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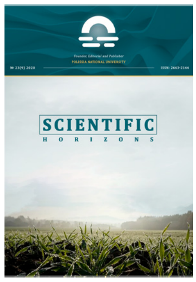

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Yield and Quality of Winter Durum Wheat Grain Depending on the Fertiliser System

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Abstract. At present, winter durum wheat is grown after its unpaired predecessors. Under such conditions, fertiliser is important. Therefore, the study of the yield formation and quality of winter durum wheat grain depending on the fertiliser system is relevant. The purpose of this study was to investigate the yield formation and quality of winter durum wheat grain under various fertiliser systems. The study was conducted in conditions of a stationary field experiment of the Uman National University of Horticulture, located in the Right-Bank Forest-Steppe of Ukraine during 2020-2021. The experiment was founded in 2011. The following crops are grown in the four-course field crop rotation: winter wheat, corn, spring barley, soybeans. The experiment scheme includes 11 variants of combinations and separate application of mineral fertilisers, including the control option without fertiliser. Grain harvest was performed by direct combining, protein content and gluten content were determined by infrared spectroscopy using Infratek 1241. Statistical data processing was performed using the STATISTICA 10 software. Yield of winter durum wheat grain significantly increased from the fertiliser. However, the effectiveness of their use varied depending on the year of study. Thus, in 2020, it increased by 1.1-1.2 times (3.9-4.1 t ha^{-1}) with long-term use of nitrogen fertilisers alone. Long-term use of complete mineral fertiliser ($N_{150}P_{60}K_{80}$) significantly affected the grain yield (4.3 t ha^{-1}) compared to variant N_{150}. In 2021, grain yields increased 1.2-1.4 times, depending on the fertiliser system. Notably, the use of $N_{150}P_{60}K_{40}$ and $N_{150}P_{30}K_{80}$ in terms of impact on grain yield was at the level of the variant $N_{150}P_{60}K_{80}$. Paired combinations of fertiliser application were effective at the level of long-term application of $N_{150}P_{30}K_{40}$. Application of $N_{75}P_{30}K_{40}$ provided the formation of only 4% lower grain yield compared to $N_{150}P_{30}K_{40}$. The protein and gluten content was most affected by the nitrogen component of the complete mineral fertiliser. The conducted studies confirm the high reaction of durum wheat to the use of nitrogen fertilisers. The results obtained can be used to predict the productivity of durum winter wheat depending on soil fertility

Keywords: nitrogen phosphorous and potash fertilisers, winter durum wheat productivity, protein content, protein collection, gluten content.

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INTRODUCTION

Wheat is one of the most important cereals in the world. Durum wheat ranks second in grain production after soft wheat. Currently, the gross production of soft wheat grain is about 765 million tonnes, of which almost 5% is accounted for by durum wheat (Food and Agriculture Organization of the United Nations, n.d.). Durum wheat grain is the main raw material for the production of high-quality pasta. Wheat is a source of carbohydrates, protein, minerals, and fibre (Mefleh *et al*., 2019). Wheat straw can be used as a litter in mixtures with organic fertilisers or as an organic fertiliser. Furthermore, it has prospects for use in bioenergy purposes (Townsend *et al*., 2018).

However, wheat grain yield and quality are the main concern of producers, as these indicators determine economic efficiency. To achieve the maximum possible yield and grain quality, agricultural enterprises can apply and combine a wide range of agrotechnical measures. Effective measures include the use of fertilisers (Wang *et al*., 2017).

The quality of grain products depends on the protein and gluten content of the grain. Currently, winter wheat is usually placed after unpaired precursors, which adversely affects the formation of protein and gluten content in the grain (Gandía *et al*., 2021). In addition, hard wheat reduces grain yields more strongly due to adverse environmental factors compared to soft wheat (Laurent *et al*., 2020). One of the ways to improve the quality of wheat grain when growing after unpaired predecessors is to use nitrogen fertilisers (Novak *et al*., 2019). In the agrotechnology of grain crops, the use of fertilisers is the main component that ensures the formation of a high yield of high-quality grain (Hospodarenko *et al*., 2019). Nitrogen fertilisers most increase wheat productivity in modern agricultural systems. However, it is known that very high doses of nitrogen fertilisers can pollute the environment, due to the active substance not used by plants. The effectiveness of fertilisation of durum winter wheat depends on many factors, of which weather conditions and the reaction of the variety of this crop are most strongly influenced (Zhang *et al*., 2016).

In modern conditions, it is important not only to implement measures to increase crop yields, but also to reduce the cost of production, that is, to increase the production of competitive products. Therefore, it is necessary to maximise the use of low-cost techniques in agricultural technologies. Reducing the cost of production can be achieved by using highly productive wheat varieties (Mefleh *et al*., 2019). C. Li *et al*. (2018) it was found that with the systematic use of fertilisers, high yields of agricultural crops can be obtained by applying considerably lower doses, which is explained by the after-effect of fertilisers applied for previous crops of crop rotation. In the system of applying fertilisers for durum wheat, it is also necessary to consider soil fertility. If the nitrogen content of mineral compounds is higher, the dose of nitrogen fertilisers should be reduced so that there is no overspending (Marinaccio *et al*., 2016). Prolonged application of fertilisers increases the radioactivity of the soil due to the content of ^{40}K and ^{226}Ra. However, this radiation is safe for human health (Šimanský & Jonczak, 2019). Furthermore, the use of fertilisers improves the quality of grain, which is important for the production of high-quality products (Hrčková *et al*., 2018).

Thus, the effectiveness of applying fertilisers depends on the doses of their application. The optimal dose of fertilisers should consider the biological features of the durum wheat variety and the planned level of its yield, weather conditions and soil fertility, the level of agricultural technology, the placement of crops in the crop rotation and its saturation with fertilisers, the forms of fertilisers, the timing, and methods of their application, and other factors. Therefore, determining fertiliser doses is one of the most difficult issues of modern agronomic science and practice.

The purpose of this study was to investigate the yield formation and quality of winter durum wheat grain under various fertiliser systems in field crop rotation.

LITERATURE REVIEW

Nitrogen, phosphorus, potassium, and sulphur fertilisers, as well as microfertilisers, are most frequently used for wheat. However, wheat is a nitrogenophilic crop, so the main part of this study is devoted to studying the effectiveness of nitrogen fertilisers. It is established that the application of N_{90} for durum wheat, the grain yield increased on average from 5.10 t ha^{-1} in the variant without fertilisers up to 7.01 t ha^{-1}. Application of N_{180} increased it only to 7.75 t ha^{-1}, application of N_{240} – up to 8.09 t ha^{-1}, while N_{300} did not increase the yield (8.05 t ha^{-1}). In addition, the effectiveness of fertiliser significantly varied depending on weather conditions. Thus, the yield of durum wheat from the use of N_{90} it varied from 6.25 to 8.21 t ha^{-1}. The trend of nitrogen fertilisers affecting protein content was different. Thus, this indicator grew from 10.5 in the version without fertilisers to 11.9% per N_{90}, and when applying N_{300} it grew to 14.4%. The protein content also significantly varied depending on weather conditions. Thus, in the variant of application of N_{90}, this figure ranged from 10.2% to 12.4% (Ma *et al*., 2019). However, the conditions under which such studies were conducted differ from the Right-Bank Forest-Steppe of Ukraine. Better soil and climatic conditions contributed to the formation of a higher grain yield compared to the experiments of the authors of this paper.

In studies by F. Orlando *et al*. (2017) the use of N_{80-120} was effective. The yield of durum winter wheat under this fertiliser scenario was at the level of 5.30 t ha^{-1}. Czech scientists L. Hlisnikovský *et al*. (2020) found that winter wheat responds well to the use of fertilisers, but their effectiveness varies depending on weather conditions. Thus, in areas without fertilisers, the yield varied from 2.89 to 6.99 t ha^{-1} depending on the year of study. In an unfavourable year, the grain yield was at the level of the fertiliser-free option (2.78-2.86 t ha^{-1}). Application of mineral fertilisers ($N_{120}P_{26}K_{50}$) against the background of pus after-effect (40 t ha^{-1}) was the most effective. Under this scenario, the average yield of winter wheat grain increased to 8.10 t ha^{-1} against 5.73 t ha^{-1} in the control variant. However, there are no variants using smaller and higher doses of nitrogen fertilisers in these studies. With such an experiment scheme, only one experiment option will be effective – $N_{120}P_{26}K_{50}$. Furthermore, nitrogen fertilisers were applied in three periods – before sowing, in the spring, and during the earing of winter wheat. In the conditions of the Right-Bank Forest-Steppe, if there is a lack of moisture and hot temperature, such a fertiliser system is ineffective. Notably, the study was conducted with soft wheat, the fertiliser system of which differs from durum wheat (Hlisnikovský *et al.*, 2020).

The use of phosphorous and potassium fertilisers is less effective than nitrogen fertilisers. In research by S. Turebayeva *et al.* (2022), application of P_{30} increased the yield of winter wheat grain from 1.28 to 1.76 t ha^{-1}. Increasing the dose to P_{45} provided a yield of 1.96 t ha^{-1}. The highest efficiency of phosphorous and potassium fertilisers is provided by nitrogen fertilisers (Turebayeva *et al.*, 2022). Thus, the application of $N_{50}R_{30}$ provided the receipt of 3.18 t ha^{-1} of winter wheat grains (Turebayeva *et al.*, 2022). However, these studies were conducted with soft winter wheat. Given the insufficient study of the issue of optimal fertilisation of durum winter wheat, the purpose of this study is relevant.

MATERIALS AND METHODS

The study was conducted in 2020-2021 in a stationary experiment of the Department of Agrochemistry and Soil Science. The stationary field experiment was carried out at the Uman National University of Horticulture (certificate of the National Academy of Agricultural Sciences No. 87) (Stationary field experiments of Ukraine, 2014) in the Right-Bank Forest Steppe of Ukraine with Greenwich geographical coordinates 48° 46' of northern latitude and 30° 14' of eastern longitude. The experiment was launched in 2011. The following crops were cultivated in the four-field crop rotation: winter wheat, corn, spring barley and soya. The purpose of the field experiment is to establish the efficiency of the action of different types, rates, and proportions of mineral fertilisers on the yielding capacity and quality of grain and seeds of field crops, and fertility of the black soil. The scheme of the experiment includes 11 variants of combinations and separate applications of mineral fertilisers including the control variant without fertilisers (Table 1).

***Table 1**. The design of application of fertilisers in the experiment*

Variant of the experiment: Average rates of nutrients in the crop rotation (kg of active substance ha^{-1} per year)	Application of fertilisers under crops in the crop rotation			
	Winter wheat	Corn	Spring barley	Soy
Without fertilisers (control)	–	–	–	–
N_{55}	N_{75}	N_{80}	N_{35}	N_{30}
N_{110}	N_{150}	N_{160}	N_{70}	N_{60}
$P_{60}K_{80}$	$P_{60}K_{80}$	$P_{60}K_{110}$	$P_{60}K_{70}$	$P_{60}K_{60}$
$N_{110}K_{80}$	$N_{150}K_{80}$	$N_{160}K_{110}$	$N_{70}K_{70}$	$N_{60}K_{60}$
$N_{110}P_{60}$	$N_{150}P_{60}$	$N_{160}P_{60}$	$N_{70}P_{60}$	$N_{60}P_{60}$
$N_{55}P_{30}K_{40}$	$N_{75}P_{30}K_{40}$	$N_{80}P_{30}K_{55}$	$N_{35}P_{30}K_{35}$	$N_{30}P_{30}K_{30}$
$N_{110}P_{60}K_{80}$	$N_{150}P_{60}K_{80}$	$N_{160}P_{60}K_{110}$	$N_{70}P_{60}K_{70}$	$N_{60}P_{60}K_{60}$
$N_{110}P_{30}K_{40}$	$N_{150}P_{30}K_{40}$	$N_{160}P_{30}K_{55}$	$N_{70}P_{30}K_{35}$	$N_{60}P_{30}K_{30}$
$N_{110}P_{60}K_{40}$	$N_{150}P_{60}K_{40}$	$N_{160}P_{60}K_{55}$	$N_{70}P_{60}K_{35}$	$N_{60}P_{60}K_{30}$
$N_{110}P_{30}K_{80}$	$N_{150}P_{30}K_{80}$	$N_{160}P_{30}K_{110}$	$N_{70}P_{30}K_{70}$	$N_{60}P_{30}K_{60}$

In the variant of the experiment with an average rate of nutrients in the crop rotation per ha of $N_{110}P_{60}K_{80}$, the total (100%) compensation with fertilisers of average annual removal of the nutrients by the crops in the crop rotation is planned. The scheme of the experiment was developed so that it could be possible to determine the opportunity to decrease the rates of certain types of mineral fertilisers. The placement of the variants in the experiment is successive. Performance of the experiment simultaneously on four fields provides annual data about yielding capacity of all crops in the four-field crop rotation. The experiment was repeated three times. The total area of the experimental plot is 110 m^2, the accounting area is 72 m^2. Phosphorus (granulated superphosphate) and potassium (potassium chloride) fertilisers were applied during fall tillage, nitrogenous fertilisers (ammonium nitrate) during pre-sowing cultivation and fertilising of winter wheat. Phosphorous and potassium fertilisers were used in autumn for the main tillage, nitrogen fertilisers – in early spring. In the experiment, winter durum wheat (Andromeda variety) was grown after soybeans.

Characteristics of durum winter wheat of the Andromeda variety. Originator – Institute of Irrigated Agriculture (Ukraine). Type of development – winter, early ripening. Plant height 75-100 cm. It is recommended for growing in forest-steppe and steppe. The potential yield is 3.6-6.0 t/ha. Resistance to lodging – 5 points, to shedding – 7, to root rot – 5, to Septoria – 9, to Fusarium – 7, to brown rust – 8, to powdery mildew – 6 points. Pasta properties are high (4.4 points).

The soil on the experimental plot is the black podzolised heavy loamy soil on loess with 3.8% of humus content, the content of nitrogenous hydrolysed compounds (by Cornfield method) is low (105 mg kg), the content of mobile compounds of phosphorus and potassium (by Chirikov method (DSTU 4115-2002, 2003), extraction 0.5 m CH_3COOH) is increased (106 mg kg) and high (132 mg kg) respectively, pH_{KCl} – 5.7.

Combined harvesters were used to harvest the grain. The accounting of the harvest of non-marketable produce was conducted by the method of the trial sheaf. Non-marketable part of the harvest of the crop rotation plants (straw, stems) was left in the field for fertilising. Protein and gluten content were determined by infrared spectroscopy using Infratek 1241.

Statistical data processing was performed using STATISTICA 10. The null hypothesis was confirmed or refuted during the performing of variance analysis. The p-value was determined for this purpose, which showed the probability of the corresponding hypothesis. In cases, where $p<0.05$, 'the null hypothesis' was refuted and the influence of the factor was significant.

Weather conditions differed in precipitation distribution and air temperature (Table 2). In 2020, 44.9 mm of precipitation fell in March-April, and in 2020 – 1.8 times more (82.3 mm). However, in the autumn of 2019, there was no precipitation, and the total amount was 376.6 mm, which is 1.6 times less than the long-term average (586 mm). The air temperature in 2021 in March and April was lower compared to 2020. Notably, winter durum wheat plants were damaged by frost in the first decade of May 2020.

***Table 2**. Weather conditions in 2020-2021*

Month	Year					
	2020	2021	1991-2020	2020	2021	1991-2020
	Precipitation (mm)			Temperature (°C)		
March	23.9	32.4	36	6.3	2.0	2.5
April	21.0	49.9	41	9.2	7.4	9.7
May	101.0	56.4	52	12.5	14.0	15.4
June	70.4	107.7	81	20.9	19.8	19.0
July	21.4	89.8	68	21.6	23.2	20.9

Due to the lack of moisture in autumn 2019, durum winter wheat seedlings were obtained in January 2020, which affected the formation of fewer productive stems (Table 3). Furthermore, the adverse impact of frosts in the BBCH 30 phase led to the formation of lower grain yields compared to 2021.

***Table 3**. Winter durum wheat sowing and harvesting time date during trial years*

Indicators	Year of research	
	2020	2021
Sowing time	October 17th, 2019	October 30th, 2020
BBCH 10	January 25th	November 20th
BBCH 20	February 25th	April 13th
BBCH 30	May 1st	May 10th
BBCH 50	June 5th	June 6th
BBCH 73	June 20th	June 20th
Harvesting time	July 15th	July 22nd

RESULTS AND DISCUSSION

The results of the research show that all fertiliser systems, except for phosphorus-potassium in 2020, significantly increased the yield of winter durum wheat grain compared to the option without fertilisers ($p≤0.05$) (Fig. 1). The lowest fertiliser efficiency was set in 2020. Thus, the yield of winter durum wheat grain increased by 1.1-1.2 times (3.9-4.1 t ha^{-1}) with long-term use of only nitrogen fertilisers. Long-term use of complete mineral fertiliser ($N_{150}P_{60}K_{80}$) significantly affected the grain yield (4.3 t ha^{-1}) compared to variant N_{150}. However, the yield under this fertiliser scenario was only 5 % higher. Paired combinations of fertiliser use, as well as long-term use of fertiliser systems with incomplete return of phosphorous and potassium fertilisers, provided only 2-5% lower grain yield compared to $N_{150}P_{60}K_{80}$.

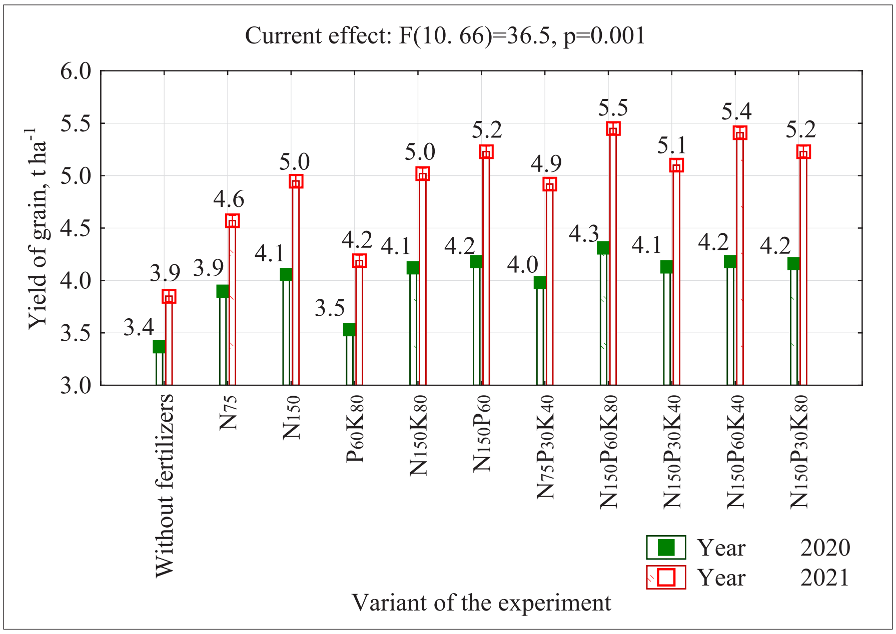

Figure 1. *Winter durum wheat grain yield depending on the fertiliser system*

In the best weather conditions of 2021, grain yields were 15% higher in areas without fertilisers compared to 2020. In the variants of long-term application of fertilisers, it was higher by 18-28%. The yield increased by 1.2 times with prolonged use of N_{75} and 1.3 times – in the variant with N_{150}. Significantly higher yields (by 4-10%) were provided by long-term use of the nitrogen-phosphorus system and variants $N_{150}P_{60}K_{80}$, $N_{150}P_{60}K_{40}$, $N_{150}P_{30}K_{80}$ compared to long-term use of N_{150}. Notably, the use of $N_{150}P_{60}K_{40}$ and $N_{150}P_{30}K_{80}$ in terms of impact on grain yield was at the level of the variant $N_{150}P_{60}K_{80}$. Paired combinations of fertiliser application were effective at the level of long-term application of $N_{150}P_{30}K_{40}$. Application of $N_{75}P_{30}K_{40}$ provided the formation of only 4% lower grain yield compared to $N_{150}P_{30}K_{40}$. The lowest yield was provided by a phosphorus-potassium fertiliser system (4.2 t ha^{-1}).

Nitrogen fertilisers are a crucial factor in the agricultural technology of winter wheat. Their use leads to a considerable increase in grain yield compared to options without fertilisers (Klikocka *et al.*, 2016). The magnitude of the impact of nitrogen fertilisers on winter wheat can be determined by weather conditions. Sufficient moisture during the wheat growing season contributes to higher efficiency of nitrogen fertilisers (Tosti *et al.*, 2016). Furthermore, unfavourable conditions of the autumn-winter period also affect the productivity of the plant. Under conditions of higher individual productivity of wheat plants, the yield increase from fertilisers will also be greater (Rossini *et al.*, 2018).

In the conditions of the research conducted by the authors of this paper in 2020, the lack of moisture during the sowing period caused late shoots. In addition, the plants were affected by low temperatures during the phase of plants entering the tube. It was found that winter durum wheat plants formed a larger number of stems in 2021 compared to 2020 (Table 4). A larger number of stems is conditioned upon the early resumption of spring vegetation. In addition, the tillering phase lasted 65 days, and in 2021 the tillering phase lasted only 27 days. However, the mass of grain in one ear of winter durum wheat in 2020 was the lowest due to the influence of sub-zero temperatures. Therefore, the grain yield in 2020 was the lowest.

Table 4. *Number of plants and productive stems of winter durum wheat under different fertiliser systems, pcs/m^2*

Experiment variant	**Year of the study**			
	2020		**2021**	
	1	**2**	**1**	**2**
Without fertilisers (control)	291	1.29	239	1.73
N_{75}	338	1.27	251	1.98
N_{150}	397	1.14	304	1.75
$P_{60}K_{80}$	295	1.33	245	1.87
$N_{150}K_{80}$	404	1.14	310	1.74
$N_{150}P_{60}$	408	1.14	318	1.81
$N_{75}P_{30}K_{40}$	346	1.27	274	1.96
$N_{150}P_{60}K_{80}$	415	1.16	320	1.85
$N_{150}P_{30}K_{40}$	410	1.13	310	1.77
$N_{150}P_{60}K_{40}$	404	1.15	319	1.83
$N_{150}P_{30}K_{80}$	401	1.16	317	1.77

Note: *1 – number of productive stems, 2 – weight of grain in one ear, g.*

Research by S. Turebayeva *et al*. (2022) showed that wheat has a lower response to the use of phosphorous and potassium fertilisers, especially with an average content of their mobile compounds in the soil. Therefore, the grain yield in variants with incomplete return of phosphorous to potassium fertilisers decreases little compared to full mineral fertilisers. Furthermore, the higher efficiency of fertilisers may be conditioned upon their long-term use in crop rotation, which is confirmed in the article (Šimanský & Jonczak, 2019).

The protein content was most affected by the nitrogen component of the complete mineral fertiliser (Fig. 2). All variants using nitrogen fertilisers significantly increased the protein content in the grain. Thus, this indicator increased by 4-26% in variants with 75-150 kg/ha of fertiliser compared to plots without fertilisers. In conditions of less precipitation during the ripening period of winter durum wheat grain and higher air temperatures in 2020, the protein content was 8-21% higher compared to 2021. Thus, all fertiliser systems, except phosphorus-potassium, significantly affected the growth of protein content in winter durum wheat grain. Notably, the use of a double dose of nitrogen fertilisers (N_{150}) in the composition of a complete mineral fertiliser significantly increased the protein content compared to long-term use of N_{75}. The protein content increased by 18% when N_{75} was added, by 21% – upon adding $N_{75}P_{30}K_{40}$. Application of N_{150} increased protein content by 23%, and options with full mineral fertiliser – by 25-26% compared to plots without fertiliser.

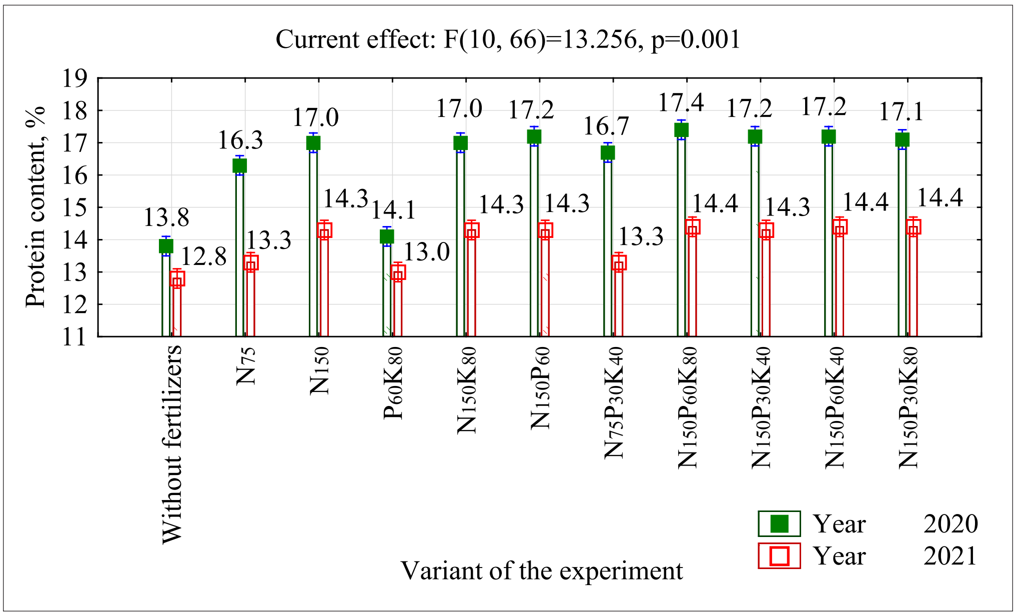

Figure 2. *Protein content in durum winter wheat grain depending on the fertiliser system*

In 2021, protein content in variants using N_{75} increased by 4%, and the use of N_{150} increased it by 12-13%. The protein content of the phosphorus-potassium fertiliser system was at the level of the option without fertilisers since it did not significantly exceed it. In variants with incomplete return of phosphorous and potassium fertilisers, the protein content was at the level of the nitrogen fertiliser system.

Research results of other scientists (Ostmeyer *et al*., 2020) indicate that the use of nitrogen fertilisers increases the protein content in winter wheat grains. With a lower grain yield, the protein content may be higher compared to years where a higher grain yield was formed. Therefore, at a yield of 3.9-4.3 t ha^{-1} protein content was at the level of 16.3-17.4%, and at a yield of 4.6-5.5 t ha^{-1} its content was only 13.3-14.4%. However, the use of nitrogen fertilisers not only increased grain yield, but also increased protein content.

Long-term use of mineral fertilisers in field crop rotation significantly increased protein harvesting from the winter durum wheat crop compared to the variant without fertilisers (Fig. 3). Protein harvesting from the 2021 grain harvest was 6-8% higher compared to 2020, except the application of N_{75} variants. Prolonged use of N_{75} increased protein collection by 1.2 times, and $N_{75}P_{30}K_{40}$ – by 1.3 times compared to the control. According to the nitrogen-potassium and nitrogen-phosphorus fertiliser systems, protein collection was 1.5 times higher. The use of the highest dose of nitrogen fertilisers on a phosphorus-potassium background was 1.5-1.6 times higher. Similarly, protein harvesting changed in 2020. The use of a phosphorus-potassium fertiliser system had the least effect on protein harvesting from the winter durum wheat crop. Despite the high yield of winter durum wheat grain in 2021 variants with long-term use of N_{75} and $N_{75}P_{30}K_{40}$ the highest protein collection in 2020. The protein collection rate is conditioned upon the formation of a higher protein content in 2020.

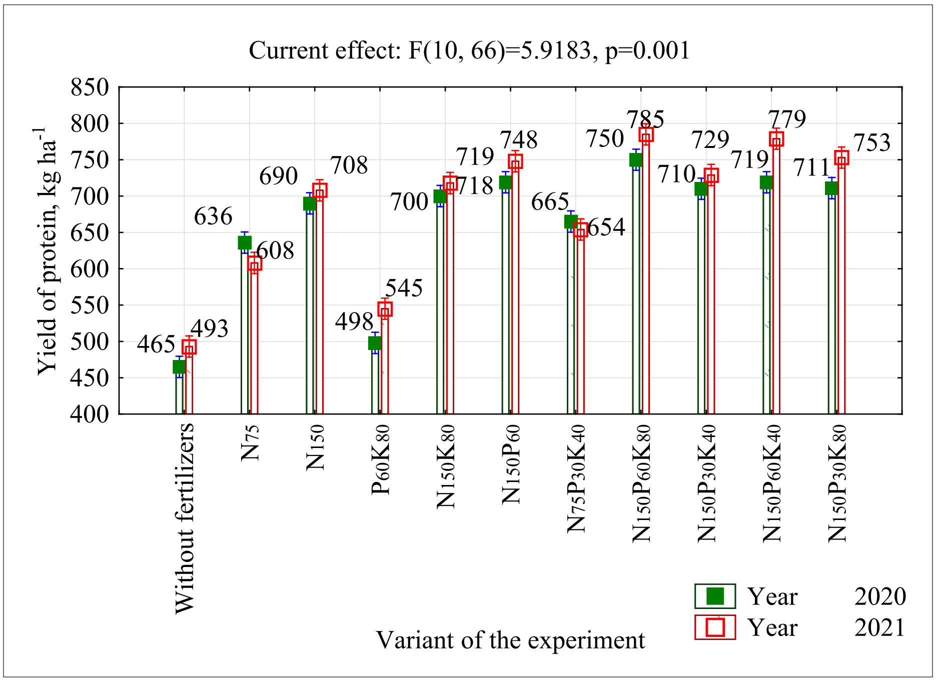

***Figure 3**. Protein harvesting from durum winter wheat crops depending on the fertiliser system*

The trend of influence of prolonged fertiliser use in field crop rotation on gluten content was similar to that of grain protein (Fig. 4). Furthermore, the gluten content was influenced by the weather conditions of the years of experiments. In 2021, the gluten content in areas without fertilisers was 17% lower compared to 2020. In fertiliser applications, this indicator was 25-30% lower.

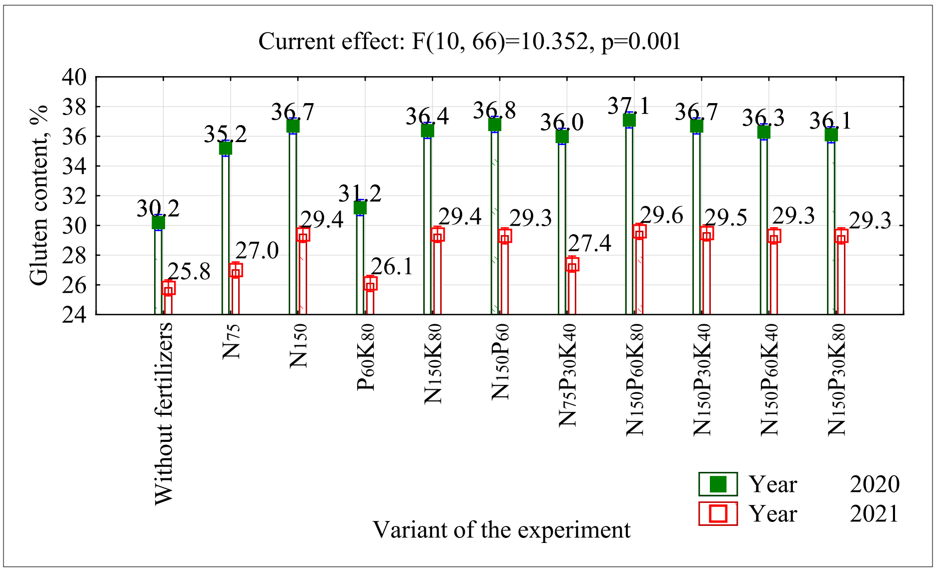

***Figure 4**. Gluten content in durum winter wheat grain depending on the fertiliser system*

Notably, all fertiliser systems that contained the nitrogen component significantly increased the gluten content in the grain during both years of experiment. In 2020, this indicator grew by 17-19% in the cases of applying N_{75} variants compared to the fertiliser-free option. In the variants of using the highest dose of nitrogen fertilisers, the gluten content increased by 22-23%. In 2021, this indicator grew by 4-6% for the cases of N_{75} application. In variants using N_{150} the gluten content increased by 14-15%. The use of a phosphorus-potassium fertiliser system did not significantly affect this indicator.

The formation of gluten content in winter wheat grain varies significantly depending on the weather conditions of the growing season, especially during its ripening period (Wu *et al.*, 2019). The effect of nitrogen fertilisers on these indicators also depends on weather conditions. Usually, precipitation during this period reduces the gluten content. Furthermore, an increase in grain yield leads to the formation of a lower gluten content, since the amount of nitrogen of mineral compounds in the soil applied with fertilisers, which can be used for its synthesis, decreases (Yang *et al.*, 2019). If the productive stems are reduced, excess nitrogen mineral compounds can be used by wheat plants to synthesise gluten (Rossini *et al.*, 2020). In the experiments of the authors of this paper, the lack of moisture during the milk ripeness of winter durum wheat grain in 2020 caused the formation of a higher protein and gluten content in the grain compared to 2021. In addition, the grain yield in 2020 was the lowest. In 2021, the grain yield is 5.2-5.5 t ha^{-1} the gluten content was at the level of 29.3-29.6%.

Therefore, the introduction of nitrogen fertilisers is an effective way to improve the quality of grain without reducing the yield of durum winter wheat. However, the results obtained can be applied to conditions similar to the Right-Bank Forest-Steppe of Ukraine. If individual weather elements change, the impact of fertiliser systems on the productivity of durum winter wheat may vary. This should be considered upon conducting research in other soil and climatic conditions. Furthermore, growing more productive varieties of this crop will also change the effectiveness of fertiliser application.

The results of statistical processing of experimental data confirm that paired combinations and variants with incomplete return of phosphorus and potassium fertilisers on the background of N_{150} use have almost the same effect compared with long-term use of $N_{150}P_{60}K_{80}$ (Fig. 5). The optimal protein and gluten content ensures the use of N_{150} regardless of the dose of phosphorous and potassium fertilisers. Considering the grain yield, protein content, its collection and gluten content, variants with prolonged use of $N_{150}P_{60}$, $N_{150}P_{30}K_{40}$, $N_{150}P_{60}K_{40}$ and $N_{150}P_{30}K_{80}$ have almost the same efficiency compared to variant $N_{150}P_{60}K_{80}$.

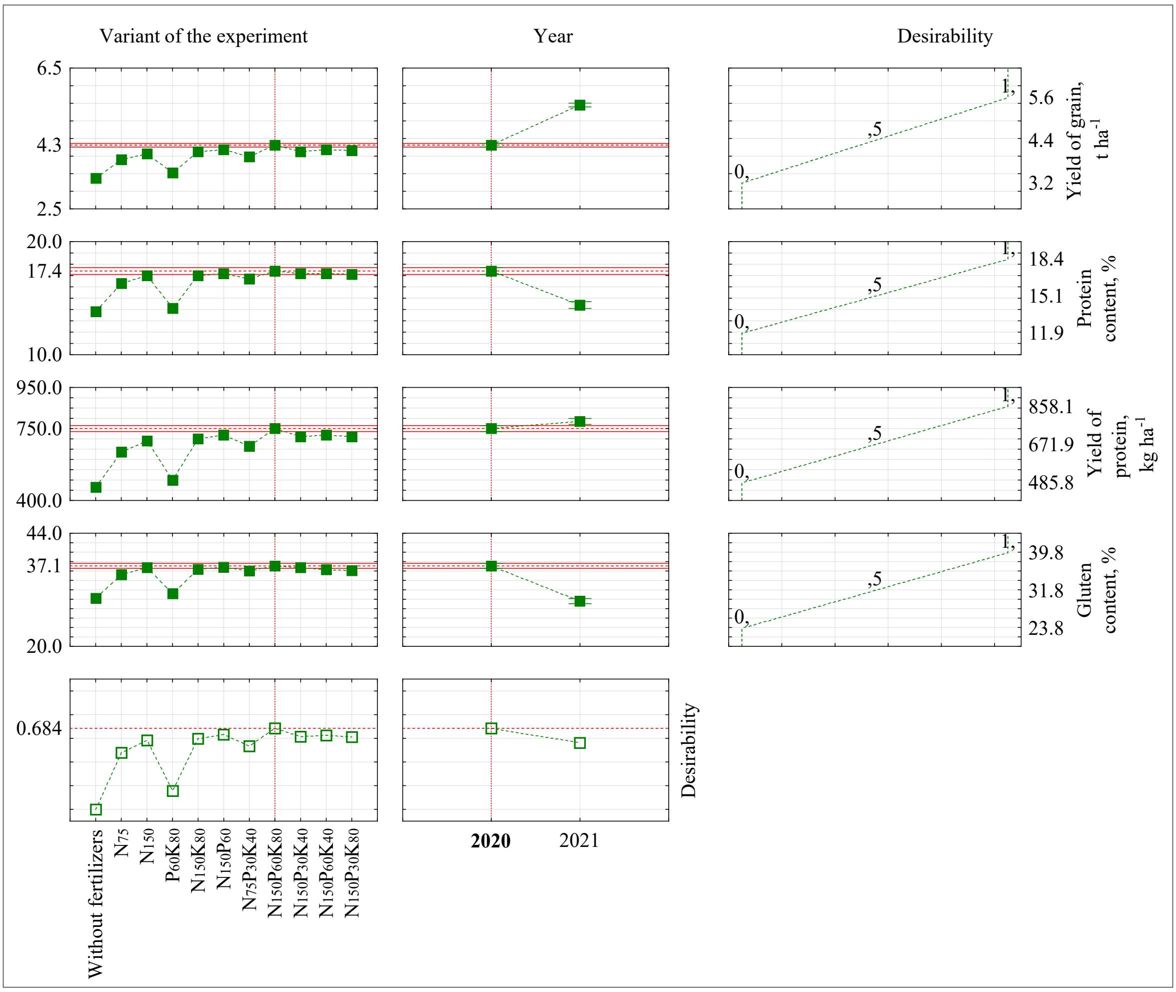

***Figure 5**. Optimisation of the choice of fertiliser system to ensure the formation of high yield and quality of winter durum wheat grain*

CONCLUSIONS

Long-term use of fertilisers, in addition to the phosphorus-potassium system, in field crop rotation significantly affects the formation of the winter durum wheat crop (Andromeda variety). Fertiliser systems with a nitrogen component have the highest efficiency. Phosphorus-potassium fertilisers have the least impact on the yield and quality of winter durum wheat grain. The effectiveness of fertiliser application varies depending on the weather conditions of the growing season. Thus, in less favourable growth conditions, the yield increases from 3.4 to 3.5-4.3 t ha^{-1}, and in the best – from 3.9 to 4.2-5.5 t ha^{-1} ($p \leq 0.05$). Under conditions of hot air temperature and less precipitation, all fertiliser systems with a nitrogen component significantly affected the protein and gluten content in the grain. The protein content increases from 13.8 to 16.3-17.4%, depending on the fertiliser system, and its collection from 465 to 636-750 kg ha^{-1} ($p \leq 0.05$). In conditions of sufficient moisture, fertiliser systems using N_{150} had a significant effect. The protein content in this scenario increases from 12.8 to 14.4%, and its collection from 493 to 785 kg ha^{-1} ($p \leq 0.05$). Prolonged use of phosphorus-potassium fertilisers did not significantly affect the quality of winter durum wheat grain. The gluten content varies similarly to the protein content, depending on the fertiliser system. Thus, in 2020, the gluten content increases from 30.2 to 35.2-37.1%, and in 2021 – from 30.2 to 36.7-37.1% ($p \leq 0.05$), depending on the fertiliser system.

REFERENCES

[1] DSTU 4115-2002 "Soils. Determination of mobile phosphorus and potassium compounds by the modified Chirikov method". (January, 2003). Retrieved from https://kzref.org/vidbir-zrazkiv-runtu-i-pidgotovka-yih-do-analizu.html?page=11.

[2] Food and Agriculture Organization of the United Nations. (n.d.). Retrieved from http://www.fao.org/faostat/en/#data/QC.

[3] Gandía, M.L., Del Monte, J.P., & Tenorio, J.L. (2021). The influence of rainfall and tillage on wheat yield parameters and weed population in monoculture versus rotation systems. *Scientific Reports*, 11, article number 22138. doi: 10.1038/s41598-021-00934-y.

[4] Hlisnikovský, L., Vach, M., Abrhám, Z., Mensik, L., & Kunzová, E. (2020). The effect of mineral fertilisers and farmyard manure on grain and straw yield, quality and economical parameters of winter wheat. *Plant, Soil and Environment*, 66, 249-256. doi: 10.17221/60/2020-PSE.

[5] Hospodarenko, H.M., & Liubych, V.V. (2021). Influence of long-term fertilization on yield and quality of spring triticale grain. In *Annual 27th international scientific conference research for rural development 2021,* 29-35. doi: 10.22616/rrd.27.2021.004.

[6] Hrčková, K., Mihalčík, P., Žák, Š., Hašana, R., Ondreičková, K., & Kraic, J. (2018). Agronomic and economic performance of genetically modified and conventional maize. *Agriculture*, 64, 87-93. doi: 10.2478/agri-2018-0009.

[7] Klikocka, H., Cybulska, M., Barczak, B., Narolski, B., Szostak, B., Kobiałka, A., Nowak, A., & Wójcik, E. (2016). The effect of sulphur and nitrogen fertilization on grain yield and technological quality of spring wheat. *Plant, Soil and Environment*, 62, 230-236. doi: 10.17221/18/2016-PSE.

[8] Laurent, E.-A., Ahmed, N., Durieu, C., Grieu, P., & Lamaze, T. (2020). Marine and fungal biostimulants improve grain yield, nitrogen absorption and allocation in durum wheat platns. *The Journal of Agricultural Science*, 158, 279-287. doi: 10.1017/S0021859620000660.

[9] Li, C.X., Ma, S.C., Shao, Y., Ma, S.T., & Zhang, L.L. (2018). Efects of long-term organic fertilization on soil microbiologic characteristics, yield and sustainable production of winter wheat. *Journal of Integrative Agriculture*, 17, 210-219. doi: 10.17221/60/2020-PSE.

[10] Ma, G., Liu, W., Li, S., Zhang, P., Wang, C., Lu, H., Wang, L., Xie, Y., Ma, D., & Kang, G. (2019). Determining the optimal N input to improve grain yield and quality in winter wheat with reduced apparent N loss in the North China plain. *Frontiers in Plant Science*, 10, article number 181. doi: 10.3389/fpls.2019.00181.

[11] Marinaccio, F., Blandino, M., & Reyneri, A. (2016). Effect of nitrogen fertilization on yield and quality of durum wheat cultivated in Northern Italy and their interaction with different soils and growing seasons. *Journal of Plant Nutrition*, 39, 643-654. doi: 10.1080/01904167.2015.1087027.

[12] Mefleh, M., Conte, P., Fadda, C., Giunta, F., Piga, A., Hassoun, G., & Motzo, R. (2019). From ancient to old and modern durum wheat varieties: Interaction among cultivar traits, management, and technological quality. *Journal of the Science of Food and Agriculture,* 99, 2059-2067. doi: 10.1002/jsfa.9388.

[13] Novak, L., Liubych, V., Poltoretskyi, S., & Andrushchenko, M. (2019). Technological indices of spring wheat grain depending on the nitrogen supply. *Modern Development Paths of Agricultural Production: Trends and Innovations*, 753-761. doi: 10.31388/2220-8674-2019-1-55.

[14] Orlando, F., Mancini, M., Motha, R., Qu, J.J., Orlandini, S., & Dalla Marta, A. (2017). Modelling durum wheat (*Triticum turgidum* L. var. *durum*) grain protein concentration. *The Journal of Agricultural Science,* 155, 930-938. doi: 10.1017/S0021859616001003.

[15] Ostmeyer, T., Parker, N., Jaenisch, B., Alkotami, L., Bustamante, C., & Jagadish, S.K. (2020). Impacts of heat, drought, and their interaction with nutrients on physiology, grain yield, and quality in field crops. *Plant Physiology Reports*, 25(4), 549-568. doi: 10.1007/s40502-02000538.

[16] Rossini, F., Provenzano, M.E., Sestili, F., & Ruggeri, R. (2018). Synergistic effect of sulfur and nitrogen in the organic and mineral fertilization of durum wheat: Grain yield and quality traits in the mediterranean environment. *Agronomy*, 8, 2-16. doi: 10.3390/agronomy8090189.

[17] Šimanský, V., & Jonczak, J. (2019). Sorption capacity of sandy soil under long-term fertilisation. *Agriculture (Poľnohospodárstvo)*, 65(4), 164-171. doi: 10.2478/agri-2019-0017.

[18] Tosti, G., Farneselli, M., Benincasa, P., & Guiducci, M. (2016). Nitrogen fertilization strategies for organic wheat production: Crop yield and nitrate leaching. *Agron Journal*, 108, 770-781. doi: 10.2134/AGRONJ2015.0464.

[19] Townsend, T.J., Sparkes, D.L., Ramsden, S.J., Glithero, N.J., & Wilson, P. (2018). Wheat straw availability for bioenergy in England. *Energy Policy*, 122, 349-357. doi: 10.1016/j.enpol.2018.07.053.
[20] Turebayeva, S., Zhapparova, A., Yerkin, A., Aisakulova, K., Yesseyeva, G., Bissembayev, A., & Saljnikov, E. (2022). Productivity of rainfed winter wheat with direct sowing and economic efficiency of diversified fertilization in arid region of South Kazakhstan. *Agronomy*, 12, article number 111. doi: 10.3390/ agronomy12010111.
[21] Wang, L.F., Sun, J.T., Zhang, Z.B., Xu, P., & Shangguan, Z.P. (2017). Winter wheat grain yield in response to diferent production practices and soil fertility in northern China. *Soil and Tillage Research*, 176, 10-17. doi: 10.1016/j.still.2017.10.001.
[22] Wu, W., Ma, B.L., Fan, J.J., Sun, M., Yi, Y., Guo, W.S., & Voldeng, H.D. (2019). Management of nitrogen fertilization to balance reducing lodging risk and increasing yield and protein content in spring wheat. *Field Crops Research*, 241, article number 107584. doi: 10.1016/j.fcr.2019.107584.
[23] Yang, D., Cai, T., Luo, Y., & Wang, Z. (2019). Optimizing plant density and nitrogen application to manipulate tillergrowth and increase grain yield and nitrogen-use efficiency in winter wheat. *Peer J*, 7, article number e6484. doi: 10.7717/peerj.6484.
[24] Zhang, Y., Dai, X., Jia, D., Li, H., Wang, Y., & Li, C. (2016). Effects of plant density on grain yield, protein size distribution, and breadmaking quality of winter wheat grown under two nitrogen fertilisation rates. *European Journal of Agronomy*, 73, 1-10. doi: 10.1016/j.eja.2015.11.015.

Урожайність і якість зерна пшениці твердої озимої залежно від системи удобрення

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Анотація. Нині пшеницю тверду озиму вирощують після непарових попередників. За таких умов важливе значення має удобрення. Тому вивчення формування урожайності та якості зерна пшениці твердої озимої залежно від системи удобрення є актуальним. Метою роботи було вивчення формування урожайності та якості зерна пшениці твердої озимої за різних систем удобрення. Дослідження проводили в умовах стаціонарного польового досліду Уманського національного університету садівництва, розміщеного в Правобережному Лісостепу України упродовж 2020–2021 рр. Дослід закладено в 2011 році. У чотирипільній польовій сівозміні вирощуються такі культури: пшениця озима, кукурудза, ячмінь ярий, соя. Схема досліду включає 11 варіантів комбінацій і окремого внесення мінеральних добрив і, в тому числі, контрольний варіант без удобрення. Збирання врожаю зерна проводили прямим комбайнуванням, вміст білка та вміст було визначено методом інфрачервоної спектроскопії, використовуючи Infratek 1241. Обробку статистичних даних було зроблено за допомогою програми STATISTICA 10. Урожайність зерна пшениці твердої озимої достовірно збільшувалась від удобрення. Проте ефективність їх застосування змінювалась залежно від року дослідження. Так, у 2020 р. вона збільшувалась у 1,1–1,2 рази (3,9–4,1 t ha^{-1}) за тривалого застосування лише азотних добрив. Тривале застосування повного мінерального добрива ($N_{150}P_{60}K_{80}$) достовірно впливало на врожайність зерна (4,3 t ha^{-1}) порівняно з варіантом N_{150}. У 2021 р. врожайність зерна зростала в 1,2–1,4 рази залежно від системи удобрення. Варто відзначити, що застосування $N_{150}P_{60}K_{40}$ і $N_{150}P_{30}K_{80}$ за впливом на врожайність зерна було на рівні варіанту $N_{150}P_{60}K_{80}$. Парні комбінації застосування добрив за ефективністю були на рівні тривалого застосування $N_{150}P_{30}K_{40}$. Застосування $N_{75}P_{30}K_{40}$ забезпечувало формування лише на 4 % меншої врожайності зерна порівняно з $N_{150}P_{30}K_{40}$. На вміст білка та вміст клейковини найбільше впливала азотна складова з повного мінерального добрива. Проведені дослідження підтверджують високу реакцію пшениці твердої на застосування азотних добрив. Отримані результати можна використовувати для прогнозування продуктивності пшениці твердої озимої залежно від родючості ґрунту

Ключові слова: азотні фосфорні та калійні добрива, продуктивність пшениці твердої озимої, вміст білка, збір білка, вміст клейковини