently face lower invasion pressures, with agricultural producers still noting fewer new invasive species at alitutudes >500 m (Stričević et al., 2019), and the number of IPAs and their total cover being negatively correlated with altitude (Anđelković et al., 2022), an increase in both their number and abundance can be expected in the future. The river basin of the Timok Rivers currently represents one of the invasion hotspots in Eastern Serbia (Figure 1), which could eventually spread upwards into the surrounding mountains of the Carpathian range. Another high-altitude zone which can experience increased invasion pressures in the conditions of climate change is located in the southeastern part of the country, in the mountains surrounding the Južna Morava river basin, which is also highlighted by several invasion hotspots (Figure 1).

We can also expect that riparian areas in the southwestern part of the country (Lim and Ibar river valleys) will face strong pressures from biological invasions in the following period (Figure 31 in Anđelković, 2019). Bearing in mind the potential for the spread of invasive plants downstream, from the territory of the neighboring Montenegro, and the fact that some of the highly invasive plant species, such as *Helianthus tuberosus*, *Reynoutria*×*bohemica*, *Robinia pseudoacacia* and *Xanthium strumarium* subsp. *italicum* have already been observed in riparian areas of the Lim river (Anđelković et al., 2022), their further spread and increase in their number and abundance is expected to happen.

4. CONCLUSION

Although it is difficult to forecast how climate change and invasive alien plants are going to interact in the future, based on the data we possess on their current distribution within riparian and roadside habitats, some scenarios and illustrative predictions can be made. It can be expected that the river basins of the Sava and Velika Morava rivers will fall under a strong pressure of spread and dominance of invasive species, expanding from their current invasion hotspots. Also, given that mountain areas worldwide are predicted to face increased temperatures, changing precipitation patterns, and anthropogenic disturbances, making them more susceptible to plant invasions, we can expect that the mountains surrounding the Timok and Južna Morava river basins, along with the areas in the southwestern part of the country (Lim and Ibar river valleys) will experience increasing invasion pressures in the future.

5. ACKNOWLEDGMENT

The research presented in this article is part of Contracts No. 451-03-66/2024-03/200010, 451-03-66/2024-03/ 200125 and 451-03-65/2024-03/200125 financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

6. REFERENCES

Anđelković, A. (2019). Akvatični koridori biljnih invazija u Srbiji. Doktorska disertacija, Univerzitet u Novom Sadu, Prirodno-matematički fakultet, Departman za biologiju i ekologiju, Novi Sad. /in Serbian/

Anđelković, A., Pavlovic, D., Marisavljević, D., Živković, M., Novković, M., Popović, S., ... Radulović, S. (2022a). Plant invasions in riparian areas of the Middle Danube Basin in Serbia. NeoBiota, 71, 23-48.

Anđelković, A., Popović, S., Živković, M., Cvijanović, D., Novković, M., Marisavljević, D., ... Radulović, S. (2022b). Catchment area, environmental variables and habitat type as predictors of the distribution and abundance of Portulaca oleracea L. in the riparian areas of Serbia. Acta Agriculturae Serbica, 27(53), 9-15.

Anđelković, A., Tmušić, G., Marisavljević, D., Marković, M., Cvijanović, D., Anačkov, G., ... Pavlović, D. (2021). Distribution of economically important weed species in the riparian and roadside vegetation of Serbia. Acta herbologica, 30(1), 51-64.

Anđelković, A., Tmušić, G., Šikuljak, D., Marisavljević, D. (2024). Highways and pathways: The role of roads in the spread of invasive alien plants in Serbia. In: IX Congress on Plant Protection, Book of Abstracts. Obradović A., Jevremović D. (Eds.), Zlatibor, Serbia, p. 76. /in Serbian/

Anđelković, A., Zivković, M. M., Cvijanović, D. L., Novković, M., Marisavljević, D., Pavlović, D., Radulović, S. (2016). The contemporary records of aquatic plants invasion through the Danubian floodplain corridor in Serbia. Aquatic Invasions, 11(4), 381-395.

Bacher, S., Galil, B.S., Nuñez, M.A., Ansong, M., Cassey, P., Dehnen-Schmutz, K., Fayvush, G., Hiremath, A.J., Ikegami, M., Martinou, A.F., McDermott, S.M., Preda, C., Vilà, M., Weyl, O.L.F., Fernandez, R.D., Ryan-Colton, E. (2023). Chapter 4: Impacts of invasive alien species on nature, nature's contributions to people, and good quality of life. In: Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Roy, H.E., Pauchard, A., Stoett, P., Renard Truong, T. (Eds.). IPBES secretariat, Bonn, Germany. https://doi.org/10.5281/zenodo.7430731

Beerling, D.J., Huntley, B., Bailey, J.P. (1995). Climate and the distribution of *Fallopia japonica*: use of an introduced species to test the predictive capacity of response surfaces. Journal of Vegetation Science, 6(2), 269-282.

Božanić, D., Mitrović, Đ. (2019). Study on the Socio-economic Aspects of Climate Change in the Republic of Serbia. United Nations Development Programme, Belgrade. www.klimatskepromene.rs/wp-content/uploads/2020/07/engl-screen-_06-04-2020_DRAFT_-

Study-on-the-Socio-economic-Aspects-of-Climate-Change-on-the-Republic-of-Serbia_UNDP.pdf
Božić, D., Adamović, J., Tojić, T., Obradović, A., Vrbničanin, S. (2024). Screening for *Sorghum halepense* resistance to ALS inhibitors: new apprach based on real-time PCR. Book of Abstracts of the IX Congress on Plant Protection. Zlatibor, Serbia. /in Serbian/
Dukes, J.S., Mooney, H.A. (1999). Does global change increase the success of biological invaders?. Trends in Ecology & Evolution, 14(4), 135-139.
Essl, F., Dullinger, S., Kleinbauer, I. (2009). Changes in the spatio-temporal patterns and habitat preferences of *Ambrosia artemisiifolia* during its invasion of Austria. Preslia, 81(2), 119-133.
Follak, S., Essl, F. (2013). Spread dynamics and agricultural impact of Sorghum halepense, an emerging invasive species in Central Europe. Weed research, 53(1), 53-60.
Iler, A.M., Compagnoni, A., Inouye, D.W., Williams, J.L., CaraDonna, P.J., Anderson, A., Miller, T.E. (2019). Reproductive losses due to climate change-induced earlier flowering are not the primary threat to plant population viability in a perennial herb. Journal of Ecology, 107(4), 1931-1943.
IPBES (2019). Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (E.S. Brondizio, J. Settele, S. Díaz, H.T. Ngo, Eds.). IPBES secretariat, Bonn, Germany. doi.org/10.5281/zenodo.3831673
IPBES (2023). Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (H.E. Roy, A. Pauchard, P. Stoett, T. Renard Truong, Eds.). IPBES secretariat, Bonn, Germany. doi.org/10.5281/zenodo.7430682
IPCC (2022). Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (H.O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Møller, A. Okem, B. Rama, Eds.). Cambridge University Press. doi.org/10.1017/9781009325844
Jovanović, S., Hlavati-Širka, V., Lakušić, D., Jogan, N., Nikolić, T., Anastasiu, P., ... Šinžar-Sekulić, J. (2018). Reynoutria niche modelling and protected area prioritization for restoration and protection from invasion: A Southeastern Europe case study. Journal for Nature Conservation, 41, 1-15.
Kolar, C.S., Lodge, D.M. (2001). Progress in invasion biology: predicting invaders. Trends in Ecology & Evolution, 16(4), 199-204.
Mina, M., Bugmann, H., Cordonnier, T., Irauschek, F., Klopcic, M., Pardos, M., Cailleret, M. (2017). Future ecosystem services from European mountain forests under climate change. Journal of Applied Ecology, 54(2), 389-401.
Richter, R., Berger, U.E., Dullinger, S., Essl, F., Leitner, M., Smith, M., Vogl, G. (2013). Spread of invasive ragweed: climate change, management and how to reduce allergy costs. Journal of Applied Ecology, 50(6), 1422-1430.
Schierenbeck, K.A. (2017). Population-level genetic variation and climate change in a biodiversity hotspot. Annals of Botany, 119(2), 215-228.
Seebens, H., Meyerson, L.A., Rahlao, S.J., Lenzner, B., Tricarico, E., Aleksanyan, A., Courchamp, F., Keskin, E., Saeedi, H., Tawake, A., Pyšek, P. (2023). Chapter 2: Trends and status of alien and invasive alien species. In: Thematic Assessment Report on Invasive Alien Species and their Control of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Roy, H.E., Pauchard, A., Stoett, P., Renard Truong, T. (Eds.). IPBES secretariat, Bonn, Germany. doi.org/10.5281/zenodo.7430725
Simpson, M., Prots, B. (2013). Predicting the distribution of invasive plants in the Ukrainian Carpathians under climatic change and intensification of anthropogenic disturbances: implications for biodiversity conservation. Environmental conservation, 40(2), 167-181.
Stričević, R., Prodanović, S., Đurović, N., Petrović Obradović, O., Đurović, D. (2019). Report on observed climate change impacts on agriculture in Serbia and future projections of climate

impacts based on different scenarios regarding future emissions. United Nations Development Programme, Belgrade.
Vilà, M., Corbin, J.D., Dukes, J.S., Pino, J., Smith, S.D. (2007). Linking plant invasions to global environmental change. In: Canadell, J.G., Pataki, D. E., Pitelka, L.F. (Eds.). Terrestrial ecosystems in a changing world. Springer, Berlin, Heidelberg, 93-102.
Vilà, M., Basnou, C., Pyšek, P., Josefsson, M., Genovesi, P., Gollasch, S., Nentwig, W., Olenin, S., Roques, A., Roy, D., Hulme, P.E. (2010). How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. Frontiers in Ecology and the Environment, 8(3), 135-144.
Vilà, M., Beaury, E.M., Blumenthal, D.M., Bradley, B.A., Early, R., Laginha, B.B. et al. (2021) Understanding the combined impacts of weeds and climate change on crops. Environmental Research Letters, 16, 034043
Vrbničanin, S., Malidža, G., Stefanović, L., Elezović, I., Stanković-Kalezić, R., Marisavljević, D., Jovanović-Radovanov, K., Pavlović, D., Gavrić, M. (2008). Distribucija nekih ekonomski štetnih, invazivnih i karantinskih korovskih vrsta na području Srbije - I deo: Prostorna distribucija i zastupljenost osam korovskih vrsta. Biljni lekar, 36(5), 303-313.
Vrbničanin, S., Malidža, G., Stefanović, L., Elezović, I., Stanković-Kalezić, R., Marisavljević, D., Jovanović-Radovanov, K., Pavlović, D., Gavrić, M. (2009). Distribucija nekih ekonomski štetnih, invazivnih i karantinskih korovskih vrsta na području Srbije, III deo - prostorna distribucija i zastupljenost osam korovskih vrsta. Biljni lekar, 37(1), 21-30.
Walther, G.R., Roques, A., Hulme, P.E., Sykes, M.T., Pyšek, P., Kühn, I., Zobel, M., Bacher, S., Botta-Dukat, Z., Bugmann, H., Czucz, B. (2009). Alien species in a warmer world: risks and opportunities. Trends in Ecology & Evolution, 24(12), 686-693.
Wang, W.J., Thompson, III F.R., He, H.S., Fraser, J.S., Dijak, W.D., Jones-Farrand T. (2019). Climate change and tree harvest interact to affect future tree species distribution changes. Journal of Ecology, 107(4), 1901-1917.
Webber, B.L., Scott, J.K. (2012). Rapid global change: implications for defining natives and aliens. Global Ecology and Biogeography, 21(3), 305-311.
Ziska, L.H., Blumenthal, D.M., Runion, G.B., Hunt, E.R., Diaz-Soltero, H. (2011). Invasive species and climate change: an agronomic perspective. Climatic Change, 105(1-2), 13-42.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.
doi:10.46793/MAK2025.301S

OPPORTUNITIES FOR SUSTAINABLE FOOD PRODUCTION - ANALYSIS OF THE CITIZENS ATTITUDES IN EASTERN SERBIA

Marija Stevanović[1*], Violeta Jovanović [2], Marko Vojvodić[3]

[1]High School of Health and Sanitation of Vocational Studies "Visan", Belgrade, Serbia,
*marijatf@yahoo.com
[2]Metropolitan University, Faculty of Managemnt, Belgrade, Serbia
violeta.jovanovic@metropolitan.ac.rs
[3]High School of Health and Sanitation of Vocational Studies "Visan", Belgrade, Serbia
m.vojvodic84@gmail.com

Abstract: Sustainable food production is becoming an increasingly important aspect in the fight against climate change and the protection of natural resources. The aim of the paper is to investigate the citizens attitudes of Eastern Serbia towards sustainable food production and the factors that influence their willingness to support sustainable practices. The survey analyzed key attitudes about the benefits and challenges of sustainable agriculture, which were statistically processed and presented in the paper. The results show a high level of awareness of the importance of sustainability, but also insufficient information about concrete steps, and guidelines are proposed for improving education and promotion of sustainable production in this region.

Key words: Sustainable development, Sustainable agriculture, Food production, Eastern Serbia

1. INTRODUCTION

Considering man's need to feed the increasing number of inhabitants on the planet, to grow as much food as possible, in a shorter time, to transport and process that food, the development of agriculture was one of the more aggressive ways of destroying the Earth's natural resources. Agriculture as we know it has largely influenced the creation of problems that are becoming more pronounced every day: climate change, global warming, destroyed environment, health problems of both direct participants in production and consumers of products. Whether traditional or modern, agriculture over time has led to the devastation of the land as a base of production as well as other factors. Cultivating agricultural land to the desired results, i.e. yield, generally requires excessive use of fertilizers, pesticides and herbicides.

This leads to changes in the composition of the soil, there is less organic matter, the chemical properties change, especially the reaction or pH of the soil. The soil that has undergone these changes is no longer able to adequately receive water, its biological activity decreases, and all of this together leads deeper and deeper into the processes of using new means and measures, indefinitely. A special problem is the leaching of these substances into the deeper layers of the soil, which causes water pollution and, directly through the vapors, air pollution. All the aforementioned problems require that food production, i.e. agriculture becomes sustainable.

Sustainable food production has become one of the most important global challenges in the 21st century. Given the growing world population, climate change and increasing awareness of the impact of the food system on the environment, the demand for sustainable and healthy food products is constantly growing. By introducing ecological principles into food production, a transition is made from intensive (conventional) agriculture to alternative or sustainable agriculture, which is much more environmentally friendly.

The topic of sustainable food production has become the subject of intensive research in the last few decades. Numerous publications deal with different aspects of this complex issue. There is a wide range of definitions and approaches to sustainable food production, which differ depending on the discipline and perspective of the author (Ericksen, 2008; Hinrichs, 2016; El Bilali et al., 2019; Vermeir et al., 2020).

The impact of the food system on the environment has been analyzed in numerous publications. Research focuses on the impact of agriculture on climate change, biodiversity loss, water and soil pollution, and energy consumption (Kroyer, 1995; Hendrickson et al., 2020; Ritchie et al., 2022).

Economic aspects of sustainable food production were also the subject of numerous researches. These publications analyze the economic viability, profitability and competitiveness of sustainable agricultural systems (Tisdell, 1999; Cvijanović et al., 2020; Borowski and Patuk, 2021). There are publications dealing with the social aspects of sustainable food production, where the impacts of sustainable production on rural development, farmers' well-being and access to food are investigated (Desiderio et al., 2022; Borowski and Patuk, 2021).

End consumers, their behavior and preferences are also important for the development of sustainable food production systems. Numerous publications analyze consumers' attitudes towards sustainable food, their willingness to pay more for sustainable products and the factors that influence their purchasing decisions (Feil et al., 2020; O'Neill et al., 2023; Badea, 2024; Šostar and Ristanović, 2024).

The state, with its policies and measures, should help and promote sustainable food production. Numerous publications explore the different policies and instruments used by governments and other institutions to support the development of sustainable food production (Galli et al., 2020; Balázs et al., 2021; Ammann et al., 2023). In this context, Eastern Serbia represents an interesting area for research, considering its agricultural tradition and potential for the development of sustainable food production, on the one hand, and the mining industry, which can be a factor hindering this type of production, on the other hand.

The aim of the paper is to investigate the citizens attitudes of Eastern Serbia towards sustainable food production and the factors that influence their willingness to support sustainable practices, and identification of the main obstacles to the development of sustainable agriculture in the region.

2. MATERIALS AND METHODS

The research for the work was conducted during February and March 2024, in the territory of Eastern Serbia. For the purposes of the research, a quantitative methodology was used, with the application of a survey as the main instrument for data collection. The survey was structured and consisted of several sections that included demographic data, level of information about sustainable food production, perceptions of advantages and challenges, willingness to support local producers and consumption of sustainably produced food, as well as attitudes of agricultural producers.

The questionnaire was created based on the research objectives and consisted of the following parts:
1. Demographic data - questions about gender, age, level of education and place of residence.
2. Information about sustainable food production - questions about knowledge of the concept, sources of information and self-assessment of the level of information.
3. Perceptions of sustainable food production - questions about recognized benefits and challenges.

4. Willingness to support sustainable practices - questions about willingness to support local production and consume products produced by sustainable methods.
5. Attitudes of agricultural producers - questions about motives, challenges and possible solutions for the development of sustainable food production.
6. Obstacles to sustainable food production - questions about the factors that prevent the development of sustainable agriculture.

The survey contained closed questions with multiple choice answers. The research was conducted on a sample of 134 citizens of Eastern Serbia. The sample was stratified according to the criteria of age group, gender and place of residence (urban/rural), in order to ensure representativeness. The survey was conducted in person, and participation was voluntary and anonymous. The collected data were analyzed using descriptive statistical methods. All ethical principles were respected during the research. The aim of the research was explained to the participants in advance, and their participation was completely voluntary, with the right to withdraw at any time. Anonymity and confidentiality of data are guaranteed.

3. RESULTS AND DISCUSSION

The questionnaire contained 16 questions divided into 6 groups. It was possible to give more than one answer to certain questions. The answers to the questions are shown in the following tables.

Table 1. Demographic data

Gender structure of respondents				
Male (46%)		Female (54%)		
Age structure of respondents				
18-25 years old (7%)	26-35 years old (14%)	36-45 years old (22%)	46-55 years old (39%)	Over 56 years old (18%)
Education				
Basic (11%)	Secondary education (54%)	Higher school (21%)	Faculty (14%)	
Do you live in an urban or rural area?				
Urban (58%)		Rural (42%)		

It can be seen from the table that slightly more female respondents than male respondents participated in the research. The largest number of respondents (61%) belongs to the age group between 36 and 55 years. When it comes to education, the largest number of respondents have secondary (54%) and higher education (21%). More respondents from urban areas participated in the survey (58%) compared to respondents from rural areas, i.e. agricultural producers.

Table 2. Awareness of sustainable food production

Have you heard of the concept of sustainable food production?				
Yes (68%)			No (32%)	
How did you learn about this concept?				
Internet (23%)	TV/radio (2%)	School/educational institutions (52%)	Friends/family (17%)	From agricultural producers (6%)
Do you think you have enough information about sustainable food production?				
Yes (35%)			No (65%)	

The obtained data indicate that there is a significant number of respondents who are familiar with the concept of sustainable food production (68%), and over 50% of them acquired this information during schooling. Also, the Internet is not a negligible source of this information. However, many respondents (65%) stated that they do not have enough information about sustainable food production. This is significant information that indicates the need for education on the topic of sustainable food production, i.e. sustainable agriculture.

Table 3. Perceptions of sustainable food production

What benefits of sustainable food production do you recognize?			
Conservation of natural resources (16%)	Pollution reduction (48%)	Improving food quality (57%)	Support for local communities (12%)
What are the biggest challenges of sustainable food production in your opinion?			
Higher production costs (43%)	Lack of state support (52%)	Insufficient consumer information (55%)	Technological obstacles (23%)

Based on the data in the table, it can be seen that reducing pollution and improving food quality are the main advantages of sustainable agriculture recognized by the respondents. They see insufficient consumer information and lack of state support as the biggest challenges of sustainable agriculture. These responses are consistent with the previous ones, which indicate the need for education on this topic. Education is needed, both for the population from urban areas, and for agricultural producers living in rural areas. Also, a significant percentage of respondents (43%) cited higher production costs as a challenge in sustainable food production.

Table 4. Willingness to support sustainable food production

Are you willing to pay more for products produced using sustainable methods?				
Yes (24%)		No (32%)		Maybe (46%)
How often do you buy products from local producers?				
Always (9%)	Often (18%)	Occasionally (41%)	Rarely (28%)	Never (4%)
Do you think that greater availability of information about sustainable production would influence your purchase?				
Yes (67%)		No (33%)		

The results of the research show that a small percentage of those who are willing to pay more for products produced by sustainable methods (only 24%). Over 30% of them declared that they are not ready to pay more for products produced with sustainable methods, while a significant percentage of those who are undecided (46%). Attention should be paid to this group of respondents and adequate methods should be found to influence their awareness. One of the important methods in this case would be education, which would show people the benefits and advantages of consuming healthy food, and healthy food is precisely food produced with sustainable methods.

Table 5. Attitudes of agricultural producers

Do you practice sustainable agriculture??		
Yes (7%)	No (93%)	
Do you know farmers who practice sustainable production??		
Yes (11%)	No (89%)	
What do you think are their main motivations for switching to sustainable production??		
Economic benefits (52%)	Environmental awareness (43%)	Market pressure (5%)

When it comes to farmers' attitudes towards sustainable agriculture, the data indicate that a very small number of farmers practice sustainable agriculture (only 7%). Given the possible confusion about the detailed understanding of this concept, it is possible that the number is even lower. This indicates that the agricultural producer practices conventional agriculture. Conventional agriculture is the current way of agricultural production that relies on synthetic fertilizers, pesticides and herbicides in order to achieve maximum yield. This approach often leads to the use of chemicals that can leave residues on food, impairing its quality and the long-term health of consumers. In addition, conventional agriculture creates a large carbon footprint, as it intensively uses resources and chemicals that pollute soil and water, reduce biodiversity and contribute to ecosystem degradation. This can lead to a reduction in the nutritional value of food and an increase in the risk of negative effects on human health.

When asked about the main motives for switching to sustainable production, many respondents stated that these were economic benefits (52%). Also, a significant percentage (43%) mentioned environmental awareness. Sustainable agriculture focuses on preserving the environment, but also brings significant economic benefits, such as cost reduction through less use of inputs such as expensive chemicals, reduced water consumption through the use of drip irrigation techniques and rainwater harvesting. Significant advantages also relate to the increase in income through premiums for organic products, because consumers are increasingly looking for ecologically produced food, which enables farmers to achieve higher prices for their products.

Table 6. Obstacles to Sustainable Food Production

What obstacles do you consider the most important for the development of sustainable production in Eastern Serbia?				
Lack of financial support (48%)	Inadequate infrastructure (32%)	Lack of education for producers (58%)	Low demand for sustainable products (36%)	Mining industry in this area (67%)
What, in your opinion, would be the best way to encourage sustainable food production in your region?				
Changing of agricultural practices (23%)	Support for local producers (51%)	Education and change of consciousness (63%)	Policies and incentives from local governments and the state (46%)	Use of new technologies and innovations (27%)

The results of the research show that the most important obstacles for the development of sustainable agriculture were mentioned by the respondents, including lack of education for producers (58%), lack of financial support (48%), and as one of the biggest obstacles for the development of sustainable food production in Eastern Serbia they mention the impact of the mining industry (67%). Numerous publications have analyzed the impact of the mining industry on agriculture and sustainable food production (Haruna et al., 2022; Padhiary and Kumar, 2024; Wang and Yang, 2024; Dehkordi et al., 2024).

The main negative impacts include:
- Soil pollution: Mineral extraction and mining wastes often contaminate the soil with heavy metals and chemicals such as cyanide and mercury, which can reduce soil fertility and threaten food security.
- Water contamination: The release of toxic substances from mines into surface and groundwater can seriously threaten irrigation water sources, reducing the availability of clean water for agriculture.
- Land use change: Mining operations often occupy fertile land, reducing the area available for agriculture. After exploitation, the soil may become unusable due to damage and contamination.
- Eruption of dust and gases: Mining processes release dust and harmful gases that can reduce air quality and affect the health of plants, animals and people.
- Loss of biodiversity: Mining operations destroy natural ecosystems, which can negatively affect pollinators and natural processes important for sustainable agriculture.

4. CONCLUSION

The research results indicate that the citizens of Eastern Serbia recognize the importance of sustainable food production, but also that there are numerous obstacles to its wider adoption. Key issues include a lack of education and financial support, as well as the negative impact of the mining industry on land, water and biodiversity. These challenges require a multidisciplinary approach and coordination between the state, local communities and experts.

Although most respondents are familiar with the concept of sustainable food production, the lack of in-depth knowledge and willingness to invest additional funds for products produced with sustainable methods indicate the need for more intensive educational campaigns. Special attention should be paid to farmers, who mostly rely on conventional production methods, but also to indecisive consumers, who need a better understanding of the benefits of sustainable food.

The development of sustainable agriculture can bring significant environmental and economic benefits, including conservation of natural resources, reduction of production costs and higher value of ecological products on the market. However, the key prerequisites for this are greater investment in education, promotion of sustainable methods and creation of financial incentives for farmers.

It is necessary to address the impact of the mining industry through stricter regulations and environmental protection measures, in order to ensure a long-term balance between economic development and conservation of resources for sustainable food production. Such a comprehensive approach can contribute to improving the quality of life of citizens and preserving natural resources for future generations.

5. REFERENCES

Ammann, J., Arbenz, A., Mack, G., Nemecek, T., El Benni, N. (2023). A review of policy instruments for sustainable food consumption. Sustainable Production and Consumption, 36, 338-353.

Badea, A.M. (2024). Sustainable Consumption Patterns: Evaluating Consumer Preferences and Barriers in the Adoption of Organic Versus Conventional Agri-Food Products. In Proceedings of the International Conference on Business Excellence, 18(1), 660-671.

Balázs, B., Kelemen, E., Centofanti, T., Vasconcelos, M.W., Iannetta, P.P. (2021). Policy interventions promoting sustainable food-and feed-systems: A Delphi study of legume production and consumption. Sustainability, 13(14), 7597.

Borowski, P.F., Patuk, I. (2021). Environmental, social and economic factors in sustainable development with food, energy and eco-space aspect security. Present Environment & Sustainable Development, 15(1).

Cvijanović, D., Ignjatijević, S., Vapa Tankosić, J., Cvijanović, V. (2020). Do local food products contribute to sustainable economic development? Sustainability, 12(7), 2847.

Dehkordi, M.M., Nodeh, Z.P., Dehkordi, K.S., Khorjestan, R.R., Ghaffarzadeh, M. (2024). Soil, air, and water pollution from mining and industrial activities: Sources of pollution, environmental impacts, and prevention and control methods. Results in Engineering, 102729

Desiderio, E., García-Herrero, L., Hall, D., Segrè, A., Vittuari, M. (2022). Social sustainability tools and indicators for the food supply chain: A systematic literature review. Sustainable Production and Consumption, 30, 527-540.

El Bilali, H., Callenius, C., Strassner, C., Probst, L. (2019). Food and nutrition security and sustainability transitions in food systems. Food and energy security, 8(2), e00154.

Ericksen, P.J. (2008). Conceptualizing food systems for global environmental change research. Global environmental change, 18(1), 234-245.

Feil, A.A., da Silva Cyrne, C.C., Sindelar, F.C.W., Barden, J.E., Dalmoro, M. (2020). Profiles of sustainable food consumption: Consumer behavior toward organic food in southern region of Brazil. Journal of Cleaner Production, 258, 120690.

Galli, F., Prosperi, P., Favilli, E., D'Amico, S., Bartolini, F., Brunori, G. (2020). How can policy processes remove barriers to sustainable food systems in Europe? Contributing to a policy framework for agri-food transitions. Food Policy, 96, 101871.

Haruna, U.A., Amos, O.A., Dara, O.O., Wuraola, S.F., Kilonzo, J.S., Olorunfemi, O.E., Lucero-Prisno III,D.E. (2022). Agriculture and food security in Northern Nigeria, Part II: The impact of mining. In Advances in Food Security and Sustainability, 7, 149-160).

Hendrickson, M.K., Howard, P.H., Miller, E.M., Constance, D.H. (2020). The food system: Concentration and its impacts. A Special Report to the Family Farm Action Alliance, 26, 1-26.

Hinrichs, C. (2016). Conceptualizing and creating sustainable food systems: How interdisciplinarity can help. In Imagining Sustainable Food Systems, Routledge, 17-36.

Kroyer, G.T. (1995). Impact of food processing on the environment-an overview. LWT-Food Science and Technology, 28(6), 547-552.

O'Neill, C., McCarthy, M.B., O'Reilly, S., Alfnes, F. (2023). Food interests, preferences and behaviours: a profile of the sustainable food consumer. British Food Journal, 125(13), 352-374.

Padhiary, M., Kumar, R. (2024). Assessing the environmental impacts of agriculture, industrial operations, and mining on agro-ecosystems. In Smart Internet of Things for Environment and Healthcare, Cham: Springer Nature Switzerland, 107-126.

Ritchie, H., Rosado, P., Roser, M. (2022). Environmental impacts of food production. Our world in data. https://ourworldindata.org/environmental-impacts-of-food

Tisdell, C.A. (1999). Economics, aspects of ecology and sustainable agricultural production. Sustainable Agriculture and Environment, 37-56.

Vermeir, I., Weijters, B., De Houwer, J., Geuens, M., Slabbinck, H., Spruyt, A., Verbeke, W. (2020). Environmentally sustainable food consumption: A review and research agenda from a goal-directed perspective. Frontiers in psychology, 11, 1603.

Wang, S., Yang, L. (2024). Mineral resource extraction and resource sustainability: Policy initiatives for agriculture, economy, energy, and the environment. Resources Policy, 89, 104657.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.308S

ASSESSMENT OF CRITICAL METEOROLOGICAL AND EDAPHIC DATA FOR DROUGHT FORECASTING

Marija Stevanović[1*], Miloš Milovančević[2]

[1]The higher health and sanitary school of vocational studies „Visan", Belgrade, Serbia
*marijatf@yahoo.com
[2]Faculty of Mechanical Engineering, University of Niš, Serbia

Abstract: Drought is a complex and expensive natural hazard, and the identification of essential drought components is vital for modelling and predicting droughts, hence facilitating the development of mitigation strategies in both spatial and temporal contexts. This project aims to use an adaptable neural fuzzy inference system (ANFIS) to categorise meteorological and soil data for drought forecasting. Accurate forecasting of droughts is essential for sustainable water management and for preventing significant harm to agricultural productivity and the economy of an area. The gradual emergence of droughts complicates their detection, although it simultaneously provides several chances for forecasting before to, during, and after an occurrence. Specific humidity at 2 meters above the ground has the greatest effect on drought measurement variability. The combination of specific humidity at 2 meters and surface temperature exhibits the lowest training error, hence exerting the greatest effect on the assessment of drought severity. The findings from this research may provide valuable insights for early agricultural drought alerts.

Key words: Drought, Soil, Forecasting, ANFIS

1. INTRODUCTION

Agricultural drought is often characterized by insufficient soil moisture, which may impair plant development and reduce agricultural output. Precise forecasting of agricultural drought with enough lead time may facilitate agricultural planning and mitigate losses in output. The Gradient Boosting Algorithm (GBM) (Adhikari et al., 2021) indicates that precipitation and soil moisture significantly contribute to droughts. Drought is a principal threat that may profoundly affect agriculture. Recent decades have seen significant progress in the scientific understanding and forecasting of droughts (Bloor et al., 2018).

The word "soil health" refers to the state of soil concerning its physical, chemical, and biological characteristics. The fluctuation in maize production during drought years may be attributed to soil health and its markers in Texas Blackland soils (Brown et al., 2021). Datasets, drought indices, and drought correlations are three essential domains of drought research (Fang et al., 2021). Physiological drought is significantly influenced by root zone characteristics, while canopy structure is relevant mostly in arid locations (Fischer et al., 2008). The resilience of soil bacterial populations and their functions to protracted drought is constrained in agricultural systems, resulting in a longer recovery period. Climate change is anticipated to elevate both the frequency and intensity of droughts in several global locations. Soil health is expected to be adversely affected by these intense occurrences (Kaur and Sood, 2021). Study (Nayak and Hassan, 2021) demonstrates that drought influences soil erosion and that water and soil conservation strategies, including afforestation and vegetation greening, are advantageous for alleviating soil erosion and drought. Soil vegetation atmosphere transport (SVAT) models are essential for quantifying water fluxes, soil water availability, drought stress, and related uncertainties in the context of climate change (Nguyen et al., 2018). Numerous drought indices assess drought severity but fail to include many critical drought-inducing elements and lack universality (Schmidt-Walter et al., 2020). Soil microorganisms influence plant responses to drought via soil-plant feedback mechanisms and drought-induced alterations in microbial community composition (Speich et al., 2018). Root biomass is a crucial predictor of soil microbial tolerance to drought in grass-dominated ecosystems, indicating that trade-offs between plant and microbial activities may significantly impact ecosystem functionality in a changing environment (Xi et al., 2018).

The adaptive neuro fuzzy inference system (ANFIS) is proficient in identifying and categorizing soil and meteorological factors for drought forecasting. ANFIS has powerful normalization and generalization capabilities, noise immunity, resilience, and fault tolerance. Consequently, modifications in diverse characteristics should not substantially affect the ANFIS-based drought prediction. The primary objective of this research is to examine the potential model for predicting droughts via the analysis of meteorological and soil data.

2. METHODOLOGY AND MATERIALS

2.1. Drought data

This research used a 180-day historical data window for forecasts, using prior drought levels, static data, and meteorological data from the preceding year. Drought scores are published weekly, although meteorological data points are released daily. This is a classification dataset including six drought levels, including no drought (absent in the dataset) and five distinct drought levels shown in Figure 1. Each item denotes a drought level at a particular moment in a certain US county, accompanied by the preceding 90 days of 18 weather indicators detailed at the conclusion of this description. The dataset exhibits imbalance, as seen in Figure 2. The statistical characterization of the input and output data variables is shown in Table 1.

Category	Description	Possible Impacts
D0	Abnormally Dry	Going into drought: ▪ short-term dryness slowing planting, growth of crops or pastures Coming out of drought: ▪ some lingering water deficits ▪ pastures or crops not fully recovered
D1	Moderate Drought	▪ Some damage to crops, pastures ▪ Streams, reservoirs, or wells low, some water shortages developing or imminent ▪ Voluntary water-use restrictions requested
D2	Severe Drought	▪ Crop or pasture losses likely ▪ Water shortages common ▪ Water restrictions imposed
D3	Extreme Drought	▪ Major crop/pasture losses ▪ Widespread water shortages or restrictions
D4	Exceptional Drought	▪ Exceptional and widespread crop/pasture losses ▪ Shortages of water in reservoirs, streams, and wells creating water emergencies

Figure 1. Description of measure of drought ranging (https://droughtmonitor.unl.edu)

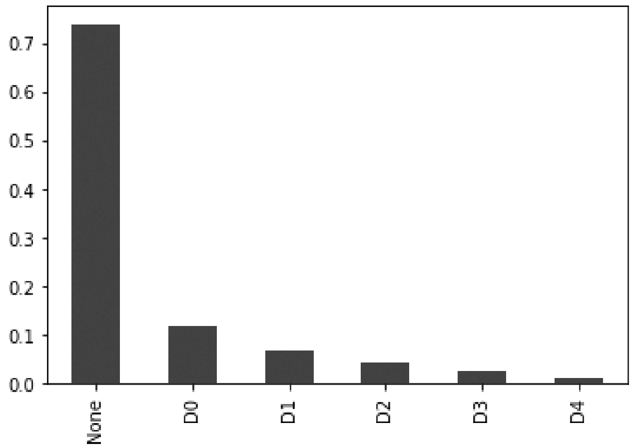


Figure 2. Data distribution of measure of drought ranging

Table 1. Input and output variables (Yu et al., 2021)

	Min.	Max.	Std.
Precipitation (mm day^{-1})	0	88.56	8.188738
Surface Pressure (kPa)	98.55	102.67	0.699874
Specific Humidity at 2 meters (g/kg)	2.01	20.86	4.584287
Temperature at 2 meters (°C)	-2.10	31.95	7.565873
Dew/Frost Point at 2 meters (°C)	-8.40	25.90	7.103609
Wet Bulb Temperature at 2 meters (°C)	-5.78	25.90	7.035616
Maximum Temperature at 2 meters (°C)	3.37	39.64	7.569476
Minimum Temperature at 2 meters (°C)	-7.11	26.70	8.049733
Temperature Range at 2 meters (°C)	1.81	20.00	3.260583
Earth Skin Temperature (°C)	-2.10	32.18	7.575904
Wind Speed at 10 meters (m/s)	0.63	9.94	0.956907
Maximum Wind Speed at 10 meters (m s^{-1})	1.14	13.18	1.290777
Minimum Wind Speed at 10 meters (m s^{-1})	0.01	8.49	0.829345
Wind Speed Range at 10 meters (m s^{-1})	0.47	10.02	0.898683
Wind Speed at 50 meters (m s^{-1})	1.11	14.69	1.482072
Maximum Wind Speed at 50 meters (m s^{-1})	2.12	19.45	1.710513
Minimum Wind Speed at 50 meters (m s^{-1})	0.02	12.73	1.549985
Wind Speed Range at 50 meters (m s^{-1})	0.88	13.54	1.321188
Measure of drought ranging	0	2.8891	0.725030

2.2. ANFIS methodology

As shown in Figure 3, the ANFIS network contains five levels. The fuzzy inference system lies at the heart of the ANFIS network. Layer 1 accepts the inputs and uses membership functions to convert them to fuzzy values. The bell-shaped membership function is employed in this study because it has the best capability for nonlinear data regression.

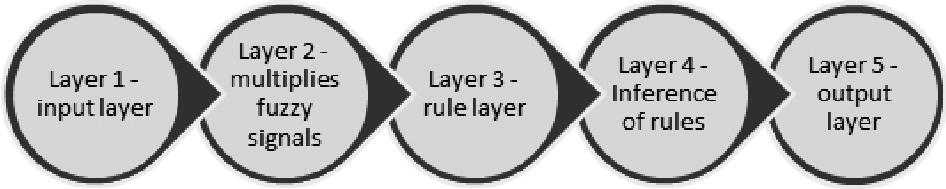


Figure 3. ANFIS layers

Bell-shaped membership functios is defined as follows:

$$\mu(x) = bell(x; a_i, b_i, c_i) = \frac{1}{1+\left[\left(\frac{x-c_i}{a_i}\right)^2\right]^{b_i}}$$

where $\{a_i, b_i, c_i\}$ is the parameters set and x is input.

The second layer multiplies the first layer's fuzzy signals and produces the rule's firing strength. The rule layers are the third layer, and they normalize all of the signals from the second layer. The fourht layer does rule inference and converts all signals to crisp values. The last layers summed all of the signals and provided a clean output value.

3. RESULTS

The best predictors for the different types of defects were chosen using the ANFIS approach. The selection is crucial, as is the preprocessing of the input parameters to eliminate irrelevant inputs. Following the command in MATLAB Software, the dataset is partitioned into a training set (odd-indexed samples) and a checking set (even-indexed samples):

```
>>[data] = drought
>>trn_data = data (1:2:end)
>>chk_data = data (2:2:end)
```

The function "exhsrch" conducts an exhaustive search of the available inputs to identify the set of inputs that have the greatest impact on the measure of drought ranging. The function's first parameter defines the number of input combinations that will be tested during the selection process. In essence, "exhsrch" creates an ANFIS model for each combination, trains it for one epoch, and then publishes the results. The command line below is used to find the one and two most important attributes in forecasting outputs:

```
>> exhsrch (1,trn_data,chk_data)
>> exhsrch (2,trn_data,chk_data)
```

Table 2 illustrates the relationships between individual input combinations and the assessment of drought severity. The effect is assessed based on the RMSE for training (trn) and validation (chk) mistakes. Input characteristic The Specific Humidity at 2 meters has the lowest training error, hence exerting the most effect on drought measurement. In other words, little fluctuations in specific humidity at two meters might result in significant variations in drought conditions.

Table 2. Correlation one input attribute with measure of drought ranging

Precipitation (mm day^{-1})→ trn=0.7241, chk=0.7249
Surface Pressure (kPa)→ trn=0.7191, chk=0.7180
Specific Humidity at 2 meters (g kg^{-1})→ trn=0.7144, chk=0.7170
Temperature at 2 meters (°C)→ trn=0.7152, chk=0.7196
Dew/Frost Point at 2 meters (°C) → trn=0.7158, chk=0.7212
Wet Bulb Temperature at 2 meters (°C) → trn=0.7156, chk=0.7211
Maximum Temperature at 2 meters (°C) → trn=0.7154, chk=0.7191
Minimum Temperature at 2 meters (°C) → trn=0.7177, chk=0.7218
Temperature Range at 2 meters (°C) → trn=0.7226, chk=0.7235
Earth Skin Temperature (°C) → trn=0.7155, chk=0.7199
Wind Speed at 10 meters (m/s) → trn=0.7218, chk=0.7236
Maximum Wind Speed at 10 meters (m s^{-1}) → trn=0.7219, chk=0.7228
Minimum Wind Speed at 10 meters (m s^{-1}) → trn=0.7222, chk=0.7266
Wind Speed Range at 10 meters (m s^{-1}) → trn=0.7199, chk=0.7221
Wind Speed at 50 meters (m s^{-1}) → trn=0.7229, chk=0.7261
Maximum Wind Speed at 50 meters (m s^{-1}) → trn=0.7237, chk=0.7253
Minimum Wind Speed at 50 meters (m s^{-1}) → trn=0.7226, chk=0.7262
Wind Speed Range at 50 meters (m s^{-1}) → trn=0.7214, chk=0.7262

Table 3 presents the ideal combination of two input features based on drought prediction metrics. The combination of specific humidity at 2 meters and surface temperature yields the minimal training error, hence exerting the most impact on the assessment of drought severity. In other words, simultaneous variations in specific humidity, 2-meter temperature, and surface temperature would result in the most significant fluctuations in drought conditions.

Table 3. Optimal correlation two input attributes with measure of drought ranging

Specific Humidity at 2 meters (g kg^{-1}) Earth Skin Temperature (°C) -->
trn=0.6938, chk=0.7004

For further analysis the optimal two attributes are extracted and analyzed. There is always preferable to use models with small number of inputs. Figure 4 shows the optimal combination of two-attributes for the measure of drought ranging.

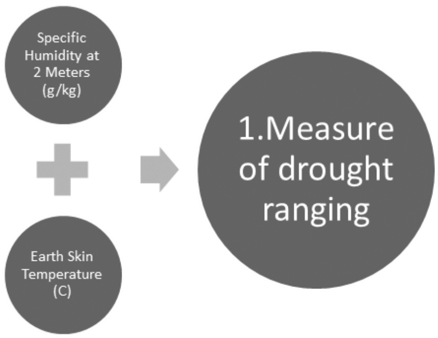


Figure 4. Optimal two-attributes influence on the measure of drought ranging

Figure 5 shows the training and checking errors for the optimal two-attributes of the measure of drought ranging. The minimal checking error occurs at 40th epoch. Figure 6 shows the ANFIS decision surface for the minimal checking error. Data distribution of the optimal two-attributes is shown in Figure 7.

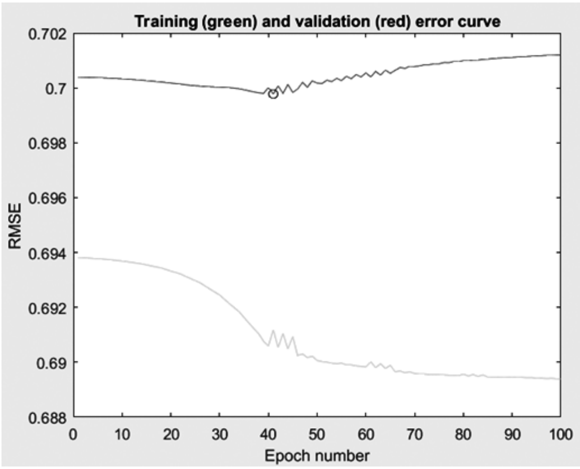


Figure 5. Training and checking errors for optimal two-attributes for measure of drought ranging

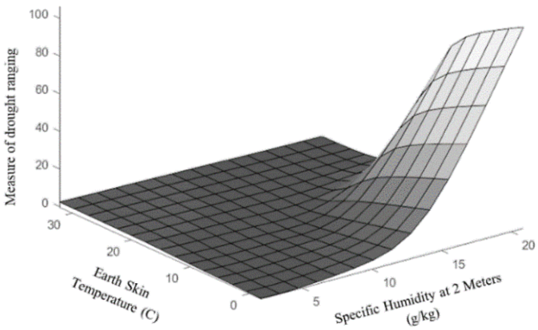


Figure 6. Relationship between the optimal two-attributes and the measure of drought ranging

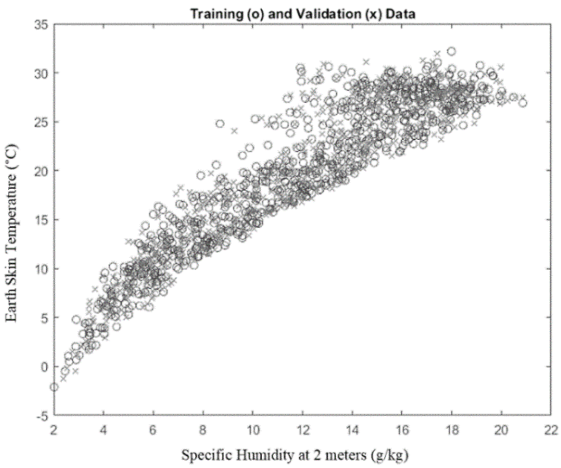


Figure 7. Data distribution of the optimal two-attributes for measure of drought ranging

4. CONCLUSION

The monitoring and evaluation of drought are essential due to the profound impacts it imposes on various sectors, particularly in economies where agricultural and energy systems are deeply reliant on water resources. Drought's gradual onset adds complexity to its detection but also provides multiple opportunities for forecasting that can be leveraged across different stages: before, during, and after a drought event. Effective drought early warning systems are built on the strategic integration of diverse information sources, each contributing unique insights and strengths to enhance prediction accuracy. In this context, the Adaptive Neural Fuzzy Inference System (ANFIS) has proven to be a valuable tool for classifying meteorological and soil data to forecast drought conditions. Simulation results demonstrate that ANFIS performs satisfactorily in anticipating drought, with findings underscoring the significant influence of specific humidity at a 2-meter height on drought severity. The data indicates that the interaction between this specific humidity level and the earth’s surface temperature is particularly impactful, suggesting that these variables collectively provide a strong basis for measuring drought intensity. The application of ANFIS in drought monitoring represents an advancement in forecasting capability, offering a robust approach to mitigate drought’s adverse effects by enhancing prediction precision. This refined understanding can enable stakeholders to develop more responsive and resilient strategies to protect water-dependent sectors, supporting sustainable economic stability in the face of climate challenges.

5. REFERENCES

Adhikari, K., Smith, D.R., Collins, H., Haney, R.L., Wolfe, J.E. (2021). Corn response to selected soil health indicators in a Texas drought. Ecological Indicators, 125, 107482.

Bloor, J.M., Zwicke, M., Picon-Cochard, C. (2018). Drought responses of root biomass provide an indicator of soil microbial drought resistance in grass monocultures. Applied Soil Ecology, 126, 160-164.

Brown, R.W., Chadwick, D.R., Zang, H., Jones, D.L. (2021). Use of metabolomics to quantify changes in soil microbial function in response to fertilizer nitrogen supply and extreme drought. Soil Biology and Biochemistry, 160, 108351.

Fang, B., Kansara, P., Dandridge, C., Lakshmi, V. (2021). Drought monitoring using high spatial resolution soil moisture data over Australia in 2015–2019. Journal of Hydrology, 594, 125960

Fischer, G., Nachtergaele, F., Prieler, S., van Velthuizen, H.T., Verelst, L., Wiberg, D. (2008). Global Agro-ecological Zones Assessment for Agriculture (GAEZ 2008). IIASA, Laxenburg, Austria and FAO, Rome, Italy.

Kaur, A., Sood, S.K. (2021). Energy efficient cloud-assisted IoT-enabled architectural paradigm for drought prediction. Sustainable Computing: Informatics and Systems, 30, 100496.

Nayak, M.A., Hassan, W.U. (2021). A synthesis of drought prediction research over India. Water Security, 13, 100092.

Nguyen, L.T., Osanai, Y., Lai, K., Anderson, I.C., Bange, M.P., Tissue, D.T., Singh, B.K. (2018). Responses of the soil microbial community to nitrogen fertilizer regimes and historical exposure to extreme weather events: flooding or prolonged drought. Soil Biology and Biochemistry, 118, 227-236.

Schmidt-Walter, P., Trotsiuk, V., Meusburger, K., Zacios, M., Meesenburg, H. (2020). Advancing simulations of water fluxes, soil moisture and drought stress by using the LWF-Brook90 hydrological model in R. Agricultural and Forest Meteorology, 291, 108023.

Speich, M.J., Zappa, M., Lischke, H. (2018). Sensitivity of forest water balance and physiological drought predictions to soil and vegetation parameters-A model-based study. Environmental Modelling & Software, 102, 213-232.

Xi, N., Chu, C., Bloor, J.M. (2018). Plant drought resistance is mediated by soil microbial community structure and soil-plant feedback in a savanna tree species. Environmental and Experimental Botany, 155, 695-701.

Yu, Y., Shen, Y., Wang, J., Wei, Y., Liu, Z. (2021). Simulation and mapping of drought and soil erosion in Central Yunnan Province, China. Advances in Space Research, 68(11), 4556-4572.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.315S

THE ROLE OF NATURAL BIOSTIMULANTS IN CLIMATE-SMART AGRICULTURE: ASCOPHYLLUM NODOSUM'S IMPACT ON ALFALFA YIELD

Zoran Ž. Sekulić[1*], Sanja Đurović[2], Boris Pisinov[2], Tamara Stamenić[3], Maja Petričević[3], Maša Radojičić[3], Tanja Keškić[3]

[1]Institute of Public Health of Belgrade, Belgrade, Serbia, *zoran.sekulic@zdravlje.org.rs
[2]Institute for Plant Protection and Environment, Belgrade, Serbia
[3]Institute for Animal Husbandry, Belgrade-Zemun, Serbia

Abstract: In the context of growing challenges posed by climate change, sustainable agriculture increasingly recognizes the importance of biostimulants derived from natural bioactive molecules, which offer an ecological alternative to synthetic fertilizers. The significant variability in bioactive compounds and sources of biostimulants highlights a broad spectrum of potential solutions for improving crop yields and enhancing plant stress tolerance, particularly in response to climate-induced stresses such as drought and temperature extremes. This study aims to evaluate the efficacy of Ascophyllum nodosum liquid extract as a biostimulant in promoting the growth and yield of the hybrid alfalfa variety Banat VS during its first year of vegetation. The experiment was conducted under the agroecological conditions of the Banat region in the eastern part of Vojvodina, Republic of Serbia. Alfalfa seeds were treated by irrigation with liquid seaweed extract, and their effect on yield was assessed after three harvests. The average mass of treated plants was 19.82 g, representing a 4.6% increase compared to the control group (18.95 g). In addition to quantitative results, treated plants demonstrated an accelerated flowering phase and a higher percentage of inflorescences compared to control samples. The application of Ascophyllum nodosum-based biostimulant significantly enhanced the vegetative growth and yield of alfalfa, confirming its potential in sustainable agriculture. These findings highlight the efficacy of biostimulants in stimulating plant growth, particularly under challenging growth conditions that may become more frequent due to climate variability.

Key words: Sustainable agriculture, Biostimulants, *Ascophyllum nodosum*, Alfalfa, Yield improvement

1. INTRODUCTION

Agricultural production today faces mounting challenges due to the dual pressures of increasing demand for higher yields and better crop quality, alongside the urgent need to mitigate the environmental impacts intensified by climate change (Bell et al., 2022). The accelerating consequences of global warming-such as increased temperatures, unpredictable rainfall, and more frequent extreme weather events-necessitate innovative solutions to sustain productivity and ecological balance. In this context, biostimulants have emerged as a promising technology for advancing sustainable agriculture by enhancing resource efficiency and strengthening plant resilience to climate-induced stresses (Pooja and Munjal, 2020).

Biostimulants, derived from plants, microbes, animals, or synthetic sources, promote vital physiological processes in plants, thereby boosting their ability to withstand both abiotic and biotic stresses, improving nutrient absorption, and enhancing overall yield and quality. Their application is gaining significance within the global trend toward sustainable and economically viable agriculture (Bhuyan et al., 2020).

Ascophyllum nodosum, a brown marine alga from the Fucaceae family commonly known as "seaweed" is a vital natural resource found along the Atlantic Ocean's northeastern coast of America and northwestern Europe. This seaweed is gaining attention for its multifaceted role in promoting plant health and its contribution to sustainability through minimal environmental impact (Alam et al., 2013; Pereira et al., 2020). Its potential to support agriculture in adapting to climate variability makes it a key focus for sustainable development.

Algal extracts, particularly those from macroalgae, have shown significant promise over recent decades as eco-friendly biostimulants. Rich in bioactive compounds such as phytohormones (auxins, cytokinins, and gibberellins), polysaccharides, amino acids, vitamins, and minerals, these extracts can enhance plant growth, improve photosynthetic capacity, and bolster resistance to climate-related adversities, including droughts and heat stress (Sarwar et al., 2023). Additionally, studies indicate that these extracts can improve nitrogen fixation and soil quality, vital factors for sustainable legume cultivation, including alfalfa (Do Nascimento et al., 2015). The qualitative traits of alfalfa, such as the leaf-to-stem ratio, are crucial for its nutritional value and digestibility as animal feed. Enhanced plant quality through the use of algal extracts, particularly increased protein content and reduced indigestible lignin fibers, can lead to more sustainable feed production and reduced environmental impact (Kocira et al., 2020).

This study explores the use of Ascophyllum nodosum extracts in improving alfalfa yield, growth, and quality, with a specific focus on their potential role in creating climate-resilient and ecologically sustainable agricultural practices. We explored the mechanisms of action of algal extracts and their impact on physiological processes in the plant (De Saeger et al., 2020) and assess the challenges and opportunities associated with their use in modern farming, aiming for sustainable and economically viable outcomes (Chojnacka et al., 2015). By addressing these aspects, our research contributes to the development of reliable, climate-adaptive biostimulant products that support the sustainability of agricultural systems (Pan et al., 2019).

The aim of this study is to evaluate the efficacy of Ascophyllum nodosum liquid extract as a biostimulant in promoting the growth and yield of the hybrid alfalfa variety Banat VS.

2. MATERIAL AND METHODS

The research was conducted in the Banat region, specifically in Žitište, on a test plot established within an agricultural estate, adhering to standardized methodologies (Zhao and Naeth, 2022). The experimental period spanned six months, from April 10 to September 20, 2023, coinciding with the vegetative development phase of alfalfa. The study encompassed three sowing seasons. The experimental design comprised a total plot area of 50 m², which was divided into two equal sections: an experimental section (25 m²) treated with the biostimulant and a control section (25 m²) without treatment. On the experimental plots, a 10% aqueous solution of *Ascophyllum nodosum* extract was applied by spraying twice daily at three-day intervals. Alfalfa yield was measured after each sowing season, and the data were statistically processed using analysis of variance (ANOVA) to determine the significance of differences between treated and untreated plants. Factors such as biomass quantity, the number of harvested plants, and the general condition of the plants in terms of height, leaf count, and resistance to stress conditions were considered to assess the efficacy of the biostimulant accurately (Ricci et al., 2019). No biostimulant was applied to the control plots, allowing for a comparison of the natural growth dynamics with the treated group. Data were analyzed at the end of each sowing season to monitor the cumulative effects of the biostimulant application.

3. RESULTS AND DISCUSSION

The alfalfa variety Banat VS yield was assessed during three harvests in the first year of growth. Data on the control group's yield, including the total plant weight, stem weight, leaf weight, and inflorescence weight, were recorded and are presented in Table 1. During the second harvest, the highest total plant weight of 20.05 g was recorded, with the weights of stems, leaves, and inflorescences being 10.04 g, 8.35 g, and 1.66 g, respectively. The lowest yield was observed in the first harvest, where the following parameters were recorded: a total mass of 17.96 g, a stem weight of 10.52 g, a leaf mass of 7.22 g, and an inflorescence weight of 0.22 g.

Table 1. Yield and structure of the alfalfa variety Banat VS in the first year of growth without the application of a 10% *Ascophyllum nodosum* algal extract

Traits	Number of harvests		
	1	2	3
Total Weight (g)	17.96	20.05	18.83
Stem Weight (g)	10.52	10.04	10.01
Leaf Weight (g)	7.22	8.35	6.99
Inflorescence Weight (g)	0.22	1.66	1.83
Stem Weight as % of Total	58.58	50.08	53.16
Leaf Weight as % of Total	40.20	41.63	37.10
Inflorescence Weight as % of Total	1.22	8.29	9.74

During the second harvest of the control group, the highest leaf yield was recorded at 8.29%, indicating optimal growth conditions and the application of a 10% *Ascophyllum nodosum* algal solution. The highest stem-to-total plant mass ratio was observed in the first harvest, reaching 58.58%. These data suggest that in the early growth stages, the plant directs its resources toward stem development, which may indicate its adaptability to cultivation conditions. In the third harvest, the highest percentage of inflorescence in the total plant mass was recorded at 9.74%, which may be a result of stress caused by earlier harvests, as well as the effective application of the biostimulant. Yield and structural components of the alfalfa variety Banat VS during the first year of growth on the test plot treated with a 10% *Ascophyllum nodosum* solution, underscoring the significance of biostimulants in enhancing yield and improving crop quality (Table 2).

Table 2. Yield and structure of the alfalfa variety Banat VS in the first year of growth with the application of a 10% *Ascophyllum nodosum* solution

Traits	Number of harvests		
	1	2	3
Total Weight (g)	18.24	21.66	19.56
Stem Weight (g)	10.70	9.91	10.41
Leaf Weight (g)	7.30	9.93	7.16
Inflorescence Weight (g)	0.24	1.82	2.00
Stem Weight as % of Total	58.65	45.76	53.20
Leaf Weight as % of Total	40.02	45.86	36.60
Inflorescence Weight as % of Total	1.33	8.38	10.20

During the yield structure analysis of the alfalfa variety Banat VS in the experimental group, the highest percentage of leaves relative to the total plant mass was observed in the second harvest, reaching 45.86%. In the first harvest, the highest stem-to-total yield ratio was recorded at 58.65%, while the third harvest was characterized by the highest inflorescence yield, amounting to 10.2%. These results indicate variations in biomass distribution during different growth stages, which may be attributed to differing environmental conditions and applied treatments. The average values of the yields obtained, including total mass, leaf mass, stem mass, and inflorescence mass of the alfalfa variety Banat VS, are presented in Table 3. Statistical analyses were performed to assess the significance of these differences, aligning with previous studies that have documented similar trends in biomass allocation in leguminous crops. These findings may have important implications for enhancing alfalfa cultivation practices and improving crop management strategies.

Table 3. Average yield values obtained in both groups (control and experimental)

Measurement Parameters	Total Weight	Weight of Stems	Leaf Mass	Weight of Inflorescences
Control Group (g)	18.95±0.61	10.19±0.17	7.52±0.42	1.24±0.51
Experimental Group (g)	19.82±1.0	10.34±0.23	8.13±0.90	1.35±0.56
Increase (%)	4.6*	1.5*	8.1*	8.9*

NS-nonsignificant difference, $p > 0.01$*

The statistical analysis of crop structure data obtained from three harvests indicated a degree of variability. However, as a perennial forage crop, alfalfa necessitates a minimum of three years of study to comprehensively evaluate its structural characteristics. Preliminary findings suggest that the total weight of various alfalfa plant parts increased under the experimental treatment, averaging 19.82 g, which corresponds to a 4.6% increase compared to the control group, which recorded an average weight of 18.95 g. This upward growth trend was consistently observed across all measurements. However, statistical analysis showed that the differences in stem weight (experimental group: 10.34 g; control group: 10.19 g), leaf weight (experimental group: 8.13 g; control group: 7.52 g), and inflorescence weight (experimental treatment: 1.35 g; control group: 1.24 g) were not statistically significant ($p > 0.01$). The significance levels ($p > 0.01$) indicate that the results at this stage of the research cannot be considered statistically significant, necessitating further studies to determine the long-term effects of the treatment. Although the experimental group showed increases in stem development, leaf mass, and inflorescence weight, these differences did not reach statistical significance, suggesting that the observed trends may not be robust and require additional investigation.

Under experimental conditions, the utilization of *Ascophyllum nodosum* algae as a biostimulant demonstrated potential for accelerating plant growth and reproductive phases. In our study, the *Ascophyllum nodosum* treatment led to earlier flowering in alfalfa plants, suggesting that this addition may expedite the plant's phenological development, particularly its entry into the reproductive phase. Early flowering can positively impact yield and forage quality, as the floral components are considered valuable in livestock feed due to their high nutrient content. Preliminary results show that the *Ascophyllum nodosum* treatment significantly increased the inflorescence weight in the experimental group (1.35 g), marking an 8.9% increase compared to the control group (1.24 g). This increase in inflorescence mass may indicate improved productivity and potentially higher nutritional value of alfalfa. Since inflorescences are rich in essential amino acids and other nutrients, their rise in total biomass could enhance the quality of livestock feed.

4. CONCLUSION

The application of an *Ascophyllum nodosum*-based solution demonstrated a positive effect on the yield structure of the hybrid alfalfa variety Banat VS during its first year of cultivation. Across three harvests, the average total plant weight in the treated group exceeded that of the control group by 4.6%. Notably, the experimental treatment resulted in higher stem weight (1.5%), leaf weight (8.1%), and inflorescence weight (8.9%) compared to the control. The observed accelerated flowering of alfalfa suggests potential growth-promoting properties that warrant further exploration.

From a sustainability perspective, the use of Ascophyllum nodosum as a biostimulant aligns with climate-adaptive agricultural strategies. By enhancing plant growth and productivity, such treatments can contribute to more resilient agricultural practices, helping mitigate the effects of climate variability and supporting stable food production systems. The promotion of natural biostimulants like Ascophyllum nodosum can reduce reliance on synthetic fertilizers, thereby lowering environmental impact and improving the ecological footprint of farming practices.

Future research should explore the mechanisms of action behind this biostimulant and assess its long-term benefits on yield, quality, and nutritional value of alfalfa under diverse and potentially more extreme agroecological conditions. Such studies will be essential to understanding the role of biostimulants in building sustainable and climate-resilient agricultural systems.

5. REFERENCES

Bell, J.C., Bound, S.A., Buntain, M. (2022). Biostimulants in agricultural and horticultural production. In Horticultural Reviews, Wiley, 35-95.

Pooja, Munjal, R. (2020). Use of biostimulants in conferring tolerance to environmental stress. In M. Hasanuzzaman (Ed.), Plant Ecophysiology and Adaptation under Climate Change: Mechanisms and Perspectives II: Mechanisms of Adaptation and Stress Amelioration, Springer, 231-244.

Bhuyan, M.H.M.B., Mohsin, S.M., Mahmud, J.al, Hasanuzzaman, M. (2020). Use of biostimulants for improving abiotic stress tolerance in Brassicaceae plants. In Use of Biostimulants for Improving Abiotic Stress Tolerance in Brassicaceae Plants. doi.org/10.1007/978-981-15-6345-4_19

Alam, M.Z., Braun, G., Norrie, J., Hodges, D.M. (2013). Effect of Ascophyllum extract application on plant growth, fruit yield, and soil microbial communities of strawberry. Canadian Journal of Plant Science, 93(1), 23-36.

Pereira, L., Morrison, L., Shukla, P.S., Critchley, A.T. (2020). A concise review of the brown macroalga *Ascophyllum nodosum* (Linnaeus) Le Jolis. Journal of Applied Phycology, 32(5), 3561-3584.

Sarwar, B., Sher, A., Ijaz, M., Irfan, M., Ul-Allah, S. (2023). Exogenous application of biostimulants and commercial utilization. In M. Hasanuzzaman (Ed.), Climate-resilient agriculture, Vol. 2. Springer.

Do Nascimento, M., Rizza, L.S., Di Palma, A.A., de los Angeles Dublan, M., Salerno, G., Rubio, L.M., Curatti, L. (2015). Cyanobacterial biological nitrogen fixation as a sustainable nitrogen fertilizer for the production of microalgal oil. Algal Research, 12, 142-148.

Kocira, S., Szparaga, A., Findura, P., Treder, K. (2020). Modification of yield and fiber fractions biosynthesis in Phaseolus vulgaris L. by treatment with biostimulants containing amino acids and seaweed extract. Agronomy, 10(9), 1338.

De Saeger, J., Van Praet, S., Vereecke, D., Park, J., Jacques, S., Han, T., Depuydt, S. (2020). Toward the molecular understanding of the action mechanism of Ascophyllum nodosum extracts on plants. Journal of Applied Phycology, 32(1), 573-597.

Chojnacka, K., Michalak, I., Dmytryk, A., Gramza, M., Słowiński, A., Górecki, H. (2015). Algal extracts plant growth biostimulants. In Marine algae extracts: Processes, products, and applications, 189-212.

Pan, S., Jeevanandam, J., Danquah, M.K. (2019). Benefits of algal extracts in sustainable agriculture. In Grand challenges in algae biotechnology, 501-534.

Zhao, Y., Naeth, M.A. (2022). Application timing optimization of lignite-derived humic substances for three agricultural plant species and soil fertility. Journal of Soil Science and Plant Nutrition, 51(5), 1035-1043.

Ricci, M., Tilbury, L., Daridon, B., Sukalac, K. (2019). General principles to justify plant biostimulant claims. Frontiers in plant science, 10, 494.

doi:10.46793/MAK2025.320ST

ECOLOGICAL SIGNIFICANCE, BIOCHEMICAL ACTIVITY AND PROTECTION OF PLANT TAXONS

Ljubica Šarčević-Todosijević[1*], Kristina Vojvodić[1], Marija Perić[1], Janko Pejović[1], Nikola Đorđević[1], Andrijana Zuber[1,2]

[1]Sanitary Medical School of Applied Sciences "Visan", Belgrade, Serbia, *ljsarcevic@gmail.com
[2]Nutrition Center dr Andrijana Zuber, Belgrade, Serbia

Abstract: Photosynthesis is the most important life process of plants, which enables the existence of life on planet Earth. Photosynthesis, which represents the primary production of organic matter, produces food for all organisms connected by food chains in ecosystems. The secondary metabolites of plants have long been considered biologically unimportant, but interest in these natural products has also been fueled by their widespread use as dyes, polymers, perfumes, drugs, and biopesticides. The paper uses the method of data analysis, which was collected from certain scientific studies, including scientific studies conducted by the authors. The importance and protection of plant taxons are discussed, with special reference to their biochemical activity and possibilities of application as medicines and biopesticides. Based on the review of available literature data, it is concluded that plants are not only organisms that enable and support the existence of life on planet Earth, but are also used in industry, medicine, pharmacy and agriculture. Also, they neutralize the negative effect of climate change. Within the measures for the protection of the entire biodiversity, the protection of plant taxons is very important.

Key words: Plant taxons, Biochemical activity, Biodiversity, Protection

1. INTRODUCTION

Photosynthesis, the life process of plants, is part of the carbon cycle and the most important process that enables and supports the existence of life on planet Earth. Photosynthesis involves the conversion of solar energy into chemically bound energy, producing carbohydrates and releasing oxygen into the atmosphere. Humans are also supplied with organic mattters which are used in various areas of the economy, as well as in the fields of medicine and pharmacy. While the primary metabolism of a plant cell is considered to be the processes of photosynthesis and transformation of the resulting glucose into polysaccharides, its breakdown and the formation of amino acids and fatty acids, in the process of secondary metabolism of plants various chemical compounds are formed and they exhibit pronounced and specific biochemical activity. Products of plant secondary metabolism have long been considered biologically unimportant and have not attracted the attention of scientists, but interest in these natural products has been stimulated by their wide application as dyes, polymers, perfumes and medicines. Knowledge of the biological properties of natural products contributes to research and the creation of new medicines, antibiotics and biopesticides (Sarić, 1983; Jančić, 2004; Šarčević-Todosijević et al., 2024a). In addition to the ecological importance of plants for the entire biosphere, as well as the practical importance for humans, plants have a huge importance for the planet and from the aspect of climate change. In the process of photosynthesis, plants absorb carbon dioxide, reduce its concentration in the atmosphere and neutralize negative greenhouse effect. Also, they enable more efficient biogeochemical cycles in ecosystems (Šarčević-Todosijević et al., 2023a). Because of all the above, within the biodiversity protection activities, the protection of plant taxons is particularly important.

The aim of work is analysis of the importance and protection of plant taxons, focused to their biochemical activity and possibilities of application as medicines and biopesticides.

2. MATERIAL AND METHODS

In this paper, a method of data analysis, which were collected from certain studies, was performed. Relevant scientific data, published in scientific papers (in scientific journals and at scientific conference), as well as data from scientific papers published by the authors (self-citations) were used.

3. RESULTS AND DISCUSSION

Photosynthesis, a life process that occurs in plants, is part of the carbon cycle. In this process, plants use chlorophyll, the green pigment of the leaves, to absorb solar energy, and convert water and carbon dioxide, adopted from the environment, into organic compounds rich in energy. By enabling the process of photosynthesis, green plants provide the first condition for the existence and development of life on planet Earth. The results of scientific research have shown that, although the amount of carbon dioxide in the atmosphere is very small, the photosynthetic production on the earth's surface is enormous. As sources of food, humans mostly use the photosynthetic production of cultural plants, directly (cereals, fruits, vegetables) or through food chains (herbivorous animals) (Sarić, 1983; Jančić, 2004; Šarčević-Todosijević et al., 2024a).

For human nutrition, plant crops are grown in agroecosystems. The results of a large number of scientific research indicate that the most significant factors affecting plant yields include the application of fertilizers, plant protection agents, as well as the effect of environmental factors in a given agroecosystem. However, in the conclusion of most of the research, the emphasis is placed on the rational application of fertilizers, with the aim of preventing environmental pollution and producing healthy crops (Kolarić et al., 2021; Šarčević-Todosijević et al., 2023b; Šarčević-Todosijević et al., 2024a).

Filipović et al. (2022) investigated the effect of different substrate mixtures on seedling quality and productivity of tomato, pepper and basil crops. These plant species are very important in the nutrition and are grown all over the world. Choosing the substrate which can improve the plant traits during the cultivation of selected tomato, pepper and basil varieties is very important task. The research was carried out at the Institute for Medicinal Plant Research "Dr. Josif Pančić" in Pančevo. Four substrate variants (different substrate mixtures) and a control variant (land without substrate) were tested. The best characteristics of morphological traits were achieved by plants produced on the commercial Klasmann Potgrond Hsubstrate. The plants that were grown on the compost produced during the production and processing of medicinal plants had the highest yield of fruits (tomatoes and peppers) and yield of fresh aboveground mass (basil) (Filipović et al., 2022).

The primary metabolism of a plant cell includes the process of photosynthesis and transformation of glucose to polysaccharides, its breakdown and formation of amino acids, as components of proteins, and fatty acids, as components of lipids. In the process of secondary metabolism of plants, various chemical compounds are formed, which exhibit pronounced biochemical and pharmacological activity. Products of plants secondary metabolism have long been considered biologically unimportant and have not attracted the attention of scientists, but interest in these natural products has been stimulated by their wide application as dyes, polymers, perfumes and medicines. As already mentioned, knowing the biological properties of natural products contributes to research and the discovery of new drugs and antibiotics. In addition, the study of biochemical and biological effects of secondary metabolites of plants creates opportunities for their application as allelopathic substances in ecosystems, that is, biopesticides (Kovačević, 2004; Šarčević-Todosijević et al., 2019a; Popović et al., 2021, Petrović et al., 2022; Šarčević-Todosijević et al., 2024a,b). Due to the pronounced biochemical activity of products of secondary metabolism, plants are widely used in medicine and pharmacy. The use of plants and their metabolites in pharmacy is defined by the pharmacopoeia, which is a collection of prescribed norms and standards for substances and the manufacture of medicines (Kovačević, 2004; Šarčević-Todosijević et al., 2024b). The products of the secondary metabolism of plants are very complex organic compounds. They include: alkaloids, heterosides, saponosides, tannins, terpenoids. Significant biochemical activity is shown by other plant ingredients, such as: resins, balsams, fats and oils, heteropolysaccharides, amino acids, proteins, vitamins, minerals (Kovačević, 2004, Šarčević-Todosijević et al., 2019a,b, Popović et al., 2021). Plants rarely exhibit strong biochemical activity due to the presence of only one group of compounds. Thus, Šarčević-Todosijević et al. (2019b) state that numerous biochemical components of plants, such as phenolic acids and their heterosides, flavonoids, tannins and other phenolic compounds, as well as essential oils, exhibit strong antioxidant, anti-inflammatory, anticancer and antimicrobial activity. Similarly, the biochemical characterization of the plant taxon *Achillea millefolium* L., an ancient medicinal plant, which has been used in traditional medicine and pharmacy since ancient times, indicates the diversity of the compounds present. *Achillea millefolium* L. belongs to the Asteraceae family (Figure 1). It is a herbaceous perennial plant with an aromatic smell. The stem is 20-80 cm high, with many leaves, which are pinnately divided 2-3 times. Leaves and inflorescences are used. The plant lives by the roadsides and in dry meadows (Jančić, 2004).

Figure 1. *Achillea millefolium* L., Asteraceae, herbal material, plant collected from natural habitats, locality: wider area of mountain Fruška Gora, Serbia (authors collection)

Over 120 chemical compounds have been identified in *Achillea millefolium* (Chandler et al., 1982). The dominant active components of *Achillea millefolium* (yarrow) can be classified into several groups:

- essential oil, monoterpenes and sesquiterpenes,
- phenolic compounds,
- triterpenes and sterols,
- alkaloids,
- minerals and vitamins and
- other compounds (Chandler et al., 1982).

Biochemical analyzes in *Achillea millefolium* revealed compounds from the group of alkaloids (achilein and achilicine), that have hemostatic and antimicrobial properties. Alkaloids are products of secondary metabolism of plants, which exhibit strong biochemical activity (Kovačević, 2004; Šarčević-Todosijević et al., 2024b). In experiments conducted on animals, it was determined that various extracts of yarrow and the isolated ingredient - flavonoid artemetin show a significant hypotensive effect, which scientifically justifies the traditional use of this plant in cardiovascular diseases. Also, the extract whose main ingredients are flavonoids (10%) and dicaffeoylquinic acid derivatives (12%) showed a vasoprotective effect, which is consistent with the use of the plant in case of venous inflammation (Roy, 2017). Based on the experience of traditional medicine, as well as modern research, it has been established that yarrow has a favorable effect on the digestive system, has a mild sedative effect, and also acts as an analgesic and antiseptic (Heinrich et al., 2021).

In study Krvžić (2015) conducted analysis of the herbal drugs in the Serbian climate, which are used in traditional and official medicine to alleviate various types of pain. The study describes the plant taxon *Chelidonium majus* L., i.e. the herbal drug *Chelidonii herba* and its analgesic effect (Kvržić, 205). *Chelidonium majus* belongs to the plant family Papaveraceae. It is a perennial herbaceous plant with branched roots. The stem is upright, covered with hairs. The leaves are large, odd-pinnate. The flowers are hermaphroditic, actinomorphic symmetry, and the fruit is a pod. It grows by the roadside (Jančić, 2004). The whole plant is used, especially the root, it contains a juice of a specific orange color, which contains 0.1% to 1% alkaloids. Alkaloids are related to organic acids, such as fumaric and meconic. Kvržić (2015) states that today it is known that the composition of this plant taxon includes more than 20 alkaloids of the benzophenanthridine, protoberberine and protopine type. Dry ethanol extracts with a precisely defined amount of active substances were tested, as well as each of the alkaloids separately. Three different tests for spasmolytic effect were performed on a pig ileum model. Chelidonine and protopine showed a musculotropic effect similar to papaverine, while this effect was absent in the study of coptisine. Both tested ethanolic extracts showed a significant relaxant effect (Kvržić, 2015).

Alkaloids, as active ingredients of drugs, are important drugs in therapeutic doses, however, higher doses can be toxic and even lethal. They are used for the production of dosed pharmaceutical forms. Of the numerous pharmacological properties of alkaloids, it is important to emphasize their cytostatic effects. These effects have been established for certain alkaloids, isolated from plants. The molecular mechanisms of action of plant antitumor substances are very complex. Vinca alkaloids are isolated from the plant species *Vinca rosea*, and the first alkaloids isolated were vincristine, vinblastine and vindesine. Later, second-generation vinca alkaloids appeared. Vinca alkaloids are standard chemotherapy drugs, and the second group in terms of the degree of use of chemotherapy drugs (Kovačević, 2004; Kipić and Milovanović, 2014, Popović et al., 2021).

It has been scientifically confirmed that polyphenols, as plant ingredients, exhibit strong biochemical activity, especially antioxidant, antimutagenic, anticarcinogenic and anti-inflammatory (Kovačević, 2004; Šarčević-Todosijević et al., 2024b). Matić et al. (2019) investigated the potential antigenotoxicity of phenolic acids (gallic and ellagic) in relation to ethyl methanesulfonate (EMS), a proven mutagen, induced DNA damage in germ and somatic cells of *Drosophila melanogaster*. After *in vivo* combined treatment with EMS and gallic acid, the percentage of reduction of DNA damage was 67.2%, while this percentage in the combined treatment with EMS and ellagic acid was 55.6%. Based on the obtained results, Matić et al. (2019) confirm the justification of the application of the investigated phenolic acids as agents with antigenotoxic activity in preventing the occurrence or reducing the rate of genetic damage, which can be the cause of numerous diseases.

The most important sources of phenolic compounds, as antioxidants, are fruits and vegetables, various drinks (red wine, fruit juices, green and black tea, coffee, beer), cocoa, dark chocolate. Flavonoids are particularly important among plant polyphenols. The intake of flavonoids in the body leads to the interruption of free radical reactions, which lead to oxidative stress and cause damage to cells and tissues. Dried fruits are particularly rich in polyphenols and flavonoids. Petrović et al. (2019) determined the content of total polyphenols and flavonoids, as well as the antioxidant activity of seven samples of commercially available dried fruit: apricot (*Prunus armeniaca*), plum (*Prunus domestica*), fig (*Ficus carica*), cranberry (*Vaccinium macrocarpon*), date palm (*Phoenix dactylifera*), white and black grapes (*Vitis vinifera*) using UV/VIS spectrophotometric methods. The obtained results indicated that the dry fig sample has the lowest content of polyphenols and flavonoids, as well as weak antioxidant activity. White grapes had the highest content of polyphenols, high content of flavonoids and the highest antioxidant activity (Petrović et al., 2019). Similarly, Kovačević (2004) points out that white grape varieties, young leaves and seeds contain an interesting proanthocyanidin complex, which is used in the prevention of breast cancer. Also, after processing in the food and alcoholic beverage industry, a complex of polyphenols is extracted from black varieties of grapes and used in the therapy of peripheral circulation disorders. Scientific research has confirmed the highly pronounced antimicrobial activity of plant extracts rich in polyphenols, especially against the bacterial taxons *Escherichia coli* and *Staphylococcus* sp. (Šarčević-Todosijević et al., 2019b).

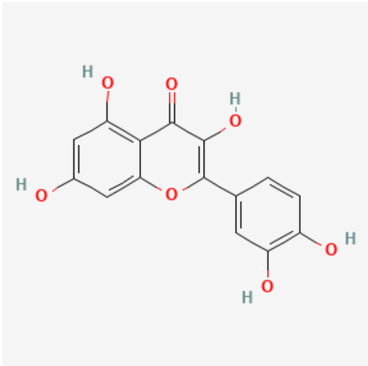


Figure 2. Plant secondary metabolism, quercetin-structure
(https://pubchem.ncbi.nlm.nih.gov/compound/Quercetin#section=Structures,
National Library of Medicine/ National Center for Biotechnology Information)

The plant species *Ligustrum vulgare* L. is a deciduous or semi-evergreen shrub, up to 5 m. It belongs to the Oleaceae family. It lives on a humus substrate, in light forests or hills (Jančić, 2004). Biochemical analyzes showed that the composition of *Ligustrum vulgare* is dominated by flavonoids, phenylpropanoids, secoiridoids, and quercetin (Figure 2). The plant exhibits antimicrobial, antimutagenic and anticarcinogenic effects. Milutinović at al. (2019) investigated the anticancer properties of leaves and fruit extracts of the plant taxon *Ligustrum vulgare* on SW480 colorectal carcinoma cells. Plant extracts showed cytotoxic effects on SW480 cells after 24 and 72h, without negative effects on normal skin fibroblasts. Methanol extracts of this plant cause significant proapoptotic potential, inducing apoptosis, i.e. programmed cell death, which occurs in pathological processes in the body. Based on the obtained research results, Milutinović et al. (2019) point out that *Ligustrum vulgare* represents a significant source of natural bioactive substances with anticancer activity.

Minerals are also necessary for the normal functioning and health of organism. Numerous plant species are important sources of mineral substances and are used in the prevention and therapy of disorders that arise as a result of a lack of these substances in the body. The most important herbal drugs with mineral substances are: birch leaf, nettle herb, yarrow herb, rhizome of *Agropyrum repens*, bean pods, *Equiseti herba* (Figure 3), seaweed thallus and others (Kovačević, 2004; Šarčević-Todosijević et al., 2022).

Given that minerals constitute a special group of essential nutritional factors, Janković et al. (2019) determined the mineral composition of parsley leaves and rosemary leaves using the ICP-OES method. Based on the conducted analyses, they proved the presence of 21 elements in the parsley and rosemary samples, namely: Al, As, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Pb, Se, Si, V and Zn. The authors conclude that the examined plants are rich sources of macroelements. Calcium was found in the highest concentration in both examined plant species. Of the essential microelements, iron is present in the highest concentration in rosemary, while zinc is present in parsley. Al, As and Cd were not detected. The concentration of Pb in all the analyzed samples was within the permissible values (Janković et al., 2019).

Figure 3. *Equiseti herba*, *Equisetum* sp., Equisetaceae,
locality: Derventa, Bosnia and Herzegovina (authors collection)

In addition to minerals, vitamins are also necessary for the normal functioning of the body. Vitamins are essential organic compounds, which are provided by food. The largest number of herbal vitamin drugs, such as rose hip (*Rosae caninae fructus*), are used to make vitamin drinks, teas or infusions, as invigorating and refreshing agents (Kovačević, 2004).

Figure 4. *Rosa canina* L., Rosaceae,
locality: wider area of mountain Rajac, Serbia (authors collection)

They are used preventively to strengthen the immune system to fight flu, colds and infectious diseases, as a supplementary therapy for rheumatism and arthritis. They have a mild diuretic effect and stimulate digestion (Kovačević, 2004). The plant species *Rosa canina* L. is a shrub up to 2.5 m high (Figure 4). It belongs to the Rosaceae family. The branches are bent or upright. The leaves are odd-pinnate compound. The fruit is rose hip. Wild rose habitats include glades, light forests, meadows (Jančić, 2004).

Considering the current trends in drug safety monitoring, vitamins can be considered a relatively safe group of compounds. In addition, a large number of possible risks caused by their use have been identified, so reporting these observations is the most important task of pharmacovigilance, in order to ensure the rational use of vitamins and minerals (Kovačević, 2009).

In addition to the possibility of applying the products of the secondary metabolism of plants in pharmacy and medicine, secondary metabolites also have an allelopathic role, that is, they regulate the relationships of the plant in which they are formed with other plants, but also with other elements of the biocenosis and ecosystem (soil, insects and other animals, microorganisms and humans), which opens up the possibilities of their application as biopesticides. Application of biopesticides is the most important link in the production of healthy food. Essential oils of plants are very often used as biocontrol agents (Kovačević, 2004, Oljača, 2008; Šarčevič-Todosijević et al., 2019a; Golijan-Pantović et al., 2023; Filipović et al., 2024).

Meseldžija et al. (2019) examined the herbicidal effect of rosemary and sage essential oils on the weed species *Chenopodium album* L. Essential oils were applied in concentrations of 1, 5 and 10%. The plants were also treated with essential oil of clove (4%) as a standard, wine vinegar solution (1:10) and kitchen salt NaCl (1:8), while the control variants were not treated. The evaluation was carried out at time intervals of 1-144 h after application. Rosemary and sage essential oils showed high efficacy compared to the control. Phytotoxic changes like loss of turgor, chlorotic and necrotic spots, were determined already after 24 hours of application. The wine vinegar solution showed low efficiency, and the treatment with NaCl solution showed high efficiency. The essential oil of clove in the application amount of 4% caused the greatest damage compared to the applied essential oils (Meseldžija et al., 2019).

Greenhouse gases, carbon dioxide, methane, nitrogen oxides and halocarbons, enter the atmosphere mainly as coal combustion products, natural gas andoil for the production of electricity and to a lesser extent through other industrial and agricultural activities. Higher concentrations of greenhouse gases, cause the retention of solar heat energy and increase in the average global temperature on the planet. Plants neutralize the negative effect of the greenhouse by absorbing carbon dioxide and reducing its concentration in the atmosphere (Keeling, 1997; Đuković and Bojanić, 2000; Šarčević-Todosijević et al., 2023a).

4. CONCLUSION

Based on all of the above, it is clear that plants are not only key organisms that enable and support the existence of life on planet Earth, but also find enormous application in many areas of human activity. Thanks to their pronounced biochemical and pharmacological activity, plant taxons or their metabolites are intensively used in medicine, pharmacy, phytopharmacy and environmental protection. For the above reasons, within the framework of measures for the protection of the entire biodiversity, the protection of plant taxons is particularly important.

5. REFERENCES

Chandler, R., Hooper, S., Harvey, M. (1982). Ethnobotany and phytochemistry of yarrow, *Achillea millefoium*, Compositae. Economic Botany, 36, 203-223.

Đuković, J., Bojanić, V. (2000). Air pollution. Institute for Protection and Ecology, 1-13. Banjaluka, Bosnia and Herzegovina. /in Serbian/

Filipović, V., Šarčević-Todosijević, Lj., Ugrenović, V., Popović, S., Ugrinović, M., Dimitrijević, S., Popović, D. (2022). The influence of different substrate mixtures on seedlings quality and economically high yield mixtures of tomato, pepper and basil. 26th International Eco-conference: 12nd Safe food. Ecological movement of Novi Sad, Novi Sad, Serbia, Proceedings, 103-111.

Filipović, V., Šarčević-Todosijević, Lj., Ugrenović, V., Dimitrijević, S., Popović, M., Mrđan, S., Popović, V. (2024). Application of yarrow broth in order to reduce the intensity of infection of pot marigold leaf powdery mildew (*Podosphaera xanthii* (Castagne) U. Braun & Shishkoff.). International Symposium on Agricultural Sciences, Faculty of Agriculture of the University of Banja Luka, Trebinje, Book of Abstracts, p. 99.

Golijan Pantović, J., Sečanski, M., Gordanić, S., Šarčević-Todosijević, Lj. (2023). Weed biological control with fungi-based bioherbicides. Acta Agriculturae Serbica, 28(55), 23-37.

Heinrich, M., Mah, J., Amirkia, V. (2021). Alkaloids Used as Medicines: Structural Phytochemistry Meets Biodiversity-An Update and Forward Look. Molecules, 26(7), 1836.

Jančić, R. (2004). Pharmaceutical botany. Official Gazette of SCG, 1-269. Belgrade, Serbia. /in Serbian/

Janković, S., Mitić, M., Mašković, P., Mitić, S., Kocić, G. (2019). Determination of mineral compostions of parsley and rosemary using ICP-OES method. XXIV Counseling on Biotechnology, Faculty of Agronomy, Čačak, Proceedings 1, 453-458. /in Serbian/

Keeling, C.D. (1997). Climate change and carbon dioxide: An introduction. Proc Natl Acad Sci., 94(16), 8273-8274.

Kipić, M., Milovanović, O. (2014). Some natural sources of substances with antitumor effects. History of Medicine. Pons Med J., 11(1), 25-31.

Kolarić, L., Popović, V., Živanović, L., Ljubičić, N., Stevanović, P., Šarčević Todosijević, L., Simić, D., Ikanović, J. (2021). Buckwheat Yield Traits Response as Influenced by Row Spacing, Nitrogen, Phosphorus, and Potassium Management. Agronomy, 11, 2371. Basel, Switzerland.

Kovačević, N. (2004). Basics of pharmacognosy. Serbian school book, 1-409. Belgrade, Serbia. /in Serbian/

Kovačević, I. (2009). Adverse effects of vitamins and minerals. Archives of Pharmacy, 59, 2-3, 153-166. /in Serbian/

Kvržić, J. (2015). Herbal drugs of the local origin with analgetic activity. Medicinal Raw Materials, XXXV, 35, 61-74. /in Serbian/

Matić, S., Stanić, S., Kanjevac, M. (2019). *In vivo* antigenotoxic activity of ellagic and gallic acids. XXIV Counseling on Biotechnology. Faculty of Agronomy, Čačak, Proceedings 2, 785-790. /in Serbian/

Meseldžija, M., Dudić, M., Dušanić, A., Petković, M. (2019). Effects of rosemary (*Rosmarinus officinalis* L.) and sage (*Salvia officinalis* L.) essential oils as potential bioherbicides on *Chenopodium album* L. XXIV Counseling on Biotechnology, Faculty of Agronomy, Čačak, Proceedings 1, 371-376. /in Serbian/

Milutinović, M., Nikodijević, D., Stanković, M., Maksimović, V., Marković, S. (2019). Anticancer potential of leaves and fruits of *Ligustrum vulgare* L. on SW480 colorectal carcinoma cells. XXIV Counseling on Biotechnology. Faculty of Agronomy, Čačak, Proceedings 2, 757-764. /in Serbian/

Oljača, S. (2008). Agroecology. Faculty of Agriculture, University of Belgrade, Belgrade, Serbia. /in Serbian/

Petrović, S., Dubovac, M., Mrmošanin, J., Pavlović, A., Tošić, S. (2019). Dried fruits as a source of antioxidants. XXIV Counseling on Biotechnology. Faculty of Agronomy, Čačak, Proceedings 2, 587-592. /in Serbian/

Petrović, B., Vukomanović, P., Popović, V., Šarčević-Todosijević, Lj., Burić, M., Nikolić, M., Đorđević, S. (2022). Significance and efficacy of triterpene saponin herbal drugs with expectorant action in cough therapy. Agriculture and Forestry, 68(3), 221-239.

Popović, V., Šarčević-Todosijević, Lj., Petrović, B., Ignjatov, M., Popović, D., Vukomanović, P., Milošević, D., Filipović, V. (2021). Economic Justification Application of Medicinal Plants in Cosmetic and Pharmacy for the Drugs Discovery. Chapter 3, pp. 63-106. In: Book „An Introduction to Medicinal Herbs (Ed. Emerald, M.), 1-365. NOVA Science publishers, New York, USA.

Roy, A. (2017). A review on the alkaloids an important therapeutic compound from plants. International Journal of Plant Biotechnology, 3(2), 1-9.

Sarić, M. (1983). Plant physiology. Science book, 129-169, Belgrade, Serbia. /in Serbian/

Šarčević-Todosijević, Lj., Popović, V., Živanović, Lj, Popović, S. (2019a). The Possible Use of Allelopathic Relationships in Plant Growing, pp. 105-121. In: Book „Serbia: Current Issues and Challenges in the Areas of Natural Resources, Agriculture and Environment (Ed. Janev, I.), NOVA Science Publishers, Inc., New York, USA.
Šarčević-Todosijević, Lj., Petrović, B., Vukomanović, P., Živanović, Lj., Garčić, J., Popović, V. (2019b). Antimicrobial activity of plant secondary metabolites. XXIV Counseling on Biotechnology. Faculty of Agronomy, Čačak, Proceedings 1, 357-364. /in Serbian/
Šarčević-Todosijević, Lj., Đorđević, S., Popović, V., Živanović, Lj., Petrović, B., Đorđević, N., Golijan, J. (2022). Health aspects of significance of food. XXVII Counseling on Biotechnology. Faculty of Agronomy, Čačak, Proceedings, 437-442. /in Serbian/
Šarčević-Todosijević Lj., Vojvodić, K., Malivuk, A., Perić, M., Popović, V., Golijan, J., Živanović, Lj. (2023a). Environmental pollution - the leading challenge of the 21st century. XXVII Eco Conference, XV Environmental protection of urban and suburban settlements, Ecological movement of Novi Sad, Proceedings, 387-394.
Šarčević-Todosijević, Lj., Vovodić, M., Vojvodić, K., Popović, V., Ivetić, A., Đukić, D., Bošković, J. (2023b). Environmental and economic challenges of plant production under the conditions of climate change. 5th International Symposium, Modern Trends in Agriculture Production, Rural Development Agro-Economy Cooperatives and Environmental Protection. The Balkans Scientific Center of the Russian Academy of Natural Sciences, Vrnjačka Banja, Proceedings, 320-334.
Šarčević-Todosijević, Lj., Vojvodić, K., Perić, M., Đorđević, N. (2024a). Plant production, importance and protection of plant genetic resources. 11th International Scientific Agribusiness Conference "Food for the Future - a vision of Serbia, the region and SE Europe", MAK, 2024, Proceedings, Kopaonik. /in Serbian/
Šarčević-Todosijević, Lj., Đorđević, S., Petrović, B., Popović, V., Golijan Pantović, J., Filipović, V., Đorđević, N. (2024b). Biological activity of plant metabolites. 2nd international symposium on biotechnology, Faculty of Agronomy in Čačak, University of Kragujevac, Proceedings, 249-254.
Quercetin - structure (https://pubchem.ncbi.nlm.nih.gov/compound/ Quercetin#section=Structures, National Library of Medicine/National Center for Biotechnology Information, Accessed: November, 2024.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.329I

INNOVATION IN SUSTAINABLE AGRICULTURE

Aleksandra Ivetić[1*], Nedjeljko Karabasil[2], Bojan Stojanović[3], Milivoje Ćosić[4], Slađan Stanković[1], Božidar Milošević[5], Blagoje Stojković[3]

[1]Institute for the Application of Science in Agriculture, Belgrade, Serbia
*farmainova.aleksandra@gmail.com
[2]Faculty of Veterinary Medicine, University of Belgrade, Belgrade, Serbia
[3]Faculty of Agriculture, University of Belgrade, Belgrade, Serbia
[4]University of Bijeljina, Faculty of Agriculture, Republic of Srpska, Bosnia and Herzegovina
[5] University of Priština temporarily settled in Kosovska Mitrovica,
Faculty of Agriculture, Lešak, Serbia

Abstract: The transformative period in agriculture is characterized by using novel technology which significantly changes the agricultural sector. According to the FAO, agriculture to be sustainable must meet the needs of present and future generations, while ensuring profitability, environmental health, and social and economic equity. Sustainable agricultural systems offer ecosystem services, products, and scientific methods in a way that protects and improves the natural environment, and the social and economic conditions of farmers, and local communities while minimizing further environmental degradation. The United Nations Sustainable Development Goals consist of 17 goals designed to address critical environmental, social, and economic challenges. The Sustainable Development Report is a global assessment of countries' progress towards achieving the Sustainable Development Goals (SDG). It is a complement to the official SDG indicators and the voluntary national reviews. For the countries in the region, their ranking levels and scores are: 8. Croatia (82.19), 11. Slovenia (81.34), 20. Hungary (79.53), 29. Greece (78.17), 35. Serbia (77.03), 40. Romania (76.70), 42. Albania (75.03), 50. Bosnia and Herzegovina (73.99), 51. North Macedonia (73.80), and 57. Montenegro (73.05). The Spillover Index of the UN assesses such spillovers along three dimensions: environmental and social impacts embodied in trade, economy and finance, and security. A higher score means that a country causes more positive and fewer negative spillover effects. For Serbia, the spillover score is 85.98/100, and the spillover rank: is 106/166, which indicates that positive changes are made and improvements for the achievement of the sustainability goals.

Keywords: Sustainable agriculture, Iinnovations, Sustainable development goals

1. INTRODUCTION

Nowadays, the transformative period in agriculture is characterized by using novel technology, which provides solutions that effectively address ecological concerns while also ensuring economic viability, (Gamage et al., 2024). The authors state that emerging technologies, such as precision farming enabled by drones, sensor-based monitoring systems, and genetic editing techniques that result in drought-resistant crops, are significantly changing the agricultural sector. Integrating data analytics and machine learning algorithms is transforming supply chain management and enhancing the capabilities of predictive analytics in the context of crop diseases, (Gamage et al., 2024).

US Department of Agriculture back in the 1977 and 1990 "Farm Bills" first described sustainable agriculture as an integrated system of plant and animal production practices having a site-specific application that will, over the long term: satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole. According to the FAO, sustainable food and agriculture contribute to all four pillars of food security - availability, access, utilization, and stability - and the dimensions of sustainability (environmental, social, and economic). Each is indispensable in achieving a form of agriculture that meets this global challenge and reduces many risks in farming, followed by significant costs. There is no single point of origin of this three-pillar conception, but rather a gradual emergence from various critiques in the early academic literature of the economic status quo from both social and ecological perspectives on the one hand, and the quest to reconcile economic growth as a solution to social and ecological problems on the part of the United Nations on the other (Purvis et al., 2019). The 1972 UN Conference on the Human-Environment in Stockholm marked the first global summit to consider human impacts on the environment, and the first major attempt to reconcile economic development with environmental integrity which were commonly regarded as incompatible (Caldwell, 1984), which by 1973 had been coined as 'eco-development' (Mebratu et al., 1998). After that time, it was becoming apparent to many that the 'progress' had been promised by the early economic growth-based development programs was in many ways failing to materialize (Purvis et al., 2019). Too often, agricultural production systems are considered separate from other natural ecosystems, and insufficient attention has been paid to how services can flow to and from agricultural production systems to surrounding ecosystems (Rehman et al., 2022). In the 2024 report Progress Towards the Sustainable Development Goals of the UN, it mentions that out of 135 targets with trend data and additional insights from custodian agencies, only 17% are progressing as expected to be achieved by 2030 (UN, 2023).

The paper aims to point out the importance of the SDGs and national achievement according to the UN agenda until 2030. Therefore, the research in the paper was based on several axes: 1. Innovation in sustainable agriculture, 2. Serbia's position in the region according to the Sustainable Development Report from 2024, and 3. Research on the positions of countries in the region according to the Global Innovation Index 2024.

2. SUSTAINABLE AGRICULTURE

The evolution of agriculture, from primitive subsistence methods to modern practices, is documented in its history while pressing environmental challenges and crisis (Chbika et al., 2023). In the situation of increasing pollution endangers the quality of natural resources, jeopardizing agricultural productivity and global biodiversity, the authors above mention emphasize that to meet these challenges and simultaneously cater to the world's growing food demand, sustainable farming practices, judicious water management, and the integration of scientific methods are imperative. Sustainable agriculture-farming in sustainable ways based on an understanding of ecosystem services-is a practical option for achieving global food security while minimizing further environmental degradation (Rehman et al., 2022). Technological interventions optimize efficiency and reduce the adverse ecological effects associated with farming, promoting sustainable agriculture goals (Gamage et al., 2024).

The Farm to Fork strategy and the European Green Deal policy are important tools related to the success of food system transformation to shift towards a more sustainable and healthy diet (Varzakas and Smaoui, 2024). Also, The United Nations Sustainable Development Goals (SDG), a new report from 2024, and the European Green Deal are considered essential to mitigate the anthropogenic climate change crisis (Varzakas and Smaoui, 2024). Adopted in 2015 as part of the 2030 Agenda for Sustainable Development, the SDGs consist of 17 goals designed to address critical environmental, social, and economic challenges, with several goals directly influencing sustainable agriculture, Figure 1. Key SDGs, such as SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 9 (Industry, Innovation, and Infrastructure), have been pivotal in driving research and the adoption of new technologies in agriculture (Gamage et al., 2024).

Figure 1. Sustainable Development Goals, United Nations, Department of Economic and Social Affairs Sustainable Development, https://sdgs.un.org/goals

The first prominent occurrence of the phrase 'sustainable development' in published literature appeared in 1980 when the IUCN, in collaboration with the UNEP and the World Wildlife Fund (WWF), published their 'World Conservation Strategy', subtitled 'Living Resource Conservation for Sustainable Development' (World Wildlife Fund, 1980). This early conception of sustainable development is motivated by the need for economic development, with its social and economic objectives, to take conservation into account by considering resource limitations and ecosystem carrying capacity (Purvis et al., 2019).

Sustainable agriculture is defined as "the efficient production of safe, high-quality agricultural products, in a way that protects and improves the natural environment, the social and economic conditions of farmers, their employees and local communities, and safeguards the health and welfare of all farmed species" (Buckwell et al., 2015). Sustainable agricultural systems offer ecosystem services, such as pollination, biological pest control, regulation of soil and water quality, maintenance of soil structure and fertility, carbon sequestration and mitigation of greenhouse gas emissions, nutrient cycling, hydrological services, and biodiversity conservation (Rehman et al., 2022). Brodt et al. (2011) enhanced that prominent among these are topsoil depletion, groundwater contamination, air pollution, greenhouse gas emissions, the decline of family farms, neglect of the living and working conditions of farm laborers, new threats to human health and safety due to the spread of new pathogens, economic concentration in food and agricultural industries, and disintegration of rural communities.

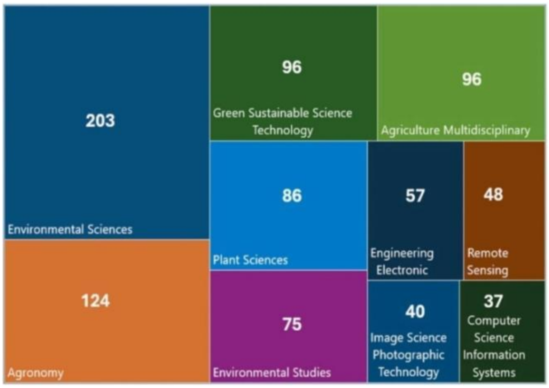


Figure 2. The most prominent Web of Science categories for research works in the agriculture and new technologies domain (Gamage et al., 2024)

Gamage et al. (2023) used two main databases, the Science Citation Index Expanded (SCI-E) and the Social Science Citation Index (SSCI), which cover more than 20.000 journals, books, and conferences in the Web of Science Core Collection, for the estimation the research direction of sustainability domain, Results are shown in Figure 3. The tree map chart showcases the ten most prominent Web of Science categories for research works in the agriculture and new technologies domain by the results of Gamage et al. (2023).

Treemap chart showcases the ten most prominent Web of Science categories for research works in the agriculture and new technologies domain by the results of Gamage et al. (2024). Obtain results in these studies indicate that the research works related to Environmental Sciences, Agronomy, Green Sustainable Science Technology, and Agriculture Multidisciplinary have been exhibiting exceptional performance. To be relevant to the Sustainable Development Goals, more scientific activity should be conceived and produced outside of high-income countries, but the current imbalances severely curtail the capacity of many low- and middle-income countries to attain the Goals by generating context-specific solutions in their region (UN, Progress towards the Sustainable Development Goals, 2023).

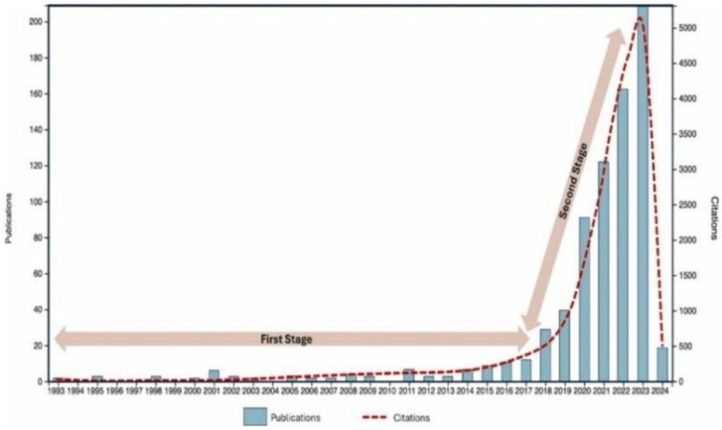


Figure 3. Changes in the number of publications related to Sustainable Agriculture and New Technology from 1993 to 2024 (Gamage et al., 2024)

The scientific method, based on observations and testing hypotheses, can reduce uncertainty, identify tipping points, accelerate the uptake of innovations, and lay the foundations for the next frontier of ideas (Haas, 1992). Figure 3 presents changes in the number of publications related to Sustainable Agriculture and New Technology from 1993 to 2024. The breakeven point could be 2018 year (second stage) which has seen a significant increase in the number of publications, with 200 published works per year and citation counts reaching an impressive 5000 annually by 2023. The surge in publications related to Sustainable Agriculture and New Technology after 2018 can be attributed to several key factors, including heightened concerns about climate change, advancements in digital agriculture, and increased policy support for sustainable farming practices (Gamage et al., 2024). Also, the international community has created platforms through which scientists, policymakers, and knowledge brokers can interact and capitalize on the latest information, with a wide range of other knowledge intermediaries, including universities, think tanks, and Indigenous and local communities. In the UN report Progress Towards the Sustainable Development Goals (2023), are point panels: the Montreal Protocol for the Ozone Layer (1987), the Intergovernmental Panel on Climate Change (1988), and the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (2012).

Agriculture often places significant pressure on natural resources and the environment and sustainable agricultural practices are intended to protect the environment, expand the Earth's natural resource base, and maintain and improve soil fertility (NIFA, 2024). Studies of different types of natural and human systems have taught us that systems that survive over time usually do so because they are highly resilient, adaptive, and have high diversity (Brodt et al., 2011). Mention authors explain that:

1. Resilience is critical because most agroecosystems face conditions (including climate, pest populations, political contexts, and others) that are often highly unpredictable and rarely stable in the long run.
2. Adaptability is a key component of resilience, as it may not always be possible or desirable for an agroecosystem to regain the precise form and function it had before a disturbance, but it may be able to adjust itself and take a new form in the face of changing conditions.
3. Diversity often aids in conferring adaptability, because the more variety that exists within a food system, whether in terms of types of crops or cultural knowledge, the more tools and avenues a system will have to adapt to change.

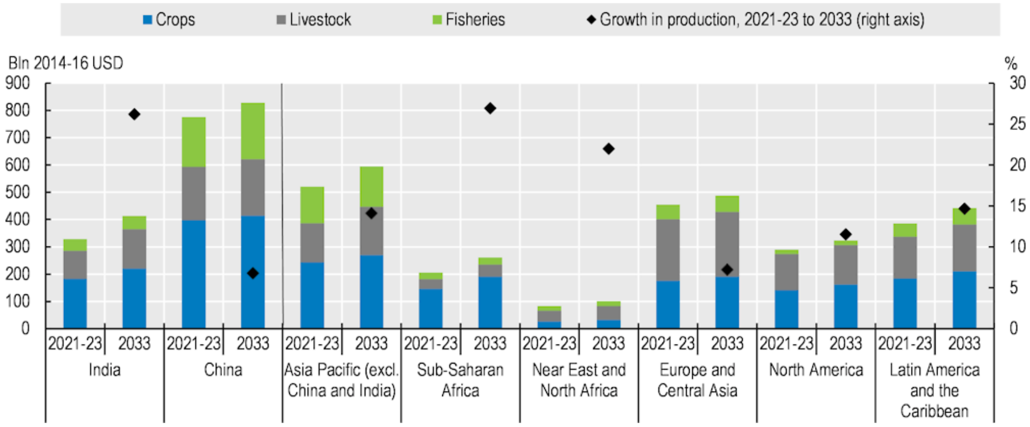


Figure 4. Trends in global agricultural production, OECD 2024, www.oecd.org/en/publications/oecd-fao-agricultural-outlook-2024-2033_4c5d2cfb-en.html

Over the next ten years 2024-2033, the value of global agricultural production is projected to increase by 1.1% annually (measured at constant prices) (OECD, 2024). Middle- and low-income countries are expected to remain the main locations of global agricultural expansion (Figure 4), contributing nearly 80% of global agricultural output by the end of the OECD projections period. In OECD-FAO Agricultural Outlook 2024-2033, highlights that developed economies are expected to derive growth primarily from productivity gains, given the long-term decline in agricultural land use, but stricter regulations related to environmental sustainability and animal welfare may temper yield improvements if they are tightened later.

The Sustainable Development Report (formerly the SDG Index and Dashboards) is a global assessment of countries' progress towards achieving the Sustainable Development Goals. It is a complement to the official SDG indicators and the voluntary national reviews. All data presented are based on the publication by Sachs et al. (2024). In the total estimation of sustainability achievements, countries are ranked countries are ranked by their overall score. The overall score measures the total progress towards achieving all 17 SDGs. The score can be interpreted as a percentage of SDG achievement. A score of 100 indicates that all SDGs have been achieved. The top ten ranking countries and their scores are: 1. Finland (86.35), 2. Sweden (85.70), 3. Denmark (85.00), 4. Germany (83.45), 5. France (82.76), 6. Austria (82.55), 7. Norway (82.23), 8. Croatia (82.19), 9. United Kingdom (82.16), and 10. Poland (81.69). For the countries in the region, their ranking levels and scores are: 8. Croatia (82.19), 11. Slovenia (81.34), 20. Hungary (79.53), 29. Greece (78.17), 35. Serbia (77.03), 40. Romania (76.70), 42. Albania (75.03), 50. Bosnia and

Herzegovina (73.99), 51. North Macedonia (73.80), and 57. Montenegro (73.05). Serbia occupies a solid position compared to the countries in the region, indicating the efforts made to reach sustainability development goals according to the UN agenda. Each country's actions can have positive or negative effects on other countries' abilities to achieve the SDGs. The Spillover Index assesses such spillovers along three dimensions: environmental and social impacts embodied in trade, economy and finance, and security, (Sachs et al., 2024). A higher score means that a country causes more positive and fewer negative spillover effects. For Serbia, the spillover score is 85.98/100, and the spillover rank is 106/166, which indicates that positive changes are made and improvements to achieve the sustainability goals.

3. INNOVATION IN SUSTAINABLE AGRICULTURE

The rapid pace of advancement and innovation in future technologies is poised to significantly influence the stability and productivity of agriculture, especially the development and dissemination of new agricultural technologies are particularly impactful for the world’s 475 million small farms (Gamage et al., 2024). The agricultural sector stands poised for significant growth with the advent of novel technological advancements such as precision agriculture, biotechnology, IoT and automation, and enhanced supply chain management, Figure 5. Agriculture sustainability is among the core elements of the fourth industrial revolution in line to meet the challenges of increasing demands of the rising global population (expected to be 9.9 billion by the year 2050) and climate change (Sarfraz et al., 2023).On the demographic front, globally we are likely to reach 9.7 billion by 2050 demanding an increase of food production by 70%, which would mean increased pressure on cultivable land and natural resources demanding scaling of innovations around sustainable farming systems and practices (Paroda, 2023).

Many authors agree that the top 21 innovations in sustainable farming are in areas:

1. Precision Agriculture
2. Vertical Farming
3. Hydroponics and Aquaponics
4. Cover Cropping and No-Till Farming
5. Agroforestry
6. Renewable Energy Integration
7. Biological Pest Control
8. Smart Water Management
9. Lab-Grown Meat
10. Blockchain for Supply Chain Transparency
11. Farm Automation
12. IoT in Agriculture
13. Geographic Information Systems in Agriculture
14. AI/ML and Data Science in Agriculture Technology
15. Regenerative Agriculture
16. Controlled Environment Agriculture
17. Agricultural Robotics
18. Drones
19. Agricultural Biotechnology
20. Big Data and Analytics
21. Connectivity Technologies

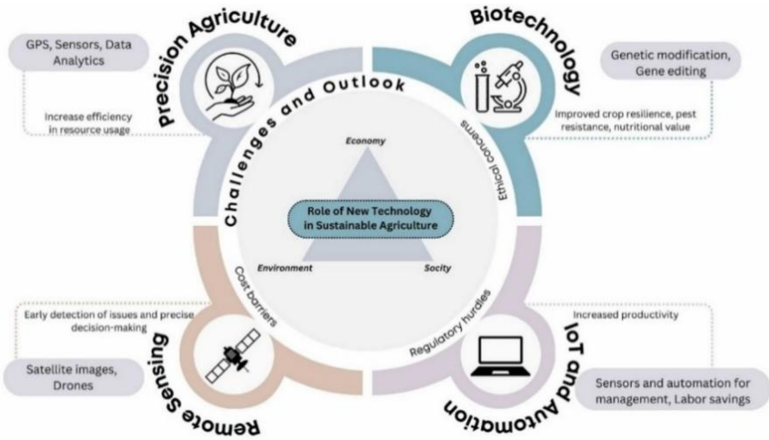


Figure 5. A simplified diagram outlining the role of new technology in sustainable agriculture (Gamage et al., 2024)

According to the Agency Grand View Research, the global innovation management market size projection was estimated at USD 1.55 billion in 2023 and is expected to grow at a compound annual growth rate (CAGR) of 9.7% from 2024 to 2030. Various factors, such as the increased focus on innovation, the need for faster innovation cycles, customer demand for new and personalized products, and the rise in advanced technologies collectively drive the market growth, (Grand View Research). The international Agency Markets and Markets™ reports that the Global Innovation Management Market size is projected to grow from USD 1.3 billion in 2023 to USD 2.1 billion by 2028, at a Compound Annual Growth Rate (CAGR) of 10.8% (Figure 6).

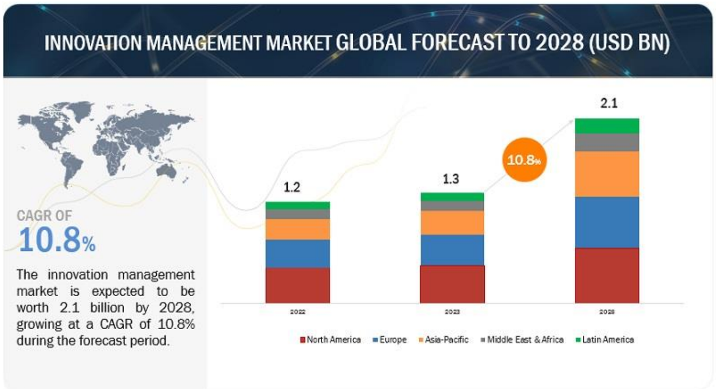


Figure 6. Global Innovation Management Market projection, Agency Markets and Markets™

With this higher CAGR of 10.18%, Markets and Markets™, in their report explains that technological advances act as a catalyst for innovation management, creating novel pathways that reshape industries, and emerging technologies drive new product development, offering innovative solutions beyond imagination. Innovation management, with its emphasis on optimizing resource allocation and minimizing operational costs, serves as a strategic catalyst for driving the growth of innovation within organizations.

World Intellectual Property Organization has published The Global Innovation Index 2024 (GII) ranks the most innovative economies in the world in 2024 amongst 133 economies and unveils the world's top S&T innovation clusters (WIPO, 2024). Europe still hosts the highest number of innovation leaders among the top 25-15 in total, with seven among the top 10. Out of the 39 European economies covered, only nine move up the ranking this year (10 fewer than last year):

namely, Austria (17th), Ireland (19th) and Luxembourg (20th) (the latter two both entering the top 20), Spain (28th), the Czech Republic (30th) (entering the top 30), Poland (40th) (entering the top 40), Croatia (43rd), Serbia (52nd), and Montenegro (65th) (reaching the top 70). Serbia gets closer to the top 50 with a strong performance in Domestic industry diversification (11th), ICT services exports (12th), Scientific and technical articles (13th), and Cultural and creative services exports (14th).

The EU research and innovation policy framework supports the transition towards maintainable, innovative, and comprehensive food systems that respect planetary boundaries, and the implementation of these systems will benefit human health, the climate, the planet, and communities (Varzakas and Smaoui, 2024). However, sustainable transitions can also fail or veer off along undesirable pathways. This might, for example, be the result of lock-ins to old technologies and practices, political opposition or backlash from vested interests or affected communities, stubborn social norms and behaviors that are difficult to change, or gaps in human, financial, and institutional capacities or supporting infrastructure (UN, Progress towards the Sustainable Development Goals, 2023).

4. CONCLUSION

Adopted in 2015 as part of the 2030 Agenda for Sustainable Development, the SDGs consist of 17 goals designed to address critical environmental, social, and economic challenges, with several goals directly influencing sustainable agriculture. Such as SDG 2 (Zero Hunger), SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), and SDG 9 (Industry, Innovation, and Infrastructure). Serbia occupies a solid 35. position rank compared to the countries in the region, indicating the efforts made to reach sustainability development goals according to the UN agenda. The spillover score for Serbia is 85.98/100, and the spillover rank is 106/166, which signifies that positive changes are made. Improvements to achieve sustainability goals, especially in the field of innovation development, in our country are done through Domestic industry diversification, ICT services exports, Scientific and technical articles, and Cultural and creative services exports.

5. REFERENCES

Gamage, A., Gangahagedara, R., Subasinghe, S., Gamage, J., Guruge, C., Senaratne, S., Randika, T., Rathnayake, C., Hameed, Z., Madhujith, T., Merah, O. (2024). Advancing sustainability: The impact of emerging technologies in agriculture Current Plant Biology, 40,100420, ISSN 2214-6628

Brodt, S., Six, J., Feenstra, G., Ingels, C., Campbell, D. (2011). Sustainable Agriculture. Nature Education Knowledge, 3(10), 1.

NIFA (2024). National Institute of Food and Agriculture, U.S. Department of Agriculture www.nifa.usda.gov/topics/sustainable-agriculture

Chbika, S., Rkhaila, A., Rahali, K., Kouddane, N., Berrid, N., Aouane, M. (2023). Natural Resources, Agriculture, and the Environment: From Traditional Practices to Modern Challenges and Solutions, 23, 325-330.

Purvis, B., Mao, Y., Robinson, D. (2019). Three pillars of sustainability: in search of conceptual origins. Sustain Sci., 14, 681–695. doi.org/10.1007/s11625-018-0627-5

Caldwell, L.K. (1984). Political aspects of ecologically sustainable development. Environ Conserv., 11, 299–308.

Mebratu, D. (1998). Sustainability and sustainable development: historical and conceptual review. Environ Impact Assess Rev., 18, 493-520.

World Wildlife Fund (1980). World conservation strategy: Living resource conservation for sustainable development (Vol. 1). Gland, Switzerland: IUCN.

Rehman, A., Farooq, M., Lee, DJ. et al. (2022). Sustainable agricultural practices for food security and ecosystem services. Environ Sci Pollut Res., 29, 84076-84095 doi.org/10.1007/s11356-022-23635-z

Varzakas, T., Smaoui, S. (2024). Global Food Security and Sustainability Issues: The Road to 2030 from Nutrition and Sustainable Healthy Diets to Food Systems Change. Foods, 13(2), 306. doi: 10.3390/foods13020306. PMID: 38254606; PMCID: PMC10815419

United Nations (2023). The Sustainable Development Goals Report 2023. https://sdgs.un.org/goals https://digitallibrary.un.org/record/4053200?v=pdf

United Nations (3023). The Sustainable Development Report. https://sdgs.un.org/gsdr/gsdr2023

United Nations, Department of Economic and Social Affairs, Sustainable Development. Sustainable development goals,https://sdgs.un.org/goals#:~:text=The%20%EE%80%802030%EE%80%81%20Agenda%20for%20Sustainable%20Development,adopted

United Nation (2023). Progress towards the Sustainable Development Goals. Sustainable Development Economic and Social Council General Assembly Seventy-ninth Session Item 18 of the preliminary list. High-level political forum on sustainable development, convened under the auspices of the Economic and Social Council Available online https://unstats.un.org/sdgs/files/report/2024/SG-SDG-Progress-Report-2024-advanced-unedited-version.pdf

European Commission (2021). The European Green Deal: Striving to Be the First Climate-Neutral Continent. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en (Accessed on 29 December 2024).

Buckwell, A., Capodieci, G.L., Graeff, R.De., Dijkhuizen, A., Frabetti, E., Large, A., Reynolds, C., Rosati, A., Scholten, M., Schreiber, R., Tice, G., Verdonk, D.J., Williams, A., Kanli, A., Chavez, M. (2015). Sustainable Livestock Production in Europe A Question of Food Security, Climate and Innovation.

Haas, P.M. (1992). Introduction: Epistemic Communities and International Policy Coordination. International Organization, 46(1), 1-35. www.jstor.org/stable/2706951

United Nations Environment Programme Ozone Secretariat (2022).

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (2023).

The Intergovernmental Panel on Climate Change (2023).

OECD/FAO (2024). Agricultural Outlook 2024-2033. OECD Publishing, Rome. doi.org/10.1787/4c5d2cfb-en

Sachs, J.D., Lafortune, G., Fuller, G. (2024). All data presented on this website are based on the publication The SDGs and the UN Summit of the Future. Sustainable Development Report 2024. Paris: SDSN, Dublin: Dublin University Press. 10.25546/108572. ISBN: 978-0-903200-18-9

Grand View Research (2024). www.grandviewresearch.com/industry-analysis/innovation-management-market-report. (Accessed 31. January 2024)

Markets and Markets™ (2024) www.marketsandmarkets.com/Market-Reports/innovation-management-market-238981272.html. (Accessed 31. January 2024)

World Intellectual Property Organization (WIPO) (2024). Global Innovation Index 2024: Unlocking the Promise of Social Entrepreneurship, Geneva, WIPO. 10.34667/tind.5006.

Sarfraz, S., Ali, F., Hameed, A., Ahmad, Z., Riaz, K. (2023). Sustainable Agriculture Through Technological Innovations. In: Prakash, C.S., Fiaz, S., Nadeem, M.A., Baloch, F.S., Qayyum, A. (Eds.) Sustainable Agriculture in the Era of the OMICs Revolution. Springer, Cham. doi.org/10.1007/978-3-031-15568-0_10

Paroda, R. (2023). Sustainable Agriculture and the Environment. Farooq, M., Gogoi, N., Pisante, M. (Eds.). Academic Press, Page xv, ISBN 9780323905008, doi.org/10.1016/B978-0-323-90500-8.00021-X.

doi:10.46793/MAK2025.338M

CLIMATE CHANGES BETWEEN TWO STANDARD PERIODS IN MONTENEGRO (1961-1990 AND 1991-2020) USING THE THORNTHWAITE MOISTURE INDEX

Jovan Mihajlović[1], Dragan Burić[1], Ivana Penjišević[2*], Jovan Dragojlović[2], Miroslav Doderović[1]

[1]University of Montenegro, Faculty of Philosophy, Department of Geography, Nikšić, Montenegro
jovanm@ucg.ac.me, buricd@ucg.ac.me, miroslavd@ucg.ac.me
[2]University of Priština in Kosovska Mitrovica, Faculty of Sciences and Mathematics, Kosovska Mitrovica, Serbia, *ivana.penjisevic@pr.ac.rs, jovan.dragojlovic@pr.ac.rs

Abstract: One of the models for differentiating climates in each area is the Thornthwaite Climate Classification (TCC). To analyze climate changes in Montenegro, using the criteria underlying the TCC, this study aims to classify the country's climate across two standard climatic periods: 1961-1990 and 1991-2020. Using the Thornthwaite Moisture Index (PE), a bioclimatic delineation of regions with varying degrees of moisture in Montenegro was first conducted for the entire period (1961-2020), and subsequently for the two aforementioned subperiods (1961-1990 and 1991-2020). The study utilized air temperature and precipitation data from 18 meteorological stations (MS). All calculations were performed on a monthly basis using the PAST 4.13 software package, while the maps were created using QGIS 2.8.1. For mathematical modeling of the cartographic representation of the Thornthwaite climate classification, the Inverse Distance Weighted (IDW) geostatistical interpolation method was applied. The results, spanning a 60-year period, indicate that the Thornthwaite Moisture Index (PE) values range from 631.5 (MS Crkvice), corresponding to a humid (A) climate, to 95 (MS Pljevlja), indicating a humid (B) climate. The majority of meteorological stations in Montenegro exhibit values of this index that classify them within the A climate. The average RE value across the 18 meteorological stations for the 60-year period is 198.3, indicating that Montenegro's climate was generally humid overall. Based on PE values, the lowest effects were observed at stations in the northern and northeastern regions of Montenegro, as well as in the far southeast, while the highest effects were recorded at stations in the southwestern and western parts of the country. This can be linked to the spatial distribution and precipitation patterns across Montenegro's territory. The bioclimatic classification based on PE for the two subperiods reveals certain climate changes in Montenegro. Specifically, the A climate was represented at 66.7% of meteorological stations during the first period (1961-1990) and at 61.1% during the second period (1991-2020). Conversely, the B climate was represented at 33.3% of stations in the first period and at 38.9% in the second, indicating a slight aridification of the climate in the latter subperiod. Sub-humid (S), semi-arid (D), and arid (E) climates were not observed at any of the meteorological stations included in the analysis.

Key words: Climate change, Climate classification, Standard climate periods, Thornthwaite Moisture Index, Montenegro

1. INTRODUCTION

Thornthwaite, an American geographer and climatologist, introduced a rational approach to climate classification based on the complex relationship between potential evapotranspiration and precipitation (Thornthwaite, 1931, 1943, 1948; Feddema, 2005; Carter and Mather, 1966). "We cannot say whether a climate is humid or dry based solely on precipitation; we must know whether precipitation is greater or less than potential evapotranspiration" (Thornthwaite, 1948). In fact, Thornthwaite (1931) introduced the Precipitation Effectiveness Index (P/E), defined as the ratio of precipitation (P) to evaporation (E). He developed the formula for this index by examining the complex relationships among three variables in the western United States: precipitation, temperature, and evaporation. Thornthwaite himself acknowledged in his work that applying his formula to other regions of the world represents an "insufficiently justified extrapolation." Unlike Köppen's and most other classifications available at the time, Thornthwaite’s method delved deeper into the relationship between precipitation, vegetation, and the effects of evapotranspiration. Thornthwaite criticized Köppen's system for not accounting for a "rational" variable such as evaporation. Today, Thornthwaite's classification system from 1948, which is based on the complex concept of potential evapotranspiration (PE), holds the greatest significance. This new approach considers water loss through the combined processes of evaporation and transpiration in plants. However, Thornthwaite’s approach to climate classification is now primarily of historical importance and has not gained widespread global application (Sanderson, 1999). In the study by Carter and Mather (1966), all of Thornthwaite's contributions resulting from his classification were described in detail.

Figure 1 shows a map of the distribution of Thornthwaite’s main climate types on Earth, which the author himself published with David I. Blumenstock in the Yearbook of Agriculture in 1941 (Climate and Man; Yearbook of Agriculture, “Climate and the World Pattern,” 1941). According to Field (2005), Thornthwaite’s collaborators worked on collecting the climatic data necessary for his empirical equations on a global scale. Another drawback of Thornthwaite’s classification of the Earth’s climate was the complexity of its interpretation for everyday use, a challenge recognized by John “Russ” Mather, whose idea was to create such a map (Feddema, 2005). Thornthwaite made two attempts to improve the “moisture” criteria, incorporating class intervals into his system (Feddema, 2005; Thornthwaite, 1943, 1948).

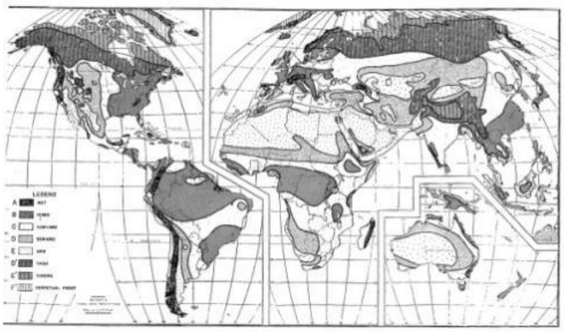


Figure 1. Distribution of main climate types on Earth
(Blumenstock and Thornthwaite, 1941)

The first simplified map of Thornthwaite’s climate classification on a global scale was provided by Feddema (2005). According to the same author (Feddema, 2005), the world map of Thornthwaite’s climatic provinces was created using adapted empirical equations and data from gridded monthly values of temperature and precipitation at a half-degree resolution of latitude and longitude, as well as a water balance model (Legates and Willmott, 1990; Mather, 1978). Figure 2 shows the climate types on Earth based on Thornthwaite’s 1948 Moisture Index (left) and the climatic provinces according to Thornthwaite’s nomogram (right).

Based on data from 96 meteorological stations for the periods 1925-1940 and 1946-1958, a generalized climate classification of the former SFR Yugoslavia was made according to Thornthwaite.

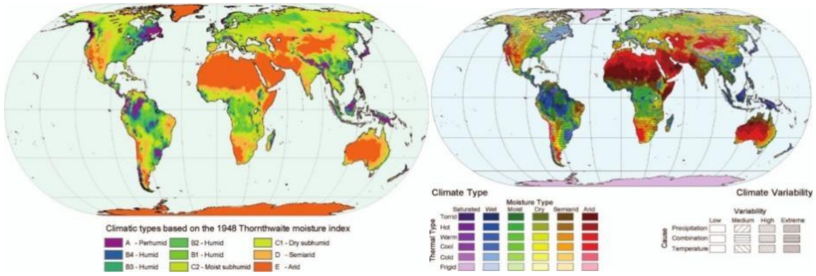


Figure 2. Map of climate types based on Thornthwaite's 1948 Moisture Index (left) and map of climate types according to Thornthwaite (right) (Feddema, 2005)

According to the map of the SFR Yugoslavia according to Thornthwaite (Figure 3), it can be concluded that only climate types belonging to the humid climate (B, C, and A) are present in the mentioned territory. The existence of an arid climate was not determined (Obuljen, 1979). Using the criteria established by Köppen, Burić et al. (2014) provided a detailed climate classification for Montenegro for the period 1961-1990. However, the classification of climate categories according to Thornthwaite for the territory of Montenegro has never been done before.

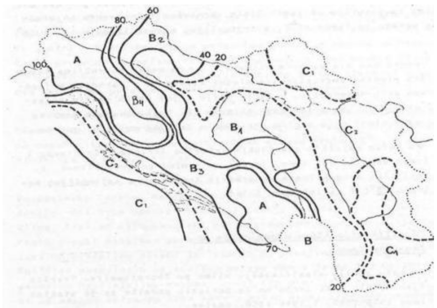


Figure 3. Map of climate classifications according to Thornthwaite for the former SFRY created using the isoline method: B-semihumid climate; C-humid climate; A-moist climate (Obuljen, 1979)

The main objective of this study is to perform a bioclimatic delineation of regions with varying degrees of humidity in Montenegro using the Thornthwaite Moisture Index. The following initial hypotheses were formulated: (*h1*) Climate classification according to Thornthwaite is largely conditioned by dynamic-orographic factors, i.e., the result of differences in the spatial distribution and annual variation of air temperature and precipitation in Montenegro; (*h2*) Between the two 30-year standard climate periods, changes have occurred in the spatial distribution and variation of climatic classification categories according to Thornthwaite.

2. MATERIAL AND METHODS

Montenegro occupies the southernmost part of the Adriatic and, in terms of its territory size (13,812 km²), ranks among the smaller countries in the Mediterranean. In relation to the great circle - the equator, Montenegro's mathematical-geographical position is determined by the parallels $\varphi=+41^{0}50'$ and $\varphi=+43^{0}32'$, and meridians $\lambda=+18^{0}26'$ and $\lambda=+20^{0}21'$. In terms of hypsometry, the absolute elevation difference between the lowest and highest points is 2.534 meters. Along with the mathematical-geographical position, proximity to the Adriatic Sea, orography, and the dissection of the relief, the climate of Montenegro is also greatly influenced by the synoptic patterns throughout the year (Burić et al., 2023).

A 60-year dataset (1961-2020) was used, covering air temperature and precipitation totals from 18 meteorological stations (MS) (Figure 4). The mentioned 60-year period was divided into two standard climate subperiods: 1961-1990 and 1991-2020, in order to detect potential changes in the spatial distribution of the climate. The analysis was performed on a multi-year monthly basis, and the calculations were carried out using the software package *PAST 4.13*[16], and the maps were drawn using the software *QGIS 2.8.1*[17].

Figure 4. Display of meteorological stations (MS) used in the analysis on the hypsometric map

In the modern period, the most significant is Thornthwaite's 1948 classification, which is based on the complex concept of potential evapotranspiration (PE). This new approach considers water loss through the combined process of evaporation and transpiration by plants. Thornthwaite (1948) proposes his evaporation equation:

$$E = 1.6 \times 10t / I^b , \quad (1)$$

where $\boldsymbol{E}$ is evaporation, $\boldsymbol{t}$ is the monthly temperature, $\boldsymbol{I}$ is the heat index, and $\boldsymbol{b}$ is a constant. Thornthwaite (1948) then introduces the term "thermal efficiency" instead of the term evaporation, so the equation for potential evapotranspiration takes the following final form:

$$PE = P / E , \quad (2)$$

where $\boldsymbol{P}$ is the monthly precipitation (cm) and $\boldsymbol{E}$ is "thermal efficiency" (evaporation) (cm).

Thornthwaite (1931) proposed his empirical classification using complex equations, which result in the precipitation effectiveness index (PE). This index is obtained by establishing the ratio between monthly precipitation totals (P) and monthly evaporation (E) on an annual basis as the sum of the 12-month values of these two parameters (P/E). Since evaporation is measured at a small number of stations, Thornthwaite (1931) introduced a complex equation that shows the relationship of P/E as a function of the monthly precipitation amount (mm) and the mean monthly temperature (°C). Thornthwaite arrived at this equation by examining the relationship between temperature, precipitation, and evaporation at 21 stations in the western part of the U.S., where evaporation was measured over a period of 4-12 years, from April to September (Vujević, 1956; Radinović, 1984). The equation is as follows:

[16] https://folk.uio.no/ohammer/past/
[17] www.qgis.org/en/site/

$$PE = \sum_{1}^{n=12} 1.65 \times (p/t + 12.2)^{10/9},$$

(3)

where ***p*** represents the monthly precipitation (mm), and ***t*** the monthly temperature (°C).

Thornthwaite (1931) notes that the application of equation (3) to other areas and periods of the year represents an insufficiently justified extrapolation. This equation (3) yields good results for a temperature range between 5°C and 30°C. Equation (3) is obtained by determining the sum of the ratios P/E for each month of the year and multiplying by a factor of 10 to eliminate fractions. This equation (3) is the basic quantity for climate classification according to the moisture index. A drawback is that it is not possible to derive the amount of water available to plants from temperature and precipitation alone (Radinović, 1984). Based on equation (3), Thornthwaite (1931), by comparing the values from the moisture index with vegetation in different areas, defined five different climate classification categories, which are presented in Table 1.

Table 1. Climate classification based on the moisture index (PE) according to Thornthwaite 1931 (Vujević, 1956)

Climate type	Symbol	Vegetation type	PE index
Humid	A	forest with persistent rain	>128
Humid	B	forest	64-127
Sub-humid	C	grassland	32-63
Semi-arid	D	steppe	16-31
Arid	E	desert	<16

The calculation of these climate types, especially the PE index, is also possible using Thornthwaite's nomogram, which is an adaptation of the classification from 1931. The nomogram is shown in Table 2.

Table 2. Thorntwaite's nomogram of climate types (Essenwanger, 2001)

<table>
<tr><td>0</td><td colspan="5">F' Frost</td><td>F’</td></tr>
<tr><td>16</td><td colspan="5">E' Tundra</td><td>E'</td></tr>
<tr><td>32</td><td colspan="5">D' Taiga</td><td>D'</td></tr>
<tr><td>64</td><td rowspan="3">E Desert</td><td rowspan="3">D Steppe</td><td rowspan="3">C Grassland</td><td rowspan="3">B Forest</td><td rowspan="3">A Forest with persisten rain</td><td>C'</td></tr>
<tr><td rowspan="2">128</td><td>B'</td></tr>
<tr><td>A'</td></tr>
<tr><td></td><td colspan="5">PE index</td><td></td></tr>
</table>

Finally, Thornthwaite (1933), similar to Köppen, distinguishes climates based on the amount of precipitation a specific area receives throughout the year, by seasons. Therefore, he introduces a third letter (Table 3) in his formula, which defines the precipitation regime.

Table 3. Third letter according to Thornthwaite (1933)

Letter	Precipitation Regime Throughout the Year
r	precipitation is evenly distributed throughout the year
s	summer precipitation deficit
w	winter precipitation deficit
d	precipitation deficit in all seasons

Since not every climate can have every precipitation regime, i.e., every letter, this relationship according to Thornthwaite (1933) is shown in Table 4.

Table 4. Climate type and precipitation regime according to Thornthwaite (1933)

Climate type	Third letter (precipitation regime)
Humid (A)	r
Humid (B)	r, s, w
Sub-humid (C)	r, s, w, d
Semi-arid (D)	s, w, d
Arid (E)	d

Thornthwaite (1933) in his formula does not define the shift of extremes in the precipitation regime. In this sense, the authors propose an addition to Thornthwaite's formula by introducing a fourth letter that will more accurately describe the climate of a place or territory, i.e., complement the existing formula. The modification is presented in Table 5.

Table 5. Climate type accodrding to Thornthwaite (1933) and shift of extremes according to the authors

<table>
<tr><th>Climate type</th><th>Fourth letter
(shift of extremes)</th></tr>
<tr><td>Humid (A)</td><td rowspan="4">m' - maximum precipitation in the summer months
m'' - maximum precipitation in the winter months
m''' - maximum precipitation in late spring or late autumn</td></tr>
<tr><td>Humid (B)</td></tr>
<tr><td>Sub-humid (C)</td></tr>
<tr><td>Semi-arid (D)</td></tr>
<tr><td>Arid (E)</td><td>------</td></tr>
</table>

By applying Thornthwaite's formula, it is possible to arrive at 120 different climatic classification categories, which can pose a problem when creating a map or determining the climate in different parts of the Earth. Therefore, Thornthwaite (1933) created a map of the North American continent with 32 climatic categories for his classification. Finally, the formula according to Thornthwaite would have the following form (according to the authors):

$$\mathrm{TH} = N + N' + n + (n'), \tag{4}$$

where N is the first letter that denotes the climate type based on humidity, N' represents the type of vegetation related to the humidity type, n indicates the precipitation regime, and n' is the letter that denotes the occurrence of the precipitation maximum during the year. By applying this formula, the climate of the meteorological station in Podgorica ($\varphi=+42^{0}26'$, $\lambda=+19^{0}16'$) for the period 1961-2020 can be defined:

MS Podgorica – *AA's(m''')*,

it reads: a humid climate with forest, with persistent rain as the dominant type of vegetation, and a summer precipitation deficit with a precipitation maximum in late autumn.

For the mathematical modeling of the cartographic representation of Thornthwaite's climatic classification, the Inverse Distance Weighted (IDW) geostatistical interpolation method was used. In this geostatistical method, sample points are measured during interpolation so that the influence of one point on another decreases with the distance from the unknown point that you want to create. The weight measurement is assigned to the sample points using a weighting coefficient that controls how the influence of the weight decreases as the distance from the new point increases. The higher the weighting coefficient, the smaller the effect the points will have if they are far from the unknown point during the interpolation process. As the coefficient increases, the value of the unknown point gets closer to the value of the nearest observed point. This geostatistical interpolation method was used due to the complexity of Thornthwaite's formula.

The hythergraph method was used for the graphical representation of stations that are typical representatives of climates in the Thornthwaite classification system. In the specific case, temperatures (°C) are presented on the *x*-axis, and precipitation (mm) is represented on the *y*-axis. Temperatures and precipitation are entered at specific points in the coordinate system on the graph (Ducić and Anđelković, 2004), resulting in 12 points - corresponding to the 12 months of the year, marked with Roman numerals. All points are connected with lines, and as a result, hythergraphs of various shapes are obtained, which illustrate the relationship between air temperature and precipitation by month throughout the year, i.e., they "describe" the climate of a specific area.

3. RESULTS AND DISCUSSION

The analysis of the spatial distribution and variation of the humidity index (PE) according to Thornthwaite, used in the analysis, was conducted in accordance with the previously defined objectives and research hypotheses. A total of 6 thematic maps were created, specifically for climate types and for the corresponding vegetation type, for the main observation period (1961-2020), as well as for both subperiods (1961-1990, 1991-2020). A comparative method was then used to analyze the subperiods, and potential changes in the spatial distribution of the RE index were numerically defined. The maps were thoroughly analyzed and reviewed.

3.1. The first subperiod (1961-1990)

In Figure 5, for the period 1961-1990, the Thornthwaite moisture index (PE) is shown, with values ranging from 653.4 (Crkvice), i.e., a humid (A) climate with forest and constant rainfall, to 98.3 (Pljevlja), indicating a humid climate with forest as vegetation. The absolute difference in the moisture index (PE) between these two meteorological stations in this period is 555.1. The high mountainous areas of western and southwestern Montenegro, as well as the central region, represent the wettest and spatially largest climatic region in Montenegro with forest and constant rainfall. In addition to the meteorological station Crkvice, another 11 meteorological stations have characteristics of a humid (A) climate, i.e., the largest percentage of stations fall into this category (12 out of 18 stations, or 66.7% of the stations). Figure 5 shows the range of climatic classification categories from humid (V) to wet (A) climates.

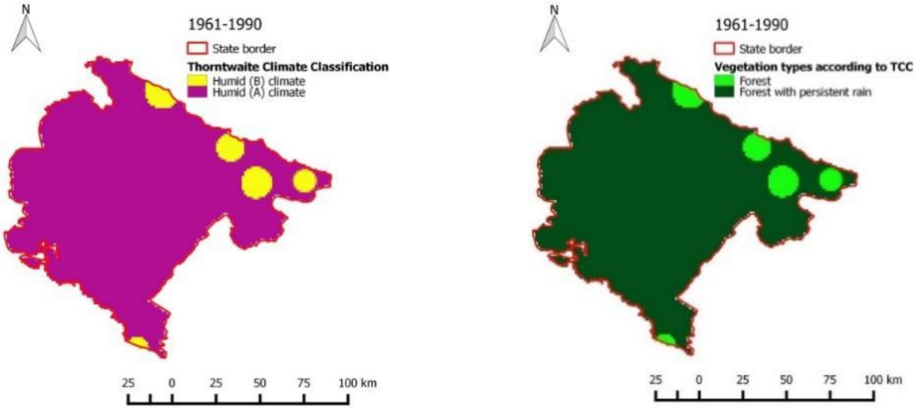


Figure 5. Thornthwaite classification according to the moisture index (PE) (left) and vegetation types (right) for 1961-1990

The highest and lowest values of the Thornthwaite moisture index (PE) are given in Table 6.

Table 6. Meteorological stations (MS) with maximum and minimum values of PE for the period 1961-1990

Max *PE*					Min *PE*				
MS	φ[o]	λ[o]	*h*	*PE*	MS	φ[o]	λ[o]	*h*	*PE*
Crkvice	42.57	18.63	937	653.4	Pljevlja	43.35	19.35	784	98.3
Cetinje	42.38	18.93	640	430.3	B. Polje	43.03	19.73	606	109.4
Kolašin	42.83	19.52	944	313.2	Berane	42.83	19.88	691	110.4
Žabljak	43.15	19.12	1450	238.2	Ulcinj	41.92	19.22	1	116.4
Krstac	43.00	18.70	1017	236.4	Rožaje	42.85	20.17	1012	123.6

The humid (B) climate was confirmed in a total of 6 meteorological stations (or 33.3% of the total number of stations), located in the northeastern, southeastern, and northern parts of Montenegro. It can be said that this is consistent with the results of previous studies and the physical-geographical characteristics of these regions of Montenegro. The average value of Thornthwaite's humidity index (PE) for 18 stations over the 30-year period is 205.9, indicating that the climate of Montenegro during this period was humid (A) with forest and constant rain as the dominant type of vegetation. According to Thornthwaite's humidity index (PE), the lowest effects were discovered at stations in the extreme northeastern and southeastern parts, as well as at the Pljevlja station. The highest effects were recorded at stations in the southwest, west, and extreme south of Montenegro. This can be related to the spatial distribution and precipitation regime across the territory of Montenegro.

3.2. The second subperiod (1991-2020)

Figure 6 shows the values of the Thornthwaite moisture index (PE) for the period 1991-2020. The values of this index range from a wet (A) climate at the Crkvice station (610.9) to a humid (B) climate at the Pljevlja station (92.1). The absolute difference in the moisture index (PE) between these two stations in this period is 518.8. As in the first period, the values of the moisture index (PE) are consistent with the general distribution of precipitation in Montenegro. The range of climatic classification categories is the same as in the first period, i.e., it ranges from humid (B) to wet (A) climate.

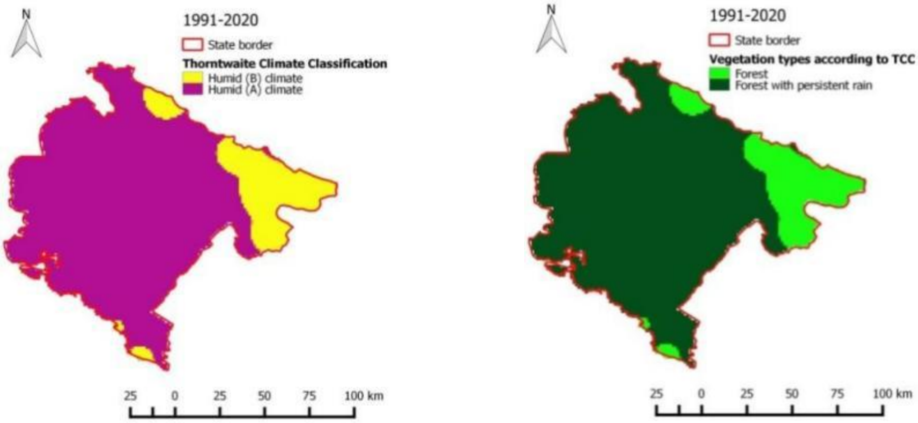


Figure 6. Thornthwaite classification based on the moisture index (PE) (left) and vegetation types (right) for 1991-2020

The highest and lowest values of the Thornthwaite moisture index (PE) are given in Table 7.

Table 7. Meteorological stations (MS) with maximum and minimum values of PE for the period 1991-2020

Max *PE*					Min *PE*				
MS	φ[o]	λ[o]	*h*	*PE*	MS	φ[o]	λ[o]	*h*	*PE*
Crkvice	42.57	18.63	937	610.9	Pljevlja	43.35	19.35	784	92.1
Cetinje	42.38	18.93	640	422.8	Berane	42.83	19.88	691	99.7
Kolašin	42.83	19.52	944	280.5	B. Polje	43.03	19.73	606	102.3
Žabljak	43.15	19.12	1450	223.6	Ulcinj	41.92	19.22	1	114.8
Nikšić	42.77	18.95	647	216.2	Plav	42.60	19.93	933	116.2

From Table 7, it can be concluded that the northeastern (MS Bijelo Polje, Rožaje, Berane, and Plav), northern (MS Pljevlja), and southeastern (MS Ulcinj and Bar) parts of Montenegro show the lowest effects of the humidity index (PE). The average value of the humidity index (PE) for the observed period is 191.03, which is 14.9 lower compared to the first subperiod. From this, it can be concluded that there were very small changes at the macro level, though these changes are still evident at certain MS in Montenegro. The result obtained in this analysis is a very important fact that can help in understanding and identifying possible signals of climate change related to global warming. The characteristics of a humid (B) climate with different RE index values are present in 11 out of the total 18 MS included in the analysis (or 61.1%), while 38.9% of MS have characteristics of a humid (B) climate with different RE index values. As in the first subperiod, the humidity index (PE) shows higher values at mountain stations that receive a larger amount of precipitation during the year, i.e., those that are under a stronger influence of maritime air masses.

If the spatial distribution and variation of Thornthwaite's humidity index (PE) in Figures 5 and 6 are compared for the periods 1961-1990 and 1991-2020, it can be concluded that changes at the macro level are visually noticeable, but also detected at certain MS. These changes are best represented by the recorded values of Thornthwaite's humidity index (PE) at the MS in the first and second subperiods of observation.

Table 8 provides a comparative overview of the values of Thornthwaite's humidity index (PE) for the two observed subperiods, 1961-1990 and 1991-2020, in order to gain a better understanding of the changes in the spatial distribution of this climatic index.

From Table 8 it can be concluded that no subhumid (S), semiarid (D), or arid (E) climate has been detected in the territory of Montenegro. The percentage of humid (B) climate ranges from 33.3% to 38.9%, indicating an increase compared to the wet (A) climate in the second subperiod. It can be said that there is a slight aridization of the climate in the second subperiod, which is in line with the trend of rising temperatures, especially in the last two decades of this 30-year climate period. The wet (A) climate has shown the least variation, from 66.7% to 61.1%.

Table 8. Classification of climate on the base according to Thornthwaite's humidity index (1931) for the periods 1961-1990 and 1991-2020

		1961-1990		1991-2020	
Climate	PE	Frequency of PE	Ratio of PE (%)	Frequency of PE	Ratio of PE (%)
Wet (A)	>128	12	66.7	11	61.1
Humid (B)	64-127	6	33.3	7	38.9
Sub-humid (C)	32-63	0	0	0	0
Semi-arid (D)	16-31	0	0	0	0
Arid (E)	<16	0	0	0	0

3.3. The entire period (1961-2020)

In Figure 7 and Table 9, the spatial distribution as well as the maximum and minimum values of the Thornthwaite Moisture Index (PE) for the 60-year observation period (1961-2020) are shown. It can be concluded that throughout the entire period (1961-2020), as well as in the two subperiods (1961-1990, 1991-2020), the territory of Montenegro was dominated by humid (A) climate with forests and persistent rain and humid (B) climate with forests as the dominant vegetation type. However, changes are noticeable at the station level. The maximum effects of the Thornthwaite Moisture Index (PE) were detected at the Crkvice station, with a value of 631.5, while the minimum effects were recorded at the Pljevlja station, with a value of 95.1. The absolute difference in the moisture index (PE) between these two stations in this period is 536.4. As in the first and second subperiods, the values of the moisture index (PE) align with the general precipitation distribution in Montenegro. The range of climatic classification categories is the same as in the first two subperiods, i.e., from humid (B) to wet (A) climate.

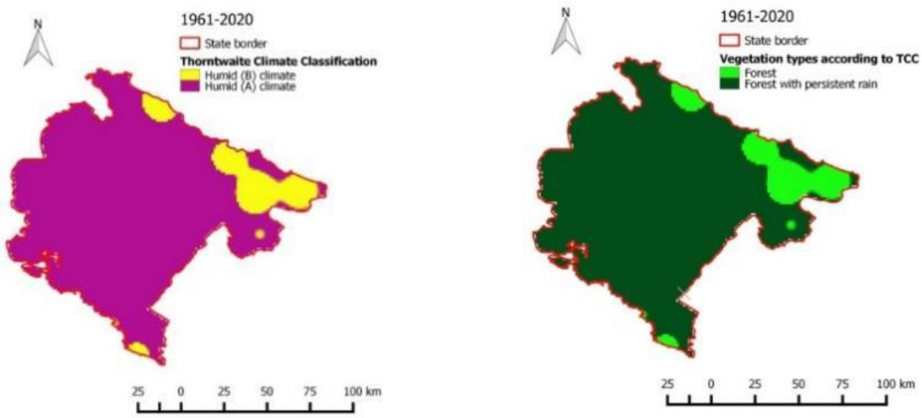


Figure 7. Thornthwaite Classification According to the Moisture Index (PE) (left) and Vegetation Types (right) for 1961-2020

Table 9. Meteorological stations (MS) with maximum and minimum values of PE for the period 1961-2020

Max *PE*					Min *PE*				
MS	φ[o]	λ[o]	*h*	*PE*	MS	φ[o]	λ[o]	*h*	*PE*
Crkvice	42.57	18.63	937	631.5	Pljevlja	43.35	19.35	784	95.1
Cetinje	42.38	18.93	640	426.5	Berane	42.83	19.88	691	104.8
Kolašin	42.83	19.52	944	296.3	B. Polje	43.03	19.73	606	105.7
Žabljak	43.15	19.12	1450	230.6	Ulcinj	41.92	19.22	1	115.6
Nikšić	42.77	18.95	647	225.7	Rožaje	42.85	20.17	1012	120.9

The comparative display of the relationship between the values of the Thornthwaite Moisture Index (PE) at the observed meteorological stations is shown in Figure 8.

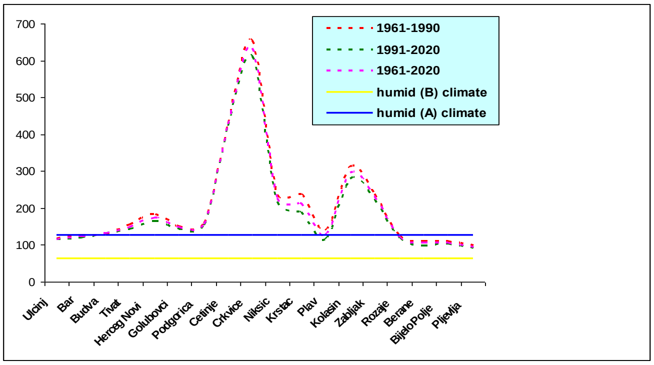


Figure 8. Comparative display of the values of the Thornthwaite Moisture Index (PE) for the eteorological stations included in the analysis for the three periods: 1961-1990, 1991-2020, and 1961-2020.

3.4. Hythergraphs Representation of Meteorological Stations as Typical Representatives of Climate Types

The annual cycle of air temperature and precipitation for two selected meteorological stations, typical representatives of the climate, is presented in hythergraphs (Figure 9 a,b,c, left and right) for MS Nikšić and MS Pljevlja. If the hythergraph is elongated horizontally, it means that there are large differences between the seasons, in this case, regarding the annual precipitation sum, as represented on the *x*-axis (MS Nikšić). If the hythergraph is spherical or similar in shape, it means that there are no significant differences between the seasons in terms of air temperature and precipitation. If the hythergraph is elongated in the vertical direction, it means that there are greater differences between the warmest and coldest months (MS Pljevlja). Both stations shown in Figure 9 (left and right) generally display an irregular, elongated shape in both the horizontal and vertical directions, which means that the annual amplitudes of temperature and precipitation are large, i.e., there are clear differences between the seasons. In Table 10, the representation of Thornthwaite's climatic formula for the meteorological stations included in the analysis for all three periods: 1961-1990, 1991-2020, and 1961-2020 is given.

Table 10. Thornthwaite's Climatic Formula for MS included in the analysis for all three periods: 1961-1990, 1991-2020 and 1961-2020, according to the authors

Meteorological station (MC)	Thornthwaite's Climatic Formula		
	1961-1990	1991-2020	1961-2020
Ulcinj	BB's (m''')	BB's (m''')	BB's (m''')
Bar	BB's (m''')	BB's (m''')	BB's (m''')
Budva	AA's(m''')	AA's(m''')	AA's(m''')
Tivat	AA's(m''')	AA's(m''')	AA's(m''')
Herceg Novi	AA's(m''')	AA's(m''')	AA's(m''')
Golubovci	AA's(m''')	AA's(m''')	AA's(m''')
Podgorica	AA's(m''')	AA's(m''')	AA's(m''')
Cetinje	AA's(m'')	AA's (m')	AA's (m'')
Crkvice	AA's(m''')	AA's(m''')	AA's(m''')
Nikšić	AA's(m''')	AA's(m''')	AA's(m''')
Krstac	AA's(m''')	AA's(m''')	AA's(m''')
Plav	BB's (m'')	AA's (m'')	BB's (m'')
Kolašin	AA's(m''')	AA's(m''')	AA's(m''')
Žabljak	AA's(m''')	AA's(m''')	AA's(m''')
Rožaje	BB'r (m')	BB'r (m')	BB'r (m')
Berane	BB's (m''')	BB's (m''')	BB's (m''')
Bijelo Polje	BB'r (m''')	BB'r (m''')	BB'r(m''')
Pljevlja	BB'r (m')	BB'r (m')	BB'r (m')
	* The shaded fields in the table indicate changes in the climatic formula between the observed periods.		

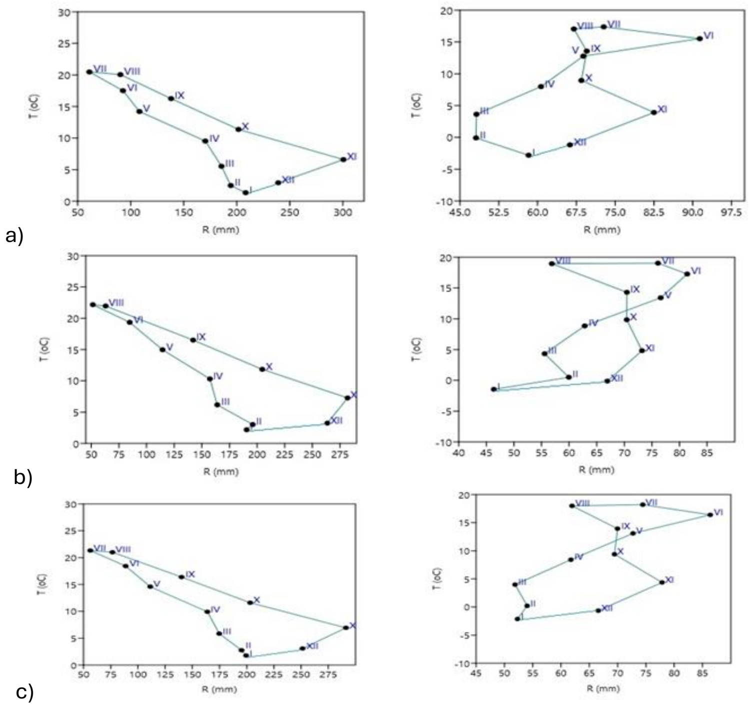


Figure 9. Hythergraphs of MS Nikšić (left) and MS Pljevlja (right) for the periods: a.) 1961-1990; b.) 1991-2020; c.) 1961-2020

4. CONCLUSION

The goal of this research was to perform a bioclimatic delineation of regions with varying degrees of humidity in Montenegro using the Thornthwaite humidity index (PE). The calculations were performed for 18 meteorological stations in Montenegro for a 60-year period (1961-2020) and two 30-year climate periods (1961-1990 and 1991-2020). The initial hypotheses *h1* and *h2* are assured. The bioclimatic classification according to the Thornthwaite moisture index (PE) indicates that, in all three observed periods, two types of climates are present in Montenegro: the humid (A) climate with forests and year-round rainfall as the dominant vegetation type, and the humid (B) climate with forests as the dominant vegetation type (in the majority of stations included in the analysis - 66.7% in the first period, and 61.1% in the second period). The humid (B) climate with forests as the vegetation type appears only at a smaller number of stations (33.3% in the first period, and 38.9% in the second period). Sub-humid (S), semi-arid (D), and arid (E) climates were not detected at any of the stations included in the analysis. The average annual Thornthwaite moisture index (PE) for all three periods indicates that the climate in Montenegro is generally characterized as a humid (A) climate with forests and year-round rainfall as the dominant vegetation type. The results presented can be said to align with the physical-geographical characteristics of the area where Montenegro is located, i.e., in accordance with the general climate-vegetation laws. The hyetograph represents two stations - Nikšić and Pljevlja, typical representatives of the humid (A) and humid (B) climates, respectively. Both stations exhibit an irregular, elongated shape in the horizontal and vertical directions, meaning that the annual amplitudes of temperature and precipitation are large, i.e., that there are clear seasonal differences. The main conclusion of this chapter is that the spatial distribution and variation of Thornthwaite's climatic classification categories are primarily determined by dynamic-orographic factors, i.e., that they are the result of differences in the spatial distribution and annual course of temperature and precipitation in Montenegro. The application of Thornthwaite's classification to the territory of Montenegro can only be justified when combined with another "supporting" classification and modifying the climate formula proposed by Thornthwaite in 1931.

Climate classification, like many other classification systems used in science and globally, is subject to criticism. Starting from the fact that no classification can necessarily be perfect in its essence, Thornthwaite's 1948 classification is of historical significance today. At the time of publishing his North American climate map and laying the theoretical foundations of his classification, Thornthwaite made a significant step in science overall and left a considerable legacy for future generations of climatologists. They would learn from his scientific discoveries and perhaps attempt to create an even "more rational" model of Thornthwaite’s classification. Today's climate classification systems use modern mathematical-statistical methods to group similar climates into specific categories, and such methods rely on lesser-known algorithms that use one or more inputs (climatic variables). These statistical models have proven scientifically legitimate in many cases, as evidenced by numerous recent scientific studies in climatology, while physical classification models, such as Köppen’s and Thornthwaite's, remain as a benchmark for future climate classification research on Earth.

5. ACKNOWLEDGMENT

The study was supported by project No: 451-03-65/2024-03/200123.

6. REFERENCES

Burić, D., Ducić, V., Mihajlović, J. (2014). Klima Crne Gore: Modifikatori i tipovi - drugi deo. Glasnik Srpskog geografskog društva, 94(1), 73-90.

Burić, D., Mihajlović, J., Ducić, V. (2023). Climatic Regionalization of Montenegro by Applying Different Methods of Cluster Analysis. Geographica Pannonica, 27(2), 119-131. doi.org/10.5937/gp27-43776

Carter, D.B., Mather, J.R. (1966). Climatic classification for environmental biology. Puhlications in Climatology, 19(1), 305-395.

Ducić, V., Anđelković, G. (2004). Climatology. Practicum textbook for geographers. Faculty of Geography, Belgrade. /in Serbian/

Feddema, J.J. (2005). A revised Thornthwaite-type global climate classification. Physical Geography, 26, 442-466.

Field, R.T. (2005). John Russell (Russ) Mather at the Laboratory of Climatology. Physical Geography, 26, 434-441.

Legates, D.R., Willmott, C.J. (1990). Mean seasonal and spatial variability in global surface air temperature. Theoretical and Applied Climatology, 41, 11-21.

Mather, J.R. (1978). The Climatic Water Budget in Environmental Analysis. Lexington, MA: Lexington Books.

Obuljen, A. (1979). Climatic classification of Yugoslavia according to Thornthwaite. Contributions to the knowledge of weather and climate of the SFRY, vol. 7. Belgrade: SHMZ. /in Serbian/

Radinović, Đ. (1984). Climatology. Faculty of Science and Mathematics of the University of Belgrade and the Yugoslav Institute for Labor Productivity and Information Systems. Belgrade, p. 236. /in Serbian/

Sanderson, M. (1999). The classification of climates from Pythagoras to Koeppen. Bull. Am. Meteorol. Soc., 80, 669-673.

Thornthwaite, C.W.(1943). Problems in the classification of climates, Geographical Review, 33(2), 233-255.

Thornthwaite, C.W. (1931). The climates of North America according to a new classification. Geographical Review, 21, 633-655.

Thornthwaite, C.W. (1948). An approach toward a rational classification of climate. Geographical Review, 38, 55-94.

Thornthwaite, C.W. (1933). The climates of the earth. Geographical Review, 23, 433-440.

Vujević, P. (1956). Climatological statistics. Scientific book, Belgrade.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.352S

THE IMPORTANCE OF INNOVATION POLICY FOR SUSTAINABLE TRANSFORMATION OF AGRICULTURE IN SERBIA

Jovana Simić[1*], Dragan Miletić[2]

[1]Faculty of Economics, University of Kragujevac, Liceja Kneževine Srbije, Kragujevac, Serbia
*simjovana@gmail.com
[2] Sanitary medical school of applied sciences VISAN, Belgrade, Serbia

Abstract: Innovation in agriculture is increasingly recognized as a critical driver of sustainable economic growth, particularly in developing countries like Serbia. The agricultural sector in Serbia plays a vital role in the national economy, necessitating a shift towards sustainable agricultural practices that leverage innovation and technology. Government support is essential for fostering an innovative agricultural environment. Effective policies that promote agricultural extension services and provide financial assistance are crucial for encouraging farmers to adopt new technologies and practices. Given the centralized system of innovation support, Serbian government has a pivotal role in creating a conducive regulatory framework that not only facilitates innovation but also addresses the unique challenges faced by the agricultural sector, such as land management and environmental sustainability. This paper examines specific ways in which public support for innovation in agricultural sector is carried out in Serbia, mainly through analyzing the activities of the Innovation Fund of Serbia.

Key words: Agriculture, Innovation, Sustainability, Public policy, Innovation Fund

1. INTRODUCTION

Innovation in agriculture is increasingly recognized as a critical driver of sustainable economic growth, particularly in developing countries like Serbia. The agricultural sector in Serbia plays a vital role in the national economy, necessitating a shift towards sustainable agricultural practices that leverage innovation and technology. Research indicates that the adoption of innovative approaches, such as precision agriculture, can significantly enhance productivity and sustainability in Serbian agriculture (Dimitrijević, 2024; Jurjević et al., 2019). Furthermore, the integration of advanced technologies, including drone applications for plant protection, has been identified as a promising avenue for improving agricultural efficiency and environmental stewardship (Ivezić, 2023).

Government support is essential for fostering an innovative agricultural environment. Effective policies that promote agricultural extension services and provide financial assistance, such as agricultural loans, are crucial for encouraging farmers to adopt new technologies and practices (Madžar, 2021). The Serbian government has a pivotal role in creating a conducive regulatory framework that not only facilitates innovation but also addresses the unique challenges faced by the agricultural sector, such as land management and environmental sustainability (Milošević et al., 2020). Moreover, the promotion of organic agriculture through tax incentives and supportive legislation has been shown to enhance the competitiveness of Serbian agriculture on both national and international stages (Kryszk et al., 2022; Despotović et al., 2019). Thus, the synergy between innovation and government support is fundamental for the advancement of agriculture in Serbia. By prioritizing innovative practices and providing robust support mechanisms, the Serbian agricultural sector can enhance its competitiveness, ensure sustainable development, and contribute significantly to the overall economic growth of the country. The ongoing commitment to innovation, coupled with effective government policies, will be essential for transforming Serbia's agricultural landscape and achieving long-term sustainability.

The aim of paper is to provides an overview of policy support for innovation in agricultural sector in Serbia, connected to the centralized way of innovation policy is operationalized through the activities of the Innovation Fund - to support agricultural sector.

2. LITERATURE REVIEW

Public expenditure in agriculture is a critical area of research, particularly in developing countries where agriculture plays a vital role in economic development and poverty alleviation. This literature review synthesizes various studies that explore the impacts, effectiveness, and dynamics of public spending in the agricultural sector across different contexts. One significant aspect of public expenditure in agriculture is its relationship with rural welfare and poverty reduction. Mogues et al. (2011) highlight that while substantial public spending on agriculture in Ethiopia is aligned with the government's development strategy, the effectiveness of such expenditures can be undermined by critical shortcomings in public policy. Similarly, Arham et al. (2020) argue that public expenditure alone does not necessarily lead to a reduction in rural poverty in Indonesia, attributing this to a misalignment between spending and agricultural productivity. This suggests that the mere allocation of funds is insufficient; rather, the strategic implementation of these resources is crucial for achieving desired outcomes in poverty alleviation. Moreover, the interaction between public and private investment is a recurring theme in the literature. Ayuba's study on Nigeria indicates that public agricultural spending can either crowd out or complement foreign direct investment (FDI), depending on the context and implementation (Ayuba, 2021). This is echoed by Nwosa (2021), who found that public expenditure significantly affects agricultural productivity and that it works in tandem with private investment to enhance overall agricultural output.

The complementarity between public and private investments is further supported by Akber and Paltasingh (2019), who explore the dynamics of public and private investments in Indian agriculture, suggesting that effective public investment can stimulate private sector engagement. The role of public investment in enhancing agricultural productivity is also emphasized in the context of specific interventions. For instance, Fan et al. (2008) discuss how targeted subsidies and investments in research, education, and infrastructure have been instrumental in promoting agricultural growth and reducing poverty in India. Similarly, Abate et al. (2016) note that Ethiopia's significant allocation of public spending to agriculture has led to increased cereal production and growth in the agricultural gross domestic product. These findings underscore the importance of not only the quantity of public expenditure but also the quality and focus of these investments.

Additionally, the literature highlights the importance of financing mechanisms in agricultural development. Gao et al. (2022) discuss how digital inclusive finance can enhance agricultural productivity by fostering technological innovation and optimizing industrial structures. This aligns with the findings that rural financial development is crucial for agricultural technology innovation, thereby contributing to sustainable agricultural practices (Liu et al., 2021). The interplay between financial inclusion and agricultural productivity is further explored by Fowowe (2020), who suggests that enhancing financial access can significantly improve agricultural outcomes, particularly for marginalized groups. Therefore, the literature indicates that public expenditure in agriculture is multifaceted, with its effectiveness contingent upon strategic alignment with productivity goals, the interplay between public and private investments, and the incorporation of innovative financing mechanisms. Future research should continue to explore these dynamics, particularly in the context of evolving agricultural challenges and the need for sustainable practices.

3. IMPORTANCE OF INNOVATION IN SERBIAN AGRICULTURE

Innovation in agriculture is crucial for enhancing productivity, sustainability, and resilience in Serbia's agricultural sector. Over the past years, the integration of advanced technologies and innovative practices has emerged as a key driver for improving agricultural output and addressing challenges such as climate change, resource scarcity, and market competitiveness. This section synthesizes relevant literature to highlight the importance of innovation in Serbian agriculture.

The adoption of precision agriculture technologies, including GPS, Geographic Information Systems (GIS), and data analytics, has been shown to significantly enhance agricultural productivity in Serbia. Jurjević et al. (2019) emphasize that these technologies facilitate better resource management and optimize crop yields while minimizing environmental impacts. The implementation of precision farming techniques allows farmers to make informed decisions based on real-time data, which is essential for improving efficiency and sustainability in agricultural practices (Gawande et al., 2023). This aligns with their findings that precision farming promotes eco-friendly agriculture by optimizing resource allocation and reducing environmental pollution (Gawande et al., 2023). Moreover, the integration of Internet of Things (IoT) and artificial intelligence (AI) into agricultural practices is revolutionizing livestock management and crop production. As highlighted by Issa (2024), these technologies are part of the broader Agriculture 4.0 movement, which aims to create a more advanced and sustainable agricultural system. The potential of AI in agriculture extends to various applications, including yield prediction, crop health monitoring, and resource optimization, thereby enhancing overall productivity (Uzhinskiy, 2023).

Innovation is not only vital for increasing productivity but also for achieving sustainable agricultural development in Serbia. Innovation is a key factor in promoting sustainable economic growth and agricultural development (Despotović et al., 2019). The authors emphasize that Serbia, as a country where agriculture plays a significant role in the economy, must prioritize innovation to ensure long-term sustainability and competitiveness in the global market. This perspective is supported by the findings of Basso (2024), who notes that technological advancements in agriculture can significantly contribute to sustainability by improving resource efficiency and reducing environmental impacts. Furthermore, the importance of knowledge transfer and extension services in disseminating innovative practices to farmers cannot be overstated, given that effective dissemination of improved agricultural technologies is crucial for advancing the sector (Oladoyinbo, 2023). The role of agricultural extension services in facilitating access to information and training on new technologies is essential for empowering farmers and enhancing their productivity.

Despite the potential benefits of innovation in agriculture, several challenges persist in Serbia. The adoption of advanced technologies can be hindered by factors such as limited access to financing, inadequate infrastructure, and a lack of digital literacy among farmers. Additionally, the historical focus on traditional agricultural practices may slow the transition to more innovative approaches. Therefore, targeted policies and investments are necessary to foster an environment conducive to innovation. Future research should focus on evaluating the effectiveness of current agricultural policies in promoting innovation and identifying best practices for technology adoption among Serbian farmers. Enhancing collaboration between research institutions, government agencies, and the private sector will be crucial for driving innovation and ensuring that Serbian agriculture remains competitive in the global market. In conclusion, innovation plays a pivotal role in enhancing productivity, sustainability, and resilience in Serbian agriculture. By embracing advanced technologies and fostering knowledge transfer, Serbia can position itself to meet the challenges of modern agriculture and achieve sustainable development goals.

4. THE ROLE OF INNOVATION POLICY IN SUPPORTING SUSTAINABLE AGRICULTURE IN SERBIA

The analysis of public expenditure on agriculture in Serbia over the past 15 years reveals a complex interplay of policy decisions, economic conditions, and external influences that have shaped the agricultural landscape. Public expenditure on agriculture in Serbia has shown a gradual increase, particularly in the context of aligning with European Union (EU) standards and policies. According to Đurić et al. (2019), government support for farmers has been primarily through market measures and budgetary transfers, which have been evaluated using the Producer Support Estimate (PSE) methodology. This approach indicates that while there has been an increase in budgetary transfers, the overall support level remains lower than that of EU countries, with Serbian subsidies per hectare being significantly less than those in the EU (Babić et al., 2015). In recent years, the agricultural budget has been reported to constitute approximately 5% of the total national budget, with direct payments emerging as a dominant form of subsidy (Đurić, 2024). Dimitrijević (2023) notes that this trend reflects a broader recognition of agriculture's critical role in Serbia's economic development, particularly in light of its contribution to GDP and employment. The increase in the agrarian budget has been accompanied by a rise in lending to farmers by commercial banks, which is essential for enhancing agricultural productivity and sustainability.

Despite the upward trend in public expenditure, significant challenges remain. Ristić et al. (2018) highlight that insufficient financial resources allocated to agriculture are a key limitation for the sector's development. The agricultural budget has historically been low, with less than 5% of the national budget allocated to agriculture for an extended period (Mizik, 2016). This underfunding hampers the potential for agricultural growth and rural development, emphasizing the need for increased budgetary support to enhance the economic viability of the agricultural sector (Grujić-Vučkovski et al., 2022). Moreover, the structure of subsidies has been criticized for being inadequate to meet the diverse needs of farmers. The existing agricultural policies have often favored larger producers, leaving smallholder farmers at a disadvantage (Đurić, 2024). This disparity in support can lead to uneven development within the agricultural sector, exacerbating rural poverty and limiting the overall effectiveness of public spending. The process of EU integration has significantly influenced Serbia's agricultural policy and public expenditure. As Serbia aligns its agricultural strategies with EU standards, there has been a push towards improving the quality and effectiveness of public spending in agriculture. Ljubojević et al. (2022) discuss how the harmonization of national legislation with EU rules has led to a more structured approach to agricultural financing, aiming to enhance competitiveness and sustainability. This alignment is crucial for accessing EU funds, such as the Instrument for Pre-Accession Assistance for Rural Development (IPARD), which provides additional resources for agricultural development (Grujić et al., 2019).

5. THE INNOVATION FUND’S ROLE IN SUPPORTING AGRICULTURAL INNOVATION

The Smart Specialization Strategy 2020, which delineated strategic orientations and priorities for innovation policy in the upcoming years, serves as the cornerstone of innovation policy in Serbia. The 4S identifies four priority areas-food for the future, ICT, future machinery and manufacturing processes, and creative industries-that should be the focus of policy initiatives and resource allocation due to their strategic importance and competitive advantages. In the process of raising the general productivity and competitiveness of the national economy, these four domains were determined to have the best chance of successfully developing and implementing innovations. The entrepreneurial discovery process, which involved a careful examination of domestic capabilities and available resources, led to the selection of innovation priorities rather than being arbitrary. This process involved a thorough analysis of available resources and domestic capacities, as well as the prospects for growth and development based on knowledge and innovation, and it was carried out in the form of a widespread social dialogue including key stakeholders within the national innovation system (businesses, science and research sector, academia, policymakers and civil society experts). This fact further corroborates the fact that agriculture is recognized as a valuable national resource with significant and robust potential for future development.

Given Serbia's centralized approach to smart specialization, the government plays the most important role in this top-down framework. This includes innovation policy, which is primarily carried out by the Innovation Fund (IF). Although it has been in operation since 2011, the institution technically predates S4, and its strategies and operations have evolved to align with the 2020 Smart Specialization Strategy's priorities. Within the scope of innovation policy, IF's role is to fund, promote, and advise two important clusters of innovation carriers: the business sector and the scientific research sector. It does this both independently and by promoting cooperation between academics and entrepreneurs. Given the importance of the Innovation Fund in the Serbian system for promoting innovation, a review of its resources and their allocation along the lines of industrial sectors can reveal to what extent public support resembles strategic priorities defined by the Smart Specialization Strategy.

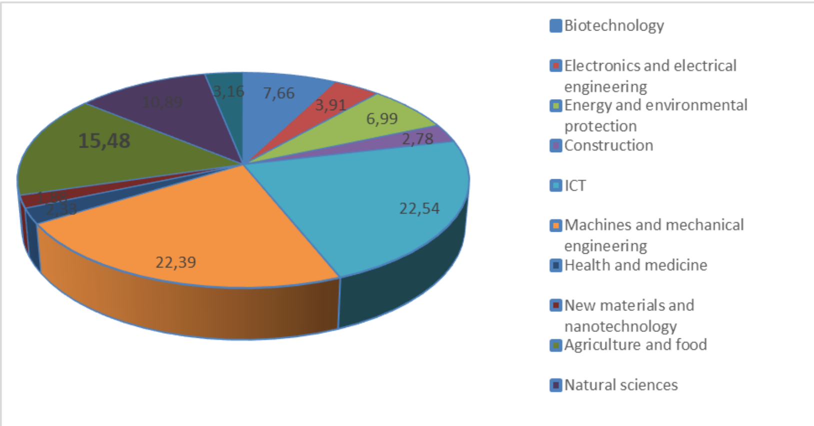


Figure 1. Distribution (%) of approved projects across industry sectors

The above graph reveals one of the most relevant aspects of the Innovation Fund’s activities - the industrial sector breakdown of approved projects. By analyzing sectoral distribution of IF’s support, it is possible to ascertain whether and to what extent the IF’s activities align with priority areas outlined in the Smart Strategy. Several conclusions can be drawn from observing dominant industries that are being supported by the IF. Firstly, it is evident that ICT and Machines and mechanical engineering combined account for roughly half of the funded projects, followed by Agriculture and food industry and projects related to Natural sciences. Other prominent sectors include Biotechnology and Energy and environmental protection. Broadly speaking, this distribution of funds corresponds to the 4S priority areas and in that regard, it can be considered that IF practices are generally in accordance with the strategic direction of innovation policy. The one priority area that is not represented in the IF’s portfolio is related to Creative industries. However, given that the classification of the Innovation Fund and the one deployed in 4S differ from each other, it can be assumed that the significant portion of innovative activities involved in creative industries is related to various aspects of implementation of information technologies and therefore falls under the ICT category placement in IF’s project portfolio.

Second, the way projects are distributed across industry sectors can be seen as a reflection of the resource availability, competitive advantages, and ultimately capacity for innovation in different industries. Given that the programs' selection criteria and general process are intended to mimic market conditions, the results of IF's selection process ought to mirror the performance structure that would be attained through market selection. Consequently, the structure of inputs inevitably determines the distribution and structure of approved projects, i.e. the ability of the applicants to develop innovations effectively. At the macro level, the sectoral allocation of IF projects are inevitably conditional upon the initial concentration of competitive advantages, which significantly impacts the innovative capacity of individual applicants. Therefore, the way that projects are distributed across various industries also reflects how and in which specific economic sectors Serbia's innovation resources are distributed, as well as how the initial allocation of innovation capacities affects the results of individual projects in terms of obtaining public funding.

Thus, the fact that agriculture occupies a prominent place in the IF's portfolio of supported projects reflects the inherent reality of its innovative potential as well as the current capacities (on behalf of farmers) to capitalize on the available opportunities to secure public funding. The programme of Innovation Vouchers, which connects small businesses with scientific institutions in the process of developing novel products and applicable solutions, has proven to be particularly popular among agricultural entrepreneurs, as it affords them the necessary flexibility in choosing academic partners and types of services rendered. Innovation Vouchers have numerous advantages for entrepreneurs: Advantages for entrepreneurs:

- Increasing competitiveness: Helping in the development of new technologies, products or services allows companies to become more competitive in the market.
- Access to expertise: Entrepreneurs can use the services of experts and research institutes without the need for large investments in their own resources.
- Stimulating innovation: The program enables companies to implement faster innovation and business improvement through the use of the latest technologies and business practices.

However, not every indicator is equally optimistic. For instance, annual data on the use of available IPARD funds in Serbia reveals a somewhat underwhelming picture regarding the farmers' capacities to obtain and effectively employ available funds. In the most recent year with published data (2021), only slightly above one third (35%) of available funds from IPARD were used by agricultural producers (Miletić and Simić, 2024). This finding suggests the existence of substantial barriers which hamper the agricultural community's ability to access and benefit from these (quite significant) funds. It may also signal the fact that a substantial population of agricultural subjects are effectively out of reach of the innovation policy and thus find themselves out of the domain covered by the activities of the Innovation Fund. Moreover, these subjects are usually the ones with fewest own capacity to generate innovation, while conversely (due to their low level of technological advancement) possessing the biggest marginal benefit of introducing (even very modest) innovative solutions and practices into their business. Having in mind the fact that Innovation Fund's mandate is not only to provide direct financial support (even though providing funds makes up the bulk of its activities) to innovators, but to encourage and actively engage in making productive connections and cooperation between innovators and academia, this 'soft skill' part of the IF's activity may be particularly useful in the endeavor to approach those businesses that are currently inactive regarding innovation and whose innovation potential is dormant due to different constraints (financial and otherwise). Agricultural producers could benefit significantly from establishing connections with the scientific sector in the process of boosting their innovation capacity and improving competitive advantages on the market, while transforming their business on sustainable grounds.

6. CONCLUSION

In conclusion, public expenditure on innovation in agriculture in Serbia plays a crucial role in enhancing the sector's competitiveness and sustainability. The agricultural landscape in Serbia is characterized by a predominance of small and family farms, which are vital for food security, employment, and ecological preservation. However, these farms often face significant challenges, including low investment levels and a lack of access to modern technologies, which hinder their ability to innovate and adapt to changing market demands. Government support through public expenditure is essential for fostering innovation, as it can facilitate the adoption of advanced agricultural practices and technologies. This support is particularly relevant in the context of Serbia's integration into the European Union, where alignment with EU agricultural policies is necessary for accessing funding and resources. The implementation of programs such as the Instrument for Pre-accession Assistance for Rural Development (IPARD II) highlights the importance of targeted financial assistance in addressing the unique needs of Serbian agriculture.

Moreover, the promotion of research and development initiatives, as well as the encouragement of open innovation practices among agricultural enterprises, can significantly enhance productivity and sustainability. By investing in innovation, Serbia can not only improve its agricultural output but also contribute to broader economic development goals, including rural revitalization and environmental sustainability. Therefore, a strategic approach to public expenditure that prioritizes innovation in agriculture is essential for the long-term viability and growth of this critical sector in Serbia. In that regard, innovation policy measures can play a substantial role in terms of facilitating technological advancement and transformation of Serbian agriculture on sustainable grounds. Innovation policy in Serbia, as outlined by the Smart Specialization Strategy 2020 defines the area of modern agriculture and food industry as one of its strategic priorities. By analyzing the Innovation Fund's approved projects and their distribution along sectoral lines, we show that agriculture and food production indeed takes a prominent position among the funded projects, which is in line with the strategic orientation established in the S4 and further underlines this sector's innovation potential and capacities. On the other hand, there are significant weaknesses which may pose threats to future development, unless addressed properly by the policymakers. The suboptimal use of available IPARD funds suggests that there are numerous barriers that inhibit the capacity of agricultural businesses to effectively use available resources, which is the one key area of concern that public policy needs to tackle in order to alleviate identifies shortcomings.

To summarize, while public expenditure on agriculture in Serbia has increased over the past 15 years, challenges related to funding adequacy, subsidy structure, and the need for alignment with EU policies persist. Future research should focus on evaluating the effectiveness of these expenditures in promoting sustainable agricultural practices and rural development. Additionally, exploring innovative financing mechanisms and enhancing support for smallholder farmers will be essential for maximizing the impact of public spending in the agricultural sector.

7. REFERENCES

Ayuba, A. (2021). Can foreign direct investment complement or substitute public agricultural spending for the sustainability of the agricultural sector in Nigeria? Empirical evidence using MonteCcarlo simulation. JAES, 16(16), 302. doi.org/10.57017/jaes.v16.3(73).05

Abate, G., Rashid, S., Borzaga, C., Getnet, K. (2016). Rural finance and agricultural technology adoption in Ethiopia: Does the institutional design of lending organizations matter?. World Development, 84, 235-253. doi.org/10.1016/j.worlddev.2016.03.003

Akber, N., Paltasingh, K. (2019). Is public investment complementary to private investment in Indian agriculture? Evidence from NARDL approach. Agricultural Economics, 50(5), 643-655. doi.org/10.1111/agec.12515

Arham, M., Fadhli, A., Dai, S. (2020). Does agricultural performance contribute to rural poverty reduction in Indonesia?. JEJAK, 13(1), 69-83. doi.org/10.15294/jejak.v13i1.20178

Babić, V., Milosevic, B., Maksimović, G. (2015). Economic subsidies in agriculture. Ekonomika Poljoprivrede, 62(3), 693-704. doi.org/10.5937/ekopolj1503693b

Basso, M. (2024). Agriculture evolution, sustainability and trends, focusing on Brazilian agribusiness: a review. Frontiers in Sustainable Food Systems, 7. doi.org/10.3389/fsufs.2023.1296337

Despotović, D., Ristić, L., Dimitrijević, M. (2019). Significance of innovation for sustainable economic and agricultural development in the Reublic of Serbia. Facta Universitatis Series Economics and Organization, 389. doi.org/10.22190/fueo1904389d

Dimitrijević, M. (2023). Trends in the financing of agriculture in the Republic of Serbia. Bankarstvo, 52(4), 70-103. doi.org/10.5937/bankarstvo2304070d

Dimitrijević, M. (2024). Innovativeness of the agri-food sector as a function of sustainable development. Ekonomika Preduzeca, 72(5-6), 333-342. doi.org/10.5937/ekopre2406333d

Fan, S., Gulati, A., Thorat, S. (2008). Investment, subsidies, and pro-poor growth in rural India. Agricultural Economics, 39(2), 163-170. doi.org/10.1111/j.1574-0862.2008.00328.x

Fowowe, B. (2020). The effects of financial inclusion on agricultural productivity in Nigeria. Journal of Economics and Development, 22(1), 61-79. doi.org/10.1108/jed-11-2019-0059

Gao, Q., Cheng, C., Sun, G., Li, J. (2022). The impact of digital inclusive finance on agricultural green total factor productivity: Evidence from China. Frontiers in Ecology and Evolution, 10. doi.org/10.3389/fevo.2022.905644

Gawande, V., Saikanth, D., Sumithra, B., Aravind, S., Swamy, G., Chowdhury, M., Singh, B. (2023). Potential of precision farming technologies for eco-friendly agriculture. International Journal of Plant & Soil Science, 35(19), 101-112. doi.org/10.9734/ijpss/2023/v35i193528

Grujić, B., Nikolić, S., Simonović, Z. (2019). The scope and structure of the incentives in agriculture and rural development in the Republic of Serbia. Facta Universitatis Series Economics and Organization, 327. doi.org/10.22190/fueo1903327g

Grujić-Vučkovski, B., Simonović, Z., Ćurčić, N., Miletić, V. (2022). The role of agriculture in the economic structure of Serbia and budget support for rural development of Kladovo municipality. Ekonomika Poljoprivrede, 69(3), 863-876. doi.org/10.5937/ekopolj2203863g

Issa, A. (2024). IOT and AI in livestock management: a game changer for farmers. E3s Web of Conferences, 491, 02015. doi.org/10.1051/e3sconf/202449102015

Ivezić, A. (2023). Drone-related agrotechnologies for precise plant protection in Western Balkans: applications, possibilities, and legal framework limitations. Agronomy, 13(10), 2615. doi.org/10.3390/agronomy13102615

Jurjević, Ž., Bogićević, I., Đokić, D., Matkovski, B. (2019). Information technology as a factor of sustainable development of Serbian agriculture. Strategic Management, 24(1), 41-46. doi.org/10.5937/straman1901041j

Kryszk, H., Kurowska, K., Marks-Bielska, R. (2022). Legal and socio-economic conditions underlying the shaping of the agricultural system in poland. Sustainability, 14(20), 13174. doi.org/10.3390/su142013174

Liu, Y., Ji, D., Lin, Z., An, J., Wei, S. (2021). Rural financial development impacts on agricultural technology innovation: Evidence from china. International Journal of Environmental Research and Public Health, 18(3), 1110. doi.org/10.3390/ijerph18031110

Ljubojević, R., Blanuša, A., Petrović, S. (2022). Agrarian strategy and policy of the Republic of Serbia. Ekonomika Poljoprivrede, 69(3), 897-909. doi.org/10.5937/ekopolj2203897l

Madžar, L. (2021). Agricultural innovations, extension, finance and rural loans in the Republic of Serbia: the case of logistic regression. Annals of the Polish Association of Agricultural and Agribusiness Economists, XXIII (4), 129-148. doi.org/10.5604/01.3001.0015.5786

Milošević, G., Kulić, M., Đurić, Z., Đurić, O. (2020). The taxation of agriculture in the Republic of Serbia as a factor of development of organic agriculture. Sustainability, 12(8), 3261. doi.org/10.3390/su12083261

Miletić, D., Simić, J. (2024). Factors for improving the agricultural sector in the Republic of Serbia. In M. Jovičić (Ed.) 11. Jeep International Scientific Agribusiness Conference MAK 2024 Kopaonik "Food for the future - vision of Serbia, region and Southeast Europe" Proceedings. WORLD Kraljevo & Institute for plant protection and environment Belgrade

Mizik, T. (2016). Land policy and farm structure: challenges and opportunities for agriculture in the Western Balkans. Society and Economy, 38(2), 157-170. doi.org/10.1556/204.2016.38.2.2

Mogues, T., Ayele, G., Paulos, Z. (2011). The bang for the birr: public expenditures and rural welfare in Ethiopia. The Journal of Development Studies, 47(5), 735-752. doi.org/10.1080/00220388.2010.509925

Nwosa, P. (2021). Unconditional factor demands and supply response for livestock products: a farm-level analysis of the southern rangelands of Kenya. African Journal of Agricultural and Resource Economics, 16(3), 253-263. doi.org/10.53936/afjare.2021.16(3).17

Oladoyinbo, O. (2023). Comprehensive synthesis and integrative review of agricultural dynamics in southwest Nigeria: assessing economic viability, technological advances, and rural development approaches. Asian Journal of Agricultural Extension Economics & Sociology, 41(11), 312-328. doi.org/10.9734/ajaees/2023/v41i112288

Ristić, L., Todorović, V., Jakšić, M. (2018). Limitations and opportunities for funding agriculture and rural development in the Republic of Serbia. Ekonomika Poljoprivrede, 65(3), 1123-1138. doi.org/10.5937/ekopolj1803123r

Uzhinskiy, A. (2023). Advanced technologies and artificial intelligence in agriculture. AppliedMath, 3(4), 799-813. doi.org/10.3390/appliedmath3040043

Đurić, K. (2024). Direct payments as a factor of agriculture development in the Republic of Serbia. Journal of Agronomy Technology and Engineering Management, 7(3), 1105-1113. doi.org/10.55817/iegh1390

Đurić, K., Cvijanović, D., Prodanović, R., Čavlin, M., Kuzman, B., Bulatović, M. (2019). Serbian agriculture policy: economic analysis using the PSE approach. Sustainability, 11(2), 309. doi.org/10.3390/su11020309

doi:10.46793/MAK2025.361G

THE IMPACT OF EU CLIMATE AND AGRICULTURAL POLICIES: SUSTAINABILITY, FOOD SECURITY, AND GLOBAL SHIFTS

Vesna Gantner[1*], Krunoslav Zmaic[1], Dragan Solić[2], Milivoje Ćosić[3], Zvonimir Steiner[1], Krešimir Kuterovac[4]

[1]Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences, Osijek, Croatia, *vgantner@fazos.hr
[2]Croatian Agency for Agriculture and Food, Osijek, Croatia
[3]Bijeljina University, Faculty of Agriculture, Bijeljina, Bosnia and Hercegovina
[4]Agroporc d.o.o., Petrinja, Croatia

Abstract: The European Union's agricultural sector is undergoing transformative changes driven by sustainability policies and climate objectives. While these measures position the EU as a global leader in environmental stewardship, they also expose the sector to significant vulnerabilities. Declining production, coupled with increased reliance on imports from regions with less stringent environmental standards, risks undermining EU environmental goals and competitiveness. These dynamics pose critical challenges to the resilience of EU food systems and rural economies.

Key words: European Union, Agricultural policy, Sustainability, Climate change, Food security

1. INTRODUCTION

The agricultural sector of the European Union (EU) plays a vital role in ensuring food security, supporting rural livelihoods, and contributing to the broader economy. However, it operates within a rapidly changing landscape shaped by environmental challenges, market dynamics, and evolving societal demands. The EU has implemented a range of policies and legislative frameworks aimed at fostering sustainability, mitigating climate change, and modernizing agriculture. This review delves into trends observed over the past decade, highlighting shifts in production, consumption, and innovation. Additionally, the legislative frameworks underpinning EU agriculture are analysed to understand their role in shaping the sector. Finally, the review considers the global context, assessing how EU policies align with or diverge from trends and practices worldwide. Together, these sections provide a comprehensive understanding of the EU's agricultural landscape and its future trajectory in a globalized world.

This review aimed to analyse the current state of the EU agricultural sector, examining its production capacity, challenges, and strategic importance.

2. CURRENT STATE OF THE EU AGRICULTURAL SECTOR

Over the past decade, the European Union (EU) has demonstrated significant resilience in its agricultural production, maintaining a high level of self-sufficiency, particularly in the animal production sector. The current state of the EU's agriculture reflects a complex balance between productivity, sustainability, and compliance with stringent regulations.

The EU continues to achieve high self-sufficiency rates in key animal products, including meat and dairy. Meat production within the EU remains robust, with self-sufficiency rates exceeding 100%, ensuring that domestic production is sufficient to meet consumption needs. The sector, however, has witnessed some notable shifts. For example, while overall meat production remains high, the production of pig meat has experienced a decline, partially offset by an increase in poultry meat production. These changes are driven by evolving consumer preferences, which favour poultry due to its lower environmental impact and affordability (European Commission, 2023a).

The dairy sector in the EU has maintained remarkable stability, consistently producing surplus quantities that not only meet domestic demand but also support significant export activities. The EU remains one of the largest global exporters of dairy products, including milk powders, cheeses, and butter. This strength is attributed to well-developed production systems, advanced processing technologies, and effective market integration. Despite these achievements, challenges persist, including price volatility, rising input costs, and increasing regulatory requirements for environmental sustainability (European Commission, 2023a).

Nevertheless, the EU livestock sector is facing structural changes. Since the year 2017, the population of animals has been decreasing, a trend projected to continue in the coming years. This decrease was caused by various factors, including high production costs, including feed, energy, and labour, alongside stricter regulatory frameworks aimed at reducing greenhouse gas emissions and enhancing animal welfare.

Furthermore, a significant challenge facing the European Union (EU) is its reliance on imports of plant-based proteins, particularly soybeans, which are essential for animal feed. This dependency, primarily on imports from South America, raises sustainability concerns and places the sector at risk due to geopolitical instability and potential supply chain disruptions. Efforts are currently underway to enhance local protein crop production, bolstered by EU strategies such as reforms to the Common Agricultural Policy and initiatives aimed at increasing the cultivation of legumes. However, progress in this area remains gradual (European Commission, 2024).

3. TRENDS OVER THE PAST DECADE

Over the past decade, the EU has witnessed significant shifts in production trends driven by policy reforms, market dynamics, and sustainability objectives. Reforms to the Common Agricultural Policy (CAP) have shifted financial support towards sustainable farming practices, influencing production decisions and profitability across the sector (European Commission, 2023b). For example, the heightened emphasis on animal welfare and environmental regulations has encouraged the adoption of lower-emission production systems, although it has also resulted in increased costs for producers (USDA Foreign Agricultural Service, 2023). Furthermore, consumer demand has played a crucial role in shaping the sector as well, notably with a shift towards plant-based alternatives that has impacted traditional meat and dairy consumption. This trend is particularly evident in Northern and Western Europe, where environmentally and health-conscious consumers are increasingly choosing vegetarian or flexitarian diets.

3.1. Decline in the number of livestock farms

The number of livestock farms within the European Union has experienced a significant decrease over the past decade. Between the year 2010 and 2020, the total number of livestock farms declined by 39.3%, indicative of a trend toward consolidation and the gradual phasing out of smaller agricultural operations. This trend is primarily driven by economic pressures, including escalating production costs and increasingly stringent regulatory requirements, which pose considerable challenges for smaller farms. Additionally, this consolidation aligns with broader transitions toward more industrialized and efficient farming systems (European Commission, 2023).

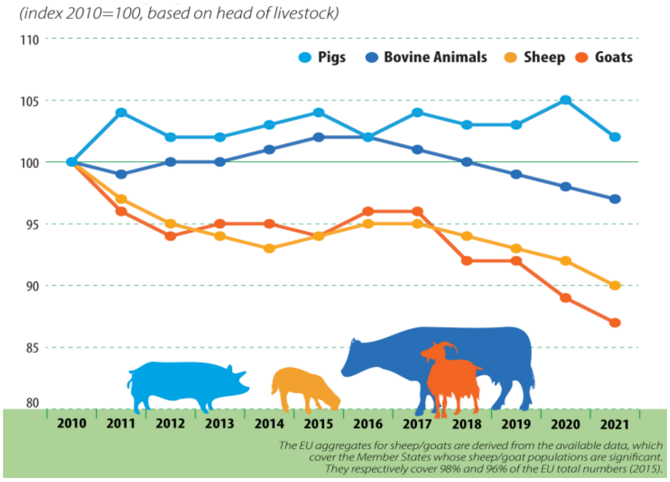


Figure 1. Livestock population in the EU in the period 2010-2021 (Eurostat, 2022)

3.2. Reduction in beef and pork production

The production levels of beef and pork within the European Union have experienced a steady decline over recent years, culminating in significant challenges by the year 2023. Specifically, beef production has fallen to historically low levels, primarily driven by a combination of factors. Rising costs associated with feed and energy have placed considerable financial strain on producers, while simultaneously, consumer demand for beef has diminished due to shifting dietary preferences and growing awareness of environmental sustainability. These concerns have led consumers to seek alternative protein sources, further impacting the beef market.

Similarly, the pork industry has faced its own set of obstacles. The outbreak of African Swine Fever has severely disrupted pork production, contributing to a decline in herd sizes and production capacities. This, combined with increasingly stringent regulatory measures aimed at ensuring food safety and animal welfare, has further complicated the industry's recovery. Additionally, changing consumer preferences influenced by health trends and ethical considerations are prompting a re-evaluation of traditional dietary habits, causing pork to face competition from other sources of protein. Despite pork maintaining its status as a dietary staple in many EU countries, it is anticipated that production levels will not rebound to the highs experienced in previous years. The combination of these challenges indicates a significant transformation within the EU's meat production landscape, marking a departure from historical trends (USDA Foreign Agricultural Service, 2023).

3.3. Increased poultry production

In contrast to the declines seen in beef and pork production, poultry production has experienced a modest but consistent increase over the past decade. This growth can be attributed to consumer preferences for more affordable and lower-fat meat options, along with the reduced environmental impact of poultry compared to other animal proteins. Consequently, poultry now accounts for the largest share of meat consumption in the EU (European Commission, 2023).

3.4. Stability in dairy production

The dairy sector within the European Union (EU) has demonstrated a noteworthy degree of stability over the past decade, with production levels experiencing modest increases. This resilience is significantly supported by a robust demand for exports, especially in key products such as milk powders, butter, and various types of cheese, which are highly sought after in both domestic and international markets. Nevertheless, dairy farms are currently grappling with a range of challenges, most notably escalating operational costs. These rising expenses are attributable to factors such as increased feed prices, labour costs, and investments in technology and infrastructure. Furthermore, the dairy industry is under growing pressure to adopt more sustainable practices, which includes implementing strategies aimed specifically at reducing greenhouse gas emissions, particularly methane. This shift towards sustainability not only aligns with broader environmental goals set by the European Commission but also addresses consumer expectations for more ethically produced food. As a result, dairy farmers are exploring innovative methods and technologies to enhance their production while minimizing their ecological footprint (European Commission, 2023).

3.5. Increased productivity despite declining herd sizes

Despite a notable decline in the total livestock population, there have been significant advancements in productivity per animal. This improvement can be attributed to several key factors, including innovations in breeding techniques, enhanced feed efficiency, and improved farm management practices (European Commission, 2023).

Breeding programs have focused on selecting for traits that promote health, growth rates, and reproductive efficiency, leading to animals that produce more with less input. Additionally, advancements in nutrition have optimized feed formulations, allowing livestock to convert feed into energy and growth more effectively, thereby reducing waste. Moreover, adopting modern farm management practices has further contributed to productivity gains. These practices include better animal health monitoring, precision farming technologies, and comprehensive data analysis that help farmers make informed decisions. As a result, the European Union has been able to maintain substantial levels of livestock production while simultaneously achieving a reduction in its environmental impact, such as lower greenhouse gas emissions and decreased land and resource use (European Commission, 2023).

3.6. Shifts in consumer preferences

In recent years, there has been a notable transformation in consumer behaviour, marked by a growing interest in plant-based and alternative protein sources. This shift is particularly prominent in Northern and Western Europe, where a combination of environmental concerns, health consciousness, and ethical considerations is fuelling the popularity of vegetarian and flexitarian diets. Consumers are increasingly aware of the ecological footprint associated with traditional animal farming, prompting many to explore sustainable dietary options that align with their values.

This evolving landscape has led to significant adjustments in the food industry, as traditional animal production sectors recognize the need to adapt to these changing preferences. Many companies are now diversifying their product lines to include more plant-based offerings and alternative proteins, such as those derived from legumes, grains, and innovative lab-grown solutions. As a result, the marketplace is becoming more inclusive, catering to the desires of a consumer base that prioritizes health, sustainability, and ethical eating (European Consumer Organization, 2023).

3.7. Focus on sustainability

Sustainability has become a fundamental principle guiding the agricultural policy framework of the European Union. In recent years, significant reforms to the Common Agricultural Policy (CAP) have shifted the focus towards enhancing environmental protection, promoting animal welfare, and improving resource efficiency. This newfound emphasis has not only reshaped the landscape of agricultural practices but has also played a crucial role in influencing decision-making among farmers. Financial incentives offered by the EU encourage the adoption of innovative and sustainable farming techniques, thereby fostering a more environmentally responsible approach to agriculture (European Commission, 2023).

3.8. Efforts to reduce dependency on imported feed proteins

The European Union faces a considerable challenge due to its heavy dependence on imported feed proteins, especially soybeans sourced from South America. This reliance not only raises sustainability concerns but also highlights vulnerabilities in the supply chain. In response, there has been a growing movement to encourage the cultivation of local protein crops, such as legumes, within Europe. While the strides made in this direction have been slow, they are fuelled by an urgent desire to reduce imports and lessen the negative environmental effects associated with large-scale agricultural practices. This initiative reflects a broader commitment to achieving greater food sovereignty and fostering sustainable agricultural practices across the continent (European Commission, 2024).

4. THE LEGISLATION BEHIND THE EU AGRICULTURE

The trends in EU agriculture, particularly in livestock production, are shaped by the legislative frameworks that prioritize sustainability, environmental responsibility, and resilience. The Common Agricultural Policy (CAP) remains the most influential policy, but the Farm to Fork Strategy, Biodiversity Strategy, and Green Deal are all driving a transformation towards more sustainable and climate-friendly farming practices. By aligning agricultural practices with these policies, the EU aims to ensure food security while reducing its environmental footprint and addressing climate change.

4.1. Common agricultural policy (CAP)

The Common Agricultural Policy (CAP) is the cornerstone of EU agricultural legislation, driving policy decisions and financial support mechanisms for farmers across the Union. Over the past decade, CAP has undergone significant reforms with a focus on sustainability, climate action, and environmental conservation (European Commission, 2021).

The latest reform (2023-2027 CAP Reform) emphasizes the Green Deal, including goals to reduce greenhouse gas emissions, enhance biodiversity, and promote a circular economy. It introduces the concept of "eco-schemes" which incentivize farmers to adopt environmentally friendly practices, such as reducing fertilizer use, improving soil health, and fostering biodiversity. Furthermore, direct payments to farmers are increasingly conditional upon compliance with environmental and climate-related practices, aiming to reduce agriculture's environmental footprint (linking payments to sustainability). This has encouraged the adoption of precision farming and other sustainable agricultural methods. The CAP also supports rural development initiatives, providing funds for infrastructure, innovation, and diversification of rural economies (European Commission, 2021).

4.2. EU Farm to fork strategy

The Farm to Fork Strategy, an integral component of the European Green Deal, is designed to establish a food system within the European Union that is equitable, health-oriented, and environmentally sustainable. It addresses a range of critical issues throughout the entire food chain, with the objectives of diminishing the environmental impacts of food production, promoting public health through shifts in dietary habits, and enhancing the overall sustainability of agricultural practices (European Commission, 2020a).

A key element of the strategy is the establishment of ambitious targets aimed at significantly reducing the reliance on pesticides, fertilizers, and antibiotics in agricultural production. By advocating for the adoption of more plant-based diets, the strategy seeks to not only improve overall public health outcomes but also to lower greenhouse gas emissions associated with food production.

Plant-based diets are not only less resource-intensive but also offer a pathway to healthier eating patterns, potentially reducing the incidence of diet-related diseases.

The Farm to Fork Strategy also places a strong emphasis on enhancing transparency within food supply chains. This transparency is crucial for empowering consumers, enabling them to make informed choices about the food they purchase and consume.

4.3. EU Biodiversity strategy for 2030

The EU Biodiversity Strategy for 2030 has been developed with the primary objective of reversing the alarming decline in biodiversity across Europe. This initiative specifically addresses the pressing issue of habitat degradation and the loss of various species that are vital to healthy ecosystems. Significant consideration is given to the agricultural sector, which is responsible for much of the land use throughout the continent and thus plays a crucial role in the overall success of the strategy (European Commission, 2020b).

To enhance biodiversity within agricultural landscapes, the strategy advocates for several key measures. One major focus is on the implementation of agroecological farming practices, which prioritize sustainable farming techniques that work in harmony with nature. This includes methods such as crop rotation, organic fertilization, and reduced pesticide use, all aimed at improving soil health and fostering a diverse range of crops. The promotion of organic farming is also emphasized, as it not only minimizes chemical inputs but also encourages more balanced ecological systems. Additionally, the establishment of wildlife corridors is a critical component of the strategy. These corridors serve as vital habitats that connect fragmented landscapes, allowing for the safe movement of wildlife between areas, thus maintaining genetic diversity and promoting healthy populations of various species.

Given the integral role that pollinators, such as bees and butterflies, play in supporting agricultural production, the strategy also incorporates specific measures aimed at protecting these essential creatures. By ensuring the preservation of pollinator populations, the strategy directly addresses the implications for both crop yields and livestock productivity, recognizing that healthy ecosystems are fundamental to sustainable agriculture. Overall, the EU Biodiversity Strategy for 2030 seeks not only to restore biodiversity but also to ensure that agricultural practices enhance the resilience and sustainability of the environment.

4.4. European green deal

The European Green Deal establishes a comprehensive framework that guides various EU policies with the ambitious goal of achieving carbon neutrality by 2050. Among the key sectors addressed within this framework is agriculture, which plays a crucial role due to its substantial contribution to greenhouse gas emissions in the EU (European Commission, 2019). To facilitate the decarbonization of the agricultural sector, the Green Deal emphasizes the importance of adopting climate-neutral farming practices. This initiative encompasses a variety of sustainable agricultural methods, including regenerative agriculture, which focuses on restoring and enhancing soil health, increasing biodiversity, and promoting ecological balance. Additionally, it highlights the importance of carbon sequestration techniques that capture and store atmospheric carbon dioxide in soil and vegetation, thereby mitigating climate change.

Another critical aspect of the Green Deal is its emphasis on improving livestock management practices to significantly reduce methane emissions, a potent greenhouse gas. This involves implementing strategies such as optimizing feeding practices, enhancing manure management, and utilizing innovative breeding techniques to improve the overall efficiency and sustainability of livestock production.

The Green Deal also advocates for the transition towards a Circular Economy within the agricultural sector. This approach emphasizes the importance of reusing agricultural waste and by-products, which can involve transforming manure into renewable energy sources or converting it into high-quality organic fertilizers. By adopting such practices, the agricultural sector can significantly lessen its environmental impact, minimize waste, and contribute to a more sustainable and resilient food system in the EU.

4.5. CAP and climate adaptation

The European Union (EU) has implemented a range of specific measures aimed at facilitating climate adaptation within the agricultural sector. As climate change continues to pose significant challenges, including an increase in extreme weather events and alterations in growing conditions, these policies are designed to enhance the resilience of agriculture across member states (European Commission, 2021b).

One key aspect of the Common Agricultural Policy (CAP) is its promotion of Climate-Smart Agriculture (CSA). This approach encourages the adoption of a variety of innovative and sustainable agricultural practices. For instance, farmers are urged to improve their irrigation management, ensuring that water resources are used more efficiently, which is crucial in regions facing drought or unpredictable rainfall. Additionally, the CAP advocates for crop diversification, which helps mitigate risks associated with monoculture and enhances soil health, while also making farms more adaptable to changing climate conditions. Furthermore, the policy encourages a reduction in reliance on chemical fertilizers, promoting organic alternatives that can improve soil resilience and decrease environmental impact.

To support these initiatives, the EU has also invested in risk management tools designed to assist farmers in navigating the financial uncertainties that arise from climate-related impacts, including those resulting from severe weather events like floods and storms. These tools not only provide financial safety nets for farmers but also encourage the adoption of proactive measures to prepare for and respond to climate challenges. By fostering a more adaptive and resilient agricultural system, these policies aim to secure food production in the face of an uncertain climate future.

5. EU AGRICULTURAL AND CLIMATE POLICIES IN GLOBAL SCALE

The benefits of the European Union’s policies to reduce agricultural production and align with climate change mitigation efforts must be evaluated within a global context. The EU's approach is ambitious, aiming to set an example for sustainable agriculture, improve environmental resilience, and address the pressing challenges of global warming. However, these efforts must also contend with the reality of increasing production in other regions, such as Asia, South America, and China, where sustainability practices may not be as stringent. Additionally, geopolitical shifts, such as the election of leaders like Donald Trump who have questioned the existence of climate change, add complexity to the EU's environmental and agricultural strategies.

5.1. Benefits of EU policies

The European Union’s agricultural policies offer significant benefits, positioning the region as a global leader in sustainability. Through initiatives like the European Green Deal, the Farm to Fork Strategy, and reforms to the Common Agricultural Policy (CAP), the EU has implemented measures designed to mitigate climate change by reducing greenhouse gas emissions, enhancing soil health, and promoting biodiversity. This leadership role not only strengthens the EU’s own agricultural sector but also has the potential to inspire other nations to adopt similar policies, fostering greater global cooperation on climate change mitigation.

One of the key benefits of these policies is their contribution to environmental and climate resilience. By reducing agricultural production, particularly in high-emission sectors such as beef and pork, the EU has lowered methane emissions and decreased land use, helping to preserve biodiversity and reduce deforestation pressures. These efforts align with the Paris Agreement targets to limit global warming, ensuring the long-term sustainability of European agriculture despite the challenges posed by climate change.

Additionally, EU policies emphasize innovation and efficiency, incentivizing advancements in precision farming, carbon sequestration, and sustainable feed production. These innovations not only enhance productivity but also reduce resource inputs, making agriculture more sustainable and environmentally friendly. By exporting these technologies and practices, the EU can extend its impact, contributing to global sustainability efforts.

Moreover, the EU's focus on reducing pesticide and fertilizer use while encouraging plant-based diets has led to improvements in public health and food quality. These measures reduce the environmental burden of the food system while promoting healthier consumption patterns, aligning closely with the objectives of the Farm to Fork Strategy.

However, the benefits of these policies must be evaluated within a global context, where agricultural production trends are increasingly divergent. While the EU reduces its output in certain areas to prioritize sustainability, other regions, such as South America, Asia, and China, are ramping up agricultural production, often with less emphasis on environmental responsibility. This discrepancy creates a risk of "carbon leakage," where reduced production in the EU leads to increased emissions elsewhere to meet global demand. Furthermore, geopolitical factors, such as the election of leaders who deny the existence of climate change, pose challenges to international cooperation and weaken the impact of global agreements like the Paris Agreement.

In this context, the EU's agricultural policies remain critical in setting a benchmark for sustainability and innovation. However, their global impact will depend on the ability to foster collaboration and align agricultural practices worldwide, ensuring that the benefits of these efforts extend beyond European borders.

5.2. Challenges in a global context

The environmental benefits of the EU's agricultural policies are significant, but their global impact can be diluted when other regions increase production without similar sustainability commitments. For instance, countries such as China and Brazil have significantly expanded their agricultural output, often prioritizing volume over environmental responsibility. This trend is associated with higher rates of deforestation, biodiversity loss, and greenhouse gas emissions. Consequently, the EU's decision to reduce production in certain areas may inadvertently shift global demand to these regions, creating a "carbon leakage" effect. In this scenario, global emissions may remain unchanged or even increase, undermining the EU's efforts to combat climate change.

Geopolitical dynamics further complicate the situation, especially when major world leaders, such as Donald Trump during his presidency, openly deny the existence of climate change. Such positions weaken international climate agreements and hinder global progress toward sustainability. When significant economies like the United States prioritize deregulation and increased agricultural production without considering environmental consequences, they create uneven global efforts to address climate change. This lack of alignment poses a challenge to the EU's leadership in sustainability and its capacity to influence global agricultural practices.

Additionally, the pressures of a globalized market present further obstacles. The EU's reduction in production can lead to increased imports from regions with lower environmental standards. This not only creates trade imbalances but also risks undercutting EU farmers who must comply with stricter regulations. As a result, the EU agricultural sector faces challenges to its competitiveness, particularly in a market that does not uniformly value sustainability. These dynamics underscore the importance of fostering international collaboration and aligning global agricultural policies with sustainability goals. Without such efforts, the EU's progressive policies may have limited global influence, and the broader fight against climate change could falter in the face of competing economic and political priorities.

6. CONCLUSION

The EU's agricultural and climate policies represent an ambitious effort to balance environmental sustainability with the need to maintain a robust food production system. These policies demonstrate the EU's leadership in addressing global challenges such as climate change, biodiversity loss, and resource efficiency. However, they also expose the European agricultural sector to significant risks and vulnerabilities within a highly competitive and uneven global landscape. One of the most pressing concerns is the risk of reduced EU food production being offset by increased imports from regions with lower environmental standards. This not only undermines the EU's environmental goals but also creates economic disadvantages for European farmers, who must adhere to stricter regulations. Furthermore, the EU's policies may inadvertently contribute to "carbon leakage," where emissions are displaced rather than reduced, diminishing the global impact of its efforts.

The competitive pressures of a globalized market, coupled with uneven climate commitments from major agricultural producers such as the United States, South America, and Asia, further challenge the viability of the EU's approach. In particular, the shift in production to regions prioritizing volume over sustainability erodes the global environmental benefits of the EU's policies while threatening the resilience and self-sufficiency of European food systems.

If these trends persist, the EU's agricultural sector could face significant declines, resulting in reduced food security, loss of rural livelihoods, and diminished economic contributions to the broader EU economy. To address these risks, it is essential for the EU to strengthen support for its farmers, enhance innovation and efficiency, and foster global cooperation to align agricultural practices with sustainability objectives. Without such measures, the EU's leadership in sustainable agriculture may come at the cost of its food production capacity, undermining both environmental and economic goals.

7. REFERENCES

European Commission (2019). The European Green Deal. https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission (2020a). Farm to Fork Strategy. Retrieved from https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en

European Commission (2020b). EU Biodiversity Strategy for 2030. https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en

European Commission (2021a). Common Agricultural Policy (CAP) 2023-2027. https://agriculture.ec.europa.eu/common-agricultural-policy/cap-overview/cap-2023-27_en

European Commission (2021b). EU Climate Adaptation Strategy. https://climate.ec.europa.eu/eu-action/adaptation-climate-change/eu-adaptation-strategy_en

European Commission. (2023a). Overview of the Agricultural Markets. https://agriculture.ec.europa.eu/data-and-analysis/markets/overviews/market-overview-sector_en

European Commission. (2024). Reducing the plant protein deficit in the European Union. https://agriculture.ec.europa.eu/news/reducing-plant-protein-deficit-european-union-2024-10-08_en

Eurostat (2022). Livestock population in numbers. https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/ddn-20220517-2

USDA Foreign Agricultural Service. (2024). Livestock and Products Annual Report. https://fas.usda.gov/data/european-union-livestock-and-products-annual-4

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.370LJ

ANTIBIOTIC USE IN DAIRY FARMING: IMPLICATIONS FOR ENVIRONMENTAL SUSTAINABILITY AND RESISTANCE MITIGATION

Boris Ljubojević[1], Zvonimir Steiner[2], Vesna Gantner[2*]

[1]Hrvatske šume d.o.o., Zagreb, Croatia
[2]Josip Juraj Strossmayer University of Osijek, Faculty of Agrobiotechnical Sciences, Osijek, Croatia
*vgantner@fazos.hr

Abstract: Antibiotics are essential in dairy farming but contribute to antimicrobial resistance (AMR) and environmental contamination. This review explores antibiotic use practices, impacts on AMR and ecosystems, and strategies such as selective dry cow therapy (SDCT), non-antibiotic alternatives, and improved management. Emphasizing the "One Health" approach, it highlights sustainable pathways to reduce antibiotic dependency while safeguarding animal health, productivity, and the environment.

Key words: Antibiotic use, Antimicrobial resistance, Dairy farming, Environmental impact, Sustainable agriculture.

1. INTRODUCTION

The widespread use of antibiotics in dairy farming has been instrumental in managing diseases such as mastitis, ensuring animal health and maintaining milk production. However, this reliance has led to significant challenges, particularly the development of antimicrobial resistance (AMR) and environmental contamination. AMR poses a critical threat to global health, as resistant bacteria can be transferred from farms to human and ecological ecosystems, exacerbating public health risks. Antibiotics administered to dairy cows often enter the environment via manure and runoff, where they remain in soil and water systems. These residues exert selective pressure, promoting the spread of resistant bacteria and resistance genes. Consequently, there is a growing global effort to reduce the use of antibiotics in livestock farming, while ensuring animal productivity and health. This review aims to explore the patterns and implications of antibiotic use in dairy farming, with a focus on their environmental impacts and resistance. In addition, the paper examines viable alternatives, including selective dry cow therapy (SDCT), improved biosecurity and new non-antibiotic interventions. These approaches represent avenues for balancing disease management with ecological sustainability and mitigating resistance.

The aim of this paper was to analyse antibiotic use in dairy farming, its environmental impacts, and resistance, while exploring sustainable alternatives for disease management.

2. OVERVIEW OF ANTIBIOTIC USE IN DAIRY FARMING

2.1. Common practices in antibiotic use

Antibiotics are widely used in dairy farming for managing bacterial infections and ensuring herd health. Blanket dry cow therapy (BDCT) remains a prevalent practice, where all cows are treated with antibiotics during the dry-off period, regardless of infection status (Kupczyński et al., 2024). While effective at preventing mastitis, BDCT significantly contributes to antibiotic overuse and resistance. In response, selective dry cow therapy (SDCT) is gaining attention, targeting only infected animals. SDCT reduces overall antibiotic consumption without compromising milk production, particularly when paired with diagnostic tools like somatic cell count monitoring (Rowe et al., 2023).

Beta-lactams, tetracyclines, and macrolides are among the most frequently used antibiotic classes, administered intramammary or systemically for diseases such as mastitis, respiratory infections, and metritis (Rajala-Schultz et al., 2021). However, concerns remain about the prophylactic use of these drugs during high-risk periods, which is increasingly restricted under regional regulations (Llanos-Soto et al., 2021).

2.2. Role of antibiotics in disease management

Mastitis is the leading cause of antibiotic use in dairy farming. Pathogens like Escherichia coli and Staphylococcus aureus are common culprits, with some strains exhibiting resistance to widely used antibiotics (Saini et al., 2012). Effective mastitis management not only ensures animal welfare but also minimizes economic losses from reduced milk yields and culling (Casseri et al., 2022). In intensive dairy systems, as many as 20% of lactating cows may require antibiotic treatment annually for clinical mastitis.

In addition to mastitis, uterine infections and respiratory diseases are significant drivers of antibiotic use. Conditions such as metritis and pneumonia are treated with cephalosporins, sulfonamides, and macrolides (Christaki et al., 2020). However, these treatments often rely on prophylactic applications, raising concerns about resistance development and environmental contamination from residues (Wichmann et al., 2014).

2.3. Emerging trends in antibiotic use

Efforts to optimize antibiotic use in dairy farming are underway globally. In Switzerland, evidence-based prevention strategies, including enhanced udder health programs and metabolic disease management, have substantially reduced antibiotic use (Gerber et al., 2021). Similarly, European Union regulations now mandate veterinary oversight for antibiotic applications and prohibit routine prophylactic treatments (Lam et al., 2020).

Consumer demand for antibiotic-free dairy products has further encouraged the adoption of sustainable practices. Culture-guided therapy and selective treatments are becoming more common, although challenges like high costs and limited access to diagnostics hinder widespread implementation (Ferroni et al., 2020). Advances in automated health monitoring systems and diagnostic tools are expected to support more precise antibiotic use in the future (Rowe et al., 2023).

3. IMPACTS OF ANTIBIOTIC USE

3.1. Development of antimicrobial resistance (AMR)

Antibiotic use in dairy farming is a significant contributor to the emergence of antimicrobial resistance (AMR). As shown in Figure 1, the relationship between AMU and AMR spans animals, humans, and food systems (Bennani et al., 2020). Over time, the misuse and overuse of antibiotics have allowed resistant bacteria to thrive, particularly pathogens like Escherichia coli and Staphylococcus aureus, which are commonly associated with mastitis (Saini et al., 2012). The proliferation of resistance genes in farm environments has global implications, as these genes can transfer across bacteria, facilitating the spread of AMR (Davies and Davies, 2010). Manure from antibiotic-treated cows is a primary vector for introducing resistance genes into soil ecosystems. These genes persist long after application, posing risks to agricultural productivity and human health

(Wichmann et al., 2014). Studies show that resistance determinants are particularly prevalent in intensive farming systems, where higher antibiotic use is common (Suzuki et al., 2022).

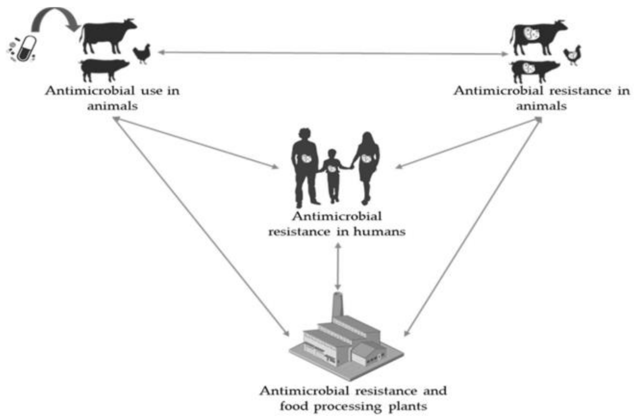


Figure 1. Links between different fields of data identified on the relationship between anti-microbial use (AMU) and anti-microbial resistance (AMR) in the food chain and people (Bennani et al., 2020).

3.2. Environmental contamination

Antibiotic residues from dairy farming often end up in soil and water through manure application and runoff. These residues create selective pressures in microbial communities, leading to the dominance of resistant strains (Christaki et al., 2020). Additionally, antibiotic residues disrupt natural microbial processes in ecosystems, affecting nutrient cycling and water quality (Ferroni et al., 2020). Environmental contamination is not limited to the farm. Resistance genes originating from dairy operations have been detected in surrounding aquatic systems, indicating their potential for far-reaching ecological impacts (Wichmann et al., 2014). The movement of these genes through environmental pathways underscores the interconnected nature of AMR as a "One Health" issue (Bennani et al., 2020).

3.3. Socioeconomic impacts

The economic consequences of antibiotic resistance in dairy farming are profound. Resistant infections often require prolonged treatment and higher veterinary costs, leading to increased milk discard periods and reduced profitability (Casseri et al., 2022). Additionally, regulatory pressures to reduce antibiotic use have driven farmers to adopt costly alternatives, which may not be accessible to all, particularly smaller farms (Gerber et al., 2021). Consumer demand for antibiotic-free products has further impacted farming practices. While creating opportunities for premium markets, meeting these demands often requires significant investments in new technologies and management strategies (Ferroni et al., 2020). This dual pressure of compliance and consumer expectations poses challenges for many farmers.

4. STRATEGIES FOR REDUCING ANTIBIOTIC DEPENDENCY

4.1. Selective dry cow therapy (SDCT)

Selective dry cow therapy (SDCT) is a critical approach to reducing antibiotic use in dairy farming. Unlike blanket dry cow therapy (BDCT), SDCT targets only cows with existing infections, significantly lowering overall antibiotic consumption while maintaining udder health (Rowe et al., 2023). Research shows that SDCT is particularly effective when paired with diagnostic tools like somatic cell count analysis and milk culture testing (Virto et al., 2022).

The success of SDCT depends on appropriate herd management practices, including strict hygiene protocols and regular health monitoring. In countries like Switzerland, widespread adoption of SDCT has been driven by consumer demand and supportive regulatory frameworks (Gerber et al., 2021). However, barriers such as high initial costs for diagnostic equipment and the need for farmer training continue to limit its adoption in some regions (Llanos-Soto et al., 2021).

4.2. Alternative disease management approaches

The search for non-antibiotic alternatives has yielded promising results in recent years. Antimicrobial peptides (AMPs) and bacteriophages are among the most innovative solutions, offering targeted treatments for bacterial infections with minimal risk of resistance development (Li et al., 2023). Vaccines are another effective tool for disease prevention, particularly in managing mastitis and respiratory infections (Rajala-Schultz et al., 2021). Probiotic treatments and herbal remedies have also gained attention for their ability to enhance immunity and reduce pathogen load without relying on antibiotics (Tomanić et al., 2023). While these alternatives hold significant promise, their widespread adoption requires further validation, cost reduction, and education for farmers (Bonsaglia et al., 2017).

4.3. Improved farm management and biosecurity

Enhanced farm management practices are essential for minimizing antibiotic dependency. Key interventions include maintaining proper hygiene during milking, using clean bedding, and ensuring adequate ventilation to reduce the spread of infectious agents (Christaki et al., 2020). Pre- and post-milking teat disinfection and regular equipment maintenance are also vital in preventing mastitis (Ferroni et al., 2020). Biosecurity measures, such as isolating sick animals and quarantining new arrivals, play a critical role in preventing the introduction and spread of disease. In addition to reducing antibiotic use, these practices help improve overall herd health and productivity (Gerber et al., 2021). Collaborative efforts between farmers and veterinarians are crucial in implementing and sustaining these measures (Rajala-Schultz et al., 2021).

5. POLICY AND BEHAVIORAL INSIGHTS

5.1. Regulatory frameworks and global trends

Governments and international organizations have established regulations to address antimicrobial resistance (AMR) and promote sustainable antibiotic use in dairy farming. In the European Union, policies prohibit prophylactic antibiotic use and mandate veterinary oversight for all antimicrobial applications. These measures have significantly reduced antibiotic consumption, particularly in countries like the Netherlands and Denmark, where evidence-based practices such as selective dry cow therapy (SDCT) are widely implemented (Lam et al., 2020).

In contrast, the United States relies on voluntary guidelines, including restrictions on medically important antibiotics in livestock feed. Consumer-driven certification programs, such as organic labeling, have also contributed to reduced antibiotic use (Gerber et al., 2021). However, regional disparities in enforcement and farmer adoption remain a challenge globally, particularly in low- and middle-income countries where regulatory frameworks may be less robust (Bennani et al., 2020).

5.2. Farmer and veterinarian roles

Farmers and veterinarians are central to promoting judicious antibiotic use. Surveys show that veterinarians are the primary source of guidance for farmers on treatment protocols and herd management practices (Llanos-Soto et al., 2021). However, economic pressures and a lack of understanding about AMR often lead to overprescription or inappropriate use of antibiotics. Educating both farmers and veterinarians about AMR risks and sustainable alternatives is crucial for driving behavior change (Bucher and Bleul, 2019). Collaborative approaches, including veterinarian-led workshops and decision-making tools, have been effective in improving farmer compliance with sustainable practices. These efforts highlight the importance of aligning economic incentives with responsible antibiotic use (Farrell et al., 2021).

5.3. Public and consumer influence

Consumer awareness of AMR and demand for antibiotic-free dairy products are increasingly influencing farming practices. Organic certification and "antibiotic-free" labels have created opportunities for farmers to access premium markets, encouraging the adoption of alternative disease management strategies (Casseri et al., 2022). However, meeting consumer expectations often requires significant investments in diagnostics, biosecurity, and non-antibiotic treatments, which may be prohibitive for smaller farms (Ferroni et al., 2020).

Public perceptions also shape policies, as seen in countries with proactive AMR mitigation frameworks like the European Union. Consumer advocacy has driven stricter regulations and increased transparency in farming practices, underscoring the interconnected role of public opinion in shaping agricultural sustainability (Bennani et al., 2020).

6. FUTURE OUTLOOK

6.1. Innovations in alternative therapies

Future strategies to reduce antibiotic use in dairy farming will hinge on the development of alternative treatments. Antimicrobial peptides (AMPs) and bacteriophages are emerging as promising tools for targeted bacterial control without fostering resistance (Li et al., 2023). Vaccination programs are also expected to play an expanded role in disease prevention, particularly for mastitis and respiratory illnesses, which are major drivers of antibiotic use (Rajala-Schultz et al., 2021). Probiotic applications and herbal remedies are gaining traction for their ability to boost natural immunity and reduce pathogen loads in livestock (Tomanić et al., 2023). These therapies require further validation and scaling to become affordable and accessible to a broader range of farmers (Bonsaglia et al., 2017).

6.2. Precision farming and digital technologies

Advances in precision farming technologies have the potential to revolutionize antibiotic use. Automated health monitoring systems, such as those tracking somatic cell counts and behavioural patterns, allow for earlier disease detection and more targeted interventions (Rowe et al., 2023). Artificial intelligence (AI) and machine learning are increasingly being employed to analyse farm data, providing actionable insights for optimizing herd management and reducing reliance on antibiotics (Kupczyński et al., 2024).

6.3. The “One Health” approach

The "One Health" approach as shown in Figure 2, emphasizes the interconnectedness of human, animal, and environmental health, will be central to future AMR mitigation efforts. Collaborative global initiatives are already addressing the broader implications of antibiotic use, including environmental contamination and zoonotic disease risks (Bennani et al., 2020). By aligning human, veterinary, and environmental policies, the "One Health" framework ensures a comprehensive approach to sustainable antibiotic use (Ferroni et al., 2020).

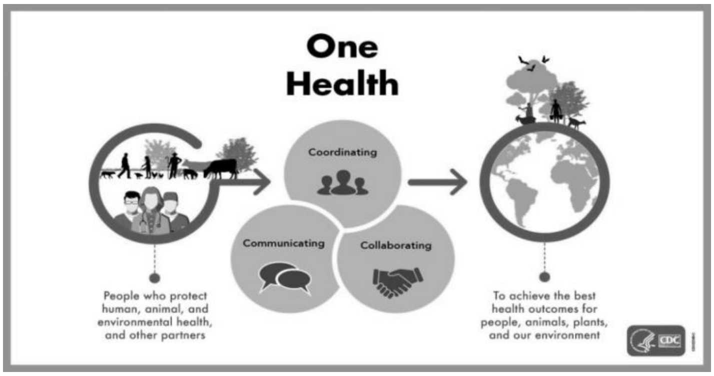


Figure 2. One health framework (Centers for Disease Control and Prevention, n.d.)

6.4. Pathways to sustainability

Achieving long-term sustainability in dairy farming will require coordinated efforts across stakeholders. Governments must strengthen regulatory frameworks and provide incentives for farmers to adopt sustainable practices, such as subsidies for diagnostic tools and biosecurity enhancements (Lam et al., 2020). Research institutions must continue to innovate in alternative therapies and precision technologies, while educating farmers and veterinarians about AMR risks and mitigation strategies (Gerber et al., 2021).

Global consumer demand for antibiotic-free products will also drive change, encouraging transparency and accountability in farming practices. By investing in sustainable solutions, the dairy industry can address the dual challenges of AMR and environmental contamination while maintaining productivity and profitability (Casseri et al., 2022).

7. CONCLUSION

Antibiotics have been indispensable in dairy farming for managing diseases and ensuring animal welfare. However, their widespread use has led to critical challenges, including antimicrobial resistance (AMR) and environmental contamination. This review highlights the urgent need to balance effective disease control with minimizing the broader impacts of antibiotic use.

Strategies such as selective dry cow therapy (SDCT), alternative treatments, and improved farm management practices offer practical pathways to reduce dependency on antibiotics. These approaches, coupled with advances in precision farming and diagnostic tools, can significantly mitigate AMR risks while maintaining productivity. Regulatory frameworks, consumer demand, and collaborative efforts between farmers, veterinarians, and policymakers are key drivers for fostering sustainable practices.

Looking ahead, the integration of the "One Health" framework will be vital for addressing AMR on a global scale. By prioritizing judicious antibiotic use and investing in innovative solutions, the dairy industry can pave the way for a sustainable future that safeguards animal health, environmental integrity, and public well-being.

8. REFERENCES

Bennani, H., Mateus, A., Mays, N., Eastmure, E., Stärk, K.D.C., Häsler, B. (2020). Overview of Evidence of Antimicrobial Use and Antimicrobial Resistance in the Food Chain. Antibiotics, 9(2), 49. doi.org/10.3390/antibiotics9020049

Bonsaglia, E.C.R., Gomes, M.S., Canisso, I.F., Zhou, Z., Lima, S.F., Rall, V.L.M., Oikonomou, G., Bicalho, R.C., Lima, F.S. (2017). Milk microbiome and bacterial load following dry cow therapy without antibiotics in dairy cows with healthy mammary gland. Scientific reports, 7(1), 8067. doi.org/10.1038/s41598-017-08790-5

Bucher, B., Bleul, U. (2019). Die Auswirkung des selektiven Trockenstellens auf die Eutergesundheit in Schweizer Milchviehbetrieben [The Effect of Selective Dry Cow Treatment on the Udder Health in Swiss Dairy Farms]. Schweizer Archiv fur Tierheilkunde, 161(9), 533–544. doi.org/10.17236/sat00219

Casseri, E., Bulut, E., Llanos Soto, S., Wemette, M., Stout, A., Greiner Safi, A., Lynch, R., Moroni, P., Ivanek, R. (2022). Understanding Antibiotic Resistance as a Perceived Threat towards Dairy Cattle through Beliefs and Practices: A Survey-Based Study of Dairy Farmers. Antibiotics (Basel, Switzerland), 11(8), 997. doi.org/10.3390/antibiotics11080997

Centers for Disease Control and Prevention. (n.d.). One Health basics. U.S. Department of Health and Human Services. Retrieved December 23, 2024, www.cdc.gov/one-health/about/index.html

Christaki, E., Marcou, M., Tofarides, A. (2020). Antimicrobial resistance in bacteria: mechanisms, evolution, and persistence. Journal of molecular evolution, 88(1), 26-40. doi.org/10.1007/s00239-019-09914-3

Davies, J., Davies, D. (2010). Origins and evolution of antibiotic resistance. Microbiology and molecular biology reviews: MMBR, 74(3), 417–433. doi.org/10.1128/MMBR.00016-10

Ferroni, L., Lovito, C., Scoccia, E., Dalmonte, G., Sargenti, M., Pezzotti, G., Maresca, C., Forte, C., Magistrali, C.F. (2020). Antibiotic Consumption on Dairy and Beef Cattle Farms of Central Italy Based on Paper Registers. Antibiotics (Basel, Switzerland), 9(5), 273. doi.org/10.3390/antibiotics9050273

Gerber, M., Dürr, S., Bodmer, M. (2021). Reducing Antimicrobial Use by Implementing Evidence-Based, Management-Related Prevention Strategies in Dairy Cows in Switzerland. Frontiers in veterinary science, 7, 611682. doi.org/10.3389/fvets.2020.611682

Kupczyński, R., Bednarski, M., Sokołowski, M., Kowalkowski, W., Pacyga, K. (2024). Comparison of Antibiotic Use and the Frequency of Diseases Depending on the Size of Herd and the Type of Cattle Breeding. Animals, 14(13), 1889. doi.org/10.3390/ani14131889

Lam, T.J.G.M., Heuvelink, A.E., Gonggrijp, M.A., Santman-Berends, I.M.G.A. (2020). Antimicrobial use in dairy cattle in the Netherlands. Journal of animal science, 98, (Suppl 1), S9–S14. doi.org/10.1093/jas/skaa143

Li, X., Xu, C., Liang, B., Kastelic, J.P., Han, B., Tong, X., Gao, J. (2023). Alternatives to antibiotics for treatment of mastitis in dairy cows. Frontiers in veterinary science, 10, 1160350. doi.org/10.3389/fvets.2023.1160350

Llanos-Soto, S.G., Vezeau, N., Wemette, M., Bulut, E., Greiner Safi, A., Moroni, P., Shapiro, M. A., Ivanek, R. (2021). Survey of perceptions and attitudes of an international group of veterinarians regarding antibiotic use and resistance on dairy cattle farms. Preventive veterinary medicine, 188, 105253. doi.org/10.1016/j.prevetmed.2020.105253

Rajala-Schultz, P., Nødtvedt, A., Halasa, T., Persson Waller, K. (2021). Prudent Use of Antibiotics in Dairy Cows: The Nordic Approach to Udder Health. Frontiers in veterinary science, 8, 623998. doi.org/10.3389/fvets.2021.623998

Rowe, S., Kabera, F., Dufour, S., Godden, S., Roy, J.P., Nydam, D. (2023). Selective dry-cow therapy can be implemented successfully in cows of all milk production levels. Journal of dairy science, 106(3), 1953–1967. doi.org/10.3168/jds.2022-22547

Saini, V., McClure, J.T., Léger, D., Keefe, G.P., Scholl, D.T., Morck, D.W., Barkema, H.W. (2012). Antimicrobial resistance profiles of common mastitis pathogens on Canadian dairy farms. Journal of dairy science, 95(8), 4319–4332. doi.org/10.3168/jds.2012-5373

Suzuki, Y., Hiroki, H., Xie, H., Nishiyama, M., Sakamoto, S.H., Uemura, R., Nukazawa, K., Ogura, Y., Watanabe, T., Kobayashi, I. (2022). Antibiotic-resistant Escherichia coli isolated from dairy cows and their surrounding environment on a livestock farm practicing prudent antimicrobial use. International journal of hygiene and environmental health, 240, 113930. doi.org/10.1016/j.ijheh.2022.113930

Tomanić, D., Samardžija, M., Kovačević, Z. (2023). Alternatives to antimicrobial treatment in bovine mastitis therapy: A Review. Antibiotics, 12(4), 683. doi.org/10.3390/antibiotics12040683

Virto, M., Santamarina-García, G., Amores, G., Hernández, I. (2022). Antibiotics in Dairy Production: Where Is the Problem? Dairy, 3(3), 541-564. doi.org/10.3390/dairy3030039

Wichmann, F., Udikovic-Kolic, N., Andrew, S., Handelsman, J. (2014). Diverse antibiotic resistance genes in dairy cow manure. mBio, 5(2), e01017. doi.org/10.1128/mBio.01017-13

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.377C

PREDICTORS OF ATTITUDES TOWARD THE PURCHASE AND INTENTIONS TO PURCHASE ORGANIC MILK

Milivoje Ćosić[1], Aleksandra Ivetić[2], Miroljub Ivanović[3]

[1]University of Bijeljina, Faculty of Agriculture, Republic of Srpska
[2] Institute for the Application of Science in Agriculture, Belgrade, Serbia
[3]Serbian Academy of Innovation Sciences, Belgrade, Serbia

Abstract: Even though the consumption of organic milk in the world is significantly increasing, the behavior of consumers of organic milk in the Serbian population has not yet been examined. This cross-sectional study aimed to define the variables that contribute to the attitude towards organic milk and those that explain the variance of the intention to purchase organic milk. Statistically significant impact on the attitude towards the purchase of organic milk was shown by the predictors: a) the belief in organic milk, b) the dietary lifestyle of the respondents, c) the level of trust in the domestic eco symbol/trademark as well as in the symbol of the European Union, d) real knowledge, and e) the gender of the respondents. Significant and positive contributions to the intention to purchase organic milk were observed in independent variables: tendentious belief in organic milk, real knowledge, and attitude towards the purchase of organic milk. The findings of multiple regression analysis and analysis of variance (univariate ANOVA) provide implications for marketing and management practice, especially for the construction of communication-political strategy.

Keywords: Organic milk certificate, Domestic eco symbols, Objective knowledge, Gender

1. INTRODUCTION

In the last decade of the 21st century, there has been an evident trend of increasing organic food products. The reasons for this are the following: increased consumer concern for the environment, the planet, and the climate, and that individuals no longer want to consume foods of dubious origin that contain various pesticides and genetically modified organisms (Elhalis et al., 2024). Organic farming is defined by the *International Federation of Organic Agriculture Movements* (IFOAM). The International Federation of Organic Agriculture Movements is a system of production that maintains the health of soils, ecosystems, and people. It is a production system that incorporates ecological processes, biodiversity, and natural cycles adapted to local conditions, rather than using inputs with harmful effects (Paull, 2024). The dominant principle of the organic farming system is that neither products nor animals should be accelerated beyond their natural potential. A growing awareness of the risks to human health and the need to protect the environment are factors that drive the growth of organic production. Organic farming protects the natural environment, but it is also an advanced sector of the economy. It affects the favorable utilization of resources, the development of rural territories, sustainable exports, economic growth, and increased living standards (Radović and Jeločnik, 2021). Organic milk produced according to organic farming standards implies that it is free of growth hormones, antibiotics, disinfectants, and other harmful substances (Linehan, et al., 2024). Cows that are in the organic production system are allowed a more "natural" way of keeping, where they are generally raised freely on pasture for most of the year (Dinçer et al., 2023). This method of production has relevant advantages compared to conventional milk production. Organic milk contains a higher percentage of polyunsaturated and omega-3 fatty acids, as well as a higher proportion of CLA, as well as a lower ratio of omega-6: omega-3 fatty acids (Calabro and Vieri, 2023). The predominance of organic milk has been recognized by consumers, and the consumption of organic milk is increasing significantly. That is why latent consumer behavior should be examined, i.e. psychological phenomena that are relevant when making a purchase decision. First, the factors that contribute to attitudes and purchase intention should be examined, since positive or negative emotions, valuations, and behaviors indirectly, and purchase intention directly influences purchasing behavior (Adhitjan et al., 2024).

In the last decade of the 21st century, the influence of various factors on attitudes toward organic food products and purchase intention has been increasingly examined. Knowledge objectively and subjectively contributes positively to attitudes towards organic food products (Rivera and Barcellos-Paula, 2024). According to research (Khaled et al., 2024), the most intense contributions to attitudes toward organic food products are shown by beliefs correlated with the health and taste of these products. The authors (Albarq et al., 2022) conclude a significant mediating function of lifestyle in predicting attitudes towards organic food, that is, that a healthy lifestyle of people results in more positive attitudes towards organic food. At the same time, researchers (Prakash et al., 2023; Tankosić et al., 2022) defined that eco-symbols on a product have a positive effect on consumers' experience of the overall quality of the product.

Differences in attitudes towards organic food were examined with the individual socio-demographic characteristics of the respondents. In empirical studies, it has been found that the female sex compared to the male sex, as well as younger people compared to the elderly, manifest more positive attitudes toward organic food products (Górka-Chowaniec et al., 2024). Studies have found that attitudes influence the intention to buy organic food products, personal knowledge, and attitudes toward organic food products (Bazhan et al., 2024; Čolović and Mitić, 2023). In the Republic of Serbia, given the evident available natural resources, the production of organic products is not sufficiently developed, which is probably a consequence of the unpreparedness of producers and consumers for organic production. To encourage and improve the production of organic products, it is primarily necessary to ensure certain environmental monitoring, to assess organic products as often as possible, and to inform the public about their characteristics and welfare. Since in the Serbian-speaking area, there is still no research on the relationship between attitudes and purchase intentions of organic milk, and the deficit of information on their characteristics, this research aims to examine the impact of variables on organic milk, and variables on health, knowledge, and taste of milk (as predictors) on the attitude towards the purchase of organic milk and the intention to buy organic milk (as criterion variables) on the population of adult citizens. By this goal, two alternative hypotheses have been defined: H1: It is expected that certificates about organic milk will statistically significantly affect the attitude of respondents towards the purchase of organic milk, and H2: It is assumed that respondents who have a higher degree of belief in the health and taste of organic milk, as well as personal knowledge about organic milk, will manifest a more intense perception of the intention to buy organic milk. Given the deficit of empirical studies in this area, as well as the different results, this study of transversal design can contribute to a more complete understanding of the prediction of variance of attitudes towards the purchase of organic milk and the intention to purchase organic milk.

This research aims to define the variables that contribute to the attitude towards organic milk and those that explain the variance of the intention to purchase organic milk.

2. MATERIAL AND METHODS

2.1. Subjects and research procedure

A total of (N = 240) respondents from the territory of the Republic of Serbia participated in the research, as follows: 54% female and 46% male. The age range of the subjects ranged from 18 to 62 years (Mage = 43.88, SD age = 2.86). The criteria for the selection of citizens were the age period over 18 years and the use of social networks. Of the total sample, 17 individuals are of below-average financial status (7.08%), 193 candidates have an average financial status (80.41%) and 30 people have an above-average financial status (12.50%). The sample was appropriate, and the respondents, after giving their informed consent, were asked to send the invitation to participate with the measuring instruments in an online form via the platform (Google Forms) and other people from different districts of Serbia. Electronic participation in the research through the "snowball" method was voluntary, without financial compensation. The completed questionnaire and scales could not be correlated with the identity of the respondents who filled them out since instead of their name and e-mail address; they entered their passwords using all available characters. At the beginning of the study, the subjects were given a brief explanation of how to respond. The survey was completely anonymous, and subjects could opt out of it at any time without any consequences. Filling out the scales and questionnaires took between 10 and 15 minutes. The research was conducted in November 2024 and approved by the Ethics Committee of the Serbian Academy of Innovation Sciences in Belgrade.

2.2. Online survey questionnaire

The online questionnaire via social networks included the following sets of questions: a) purchase of organic milk in the last 10 milk purchases (yes/no), b) place of purchase of organic milk, c) subjective and objective knowledge of organic food products and organic milk, d) certificates of organic milk, e) dietary lifestyle, f) trust in the domestic eco symbol and foreign eco symbols, g) attitudes towards the purchase of organic milk, h) purchasing intention concerning organic milk, and i) sociodemographic characteristics of the respondents. On a five-point Likert scale (1 = disagree at all, 5 = strongly agree), the following items were examined: a) beliefs about organic milk - two statements (Magnusson et al., 2001), b) dietary lifestyle - five items (Ureña et al., 2008), c) self-perceived knowledge about organic milk - one item), d) trust in eco-labels (trust in domestic and trust in EU labels), and (e) the intention to purchase organic milk (one is the intention to purchase organic milk in the next five purchases). Claims that focused on questions of how good, wise, and important it is to buy organic milk (Magnusson et al., 2001) were also examined using the Likert five-point scale. The independent variable objective knowledge was measured using the following three items, which are based on facts related to organic milk: a) Organic products are products without synthetic chemicals, b) Organic and regular milk include identical unique nutritional substances, (c) There are no statistically significant differences in the quantities of milk produced per cow in organic and traditional production. Respondents have to answer whether each of the statements is true or false.

2.3. Statistical analysis

Before the multivariate analysis, the normality of the Gaussian distribution of manifest variables was tested. The reliability of the results is determined by the Chrombach α coefficient of internal coexistence. The normality of the distribution of variables was verified by the coefficient of asymmetry of the distribution - skewness, the coefficient of roundness or flattening of the distribution - kurtosis. Statistical methods of descriptive statistics (arithmetic mean and standard deviation), parametric univariate analysis of variance - ANOVA, and multiple linear regression analysis were used. The estimation was drawn at the level of statistical error of 5% or 1% ($p \leq 0.05$). The data were analyzed in the computer program SPSS, version 26, i.e. the IBM statistical software package.

3. RESULTS AND DISCUSSION

Table 1 shows the basic descriptive parameters of measures of central tendency, variability, and coefficients of the form distribution of asymmetry (skewness) and roundness (kurtosis) and standard errors of the coefficients of asymmetry and externality of the distribution of the examined variables.

The Gaussian distribution of the obtained data was tested according to symmetry and flattening criteria (Tabachnick and Fidell, 2021). Asymmetry coefficients - the slope of the curve flattening coefficients - curvature of the top of the curve, the distribution of variables was within an acceptable deviation interval (indices less than +/- 2). After it was determined that all variables meet the stated standards of asymmetry and courtesy of the normal Gaussian distribution, the basic descriptive parameters for all variables used in the research were calculated, and later, at the level of statistical error of 5% in data processing, parametric statistical methods were applied.

Table 1. Descriptive parameters of the variables examined (N = 250)

Scales and questionnaire	M	SD	Sk (SE)	Ku (SE)
Opinion about Organic Milk	1.56	0.68	0.49 (0.20)	0.80 (0.24)
Trust in national Ecolabel	3.24	0.57	0.68 (0.10)	0.55(0.27)
Trust in the EU Ecolabel	3.28	0.70	-0.37 (0.15)	0.72 (0.21)

M = arithmetic mean; SD = standard deviation; SK = skewness/skewness of the sample distribution, Ku = kurtosis (kurtosis - flattening/roundness of the sample distribution); SE = standard error, $p \leq 0.05$

3.1. Anticipation of the purchase of organic milk

To check the relative contribution of predictor variables, the belief in organic milk, and confidence in the home. Eco UN and trust in the EU eco-label, in explaining the variance of the criteria - the purchase of organic milk on a sample of citizens in Table 1, a multiple linear regression model was implemented. Before the implementation of the statistical method MRL, the prerequisites for its operationalization were tested. Tolerance test values range from 0.38 to 0.96, while Variance Increase Factor (Variance) values range from 0.38 to 0.96. The Variance Inflation Factor ranges from 1.15 to 29. It has been found that there is no tolerance value. Tolerance test) is not less than 0.20, and no VIF value is greater than 5, it was concluded that they are within acceptable values, because none of the predictor variables showed harmful multilinearity, so the reliability of the model is not disputed for the implementation of multiple linear regression (Charlton et al., 2024). Table 2 shows the results of the tested relationships between the variables of the regression model.

Table 2. Multiple linear regression analysis to predict attitudes towards the purchase of organic milk (N = 250)

Predictors	*β*	SE	t
Opinion about Organic Milk	0.49**	0.03	8.55
Trust in national Ecolabel	0.42**	0.05	4.79
Trust in the EU Ecolabel	0.24**	0.02	2.63
R	0.46		
R^2	0.54		

β = the value of the standard Beta-coefficient; R = multiple correlation coefficient; R^2 = multiple determination coefficient - the percentage of the variance of the criteria explained by the predictors in the model; SE = standard error of the forecast, t-test = testing the difference between the mean values of the 2 data sets, $**p \leq 0.01$

By performing the statistical method of MLR between linear combinations of a set of predictors/explanatory variables and criteria, a significant coefficient of multiple correlation, mean intensity, was obtained, where the coefficient of determination - the total contribution to the explained variance - predicts 54% of the proportion of the total variability of the criterion - the sum of the squares of the total deviations of the criterion variable from its arithmetic mean (Table 3). This means that based on more than 1/2 of the variation, predictor variables, the construct of buying organic milk can be predicted. Although this level of variance is considered acceptable in the social sciences, it is important to note that the remaining 66% of unexplained deviations/residuals are not explained by the linear dependence of other factors. This suggests that there are other components of total variability, i.e. Other unknown regressors, which also potentially mediate the purchase of organic milk, were not controlled in this quantitative study. Further inspection of the values of the standard Beta-coefficients shows a statistically significant positive contribution of the variable of the certificate of organic milk (healthier and tastier than usual) to the attitude towards the purchase of organic milk. This suggests that the respondents, at the level of p value of 0.01, who manifested a higher level of trust in the domestic and EU eco symbol - perceived a significantly more positive attitude towards the purchase of organic milk. Therefore, the applied regression diagnostics and the Student's t-distribution indicate that the investigated predictor variables are not the result of chance, since stochastic significantly contributes to explaining the variability in the purchase of organic milk by citizens. Therefore, the regression model presented may have important implications for understanding the problem of buying organic milk. Table 3 shows the influence of independent variables on the attitude towards the purchase of organic milk.

A statistically significant impact of objective knowledge on attitudes towards the purchase of organic milk has been defined, which is in line with the findings of the research (Rosimana et al., 2024). Respondents who had information that organic products did not contain synthetic chemicals showed a more positive attitude towards buying organic milk than respondents who did not know. Respondents who knew that there were no differences in the food system between organic and regular milk showed a more negative attitude towards buying organic milk than respondents who did not. On the other hand, the third examined variable of objective knowledge did not significantly contribute to the attitude toward organic milk.

Sociodemographic variables that were normally distributed, only the parametric F-test in the gender variable of the respondents significantly influenced the attitude towards the purchase of organic milk, i.e. the rejection of the statistical hypothesis H0, - the assumption that all arithmetic means of the studied population are the same, with women manifesting a more positive attitude compared to men, which is in line with the findings of research on organic food products (Çakır Biçer et al., 2024; Dung and Le Huynh, 2024).

Table 3. Contribution of independent variables to the attitude towards the purchase of organic milk (ANOVA, n = 250)

Variables	Categories of independent variables	M	F	p
Dietary lifestyle Respondents	More health-conscious food consumers	4.17	5.44	0.03*
	Less health-conscious food consumers	3.85		
Objective Knowledge (1)	The respondent knows that organic products are free of synthetic chemicals	4.26	5.62	0.01**
	The respondent does not know that eco-products are free of synthetic chemicals	3.74		
Objective Knowledge (2)	The respondent knows that organic products are free of synthetic chemicals	3.86	5.80	0.05
	The respondent does not know that eco-products are free of synthetic chemicals	4.17		
Gender	Male	4.01	4.82	0.01
	Female	4.19		

M = arithmetic mean; F = multivariate Fischer's test; **p ≤ 0.01, *p ≤ 0.05

Table 4 shows the influence of predictor variables on the intention to purchase organic milk. Based on the obtained regression model, a statistically significant multiple correlation coefficient of medium intensity was obtained, where the coefficient explains 48% of the total variance of the criteria of intention to purchase organic milk. The resulting proportion of variability is satisfactory, with a note that the residual 52% variation is not explained by the linear dependence of other latent dimensions. This points to the existence of other unexplored factors that may be contributing to the purchase of organic milk that has not been investigated in this empirical study. The dependent variable intention to purchase organic milk is statistically significantly influenced by all analyzed independent variables. The obtained values of the standard Beta-coefficient and statistical t-test ($p \leq 0.01$) show that respondents with a more intense positive opinion about organic milk manifest a more intense desire to buy, as well as respondents who stated that they know more about organic milk. Identical results on the relationship between organic food products and attitudes toward the purchase of milk were obtained by the authors (Adhitjan et al., 2024; Pandey et al., 2023; Çakır Biçer et al., 2024).

Table 4. Multiple linear regression analysis to predict the intention to purchase organic milk (N = 250)

Predictors	*β*	SE	t
Opinion about Organic Milk	0.27**	0.01	4.50
Subjective knowledge about organic milk	0.23**	0.03	4.32
R	0.50		
R^2	0.48		

β = the value of the standard Beta-coefficient; R = multiple correlation coefficient; R^2 = multiple determination coefficient - the percentage of variance of the criteria explained by the predictors in the model; SE = standard forecast error, $p \leq 0.01$**

4. CONCLUSION

In this empirical study, the predictors of the variable that contribute to the attitude towards organic milk, i.e. independent variables that affect the intention to purchase organic milk. A statistically significant contribution to the attitude towards the purchase of organic milk was shown by the certificate of organic milk, the dietary lifestyle of the respondents, the level of trust in domestic and EU eco-symbols, real knowledge, and gender of the respondents. A significant and positive contribution to the intention to purchase organic milk is manifested by four predictors: 1) belief in organic milk, 2) tendentious knowledge, 3) objective knowledge, and 4) attitude towards the purchase of organic milk. Respondents who had information about significant differences in the amount of milk produced per cow in organic and usual production emphasized a more intensive intention when buying organic milk. Based on the findings of multiple linear regression and parametric univariate analysis of variance, guidelines for the implementation of a management-marketing strategy can be defined. The female gender manifested a more noticeable awareness of the correlation between nutrition and health, a more positive attitude towards organic milk, and a greater purchase intention than the male gender. Consequently, the process of information exchange based on functional information in women should be focused on conventional public communication, while in men emotional information intended to inform more people should be applied more. It has been proven that respondents who show confidence in eco-symbols also emphasize more positive attitudes towards organic milk. That is why it is necessary to present eco-symbols in public and emphasize the packaging of the product. Respondents who have more information about the privileges of organic milk have a more positive attitude towards its purchase, and vice versa. The conclusion of the paper, in addition to the usual advertising, emphasizes the education of consumers to present the advantages of organic milk compared to the established promotion.

5. REFERENCES

Adhitjan, H., Marguerite, F., Wahyu, U.R., Hendijani, R.B. (2024). Consumer Intention of Purchasing Plant-Based Milk in Indonesia. Jurnal Indonesia Sosial Teknologi, 5(5), 2269–2280. doi.org/10.59141/jist.v5i5.1083

Albarq, A.N. (2022). Digital marketing and online purchasing in Saudi Arabia: Exploring generational differences. International Journal of e Business and e-Government Studies, 14 666-683. doi.org/10.34111/ijebeg.202214151

Bazhan, M., Sabet, F.S., Borumandnia, N. (2024). Factors affecting purchase intention of organic food products: Evidence from a developing nation context. Food Science & Nutrition, 12(10), 3469-3482. doi.org/10.1002/fsn3.4015

Calabro, G., Vieri, S. (2023). Limits and potential of organic farming towards a more sustainable European agri-food system. British Food Journal, 126, 223-236. www.emerald.com/insight/0007-070X.htm

Çakır Biçer, N., Baş, D., Seçkiner, S., Kahrıman, M., Baş, M. (2023). Evaluation of Consumers' Perceptions and Purchase Decisions Regarding Plant-Based Milk Alternatives in Turkey. Izmir Democr. *Journal* of *Health Sciences,* 6, 82–102. doi.org/10.52538/iduhes.1215432

Charlton, C., Rasbash, J., Browne, W.J., Healy, M., Cameron, B. (2024). MLwiN Version 3.10. Centre for Multilevel Modelling, University of Bristol.

Čolović, M., Mitić, V.Č. (2023). The main motives for buying organic food of people of the former Yugoslavia. British *Food Journal,* 125, 2257-2274. doi.org/10.1108/BFJ-06-2021-0651

Dinçer, M.A.M., Arslan, Y., Okutan, S., Dil, E. (2023). An inquiry on organic food confusion in the consumer perception: A qualitative perspective. British Food Journal, 125, 1420-1436. doi.org/10.1108/BFJ-03-2022-0226

Dung, M.T., Le Huynh, T.N. (2024). Trends in Organic Fresh Milk Consumption for Children- A Case Study of Consumers in Vietnam. International Research Journal of Economics and Management Studies, 3(6), 130-141. doi:10.56472/25835238/IRJEMS-V3I6P115

Elhalis, H., Chin, X.H., Chow, Y. (2024). Soybean fermentation: Microbial ecology and starter culture technology. Critical Reviews in Food Science and Nutrition, 64(21), 7648-7670. doi.org/10.1080/10408398.2023.2188951

Górka-Chowaniec, A., Niewczas-Dobrowolska, M., Akbaş, A., Bezuglov, E., Sikora, T., Waśkiewicz, Z. (2024). Socio-Demographic Influences on Dietary Habits and Nutritional Awareness: A Case Study of Polish Biathlon Association National Team Members. Nutrients, 16(21), 3784. doi.org/10.3390/nu16213784

Khaled, Al.F., Abdulrahman Al.S., Abbas, N.A. (2024). The importance of environmental concern, trust and convenience in consumers' purchase intentions of organic foods in a developing country. Cogent Business & Management, 11(1), 2361319. doi.org/10.1080/23311975.2024.2361319

Linehan, K., Patangia, D.V., Ross, R.P., Stanton, C. (2024). Production, Composition and Nutritional Properties of Organic Milk: A Critical Review. Foods, 13(4), 550-563. doi.org/10.3390/foods13040550

Magnusson, M.K., Arvola, A., Koivisto Hursti, U.K., Åberg, L., Sjödén, P.O. (2001). Attitudes towards organic foods among Swedish consumers, British Food Journal, 103(3), 209-227. doi.org/10.1108/00070700110386755

Paull, J. (2024). Organic Agriculture in Europe: EU Sets Goal of Growing Organic Farmland from 10% to 25% by 2030. European Journal of Agriculture and Food Sciences, 6(1), 26–31. doi.org/10.24018/ejfood.2024.6.1.769

Prakash, G., Singh, P.K., Ahmad, A., Kumar, G. (2023). Trust, convenience and environmental concern in consumer purchase intention for organic food. Spanish Journal of Marketing-ESIC, 27, 367–388. doi.org/10.1108/SJME-09-2022-0201.

Radović, G., Jeločnik, M. (2021). Improving Food Security Through Organic Agriculture: Evidence from Serbia. In Shifting Patterns of Agricultural Trade; Erokhin, V., Tianming, G., Andrei, J.V. (Eds.), Springer, Singapore, 335-371.

Rivera, H.J.P., Barcellos-Paula, L. (2024). Personal Variables in Attitude toward Green Purchase Intention of Organic Products. Foods, 13(2), 213-221. doi.org/10.3390/foods13020213

Rosimana, N.H., Abidinb, U.F.U.Z., Hussinc, A.S.M. (2024). Analysis of Factors Affecting Intention to Purchase Buffalo Milk and Milk Products among Malaysian Consumers. International journal of academic research in business and social sciences, 14(10), 2222-6990. dx.doi.org/10.6007/IJARBSS/v14-i10/20859

Tabachnick, B.G., Fidell, L.S. (2021). Using Multivariate Statistics, 7th ed. Pearson.

Ureña, F., Bernabeu, R., Olmeda, M. (2008). Women, men and organic food: differences in their attitudes and willingnes to pay. A Spanish case study. International Journal of Consumer Studies, 32, 18-6.

Tankosić, J., Hanić, H., Bugarčić, M. (2022). Consumer′s characteristics and attitudes towards organic food products in times of COVID-19 pandemic. Ekonomika Poljoprivrede, 69, 469-481.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.385T

RAISING AWARENESS OF CLIMATE CHANGE: NLP APPROACH TO STRENGTHENING RESILIENCE IN AGRICULTURE

Adisa Tufo

Business Psychology and Human Resources, Sarajevo, Bosnia and Herzegovina
info@adisatufo.ba

Abstract: Climate change poses a global challenge, significantly impacting the sustainability of agriculture, particularly in rural communities. This paper examines how Neuro-Linguistic Programming (NLP) techniques can raise awareness of climate change and empower farmers to adapt their values and practices to emerging circumstances. Techniques such as reframing, values hierarchy, and visualization are analyzed for their potential to strengthen community resilience and encourage sustainable practices. A hypothetical scenario illustrates how NLP could transform perceptions and facilitate the adoption of innovative agricultural methods. Emphasis is placed on the interdisciplinary nature of NLP, integrating technical and psychological approaches to foster sustainability. This paper contributes to the understanding of innovative strategies for sustainable agricultural development and highlights NLP's role as a valuable tool in addressing climate challenges.

Key words: Climate change, Sustainable development, Agriculture, Resilience, Values hierarchy

1. INTRODUCTION

Climate change is one of the greatest challenges of the modern era, with far-reaching consequences for natural resources, agricultural communities, and the global economy. Sustainability in agriculture has become a crucial topic, as rural communities increasingly feel the need to adapt to new circumstances. Despite technical innovations and adaptation efforts, the mental and value-based frameworks of individuals and communities play a key role in recognizing problems and taking appropriate action (FAO, 2020; IPCC, 2021).

Neuro-Linguistic Programming (NLP) provides tools for behavioral change, developing intrinsic motivation, and building resilience, making it a valuable approach for raising awareness and encouraging action regarding climate change in agriculture (Bandler and Grinder, 1979; Dilts, 1990; United Nations, 2015).

NLP, or Neuro-Linguistic Programming, is a communication and psychological model that explores the connection between our thoughts (neuro), language (linguistic), and behavioral patterns (programming). Developed in the 1970s, NLP offers various techniques and strategies to improve communication, achieve personal and professional goals, and overcome limiting beliefs. One of the core premises of NLP is that by changing internal mental models and the language we use, positive changes in behavior and attitudes can be achieved (Bandler and Grinder, 1979; Dilts, 1990; O'Connor and Seymour, 1990).

In the context of agriculture, NLP techniques can play a crucial role in shaping attitudes toward climate change, developing environmentally responsible habits, and strengthening the ability of rural communities to adapt to increasingly uncertain conditions. This is particularly important when traditional patterns of agricultural practices are threatened by changing climate conditions, requiring rapid responses and readiness for innovation (Dilts, 1990; IPCC, 2019; Schneider and Lane, 2020).

This paper explores how NLP techniques can contribute to raising awareness of climate change through strengthening values and sustainable habits in rural communities.

2. RESEARCH

Proposed Section: Research Objectives
The objectives of this research are as follows:

1. To examine the role of NLP in raising awareness about climate change and its impacts on rural agricultural communities.
2. To analyze the potential of NLP techniques for facilitating behavioral change and strengthening resilience among farmers in the face of climate challenges.
3. To propose specific NLP tools (e.g., reframing, visualization, values hierarchy) for the development of sustainable agricultural practices and long-term adaptability.

These objectives are to demonstrate the interdisciplinary potential of NLP by integrating psychological approaches with sustainable agricultural solutions, providing a framework for addressing the human dimensions of climate adaptation.

2.1. Theoretical framework

Climate change affects not only ecosystems but also human perception and behavior. At the heart of this issue lie three key questions:

1. Awareness and values: How well do farmers understand the impact of climate change, and how do values influence their decisions?
2. Mental models: How do people process information about change, and what barriers exist to adopting new habits?
3. Resilience: What traits and skills help communities adapt and overcome challenges? NLP techniques, such as anchoring, reframing, and success modeling, offer practical methods for changing perceptions, strengthening intrinsic motivation, and shaping behavior that leads to sustainable development (IPCC, 2019; Dilts, 1990; Wake, 2010; Schneider and Lane, 2020).

2.2. Research objectives and context

The objectives of this study stem from the pressing need to adopt interdisciplinary approaches to address the challenges posed by climate change. Climate change impacts not only agricultural practices but also the mindset and value systems of individuals and communities, which are essential for sustainable decision-making. By leveraging NLP techniques, this research aims to explore how mental models, and intrinsic values can be aligned with sustainable agricultural practices to create long-term resilience.
The primary focus is to illustrate how NLP techniques, such as reframing, visualization, and value hierarchy analysis, can foster:

1. **Awareness:** Increasing understanding of the effects of climate change among farmers and empowering them to act.
2. **Behavioral change:** Encouraging the adoption of sustainable practices through shifts in perception and motivation.
3. **Resilience:** Strengthening the capacity of rural communities to adapt to evolving challenges with innovation and confidence.

This research positions NLP not merely as a psychological tool but as a systematic approach to building sustainability by integrating personal development with practical solutions. The proposed framework seeks to demonstrate how NLP can transform agricultural communities by addressing both the technical and human dimensions of climate adaptation (O’Connor and Seymour, 1990).

3. APPLICATION OF NLP IN AGRICULTURE

3.1. Raising awareness through values

NLP tools like the values hierarchy and belief analysis can raise awareness about critical climate change issues. Farmers can be guided to recognize their values that align with sustainable development (Dilts, 1990; Grinder and DeLozier, 1987). For example:

- Values Hierarchy: Through this technique, farmers can discover how important environmentally responsible practices are relative to other values, such as financial success or tradition.
- Meta-Model Questions: By breaking generalizations and limiting beliefs like "I'm too small to make a difference," farmers can gain new insights into their power to contribute to positive change.

3.2. Building resilience through reframing

NLP techniques such as reframing can help farmers change their perspectives and face climate challenges (Dilts, 1990; Bandler and Grinder, 1982):

- Meaning Change: Instead of viewing drought as an insurmountable problem, reframing can interpret it as an opportunity to develop innovative irrigation techniques.
- Anchoring Positive States: Farmers can use anchoring to develop emotional stability in stressful situations, helping them stay motivated and proactive.

3.3. Creating sustainable habits

NLP techniques are particularly useful for developing long-term habits that support environmental awareness (Dilts, 1990; Grinder and DeLozier, 1987):
Setting SMART Goals: Farmers can establish specific, measurable, achievable, relevant, and time-bound goals, such as "Reduce water consumption by 20% over the next six months."
Visualization: Through NLP visualization exercises, they can create a clear mental picture of successful sustainable practices, increasing the likelihood of their realization.
Chunking: Breaking down complex tasks, like transitioning to organic production, into smaller, achievable steps makes it easier for farmers to implement changes.

3.4. Creating a learning community

NLP can contribute to creating collaborative communities where farmers share knowledge and experiences (Dilts, 1998; Bandler and Grinder, 1979):
Success Modeling:
Using modeling techniques, successful practices can be transferred to other farmers.
Rapport: Developing trust and a shared language within communities facilitates the introduction of new ideas and practices.

4. HYPOTHETICAL SCENARIO: AN NLP APPROACH TO ADDRESSING CLIMATE CHANGE IN RURAL COMMUNITIES

4.1. Introduction to the scenario

It is not difficult to imagine a small agricultural community in a rural area of Serbia, where droughts have become increasingly frequent and severely affect farmers. Traditional farming methods are becoming unsustainable, and adapting to new climatic conditions requires not only technical solutions but also a shift in mindset and behavior. In this context, the NLP approach is proposed to support farmers in building resilience, raising awareness of key values, and adopting sustainable practices.

Phase 1: Analysis of Values and Beliefs
The first activity in this hypothetical program is an NLP workshop focused on analyzing values and identifying beliefs.
Values Hierarchy
Through a series of guided questions, farmers would uncover their own hierarchy of values. The goal is for them to understand how resource conservation and adapting to new practices can occupy a high place in their values, equally important as economic success.
Example questions:
- *"What is most important to you for the future of your family and farm?"*
- *"How could preserving fertile soil impact the generations to come?"*

Breaking Limiting Beliefs (Meta-Model Questions)
This activity focuses on identifying beliefs that hinder change, such as: *"We don't have the resources to adapt"* or *"Everything will stay the same because that's how we've always done it."* NLP-guided questions help recognize concrete steps that shift perspective:
- *"What could you do if you had support?"*
- *"Can you imagine a small step that would bring you closer to sustainable practices?"*

Phase 2: Reframing Problems and Challenges
This workshop focuses on applying the NLP technique of reframing to change the perception of problems and encourage a positive attitude toward challenges.
Identifying Problems and Creating New Frames of Meaning
- **Old frame**: *"Drought destroys our crops and reduces our income."*
- **New frame**: *"Drought motivates us to explore innovative methods for water conservation, which will protect our farm in the long run."*

Example Discussion
Farmers would share their experiences and, through guided discussion, explore how other similar problems could be transformed into opportunities. Using examples of communities that have successfully implemented sustainable methods provides additional motivation:
- *"If this practice works elsewhere, how could we adapt it to our situation?"*

Phase 3: Visualization and Planning Concrete Steps
The use of the NLP visualization technique guides farmers in creating mental images of a successful transition to sustainable practices.
Guided Visualization
Farmers would imagine:
- What their farm looks like five years after successfully implementing water conservation methods.
- How they feel when they see stable yields and security for their families.

This technique helps strengthen internal motivation and reduce resistance to change.
Developing an Action Plan
Based on the visualization exercise, farmers would collaboratively create a concrete plan using SMART goal:
- **Specific goal**: *"Reduce water consumption for irrigation by 20% over the next six months"*.
- **Measurable**: Establish a system for measuring water consumption.
- **Achievable**: Pilot-test one method on smaller plots of land.
- **Relevant**: Directly related to resilience against drought.
- **Time-bound**: Monitor progress every two months.

Phase 4: Introducing Pilot Plots and Learning Through Experience
It is proposed to establish pilot plots to test new techniques. This approach would allow farmers to directly observe how new methods can work in practice with minimal risk.
Examples of Pilot Activities:
- Testing a drip irrigation system on a small area.

- Introducing cover crops to retain moisture in the soil.

Evaluation and Feedback

Following the pilot project, farmers would review the results and, through NLP-guided discussions, analyze what was successful and what adjustments are needed for future implementation.

Phase 5: Strengthening Collective Resilience and Support

This phase proposes the formation of a learning community, where farmers share experiences, successes, and challenges.

Modeling Successful Examples

By applying the NLP technique of success modeling, successful farmers can serve as role models for the rest of the community.

Anchoring Positive States

Through the NLP technique of anchoring, farmers would reinforce emotional states of success, motivation, and resilience, helping them stay focused during stressful situations.

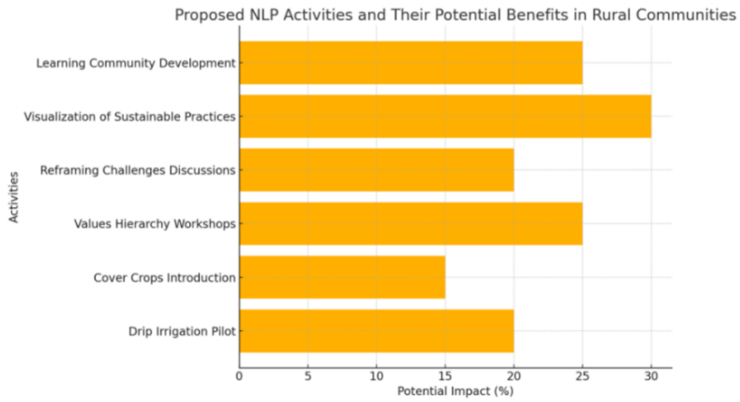


Figure 1. Potential beneficial Neuro-Linguistic Programming activities in rural communities

5. THE POTENTIAL OF NLP IN SHIFTING PERSPECTIVES AND DEVELOPING SUSTAINABLE PRACTICES

Rural communities around the world face unpredictable climate challenges that threaten their survival and sustainability. Maintaining yields, preserving resources, and adapting to new conditions require more than technical innovations - the key component of success lies in shifting mindsets and building resilience in individuals and communities. It is here that NLP demonstrates exceptional potential as a tool to support farmers through education, motivation, and structured guidance toward more sustainable practices (Dilts, 1990; IPCC, 2019; United Nations, 2015).

This hypothetical scenario illustrates how NLP techniques can play a crucial role in raising awareness and building practical solutions. Techniques such as reframing, visualization, values hierarchy, and success modeling empower farmers to recognize their capacity to influence their future while simultaneously changing their perspective on essential problems. These changes are not superficial; they reach the core beliefs and values that shape everyday decisions and behaviors (Dilts, 1990; Grinder and DeLozier, 1987).

5.1. Key benefits of NLP in building resilience

- Transforming the Perception of Challenges: Instead of viewing climate change as an insurmountable obstacle, NLP provides a framework through which challenges can be reinterpreted as opportunities for growth, innovation, and adaptation. For example, drought is not the end of agriculture but a catalyst for developing innovative irrigation and soil preservation methods.

- Developing Concrete and Actionable Strategies: The NLP approach focuses on measurable and achievable action steps. These techniques enable communities to break down complex problems, such as transitioning to environmentally sustainable methods, into smaller steps, reducing resistance and increasing the likelihood of successful implementation.
- Emotional Resilience and Motivation: Anchoring positive emotional states and creating mental images of success empower farmers to stay motivated even under the most challenging conditions. This inner stability is essential for making decisions aligned with long-term sustainability goals.
- Strengthening Collective Spirit and Collaboration: Through NLP techniques, communities can develop a collaborative learning culture, where knowledge and experiences from successful individuals are transferred to other members. In rural communities, trust and mutual support are often key to accepting change.

5.2. The broader importance of NLP in addressing climate change

This hypothetical scenario also highlights the broader application of NLP in the context of sustainable development. NLP is not merely a tool for solving current problems; it represents a systematic approach to behavioral change that can transform communities on a deeper level.
Climate change requires a holistic approach, where technical solutions are complemented by work on the human factor. NLP enables exactly that - creating intrinsic motivation to adopt sustainable practices, raising awareness of the importance of resource conservation, and developing the capacity of communities to proactively respond to changes (Dilts, 1990; Grinder and Bandler, 1987; IPCC, 2019).

By combining NLP techniques with practical steps, such as pilot projects and goal setting, the following outcomes can be achieved:

- Faster adaptation to new conditions through mental flexibility and innovative thinking
- Reduced resistance to change by breaking down beliefs that hinder progress.
- The development of a long-term vision that integrates natural resource conservation with the economic prosperity of the community.

5.3. The importance of continuous support and further research

For NLP interventions to be sustainable in the long term, it is necessary to establish regular training programs, support networks, and systematic monitoring of results. Continuous support ensures that the learned techniques become part of everyday practices, contributing to the community's long-term resilience (Dilts, 1998; Bandler and Grinder, 1979; United Nations, 2015; Schneider and Lane, 2020).

Further research can provide empirical evidence of the effectiveness of NLP in real-world conditions, further affirming its value. Special attention should be directed toward interdisciplinary approaches that connect NLP with technical solutions and sustainable development, as well as digital support through applications that track and evaluate community progress (Dilts, 1998; IPCC, 2019; Bandler, 2008).

To improve awareness of climate change, it is necessary to develop research that would be based on:
- Interdisciplinary Approaches**:** Further research could involve collaboration between NLP experts, sustainability specialists, and social psychologists to better understand how human factors, such as beliefs and values, influence communities' ability to adapt to climate change.

- Evaluation of Long-Term Effects of NLP: Longitudinal studies are recommended to follow rural communities over an extended period to assess how sustainable NLP interventions are and how they affect community resilience at different stages of climate change.
- Practical Implementation in Diverse Cultures: Comparative studies could investigate the effectiveness of NLP techniques in different cultural and economic contexts, identifying opportunities for global application of these methods.
- Technological Support for NLP Approaches: Developing and evaluating digital tools, such as applications or online platforms, could further enhance the dissemination of NLP approaches and enable better monitoring of intervention effects in rural communities.
- Connection Between Emotional Intelligence and NLP: Further studies could examine how the development of emotional intelligence through NLP techniques can additionally empower farmers to face climate challenges and make environmentally responsible decisions.
- Quantitative Assessment of NLP Effects: Research utilizing quantitative methods to evaluate the impact of NLP programs on awareness, behavior, and community resilience is needed to provide empirical evidence for the effectiveness of these approaches.

6. CONCLUSION

The NLP approach, while flexible and adaptable, represents more than a set of techniques - it is a tool for empowering communities and building sustainable mental models that enable them to face future challenges. This paper demonstrates how NLP could become an integral part of sustainability strategies in agriculture, particularly in rural areas that are most affected by climate change.

By developing inner resilience, strengthening values, and creating action plans, NLP can support farmers to not only survive change but also thrive in a dynamically changing world. Ultimately, this approach opens the door to the broader application of NLP as a valuable resource for sustainable development in various sectors, encouraging proactive action, innovation, and long-term community sustainability.

7. REFERENCES

Bandler, R., Grinder, J. (1979). Frogs into Princes: Neuro-Linguistic Programming. Real People Press.

Bandler, R., Grinder, J. (1982). Reframing: Neuro-Linguistic Programming and the Transformation of Meaning. Real People Press.

Bandler, R. (2008). Get the Life You Want: The Secrets to Quick and Lasting Life Change with Neuro-Linguistic Programming. HCI.

Dilts, R. (1990). Changing Belief Systems with NLP. Meta Publications.

Dilts, R. (1998). Modeling with NLP. Meta Publications.

FAO (2020). Climate Change and Agriculture: Impacts, Adaptation, and Mitigation. Food and Agriculture Organization of the United Nations.

Grinder, J., DeLozier, J. (1987). Turtles All the Way Down: Prerequisites to Personal Genius. Grinder, DeLozier & Associates.

IPCC (2019). Climate Change and Land: An IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems. Intergovernmental Panel on Climate Change.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Intergovernmental Panel on Climate Change.

O'Connor, J., Seymour, J. (1990). Introducing Neuro-Linguistic Programming: Psychological Skills for Understanding and Influencing People, Thorsons.

Schneider, F., Lane, M. (2020). Sustainable Agriculture and Climate Change: Challenges and Opportunities. Springer.

United Nations (2015). Transforming our World: The 2030 Agenda for Sustainable Development. United Nations.

Wake, L. (2010). NLP Principles in Practice: Practical Tools for Managers. Crown House Publishing.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.392V

WOMEN IN AGRICULTURE

Slađana Vujičić[1,2*], Mersida Jandrić[3]

[1]University Bijeljina, B&H, *sladjanakonto@gmail.com
[2]Faculty of Business, Economics and Entrepreneurship, Belgrade, Serbia
[3]University Bijeljina, Faculty of Agriculture, B&H, mersida.jandric@hotmail.com

Abstract: Today, the role of women in agriculture is crucial for the development of rural communities and the sustainability of agricultural systems. The fact remains that in many parts of the world, women are often overlooked in the agricultural sector; however, their work in this field has a profound impact on food production, biodiversity preservation, and natural resource management. This paper explores the role of women in agriculture by identifying the key challenges they face and analyzing their contribution to the modern agricultural sector. The goal of this research is to examine the position of women in agriculture, with a focus on the challenges they encounter and the opportunities to enhance women's participation in agricultural activities. The research was conducted through a survey involving 80 women farmers with varying levels of education, age groups, and work experiences. Analysis of the responses showed that most participants highlighted financial barriers and lack of education as key factors limiting their success in agricultural development.

Key words: Women, Agriculture, Education

1. INTRODUCTION

Agriculture is one of the oldest and most important sectors of the human economy, forming the foundation for food production, the preservation of natural resources, and the maintenance of social stability. Given the importance of agriculture in the global economy, the role of women in this sector is becoming increasingly important. In many parts of the world, women are essential to the functioning of agricultural systems, as they carry out a wide range of tasks related to food production and agricultural resource management. Although their work is often undervalued and unrecognized, women make up a significant portion of the agricultural workforce, and their contribution is not only in labor but also in sustainability and innovation, which they apply to agricultural farms and the communities in which they live. The issue of empowering women in agriculture is currently one of the important topics worldwide. It has been addressed by many researchers (Baig et al., 2018; Asitik and Abu, 2020; Oyawole et al., 2021; Shajahan et al., 2022; Gupta et al., 2019; Balezentis et al., 2021; Azima and Mundler, 2022).

Today, women in agriculture have diverse roles, ranging from owners of agricultural farms to workers on them. The number of women who run agricultural farms and enterprises is lower than that of men in many countries, so the role of women in agriculture should not be underestimated. According to FAO (2020), women perform around 43% of the total agricultural labor globally, and in some countries, particularly in Africa and Asia, this percentage is even higher. Women often have key responsibilities related to food production for local markets and families, as well as the task of preserving local resources and biodiversity. Women are often the primary carriers of traditions and knowledge related to sustainable agricultural practices, especially in the areas of organic farming and agro-ecological measures.

However, women in agriculture face numerous challenges. Traditionally, agricultural land is often owned by men, and women encounter legal, economic, and social barriers that prevent them from taking responsibility for land management or developing entrepreneurship. Land is the central factor of production in agrarian economies (Bell, 1990; Obeng-Odoom, 2012) Although women perform a significant portion of agricultural labor, they are often unable to utilize modern technologies that would enhance their productivity or participate in decision-making processes related to the development of agricultural policy and markets. Cultural norms have a significant impact on this, as they often impose a role on women that is limited to household and family-based work.

One of the factors that can contribute to improving the position of women in agriculture is education and training in agricultural technologies. Educating and training women in agricultural production, resource management, and entrepreneurship development can help them enhance their skills and knowledge, thus increasing their productivity and competitiveness in the market. Additionally, access to modern technologies can enable women to improve the efficiency of their work and ensure a more sustainable and environmentally friendly production method. Strategies for empowering women in agriculture, such as improving access to credit, land, markets, and education, can contribute to better economic standing for women and enable them to become drivers of change in their communities. In today's society, awareness of the importance of women in agriculture is growing, and many organizations, government institutions, and non-governmental organizations recognize the need for the implementation of policies that will support greater participation of women in this sector. Empowering women in agriculture not only means improving their economic position but also contributing more to sustainable development, poverty reduction, and increased food security. At a global level, women are increasingly recognized as key players in the fight against climate change and the preservation of natural resources (Onoh et al., 2023), as many sustainable practices in agriculture stem from their innovations and experiences.

The aim of research is examine in greater detail the (i) role of women in agriculture, identify the key challenges they face, and highlight the benefits of their involvement in decision-making related to food production and resource management (ii) analysis possible strategies for improving their living and working conditions in agriculture, as well as the role of education, technology, and economic policies in creating a more favorable environment for women in rural communities.

2. LITERATURE REVIEW

Agricultural production is one of the oldest branches of the economy and plays a particularly significant social role in feeding the growing global population (Lapčević and Nikitović, 2020). In Serbia, agriculture is positioned as a very important potential in overall social and economic development, taking into account the quality and quantity of available resources, rich tradition and favorable geographical position (Marković, 2010, p. 273). Milanović, et al. (2020) state that the agricultural sector in the Republic of Serbia holds high economic and social importance, as it contributes significantly to the Gross Domestic Product and employs many people. Family farms in Serbia are predominantly registered under men's names, while women are usually not employed on the farm but are informally engaged as labor in agricultural tasks. This means that, alongside men, women are an integral part of agricultural communities, even though their roles are often visible in specific tasks, such as household care, animal husbandry, and horticulture, while men typically handle the heavier and more technical tasks. Women take on roles as farmers, workers, and entrepreneurs, and their activities generally include the production of crops, animal husbandry, food processing and preparation, wage labor in agricultural or other rural businesses, trade and marketing, family care, and maintaining their homes (FAO, 2011). Women account for over 40% of all workers in the global agrifood system (Figure 1).

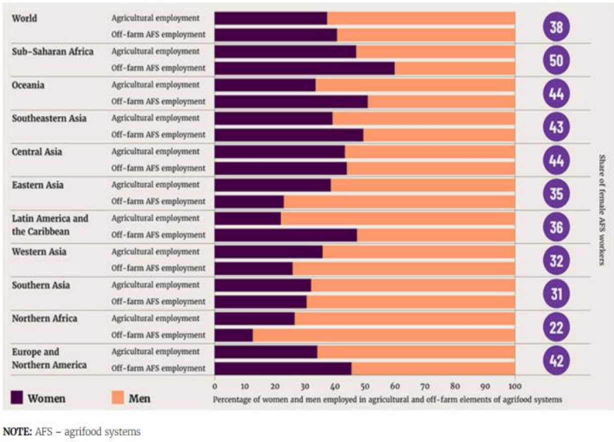


Figure 1. The share of women and men in total agrifood-system employment, and by subcomponent of agrifood systems in 2019 (Costa et al., 2023).

At the EU level (EU-28), around 30% of agricultural farms are led by women – one in five farms, and in rural areas of the EU, women represent over 50% of the rural population. Women make up about 45% of the total workforce and around 35% of workers in the agricultural sector of the EU-28, with the work of female farmers accounting for 31% of the total working hours (European Parliament, 2019). Montagnoli (2020) pointed out that 32% of agricultural enterprises in Italy are female-led, while among agri-tourism companies, this share reaches 39%.

The latest census in the Republic of Serbia showed that women are the heads of over 30% of the total registered agricultural households in the country. They are most commonly engaged in organic food production, vegetable and flower cultivation in greenhouses, agricultural product processing, beekeeping, and rural tourism.

Moreover, women in rural areas face specific challenges, such as limited access to credit, land, and markets, which contribute to their economic marginalization. In recent decades, the number of women in agriculture has increased, along with the need to recognize their rights and strengthen their positions in the industry. Ghosh and Ghosh (2014) analyzed women's participation in agriculture and estimated that 45.3% of the agricultural workforce is made up of women, though the majority remain invisible workers. According to the FAO (2020), empowering women in agriculture can contribute to increased productivity and poverty reduction, which would lead to long-term development in rural areas. However, there are also numerous challenges, such as cultural norms, lack of training, and technology, which prevent women from fully realizing their potential in agriculture.

3. RESEARCH METHODOLOGY

For research the role of women in agricultural communities, their challenges, and their perception of opportunities in contemporary agriculture conducted analysis of demographic characteristics of women engaged in agriculture were analyzed, including the number of surveyed women, their age, education level, and other factors. The study was conducted over a period of three months, from May to July 2024, in various rural areas, with the aim of gaining insights into the specific challenges and opportunities faced by women.

A total of 80 women working in agriculture in rural areas participated in the study, mostly from smaller farms. The sample was selected to reflect the demographic characteristics and socio-economic circumstances of these women, with a focus on the diversity of age groups, education levels, and duration of involvement in agriculture.

3.1. Demographic Characteristics of Respondents

Age Distribution- The surveyed women were aged between 18 and 65 years. The largest group of respondents, accounting for 55% of the total, was in the 30 to 50-year-old range. Women older than 50 years made up 25% of the sample, while women under the age of 30 represented 20%. This age distribution indicates that women in their middle years, when they tend to have larger families and more responsibilities, are most often engaged in agriculture.

Education Level- The educational background of the respondents also varied. Of the 80 women surveyed, 40% had completed primary school, 35% had completed secondary school, while 15% had attended vocational or higher education, and 10% held a university degree. This data reflects the educational challenges faced by women in rural areas, where opportunities for schooling and education are often limited. Despite this, women with higher levels of education, as well as those who had undergone specialized training, demonstrated greater ability to apply modern technologies and innovations in agriculture.

Types of Agricultural Activities- The majority of the women, 60%, were engaged in traditional agriculture, involving crop cultivation and livestock farming, while 25% of women were involved in tasks related to orchards and vineyards. 15% of women were engaged in specialized agricultural activities such as beekeeping, organic food production, or processing agricultural products. Although most women performed basic agricultural tasks, it was found that women working in specialized branches of agriculture had a higher chance of economic advancement and empowerment, as these fields often offer greater market opportunities.

Duration of Engagement in Agriculture- Most respondents had been involved in agriculture for over 10 years. Interestingly, women who had recently entered agriculture showed a greater interest in applying new technologies and innovations, while older women and those with more experience in agriculture were more focused on traditional working methods.

4. RESULTS

The results of the research indicated that the majority of respondents have extensive experience in agriculture, with 75% of women being involved in the sector for more than ten years. These women typically inherited agricultural farms or continued the tradition of family farming, which reflects a deep-rooted connection to agriculture. A smaller number of women have been engaged in agriculture for less than ten years, which still indicates that newer generations recognize agriculture as a stable source of income, albeit with certain changes in approach and technology.

Regarding the types of agricultural activities, the research showed that women are primarily involved in livestock farming and grain cultivation, while fewer focus on vegetable farming or specialized sectors such as organic production. Livestock farming is dominant, with 50% of women engaged in raising livestock or poultry, while 30% of women practice grain cultivation. Only 5% of women are involved in organic farming or beekeeping. This suggests that there is potential for greater investment in specialized sectors, but women often lack access to the necessary resources, education, and markets that would enable them to expand their production.

One of the key issues women face in agriculture is financial difficulties. Half of the respondents stated that financial problems are the biggest barrier to their work, as many women lack access to credit or subsidies that would allow them to improve equipment and production. In addition to financial issues, 45% of women face challenges in accessing markets, which makes it difficult to sell their products and reduces their competitiveness. Outdated agricultural tools are also a problem for many women, with 30% complaining about poor infrastructure and outdated machinery that reduce production efficiency. Additionally, 20% of women feel it is difficult to obtain necessary training or support in the agricultural sector, highlighting the need for stronger educational programs and institutional support.

Despite facing numerous challenges, women recognize the importance of education in agriculture. Half of the respondents believe that education is key to progress in the sector, while the main motivation for engaging in agriculture is primarily economic. Half of the women stated that they engage in agriculture to provide financial stability for themselves and their families. Furthermore, 30% of women emphasized that their motivation lies in preserving family traditions and values, while 15% pursue agriculture out of love for the profession. These results indicate that agriculture is not only an economic activity but also an important factor in preserving cultural identity and family values.

Family support is, according to the responses, crucial for women's success in agriculture. 40% of respondents receive adequate support from their families, which allows them to continue their agricultural work. However, there is also a significant number of women who do not receive sufficient support from institutions. 35% of women believe they have little institutional support, while 25% feel they receive no support at all, indicating that government and local authorities are not investing enough in women in agriculture. Additionally, 10% of women believe that the state should provide greater assistance in terms of education and subsidies.

The majority of respondents consider market access to be one of the biggest issues in their production. 50% of women feel that the market is difficult to access, while only 20% of women rate their market access as easy. This response indicates that women often lack developed networks and strategies for distributing their products, which hinders their competitiveness in the market.

Regarding specialized branches of agriculture, many women show interest in these areas. 45% of women stated that they would like to engage in specialized fields such as organic production or beekeeping, while 20% of women consider specialized fields irrelevant to them. This result suggests that women recognize the potential for production diversification, but they lack the resources and knowledge to initiate such activities.

Finally, the majority of women believe that better training and education would help improve their work in agriculture. 40% of respondents stated that training would help them enhance their skills and techniques, while 30% believe that financial resources would allow them to progress. Additionally, 20% of women believe that better infrastructure would help them improve their production.

The research clearly indicates that women in agriculture have significant potential but also face considerable challenges. Greater investments in education, infrastructure, and financial support are necessary to enable women to enhance their production capacities and become more competitive in the market. Only through appropriate support measures can women in agriculture realize their full potential and become key figures in the future development of the agricultural sector.

5. DISCUSION

The results of the research show that women in agriculture, although facing significant challenges, possess considerable potential for improving their production activities, but lack the necessary resources, education, and support. Based on the analysis of the research findings, several key points can be discussed, including access to markets, financial support, education, as well as the cultural and social context.

One of the most important findings of the research is the fact that many women in agriculture face serious financial problems. As many as 50% of respondents cite finances as the main obstacle to their work. This is in line with global trends, as women, particularly in rural areas, often lack access to capital or financial instruments needed for modernizing agricultural production. Munitlak et al. (2016) point out that female entrepreneurs are very rare among rural women, which is a consequence of lack of education, insufficient (first of all, financial) means, but also will. Women in rural areas face additional difficulties in accessing banks and financial institutions, which has resulted in many women being unable to invest in modern technologies or environmentally-friendly production methods. This highlights the need for the implementation of specific policies that would facilitate women's access to financial resources, such as microloans, subsidies, or favorable loans, as well as easier access to markets.

Similarly, the issue of access to markets is another key challenge for female farmers, highlighted by 45% of respondents in the research. Women often lack developed marketing strategies and sufficient access to distribution channels, which limits their potential to achieve competitive prices or increase sales of their products. Since agriculture in many parts of the world still has a distinctly traditional structure, women find it difficult to develop modern sales systems and connect with markets beyond local communities. Women in rural areas often lack access to adequate marketing information and resources, which limits their ability to market their products effectively (Cikić et al., 2011). Lack of access to market information and limited opportunities for product marketing represent significant obstacles for women farmers in region (Ilić Krstić and Miltojević, 2011). A recommended solution to this problem is the development of market networks and digital platforms for product sales, which could help women more efficiently market their products. Additionally, it is important to develop educational programs that will help women in agriculture better understand the market, sales strategies, and business management.

Education is another key factor in improving the position of women in agriculture. Half of the respondents believe that further education would help them improve their skills and expand their knowledge in the field of agriculture. This indicates a significant need for educational programs tailored to the needs of women in rural areas. Female farmers should have easier access to specialized training, such as courses on farm management, modern agricultural techniques, ecological practices, or the use of new technologies. Moreover, training programs should be available in rural areas and be financially affordable so that women can acquire relevant skills that will make them more competitive in the market. Women in agriculture should also have the opportunity to learn about the importance of ecological methods and sustainable practices, which could become an additional source of competitive advantage in the market.

The analysis of responses related to the motivation for engaging in agriculture shows that women in agriculture are motivated both by economic security and the preservation of family traditions. Half of the respondents stated that they engage in agriculture to ensure their family's stability, while 30% highlighted the importance of preserving family traditions. Ilak Perišić and Žutinić (2011) in their research cite women's motives for farming as support for their husband/family 42.9% of respondents, contribution to family finances 36.6%, while the application of knowledge is only 14.2% and the remaining part of women do not state specific reasons for practicing agriculture. These findings suggest that agriculture, in many cases, is more than just an economic activity, it is also a cultural, social, and emotional component of rural women's lives. In this regard, policies should be developed that not only enable economic development but also promote the preservation of rural values and family traditions.

Social and cultural factors play a significant role in how women perceive their position in agriculture. Although the research showed that women have considerable potential to expand their production activities, cultural norms and social pressures often prevent them from recognizing or realizing these opportunities. For example, many women believe their primary role and responsibility lies within the household, which limits their engagement in the broader business environment. Through educational and social changes, there is a need to influence a shift in the awareness of women's role in agriculture and strengthen women's entrepreneurial rights and opportunities. Ilić Krstić and Miltojević, (2022) emphasize that cultural patterns that emphasize women's traditional roles in the family pose an additional challenge for their participation in decision-making about agricultural activities.

Finally, although they face significant challenges, women in agriculture demonstrate a high level of resilience, resourcefulness, and a strong will to progress. Strong institutional and financial support is needed, as well as changes in the educational system that will allow women to more easily recognize and seize economic and market opportunities. Investing in women farmers is not only a matter of equality but also a key factor for the sustainable development of rural areas and the increase of productivity in agriculture.

6. CONCLUSION

The results of the research clearly show that women in agriculture, although facing numerous challenges, possess significant potential to improve their production activities and contribute to rural development. A large number of respondents highlight financial difficulties as the main barrier to developing their businesses, while the lack of access to markets and education further hampers their progress in agriculture. Additionally, cultural and social norms, which often limit women's freedom to fully engage in the market, represent another challenge that must be overcome through changes in societal awareness.

Although the challenges are numerous, women in agriculture have considerable potential for positive change. Recognizing and addressing these issues, through educational and financial initiatives, could contribute to greater involvement of women in agriculture and improve their position. It is essential to develop specialized educational programs and support women with easier access to financial resources and markets. These changes could have long-term benefits not only for women farmers but also for the entire community and rural economy.

To improve the position of women in agriculture, concrete strategies and policies need to be implemented that will enable women to have easier access to resources, education, and markets. Investing in women in agriculture is not only a matter of gender equality but is also crucial for the sustainable development of rural communities, strengthening agricultural production, and reducing poverty in rural areas.

7. REFERENCES

Asitik, A.J., Abu, B.M. (2020). Women empowerment in agriculture and food security in Savannah accelerated development authority zone of Ghana. African Journal of Economic and Management Studies, 11(2), 253-270. doi.org/10.1108/AJEMS-03-2019-0102

Azima, S., Mundler, P. (2022). The gendered motives and experiences of Canadian women farmers in short food supply chains: Work satisfaction, values of care, and the potential for empowerment. Journal of Rural Studies, 96, 19-31.

Baig, I.A., Batool, Z., Ali, A., Baig, S.A., Hashim, M., Zia-ur-Rehman, M. (2018). Impact of women empowerment on rural development in southern Punjab, Pakistan. Quality & Quantity, 52, 1861-1872. doi.org/10.1007/s11135-017-0572-x

Balezentis, T., Morkunas, M., Volkov, A., Ribasauskiene, E., Streimikiene, D. (2021). Are women neglected in the EU agriculture? Evidence from Lithuanian young farmers. Land Use Policy, 101, 105129. doi.org/10.1016/j.landusepol.2020.105129

Bell, C. (1990). Reforming Property Rights in Land and Tenancy. The World Bank Research Observer, World Bank, 5(2), 143-166.
Costa, V., Piedrahita, N., Mane, E., Davis, B., Slavchevska, V., Gurbuzer, Y. L. (2023). Women's employment in agrifood systems. Background paper for the status of women in agrifood systems, Rome, FAO.
Cikić, J., Petrović, M., Petrović, Ž. (2011). Žene u selu i razvoj preduzetništva. Ekonomika poljoprivrede, 58(3), 487-502.
European Parliament (2019). The Professional Status of Rural Women in the EU. www.europarl.europa.eu/RegData/etudes/STUD/2019/608868/IPOL_STU(2019)608868_EN.
FAO (2011). The role of women in agriculture. Food and Agriculture Organization of the United Nations.
FAO (2020). www.gao.org
Ghosh, M., Ghosh, A. (2014). Analysis of women participation in Indian Agriculture. IOSR Journal of humanities and social science, 19(5), IV, 01-06.
Gupta, S., Vemireddy, V., Pingali, P.L. (2019). Nutritional outcomes of empowerment and market integration for women in rural India. Food Security, 11(3), 1243-1256. doi.org/10.1007/s12571-019-00978-z
Ilak Peršurić, A.S, Žutinić, Đ. (2011). The Economic Position of Women on Family Farms, Sociologija i prostor: časopis za istraživanje prostornoga i sociokulturnog razvoja, 49, 2.
Ilić Krstić, I.,Miltojević, V. (2022) Women farmers' empowerment in South-eastern Serbia: A case study, Sociološki pregled, 56(4), 1298-1324.
Obeng-Odoom, F. (2012). Neoliberalism and the Urban Economy in Ghana: Urban Employment, Inequality, and Poverty**.** Growth and Change, 43, 1.
Onoh, U., Erezi, E., Clement, B. (2023). Analyzing the Role of Women in Climate Resilience Building and Sustainable Farming Practices in Nigeria, IIARD International Journal of Geography & Environmental Management (IJGEM), 9, 4.
Oyawole, F.P., Shittu, A., Kehinde, M., Ogunnaike, G., Akinjobi, L.T. (2021). Women empowerment and adoption of climate-smart agricultural practices in Nigeria. African Journal of Economic and Management Studies, 12(1), 105-119.
Shajahan, K., Sahati, W., Radović-Marković, M. (2022). Women empowerment through agricultural technology: Case study of Mymensingh-Bangladesh. International Review, 3(4), 57-66.
World Bank. (2019). Women, business and the law 2019. World Bank Group.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.400V

DEVELOPMENT OF AGRICULTURE PRODUCTION AND AGROBUSSINES IN CLIMATE CHANGE CONDITIONS IN SERBIA AND NEIGHBOR REGION

Slađana Vidaković[1*], Tatjana Ivanović[2], Adriana Radosavac[3]

[1]MV Konstrukt d.o.o., Nova Pazova, Serbia, *biohranasv@gmail.com
[2]University of Pristina temporary settled in Kosovska Mitrovica, Faculty of Agriculture, Lešak, Kosovo and Metohia, Serbia
[3]University Business Academy in Novi Sad, Faculty of Applied Management, Economics and Finance in Belgrade, Belgrade, Serbia

Abstract: Agribusiness in Serbia, the region, and Southeastern Europe faces significant challenges due to climate change and shifting market conditions. The aim of this paper is to analyze the impact of climate change on agricultural production and the supply/demand of agricultural products at the regional and European levels, as well as to explore strategies for agribusiness adaptation to new market and climate conditions. The materials and methods include an analysis of market data, climate trends, and relevant agricultural policies. The main findings indicate that agribusiness must adopt sustainable practices and innovations to remain competitive in changing conditions. The conclusion is that adapting to these challenges requires the integration of new technologies, improvement of agricultural methods, and cooperation with European markets to ensure the sector's sustainable future.

Keywords: Agribusiness, Climate change, Sustainability, Innovation, Adaptation

1. INTRODUCTION

Climate change, driven by natural cycles and anthropogenic activities, poses an increasing risk to agricultural production, the supply and demand of agricultural products, both at the regional and European levels. Climate change disturbs the agro-ecosystem, due to changes in weather conditions such as temperature, precipitation, and sunlight, while further influencing the arable, livestock, and hydrology sectors. The impact of climate change on arable lands expressed in changes of agricultural production related to change of efficiency flowering, fertilisation, harvesting time (Young-Eun et al., 2007). Although it is challenging to predict all consequences with certainty, research indicates a growing frequency and intensity of extreme weather events, such as droughts, heavy rainfall, and floods, which directly affect yields, product quality, and the economic stability of the agricultural sector (Stričević et al., 2021).

In Serbia, these effects are particularly pronounced, with increasingly frequent extreme climate events significantly impacting crops and local economies (Mihailović et al., 2015). Yield losses, rising production costs, and market price fluctuations further complicate producers' efforts to adapt to new conditions.

Addressing these challenges requires the development and implementation of strategies for adapting agribusiness to new climate and market conditions. Key measures include optimizing irrigation, introducing more resilient crop varieties, improving storage capacities, and enhancing the connection between local producers and regional and European markets (Jančić et al., 2015; Starčević et al., 2018). Additionally, attention must be directed towards building resilience across the entire supply chain, with the support of local authorities, policymakers, and international partners.

This paper analyzes the impact of climate change on agricultural production and the agricultural product market, exploring adaptation strategies for agribusiness to achieve sustainable development and competitiveness at the regional and European levels.

2. RESEARCH METHODOLOGY

The methodology applied in this paper follows the structure of a review article, synthesizing existing knowledge and data on the impact of climate change on agriculture in Southeastern Europe and Serbia. It combines quantitative and qualitative approaches to analyze secondary data collected from reliable sources such as Eurostat, FAO, and national statistical agencies. A systematic review of academic and institutional literature was conducted to examine agricultural production trends, economic indicators, and adaptation strategies.

Statistical data were analyzed to provide a comprehensive overview of agricultural conditions, including comparative analysis of different countries in the region to identify patterns and differences in responses to climate change and market challenges.

Historical and projected climate data were used to assess trends in temperature, precipitation, and their impact on agricultural yields. Key issues such as water scarcity, extreme weather events, pest outbreaks, and soil fertility degradation were identified and analyzed to understand their influence on agriculture.

Although no primary interviews were conducted, qualitative insights from existing studies and reports involving farmers, policymakers, and climate experts were integrated to add depth and context to the analysis. This approach ensures that the research is based on robust evidence, offering valuable insights and recommendations for adapting agricultural practices in Southeastern Europe and Serbia to the challenges posed by climate change.

3. CHARACTERISTICS OF AGRICULTURE, CLIMATE AND AGRIBUSINESS IN SERBIA, REGION AND SOUTHEAST EUROPE

3.1. Structure and dynamics of agriculture in the region and SE Europe

Agriculture holds a significant role in the economies of Southeastern European countries, contributing 7-10% to their gross national income, depending on each country's specific economic and structural conditions. For instance, Serbia's agricultural sector employs around 20% of the population, while neighboring countries such as Croatia and Bosnia and Herzegovina have slightly higher shares, with family farms dominating production (Eurostat, 2023). In Croatia, over 150,000 agricultural households were registered in 2023, with 99% being family farms averaging 6 hectares in size (National Statistical Agency, 2023). Bosnia and Herzegovina face similar challenges, such as land fragmentation, outdated cultivation practices, and increasing vulnerability to climate change, notably droughts and floods. These climate impacts, particularly for staple crops like corn and wheat, are expected to reduce yields (FAO, 2022).

Regional challenges include systemic barriers such as fragmented land holdings and outdated infrastructure, which hinder adaptation to new climatic conditions. In 2024, total yields are expected to decline due to unfavorable weather patterns (Eurostat, 2023). To address these issues, regional countries are focusing on modernizing agriculture with sustainable practices and infrastructure improvements, with key data provided by Eurostat, FAO, and national statistical agencies (Eurostat, 2023; FAO, 2022)

3.2. Structure and dynamics of agriculture in Serbia

Agriculture is crucial for Serbia's economy, contributing about 6-6.8% to its gross national income between 2015 and 2017. The sector is predominantly composed of small family farms, with approximately 631,552 households and 1,442,628 workers, making up about 20% of the population (Statistical Office of the Republic of Serbia, 2023). The average farm size is relatively small, at 5.4 hectares, often spread across multiple plots, which increases vulnerability and hinders sector development (Statistical Office of the Republic of Serbia, 2023). Preliminary data from the 2023 Agricultural Census reveals that 99.6% of the 508,365 registered farms are family-owned, averaging 6.4 hectares, typically involving livestock such as cattle, pigs, sheep, poultry, and beehives (Statistical Office of the Republic of Serbia, 2023).

Climate change, including droughts, is expected to cause a decline in crop yields in 2024, particularly for corn, soybeans, and sunflowers, which could negatively affect livestock production and overall GDP (Eurostat, 2023; FAO, 2022). Serbia's diverse terrain supports different forms of agriculture: flatlands for crops and vegetables and hilly regions for fruit cultivation. However, to build resilience and improve productivity, adaptation to climate change and improved cultivation practices are essential. Full data from the 2023 census will be published in 2024 (Eurostat, 2023).

3.3. Impact of climate change on agribusiness in Serbia and the region

Climate change is severely affecting agriculture in Serbia and Southeastern Europe. Rising global temperatures and increasing frequency of extreme weather events such as droughts and floods are disrupting food production, market structures, and the economic stability of the agricultural sector. According to the FAO, climate change is expected to reduce yields for staple crops like wheat, corn, and soy, worsening food security in the region (FAO, 2022). Between 2020 and 2022, adverse weather led to declines in cereal production, with predictions of a 10-20% decrease in crop yields by 2030 (Petrović, 2021).

Traditional agricultural practices in Southeastern Europe are largely ill-equipped to handle these challenges. The European Commission has found that many farms lack modern adaptation strategies, exacerbating vulnerability to climate disruptions (EC, 2023). Contributing factors include limited financial resources, lack of access to knowledge and training, and weak infrastructure. Beyond production, climate change also affects broader socioeconomic factors. For instance, rural-to-urban migration is expected to increase as farmers face lower incomes and fewer job opportunities (Marković and Janković, 2022), adding pressure on urban areas and potentially leading to social instability. To mitigate these effects, adopting sustainable agricultural practices and innovations is vital. This includes using climate-resilient crop varieties, precision agriculture, and efficient water resource management (Ristić and Petković, 2023). The EU's Common Agricultural Policy (CAP) provides a framework of financial and technical support to help farmers transition to sustainable practices (EU, 2022). However, urgent action, innovation, and collective support are needed to ensure long-term agricultural stability and sustainability.

3.4. Agribusiness in Serbia, the region, and SE Europe: Adapting to changing market and climate conditions

Soil fertility is a critical challenge for agriculture in Serbia and the broader region, where rising temperatures and unpredictable rainfall patterns lead to soil degradation. FAO reports that declining soil fertility could severely hinder agricultural economic development in Southeastern Europe (FAO, 2022). Adapting farming practices to address these challenges is crucial, especially through sustainable land management practices like crop rotation and organic methods (Biočanin, 2021). These strategies help maintain soil fertility and build resilience against climate change.

A holistic approach is required, encompassing education, training, and the adoption of innovative technologies to improve production capacity and adaptability (Ninković, 2020). Additionally, cooperation among academia, government, and the private sector is vital for developing strategies to address climate change and market challenges, ensuring the agricultural sector's sustainability.

4. CLIMATE CHANGE AND RISK IN AGRICULTURE AND AGRIBUSSINES

4.1. Specific risks for agriculture in SE Europe and Serbia

4.1.2. Water scarcity

Climate change will significantly affect water availability, with reduced summer rainfall expected in Serbia and southern parts of Southeastern Europe. This will lower annual water supplies for irrigation, particularly in regions like Vojvodina and central Serbia, which rely heavily on irrigation. Farmers must expand irrigation systems and improve water efficiency to maintain stable production (Ministry of Agriculture, Forestry, and Water Management, 2023).

4.1.3. Extreme weather events

Extreme weather events, including heatwaves, droughts, and intense rainfall, are expected to increase. In Serbia and parts of Southeastern Europe, drought risks will rise, while central and northern regions may face more frequent floods. These events threaten agricultural production and food security (FAO, 2022).

4.1.4. Increased pest issues

Climate change will facilitate the spread of pests and diseases in crops. Serbia's farmers will need to manage pest outbreaks within the framework of EU pesticide regulations, which may limit pesticide use and further impact yields (FAO, 2022).

4.1.5. Impact on crop yields and distribution

Climate change will shift agro-climatic zones northward, affecting crop yields and distribution in Serbia. This shift is expected to increase price volatility and income risks for farmers, while agricultural producers outside the EU will also face similar challenges (FAO, 2022).

4.2. Impact of climate change on supply and demand in agribusiness

Climate change affects supply and demand in the agricultural markets of Serbia and Southeastern Europe. Reduced soil fertility and unpredictable production conditions lead to lower supply and higher prices, potentially making food less accessible to consumers (Pajić, 2021). Moreover, changing consumer demands for sustainably sourced and organic products present challenges for conventional producers (Milenković, 2022).

In this context, producers must adjust to new consumer trends and market conditions. Reduced agricultural yields may lead to higher prices for staple foods, prompting consumers to seek substitutes. These shifts require agribusinesses to adapt through diversification and the adoption of innovative technologies to stabilize supply and meet demand (Jovanović, 2020). To cope with these changes, adaptive strategies, innovation, and research are essential for strengthening the agricultural sector's resilience in the face of climate change.

5. EFFECT OF CLIMATE ON AGRICULTURE AND AGRIBUSINESS

On the base of data from 1990 to 2023 the number of agricultural households is decreasing year reflecting migration to urban areas and changes in agricultural practices, and that arable land gradually decreasing, which, also, may be caused by urbanization, land degradation, and climate change. Due to this changes the percentage of the Working-Age Population in Agriculture is change and continuously decreasing, indicating reduced interest in agriculture as a source of income (Table 1).

Table 1. Agricultural holdings, working-age population and arable land area in Serbia (National Statistical Office of Serbia, 2023)

Year	Number of Agricultural Households	Arable Land (hectares)	Percentage of the Working-Age Population in Agriculture
1990	1.400.000	3.500.000	30%
2002	1.200.000	3.200.000	23%
2008	908.102	2.900.000	18%
2012	562.856	2.800.000	14%
2023	508.365	2.800.000	14%

During the long-term period the average yield of edible plant species varied depend of year cultivated genotypes and their inteaction. The analysis of maize yield in Serbia, from 1990 to 2023, showed variation between 3.8 t ha^{-1} and 7.5 t ha^{-1} (Figure 1).

The yield in the 1990s was around 5.6 t ha^{-1}, but drought years like 2007 and 2012 led to drastic declines (3.8 t ha^{-1} and 2.5 t ha^{-1}, respectively). On the other hand, more favorable weather conditions in 2018 allowed for a yield increased to 7.5 t ha^{-1}, partly due to the introduction of more resilient varieties and modern technologies. The trend line clearly shows fluctuations in yields. Declines are visible in years of intense droughts (2007, 2012), while occasional recoveries in yields (like in 2018) show adaptation through technologies and agronomic measures (Figure 1).

The declines in yields are linked to extreme weather events, such as droughts and heatwaves, while the increase in yields in certain years is a result of investments in more resilient varieties and better agricultural practices.The percentage decrease in yields during drought years, such as 2002 and 2012, underscores the importance of adaptation to climate change, while the yield increases in years with better weather conditions show the potential for improving agricultural productivity (Figure 1).

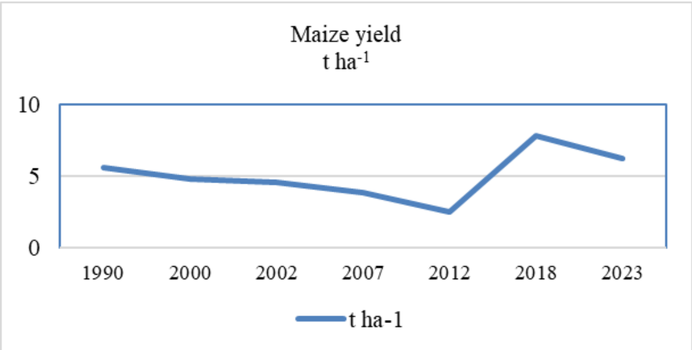


Figure 1. Variation of maize yield in long-term period (National Statistical Office of Serbia, 2023)

Although climate change generally has a negative impact on agricultural yields, there are opportunities for adaptation through innovation and investments in agricultural systems**.** In analysis of wheat yields in Serbia and Southeast Europe during the period 1990-2023 showed variability due to the impact of climate change, particularly droughts, on wheat production (Figure 2).

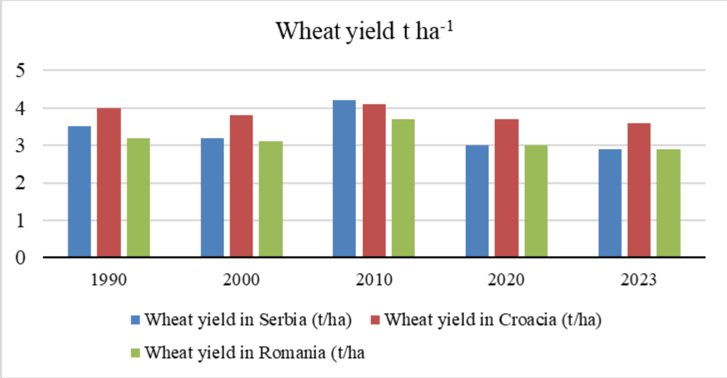


Figure 2. Variation of wheat yield in Serbia, Croatia and Romania (FAO, 2022)

In 1990s to Early 2000s,the wheat yelds were relatively stable, but fluctuations became more noticeable in the early 2000s, linked to changes in weather conditions. A major drought hit the region, occured in 2007. year leading to a significant decline in wheat production, marking one of the biggest drops on the graph. Another sharp decline in yields, occured in 2012. year again due to an extreme drought that affected the region, especially Serbia, Bulgaria, and Romania.Wheat yields show a slight recovery in some years, in period 2015-2023, but droughts in 2022 and 2023 led to reduced yields again (Figure 2). This segment of the graph emphasizes the challenges farmers face due to increasingly frequent drought periods. This analysis underscores the vulnerability of wheat production to climate extremes and the need for adaptive strategies. The variability in wheat yields in relation to drought years, indicate that climate change, particularly droughts, has become one of the main factors affecting agricultural production in Serbia and Southeast Europe. It also suggests the need for strategic adjustments in farming practices to mitigate the damage caused by droughts, such as introducing more drought-resistant wheat varieties and improving irrigation systems. These measures can help adapt to the increasing frequency of extreme weather events, ensuring more stable production despite the challenges posed by climate change.

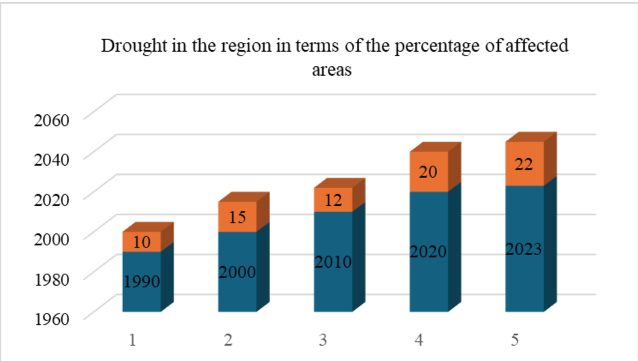


Figure 3. Share of areas affected by drought in the period from 1990 to 2023 (FAO, 2022)

The impact of agricultural areas affected by drought, was different within research period, that increased in long term period from 1990 to 2023 with expression extreme weather conditions and the reduction in arable land (Figure 3). During the early period (1990-2000) showed in the first part of the chart, the percentage of affected areas was below 10-15%. Droughts were less pronounced and rare (Figure 3). During the period 2000-2010 a gradual increase is seen, peaking in 2007, when over 20% of areas were affected by drought (Figure 3). In the last decade (2010-2023) the drought become more severe, with notable impacts in 2012 and 2022, when more than 20% of arable land was affected. The year 2023 continues this trend, confirming that climate change has become a persistent threat to agricultural yields. (Figure 3). The data show a continuous increase in areas affected by drought from

1990 to 2023, highlighting key challenges faced by farmers in Serbia and Southeastern Europe (Figure 3). This trend underscores the urgent need for strategic adjustments, such as more efficient irrigation, the introduction of drought-resistant crop varieties, and better water resource management. In the context of previous texts, this chart further illuminates the interdependence between climate change and the decline in agricultural yields, particularly in regions frequently hit by droughts.

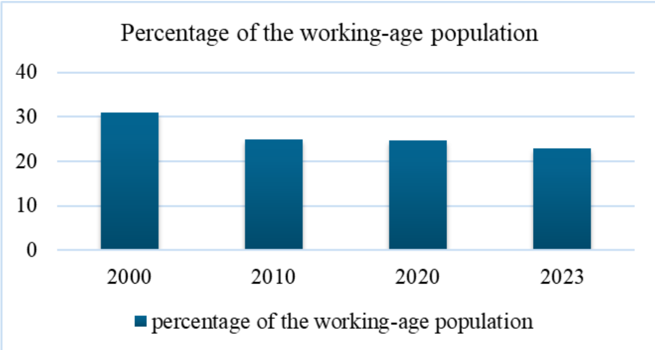


Figure 4. Variation of percentage number of working-age population (FAO, 2022)

The percentage of the working-age population over several years, from 1990 to 2023 varied during the long term period of study (Figure 4). In 1990, the percentage of the working-age population was 37%. This indicates a relatively higher proportion of people in the workforce at that time. In 2000, the percentage dropped to 31%, showing a decline in the working-age population over the decade. The percentage further decreased to 25%, in 2010, the continuing the trend of a shrinking workforce. In 2020, the percentage slightly decreased to 24.6%, showing a minimal decline in the workforce participation rate compared to 2010. The percentage in 2023 reached 23%, indicating an ongoing decline in the working-age population (Figure 4). Overall, the data show a steady decrease in the percentage of the working-age population over the past few decades. This could be due to factors like aging populations, lower birth rates, or changes in economic conditions.

6. CONCLUSION

Based on the analysis of agribusiness in Serbia, the region, and Southeastern Europe, it is clear that we are facing challenges arising from climate change and fluctuating market conditions. Adapting to these changes requires a comprehensive approach that includes innovations, sustainable practices, and collaboration among all sector participants. It is important to develop strategies in the coming period that will allow agribusiness to remain competitive in the European market, while simultaneously preserving natural resources and safeguarding local communities. Through the implementation of modern technologies, farmer education, and strengthening market infrastructure, Serbia can achieve sustainable agribusiness development. Cooperation with regional and European partners, as well as support from government institutions, plays a key role in this transition. Only through joint efforts can we ensure a prosperous future for agribusiness that will be more resilient to climate change and market fluctuations.

7. ACKNOWLEDGMENT

We would like to express our sincere gratitude to the Scientific Business Center World for their valuable support in the development of this research. Special thanks are also extended to the organizers and participants of the 12th International Agribusiness Conference MAK 2025 for providing a platform to share and discuss this.

8. REFERENCES

Biočanin, R. (2022). The Impact of Climate Change on Agriculture in Serbia. In: Proceedings, Faculty of Agriculture, University of Belgrade.

Eurostat (2023). Agriculture Statistics, Eurostat Data.

FAO (2023). The State of Food Security and Nutrition in the World, FAO Report.

Jančić, M., Lalić, B., Mihailović, D.T., Jaćimović, G. (2015). Impact of climate change and carbon dioxide fertilization effect on irrigation water demand and yield of soybean in Serbia. The Journal of Agricultural Science, 153 (8), 1365-1379.

Jovanović, D. (2020). Drought Impact on Wheat Yields in Southeastern Europe. Journal of Agricultural Research, 45(3), 123-134.

Marković, M., Janković, A. (2022). Climate Change Adaptation Strategies in Serbian Agriculture. Environmental Science Journal, 34(2), 98-110.

Mihailović, D.T., Lalić, B., Drešković, N., Mimić, G., Djurdjević, V., Jančić, M. (2015). Climate change effects on crop yields in Serbia and related shifts of Köppen climate zones under the SRES-A1B and SRES-A2. International Journal of Climatology, 35, 3320-3334.

Milenković, L. (2022). Irrigation Systems in Drought-Prone Areas. Balkan Agricultural Review, 18(4), 56-72.

Ministry of Agriculture, Forestry, and Water Management. (2023). "Climate Resilience in Serbia's Agricultural Sector, Ministry Report.

Young-Eun, Tilman, D., Jin, Z., et al. (2007). Impacts of Climate Change on Agricultural Sector and International Trends of Adaptation Measures. Journal of International Agricultural Development, 19-2, 93-100. doi.org/10.1126/science.adn 3747

National Statistical Office of Serbia (2023). Agriculture in Serbia: Statistical Overview, Report.

Ninković, Z. (2020). Trends in Corn Yields Under Changing Climate Conditions in Serbia. Agricultural Climate Studies, 29(1), 45-58.

OECD (2023). Agricultural Outlook 2023-2032, OECD Report.

Pajić, S. (2021). The Role of Drought-Resistant Crops in Modern Agriculture. Serbian Journal of Agronomy, 51(2), 32-44.

Petrović, J. (2021). Economic Impacts of Climate Change on Balkan Agriculture. Regional Economic Studies, 8(1), 12-27.

Ristić, V. (2021). Agronomic Practices for Yield Stabilization in Serbia. Agronomy Advances, 15(5), 78-90.

Ristić, V., Petković, M. (2023). Evaluation of Climate Adaptation Measures in Eastern Europe. Agricultural Policy Review, 22(6), 102-119.

Stričević, R., Vujadinović-Mandić, M., Djurović, N., Lipovac, A. (2021). Application of two measures of adaptation to climate change for assessment on the yield of wheat, corn and sunflower by the aquacrop model. Zemljiste i Biljka, 70(1), 41-59. /in Serbian/

Stričević, R., Stojaković, N., Vujadinović-Mandić, M., Todorović, M. (2018). Impact of climate change on yield, irrigation requirements and water productivity of maize cultivated under the moderate continental climate of Bosnia and Herzegovina. The Journal of Agricultural Science, 156(5), 618-627.

UNDP (2022). Climate Change Adaptation in Agriculture, Report.

World Bank. (2023). Climate Change and Agriculture: Impacts and Adaptation, Report.

12. JEEP MEĐUNARODNA NAUČNA AGROBIZNIS KONFERENCIJA-MAK 2025
12th JEEP INTERNATIONAL SCIENTIFIC AGRIBUSINESS CONFERENCE-MAK 2025
„Climate change and ecological sustainability in agriculture and food production in Serbia, the region and Southeast Europe"
SERBIA, KOPAONIK January 30th to February 2nd, 2025.

doi:10.46793/MAK2025.408GV

DIGITAL TRANSFORMATION OF THE ECONOMY AND POPULATION

Biljana Grujić Vučkovski[1*], Dragana Stevanović[1], Branko Tomić[1]

Tamiš Research and Development Institute, Pančevo, Serbia
*grujic@institut-tamis.rs

Abstract: The aim of this paper is to highlight the importance of introducing and implementing information and communication technologies (abbr. ICT) in private and professional life. More precisely, there are numerous methods for measuring the level of digitalization in society, the state, the region, etc., and this research focuses on analyzing the Digital Economy and Society Index (abbr. DESI). The observation period spans from 2017 to 2022 for the European Union (abbr. EU) and 2022 for the Western Balkans and Serbia. Additionally, the study examines the presence and use of broadband internet connections among individuals, households, and businesses in Serbia from 2015 to 2024. The results indicate that EU countries are significantly ahead of Western Balkan countries in terms of digital societal transformation. Data on the level of digitalization is published by the European Commission, while information for the Western Balkans is available in reports from the Regional Cooperation Council (abbr. RCC). Furthermore, data from the Statistical Office of the Republic of Serbia (abbr. SORS) was also utilized.

Key words: Digitalizationa, DESI index, ICT, Economy

1. INTRODUCTION

Digitalization has become an inevitable process worldwide, with the only question being whether countries will adapt to the demands of smart technologies sooner or later. Digitalization is present in all aspects of life, both private and professional.

Digitalization can replace the human factor in many processes, resulting in numerous positive outcomes. These positive results have been confirmed in all fields, particularly in the areas of the economy, biodiversity, and the environment (Rolandi et al., 2021; Vasile, 2012; Vial, 2021; Jha et al., 2019).

Moreover, digitalization is essential in all industries, especially in the agricultural sector. Various forms of digital technologies are available in agriculture, with precision farming, as a form of digitalization in agriculture, being discussed as early as the 1980s (Garg et al., 2024).

Proper management of natural resources, the environment, and environmental protection is frequently analyzed in scientific literature and applied in both developed and developing countries (Alonso and Northcote, 2013; EU, 2013; FAO, 2018; EU, 2021).

It is well-known that agriculture contributes to food production (Grujić Vučkovski et al., 2021), which is why it constantly faces numerous challenges, such as environmental protection requirements, healthy food production, and food with controlled origins (Inoue, 2020). The introduction of digitalization into agriculture marks the beginning of the fourth industrial revolution, becoming a significant indicator of economic growth, improved environmental protection, and biodiversity preservation (Javaid et al., 2022; Grujić Vučkovski and Subić, 2024; Grujić Vučkovski et al., 2024).

The application of the latest digital advancements in agri-food production can also be explained as a consequence of climate change (Androniceanu et al., 2022). Given that digitalization provides real-time data, it can help agriculture reduce dependence on weather conditions necessary for plant growth and development, ensuring higher crop yields with better plant nutrition quality. It can also reduce the number of operations, positively impacting CO_2 emission reduction and fuel consumption (Garg et al., 2024).

Digitalization in agriculture involves not only precision farming but also the use of satellites, sensors, agricultural machinery, and information technologies (Mogili et al., 2018). ICT plays a vital role in agricultural production in the modern world, significantly impacting all aspects of life (social, economic, and political). It is crucial for everyone in the agricultural industry chain to embrace digitalization by adopting new ICT technologies, with the most critical being its acceptance by agricultural producers (Pogorelskaia and Várallyai, 2020). Ultimately, these changes also affect the state as a community (Sinitsa et al., 2021).

The use of ICT can reduce environmental impact. Companies can also take certain measures to reduce their environmental footprint, such as using less energy, remote working, reducing business travel, recycling products and equipment, minimizing waste, and more. In EU countries, the number of actions implemented by companies to protect the environment is evaluated and ranked as follows: 8-10 actions represent a high level of green impact, 5-7 actions indicate a medium environmental impact, and 0-4 actions show a low environmental impact (RCC, 2022).

Digital transformation is being implemented worldwide, with this study focusing on the EU, the Western Balkans, and Serbia. The introduction of digital technologies is an integral part of private and professional life. The subject of this study is to determine the direction of digitalization in Serbia regarding the application of ICT, primarily in terms of computer and internet usage over the past decade (2015-2024). To this end, the EU established the RCC to monitor the application of the digital economy and evaluate the digital transformation of the Western Balkans and EU countries. This statistic is based on the analysis of the DESI index, which will be further discussed in the following sections.

The aim of this paper is to estimate (i) the importance of introducing and implementing information and communication technologies (abbr. ICT) in private and professional life in Serbia, (ii) monitoring of the application of the digital economy and evaluate the digital transformation of the Western Balkans and EU countries on the base and (iii) analyzing the Digital Economy and Society Index (abbr. DESI).

2. MATERIAL AND METHODS

The research on ICT usage is based on an analysis of data on the number of households (by type of settlement and total), individuals, and businesses using computers and the internet in Serbia. Considering *individuals* as ICT users, the research also includes the structure of individuals who use ICT according to the last time they used a personal computer (PC) or the internet, as well as their age group.

Regarding ICT usage *in businesses*, the analysis focuses on the frequency of internet use and website creation, as well as the ability of businesses to utilize *e-Government* services in their operations. These data on ICT adoption and usage in Serbia were analyzed for the period 2015-2024, with some parameters concluded in 2023. According to the SORS methodology, research on ICT usage by households and individuals requires that a household must have at least one member aged 16 to 74. Regarding businesses, the study includes those with 10 or more employees across various industries. The methodology applied by SORS aligns with the methodology used by EUROSTAT.

The EU has mandated that member states must measure and report on DESI index values. The core of the DESI index comprises four elements: **human capital**, **connectivity**, **integration of digital technology**, and **e-Government**. All four elements are equally important, as demonstrated by their weights (each element is assigned a maximum weight of 25%). These elements include sub-elements (nine in total), which can also be analyzed individually (European Commission, 2022). Figure 1illustrates the structure of the DESI index with its elements.

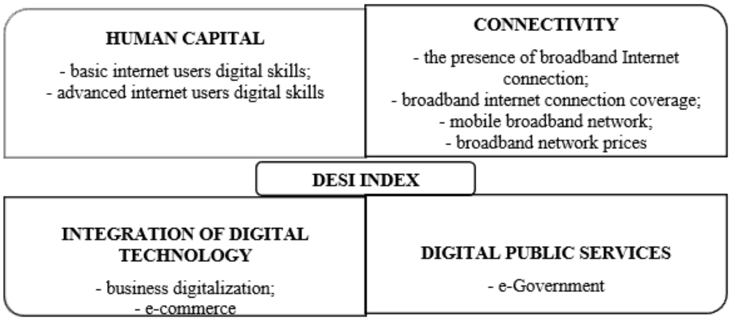


Figure 1. DESI index elements

For the EU level, data is available in the EUROSTAT database, while for Serbia and the Western Balkan countries (Montenegro, Albania, Kosovo, North Macedonia, Bosnia and Herzegovina), RCC publishes reports. DESI indices for the EU and Western Balkan countries are presented for 2022, with the analysis based on inputs from 2021. A comparative analysis of 2021 and 2022 is not possible due to methodological changes in certain indicators (RCC, 2022).

Finally, a comparative overview of DESI index values for Serbia, the Western Balkan countries, and the EU is provided to facilitate a better understanding of the level of development of these countries and their progress in terms of digitalization and digital literacy.

The study used secondary sources available from the Statistical Office of the Republic of Serbia (SORS), reports related to the Western Balkan countries, and EU reports. Changes during the observed period were described using descriptive statistical methods. Conclusions were drawn through methods of analysis and synthesis, which were previously confirmed by statistical interpretations.

3. RESULTS AND DISCUSSION

The analysis of the DESI index will start with EU countries. Data are available for the period 2017-2022. Table 1 also shows the DESI values for the EU area in the mentioned period.

Examining the results presented in Table 1, we observe that all EU countries have made progress in implementing digital platforms. Countries such as the Netherlands, Finland, and Sweden had the highest DESI index values in 2017 and maintained these leading positions in 2022. On the other hand, countries like Bulgaria and Romania have been the slowest to adopt societal digitalization, as reflected in their annual index values.

Table 1. DESI values for the EU area, 2017-2022 (%)

	2017	2018	2019	2020	2021	2022
Austria	36.4	38.4	41.2	43.6	50.5	54.7
Belgium	35.7	38.0	40.0	44.2	46.7	50.3
Bulgaria	23.9	25.8	28.0	29.8	32.6	37.7
Cyprus	29.2	30.4	32.7	35.3	40.0	48.4
Czechia	31.8	34.2	37.2	39.5	43.4	49.1
Germany	33.4	35.3	38.3	42.1	47.1	52.9
Denmark	46.5	48.7	52.1	56.0	65.3	69.3
Estonia	41.3	44.0	46.6	49.1	53.2	56.5
Greece	22.4	23.5	25.5	27.6	32.5	38.9
Spain	40.5	43.4	47.0	49.7	54.8	60.8
European Union	*33.7*	*35.9*	*38.6*	*41.7*	*46.2*	*52.3*
Finland	47.9	50.4	54.1	58.4	63.2	69.6
France	33.8	35.9	39.5	42.5	45.9	53.3
Croatia	30.4	32.2	35.1	37.0	43.1	47.5
Hungary	28.3	30.1	32.2	35.8	38.7	43.8
Ireland	41.3	44.1	46.7	50.8	57.1	62.7
Italy	28.2	30.6	34.3	36.7	40.9	49.3
Lithuania	36.5	39.6	42.2	44.7	47.0	52.7
Luxembourg	43.8	45.8	47.7	51.2	55.0	58.9
Latvia	37.4	39.4	41.0	44.1	46.1	49.7
Malta	41.7	43.8	47.4	51.5	54.5	60.9
Netherlands	45.6	48.1	50.5	54.7	62.4	67.4
Poland	24.9	27.1	29.8	33.2	36.5	40.5
Portugal	35.5	37.9	40.3	43.3	45.9	50.8
Romania	19.4	20.7	22.4	24.7	27.4	30.6
Sweden	45.7	48.7	52.0	55.7	60.5	65.2
Slovenia	35.7	37.9	40.9	42.9	48.0	53.4
Slovakia	29.8	31.7	33.3	36.2	39.9	43.4

According to the European Commission's reports on DESI index values for 2022 (EC, 2024), EU member states with advanced digital economies include Finland, Denmark, the Netherlands, as well as Spain and Malta. The lowest DESI index values were recorded by Romania, Bulgaria, and Greece (Figure 2).

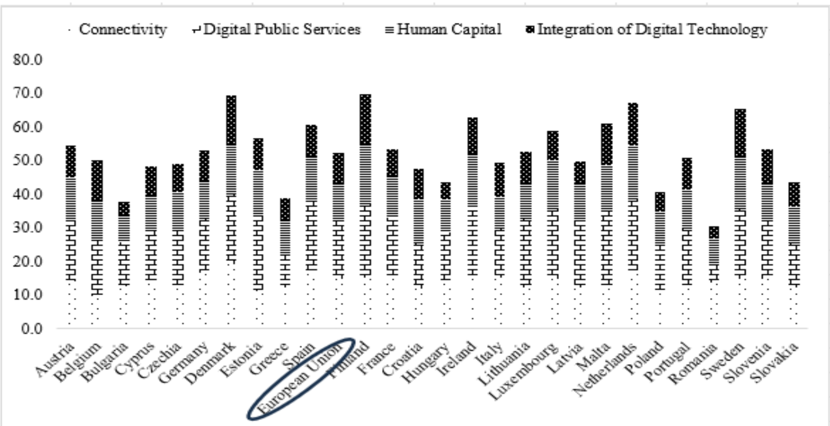


Figure 2. Values of DESI indexes for EU countries, 2022.

From Figure 2 and Table 1, we can see that certain EU member states have over 20% participation in digital public services (out of a maximum of 25%). In the overall digitalization share across all monitored elements, they reach up to 70% (out of a maximum of 100%), with Estonia, Finland, and Malta standing out in particular.

When it comes to the Western Balkan countries (Serbia, Montenegro, Albania, Kosovo, North Macedonia, Bosnia and Herzegovina), the situation is different. Specifically, DESI index values are half the EU average. The results for DESI index values in 2022 are presented in Figure 3.

	Western Balkan average	Bosnia and Herzegovina	North Macedonia	Kosovo	Albania	Serbia	Montenegro
Human capital	8.4	6.3	7.9	6.2	7.6	10.2	10.4
Connectivity	7.7	4.9	4.8	8.5	8.1	8.7	10.4
Integration of digital technology	5.2	4.4	4.0	5.8	5.6	5.4	8.5
Digital public services	8.0	7.5	8.1	5.6	8.9	10.5	5.8
Total	29.3	23.1	24.8	26.1	30.2	34.8	35.1

Figure 3. Values of DESI indexes for Westrern Balkan countries, 2022

As shown in Figure 2, Montenegro recorded the highest DESI index value in 2022, with a participation rate of 35.1%, followed by Serbia and Albania (34.8% and 30.2%, respectively), while Bosnia and Herzegovina had the lowest value (23.1%). The top three countries achieved DESI index values above the Western Balkan average but still below the EU average of 52.3% (Figure 2). Thus, the Western Balkan countries achieve only half the level of digitalization implemented in Finland. Comparing the results in Figures 2 and 3, it is also observed that Montenegro and Serbia have a higher DESI index value than Romania, an EU member state.

The following section of the study will analyze specific sub-elements of the DESI index for Serbia from 2015 to 2024. To begin, data on the prevalence of devices in Serbian households will be presented (Table 2).

Table 2. Households having a devices in Serbia, 2015-2024 (in %)

Type of device	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
TV	99.3	97.8	99.6	99.1	97.9	98.3	98.4	98.5	97.3	96.4
Mobile phone	90.3	90.2	90.5	93.0	93.7	94.1	94.6	95.0	94.4	95.9
Personal computer (PC)	64.4	65.8	68.1	72.1	73.1	74.3	76.7	77.0	75.9	73.4
Urban settlements	*71.1*	*73.3*	*73.5*	*78.2*	*79.5*	*81.6*	*82.4*	*82.9*	*81.5*	*77.5*
Other	*53.9*	*54.0*	*60.7*	*61.8*	*62.1*	*61.8*	*67.2*	*67.2*	*66.1*	*65.0*
Cable TV	53.6	57.3	58.4	-	-	-	-	-	-	-
Laptop	39.0	39.2	43.7	47.6	49.0	52.3	53.9	56.1	55.0	53.9

It has been observed that the number of TV devices decreased in 2024 compared to 2015, while other types of devices saw an increase in usage. In particular, the use of mobile phones and laptops stands out. Regarding PC usage, an increase in participation was recorded for both types of settlements.

The following section of the study presents the division of households that have an internet connection and broadband internet access, both in terms of total participation and by type of settlement (Table 3).

Table 3. Households that have an internet connection and broadband internet access in Serbia, according to the type of settlement, 2015-2024 (%)

Type of connection	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Households with internet connection	63.8	64.7	68.0	72.9	80.1	81.0	81.5	83.2	85.6	88.8
Urban settlements	*70.1*	*72.5*	*72.9*	*78.3*	*85.8*	*87.1*	*85.6*	*87.6*	*88.9*	*91.1*
Other	*53.2*	*53.8*	*59.8*	*63.9*	*70.5*	*70.4*	*74.7*	*75.8*	*79.8*	*84.3*
Households with broadband internet access	56.0	57.8	61.9	72.5	79.6	80.8	81.4	83.2	85.6	88.8
Urban settlements	-	*66.8*	*67.5*	*77.9*	*85.6*	*87.0*	*85.6*	*87.6*	*88.9*	*91.1*
Other	-	*44.0*	*52.3*	*63.5*	*69.5*	*70.1*	*74.5*	*75.8*	*79.8*	*84.3*

A significant increase has been observed in the number of households with an internet connection (for 25 p.p.) and broadband internet access (for 22.8 p.p.) in both types of settlements during the observed period.

The Western Balkan region lags behind the EU in terms of broadband internet access, particularly due to the unavailability of 5G services (2022). In this regard, Montenegro is the best positioned, followed by Serbia and Albania (RCC, 2022).

The next part of the research analyzes the frequency of computer and internet usage by individuals in Serbia from 2015 to 2024 (Table 4).

Table 4. Frequency of computer and internet usage by individuals in Serbia, 2015-2024 (%)

Indicator		2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Frequency of computer use	Never	28.7	27.2	26.1	22.8	21.7	19.8	17.6	17.3	15.5	14.2
	More than a year ago	3.3	4.7	4.9	4.5	5.0	6.4	5.5	4.6	5.9	8.2
Frequency of internet connection usage	Never	30.6	29.2	25.6	24.2	19.4	17.4	10.4	10.6	8.9	7.3
	More than a year ago	3.1	2.2	2.3	1.2	2.1	3.2	5.1	4.9	1.1	0.9

The offered answers to this question can never be used, last three months, more than three months up to one year, more than one year. The results of this analysis, presented in Table 4, encompass two extreme characteristics, as they are considered key to gaining insights into the introduction and application of information and communication technologies. Upon examining the tabular data, a significant decrease in the percentage of individuals who have never used a computer (by -14.5 p.p.) or an internet connection (by -23.3 p.p.) was observed. It was also noticed that the percentage of computer use by individuals in periods longer than one year decreased, as this percentage showed higher values in 2024 compared to 2015 (by 4.9 p.p.).

Additionally, the structure of individuals who are computer and internet users were analyzed by age group, and it was found that the age group 65-74 had the least number of users. According to data for 2024, 31.3% of them used a computer, and 57.8% had an internet connection. The highest number of computer users belonged to the age group 16-24, with a participation rate of 94.8%, while the highest number of internet users were in the 25-44 age group, reaching 99.6% (SORS, 2024).

Finally, the structure of *companies* based on the frequency of internet use and having a website was analyzed. In 2015, 99.1% of companies used the internet in their operations, and from 2020 onwards, 100% of companies used the internet in their business. However, not all companies had their own website, but a slight growth trend was noticed. Specifically, in 2015, 75.2% of companies had their own website, and ten years later (2024), this percentage reached 85%. If we consider the size of companies in 2024, the highest number of companies with a website belonged to the category with 250 or more employees (97.2%). If we classify companies based on their ability to receive orders through a website or mobile application, we can state that their number increased from 23.3% in 2015 to 28.4% in 2023. Among these companies, those with 250 or more employees stand out.

When observing the structure of companies using electronic government services (e-Government), we face the issue of data availability, as the RZS only has data for 2015 (94.5%) and 2016 (98.6%) (SORS, 2024).

Regarding the integration of digital technologies in the Western Balkan region in 2022, Montenegro stands out, followed by Kosovo, Albania, and Serbia. Compared to the EU level, the integration of digital technologies is significantly lower in the Western Balkan countries (Figures 2 and 3).

The Western Balkan region is making significant efforts to improve the implementation of digital services through the provision of public services, both for the population and for businesses. The greatest progress among the Western Balkan countries was made by Serbia, followed by Albania and North Macedonia. However, the adoption of digital public services is still far below the EU average.

When it comes to implementing measures that contribute to reducing the impact of business operations on the environment, in 2022, 56% of companies operating in the Western Balkan region undertook more than 4 ecological actions with the help of ICT, mainly focusing on activities that contribute to reducing the ecological footprint (RCC, 2022).

Digitalization and e-government can contribute to reducing costs with the goal of better utilizing opportunities to increase efficiency and develop more efficient ways of working and growing productivity in businesses and the public sector (Đorić, 2020).

As the participation of households, individuals, and companies using internet connections in their daily lives and work increases, we can say that Serbia is successfully advancing in the application of ICT in daily life and business.

4. CONCLUSION

Serbia, as a country with candidate status for EU membership, is consistently striving to join the EU's digital market. In order to achieve this goal, it is necessary to work on strengthening digital capacities and administration. Additionally, greater ICT coordination between the economy, population, and public administration needs to be established, which can be achieved by strengthening the e-Government office. In order to achieve all of this, it is essential to first strengthen the ICT infrastructure, which should support digital transformation.

Serbia and Montenegro have the highest DESI index among the Western Balkans countries, but they are only halfway through the process of digitalizing the economy and agriculture compared to EU countries. Nevertheless, Serbia is seeing a growth trend in the number of individuals, households, and businesses that use broadband internet, mobile phones, work online, and create company websites daily. It is recommended to continue this path.

A recommendation for policymakers who plan and implement the introduction of digital services in both business and private life is to focus more on improving digital literacy and education among the population, in order to keep up with the changes occurring every day in the digital world.

5. ACKNOWLEDGEMENT

Paper is a part of research financed by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia and agreed in decision no. 451-03-66/2024-03/200054, and research results on project U 01/2023 Green economy in the era of digitization, Faculty of Finance, Banking, and Auditing, Alpha BK University in Belgrade, Republic of Serbia.

6. REFERENCES

Alonso, A.D., Northcote, J. (2013). Investigating farmers' involvement in value-added activities: A preliminary study from Australia. British Food Journal, 115(10), 1407-1427. doi: 10.1108/BFJ-04-2011-0104

Androniceanu, A., Georgescu, I., Kinnunen, J. (2022). Public Administration Digitalization and Corruption in the EU Member States. A Comparative and Correlative Research Analysis. *Transylvanian Review Of Administrative Sciences, 18*(65), 5-22. doi:http://dx.doi.org/10.24193/tras.65E.1

Đorić, Ž. (2020). Digital economy: Basic aspects and the case of Serbia. Ekonomski pogledi, 22(2), 73-96. doi.org/10.5937/EkoPog2002073Q

European Commission (2022). Digital Economy and Society Index (DESI) 2022-Thematic Chapters, https://ec.europa.eu/newsroom/dae/redirection/document/88764 (Accessed December 2024).

European Commission (2024). Digital Decade DESI visualisation tool, DESI, https://digital-decade-desi.digital-strategy.ec.europa.eu/datasets/desi-2022/charts/desi-components?indicator=desi&indicatorGroup=desi_dim&breakdown=desi_hc_bsu&period=2022&unit=pc_desi&breakdownGroup=desi (Accessed December 2024).

EU (2013). REGULATION (EU) No 1305/2013 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 december 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005.

EU (2021). Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013. Official Journal of the European Union, L 435.

FAO (2018). Transforming food and agriculture to achive the SDGs. 20 interconnected actions to guide decision-makers. Food and agriculture organization of the United Nations. Rome, 2018.

Garg, S., Rumjit, N.P., Roy, S. (2024). Smart agriculture and nanotechnology: Technology, challenges, and new perspective. Advanced Agrochem, 3(2), 115-125.

Grujić Vučkovski, B., Simonović, Z., Ćurčić, N. (2021). Importance of agriculture and food industry in the economy of the Republic of Serbia. In: Harnessing Tangible and Intangible Assets in the context of European Integration and Globalization. Challenges ahead. Proceedings of ESPERA. "Costin C. Kiritescu", National Institute for Economic Research; Peter Lang GmbH, Bucharest ; Berlin, 971-982.
Grujić Vučkovski, B., Subić, J. (2024). Digitalization in agriculture and application in Serbia, Second International Scientific Conference "Challenges of digitalization in the business world", Alfa BK University, Belgrade, Serbia, 50-62.
Grujić Vučkovski, B., Marina, I., Ćurčić, N. (2024). Connection of GLOBAL G.A.P. standards and precision agriculture, Second International Scientific Conference GIRR 2024 "Global challenges through the prism of rural development in the sector of agriculture and tourism", Šabac, Serbia, 83-91.
Inoue, Y. (2020). Satellite-and drone-based remote sensing of crops and soils for smart farming - a review. Soil Science and Plant Nutrition, 66(6), 798-810. doi.org/10.1080/00380768.2020.1738899
Javaid, M., Haleem, A., Singh, R. P., Suman, R. (2022). Enhancing smart farming through the applications of Agriculture 4.0 technologies. International Journal of Intelligent Networks, 3, 150-164. doi.org/10.1016/j.ijin.2022.09.004
Jha, K., Doshi, A., Patel, P., Shah, M. (2019). A comprehensive review on automation in agriculture using artificial intelligence. Artificial Intelligence in Agriculture, 2, 1-12.
Mogili, U.R., Deepak, B.B.V.L. (2018). Review on application of drone systems in precision agriculture. Procedia computer science, 133, 502-509. doi.org/10.1016/j.procs.2018.07.063
Pogorelskaia, I., Várallyai, L. (2020). Agriculture 4.0 and the role of education. Journal of Agricultural Informatics, 11(1), 45-51, doi:10.17700/jai.2020.11.1.571
Rolandi, S., Brunori, G., Bacco, M., Scotti, I. (2021). The digitalization of agriculture and rural areas: Towards a taxonomy of the impacts. Sustainability, 13(9), 5172.
Regional Cooperation Council (RCC) (2022). Western Balkans Digital Economy Society Index, Report 2022, www.rcc.int/files/user/docs/43a521a624cf08523a2268a67a7be2ff.pdf (Accessed December 2024).
Sinitsa, Y. Borodina, O., Gvozdeva, O., Kolbneva, E. (2021). Trends in the development of digital agriculture: a review of international practices. In BIO Web of Conferences, 37, 1-5. doi.org/10.1051/bioconf/20213700172
Statistical Office of the Republic of Serbia (SORS) (2024). Eletronic database, Usage of information and communication technologies, https://data.stat.gov.rs/Home/Result/270101?languageCode=en-US (Accessed December 2024).
Vasile, C. (2012). Digital era psychology-studies on cognitive changes. Procedia-social and behavioral sciences, 33, 732-736.
Vial, G. (2021). Understanding digital transformation: A review and a research agenda. Managing Digital Transformation, 13-66.

doi:10.46793/MAK2025.417R

THE ORGANIZATION OF THE SCHOOL COOPERATIVE AS AN IMPORTANT LINK IN THE PROMOTION OF AGRICULTURE, FOOD PRODUCTION AND CLIMATE CHANGE

Ramona Ručnov

House of Knowledge, Center for Creative Education, Belgrade, Serbia
centarkucaznanja@gmail.com

Apstrakt: School cooperatives are present in the schools of the Republic of Serbia, but they are not formed to a sufficient extent, in order to follow the trends of sustainable development, and act to promote agriculture, food production and climate change. The goal of this paper is to show how a school cooperative can contribute to increasing not only the economic, but also the social effect. For such a thing, it is necessary to include the relevant ministries in the formation of the School Cooperative Program, in order to raise the school cooperative to the rank of institutions of social importance. Studying the programs and methods of program implementation, as well as the results of the work of school cooperatives in the territory of the Republic of Serbia, we came to the conclusion that it is necessary: modernize the program, expand the scope of topics that are covered/applied in schools, educate school principals for the organization of school cooperatives, educate teaching staff to work with students in school cooperatives, and connect school cooperatives with important economic institutions. As a result of our work, the Work Program of the school cooperative was created, which is an integral part of this work.

Key words: School cooperative, Sustainable development, Agriculture, Food production, Climate

1. INTRODUCTION

Introduction of change in education conducted through different mode. Many times a worthy innovation is introduced one year via workshops, courses and other means, but the implementation is not completed, and the presented programs and innovations remain in drafts and drawers. The implementation of innovation in edducation is is a difficult process and the outcome is unproductive because program change is not integrated into the broader system of education in the school and beyond (Freeman, 1989; Senge, 2000). There are numerous factors that contribute to the failure of program implementation, including: insufficient teacher trust in the presented educational philosophy (Sharan, 2002), teachers are not properly involved in the change but are told what to do, lack of ongoing support for teachers, and insurmountable differences between theory and practice (Sharan, 2002; Farrell, 2003).

A school cooperative is not only a place where educational influence is exerted and curricular and extracurricular activities are carried out, but an institution of national importance. It represents the economic, social and educational component in society (Göler von Ravensburg, 2017). By introducing cooperatives in all schools, not only economic, but also social progress would be achieved (Chamber of Commerce of Serbia, 2023). That is why it is important to include all institutions in the formation of the Program, which would represent an effective support mechanism: Ministry of Education, Ministry of Finance, Ministry of Environmental Protection, Ministry of Agriculture, Forestry and Water Management, Ministry of State Administration and Local Self-Government, Ministry of Rural Care, competent City Secretariat for Education, professional work, professional work of institutions, faculties, tourist organizations, banks, the media.

Significant support would refer to: regulatory support, tax regulation, assistance in logistics, creation of mutually beneficial conditions for the interaction of the school cooperative and the educational institution in which it operates (Rodgers, 2015).

All of the above and many other institutions would enter the algorithm for introducing cooperatives into schools. In addition, their presence would be necessary for students and teachers in the proper and optimal use of the resources of the cooperative and entrepreneurship (Vrančić and Lovrenčić, 2013).

School cooperatives are present in the schools of the Republic of Serbia, but they are not formed to a sufficient extent, in order to follow the trends of sustainable development, and act to promote agriculture, food production and climate change (Chamber of Commerce of Serbia, 2023). The program of the School Cooperative is divided into five areas of activity, and contains a wide variety of topics, which cover the current needs of the market of the Republic of Serbia, regardless of the regional affiliation of the school and its initial resources. Working in a cooperative requires constant education, both of students and teachers, as well as practice. All this contributes to "increasing the quality of education and greater social inclusion of school children in Serbia" (Chamber of Commerce of Serbia, 2023).

The aim of this paper is to estimate the necessity of a new, comprehensive Program of School Cooperatives, which would be the basis for the formation of the elaboration of systemic organizations of cooperatives in the schools of the Republic of Serbia.

2. THE IMPORTANCE OF THE SCHOOL COOPERATIVE FOR THE SOCIAL COMMUNITY

The importance of school cooperatives for the social community is the subject of numerous studies. A study of the impact of entrepreneurship education on the education system found that "participation in student cooperatives develops cooperation and solidarity among students, as well as independent recognition of problems and needs in the community", with students positively assessing the importance of practice, independence in work and problem solving, and especially learning how to become an entrepreneur (Vidović and Čabo, 2019).

The Serbian Chamber of Commerce (SCC) is the initiator of the introduction of dual education into the education system, which involves learning through work, i.e. parallel implementation of both learning and practice. The SCC has included "more than 19.000 students, 1.100 companies, 86 educational profiles and 200 schools" in this program (Chamber of Commerce of Serbia, 2023). It has proven to be a very successful "transition of young people from school to work", as students "apply functional and practical knowledge in real conditions, gain experience in a real work environment, learn the skills necessary to start their own business" (Chamber of Commerce of Serbia, 2021) In this sense, School Cooperatives, in addition to their educational influence on the younger generation, are fertile ground for forming awareness of the "synergy of economy and education".

The Croatian Association of Student Cooperatives (HSUZ) conducted a survey among student cooperatives at the end of the second decade of this century, based on which they concluded, among other things, that since the middle of the last century, the number of student cooperatives has been increasing. Cooperatives in Croatia have grown significantly thanks to the concept of "cooperative identity", based on seven principles: voluntariness, autonomy and independence, inter-cooperative cooperation, community care, education about cooperatives, democratic governance, a place of continuous learning and work.

Research conducted among student cooperatives, whose main goal was to prepare students for entrepreneurship, concluded that “the cooperative model can follow contemporary trends in education and new industries” (Vrančić and Lovrenčić, 2013).

At the beginning of the 21st century, a study was written in Germany with the intention of explaining “the connection of student cooperatives with the goals of education for sustainable development” (Goller von Ravensburg, 2017). The study states that “the cooperative model significantly contributes to the development of students, especially in secondary schools: it places them in the role of co-creators in the educational process and contributes to the development of key competences for sustainability” (Goller von Ravensburg, 2017).

School cooperatives have the opportunity to create conditions for “increasing the social inclusion of children with specific problems in the education system, whether it is on poverty, disability or something similar”, which achieves “building the capacity of school management to meet the needs of developing social inclusion in schools". (Dinkić et al., 2010).

The cooperative model of education in schools covers various aspects of the social community (social, economic, educational, environmental). The main mission of the School Cooperative is to focus on “improving the lives of cooperative members, and empowering the community through the provision of education, through social and cultural activities” (Rogers, 2015).

2.1. Economic importance of the school cooperative

The school cooperative reveals itself as a business model that can contribute to a solidarity economy The members of a cooperative commit themselves to the principles and social values of the organization, with mutual commitment, and trust among members, all acting in accordance to social norms (Avsec and Sÿtromajer, 2015; Ribas et al., 2022). The school cooperative has economic significance through the development of financial awareness, literacy, earning a first salary, students become familiar with the laws of the market and become an important actor in the formation of market relations, achieving economic profit through good business, presence in the food market, strengthening the professional orientation of the population, familiarization with the organization of cooperative business, competition, marketing, and through involvement in industrial and entrepreneurial activities.

Social significance of the School Cooperative alignment between economic and social development and taht in learning students get knowledge and skill how to define and sharing a common goal of prosperity what is competence of the operational management of cooperatives make it possible for cooperative members, how to overcome the obstacles that prevent their social and economic development (Ribas et al., 2022). In general, it was possible to understand that cooperativism is an organization created by a group of people with common interests, who seek to perform economic activities related to the economic development and welfare of the community (Ribas et al., 2022).

2.2. Social significance of the School Cooperative

The cooperative learning focused on a wide variety of outcomes, including academic achievement in many subjects, for examle, attendance to school, behavior related to classmates and teacher, acceptance of classmates with handicaps, intergroup relations, social cohesion, attitudes toward subjects, and more (Slavin, 2010, 2013; Johnson and Holubec, 2008; Rohrbeck et al., 2003). The effects of cooperative learning are largely dependent on the cohesiveness of the group. In the school cooperative the students learn to work and earn as well as how to contribute to the community. Both students and teachers participate together in social work, in the progress of the social community. Also, students are introduced to trades and professions current on the market from an early age, and what is very important students learn about humanitarian work and actively participate in humanitarian actions. The role of school cooperative is developing oportunity to student participate in teamwork, in the organization of the environment and the development of their school, gaining knowledge and experience for relatioship between school cooperatives are partners of other organizations, prepares young people for life in a changing world and what is particularly important is the transfer of knowledge from teaching to the practical activities of the cooperative and vice versa. Prepares students for choosing a future profession. Moreover, it prepares students for choosing a future profession. It ensures social security of society and inclusivity.

The social cohesion might hold that the utility of cooperative learning lie in their contribution to group cohesiveness, caring, and pro-social norms among group members, which could impact cognitive processes. Similarly, social cohesion theorists might hold that the utility of cooperative learning lie in their contribution to group cohesiveness, caring, and pro-social norms among group members, which could impact cognitive processes. In response to results of cooperative learning should be establish rewarding groups based on group performance (or the sum of individual performances) to suport group member (e.g., praise, encouragement) in accordance with social norms (Slavin, 2013). The social cohesion perspective is on preparation for cooperative learning, and group self-evaluation during and after group activities. The achievement effects of cooperative learning depend on social cohesion and the quality of group interactions (Johnson and Johnson, 2008; Webb, 2008; Barros and Michaud, 2020).

2.3. The educational importance of the school cooperative

The school cooperatives have different systems in comparidon to other companies, according to proactively contributing to the development of society (Ribas et al., 2022). Beside to economic aspect, the school cooperative learning impact on the social development, mainly in the influence that cooperativism exerts on the individual aspect of each person, and acocrdance with association with other people, they build teamwork and collective way and adopting decisions together. So, in a cohesive way, the common objectives are reached and allow the cooperativism for transcend the individualism of the human being (Amonarriz et al., 2017).

This perspective of cooperative learning holds that students help each other learn because they care about the group and its members and come to derive self-identity benefits from group membership (Johnson and Johnson, 2008). During their education in a school cooperative, students develop their own potential and work habits, acquire good educational values. Education encourages the development of students' personal abilities and preferences and enables organized spending of free time. Students voluntarily take on the obligation of work and thus become responsible for what is done or not done. In this system of education, the educational role of the school is strengthened, violence among schoolchildren is reduced, cooperative relations are strengthened, a sense of belonging to the school is increased, and independent and research-based learning is encouraged. Students develop a love for nature and the values that man has created through his work and actively work to prevent socially unacceptable behavior.

2.4. The role of the director and other participants in the work of the School Cooperative

The director is a mandatory member of the School Cooperative. He participates in the formation of the cooperative, defining the plan and program of the cooperative, and implements the personnel policy. The all person who want to be involved in the management of the School Cooperative need to get education training which last for several months, and at the end of the training, need to apply for a license. The diploma on completed training and passed exam is issued by the Ministry of Education.

As the activities of the School Cooperative are focused on "providing services, production, sales and other activities that contribute to the improvement of the educational function of schools", so the role of the school director is to "develop instruments that will enable the planning process to be improved, management, financing, monitoring and reporting on the activities that are carried out in all schools" (Dinkić, 2010).

Also, there must be a system of evaluation of teachers who participate in the work of the School Cooperative. The criterion of voluntariness cannot be decisive in the selection of teachers, who will deal with the School Cooperative. Hiring teachers is not of the volunteer type; it is a matter of serious work on the organization and implementation of multi-layered work. A teacher needs a mind. anjita fund of classes in regular classes, so that he could dedicate himself to work in the cooperative. It is necessary to provide these teachers with a system of professional support: education for opening and running a cooperative, education about cooperatives and the cooperative management process, education about social entrepreneurship, familiarization with the history of cooperatives.

3. SCHOOL COOPERATIVE PROGRAM

The program of the School Cooperative depends on the region to which the school belongs. Each region has its own point of interest (industry, tourism, agriculture), as well as the specifics of the market, so when forming the School Cooperative program, it is necessary to pay attention to these components.

The program is divided into five areas:

- Environmental changes,
- Agriculture,
- Food production,
- Entrepreneurship and
- Engagement in the local community.

It contains all areas of work.

3.1. Environmental changes

The term "environmental education" has been in use in educational circles for the last few decades. The environmental education is not new, but growing concern for the environment has been emphasized recently through initiatives for the curriculum (Palmer, 2003). Environmental education foregrounds ecology; environmental awareness (beliefs, knowledge, practical work, problems of modern society); environmental literacy; school as a factor of environmental upbringing and education; forms of poverty and methods of eradication; eradicating hunger and achieving food security; quality nutrition; people's health and quality of life for people of all generations; sustainable water management; decent work for all; ecosystem protection (forests, water, habitats, protected species); an individual in preserving a healthy and quality environment; environmental education factors (environment, personality, motivation, competence); sources of environmental education: environment, literature, media, teacher, teaching aids).

Environmental education encompasses approaches and programs that develop and support environmental attitudes, values, awareness, knowledge, and skills that prepare people to develop activities to protect and preserve the environment (Monroe and Krasny, 2016). Environmental education contributes to increased intentionality, creativity, and inclusiveness in the development and implementation of programs that affect environmental quality and conservation outcomes and, consequently, purposeful data collection and monitoring of environmental change will have an impact on knowledge outcomes, activities, and behaviors, attitudes, publics, researchers, and policymakers (Lemos et al., 2018; Toomey et al., 2017).

3.2. Agriculture

In the time of climate change, global warming and greater conservation concerns biodiversity, biological diversity, species diversity, species loss, nitrogen, adaptation in agriculture production, balance of phosphorus, ozone, emission of chlorofluorocarbons, sea level rise, water quality, water deficit, urbanization, pollution, air quality, and aerosol, is necessary to establish fundamental and creative curricula and education (Ardoin et al., 2019).

These programs in agriculture should be addressed a diversity of topics, including: Farming; fruit growing (theory, construction of orchards, cultivation, processing; production of dried fruit for compotes); vegetable growing (theory, construction of gardens), beekeeping (theory, construction of apiaries); cultivation of medicinal herbs, birch and pine buds, collecting medicinal herbs, berries and mushrooms; breeding of rabbits; animal husbandry; promoting sustainable agriculture; smart agriculture (IT technology, drones, artificial intelligence), awareness of national agriculture, urban agriculture - organization and forms; environmental factors (light, temperature, water, wind), occupations, agribusiness.

The numerous researches showed that for the improvement in the skills and knowledge of the farmers and agricultural employees we have to analyse the actual situation and needs of farmers and modern challenges of the agricultural education. Nowdays is rapidly change technology in agricultural production what require new programs for precision agriculture, more investment in new tools, machinery, education of teachers, puple and farmers. In agricultural education the most actual developments have to be included in the curricula. The educational system have to pay attention for the changing needs of the agricultural system (Kőmíves et al., 2019; Pellegrini et al., 2020).

3.3. Food production

In School Cooperative education supported free breakfast for students, and improving knowledge for hunger and obesity, traditional food production (tools, material, procedures), formation of the farm. They will learn about geographical restrictions, origin of food production primary (milk, meat, honey, eggs, fish, game, mushrooms) and secondary (wine, brandy, beer, oil, cheese, jam, sweets, bread, spreads, winter food, pasta, vegan food) products. During these program students will get experinces with digitization of business in agriculture, marketing and sales of food, food hygiene and safety, food quality and get skils and knowledge for thermal processing of food (drying, freezing), food production: soups, mayonnaise, potato dishes, vegetable and meat dishes, frozen ready meals, dehydrated ready meals, baby food.

Food production as an important factor in solving climate change, food on the domestic and foreign markets (declaration, placement, price formation), sustainable food production, agricultural land (type, size, preservation - household relationship), organic production (Ardoin et al., 2019; Raković and Perić, 2020). The developing school feeding programme impact to create markets for local producers and is very important in the process of promoting the health and education (Morgaan and Sonnino, 2010).

3.4. Entrepreneurship

The school cooperative education includes the development of entrepreneurial competence among students in grades 2-8, training of children as apprentices in shops or craft workshop, economic literacy, entrepreneurial education: commercial arithmetic, correspondence and accounting, foreign languages, technical chemistry, trade, law, political economy, trade history, commercial geography, commercial knowledge, market goods; personnel issues, entrepreneurial competence of rural youth; professional resource potential in rural areas. Entrepreneurship and cooperatives as a form of personal work engagement, connected to knowledge of personal abilities and inclinations of students and professional guidance,craftsc; photocopier, souvenir shop, handicrafts (jewelry, clothes, shoes), local tourism; rural tourism (mowing and turning hay, working with and around animals, making winter shelter, picking fruit, brandy roasting, horseback riding, safari, swimming in the river, fishing; evening meal, printing of student books, organizing events: fairs, meetings, bazaar, seminars, sale of textbooks and school supplies, hospitality and tourism activities, hairdressing and beautician activities, repairs, development of projects; financial management; managing the school library and purchasing books.

Entrepreneurial training or education should be directed to promote creativity, innovation and self-employment (European Commission, 2009). Also, education should be giving knowledge for efficient identifying business opportunities and gathering the most appropriate and diverse resources to carry these out (Vidović et al., 2019; Valenciano et al., 2019). In frame of program of education develops capacity for transformational change, the ability to experiment with their own ideas and the capacity to be flexible and react quickly (Kőmíves et al., 2019; Valenciano et al., 2019).

3.5. Engagement in the local community

Quality environmental education should be involving many partners and stakeholders who collaborate in conducting activities, decisions and creating policy for research, protection and improvement of and local culture and environment (Raković and Perić, 2020; Toomey et al., 2017). Education in local communities includes: public-communal engagement: cleaning the city, history of school cooperatives, people's quality of life, competition in professional skills, cooperation with consumer societies of local communities, personal businesses and estates, which are located near schools, hygienic conditions for everyone, horticulture (growing flowers, sales, handicrafts); Supplying a certain number of households with various types of food, socially useful work;, humanitarian work (assistance in learning, purchase of books and school supplies, collection of funds, care of disabled people - food, medicine, water, groceries), sewing uniforms, production of souvenirs for tourist organizations; hagrad excursions, participation in competitions; marking of holidays (state, religious, international). Environmental education evaluation and assessment often struggle in different spaces (Ardoin et al., 2019; Toomey et al., 2017).

4. CONCLUSION

The School Cooperative Program was created based on an analysis of the work of existing cooperatives in the schools of the Republic of Serbia, the work of cooperatives in foreign countries, and the needs of the market. School cooperatives promote the goals of sustainable development, food production and climate change with their programs and activities. This study indicate that for improving activities the School Cooperative should be stronger conection with education Institution and govermental Institution to get the status and more support for development in the school system and in official policy. Also, it is necessary support for synergistic implementation of knowledge and work in frame of program to solving local needs and achieving changes in the community. The significant advantage of school cooperative is can improve the status of the school with its income, by equipping the classrooms and classrooms with the most modern teaching aids. In addition, by engaging in specific activities, students have the opportunity to engage in practical work, as well as to learn about the basics of entrepreneurship in different field of economy as well as in the improvement of the competitiveness of agriculture in Serbia and the region.

5. REFERENCE

Amonarriz, C.A., Landart, C.I., Cantin, L.N. (2017). Cooperatives' proactive social responsibility in crisis time: How to behave? REVESCO, Rev. Estud. Coop., 123, 7-36.

Ardoin, N.M., Bowers, A.W., Gaillard, E. (2019). Environmental education outcomes for conservation: A systematic review. Biological Conservation, 108224. doi:10.1016/j.biocon

Avsec, F., Sÿtromajer, J. (2015). Development and socioeconomic environment of cooperatives in Slovenia. J. Co-Oper. Organ. Manag., 3, 40-48.

Barros, M., Michaud, V. (2020). Worlds, words, and spaces of resistance: Democracy and social media in consumer co-ops. Organization, 27, 578-612.
Chamber of Commerce of Serbia (2023). Education tailored to the economy, Belgrade, 2-5.
Dinkić, M. (2010). Student cooperatives and expanded activities of schools with the aim of increasing the quality of education and greater social inclusion of school children in the Republic of Serbia, Institute of Economic Sciences in Belgrade.
Farrell, T.S.C. (2003). Learning to teach English language during the first year: Personal issues and challenges. Teaching and Teacher Education, 19(1), 95-111.
Freeman, D. (1989). Teacher training, development, and decision making: A model of teaching and related strategies for language teacher education. TESOL Quarterly, 23, 27-45.
Göler von Ravensburg, N. (2017). Pupils' cooperatives and the acquisition of competences for sustainable development. CIRIEC Working Paper. www.ciriec.uliege.be/wp-content/uploads/2017/02/WP2017-01.pdf
Johnson, D.W., Johnson, R.T. (2008). Social independence theory and cooperative learning: The teacher's role. In: Gillies, R.B., Ashman, A.F., Terwel, J. (Eds.), The teacher's role in implementing cooperative learning in the classroom, NY, Springer, 9-37.
Lemos, M.C., Arnott, J.C., Ardoin, N.M., Baja, K., Bednarek, A.T., Dewulf, A., Fieseler, C., et al., (2018). To co-produce or not to co-produce? Nat. Sustain. doi.org/10. 1038/s41893-018-0191-0
Kőmíves, P.M., Pilishegyi, P., Novák, N., Nagy, A.S., Körösparti, P. (2019). The Role of the Higher Education in the Development of the Agriculture. International Journal of Information and Education Technology, 9(9), 607-612.
Morgaan, K., Sonnino, R. (2010). The School Food Revolution. Public Food and the Challenge of Sustainable Development, Publisher Earthscan from Routledge, p. 51.
Monroe, M.C., Krasny, M.E. (2016). Across the Spectrum: Resources for Environmental Biological Conservation, 12 Education, 3rd ed. North American Association for Environmental Education, Washington, DC.
Palmer, J.A. (2003). Environmental education in the 21st century Theory, practice, progress and promise. Published London and New York, p. 51.
Pellegrini, G., Annosi, M.C., Contò, F., Fiore, M. (2020). What Are the Conflicting Tensions in an Italian Cooperative and How Do Members Manage Them? Business Goals', Integrated Management, and Reduction of Waste within a Fruit and Vegetables Supply Chain. Sustainability, 12, 3050.
Raković, S., Perić, B. (2020). Learning by engaging in the local community, Kolping of Serbia, Federal Ministry for Economic Affairs and Energy, Novi Sad.
Ribas, W.P., Pedroso, B., Vargas, L.M., Picinin, C.T., Freitas Júnior, M.A. (2022). Cooperative Organization and Its Characteristics in Economic and Social Development (1995 to 2020). Sustainability, 14, 8470. doi.org/10.3390/ su1414847
Rodgers, D. (2015). Guidelines on cooperative principles. Brussels: International Federation of Cooperatives.www.ica.coop/sites/default/files/publication-files/2017-02-15-hrguidance- notefinal-581762885.pdf
Rohrbeck, C.A., Ginsburg-Block, M.D., Fantuzzo, J.W., Miller, T.R. (2003). Peer-assisted learning interventions with elementary school students: A meta-analytic review. Journal of Educational Psychology, 94(20), 240-257.
Senge, P. (2000). Schools that learn: A field book for teachers, administrators, parents, and everyone who cares about education. New York: Doubleday, 10.
Sharan, Y. (2002). Essential features of a teacher education program for cooperative learning. Asia Pacific Journal of Education, 22, 68-74.
Slavin, R.E. (2010). Cooperative learning. In: Baker, E., Peterson, P., McGaw, B. (Eds.), International Encyclopedia of education (3rd ed.). Oxford, England, Elsevier.
Slavin, R. (2013). Cooperative learning and achievement: Theory and research. In: Reynolds, W., Miller, G., Weiner, I. (Eds.), Handbook of psychology, (2nd ed,), Hoboken, NY Wiley, 7, 199-212.
Toomey, A.H., Knight, A.T., Barlow, J. (2017). Navigating the space between research and implementation in conservation. Conserv. Lett., 10, 619-625. doi.org/10. 1111/conl.12315
Valenciano, J.P., Uribe-Toril, J., Ruiz-Real, J.L. (2019). University of Almeria. Journal of Entrepreneurship Education, 22, 4, 1-20.
Vidović, D., Grubišić-Čabo, M. (2019). Student cooperatives: A model of learning about participation and (social) entrepreneurship within the educational system, GOOD initiative, Zagreb.
Vrančić, M., Lovrenčić, S. (2013). Innovations in the work of student cooperatives: An example of good practice. Learning for entrepreneurship, Zagreb.
Webb, N.M. (2008). Learning in small groups. In: Good, T.L. (Ed.), 21st Century Education: A Reference Handbook, Los Angeles, Sage, 203-211.

CIP - Каталогизација у публикацији Народна библиотека Србије, Београд

631(082)
63:551.583(082)
338.43(082)
338.1:502.131.1(082)
330.341.1(082)
33(082)

JEEP INTERNATIONAL scientific agribusiness conference (12 ; 2025 ; Kopaonik)
Climate changes and ecological sustainability in agriculture and food production in Serbia, the region and Southeastern Europe : proceedings / 12th JEEP International scientific agribusiness conference MAK 2025, Kopaonik, Serbia, January 30th to February 2nd, 2025. ; editors Danijela Šikuljak, Milan Jovičić. - Kraljevo : Association science and business center, "WORLD" ; Beograd : Institute for plant protection and environment, 2025 (Kraljevo : Kvark). - [16], 424 str. : ilustr. ; 25 cm

Tiraž 60. - Str. [11]: Foreword / Desimir Knežević. - Napomene i bibliografske reference uz tekst. - Bibliografija uz svaki rad.

ISBN 978-86-80510-14-9 (NPCW)

a) Пољопривредна производња -- Зборници b) Пољопривреда -- Климатске промене -- Зборници v) Привредни развој -- Одрживи развој -- Зборници g) Економија -- Зборници d) Технолошки развој -- Зборници

COBISS.SR-ID 161532425