Stupar V *et al.* (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 1, Article number 13389
DOI:10.15835/nbha52113389
Research Article

The effect of fertility control on soil conservation as a basic resource of sustainable agriculture

Vladanka STUPAR[1], Zlata ŽIVKOVIĆ[1], Aleksandar STEVANOVIĆ[1], Darko STOJIĆEVIĆ[1], Tatjana SEKULIĆ[1], Jelena Ž. BOŠKOVIĆ[2], Vera M. POPOVIĆ[3,4]*

[1]*Academy of Applied Technical Studies Belgrade, Katarine Ambrozić 3 Belgrade, Serbia; vstupar@atssb.edu.rs; zzivkovic@atssb.edu.rs; astevanovic@atssb.edu.rs; dstojicevic@atssb.edu.rs; tsekulic@atssb.edu.rs;*
[2]*Metropolitan University, Tadeuša Košćuška 63, 11586 Belgrade, Serbia; jelenaboskovic50@gmail.com*
[3]*Institute of Field and Vegetable Crops, Maxim Gorky 30, 21000 Novi Sad, Serbia; vera.popovic@ifvcns.ns.ac.rs*
[4]*University of Bijeljina, Faculty of Agriculture, Pavlovic road bb, 76300 Bijeljina, Bosnia & Hercegovina; drvvpopovic@gmail.com (*corresponding author)*

Abstract

For agricultural production is used almost 40% of the global land from where it dominates conventional agriculture which uses large amounts of inputs in the form of fertilizers and pesticides leading to the contamination of soil, water resources, air pollution and land erosion, affects biodiversity and extinction of many plants and animals. On the other hand, the world's population is constantly growing and currently numbers more than 8 billion people and it is estimated that food production will have to double by 2050. In order to meet the future needs of the population for food raw materials, food production must significantly increase, and at the same time, the impact of agriculture on the environment and natural resources must be drastically reduced. Sustainable agriculture is emerging as one of the solutions. This way of agricultural practice refers to the management and preservation of natural resources through organizational and technological changes in modern agricultural production in order to satisfy human needs and preserve the environment. One of the most important natural resources on which the entire agricultural production relies is land. In intensively cultivated lands, there is a noticeable trend of intense degradation, which represents a major problem facing humanity. The paper reviews the decrease in soil fertility based on the samples collected during the five-year monitoring, as well as a proposal for measures to increase fertility and future preservation of this environmental resource.

Keywords: fertility control; natural resources; preservation of fertility; soil degradation; sustainable agriculture

Introduction

Agriculture is imperative to human survival as it provides food for the growing world population, plays a crucial role in economic development and is an important source of livelihood. On the other hand, agriculture

Received: 07 Sep 2023. Received in revised form: 28 Nov 2023. Accepted: 15 Jan 2024. Published online: 13 Feb 2024.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

is the main source of environmental degradation because it is considered one of the main factors affecting climate change, leads to the depletion of fresh water resources, fish die-offs, contributes to the degradation of soil fertility and environmental and soil pollution through the use of fertilizers and pesticides, modifies landscape and damages the ecosystem's goods and services, including biodiversity at all levels (Horrigan *et al.,* 2002; Chen and Yada, 2011; Paoletti *et al.,* 2011; Popović, 2015; Crews *et al*., 2018; Bojović *et al*., 2022; Božović *et al*., 2022; FAO 2022; Živković *et al*., 2022). Globally agricultural land area is approximately five billion hectares, or 38% of the global land surface (FAO, 2020). About one-third of this is used as cropland, while the remaining two-thirds consist of meadows and pastures) for grazing livestock (FAO, 2020, 2022). It is estimated that food production will have to double by 2050. Approximately a billion people are chronically malnourished while, on the other hand, agricultural systems are concurrently degrading biodiversity, water, land, and climate on a global scale (Foley *et al.,* 2005; Foley *et al*., 2011; Średnicka-Tober *et al.,* 2016). With the increase in world population the demand for agricultural yields has increased significantly, which has led to the large use of pesticides and the production of chemical fertilizers in conventional agriculture. The use of these chemical agents in agricultural fields has led to the degradation of soil quality and fertility. Increased and indiscriminate use of fertilizers, especially nitrogen and phosphorus, has led to significant soil pollution by lowering pH, making these nutrients unavailable to crops resulting in loss of productivity.

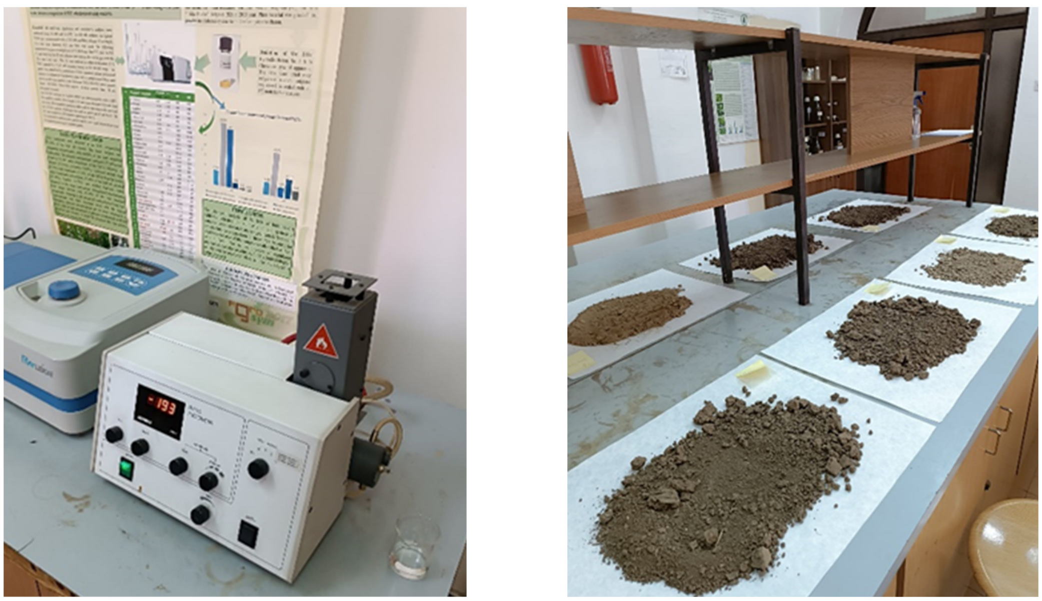
One of the characteristics of conventional agricultural production is the dominance of annual plants grown in monocultures. Such crops lead to soil erosion, ecosystem degradation, and an increased number of pests and weeds that have adapted to the cultivated crop (Crews *et al.,* 2018). Large amounts of different active substances of pesticides are used to control them, due to the appearance of resistance, which occurs as concomitant problem in monocultures. In recent decades, soil degradation has become a global problem and a threat to both agricultural output and the terrestrial ecosystem and one of the most important threats facing mankind. It is estimated that nearly 2 billion ha of soil resources in the world have been degraded (Jie *et al*., 2002). Once lost soil is irreplaceable i.e. 1 cm of soil may take more than 500 years to form, yet can be lost within a year (Alam, 2014). Some agricultural practices reduce soil fertility. Continuous cultivation disrupts the natural cycle that returns abundant in minerals material from plants to the soil, which causes soil to lose its fertility. The removal of vegetation cover from the land and the use of large fields without boundaries to slow down the movement of water stimulates soil erosion. Soil compaction resulting from the use of heavy machinery and inappropriate plowing techniques destroys soil structure and limits water infiltration (Alam, 2014). One option for managing the growing demand for food caused by population growth is sustainable agriculture, which can also provide financial benefits to agricultural producers while conserving soil and other environmental resources.

In this study, a five-year period of soil analysis was conducted. Based on literature data and reviewed results of 6943 samples, the authors of the study propose measures to improve soil quality and bring the conventional management system of agricultural production and land resources closer to sustainable. The aim of this study was: 1. Soil analysis and comparison of fertility parameters during two samplings (2017 and 2022) and 2. Proposal of measures to improve soil quality.

Materials and Methods

The soil research has been performed in the districts of Braničevo, an administrative area in eastern Serbia. It is located between 44°42′10″–44°49′08″ N and 21° 49′24″–22° 00′50″ E and covers the area of 3865 km^2. According to the latest data of the Statistical office of the Republic of Serbia, census of agriculture (2012) total available area of agricultural land in the Braničevo district is 210,234 ha, of which slightly more than half (133,748 ha) is used for agricultural production.

The area of Braničevo district is characterized by natural heterogeneity - the biggest part of the area is covered by hills and lower mountains in the southeastern part, while the lower areas cover the northwestern part of the region and are located in the valleys of the Velika Morava, Danube, Mlava and Pek rivers. Due to the presence of different geomorphological entities, surface and underground water and climatic conditions, different types and subtypes of soil were formed Chernozems (leached, marshy, degraded), Vertisols, Vertisol allluvial, Vertisol in podzolization, Eutric Cambisols, Eutric Cambisols in podzolazition, riparian black soil (Humis Gleysols), ponds and swamps (Mrvić *et al.,* 2016). Agrochemical soil analyzes in 2017 and 2022 were performed in the laboratory of the Agricultural, Expert and Advisory Service of Požarevac. In the larger area of the Branicevo district, soil samples from various agricultural producers were analyzed between 2017 and 2022 to evaluate fertility. A total of 6943 samples were examined, which were taken from a depth of 0 to 30 cm. Agrochemical analyzes were performed according to the following methods: determination of humus content by the Kotzmann method (volumetric) - VDM 01; determination of easily accessible potassium by AL method according to Enger-Riehm (flame photometric) - VDM 02 (Figures 1 a-b) and determination of easily accessible phosphorus by the AL method according to Enger-Riehm (spectrophotometric) - VDM 03.



(a) (b)

Figure 1. (a.) Flame photometric determination of K_2O; (b.) Soil samples from individual producers

Statistical data processing was performed using the program Excel 2016. Data on multi-year climate parameters of the research site (1990-2020) were collected at the meteorological station Veliko Gradište (44° 45′ 14.4 ″ N, 21° 30′ 29.4″ E, altitude 68 m) (www.hidmet.gov.rs), and are shown in Figure 2. For the area of the Braničevo district, a database was developed based on the results of both the first and second samplings, which was used to compare the soil fertility parameters. Additionally, measures for soil conservation are suggested, bringing the traditional management system of crop production closer to the more modern form of sustainable agriculture.

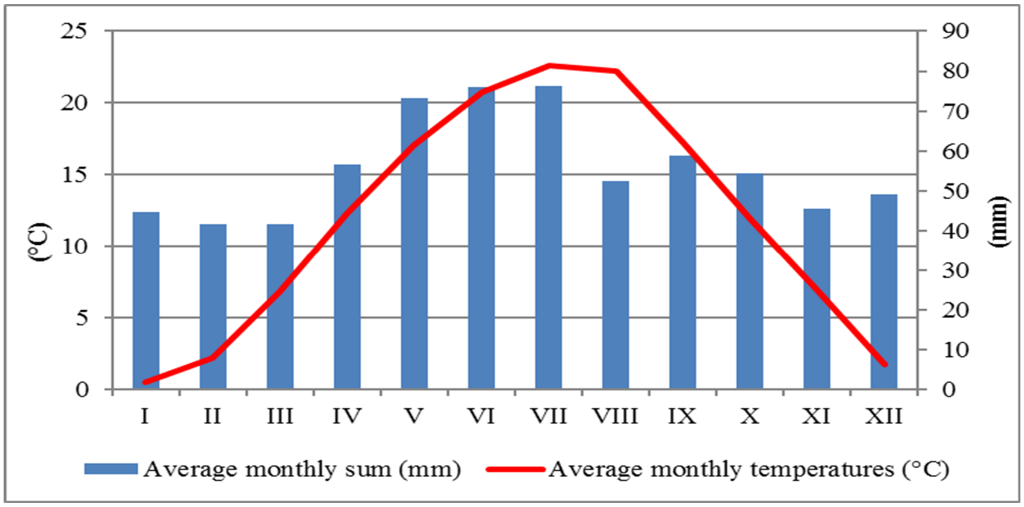


Figure 2. Multi-year average (1990-2020) of average monthly temperatures and total monthly precipitation for Veliko Gradište (44° 45′ 14.4″ N, 21° 30′ 29.4″ E, altitude 68 m)

Results

Soil analysis

Soil is one of the most important natural resources whose main function is to provide water and nutrients to the plants that grow in it. It presents the central basis for all agricultural activities. Since humanity began agriculture, land degradation has been the greatest threat to land productivity. One third of the world's soil is moderately to highly degraded (Foley *et al*., 2005; Utuk and Daniel, 2015; Lal, 2015; Delgado-Bakuerizo *et al.,* 2018). This depletion may result from improper soil management and overly intensive farming (Amara *et al*., 2017). Crop farming is an extractive process in which growing plants absorb nutrients from the soil. Once the plants are harvested, the nutrients also go with them and leave the soil system nutrient deficient. This process is done incessantly without providing enough rest to the land which causes nutrient depletion in soil (Chaudhari *et al*., 2021). Widespread deficiencies of N, P, K, S, Zn, Fe, B etc. are so intense that visual symptoms are very often observed in major crops (Singh and Mishra, 2012). In intensively cultivated soils are being depleted with available nutrients especially secondary and micronutrients. Longer use of physiologically acidic fertilizers can acidify the soil solution (Huang *et al*., 2023). Stokić *et al*. (2022) in their research state that more than half of the meadow soils (68.21%) were in the group of acidic (pH 4.5-5.5) and strongly acidic soils (pH 4.5). These acidity groups include 58.84% of field soils, 56.25% of orchards and 35.79% of vineyards (Stokić *et al.,* 2022). For that reason, evaluation of fertility status of the soils of an area or a region is one of the most important aspects in the context of sustainable agriculture (Singh and Mishra, 2012). Systematic control of soil fertility is a measure aimed at monitoring changes in various parameters of soil fertility, i.e. nutrient content. The basic parameters of soil fertility include the acidity of the soil solution, substitutional acidity, i.e. acidity of the solid phase, content of carbonate, humus, total nitrogen and readily available forms of phosphorus and potassium (Stokić *et al*., 2022)

The majority of agricultural lands in intensive production are faced with the depletion of the reserve of soil organic matter. Severe loss of soil organic matter can cause degradation and reduce soil functionality, its capacity to provide essential ecosystem services and soil health (Lal, 2020). Therefore, restoration of soil organic matter content in agroecosystems soils can reverse degradation trends, improve ecosystem services (Banwart *et al*. 2015) and advance sustainable development goals (Lal *et al.,* 2018). Most soils contain less than 2% organic matter, but fertile soil should have between 2 and 8%. Significant amounts of the organic matter in sandy, acid-leached soils is in the form of fulvic acids and plant debris. In neutral and alkaline soils a large percentage of the organic matter is present in the form of humic acids and humin (Pettit, 2004). An increase in soil organic matter content can partially replace the use of chemical fertilizers and additional irrigation, while restoring the environment (Lal, 2020). According to Lal (2020), there are two key properties affected by soil organic matter content: it increases plant available water capacity (PAWC) and increases the availability of essential nutrients to plants, especially nitrogen (N) (Lal, 2020). Sustainable management of soil organic matter content has benefits in terms of saving/replacing N and other fertilizers (Johnston *et al.,* 2008; Schjønning *et al.,* 2018; Hijbeek *et al.,* 2018), together with saving irrigation water (Williams *et al.* 2016; Ankenbauer and Loheide II, 2017).

The results of this study indicate that the average content of humus in the tested samples decreased by 0.53% in a short period of time of only five years (Tables 1). Observing the examined soils according to humus content, it is possible to see a decrease in the number of samples from the high humus class from 7.68% to 0.63%, medium humus from 58.60% to 45.38% and an increase in the proportion of low humus from 33.60% to 53.98%. Johnston *et al.* (2008) noted that the loss of reserve organic matter content can reduce the content of essential nutrients (nitrogen [N], phosphorus [P] and sulfur [S]) Severe loss can also lead to the release of some toxic elements due to the decrease in chelation and adsorption capacity of the soil (Griffiths *et al.,* 2005; Gregory *et al.,* 2015; Lehmann *et al.*, 2017). The range of adequate organic matter reserve levels can differ between different soil types, climates and farming systems.

Table 1. Average values, absolute minimum, absolute maximum, deviation standard and coefficient of variance for surveyed soil fertility elements

Elements of fertility	Hummus (%)	N (%)	P_2O_5 (mg 100 g^{-1})	K_2O (mg 100 g^{-1})
2017				
$\overline{X}$	3.53	0.18	14.98	22.39
MIN	1.87	0.09	1.03	5.13
MAX	19.79	0.99	40.00	40.00
6	1.05	0.05	19.66	6.90
CV	0.30	0.30	1.31	0.31
2022				
$\overline{X}$	3.01	0.15	13.60	26.20
MIN	1.31	0.07	2.32	5.52
MAX	5.52	0.30	40.00	40.00
6	0.68	0.03	10.17	8.99
CV	0.23	0.23	0.75	0.34

For proper plant growth and development, nitrogen (N) is a crucial macronutrient (Triptahi *et al.,* 2022). Nitrogen is essential in the formation of protein, and protein makes up the tissues of most living things (IFA, 2022). Most plants absorb nitrogen from the soil in mineral form (i.e. NO^{3-} and NH^{4+}). Most of the nitrogen in the soil is in the form of organic compounds (humus 90-95%), which can be used as a source of nitrogen for plants only after the mineralization process. Lack of nitrogen leads to reduced growth and development of plants, reduced yield and product quality, as a result of which nitrogenous mineral nutrition is an imperative in fertilization technology (Triptahi *et al.,* 2022, Stikić and Jovanović, 2017). According to the results there was a 0.03% decrease in the average nitrogen content of soil in 2022 as compared to 2017. Additionally, there were no samples in the very high nitrogen content in 2022 compared to 2.44% in 2017 (Figure 3). The number of samples in the high nitrogen content class in 2022 was also reduced by 16.8%. In contrast, there was an increase in the number of samples in the medium nitrogen content class by 12.3% (from

74.31 in 2017 to 86.61% in 2022). This is directly related to the loss of organic matter, which unavoidably causes to an increase in degradation processes in the soil.

With the intensification of agricultural production, phosphorus (P) is gaining importance as a non-renewable resource (Cordell *et al.,* 2009; Gilbert, 2009). The basic feature of phosphorus is its low availability due to slow diffusion and high fixation in the soil, which can be the main limiting factor for plant growth. Understanding the link between the soil, rhizosphere, and plants in terms of phosphorus transformation and mobilization as well as plant responses to phosphorus lack has advanced significantly in the past two decades (Shen *et al.,* 2011). Including the process of photosynthesis, phosphorus supports the ability of plants to use and store energy (IFA, 2022). Also, has significance because it helps plants survive cold temperatures and diseases, it affects yield amount and quality, and a deficiency results in chlorosis and stunted plant growth (Stikić and Jovanović, 2017). Phosphorus also plays an important role because many metabolic processes cannot be realized without its compounds and plants cannot complete their cycle of growth and development (Gupta *et al.,* 2017; Stikić and Jovanović, 2017). The average content of phosphorus in the tests conducted in 2017 was 14.98 mg 100 g^{-1}, while the average value in 2022 was 13.60, which is 1.38 mg 100 g^{-1} less than in 2017 (Figure 3). Despite of the average decrease in phosphorus content in samples in 2022, a positive trend is observed in the decrease in the number of samples in the low phosphorus content class (from 60.81% in 2017 to 49.54% in 2022) and the increase in the number of samples in the medium phosphorus content class (from 18.25% in 2017 to 31.15% in 2022). Regardless of the average decrease in phosphorus content in samples in 2022, a positive trend is observed in the decrease in the number of samples in the low phosphorus content class (from 60.81% in 2017 to 49.54% in 2022) and the increase in the number of samples in the medium phosphorus content class (from 18.25% in 2017 to 31.15% in 2022). The number of samples in the high phosphorus content class decreased slightly by 0.64%, from 19.95% to 19.31%. Positive trends in the content of phosphorus in the soil of the Braničevo district are the result of the planned monitoring of soil fertility, which was financed by the Ministry of Agriculture of the Republic of Serbia and the local self-government. Individual agricultural producers followed the recommendations for the application of mineral fertilizers in accordance with the obtained results of soil fertility and cultivated crops.

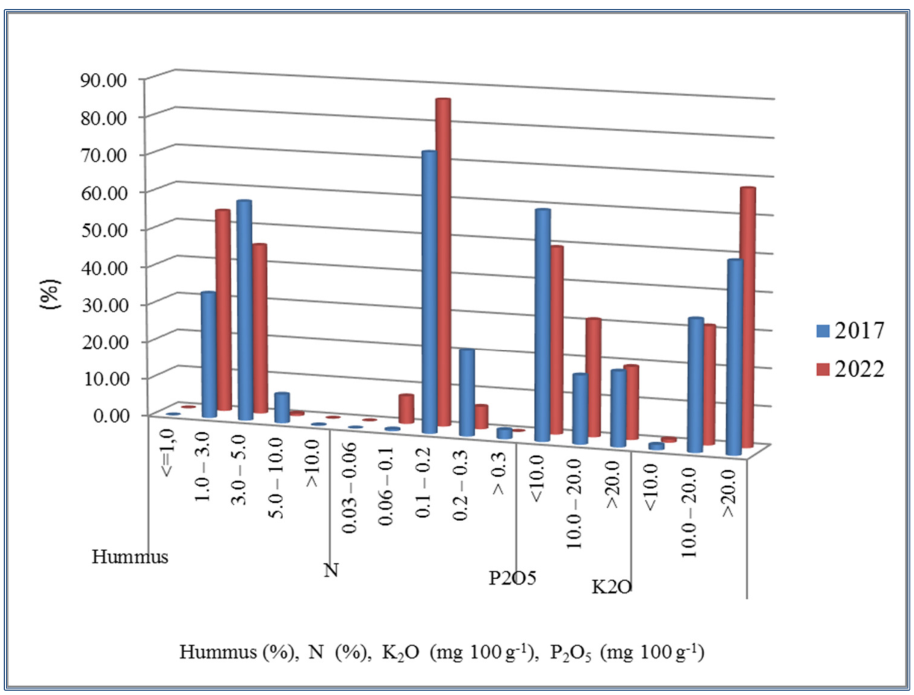


Figure 3. Grouping of soils according to the values of examined fertility elements

Of the major nutrients, potassium (K) is usually the most abundant in soil and has a major impact on plant growth and yield. The availability of K varies depending on soil properties, i.e. humidity, aeration, temperature, processing system (Mouhamad *et al.,* 2016). Although it is not a constitutional element and does not enter into the composition of organic compounds, potassium activates the work of a large number of enzymes (about 70) and manages a large number of physiological processes in plants. Potassium helps plants resist disease and has an important role in increasing crop yields and quality. Additionally, potassium protects the plant in cold or dry conditions, strengthening its root system (IFA, 2022). The soils of the Braničevo district are rich in potassium content, which is the result of the richness of the parent substrate with this element. Inadequate application of mineral fertilizers, which does not take into account the presence of potassium in the soil, led to a significant increase in the content of this element in a five-year period. The number of samples in the high K content class increased from 50.69% in 2017 to 67.72% in 2022 (Figure 3). However, high content of K in the soil can have a negative effect on the availability of N, magnesium (Mg), calcium (Ca) and some microelements such as boron (B) and molybdenum (Mo), due to their mutual antagonistic effect (Đukić *et al.,* 1998).

Based on the results, the main soil problem in Braničevo district is the lack of organic matter. The lack of organic matter leads to a lack of N, reduced activity of beneficial microorganisms, reduction of adsorptive capacity of the soil, reduced buffering capacity of the soil, destruction of structural aggregates of the soil, reduction of water and air capacity and erosion of the soil due to loss of structure. All these processes inevitably lead to further soil degradation.

Discussion

Improvement strategies based on the analysis of the fertility parameters

Soil degradation trends can be reversed by conversion to a restorative land use and adoption of sustainable management practices (Lal, 2015; Utuk and Daniel, 2015; Bastan *et al.,* 2017; Lakić *et al.*, 2020; Popović *et al.*, 2020; 2021; 2022; Burić *et al.*, 2023; Markoski *et al.,* 2023; Simić *et al.*, 2023). Sustainable agriculture includes, inter alia, soil and water conservation; crop rotation; diversified crop and livestock farming; integrated pest management practices; limited use of synthetic herbicides, pesticides, and fertilizers; low input agriculture; and organic farming (James, 2006; Stevanović *et al.*, 2022). The sustainability of agriculture can be increased and by integrating crop and livestock production, using hedgerows, cover crops and water tanks to attract populations of beneficial insects, bats and birds, favoring crop rotation and intercropping over monoculture. Planting part of the land in trees and other perennial crops, long-term rotations, managing pastures to support a diverse selection of forage plants, planting off-season cover crops (Earles and Williams, 2005), using natural organic pesticides (neem oil, lavender oil, cottonseed oil, garlic oil, peppermint oil, etc.) (Mfarre and Rara, 2019) and solid waste management (Chev *et al.,* 2019) are ways in which we can manage agricultural land and at the same time enable long-term sustainability of natural resources. For sustainable agricultural management and prevention of soil degradation processes, the dynamic nature of soil is of primary importance, which is a direct manifestation of soil microbes (Tscharntke *et al.,* 2012; Popović, 2015; Paustian *et al.,* 2016; Alfoeldi *et al.,* 2002; Gouda *et al.,* 2018).

Plant nutrients can be provided by mineral, organic or organo-mineral fixation or the weathering of soil minerals (Milunović *et al.*, 2022; Lakić *et al.*, 2022; Kosev *et al.*, 2022; Bakmaz *et al.*, 2023; Vasileva *et al.*, 2023). The fertilizer industry produces mineral or manufactured fertilizers which content nitrogen, phosphorous and potassium, (or NPK), which are the primary nutrients in plant nutrition and also in manufactured fertilizers. Plants absorb more nitrogen than any other element. A wide range of products supplying one or more essential mineral nutrients to plants are available to farmers today. Growers can also combine fertilizer applications with plant biostimulants – a tool for sustainable agriculture (IFA, 2022).

According to the IFA (2020) *plant biostimulants* are products that contain substances and/or micro-organisms whose function when applied to plants or the rhizosphere is to stimulate natural processes independently of the product's nutrient content to enhance/benefit nutrient uptake, nutrient efficiency, and tolerance to abiotic stress, yield, and crop quality. Therefore, plant biostimulants are an important tool for sustainable agriculture. They are complementary to mineral fertilizers by improving availability, assimilation, translocation, and use of certain plant nutrients.

Examples of plant biostimulant components*:*

- *Humic substances,* which include humic and fulvic acids, are among the most common organic substances, making up much of the organic matter in the world's soils and play a vital role in soil fertility and plant nutrition. They are formed in the soil as byproducts of the decomposition and microbial metabolism of plant and animal residues (Pettit, 2004; IFA, 2020). The nutritional quality of harvested food and fodder is superior if plants are grown on soils containing humus. In addition, plants grown on such soils are less susceptible to stress, are healthier and give higher yields (Pettit, 2004).
- *Plants and seaweed extracts* contain some compounds with biostimulant effects that can stimulate the growth of roots and shoots, flowering and fruit development, positively influence the development of cells and tissues, providing increased access and use of available plant nutrients (IFA, 2020).
- *Peptides and amino acids* as important molecules in plant mechanisms because they are the basis of proteins. Some bioactive peptides are able to modulate important physiological functions of plants (IFA, 2020).
- It has been shown that *microbial biostimulant products (fungi and bacteria)* enhance plant growth and increase availability and uptake of nutrients, help plants tolerate abiotic stress, improve crop quality and general soil condition. In the plant nutrient space, the most common biological products include nitrogen-fixing bacteria, phosphorus solubilizing bacteria, and mycorrhizal fungi (IFA, 2020). About 80 to 90% of plant species are colonized by arbuscular mycorrhizal fungi (AMF) which, in this symbiotic relationship, facilitate plant uptake of mineral nutrients (as first phosphate and nitrogen) and draw organic nutrients from the plant (Jiang *et al.,* 2017,). Plants with arbuscular mycorrhiza through the symbiosis, among other benefits, receive protection from pathogens (Veresoglou and Rillig, 2012; Madawala, 2021) weed control (Veiga *et al.,* 2011; Božović *et al.,* 2022) and better enduring adverse conditions (Lehmann *et al.*, 2017; Madawala, 2021).
- *Inorganic compounds* that include some chemical elements that promote plant growth and may be essential to particular taxa (IFA, 2020).

Other possibilities for improving soil quality and fertility:

- *Organic fertilizers* – their use in agriculture is significant, primarily because they release nutrients slowly and avoid giving too much nitrogen, phosphorus or potassium. In addition, they help create a good environment for beneficial soil organisms, such as earthworms, which improve soil structure by incorporating organic matter into the topsoil while creating drainage and air tunnels (Olle and Williams, 2021).
- *Biochars* are carbon-rich materials that could sequester carbon in soils improve soil properties (Glaser *et al.,* 2014) findings demonstrate that biochar-fertilizer combinations have a better performance than pure fertilizers, in terms of yield and plant nutrition;
- *Natural pesticides* are natural materials (for example - vinegar, mint or red chili pepper.) work as killers or repellents to reduce or destroy pests and unwanted organisms that affect human health, agricultural crops and environment as well. Unlike synthetic pesticides, organic pesticides help to achieve the environmental sustainability and more easily decompose (Mfarre and Rara, 2019).

- Use of *Plant growth-promoting rhizobacteria* (PGPR). Plant growth promoters function as a coevolution between plants and microbes showing antagonistic and synergistic interactions with microorganisms and soil. Soil revitalization using plant growth promoters can be achieved by bio-fertilization, root growth enhancement, rhizoremediation, disease resistance, etc. (Gouda *et al.,* 2018.)
- Using *legumes in cropping systems* increase biological nitrogen fixation. This method also reduces energy costs and improves biodiversity and soil physical conditions (Peix *et al*. 2015). Although legumes are important crops for human and livestock food, their cultivation remains below that of other crops, such as cereals. This is the result of the replacement of traditional agricultural systems by industrialized systems, mainly based on cereals, which rely heavily on fossil fuels, and as a result, the area of most legumes (pea, fava bean, vetches and lupine) in temperate conditions has declined across the world in the last 50 years (Rubiales and Mikić, 2015).

Conclusions

One of the biggest problems facing modern agriculture is soil degradation. In degraded land, there is a noticeable lack of nutrients, which inevitably leads to a decrease in crop yield and quality. Global food production will double by 2050, therefore sustainable solutions are needed to improve agriculture in order to increase yields, preserve land resources and environmental resources in a way that would guarantee the satisfaction of current human needs, as well as the provision of future generations. For the desired long-term quality of the soil, balanced plant nutrition is necessary, i.e. a balanced supply of nutrients in the soil. Some of the proposals to achieve this while promoting sustainability are:

- Reduction of all types of erosion;
- Installation of an isolation belt, trees and bushes as a natural shield;
- increasing organic matter in the soil with harvest residues and green manure;
- encouraging the work of microorganisms that will transform organic matter into a form available to plants;
- Intensification of crop rotation and diversification of crops;
- Planting clover, legumes and other crops that fix nitrogen in the soil;
- Reduction of intensive tillage and introduction of integral or conservation tillage;
- Grazing, optimal intensity;
- Production planning so that the biological potential of soil, water and other resources can be regenerated.

Long-term soil management by applying the proposed measures contributes to restoring natural soil fertility and reducing erosion, i.e. increasing crop productivity while minimizing the potential impact on land resources and the environment, which are the basic principles of sustainable agriculture.

Authors' Contributions

All authors have participated in this research. Conceptualization: VP, VS, ZŽ, AS and DS; Data curation: VS; Resources: VS; Software: AS and VP; Formal analysis: VP; AS; ZŽ and DS; Funding acquisition; TS and VS; Written – original draft: VP, VS, ZŽ, AS, DS, TS, VS and JB; Writing - review and editing: VP and VS; Supervised: VP, TS, JB and AS; Validation: JB and TS; Visualization: AS and VP; Project administration: ZŽ; AS and VP. All authors have read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This study was supported by the Environmental issues, bioeconomy and analysis of possibilities for production of health safe food in AP Vojvodina. The project is included in the Work Plan of Matica Srpska (2021-2024). Funding from the Ministry of Education, Science and Technological Development of the Republic of Serbia. Research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant numbers: 451-03-65/2024-03/200032) and APV Project (2022-2023): Analysis of nitrogen application on maize productivity of different FAO maturity group using classical and modern technology; and bilateral project Republic of Serbia and Republic of Croatia, 2023-2026: Alternative and fodder plants as a source of protein and functional food.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Alam A (2014). Soil degradation: a challenge to sustainable agriculture. International Journal of Scientific Research in Agricultural Sciences 1(4):50-55. *http://dx.doi.org/10.12983/ijsras-2014-p0050-0055*

Alfoeldi T, Fliessbach A, Geir U, Kilcher L, Niggli U, Pfifner L, Stolze M. Willer H (2002). Organic Agriculture and the Environment, in El-Hage Scialabba, Nadia and Caroline, Hattam, Eds. Organic agriculture, environment and food security, chapter 2. Environment and Natural Resources Series 4. Food and Agriculture Organisation of the United Nation (FAO).

Amara DMK, Patil PL, Kamara AM, Daniel H, Saidu DH (2017). Assessment of soil fertility status using nutrient index approach. Academia Journal of Agricultura Research 5(2):28-38.

Ankenbauer KJ, Loheide SP (2017). The effects of soil organic matter on soil water retention and plant water use in a meadow of the Sierra Nevada, CA. Hidrological Processes 31(4):891-901. *https://doi.org/10.1002/hyp.11070*

Bakmaz O., Bjelica B., Popović D (2023). Implementation of internal control mechanisms and the possibility of improving financial management in large and medium-sized agricultural enterprises. Agriculture and Forestry 69(2):35-44. *https://doi.org/10.17707/AgricultForest.69.2.03*

Burić M, Popović V, Ljubičić N, Filipović V, Stevanović P, Ugrenović V, Rajičić V (2023). Productivity of black oats - *Avena strigosa* Schreb. on chernozem and its significance as food and medicine (Produktivnost crnog ovsa - *Avena strigosa* SCHREB. na černozemu i značaj u ishrani - In Serbian). Selekcija i semenarstvo 29:21-32. *https://doi.org/10.5937/SelSem2301021B*

Banwart SA, Black H, Cai Z, Cong CZ, Gicheru PT, Joosten H, Victoria RL, Milne E, Noellemeyer E, Pascual U (2015). The global challenge for soil carbon. In: Banwart SA, Noellemeyer E, Milne E (Eds). Soil Carbon: Science, Management and Policy for Multiple Benefits. Wallingford: CABI, pp 1-9. *https://doi.org/10.1079/9781780645322.0001*

Bastan M, Khorshid-Doust RR., Sisi SD, Ahmadvand A (2017). Sustainable development of agriculture: A system dynamics model. Kybernetes 1-20. *https://doi.org/10.1108/K-01-2017-0003*

Bojovic R, Popović V, Popović D, Radojević V, Jovović Z, Spalević V, Ljubičić N (2022). Economical Crop Production and Management of Sugar Beet in Serbia and Montenegro. Chapter 3. In: Misra V, Srivastava S, Mall AK (Eds). Sugar Beet Cultivation, Management and Processing. Book, Springer, pp 1-1025.

Božović D, Popović D, Popović V, Živanović T, Ljubičić N, Ćosić M, Spahić A, Simić D, Filipović V (2022). Economical productivity of maize genotypes under different herbicides application in two contrasting climatic conditions. Sustainability 14:5629. *https://doi.org/10.3390/5629*

Chaudhari S, Upadhyay A, Kulshreshtha S (2021). Influence of organic amendments on soil properties, microflora and plant growth. In: Sustainable Agriculture Reviews 52:147-191. *https://doi.org/10.1007/978-3-030-73245-5_*

Chen H, Yada R (2011): Nanotechnologies in agriculture: new tools for sustainable development. Trends in Food Science & Technology 22(11):585-594. *https://doi.org/10.1016/j.tifs.2011.09.004*

Chew KW, Chia SR, Yen HW, Nomanbhay S, Ho YC, Show PL (2019). Transformation of biomass waste into sustainable organic fertilizers. Sustainability 11(8):2266. *https://doi.org/10.3390/su11082266*

Cordell D, Drangert JO, White S (2009). The story of phosphorus: global food security and food for thought. Global Environmental Change 19(2):292-305. *https://doi.org/10.1016/j.gloenvcha.2008.10.009*

Crews TE, Carton W, Olsson L (2018). Is the future of agriculture perennial? Imperatives and opportunities to reinvent agriculture by shifting from annual monocultures to perennial polycultures. Global Sustainability 1. *https://doi.org/10.1017/sus.2018.11*

Delgado-Baquerizo M, Oliverio M, Brewer E, Benavent-González A, Eldridge J, Bardgett D, Maestre F, Singh B, Fierer N (2018). A global atlas of the dominant bacteria found in soil. Science 359(6373):320-325. *https://doi.org/10.1126/science.aap9516*

Đukić D, Stojanović J, Đurić M (1998). Fiziologija biljaka [Physiology of plants]. Second edition, University of Kragujevac, Faculty of Agronomy Čačak (Serbian), pp 91-120.

Earles R, Williams P (2005). Sustainable agriculture an introduction. ATTRA.

FAO (2020). World food and agriculture—statistical yearbook 2020. World Food and Agriculture-Statistical Yearbook. *https://www.fao.org/*

FAO (2022). Food and Agriculture Organization of the United Nations. FAO's Statistical Yearbook for 2022 goes live. *https:// www.fao.org /*

Foley A, DeFries R, Asner P, Barford C, Bonan G, Carpenter R, … Snyder K (2005). Global consequences of land use. Science 309(5734):570-574. *http://doi.org/10.1126/science,111172*

Foley A, Ramankutty N, Brauman K, Cassidy E, Gerber J, Johnston M, … Zaks D (2011). Solutions for a cultivated planet. Nature 478(7369):337-342. *http://doi.org/10.1038/nature10452*

Gilbert N (2009). Environment: the disappearing nutrient. Nature 461:716-718. *https://doi.org/10.1038/461716a*

Glaser B, Wiedner K, Seelig S, Schmidt HP, Gerber H (2015). Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. Agronomy for Sustainable Development 35(2):667-678. *http://doi.org/10.1007/s13593-014-0251-4*

Gouda S, Kerry RG, Das G, Paramithiotis S, Shin HS, Patra K (2018). Revitalization of plant growth promoting rhizobacteria for sustainable development in agriculture. Microbiological Research 206:131-140. *https://doi.org/10.1016/j.micres.2017.08.016*

Gregory AS, Ritz K, McGrath SP, Quinton JN, Goulding KW, Jones RJ, Harris JA, Bol R, Wallace P, Pilgrim ES, Whitmore AP (2015). A review of the impacts of degradation threats on soil properties in the UK. Soil Use and Management 31(S1):1-15. *https://doi.org/10.1111/sum.12212*

Griffiths B, Hallett P, Kuan H, Pitkin Y, Aitken M (2005). Biological and physical resilience of soil amended with heavy metal-contaminated sludge. European Journal of Soil Science 56(2005):197-206. *https://doi.org/10.1111/j.1365-2389.2004.00667.x*

Gupta N, Debnath S, Sharma S, Sharma P, Purohit J (2017). Role of nutrients in controlling the plant diseases in sustainable agriculture. In: Vijay SM, Jaideep KB, Pankaj KM, Arunava P (Eds). Agriculturally Important Microbes for Sustainable Agriculture. ICAR-Vivekananda Institute of Hill Agriculture, Almora, Uttarakhand, India, pp 217-262. *https://doi.org/10.1007/978-981-10-5343-6_8*

Hijbeek R, van Ittersum MK, Berge H, Whitmore A (2018). Evidence review indicates a re-think on the impact of organic inputs and soil organic matter on crop yield. In: 2018 IFS Agronomic Conference. Cambridge, UK: International Fertilizer Society.

Horrigan L, Lawrence RS, Walker P (2002). How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environmental Health Perspectives 110(5):445-456. *https://doi.org/10.1289/ehp.02110445*

Huang K, Li M, Li R, Rasul F, Shahzad S, Wu C, Shao J, Huang G, Li R, Almari S, Hashem M, Aamer M (2023). Soil acidification and salinity: the importance of biochar application to agricultural soils. Frontiers in Plant Science 14:1206820. *https://doi.org/10.3389/fpls.2023.1206820*

IFA (2020). International fertilizer association. *https://www.fertilizer.org/*

IFA (2022). International fertilizer association. *https://www.fertilizer.org/*

James HS (2006). Sustainable agriculture and free market economics: Finding common ground in Adam Smith. Agriculture and Human Values 23(4):427-438. *http://doi.org/10.1007/s10460-006-9020-6*

Jiang Y, Wang W, Xie Q, Liu N, Liu L, Wang D, Zhang X, Yang C, Chen X, Tang D, Wang E (2017). Plants transfer lipids to sustain colonization by mutualistic mycorrhizal and parasitic fungi. Science 356(6343):1172-1175. *http://doi.org/10.1126/science.aam9970*

Jie C, Jing-Zhang C, Man-Zhi T, Zi-tong G (2002). Soil degradation: a global problem endangering sustainable development. Journal of Geographical Sciences 12:243-252. *https://doi.org/10.1007/BF02837480*

Johnston A, Poulton P, Coleman K (2008). Chapter 1. Soil organic matter: Its importance in sustainable agriculture and carbon dioxide fluxes. Advances in Agronomy 101:1-57. *https://doi.org/10.1016/S0065-2113(08)00801-8*

Kosev V, Vasileva V, Popović V, Pešić V, Nožinić M (2022). Ecological-genetic model in grass pea (*Lathyrus sativus* L.) breeding. Genetika 54(3):1385-1397. *https://doi.org/10.2298/GENSR2203385K*

Lakić Ž, Popović V, Ćosić M, Antić M (2022). Genotypes variation of *Medicago sativa* (L.) seed yield components in acid soil under conditions of cross–fertilization. Genetika 54(1):1-14. *https://doi.org/10.2298/GENSR2201001L*

Lal R (2015). Restoring soil quality to mitigate soil degradation. Sustainability *7*(5):5875-5895. *http://doi.org/10.3390/su7055875*

Lal R (2020). Soil organic matter content and crop yield. Journal of Soil and Water Conservation 75(2):27A-32A. *http://doi.org/10.2489/jswc.75.2.27A*

Lal R, Horn R, Kosaki T (2018). Soil and Sustainable Development Goals. Stuttgart: Catena-Scheizerbart.

Lehmann A, Zheng W, Rillig MC (2017): Soil biota contributions to soil aggregation. Nature Ecology & Evolution 1(12):1828-1835. *http://doi.org/10.1038/s41559-017-0344-y*

Madawala H (2021). Arbuscular mycorrhizal fungi as biofertilizers: Current trends, challenges, and future prospects. Biofertilizers 83-93. *https://doi.org/10.1016/B978-0-12-821667-5.00029-4*

Markoski M, Mitkova T, Tanaskovik V, Luiz Mincato R, Petek M, Popović V (2023): Soil distribution in Pčinja river basin, North Macedonia and its importance for agricultural production. Agriculture and Forestry 69(1):113-126. *https://doi.org/10.17707/AgricultForest.69.1.10*

Mfarre MFB, Rara FM (2019). Competitive, sustainable natural pesticides. Acta Ecologica Sinica 39(2):145-151. *https://doi.org/10.1016/j.chnaes.2018.08.005*

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 54(2):887-905. *https://doi.org/10.2298/GENSR2202887M*

Mouhamad R, Alsaede A, Iqbal M (2016). Behavior of potassium in soil: a mini review. Chemistry International 2(1):58-69. *http://doi.org/10.13140/rg.2.1.4830.7041*

Mrvić V, Saljnikov E, Jaramaz S (2016). WRB classification system and relationship with the soil classification of Serbia. Soil and Plant 65(2):1-7.

Olle M, Williams IH (2021). Organic cultivation of vegetables. In: Sustainable Agriculture Reviews 52:1-19. *https://doi.org/10.1007/978-3-030-73245-5_1*

Paoletti MG, Gomiero T, Pimentel D (2011). Introduction to the special issue: towards a more sustainable agriculture. Critical Reviews in Plant Sciences 30(12):2-5. *http://doi.org/10.1080/07352689.2011.553148*

Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smith P (2016). Climate-smart soils. Nature 532(7597):49-57. *https://doi.org/10.1038/nature17174*

Peix A, Ramírez-Bahena MH, Velázquez E, Bedmar EJ (2015). Bacterial associations with legumes. Critical Reviews in Plant Sciences 34(1-3):17-42. *https://doi.org/10.1080/07352689.2014.897899*

Pettit RE (2004). Organic matter, humus, humate, humic acid, fulvic acid and humin: their importance in soil fertility and plant health. CTI Research 10:1-7.

Popović D, Rajičić V, Popović V, Burić M, Filipović V, Gantner V, Lakić Ž, Božović D (2022). Economically significant production of *Secale cereale* L. as functional food. Agriculture and Forestry 68(3):133-145. *https://doi.org/10.17707/AgricultForest.68.3.11*

Popović V (2015). The concept, classification and importance of biological resources in agriculture. In: Milovanovic J, Đorđević S (Eds). Conservation and enhancement of biological resources in the service of eco-remediation. Monograph. Belgrade. Pp 1-407; 29-51; 1-407.

Popovic V, Ljubičić N, Kostić M, Radulović M, Blagojević D, Ugrenovic V, Popovic D, Ivosevic B (2020). Genotype x environment interaction for wheat yield traits suitable for selection in different seed priming conditions. Plants 9(12):1804. *https://doi.org/10.3390/plants9121804*

Popović V, Šarčević-Todosijević Lj, Petrović B, Ignjatov M, Popović BD, Vukomanović P, Milošević D, Filipović V (2021). Economic justification application of medicinal plants in cosmetic and pharmacy for the drugs discovery. Chapter 3. Emerald M (Ed). An Introduction to Medicinal Herbs. NOVA Science publishers, USA, pp 63-106. *https://doi.org/10.52305/TKAL3430*

Rubiales D, Mikić A (2015). Introduction: legumes in sustainable agriculture. Critical Reviews in Plant Sciences 34:2-3. *https://doi.org/10.1080/07352689.2014.897896*

Schjønning P, Jensen J, Bruun S, Jensen L, Christensen B, Munkholm L, Oelofse M, Baby S, Knudsen L (2018). The role of soil organic matter for maintaining crop yields: Evidence for a renewed conceptual basis. Advances in Agronomy 150:35-79 *https://doi.org/10.1016/bs.agron.2018.03.001*

Shen J, Yuan L, Zhang J, Li H, Bai Z, Chen X, Zhang W, Zhang F (2011). Phosphorus dynamics: from soil to plant. Plant Physiology 156(3):997-1005. *https://doi.org/10.1104/pp.111.175232*

Simić D, Janković S, Popović V, Stanković S, Rahović D, 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. *https://doi.org/10.17707/AgricultForest.69.1.03*

Singh RP, Mishra SK (2012). Available macronutrients (N, P, K and S) in the soils of Chiraigaon block of district Varansi (U.P.) in relation to soil characteristics. Indian Journal of Scientific Research 3(1):97-100.

Średnicka-Tober D, Obiedzińska A, Kazimierczak R, Rembiałkowska E (2016). Environmental impact of organic vs. Conventional agriculture-a review. Journal of Research and Applications in Agricultural Engineering 61(4):204-211.

Statistical Office of the Republic of Serbia (2012) Census of Agriculture. *https://www.stat.gov.rs/sr-latn/oblasti/poljoprivreda-sumarstvo-i-ribarstvo/popis-poljoprivre*

Stevanović A, Šarčević-Todosijević L, Bošković J, Mladenović J, Pešić V, Popović V, Ristić V (2022). Microbiological fertilizers in the function of organic production and health safe food. In: Book of Abstracts, IRASA International Scientific Conference Science, Education, Technology and Innovation (SETI IV 2022), 30 September-1 October 2022, Belgrade, pp 27-27.

Stikić S, Jovanović R (2017). Physiology of plants. Book, Second edition, University of Belgrade, Faculty of Agriculture, Belgrade. (Serbian). ISBN: 978-86-6021-088-5.

Stokić M, Živković Z, Stojićević D, Saulić M, Sekulić T, Stupar V (2022). Substitution Acidity, Phosphorus and Potassium Content in the Land of the Braničevo District in the Republic of Serbia. XIII International Scientific Agriculture Symposium "Agrosym 2022", Jahorina, October 06–09, pp 841-846.

Tripathi R, Tewari R, Singh K P, Keswani C, Minkina T, Srivastava A K, De Corato U, Sansinenea E (2022). Plant mineral nutrition and disease resistance: A significant linkage for sustainable crop protection. Frontiers in Plant Science 3116. *https://doi.org/10.3389/fpls.2022.883970*

Tscharntke T, Clough Y, Wanger TC, Jackson L, Motzke I, Perfecto, Vandermeer J, Whitbread A (2012). Global food security, biodiversity conservation and the future of agricultural intensification. Biological Conservation 151(1):53-59. *https://doi.org/10.1016/j.biocon.2012.01.068*

Utuk I, Daniel E (2015). Land degradation: a threat to food security: a global assessment. Environmental Earth Sciences 5(8):13-21.

Vasileva V, Georgiev G, Popović V (2023). Genotypic specificity of soybean [*Glycine max* (L.) Merr.] plastid pigments content under sowing date and interrow spacing. Genetika 55:455-471. *https://doi.org/10.2298/GENSR2302455V*

Veiga R, Jansa J, Frossard E, van der Heijden MG (2011). Can arbuscular mycorrhizal fungi reduce the growth of agricultural weeds? PloS One 6(12):e27825. *https://doi.org/10.1371/journal.pone.0027825*

Veresoglou S, Rillig M (2012). Suppression of fungal and nematode plant pathogens through arbuscular mycorrhizal fungi. Biology Letters 8(2):214-217. *https://doi.org/10.1098/rsbl.2011.0874*

Williams A, Hunter M, Kammerer M, Kane D, Jordan N, Mortensen D, Smith R, Snapp S, Davis A (2016). Soil water holding capacity mitigates downside risk and volatility in US rainfed maize: Time to invest in soil organic matter? PLOS One 11(8):e0160974. *https://doi.org/10.1371/journal.pone.0160974*

Živković Z, Saulić M, Stojićević D, Jevtić Đorović M, Stupar V (2022). Organic agriculture: potential of the future. 29th International Conference Ecological Truth & Environmental research, 21-24 June, Sokobanja, Serbia, EcoTer' 2022 Proceedings, 413-418.