UDC 631.4:631,5:631,8: 608: 633.1
DOI https://doi.org/10.32782/2226-0099.2024.137.28

EFFECTS OF DIFFERENT FERTILIZATION SYSTEMS ON BUCKWHEAT YIELD IN THE CONDITIONS OF NORTHERN STEPPE OF UKRAINE

Sokolovska I.M. *– Ph.D., Associate Professor,*
Associate Professor at the Department of Crop Production and Agricultural Engineering,
Kherson State Agrarian and Economic University
Mashchenko Yu.V. *– Ph.D.,*
Head of the Scientific and Technological Department for Soil Fertility Conservation,
Institute of Agriculture of the Steppe of the National Academy of Agrarian Sciences

Soil fertility plays a significant role in plant development and has a crucial influence on yield levels. Initially fertile fields are a major advantage for farmers, but they need to be maintained properly to avoid soil depletion. Agricultural production today is focused on the direction of agricultural ecology, high quality of agricultural products, transitioning to environmentally safe technologies, and abandoning harmful and dangerous plant protection products. Rational use of fertilizers dramatically changes the ecological conditions of crop vegetation and weeds, affecting their interaction and contributing to increased crop yield and productivity. Agrarians and scientists pay great attention to implementing a biological farming system – using by-products of agricultural production, cover crops, non-chemical plant protection methods, and bioregulators.

Therefore, the main goal of our research was to justify the level of buckwheat yield when grown in classical and biologized crop rotations of short rotation in the conditions of the Northern Steppe of Ukraine. Field studies were conducted from 2014-2023 in a stationary field experiment at Institute of Agriculture of the Steppe, NAAS. Buckwheat was grown in a short rotation grain-row crop rotation with soybean saturation up to 40%.

The results of our observations indicate that weather conditions not only influenced the formation of the yield of the studied crop but also determined the share of the impact of agronomic practices in cultivation, at least fertilization and elements of biologization. The highest buckwheat yield, on average over ten years of research, was provided by the biologized organo-mineral fertilization system at 2.01 t/ha, which contributed to a yield increase of 0.53 t/ha compared to the variant without a biologically active preparation. The separate effect of the biologized fertilization system had the greatest impact on buckwheat yield in the variant without fertilizers, with an increase of 0.20 t/ha (15.6 %), and the smallest impact was with the organo-mineral fertilization system, which accounted for 0.11 t/ha (6.0 %).

Key words: *buckwheat, fertilization systems, biologization, yield, crop rotation.*

Соколовська І.М., Мащенко Ю.В. Вплив різних систем удобрення на урожайність гречки в умовах Північного Степу України

Родючість ґрунту має велике значення для розвитку рослин і має вирішальний вплив на рівень врожайності. Початково родючі поля є великою перевагою для фермерів, але їх потрібно підтримувати в належному стані, аби уникнути виснаження ґрунту. Аграрне виробництво сьогодні зосереджено в напрямку екологізації землеробства, високу якість сільськогосподарської продукції, перехід на екологічно безпечні технології, відмову від шкідливих і небезпечних засобів захисту рослин. Обґрунтоване використання добрив різко змінює екологічні умови вегетації культурних рослин та бур'янів і характер їх взаємодії, сприяє підвищенню урожайності й продуктивності рослинництва. Велику увагу аграрії й науковці приділяють впровадженню біологічної системи землеробства – використанню побічної сільськогосподарської продукції, сидератів і нехімічних методів захисту рослин, біорегуляторів.

Тому, основним завданням наших досліджень було обґрунтувати рівень врожайності гречки при вирощуванні у класичних та біологізованих сівозмінах короткої ротації в умовах північного Степу України. Польові дослідження проводили протягом 2014-2023 рр.

в стаціонарному польовому досліді лабораторії землеробства Інституту сільського господарства Степу НААН. Гречку вирощували у короткоротаційній зерно-просапній сівозміні з насиченням соєю до 40 %.

Результати наших спостережень вказують на те, що погодні умови не лише впливали на формування урожайності досліджуваної культури, а й визначали частку впливу агротехнічних прийомів вирощування, принаймні, удобрення та елементів біологізації. Вищу врожайність гречки, в середньому за десять років досліджень, забезпечувала біологізована органо-мінеральна система удобрення на рівні 2,01 т/га яка сприяла отриманню врожаю на 0,53 т/га більше ніж у варіанті без біологічно активного препарату. Окрема дія біологізованої системи удобрення мала найбільший вплив на урожайність гречки у варіанті без добрив з прибавкою 0,20 т/га (15,6 %), а найменший – за органо-мінеральної системи удобрення, яка становила 0,11 т/га (6,0 %).

Ключові слова: *гречка, системи удобрення, біолоізація, урожайність, сівозміна.*

Formulation of the problem. The decrease in soil fertility on arable land is a consequence of reduced application of organic and mineral fertilizers, liming, disruption of crop rotation, and neglect of the law of returning essential nutrients to the soil. Global experience shows that extensive agriculture without the use of fertilizers inevitably leads to gradual depletion of soil fertility and reduced crop productivity [10, 30, 36, 47, 50, 54].

Analysis of recent research and publications. The strategic development of agricultural production in most countries is focused on ecological agriculture, high-quality agricultural products, transition to environmentally safe technologies, and abandonment of harmful and dangerous plant protection products that negatively affect human health and the environment [1, 2, 14, 16, 17, 23, 24, 26, 27].

An important and essential element in this context is the use of biological plant protection methods, which have noticeably intensified in the EU, USA, and most other developed countries in recent decades. This contributes to the formation of a powerful global market for environmentally friendly agricultural products, the capacity of which has already exceeded $50 billion and is expected to continue growing [4, 9, 12, 18, 19, 21, 22, 29, 31, 32, 38, 40].

The use of fertilizers in fields dramatically changes the ecological conditions of crop vegetation and weeds and affects their interaction. In this regard, it is particularly important to provide sufficient nitrogen, which promotes the strong development of crops and increases shading of weeds and their suppression [3, 13, 20, 25, 48, 51].

In recent years, following Europe, the US and Canada have intensified the trend towards biologization of crop production (starting with improving crop rotation by including grasses and legumes). If crop rotation is too simplified and specialized, intermediate and cover crops are maximally included to improve crop rotation and phytosanitary conditions of the main crop [5, 6, 11, 28, 39, 41, 42].

Some scientists argue that attention should be paid to the implementation of a biological farming system – using by-products of agricultural production, cover crops, non-chemical plant protection methods [35]. The importance of cover crops in modern agriculture is due to the reproduction of organic matter, which explains their global impact on the complex agrochemical properties of soil energy value and fertility. The reserves of humus and nitrogen in soils are replenished mainly through the application of fertilizers and significantly through organic matter in the form of plant residues [33, 52, 53].

Ecological fertilization systems such as plant residues, microfertilizers, humic and microbiological fertilizers adhere to natural biological laws – accumulation of organic matter, intensification of microbiological activity, and increased availability of nutrients for crops [7, 8, 34, 37].

The use of biostimulants promotes increased productivity due to the intensification of cellular life processes in plant organisms and acceleration of biochemical processes such as respiration and photosynthesis – resulting in better realization of the genetic potential of plants [15, 43, 44, 45, 46, 49].

Research task. Justify the yield level of buckwheat in classical and biologized short rotation crop rotations in the conditions of the Northern Steppe of Ukraine.

Materials and methods of research. Field research was conducted from 2014 to 2023 in the stationary field experiment of Institute of Agriculture of the Steppe, National Academy of Agrarian Sciences.

Buckwheat was grown in a short rotation grain-row crop rotation with a 40 % soybean saturation, which had the following sequence: 1. Soybean; 2. Winter wheat; 3. Soybean; 4. Corn for grain; 5. Buckwheat.

The technology of buckwheat cultivation was generally accepted for the Steppe zone, except for the techniques that were under study.

Buckwheat was sown using wide-row sowing method, with a seeding rate of 2.25 million seeds/ha, in three fertilization variants (1. Without fertilizer application; 2. Mineral fertilizer system ($N_{20}P_{20}K_{20}$); 3. Organic-mineral ($N_{20}P_{20}K_{20}$ and by-products of the predecessor) in classical and biologized systems.

Mineral fertilizers were applied before the main tillage in autumn. Buckwheat seeds were treated with the biopreparation Mycofriend (1.0 l/t). The overall cultivation technology included primary tillage starting with stubble cultivation, followed by plowing to a depth of 22-25 cm. Pre-sowing tillage consisted of cultivation to a depth of 5 to 8 cm.

The experiments were conducted and recorded according to the methodology of field research.

The yield was measured using the continuous method by dividing the plots and harvesting the buckwheat using a combine harvester «Sampo 2010» when 75 % of the buckwheat fruits were matured.

Buckwheat cultivation was carried out in the fields of the stationary experiment, which is part of the fundamental research of the National Academy of Agrarian Sciences on «Agricultural Systems for Optimizing Land Use in Agrolandscapes» («Agricultural Systems and Land Use») in a short rotation grain-row crop rotation during the second, third, and fourth rotations.

In the second rotation, the variety Krupynka was grown, in the third – the variety Yuvileyna 100, and in the fourth – the variety Yaroslavna. These varieties belong to the mid-early maturity group, with grain and food utilization directions, and have a potential yield of 2.5-3.0 t/ha in the conditions of the Forest-Steppe and Steppe regions of Ukraine.

Weather conditions during the research period in 2014, 2015, 2018, 2019, 2022, and 2023 were characterized by favorable temperature regimes and sufficient, with some periods (April-May) experiencing excessive rainfall, which had a positive impact on the formation of high buckwheat yields. However, they were not favorable during critical periods for water consumption (flowering). The ripening and completion of the vegetation of buckwheat plants occurred under good thermal conditions but with limited soil moisture reserves in the absence of precipitation. In other words, the weather conditions during the vegetation period of these years initially favored the establishment of the maximum yield potential of buckwheat, but due to significant moisture deficit during fruit filling, the initially high biological yield potential could not be realized.

The conditions in 2016 were moderately favorable for the growth and development of buckwheat plants, with moderately warm air temperatures and sufficient rainfall during vegetation positively influencing buckwheat yield formation.

Unfavorable conditions for achieving a high yield level were observed during the vegetation period of buckwheat in 2017, 2020, and 2021.

Therefore, elevated temperature regimes, insufficient rainfall, and uneven distribution of precipitation negatively affected the formation of buckwheat yields, which averaged 1.68 t/ha over the 10-year research period.

Results and discussion. As it is known, buckwheat is a heat- and moisture-loving crop, but excessive moisture and sharp fluctuations in temperature regime, especially during critical periods of development, do not allow plants to use their biological potential and form a harvest at the level of potential. The results of our ten-year research confirm this. In addition, we have found that weather conditions not only affected the formation of crop productivity but also determined the share of the influence of agrotechnical methods of cultivation, at least in terms of fertilization and elements of biologization.

The highest yields of buckwheat in our research were recorded in 2014, 2.09-2.69 t/ha. The data presented in Figure 1 also prove that increasing the background nutrition of plants provided an increase in yield level both in classical systems of fertilization and in biologized ones. However, it should be noted that in this year, only the application of mineral fertilizers under buckwheat did not provide a significant increase in yield, +0.10 t/ha for LSD05 = 0.17 t/ha.

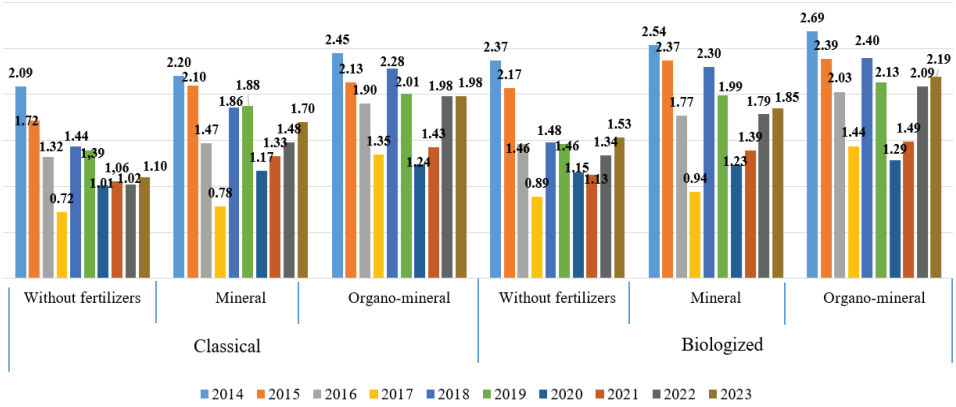

*Fig. 1. Buckwheat yield under different fertilization systems, 2014-2023**

*LSD05	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
By fertilization system	0.17	0.16	0.15	0.02	0.06	0.05	0.04	0.02	0.09	0.05
By biopreparation	0.14	0.13	0.13	0.02	0.05	0.04	0.03	0.02	0.07	0.04
General	0.24	0.23	0.22	0.03	0.08	0.07	0.05	0.03	0.12	0.08

It is believed that organic fertilizers are not directly applied under buckwheat but are used the after effect of organic fertilizers applied to previous crops. The data analysis of our research proves that ploughing the by-products of the previous crop during

field preparation for sowing buckwheat had the most significant effect on increasing crop yields, and in 2014, the yield increase in the classical organo-mineral fertilization system was 0.35 t/ha or 16.9 %. In other years, this indicator ranged from +0.24 t/ha in 2020 to +0.96 t/ha in 2022.

In biologized fertilization systems, buckwheat yield was higher than in classical systems, and this trend was observed throughout the research period. However, the share of the influence of the biological component of the fertilization system was different, and limiting factors of its effect were not only weather conditions but also the background of mineral nutrition.

In 2014, which was characterized as the most productive year for the crop, the highest yield was provided by the biologized organo-mineral fertilization system, 2.69 t/ha. The yield increase was 0.25 t/ha or 10 % compared to the system without fertilizer application, but the effectiveness of the biopreparation in this variant was the lowest. And if the largest yield increase of buckwheat in classical systems was obtained with organo-mineral fertilization, then in biologized systems, it was with the application of mineral fertilizers, +0.34 t/ha or 15.7 %.

Thus, moderate air temperatures that did not exceed 25 °C and periodic precipitation during buckwheat flowering in 2014 created favorable conditions for forming high plant productivity potential, and a long period of fruit ripening under favorable weather conditions ensured high crop yield in combination with fertilization and seed treatment with a biopreparation. But favorable meteorological conditions of the year somewhat reduced the effect of both fertilizers (+4.8 t/ha or 16.9 % of yield) and the biological component of the fertilization system (+10.0 t/ha or 15.7 %).

The yield of buckwheat in 2015 was also quite high for the conditions of the Northern Steppe, but slightly lower than the previous year, at 1.72-2.39 t/ha. The lack of precipitation in the second half of the summer had a negative impact on the realization of the plants' potential, which was laid down during flowering: the fruits were smaller and immature on the upper branches. It should be noted that the range of yield indicators in this year, 0.67 t/ha, increased, indicating an increase in the activity of the factors we studied. The result of the influence of mineral and organo-mineral fertilization systems on buckwheat yield was within a significant difference, +0.37 t/ha or 21.7 % and 0.41 t/ha or 23.7 %, respectively, for LSD05 = 0.16 t/ha, but the yield increase compared to the variant without fertilizer application was significant. Moreover, the activity of the biopreparation on the background of natural plant nutrition was the highest, +0.35 t/ha or 20.1 % of yield, while the yield indicator was the lowest in the biologized fertilization system, at 2.07 t/ha. There was no significant difference between crop yields in other fertilization systems, mineral and organo-mineral, at 2.37 t/ha and 2.39 t/ha, respectively, but these indicators were the highest in the conditions of that year.

Insufficient rainfall, their unevenness or absence in certain phases of buckwheat plant development, high air temperatures above 25 °C were the most typical weather conditions during most years of research. In these years, particularly in 2016, 2018, 2019, 2022, and 2023, crop yields ranged from 1.02-2.40 t/ha with a range of 1.38 t/ha. It was precisely under such conditions that the use of agrotechnical techniques was a limiting factor in forming buckwheat productivity, somewhat offsetting the negative impact of external environmental factors.

Especially interesting regarding the effect of the fertilization system were the years 2022 and 2023. In 2022, the yield of buckwheat without fertilization was 1.02 t/ha, the lowest indicator in the years of research, excluding 2020, which deserves separate attention. The yield increase in the classical organo-mineral fertilization system

was 0.96 t/ha or 94.2 %, almost twice as high as in other systems (LSD05 = 0.09 t/ha), and this was the highest indicator in ten years of research. The effect of only mineral fertilizers was somewhat lower, at +0.47 t/ha or 45.9 %. In the following year, 2023, due to abundant rainfall in May-June, mineral fertilizers actively transitioned into a soluble form, which contributed to an increase in the biological potential of plants. As a result, the yield increase in the mineral fertilization system was within 0.60 t/ha or 54.5 %, which was also the highest indicator in the study. At the same time, the increase in yield in the organo-mineral fertilization system, at +0.88 t/ha or 79.6 %, was slightly lower than in the previous year. The yield indicators of buckwheat in biologized fertilization systems in 2023 also differed significantly from previous years. Thus, the highest effect of the biopreparation was achieved against the background of no fertilizer application, at +0.43 t/ha or 38.7 %, which was the highest indicator in years of research. However, when only mineral fertilizers were applied, the yield increase due to the biological component of the fertilization system was only 0.15 t/ha or 8.6 %, with LSD05 = 0.04 t/ha, but the increase was significant.

In the most unfavorable years for the crop, such as 2017, 2020, and 2021, in the conditions of 2017, rainfall during the grain filling stage somewhat saved the situation, especially against the background of the organo-mineral fertilization system, allowing to harvest 1.35 t/ha in the classical system and 1.44 t/ha in the biologized system. The activity of additional nutrients and microorganisms in the soil during this period somewhat mitigated the effects of drought and provided significant yield increases, depending on the fertilization system, within a range of 0.77 t/ha. In the conditions of 2020 and 2021, on the contrary, spring rains and moderate air temperatures at the beginning of plant vegetation favored the establishment of the crop potential, but the lack of rainfall until harvest suppressed the action of fertilizers and bacterial activity. As a result, the increase in buckwheat yield due to the factors we studied was within 0.28 t/ha in 2020 and 0.43 t/ha in 2021, the lowest in years of research. The highest yield increases were obtained in the organo-mineral fertilization system, +0.24 t/ha or 23.7 % in 2020, and +0.38 t/ha or 35.7 % in 2021. The biologization of buckwheat cultivation technology had a greater effect in these years in systems without fertilizer application, +0.15 t/ha or 14.8 % and 0.07 t/ha or 6.8 %, respectively. The application of fertilizers suppressed the activity of the biological component, but the highest yield indicators were still achieved using the organo-mineral fertilization system and biopreparation, 1.29 t/ha and 1.49 t/ha in 2020 and 2023, respectively.

On average over ten years of research, we found that the highest yield of buckwheat was obtained with the biologized organo-mineral fertilization system, 2.01 t/ha. Without fertilizer application, this indicator decreased to 1.49 t/ha, but it should be noted that the use of biopreparation provided the highest yield increase – 0.20 t/ha or 15.6 % with LSD05 = 0.07 t/ha (Table 1).

By classical fertilization system, the average yield of buckwheat ranged from 1.29 to 1.90 t/ha. However, plowing of crop residues of the previous culture combined with the application of mineral fertilizers provided a higher level of crop yield, 1.90 t/ha, compared to the biologized mineral fertilization system, 1.82 t/ha. The effectiveness of mineral and organic substances in our study (yield increase of 0.61 t/ha or 47.6 % with LSD05 = 0.09 t/ha) was higher than the activity of microorganisms of the biopreparation. The yield of buckwheat in the variant with the use of mineral fertilizers and biopreparation increased only by 0.16 t/ha or 9.5 %, but considering the significant difference of 0.07 t/ha, the yield increase was significant.

Table 1

Average buckwheat yield depending on the fertilization system

Fertilization system	Average for 2014-2023	Difference			
		by fertilization system		by biopreparation	
		t/ha	%	t/ha	%
Classical					
Without fertilizers	1.29	–	–	–	–
Mineral	1.66	0.37	29.0	–	–
Organo-mineral	1.90	0.61	47.6	–	–
Biologized					
Without fertilizers	1.49	–	–	0.20	15.6
Mineral	1.82	0.33	22.1	0.16	9.5
Organo-mineral	2.01	0.53	35.4	0.11	6.0
LSD05	by fertilization system		0.09		
	by biopreparation		0.07		
	General		0.13		

Conclusions. Thus, the weather conditions during the research period favored high yields of buckwheat in the conditions of the Northern Steppe. Observations indicate that out of 10 years of research, only three years had conditions that were characterized as unfavorable for buckwheat cultivation. Weather conditions not only influenced the formation of crop yield but also determined the share of influence of agronomic practices, at least fertilization and elements of biologization.

The biologized organo-mineral fertilization system provided higher yields of buckwheat, on average over ten years of research, reaching 2.01 t/ha, which resulted in a yield increase of 0.53 t/ha compared to the variant without a biologically active preparation. The separate effect of the biologized fertilization system had the greatest impact on the yield of buckwheat in the variant without fertilizers, with a yield increase of 0.20 t/ha (15.6 %), while the smallest impact was observed in the organo-mineral fertilization system, which accounted for 0.11 t/ha (6.0 %).

REFERENCES:

1. Averchev O. V., Kyrylov Yu. E., Fesenko G. A. The current state of buckwheat market in Ukraine. *Bulletin of National Academy of Sciences of The Republic of Kazakhstan*. Volume 2, Number 390 (2021), P. 113-119. https://doi.org/10.32014/2021.2518-1467.58

2. Boone L., Roldán-Ruiz I., Van linden, V., Muylle H., Dewulf J. Environmental sustainability of conventional and organic farming: Accounting for ecosystem services in life cycle assessment. *Sci. Total Environ.* 2019, 695, 133841. https://doi.org/10.1016/j.scitotenv.2019.133841

3. Chandini Randeep Kumar, Ravendra Kumar Uttarakhand, Om Prakash. The Impact of Chemical Fertilizers on our Environment and Ecosystem. *In book:* Research Trends in Environmental Sciences. 2019. Edition: 2nd. Chapter: 5. P. 69-86. https://www.researchgate.net/publication/331132826_The_Impact_of_ Chemical_Fertilizers_on_our_Environment_and_Ecosystem

4. David B. Collinge, Dan Funck Jensen, Mojgan Rabiey, et. al. Biological control of plant diseases – What has been achieved and what is the direction? *Plant Pathology. Volume* 71, Issue 5. June 2022. P. 1024-1047. https://doi.org/10.1111/ppa.13555

5. Dionisios Yfantopoulos, Georgia Ntatsi, Anestis Karkanis, Dimitrios Savvas. Evaluation of the Role of Legumes in Crop Rotation Schemes of Organic or Conven-

tionally Cultivated Cabbage. *Agronomy*. 2024, 14(2), 297. https://doi.org/10.3390/agronomy14020297

6. Emily C. Cooledge, David R. Chadwick, Lydia M. J. Smith, Jonathan R. Leake, Davey L. Jones. Agronomic and environmental benefits of reintroducing herb- and legume-rich multispecies leys into arable rotations: a review. *Frontiers of Agricultural Science and Engineering*. May 2022. https://doi.org/10.15302/J-FASE-2021439

7. Esraa E. Ammar, Hadeer A. Rady, Ahmed M. Khattab, Mohamed H. Amer, Sohila A. Mohamed. A comprehensive overview of eco-friendly bio-fertilizers extracted from living organisms. *Environmental Science and Pollution Research.* 2023. 30:113119-113137. https://doi.org/10.1007/s11356-023-30260-x

8. Goutam Hazra. Different Types of Eco-Friendly Fertilizers: An Overview. *Sustainability in Environment*. (Online). Vol. 1, No. 1, 2016. https://doi.org/10.22158/se.v1n1p54

9. He D.-C., He M.-H., Amalin D.M., Liu W., Alvindia D. G., Zhan J. Biological Control of Plant Diseases: An Evolutionary and Eco-Economic Consideration. *Pathogens*. 2021, 10, 1311. https://doi.org/10.3390/pathogens10101311

10. Irene F. Lalrintluangi, Vinai Kumar, Singh A. K., Dipti Bisarya. Impact of Organic Farming on soil fertility and crop productivity. *Jetir January,* 2019, Volume 6, Issue 1. https://www.researchgate.net/publication/360134158_ Impact_of_ Organic_Farming_on_soil_fertility_and_crop_productivity

11. Junxian Li, Junxian Li, Kui LiuKui Liu, Jun Zhang Jun Zhang, Lidong Huang Lidong Huang, Jeffrey A. Soil-Plant Indices Help Explain Legume Response to Crop Rotation in a Semiarid Environment. *Plant Science*, 2018. Agroecology. Volume 9. https://doi.org/10.3389/fpls.2018.01488

12. Jürgen Köhl, Rogier Kolnaar, Willem J. Ravensberg. Mode of Action of Microbial Biological Control Agents Against Plant Diseases: Relevance Beyond Efficac. *Frontiers in Plant Science.* July 2019. Volume 10. Article 845. https://doi.org/10.3389/fpls.2019.00845

13. Ma G., Cheng S., He W., Dong Y., Qi S., Tu N., Tao W. Effects of Organic and Inorganic Fertilizers on Soil Nutrient Conditions in Rice Fields with Varying Soil Fertility. *Land.* 2023, 12, 1026. https://doi.org/10.3390/land12051026

14. Magdoff F. Ecological agriculture: Principles, practices, and constraints. Renewable *Agriculture and Food Systems*. 2022(2); P. 109-117. http://dx.doi.org/10.1017/S1742170507001846

15. Mashchenko Yu.V., Sokolovska I.M. Buckwheat productivity depends on fertilizer system and seed inoculation with biopreparation. *Таврійський науковий вісник*. 2023. № 133. P. 54-63. https://doi.org/10.32782/2226-0099.2023.133.8

16. Meemken E. M., Qaim M. Organic agriculture, food security, and the environment. *Annu. Rev. Resour. Econ*. 2018, 10, P. 39-63. https://doi.org/10.1146/annurev-resource-100517-023252

17. Mehmet Ali Salık, Ramazan Çakmakçı, Songü Çakmakçı. Assessment and Principles of Environmentally Sustainable Food and Agriculture Systems. *Agriculture*. 2023, 13(5), 1073; https://doi.org/10.3390/agriculture13051073

18. Moh Tariq, Amir Khan, Mohd Asif, Faryad Khan, Taruba Ansari, Mohammad Shariq. Biological control: a sustainable and practical approach for plant disease management. *Acta Agriculturae Scandinavica*, Section B – Soil & Plant Science Volume 70, 2020. Issue 6. https://doi.org/10.1080/09064710.2020.1784262

19. Mostoviak, I. Biological method as a constituent of integrated plant protection in modern conditions. *Agrology*, 3(1), 46-51. https://doi.org/10.32819/020007

20. Nuri Salem ALnaass, Hossean Khalifa Agil, Hamza Khalifa Ibrahim. Use of fertilizers or importance of fertilizers in agriculture. *International Journal of Advanced Academic Studies*. 2021. 3(2). P. 52-57. https://doi.org/10.33545/27068919.2021.v3.i2a.770

21. Pandit M. A., Kumar J., Gulati S., Bhandari N., Mehta P., Katyal R., Rawat C. D., Mishra V., Kaur J. Major Biological Control Strategies for Plant Pathogens. *Pathogens* 2022, 11, 273. https://doi.org/10.3390/pathogens11020273

22. Pisarenko V. M., Kovalenko N. P., Pospielova G. D., Pischalenko M. A., Nechyporenko N. I., Sherstiuk O. L. Modern strategy of integrated plant protection. *Bulletin of Poltava State Agrarian Academy*, (4), P. 104-111. https://doi.org/10.31210/visnyk2020.04.12

23. Rempelos L., Baranski M., Wang, J., Adams T. N., et. al. Integrated soil and crop management in organic agriculture: A logical framework to ensure food quality and human health? *Agronomy.* 2021, 11, 2494. https://doi.org/10.3390/agronomy11122494

24. Thompson B., Barnes A.P., Toma L. Increasing the adoption intensity of sustainable agricultural practices in Europe: Farm and practice level insights. *J. Environ. Manag*. 2022, 320, 115663. https://doi.org/10.1016/j.jenvman.2022.115663

25. Wenchao Li, Shufang Guo, Hongbin Liu, Limei Zhai, Hongyuan Wang, Qiuliang Lei. Comprehensive environmental impacts of fertilizer application vary among different crops: Implications for the adjustment of agricultural structure aimed to reduce fertilizer use. *Agricultural Water Management*. Volume 210, 30 November 2018, P. 1-10. https://doi.org/10. 1016/j.agwat.2018.07.044

26. Wesołowska S., Futa B., Myszura M., Kobyłka A. Residual effects of different cropping systems on physicochemical properties and the activity of phosphatases of soil. *Agriculture*. 2022, 12, 693. https://doi.org/10.3390/agriculture12050693

27. Xie H., Huang Y., Chen Q., Zhang Y., Wu Q. Prospects for agricultural sustainable intensification: A review of research. *Land*. 2019, 8, 157. https://doi.org/10.3390/land8110157

28. Yfantopoulos D., Ntatsi G., Karkanis A., Savvas D. Evaluation of the Role of Legumes in Crop Rotation Schemes of Organic or Conventionally Cultivated Cabbage. *Agronomy*. 2024, 14, 297. https://doi.org/10.3390/agronomy14020297

29. Zerihun Tsegaye, Fasil Assefa, Genene Tefera, Tesfaye Alemu, Birhanu Gizaw, Endeshaw Abatenh. Concept, Principle and Application of Biological Control and their Role in Sustainable Plant Diseases Management Strategies. International *Journal of Research Studies in Biosciences* (IJRSB). Volume 6, Issue 4, 2018, P. 18-34. (Online) 2349-0365. http://dx.doi.org/10.20431/2349-0365.0604004

30. Zhengxi Tan, Rattan Lal, Keith Wiebe. Global Soil Nutrient Depletion and Yield Reduction. *Journal of Sustainable Agriculture.* 26(1). 2005. http://dx.doi.org/10.1300/J064v26n01_10

31. Амонс С. Е. Біологічний захист рослин в системі органічного землеробства. сільське господарство та лісівництво. *Захист рослин*. 2022. № 25. https://doi.org/10.37128/2707-5826-2022-2-13

32. Білик М. О. Біологічний захист рослин від шкідливих організмів: підручник. Харків. Майдан, 2022. 356 с. https://repo.btu.kharkov.ua/bitstream/123456789/4932/1/P_VZRSHO_22.pdf

33. Горб О. О., Чайка Т. О., Яснолоб І. О. Використання сидеральних культур як відновлюваного джерела енергії в органічному землеробстві. *Вісник Полтавської державної аграрної академії.* № 4. 2017. С. 38-41. https://doi.org/10.31210/visnyk2017.04.06

34. Дегодюк Е. Г., Проненко М. М., Ігнатенко Ю. О., Пипчук Н. М., Мулярчук А. О. Сучасні системи удобрення в землеробстві України: науково-методичні та науково-практичні рекомендації. За редакцією С. Е. Дегодюка. Вінниця. ТОВ «Твори», 2020. 84 с.

35. Дегодюк С. Е., Дегодюк Е. Г., Проненко М. М., Ігнатенко Ю. О., Пипчук Н. М., Мулярчук А. О. Ефективність застосування відновлюваних місцевих ресурсів за органічного землеробства: науково-методичні рекомендації. Вінниця. ТОВ «Твори», 2020. 48 с.

36. Добряк Д. С., Дребот О. І., Мельник П. П. Наукові засади класифікації орних земель за продуктивністю ґрунтів для вирощування основних сільськогосподарських культур. *Збалансоване природокористування*. № 1/2021. С. 12-19. http://dx.doi.org/10.33730/2310-4678.1.2021.231861

37. Дубицький О. Л., Качмар О. Й., Дубицька А. О., Вавринович О. В. Вплив екологізованих систем удобрення на формування продуктивності та якості зерна пшениці озимої. *Вісник аграрної науки*. 2020, №7 (808). С. 74-79. https://doi.org/10.31073/agrovisnyk202007-10

38. Жуйков О. Г. Біологічний метод захисту рослин у сучасному органічному землеробстві україни: історичні аспекти, тренди, перспективи. *Аграрні інновації*. № 12 (2022). С. 23-27. https://doi.org/10.32848/agrar.innov.2022.12.4

39. Квасніцька Л. С. Продуктивність та енергетична оцінка кормової сівозміни залежно від насиченості трав багаторічними бобовими травами. *Корми та виробництво кормів,* (77), С. 202-208. https://fri-journal.com/index.php/journal/article/view/532

40. Крутякова В. І., Гулич О. І., Янсе Л. А. Застосування біологічного методу для захисту лісу і лісових насаджень в Україні. *Вісник аграрної науки*. 2020, №1 (802). С. 39-46. https://doi.org/10.31073/agrovisnyk202001-06

41. Кудря С. І. Вплив зерно-бурякових сівозмін із різними бобовими попередниками пшениці озимої на поживний режим чорнозему типового. *Вісник аграрної науки.* 2020, №4 (805). С. 15-20. https://doi.org/10.31073/agrovisnyk202004-02

42. Кудря С. І. Продуктивність короткоротаційної сівозміни з різними бобовими культурами на чорноземі типовому. *Вісник аграрної науки*. 2020, 1(802). С. 13-18. https://doi.org/10.31073/agrovisnyk202001-02

43. Мащенко Ю. В. Вплив мінеральних добрив і регулятора росту Емістима С при різних строках сівби на продуктивність гречки в умовах Північного Степу України. *Вісник Черкаського інституту агропромислового виробництва.* 2009. Вип. 9. С. 160-164.

44. Мащенко Ю. В. Вплив систем удобрення та ефективних мікроорганізмів на продуктивність гречки в умовах Північного Степу. *Бюлетень інституту зернового господарства*. Дніпропетровськ, 2009. № 37. С. 26-30.

45. Мащенко Ю. В. Продуктивність гречки залежно від систем удобрення та ефективних мікроорганізмів в умовах Північного Степу України. *Вісник Центру наукового забезпечення АПВ Харківської області*. 2011. № 10. С. 160-168.

46. Мащенко Ю. В., Семеняка І. М. Удосконалена технологія вирощування гречки в умовах Північного Степу України. Київ. Аграрна наука, 2018. 184 с.

47. Охорона ґрунтів. Збірник наукових праць. державна установа «Інститут охорони ґрунтів України». 2022. Випуск 12. Київ. 248 с. ttps://www.iogu.gov.ua/literature/soil/14-Випуск%20№%2012%20(2022).pdf

48. Писаренко В. М., Писаренко П. В. Органічні добрива на захисті родючості ґрунту. Монографія. Полтава 2022. 156 с. https://www.pdau.edu.ua/sites/default/files/academicdepartment/kafedra-zahyst-roslyn/organichnidobryvaknyga2022.pdf

49. Соколовська І. М., Мащенко Ю. В. Біотехнологічні прийоми вирощування гречки за різного удобрення. *Таврійський науковий вісник*. 2023. Вип. 130. С. 240–246. https://doi.org/10.32851/2226-0099.2023.130.35

50. Тихоненко О. В., Шамчук А. Ю. Показники якісного стану ґрунтів як основа раціонального використання земель. *Землеустрій, кадастр і моніторинг земель*. 2022. № 2. С. 75-84. http://dx.doi.org/10.31548/zemleustriy2022.02.07

51. Ткачук О. П., Шкатула Ю. М., Тітаренко О. М. Сільськогосподарська екологія: навчальний посібник. Вінниця: ВНАУ, 2020. 542 с.

52. Халеп Ю., Москаленко А., Шаповалюк М., Арабська К. Еколого-економічне значення сидерації для органічних агроценозів полісся. *Agricultural and Resource Economics*: *International Scientific E-Journal*. Vol. 7, No. 1, 2021. С. 211-231. https://doi.org/10.51599/are.2021.07.01.11

53. Чмель О. П., Круподеря Ю. О., Бондар І. М. Сидерація як альтернатива органічним добривам і засіб збільшення продуктивності агроценозів. *Вісник Харківського національного аграрного університету*. 2019. Випуск 2. С. 35-44. https://doi.org/10.35550/ISSN2413-7642.2019.02.04

54. Якименко І. Л., Петрашко Л. П., Димань Т. М., Салавор О. М., Шаповалов Є. Б., Галабурда М. А., Ничик О. В, Мартинюк О. В. Стратегія сталого розвитку: Європейські горизонти. Підручник. Київ. НУХТ, 2022. 337 с. https://rep.btsau.edu.ua/bitstream/BNAU/7990/1/stratehiia_staloho.pdf