UDC: 633.1(477)
DOI: 10.56407/bs.agrarian/4.2023.09

Ukrainian Black Sea Region Agrarian Science
Vol. 27, No. 4

Agroecological substantiation of technologies for growing grain crops in the conditions of the Southern Steppe of Ukraine

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Abstract. Agroecological substantiation of cereal crops cultivation technologies becomes especially relevant in conditions of insufficient moisture, as it requires sustainable and efficient agro-production systems that ensure high yields and preserve natural resources. The aim of the study is to determine the impact of nitrogen fertilisation on the growth and development of winter wheat in an arid climate. To achieve this goal, a field study was conducted at the fields of the Educational and Research Centre of Mykolaiv National Agrarian University to study mineral nutrition and the impact of different nitrogen rates on the structure and quality of winter wheat grain yield. The study found that increasing nitrogen fertiliser rates has a positive impact on crop growth and yield. The application of higher nitrogen rates, in particular N_{60} and N_{80} in spring fertilisation, increases plant height by 3.8 and 4.6 cm, respectively, compared to N_{30}. In addition, a double increase in nitrogen fertiliser rates resulted in a 3.5% increase in the number of productive stems and a 13.6% increase in the weight of 1,000 seeds. Mineral fertilisers also had a significant impact on winter wheat yields, with $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$ yielding 51.8 and 49.3 c/ha, respectively. The results of laboratory studies confirmed that nitrogen fertilizers in an increased amount lead to a decrease in the starch content in winter wheat grains, while simultaneously increasing the protein content. Correlation analysis showed a tendency to increase the yield of winter wheat with higher application of nitrogen fertilizers, however, in order to avoid deterioration of the quality of crop products, it is important to follow the recommendations. The practical significance of the obtained results lies in optimizing the cultivation of grain crops, as well as increasing their yield in conditions of limited water resources and the threat of drought

Keywords: winter wheat; fertiliser; yield; plant nutrition; dry conditions

INTRODUCTION

In today's world, agri-environmental issues are becoming increasingly relevant, as agriculture is a key sector that ensures food security and economic development. Climate change, population growth and volatile agricultural markets require the development and implementation of environmentally sustainable and

Article's History:
Received: 12.09.2023
Revised: 20.11.2023
Accepted: 12.12.2023

Suggested Citation:
Drobitko, A., & Kachanova, T. (2023). Agroecological substantiation of technologies for growing grain crops in the conditions of the Southern Steppe of Ukraine. *Ukrainian Black Sea Region Agrarian Science*, 27(4), 9-17. doi: 10.56407/bs.agrarian/4.2023.09.

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productive agricultural technologies. In the Southern Steppe of Ukraine, which has significant potential for agricultural production, this relevance is most evident through the above challenges and opportunities.

Modern agriculture faces numerous challenges, such as climate change, rapid population growth, global competition and the need to ensure environmental sustainability. To address these challenges, new technologies and crop production strategies are needed. M. Ivasyk & M. Bakhmat (2023) in their study emphasise that it is important to strive for high productivity, conservation of resources and the environment, as well as to ensure product quality and access to global markets.

A number of authors, such as J. Wang *et al.* (2021) and L.N. Jørgensen *et al.* (2020), argue that the main aspects of the agroecological approach to crop production include site selection, selection of varieties and hybrids, use of efficient agronomic practices, water management, monitoring and control of negative impacts, biodiversity conservation, and promotion of environmental awareness among farmers and consumers. Macronutrients, as integral components of important physiologically active substances, help to increase the activity of enzymes in plants, improve their ability to absorb essential nutrients and increase photosynthetic productivity and assimilation activity. The addition of mineral fertilisers has a number of beneficial effects for plants and crops. It increases the resistance of plants to adverse environmental conditions and makes them less susceptible to pests and diseases. This leads to higher yields and improved grain quality (Sallam *et al.,* 2019).

The cultivation of winter wheat is crucial for its yield. The fertilisation system for this crop includes the application of various types of nutrients. This is necessary due to the fact that winter wheat requires a large amount of nutrients for its proper growth and development, and most of these nutrients are often not available to plants in the required quantities in the soil. Nutrient deficiencies in the soil can lead to reduced yields, poor seed quality and an increased risk of disease and pest infestation. Therefore, it is important to provide winter wheat with the necessary amount of nutrients by applying fertiliser in appropriate amounts and at the optimal time, as shown in study A. Ren *et al.* (2019).

Ye. Kuzmenko *et al.* (2023) believe that the scientific and agro-ecological justification of growing cereal crops in Ukraine is an important task in the context of ensuring food security, sustainable use of natural resources and biodiversity conservation. The authors pay particular attention to the Southern Steppe of Ukraine, which is an important agricultural area but also faces a number of agro-ecological challenges and constraints. This region has unique natural conditions, but at the same time is vulnerable to threats such as drought, soil erosion, waterlogging, water pollution, and others.

According to M. Solodushko *et al.* (2021), the agro-ecological justification of grain growing technologies also affects the conservation of nature and public health. Healthy ecosystems not only ensure sustainable agricultural production, but also provide natural balance, maintain species diversity, and regulate climate processes. Prevention of soil and water pollution also affects the quality and safety of food for the population. Thus, the agro-ecological justification of crop cultivation technologies has a deep social and environmental context and relevance, and determines the future of agriculture and the environment in the Southern Steppe of Ukraine.

V. Gamayunova *et al.* (2020) point out that grain farming in Ukraine is one of the main sectors of the agricultural complex, and its development largely determines the production of food and feed resources, as well as affects the economy as a whole. Modern grain varieties, including winter wheat, have a high potential yield of up to 7 tonnes of grain per hectare, but average yields in Ukraine remain significantly lower.

The aim of the study was to investigate the impact of mineral fertilisation on the growth and development of winter wheat in the Southern Steppe of Ukraine. To achieve this goal, the following objectives were set: to study the peculiarities of mineral nutrition of winter wheat and its fertiliser requirements, as well as to determine the impact of nitrogen fertiliser rates on the yield and quality of winter wheat.

MATERIALS AND METHODS

To determine the productivity of winter wheat, a field experiment was conducted using laboratory and field observations of the growth and development of the crop grown under different conditions of mineral fertilisation. The study was conducted in 2020-2022 on the fields of the Educational and Research Centre (ERC) of Mykolaiv National Agrarian University. The study complies with all ethical standards under The Convention on Biological Diversity (2022).

The soil of the experimental plots is southern black soil on carbonate loess, characterised by high potassium, medium phosphorus and low nitrogen content. The soil has a medium loamy texture, with a humus horizon of up to 50-65 cm and a humus content of approximately 3.5%. The content of mobile forms of phosphorus is 8.8-9.6 mg per 100 soil, easily hydrolysed nitrogen in the soil is about 0.1-0.4 mg per 100 soil, and exchangeable potassium is about 30.3 mg per 100 soil. The soil reaction of the experimental plot (pH) is 7.5.

Since climatic conditions have a great influence on the formation of winter wheat grain yield, it is important to note that the study was conducted in an area that belongs to the zone with insufficient rainfall, and all years of research were characterised by a shortage of precipitation. The experiment was replicated three times, with a total plot size of 350 m^2 and an area of 80 m^2 per plot. Perennial grasses were the predecessor of winter wheat. Winter wheat was sown between 25 and 30 September, with a seeding rate of 220 kg per 1 ha or 4.5-5 million/ha of germinating seeds.

Organic fertiliser (manure) was applied to the soil for autumn ploughing before sowing winter wheat at a rate of 25 t/ha in all experimental variants. In addition, phosphorus-potassium fertilisers were applied at a rate of $P_{30}K_{30}$ during winter ploughing, and nitrogen fertilisers were applied in spring according to the appropriate scheme: Option I – N_{30}, Option II – N_{60}, Option III – N_{80}. The method of fertilisation with nitrogen fertilisers was to apply them during early spring fertilisation on frozen soil and at the beginning of the phase of winter wheat emergence into the tube. Urea was used as a nitrogen fertiliser, potassium chloride as a potassium fertiliser, and granular superphosphate as a phosphorus fertiliser.

Correlation and regression analysis was used to confirm the reliability of the results. This method is a powerful tool for establishing relationships between different variables. In the present study, this analysis was used to determine the relationship between mineral fertiliser use, winter wheat grain yield and starch and protein content in the grain. In addition, this analysis allowed us to build a model that can predict winter wheat yields depending on the use of mineral fertilisers.

The data of winter wheat growth parameters, such as plant height, number of productive stems and weight of 1,000 seeds, were obtained by measuring, counting and weighing, and the leaf area was determined by the method of notching. The starch content of seeds was determined using a Shimadzu UV-1800 spectrophotometer (Shimadzu, Japan), and the protein content was determined by refractometric method. Winter wheat grain yield was determined manually from each plot separately. During the data analysis, statistical analysis was also performed to determine the average and relative values of the effect of the level of mineral fertilisation on the yield, and comparative analysis was performed to compare the data obtained.

All experiments were repeated three times for each variant of the experiment. To verify the reliability of the research results, the multivariate method of analysis of variance MANOVA was used, which was conducted using Microsoft Excel software and Statistica 10 software package. Differences between the results obtained were defined as statistically significant if the significance level (P) was less than or equal to 0.05 according to the Student's criterion.

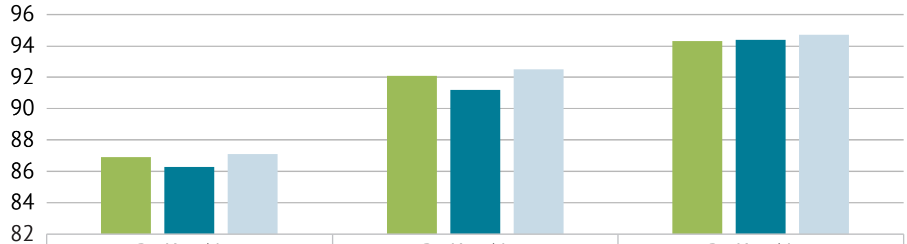
RESULTS

An important component of the fertilisation system for winter wheat is the application of the optimal amount of macro- and microelements required to meet the needs of the plants. To achieve this, both organic and mineral fertilisers can be used. Determining the optimal fertilisation system for winter wheat is a complex task, as it depends on numerous factors that can be difficult to control. These factors include climatic conditions, soil type, weather, plant variety, soil moisture availability, soil nutrient availability, and others. Therefore, the optimal fertilisation system may vary depending on the specific growing conditions (Serrago *et al.,* 2013).

An important aspect is the timely application of nitrogen fertilisers at different stages of plant organogenesis. This allows to effectively influence the formation of grain yield structure indicators, such as plant density and size. Phosphorus and potassium are equally important for the growth and development of winter wheat, particularly in the early stages of growth, when the root system and winter hardiness of plants are formed. The use of large doses of nitrogen fertilisers in the early stages of organogenesis can have a suppressive effect on young plants, so it is important to avoid their large application during pre-sowing cultivation and during sowing. However, a lack of nitrogen at these stages can negatively affect plant development and reduce yields.

One of the research objectives was to study the peculiarities of mineral nutrition of winter wheat and its fertiliser requirements, so it is important to note that to obtain a winter wheat yield of 1 tonne of grain per hectare, the following amounts of macronutrients should be provided: nitrogen – 30-35 kg, phosphorus – 10-13 kg, potassium – 20-25 kg (Holman *et al.,* 2023). As for the inheritance of plant height, this indicator is stable and genetically dependent, but environmental conditions, in particular stress factors, can significantly change this parameter. In addition, plant height can vary significantly depending on certain factors, including the year of cultivation, plant variety and environmental conditions. For example, under ideal conditions of soil moisture and nutrient supply, plants will be taller than under conditions of drought and insufficient soil nutrition (Ahmad *et al.,* 2022).

In this study, the application of different rates of nitrogen fertilisers in winter wheat crops had a significant impact on crop height over three years. It was found that an increase in nitrogen fertiliser rates promotes higher growth of winter wheat plants. Thus, in the variant of $P_{30}K_{30}+N_{30}$ application, the average plant height was 86.8 cm over the years of study. Improvement of the nutrition background in the variants $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$ contributed to an increase in the height of winter wheat plants by 3.8 and 4.6 cm, respectively (Fig. 1).



	$P_{30}K_{30}+N_{30}$	$P_{30}K_{30}+N_{60}$	$P_{30}K_{30}+N_{80}$
2020	86.9	92.1	94.3
2021	86.3	91.2	94.4
2022	87.1	92.5	94.7

Figure 1. *Effect of fertiliser on the height of winter wheat plants, cm*
Source: *compiled by the authors*

The formation of high-yielding winter wheat crops depends on the size and photosynthetic activity of its leaf surface. Optimisation of photosynthesis and efficient use of solar energy are key factors for increasing grain yields. In the arid conditions of southern Ukraine, insufficient development of the leaf surface is the main limiting factor for achieving high crop productivity. The application of mineral fertilisers, especially nitrogen, which is part of chlorophyll, plays an important role in the formation of the leaf apparatus. By improving the nutritional regime, it is possible to increase the size and productivity of the leaf surface of plants, which affects their photosynthetic activity. According to the data obtained as a result of the study, during the growing season, winter wheat plants fertilised with higher rates of nitrogen fertilisers in the variants $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$ had a larger leaf surface compared to the variant $P_{30}K_{30}+N_{30}$. The leaf surface reached its largest size at the earing stage in all experimental variants (Table 1).

Table 1. *Effect of fertilisation on the leaf area of winter wheat, thousand m²/ha (average for 2020-2022)*

Variant of the experiment	Scheme of application of mineral fertilizers	Phase of development		
		tillering	output tube	earing
1	$P_{30}K_{30}+N_{30}$	12.3	17.2	22.4
2	$P_{30}K_{30}+N_{60}$	14.4	20.1	27.1
3	$P_{30}K_{30}+N_{80}$	14.8	23.7	29.1

Source: *compiled by the authors*

In addition, it was found that different amounts of nitrogen fertiliser in winter wheat crops affected the yield structure of the crop for three years, namely the number of productive stems and the weight of 1,000 seeds. Productive stems are those stems that develop and form ears of grain. The number of productive stalks in winter wheat can vary depending on many factors, including sowing density, fertiliser use, weather conditions and plant variety. Achieving the optimum number of productive stems helps to ensure a good winter wheat harvest and increase the efficiency of agricultural production. To increase the number of productive stems, agricultural practitioners can use various agronomic measures, including optimal sowing density, timely and rational fertilisation, selection of plant varieties with higher productivity, etc. (Bilousova *et al.*, 2021).

The study found that at the level of fertilisation of $P_{30}K_{30}+N_{60}$, the largest number of productive stems was formed, which was 561 pcs. It should also be noted that the use of mineral nutrition also affected the weight of 1,000 seeds of winter wheat, despite the fact that this is a genetically determined trait. Thus, at the level of fertilisation of $P_{30}K_{30}+N_{60}$, the highest weight of 1,000 seeds was noted – 55.3 g (Table 2). Consequently, the number of productive stems was 3.5% higher with $P_{30}K_{30}+N_{60}$ than with $P_{30}K_{30}+N_{30}$, and the weight of 1,000 seeds was 13.6% higher, respectively. Therefore, it should be noted that the increase in the structural parameters of the winter wheat crop in the study was due to the supply of a sufficient amount of nutrients from mineral fertilisers, which influenced the growth and development of plants.

Table 2. *Number of productive stems and weight of 1,000 seeds of winter wheat (average for 2020-2022)*

Variant of the experiment	Scheme of application of mineral fertilizers	Number of productive stems, pieces/m^2	Weight of 1,000 seeds, g
1	$P_{30}K_{30}+N_{30}$	542	48.7
2	$P_{30}K_{30}+N_{60}$	561	55.3
3	$P_{30}K_{30}+N_{80}$	553	54.8

Source: *compiled by the authors*

The results of the study also showed that the application of mineral fertilisers had a significant impact on the yield of winter wheat. On average, over three years, the highest yields were formed by applying $P_{30}K_{30}+N_{30}$ and $P_{30}K_{30}+N_{80}$, and amounted to 51.8 and 49.3 c/ha, respectively, indicating that the level of mineral fertiliser supply is adequate. In particular, nitrogen fertilisers, contributes to the productivity of winter wheat (Table 3).

Table 3. *Winter wheat yield, tonnes per hectare*

Variant of the experiment	Scheme of application of mineral fertilizers	Year			Average for 2020-2022
		2020	2021	2022	
1	$P_{30}K_{30}+N_{30}$	48.6	49.1	48.9	48.9
2	$P_{30}K_{30}+N_{60}$	51.9	52.2	51.4	51.8
3	$P_{30}K_{30}+N_{80}$	49.4	48.8	49.6	49.3
$HIP_{0.05}$		1.26	1.37	1.31	1.19

Source: *compiled by the authors*

The starch and protein content of wheat seeds is important for the quality and use of this crop. In particular, starch is the main type of carbohydrate in wheat grain. The starch content affects the structure and texture of wheat products. The high starch content helps wheat grains to form a dense texture, which makes them excellent for bread making. The protein content also affects the quality of flour and other wheat products. The higher the protein content, the higher the nutritional and technological value of the grain. It has been established that the application of mineral fertilisers, in addition to the yield of winter wheat grain, has an impact on its starch and protein content. Thus, according to the data obtained in laboratory conditions, the starch content decreased with an increase in the rate of nitrogen fertiliser application, but the protein content, on the contrary, increased with the application of higher nitrogen rates (Table 4).

Table 4. *Starch content in seeds and protein in winter wheat grain, % (average for 2020-2022)*

Variant of the experiment	Scheme of application of mineral fertilizers	Starch content	Protein content
1	$N_{30}P_{40}K_{30}$	66.8	14.8
2	$P_{30}K_{30}+N_{30}$	62.6	16.4
3	$P_{30}K_{30}+N_{60}$	64.4	17.2

Source: *compiled by the authors*

Thus, according to the results obtained, the indicators of crop structure and quality characteristics of grain, as well as its yield, are significantly influenced by the rates of nitrogen fertiliser application. According to the correlation and regression analysis, there is a tendency to increase the yield and protein content of winter wheat grain with an increase in the level of mineral fertilisers. The value of reliability for yield is $R^2 = 1$, for protein content – $R^2 = 0.9643$. At the same time, a tendency to decrease the starch content in grain with an increase in nitrogen fertiliser application was found, with a reliability value of $R^2 = 1$. This means that the model accurately describes the available data (Fig. 2).

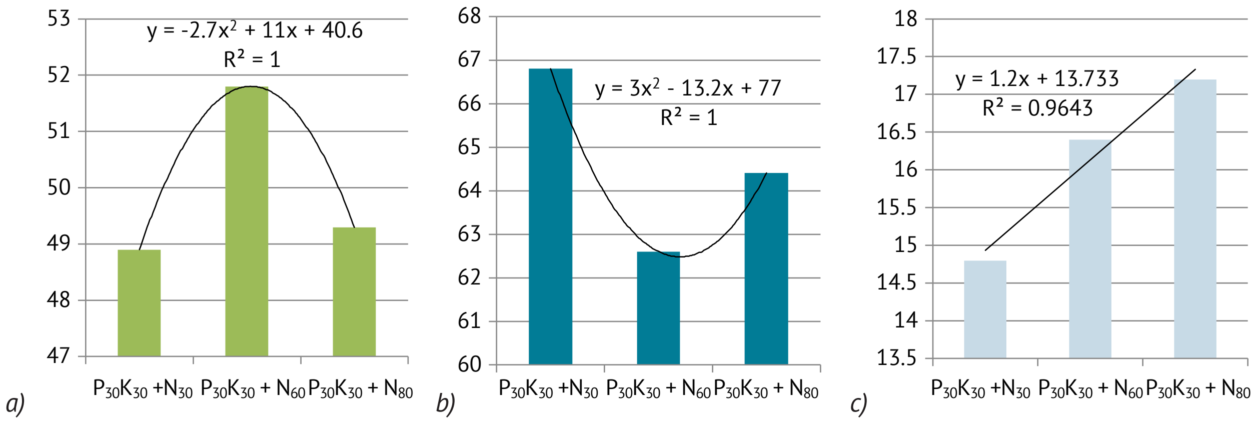


Figure 2. *Correlation and regression analysis of the effect of mineral fertilisers*

Notes: *a) grain yield of winter wheat; b) starch content in grain; c) protein content in grain*

Source: *compiled by the authors*

Thus, the study found that increasing the dose of nitrogen fertiliser can lead to an increase in the number of productive stems, plant height, leaf area, 1,000 seed weight and protein content in winter wheat grain. In addition, it has also led to increased yields, even in arid climates. Thus, it can be noted that in the conditions of insufficient moisture in the Southern Steppe of Ukraine, the methods of growing grain crops have a scientific agroecological justification.

DISCUSSION

Confirmation of the study can be found in the works of M. Solodushko *et al.* (2021), according to which the conditions of insufficient moisture supply in the Southern Steppe of Ukraine require a scientifically sound agroecological approach to grain growing technologies. This approach involves taking into account natural conditions, climatic features and water supply sources to ensure a stable harvest and preserve the environment.

The Southern Steppe region of Ukraine is characterised by a "non-flushing" water regime. This means that moisture enters the soil mainly as a result of precipitation, and there is no significant water flushing through the soil profile. The growing season of agricultural crops is characterised by a lack of moisture, and the main factor in replenishing soil moisture is autumn and winter precipitation, while in summer precipitation evaporates quickly. That is why a significant part of the moisture is retained in the surface layers of the soil, making it difficult for plants to access water. An important problem in this region is the conservation and rational use of moisture reserves to ensure crop yields (Gamayunova *et al.*, 2020).

L. Skinulienė *et al.* (2022) consider that the fertilisation system for winter wheat includes the application of different types of fertilisers with different concentrations and amounts, taking into account agronomic practices, soil type, climatic conditions and other factors. The main components of fertiliser for winter wheat include nitrogen, phosphorus, potassium and various trace elements. This integrated approach to fertilisation helps to achieve optimal results in growing the crop. Y. Su *et al.* (2021) in their research believe that organic fertilisers, unlike inorganic fertilisers, tend to decompose slowly, which allows them to gradually release nutrients into the soil over a long period of time. This ensures that winter wheat is nourished sustainably and over a long period of time, contributing to its sustainable growth and development throughout the growing season. Inorganic fertilisers, on the other hand, have a more concentrated composition and can provide a quick, intense boost to plants. They typically contain significant amounts of nitrogen, phosphorus, potassium and other essential nutrients, which can promote rapid growth and development of winter wheat. Both approaches have their advantages and disadvantages, and the choice between them usually depends on the specific growing conditions and the purpose of the agricultural production.

J. Wang *et al.* (2021) argue that integrated fertilisation has a significant effect on the gluten content of grain, which is explained by an increase in protein and reserve fractions such as prolamins and glutenins. This integrated approach helps to improve the quality of grain, in particular, by increasing the gluten content, which is an important parameter for the production of bread and other food products. Similar results were obtained in the study by M.A. Bukhari *et al.* (2021), where the authors indicate that the combined application of nitrogen fertilisers together with phosphate and potassium fertilisers leads to an increase in protein content in winter wheat grain. These results highlight the importance of integrated fertilisation to improve the quality and productivity of this crop.

However, Ye. Kuzmenko *et al.* (2023) note that it is important to consider that excessive nitrogen fertilisation can have a negative impact on plant development and crop quality. Excessive amounts of nitrogen can lead to an increase in plant height and a delay in the formation of generative organs. In addition, excessive nitrogen can lead to increased water retention in the plant and an increased risk of disease and pest spread. Therefore, it is important to follow the recommendations on the optimal doses of nitrogen fertilisers to achieve the best results in winter wheat cultivation.

The results of the study are echoed in the scientific works of L.N. Jørgensen *et al.* (2020), who argue that the fertilisation system can affect the weight of 1,000 seeds of winter wheat. The authors' research has shown that the application of phosphorus fertilisers improves the formation and development of the plant's root system, providing the necessary energy for its growth, which affects the increase in seed weight. Potassium is also an important element for the growth of winter wheat and maintaining its resistance to stressful conditions such as high or low temperatures. A lack of potassium in the soil can lead to a decrease in seed weight and overall crop yield. The results of the study confirm the importance of optimal use of these elements to achieve the best results in winter wheat cultivation.

The results of the study also coincide with the opinion of R. Vozhehova *et al.* (2021), who call for a careful consideration of mineral nutrition factors in the Southern Steppe of Ukraine. According to their data, winter wheat can achieve significant yields if the recommended mineral nutrition rates are met, which highlights the importance of proper crop care in this region. According to the authors M. Ivasyk & M. Bakhmat (2023), the application of $N_{60}P_{30}$ in autumn and additional nitrate fertilisation at N_{30} in spring ensures maximum leaf area in the tillering and earing phase for cereals, which was also confirmed in the study.

In the work of Y. Li *et al.* (2022) noted a very strong correlation between the leaf surface area in the earing phase and grain yield for cereals when using pre-sowing seed treatment with the biological product Escort-bio ($R^2 = 0.902$), as well as between the leaf surface area in the earing phase and plant height at full grain ripeness ($R^2 = 0.931$). Optimisation of the nutritional background affects the increase in the photosynthetic potential of winter wheat crops by 14-20%, as reported by S. Yue *et al.* (2012). According to the authors, the maximum values were obtained when $N_{60}P_{30}$ was applied before sowing. In addition, it was found that the net productivity of photosynthesis increased in winter wheat crops by 25-60% when the nutritional background was optimised. The maximum values of net photosynthetic productivity were achieved when $K_{30}P_{30}$ was applied before sowing and additional fertilisation with ammonium nitrate at a dose of N_{30}.

According to P. Astrauskas & G. Staugaitis (2022), mineral fertilisers and fertilisations increased the protein content of winter wheat grain from 13.5% when growing plants on unfertilised plots to 15% when optimising the nutritional background, which is also reflected in the study. O. Sydiakina & V. Dvoretskyi (2020) state that the application of mineral fertilisers at the recommended rates and the use of green manure, as well as manure feeding in the amount of 10 t/ha, led to an increase in winter wheat yields by 1.45 t/ha of grain and 1.16 t/ha of straw. Efficiency increases with the use of foliar fertilisation with complex fertilisers, in particular with the organomineral complex Organic D2-M, which additionally ensured the formation of 0.62-0.96 t/ha of grain and 0.50-0.77 t/ha of straw. Optimisation of the nutritional background also improved grain quality by increasing protein and crude gluten content, but variants using the vitamin BF-3 complex were less effective.

Considering these studies of the authors and the results of the study, it can be concluded that a scientifically based agroecological substantiation of grain crops cultivation technologies is critical in the conditions of insufficient moisture in the Southern Steppe of Ukraine. Adherence to agroecological principles and application of scientific methods contribute to increasing the drought resistance of cereals, rational use of water resources and preservation of soil and environmental quality.

CONCLUSIONS

As a result of the research, it was found that increasing the nitrogen fertilizer rates has a significant positive effect on the growth and yield of winter wheat. When applying higher nitrogen rates (options $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$), plant height increased by 3.8 and 4.6 cm, respectively, compared to option $P_{30}K_{30}+N_{30}$. In addition, doubling the rates of nitrogen fertilizers helped to increase the number of productive stems by 3.5% and the weight of 1,000 seeds by 13.6%. The application of mineral fertilizers also had an effect on the yield of winter wheat. Thus, when applying $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{80}$, the grain yield exceeded the option of applying $P_{30}K_{30}+N_{60}$ and $P_{30}K_{30}+N_{30}$ by 2.9 and 0.4 t/ha, respectively. This testifies to the important role of nitrogen fertilizers in ensuring high productivity of winter wheat. Laboratory studies have confirmed that increasing the rates of nitrogen fertilizers helps to reduce the starch content in winter wheat grain, but to increase the protein content, which can affect the quality and use of wheat grain in products. Therefore, increasing the doses of mineral fertilizers can have a positive effect on the yield structure of winter wheat and provide an additional harvest even in the arid conditions of the Southern Steppe of Ukraine. However, it is important to follow the recommendations for applying fertilizers in order not to deteriorate the quality of the products.

In general, science-based agro-ecological approaches to the cultivation of grain crops not only increase the efficiency of agricultural production, but also contribute to the sustainable development of the agricultural sector and the preservation of natural resources in conditions of insufficient moisture. The results of the study help to optimize the cultivation of grain crops, increase their yield and improve the quality of products in arid climate conditions, which will contribute to the sustainability of agricultural enterprises. The conducted analysis revealed a correlation between the increase in the application of nitrogen mineral fertilizers and the increase in the yield of winter wheat. This means that future studies can consider further increases in fertilizer rates of each individual macronutrient, as well as their combined effects on yield structure and crop quality of this crop.

ACKNOWLEDGEMENTS

None.

CONFLICT OF INTEREST

None.

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Агроекологічне обґрунтування технологій вирощування зернових культур в умовах Південного Степу України

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Анотація. Агроекологічне обґрунтування технологій вирощування зернових культур стає особливо актуальним в умовах недостатнього зволоження, оскільки вимагає стійких та ефективних агропродукційних систем, що забезпечують високу врожайність та зберігають природні ресурси. Мета дослідження – визначити вплив внесення азотних мінеральних добрив на ріст і розвиток озимої пшениці в умовах посушливого клімату. Для досягнення цієї мети проведено польове дослідження на полях Навчально-науково-практичного центру Миколаївського національного аграрного університету із вивчення мінерального живлення та впливу різних норм азоту на структуру та якість врожайності зерна озимої пшениці. Результатами дослідження встановлено, що підвищення норм азотних добрив позитивно впливає на ріст та врожайність культури. Внесення вищих норм азоту, зокрема N_{60} та N_{80} у підживлення навесні, впливає на збільшення висоти рослин на 3,8 см і 4,6 см відповідно, порівняно внесення N_{30}. Крім того, подвійне збільшення норм азотних добрив призвело до зростання кількості продуктивних стебел на 3,5 % та маси 1000 насінин на 13,6 %. Мінеральні добрива також суттєво вплинули на врожайність озимої пшениці, так при застосуванні $P_{30}K_{30}$+N_{60} і $P_{30}K_{30}$+N_{80} урожайність зерна становила відповідно 51,8 ц/га та 49,3 ц/га. Результати лабораторних досліджень підтвердили, що азотні добрива у збільшеній кількості призводять до зниження вмісту крохмалю в зерні озимої пшениці, одночасно збільшуючи вміст білка. Кореляційний аналіз засвідчив тенденцію до зростання врожайності озимої пшениці при більшому внесенні норм азотних добрив, проте задля уникнення погіршення якості продукції культури, важливо дотримуватися рекомендацій. Практичне значення отриманих результатів полягає в оптимізації вирощування зернових культур, а також збільшенні їх врожаю в умовах обмежених водних ресурсів і загрози посухи

Ключові слова: озима пшениця; добриво; врожайність; живлення рослин; посушливі умови