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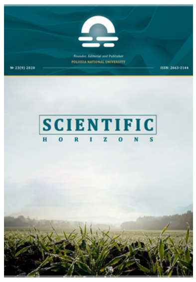

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Innovative approaches to growing grain crops in the Southern Steppe of Ukraine

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Abstract. The aim of the study was to analyse the impact of innovative approaches to cereal cultivation in the Southern Steppe of Ukraine. The study used the latest plant varieties, efficient irrigation systems and biological products to increase crop yields and resilience. The wheat varieties used were Stepova 1 and Dniprovska 1, as well as Pivdennyi 1 barley, which are highly resistant to drought and high temperatures. Drip and sub-surface irrigation systems were used, as well as bio-fertilisers and organic composts to improve soil structure and increase soil fertility. The main results of the study showed that wheat yields in the experimental groups reached 5.2-5.7 tonnes/ha, which is 1.8-1.9 tonnes/ha more than in the control groups. Water consumption in the experimental groups was reduced by 35-40%, and the cost of plant protection products by 45-50%. The protein content of wheat in the experimental groups was 14-15% and the fibre content was 30-32%, while in the control groups it was 11-12% and 25-27%, respectively. Soil analysis in the experimental groups showed higher levels of nitrogen,

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phosphorus and potassium, which indicates the effectiveness of biofertilisers. In addition, the use of biological products helped to reduce the chemical load on the environment. The results obtained indicate a significant increase in productivity, reduced resource use and improved environmental sustainability with the introduction of innovative methods of growing crops in this region, which is important for ensuring food security and economic development in Ukraine

Keywords: wheat; barley; biofertilisers; drip irrigation; biological products; fertility

INTRODUCTION

The Southern Steppe of Ukraine is one of the most important regions for growing grain crops. This region provides a significant portion of the country's grain harvest, which is a key factor for Ukraine's food security and economic development. The Southern Steppe of Ukraine faces significant climatic challenges that negatively affect grain yields. The hot and dry climate, frequent droughts and high temperatures reduce plant productivity and can lead to crop losses. Water scarcity exacerbates the situation, as traditional irrigation methods are water-intensive, leading to depletion of water reserves. Soil depletion due to intensive agriculture and the use of chemical fertilizers and crop protection products is reducing soil fertility. In addition, chemical crop protection products pollute soil and water resources, reduce biodiversity and contribute to the development of pest resistance. The high cost of traditional production reduces the economic efficiency of agricultural enterprises, which affects their competitiveness. In this regard, it is necessary to introduce innovative approaches that will ensure sustainable production, improve the environment and increase the economic efficiency of grain growing in the region.

The integration of modern technologies into agriculture requires a systematic approach to training and professional development of farmers. The introduction of innovative methods involves not only technical equipment, but also knowledge and skills to use the latest technologies. In this regard, an important aspect is the organization of educational programmes and trainings for farmers, which allows them to effectively use new techniques and increase the productivity of their farms. V. Pichura *et al.* (2024) also note that the use of biological products and biofertilisers requires careful adherence to technological standards and recommendations for their use. Failure to comply with the dosages and application periods can lead to a decrease in the effectiveness of these products and negative consequences for plants (Tonkha *et al.*, 2024). Therefore, it is important to ensure constant monitoring of plant and soil conditions to adjust agronomic measures in a timely manner.

M. Korkhova *et al.* (2023) add that in order to ensure global food security, it is necessary not only to increase grain yields, but also to improve the overall efficiency of agricultural resource use. This requires the implementation of integrated, multifaceted and sustainable strategies aimed at increasing the productivity of each unit of land. In Ukraine, smallholder farmers often grow traditional crop varieties that, while having low yields, are also vulnerable to water shortages, high temperatures, diseases, and other stressors, as shown in the study by A. Panfilova *et al.* (2021). In contrast, modern improved varieties can offer significantly better product quality, more stable yields and much higher yields.

V. Gamayunova and A. Panfilova (2019) indicate that more than 880 new varieties have been made available to farmers, generating annual economic benefits of approximately $850 million. To optimize the potential of these varieties, technology "packages" have been developed that include crop management, irrigation, and pest control strategies. With regard to the selection of new varieties, data provided by S. Shahini *et al.* (2023) show that focusing on developing perennial plants with improved traits – such as larger seed size, stronger stems, better palatability and higher productivity – is an important area of development. Developing varieties with deeper and denser root systems can improve soil structure, carbon sequestration, water and nutrient conservation, and yields.

Previous studies have shown the significant potential of innovative methods to increase grain yields in the Southern Steppe of Ukraine, but several aspects remain unexplored. In particular, many studies do not take into account the long-term effects of biological products and biofertilisers, their adaptation to specific local conditions, and their cost-effectiveness in the long term. Most studies focus on individual aspects of innovative technologies, leaving gaps in a comprehensive approach to integrating these technologies into practice. Thus, the aim of this study was to conduct a comprehensive analysis of innovative approaches to grain crops in the Southern Steppe of Ukraine. The objectives of the study included assessing the impact of the latest varieties, biofertilisers and biological products on crop yields and analysing the efficiency of drip and subsurface irrigation systems.

MATERIALS AND METHODS

The research was conducted on the territory of the Educational and Research Centre of Mykolaiv National Agrarian University on a total area of 50 hectares. The area was divided into four fields: two control fields for wheat and barley and two experimental fields for new grain varieties. The fields were located on ordinary low-humus deep micellar carbonate black soil, approximately 10 km south of the city of Mykolaiv. For the control group, the traditional wheat varieties Odeska 267 and Myronivska 808, as well as the barley variety Lutskyi 96 were used. Traditional cultivation methods included ploughing in autumn to a depth of 25-30 cm, spring harrowing and cultivation. Sowing was carried out in the second decade of October using mechanical seeders SZ-3.6 to a depth of 4-5 cm. Mineral fertilizers (ammophos and urea) were applied at a dose of 200 kg/ha during sowing. Irrigation was carried out using traditional irrigation systems (sprinklers) at a rate of 600-700 m^3/ha during the period of active growth (June-July). Herbicides (Glyphosate at a dose of 2 l/ha), insecticides (Chlorpyrifos at a dose of 1.5 l/ha) and fungicides (Tebuconazole at a dose of 1 l/ha) were used for plant protection.

New wheat varieties Stepova 1 and Dniprovska 1, as well as barley Pivdennyi 1, were used in the experimental group. Soil preparation included deep ploughing in autumn to a depth of 30-35 cm, followed by harrowing to preserve moisture, and spring cultivation using machinery to minimize soil disturbance. Sowing was carried out in the third decade of October using modern John Deere 1775NT precision seeders with precise control of depth and seeding rate. We used biofertilizers based on mycorrhizal fungi and nitrogen-fixing bacteria at a dose of 150 kg/ha during sowing. Additionally, organic composts were applied at a dose of 100 kg/ha in the phase of active plant growth (April). Irrigation was carried out using drip irrigation and sub-surface irrigation systems with automated control based on moisture sensors. The irrigation rate was 400-450 m^3/ha during the period of active growth. For plant protection, biological products based on natural entomopathogenic fungi (*Beauveria bassiana)* at a dose of 1.5 l/ha and bacteria (*Bacillus thuringiensis)* at a dose of 1 l/ha were used, as well as integrated pest management, which included biological, cultural and mechanical methods.

The experimental group used high-resolution satellite imagery and DJI Agras T20 drones to monitor the condition of the fields, which provided rapid detection of areas with insufficient or excessive moisture. The data was analysed using Trimble Ag Software to make irrigation and fertilization decisions. The drip and subsurface irrigation systems were controlled by automated systems that used data from soil moisture sensors (Sentek Drill & Drop). Irrigation was carried out in accordance with the soil moisture regime, which reduced water consumption by 35-40%. Precision agrochemical analyses were used to determine the nutrient requirements of the plants. Fertilization was carried out on a spot basis using precision seeding and fertilization systems (*Väderstad Tempo L)*. In the experimental group, biofertilizers based on mycorrhizal fungi (*MycoApply)* and nitrogen-fixing bacteria (*Azospirillum brasilense*) were used, which were applied during sowing and in the phase of active plant growth. Biological products based on natural entomopathogenic fungi (*Beauveria bassiana)* and bacteria (*Bacillus thuringiensis)* were used to control pests and diseases. The treatments were carried out according to a schedule designed to prevent and control major pests and diseases.

Drip irrigation systems provided precise water delivery directly to the root system of plants using Netafim drip lines. The irrigation was based on data from moisture sensors, which ensured optimal moisture conditions. Subsurface irrigation systems were also used to deliver water to a depth of 20-30 cm, preventing evaporation. Irrigation was carried out at intervals of 7-10 days during the period of active growth. Integrated pest management included biological methods, such as the use of natural enemies of pests such as predatory insects (*Coccinellidae)* and entomopathogenic fungi (*Metarhizium anisopliae), as* well as the application of biological products during the active growth phase and at the time of maximum pest risk. Cultural practices included crop rotation and intercropping to reduce the spread of pests, as well as mulching and cover crops to improve soil structure and reduce erosion. Mechanical methods included the use of traps (pheromone traps) and physical barriers to prevent pests from accessing plants, as well as regular manual inspections and mechanical removal of affected plants.

Monitoring of plant growth and development included regular measurements of plant height, developmental stage, leaf condition and photosynthetic rate every two weeks. Hand-held instruments (ruler, photometer) and modern digital tools (PlantEye F500) were used to estimate biomass and photosynthetic activity. Soil and plant samples were analysed in the laboratory to determine nutrient content, moisture, pH and microbiological composition. After harvesting, the weight, moisture, protein, and fibre content of the crops were determined in the laboratory. Yields were estimated as the weight of harvested grain per unit area (t/ha), and grain quality was assessed using standard methods, including the DSTU methodology (DSTU 3768:2019, 2019). The economic analysis of production costs included accounting for the costs of seeds, fertilizers, plant protection products, irrigation, maintenance, and labour. The economic efficiency was assessed based on the calculation of production costs, gross margin and profit from crop sales. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

The results of the study showed a significant increase in the efficiency of grain growing when using innovative methods compared to traditional approaches. Wheat yields in the experimental groups were 1.8-1.9 tonnes/ha higher than in the control groups. This yield increase was achieved through a set of innovative measures, including the use of the latest varieties, biofertilizers, biological products and improved irrigation systems. The control groups showed stable yields, ranging from 3.4-3.9 tonnes/ha, which is in line with the average for traditional cultivation methods in the region. These results confirm that traditional methods have a certain efficiency, providing stable yields within the established standards. However, in today's agricultural production environment, there is a need to increase productivity and optimize resource use, which stimulates the search for and implementation of new methods and technologies.

The experimental groups using innovative varieties and techniques achieved yields of 5.2-5.7 tonnes/ha. This is a significant increase compared to the control groups, which demonstrates the effectiveness of the new agronomic approaches. A yield increase of 1.8-1.9 tonnes/ha is a significant indicator that demonstrates the potential of the innovations implemented. Such results can be achieved through the use of new varieties with improved genetic characteristics, better resistance to diseases and pests, as well as through the application of more efficient tillage and plant care methods. This increase in yields has several important implications. It allows farmers to increase production without expanding their acreage, which is particularly important in regions with limited land resources. The increase in yields also helps to reduce production costs, which can have a positive impact on the competitiveness of grain crops in domestic and foreign markets.

The increase in yields in the experimental groups was achieved due to several factors. The use of new varieties resistant to drought and high temperatures has reduced yield losses under stressful conditions. This is especially important in the Southern Steppe, where frequent droughts can significantly reduce yields, and the introduction of biofertilizers and organic composts provided better plant nutrition, which contributed to their more intensive growth and development. The experimental group used new wheat varieties such as Stepova 1 and Dniprovska 1, as well as barley Pivdennyi 1. These varieties showed high resistance to drought and high temperatures, as well as excellent yield characteristics (Table 1).

***Table 1**. Characteristics of wheat and barley varieties*

Variety	Resistance to drought	Plant height (cm)	Yield (tonnes/ha)	Protein content (%)	Fibre content (%)
Stepova 1	High	90-95	5.2-5.4	14-15	30-32
Dniprovska 1	High	90-95	5.3-5.5	14-15	30-32
Pivdennyi 1	High	85-90	5.5-5.7	14-15	30-32

***Source:** compiled by the authors*

Innovative irrigation methods used in the experimental groups significantly reduced water consumption, which is an important factor in the context of limited water resources and growing demand for food. In the control groups, water consumption for wheat cultivation was 6,000-6,050 m^3/ha, while in the experimental groups this figure was much lower – only 3,900-4,000 m^3/ha. This indicates that innovative irrigation systems provide more rational use of water, which allows conserving its resources and reducing irrigation costs.

For barley, the situation is similar: water consumption in the control groups was 6,200-6,250 m^3/ha, while in the experimental groups it dropped to 4,000-4,050 m^3/ha. This reduction in water consumption is the result of the use of technologies such as drip and subsurface irrigation, which allow water to be delivered directly to the root zone of plants, minimizing losses due to evaporation and run-off. Reducing water consumption by 35-40% has significant environmental and economic benefits. Lower water consumption contributes to the conservation of water resources, which is especially important in the context of climate change and frequent droughts in the Southern Steppe of Ukraine. In addition, lower irrigation costs reduce production costs, which has a positive impact on the profitability of agricultural enterprises. The efficient use of water resources was made possible by the introduction of drip and subsurface irrigation systems that provided precise water supply directly to the root system of plants. This reduced water losses through evaporation and ensured stable soil moisture. The use of moisture sensors and automated irrigation control systems allowed optimising irrigation regimes and reducing overall water consumption.

The use of integrated pest management and biological products in the experimental groups significantly reduced the cost of plant protection products, which is a significant economic indicator. In particular, the cost of plant protection products for wheat in the control groups was 1,500-1,550 UAH/ha, while in the experimental groups these costs were reduced to 800-820 UAH/ha (Table 2). This represents an almost twofold reduction in costs, which allows farmers to save money and increase profitability. A similar situation was observed for barley: in the control groups, the cost of protection products was 1,600-1,650 UAH/ha, while in the experimental groups it fell to 850-860 UAH/ha.

***Table 2**. Costs of plant protection products (UAH/ha) in control and experimental groups*

Year	Culture	Control group	Experimental group
2021	Wheat	1,500	800
	Barley	1,600	850
2022	Wheat	1,550	810
	Barley	1,650	860
2023	Wheat	1,520	820
	Barley	1,620	830

***Source:** compiled by the authors*

Reducing the cost of crop protection products by 45-50% has several important aspects. It helps reduce the chemical burden on the environment, which contributes to the preservation of biodiversity and improves the ecological condition of soil and water resources. In addition, the use of biological products can reduce the risk of pests developing resistance to chemical protection products, which is a pressing issue in modern agriculture. Integrated pest management included the use of biological, cultural and mechanical methods, which ensured effective pest control without excessive chemical load. The use of natural enemies of pests, such as predatory insects and entomopathogenic fungi, helped reduce pest numbers to an economically unviable level. Cultural practices, such as crop rotation and intercropping, have helped to reduce the spread of pests and improve soil structure. Mechanical methods, such as traps and physical barriers, prevented pests from accessing plants.

Regular measurements of plant height, developmental stage, leaf condition and photosynthetic intensity were carried out every two weeks, which allowed monitoring the dynamics of crop growth and development in detail. The use of modern digital tools, such as PlantEye F500, provided accurate data on plant biomass and photosynthetic activity. These data became the basis for analysing the effectiveness of the implemented agrotechnical methods. In the control groups, the average height of wheat was 80-85 cm, while in the experimental groups this figure was higher and reached 90-95 cm. This indicates a positive impact of innovative methods on wheat growth, which can be attributed to improved nutrition and water supply conditions, as well as the use of more productive varieties. Similar results were obtained for barley: in the control groups, the average plant height was 75-80 cm, while in the experimental groups it was 85-90 cm. The increase in plant height in the experimental groups may indicate more intensive growth and development due to the use of innovative irrigation and fertilization methods. In addition, measurements of leaf condition and photosynthetic intensity showed that plants in the experimental groups were in better health and had higher photosynthetic activity compared to the control groups. This is important because photosynthesis is the main process that determines plant productivity. Higher photosynthetic activity indicates better conditions for growth and development, which ultimately translates into higher yields. Digital tools such as PlantEye F500 provide accurate and objective data, which is essential for scientific analysis and decision-making in agriculture. These tools help not only to identify differences between control and experimental groups, but also to evaluate the effectiveness of various agricultural practices, which ultimately contribute to the productivity and sustainability of agroecosystems.

The increase in plant height and biomass indicates an improvement in the physiological state of plants due to the use of innovative methods. This, in turn, contributes to higher yields and product quality. The improvement in photosynthetic activity of plants in the experimental groups also indicates the effectiveness of the applied methods. A higher level of photosynthesis means that plants are able to use sunlight more efficiently to synthesize organic matter, which directly affects their growth and development. The analysis of the selected soil and plant samples showed that the experimental groups had better nutrient uptake, which is an important indicator of the effectiveness of integrated pest management and biological products. The content of the main macronutrients such as nitrogen, phosphorus, and potassium in the soil and plants was higher compared to the control groups. In particular, the nitrogen content in the soil of the experimental groups was 120-130 mg/kg, while in the control groups this figure was 90-100 mg/kg. A similar trend was observed for other nutrients: the phosphorus content in the experimental groups was 45-50 mg/kg, while in the control groups this figure did not exceed 30-35 mg/kg. The potassium content in the soil of the experimental groups reached 200-210 mg/kg, compared to 150-160 mg/kg in the control groups. The increased content of nutrients in the soil and plants of the experimental groups indicates improved assimilation and efficiency of fertilizers in combination with biological products. This may be due to improved biological activity of the soil, stimulation of root growth and increased ability of plants to absorb nutrients. This confirms the effectiveness of using biofertilisers and organic composts, which help to improve soil fertility and provide plants with the necessary nutrients. Improved plant nutrition has a positive impact on plant growth, development, and yield. Higher concentrations of nutrients in the soil ensure more robust plant growth, allowing them to better withstand stressful conditions such as droughts or low temperatures.

After harvesting, the weight, moisture, protein, and fibre content of the grain was analysed (Table 3). In the experimental groups, wheat had a higher protein content (14-15%) compared to the control groups (11-12%). The fibre content in the experimental groups was also significantly higher – 30-32% compared to 25-27% in the control groups. This indicates the improved quality of the grain, which makes it more attractive to consumers and processors. High-quality grain has a higher market value, which contributes to higher farmers' incomes. Higher protein content ensures better nutritional and feed value of the products, which is an important factor for food security.

***Table 3**. Indicators of wheat grain quality in control and experimental groups*

Year	Indicator	Control group	Experimental group
2021	Protein content (%)	11	14
2021	Fibre (%)	25	30
2022	Protein content (%)	12	15
2022	Fibre (%)	27	32
2023	Protein content (%)	11.5	14.5
2023	Fibre (%)	26	31

***Source:** compiled by the authors*

The economic analysis showed that the introduction of innovative methods of growing grain crops significantly reduced production costs and increased gross income and profit from the sale of the crop. The increase in yields by 1.8-1.9 tonnes/ha provided additional profit due to the increase in production volumes. Reducing the cost of water and plant protection products helped to reduce production costs, which also had a positive impact on the economic performance of the companies. The profitability of production in the experimental groups increased by 25-30% compared to the control groups, and the gross profit per hectare exceeded the control groups' figures by 15-20%. A comparison of the effectiveness of different methods showed that the use of innovative varieties and biofertilisers had the greatest impact on increasing yields. Innovative irrigation methods have contributed to a significant reduction in water consumption, which is critical in a region with limited water resources. The use of biological products has reduced the cost of plant protection products and improved the environment. The relative impact of each method was assessed by calculating indices of impact on yield, water consumption and crop protection costs, which provided a holistic picture of the effectiveness of different agricultural practices.

The use of innovative plant varieties has proved to be one of the most effective methods, leading to a 20-25% increase in yields (Fig. 1). These varieties have improved genetic characteristics that provide them with greater resistance to diseases and pests, as well as increased productivity compared to control varieties.

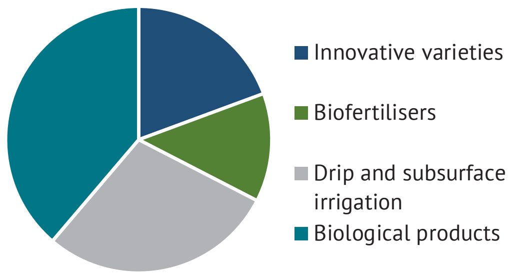

***Figure 1**. Relative impact of different innovative methods in the cultivation of grain crops*
***Source:** compiled by the authors*

The introduction of biofertilisers also had a significant impact on yields, increasing them by 15-20%. Biofertilisers help to improve soil structure, increase its fertility and stimulate plant growth due to the content of beneficial microorganisms and organic matter. Drip and sub-surface irrigation systems have demonstrated high efficiency in reducing water consumption by 35-40%. These systems provide targeted moisture to the root zone of plants, which significantly reduces water loss through evaporation and surface run-off, while ensuring optimal conditions for plant growth. The use of biological products to protect plants from pests and diseases has reduced the cost of plant protection products by 45-50%. Biological products are more environmentally friendly and less toxic to the environment than traditional chemicals, making them an attractive choice for sustainable agriculture (Ivanova *et al.*, 2022).

One of the important benefits of implementing innovative methods is the positive impact on the environment. The use of biological products and bio-fertilisers has significantly reduced the chemical load on soil and water resources. Reducing the use of chemical plant protection products helps to preserve biodiversity and improve water quality. Drip and sub-surface irrigation systems have reduced water losses through evaporation and infiltration, which helps to conserve water resources in the region. This is especially important in the context of climate change, when frequent droughts can negatively affect yields. The use of innovative varieties that are resistant to drought and high temperatures has significantly increased the plants' resistance to stressful conditions. This is critical in the context of climate change, when extreme weather conditions can significantly reduce the yield of traditional varieties. Innovative varieties ensure stable yields even in conditions of low rainfall and high temperatures.

The introduction of innovative grain growing methods also has an important socio-economic impact. Increased yields and product quality contribute to the growth of agricultural revenues, which has a positive impact on the economic development of the region. Increasing the profitability of agriculture helps to create new jobs and improve the living standards of the local population. Reducing the chemical burden on the environment improves people's quality of life by reducing the risk of diseases associated with soil and water pollution. The introduction of environmentally friendly farming methods contributes to the development of organic farming, which is in high demand on the domestic and foreign markets.

Thus, the introduction of innovative methods of growing grain crops has led to a significant increase in yields, product quality and economic efficiency. The use of innovative varieties, bio-fertilisers, biological products and improved irrigation systems has led to a significant reduction in water and plant protection products costs, improved environmental conditions and increased plant resilience to climate change. These results confirm the feasibility of introducing innovative technologies in agriculture that ensure sustainable production of high-quality products and conservation of natural resources.

DISCUSSION

The results of the study show a significant potential for innovative approaches to growing grain crops in the Southern Steppe of Ukraine. The use of the latest varieties, efficient irrigation systems and biological products has significantly increased yields, reduced inputs and improved product quality. This research is an important step towards ensuring food security and economic development in the region, especially in the face of climate change, which is increasing the challenges for traditional agriculture. The results obtained in the Mykolaiv region showed that the yields of the innovative varieties Stepova 1 and Dniprovska 1 are 5.2-5.7 tonnes/ha, which is 1.8-1.9 tonnes/ha higher than the control groups. The high protein (14-15%) and fibre (30-32%) content in the grain also indicates an improvement in product quality, which is important for domestic and foreign markets. Research by S.K. Singh *et al.* (2022) confirms that the use of drought-resistant varieties can significantly increase yields in regions prone to climate change, and a study by E.A. Chapman *et al.* (2022) shows that the introduction of the latest drought-resistant wheat varieties can increase yields by 20-25% in similar climatic conditions, which confirms the findings.

The results of the study of the introduction of new cereal varieties of the Southern Steppe of Ukraine are also consistent with the work of Y.Q. Fu *et al.* (2021), who investigated the impact of drought-tolerant maize varieties under similar climatic conditions in the Mexican Central Plain. He found that yields increased by 18-22% compared to traditional varieties. In a similar context, B. Basso *et al.* (2021) conducted a study in north-western India, where drought is also a problem. The results showed that the newest wheat varieties specially developed for arid conditions showed a 15-18% increase in yield, which confirms the conclusions about the effectiveness of the newest wheat varieties Stepova 1 and Dniprovska 1. Increased yields under conditions of limited water supply demonstrate the importance of crop adaptation to climate change.

The data of the above study also indicate a 45-50% reduction in the cost of crop protection products when using integrated pest management and biological products, which is confirmed by G. Albahri *et al.* (2023) and N. Pérez-Méndez *et al.* (2021). They note that biological methods can significantly reduce the cost of chemical plant protection products and reduce the chemical burden on the environment. The study by E. Elahi *et al.* (2022), P. Langridge and M. Reynolds (2021) also highlight the effectiveness of modern irrigation systems. They have shown that drip irrigation can reduce water consumption by up to 30-40%, which is consistent with the results in the Mykolaiv region (35-40% reduction). According to studies by H.J. Smith *et al.* (2022) and A. Périnelle *et al.* (2021), the use of drip irrigation in combination with moisture sensors can optimize water resources, reducing water consumption by 30-40%, which is fully consistent with the findings of the above study.

The above study also showed that the use of bio-fertilisers and organic composts increases the levels of nitrogen, phosphorus, and potassium in the soil. Comparison of the results shows that the experimental groups in the Mykolaiv region had higher nitrogen levels (120-130 mg/kg versus 90-100 mg/kg in the control groups), which contributes to more sustainable plant growth. This is consistent with the findings of A. Saini *et al.* (2022) and C. Bihari *et al.* (2023), who note that organic fertilizers can improve soil structure and increase soil fertility. The study by N. Carton *et al.* (2022) in Argentina and Y.I. Atta *et al.* (2021) in Brazil, which studied the impact of organic fertilizers on soil fertility and soybean yields, also confirm the results of our study. They showed that the use of organic fertilizers increased soil nitrogen levels to 135 mg/kg and 128 mg/kg, respectively, which is similar to the results in the Mykolaiv region, where nitrogen levels increased to 120-130 mg/kg. This demonstrates the effectiveness of organic fertilizers in improving soil fertility and increasing grain yields.

The economic analysis also confirmed that the introduction of innovative methods can reduce production costs and increase the profitability of agricultural enterprises (Mamchur & Studinska, 2024). In the Mykolaiv region, yields are 1.8-1.9 tonnes/ha higher than in the control groups, which generates additional profit through increased production volumes. Reduced water and crop protection costs also contribute to economic growth. X. Zhu and L. Marcelis (2023) also note that the use of the latest varieties and biofertilisers increases the economic efficiency of agricultural production. Comparison with the study by M. Dimitrijević *et al.* (2022) in Canada, who studied the economic efficiency of the latest technologies in grain production, shows similar results in terms of increased profitability. The use of innovative methods in India, described by M.A.S. Raza *et al.* (2023), increased profitability by 20-30%, which is consistent with the findings on the cost-effectiveness of introducing new varieties and irrigation systems in the Southern Steppe of Ukraine. Reducing the cost of water and plant protection products contributes to an increase in farm profits, which is an important factor for sustainable agricultural development (Bobos *et al.*, 2019).

Optimisation of water resources through the use of moisture sensors and automated irrigation control systems in the Mykolaiv region has reduced water consumption and ensured stable soil moisture, which is critical in times of water shortage. The results are consistent with international research. For example, the study by N. Sarwar *et al.* (2021) in the United States showed that the use of drought-tolerant wheat varieties can increase yields by 20-25% in regions with similar climatic conditions. Data on yield increases of 1.8-1.9 tonnes/ha in the Mykolaiv region confirm these findings. Z. Zhang *et al.* (2021) and M. Kumaresan *et al.* (2023) in China, who studied the effectiveness of drip irrigation in rice cultivation, also confirm the effectiveness of modern irrigation systems. They showed that drip irrigation reduces water consumption by 30-40%, which is consistent with the results obtained in the Mykolaiv region.

The study also showed that innovative methods can have a positive impact on the environmental sustainability of agroecosystems. The use of organic fertilizers increases the level of nitrogen, phosphorus, and potassium in the soil, which helps to improve yields and plant resistance to stress factors (Zaiets *et al.*, 2022). Compared to the control groups, which used conventional methods, the experimental groups showed significantly better results in all indicators. The nitrogen content in the soil increased to 120-130 mg/kg, which is important for healthy plant growth and increased productivity. The study by S. El-Hendawy *et al.* (2022) in the United States showed that the use of organic fertilizers reduces greenhouse gas emissions by 30% compared to traditional chemical fertilizers. The implementation of such methods not only reduces the negative impact on the environment, but also improves soil quality by improving its structure and increasing the level of organic matter. This is also consistent with the results of the study by R. Kumar *et al.* (2023), which noted a significant increase in soil nutrient levels when using organic fertilizers. This is an important aspect for reducing the impact of agriculture on climate change and confirms the need to introduce environmentally friendly methods in the Southern Steppe of Ukraine.

Thus, the comparison of the results of this study with the works of other authors confirms the effectiveness of innovative approaches to growing grain crops in the Southern Steppe of Ukraine. The use of the latest varieties, irrigation systems and biological products can increase yields, reduce inputs and improve product quality, which is important for food security and economic development in the region.

CONCLUSIONS

The study found that the application of innovative approaches to growing grain crops in the Southern Steppe of Ukraine significantly increases their yield, economic efficiency and environmental sustainability. The use of the latest varieties of wheat and barley, such as Stepova 1, Dniprovska 1 and Pivdennyi 1, has resulted in yields of 5.2-5.7 tonnes/ha, which is 1.8-1.9 tonnes/ha more than in the control groups. The high protein (14-15%) and fibre (30-32%) content in the grain confirms the improvement in product quality. The use of drip and sub-surface irrigation systems has contributed to a significant reduction in water consumption by 35-40%, which is critical given the water shortage in the region. The use of bio-fertilisers and organic composts has increased the levels of nitrogen, phosphorus, and potassium in the soil, demonstrating the effectiveness of these methods in improving soil fertility. Integrated pest management and the use of biological products have reduced the cost of crop protection products by 45-50%, which reduces the chemical burden on the environment and improves the ecological situation. These results were of great importance for increasing the productivity and sustainability of agriculture in the face of climate change. Innovative methods can reduce the use of resources, lower production costs and increase the economic efficiency of agricultural enterprises. The introduction of such methods contributes to food security and economic development in Ukraine.

The limitation of the study is that it covered only a certain period of time and a specific region, which may affect the universality of the results. In addition, some aspects of the impact of innovative methods on long-term environmental sustainability require more detailed study. Nevertheless, the results clearly demonstrate the benefits of innovative approaches to grain growing and can serve as a basis for further research and implementation in agricultural practice. To further improve the results obtained, it is recommended to conduct additional research on the adaptation of innovative methods to different local conditions, as well as to investigate the long-term effects of the use of biological products and biofertilisers. It is also important to develop educational programmes and trainings for farmers to enable them to effectively use the latest technologies and increase the productivity of their farms.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Інноваційні підходи до вирощування зернових культур у Південному Степу України

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Анотація. Метою дослідження був аналіз впливу інноваційних підходів до вирощування зернових у Південному Степу України. Під час дослідження використовувалися новітні сорти рослин, ефективні системи зрошення та біопрепарати для підвищення врожайності та стійкості культур. Було застосовано сорти пшениці «Степова 1» та «Дніпровська 1», а також ячмінь «Південний 1», які відзначаються високою стійкістю до посухи та високих температур. Використовувалися системи крапельного та підповерхневого зрошення, а також біодобрива та органічні компости для покращення структури ґрунту та підвищення його родючості. Основні результати дослідження показали, що врожайність пшениці в експериментальних групах досягала 5,2-5,7 тонн/га, що на 1,8-1,9 тонн/га більше, ніж у контрольних групах. Витрати води в експериментальних групах знизилися на 35-40%, а витрати на засоби захисту рослин – на 45-50 %. Вміст білка у пшениці експериментальних груп становив 14-15 %, а клітковини – 30-32 %, тоді як у контрольних групах – відповідно 11-12 % та 25-27 %. Аналіз ґрунту в експериментальних групах показав вищий рівень азоту, фосфору та калію, що свідчить про ефективність застосування біодобрив. Крім того, використання біопрепаратів сприяло зниженню хімічного навантаження на навколишнє середовище. Отримані результати свідчать про значне підвищення продуктивності, зменшення використання ресурсів та покращення екологічної стійкості при впровадженні інноваційних методів вирощування зернових культур у цьому регіоні, що є важливим для забезпечення продовольчої безпеки та економічного розвитку України

Ключові слова: пшениця; ячмінь; біодобрива; крапельне зрошенння; біопрепарати; родючість