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# FORMATION OF YIELD AND QUALITY OF WINTER DURUM WHEAT GRAIN DEPENDING ON LONG-TERM FERTILIZATION

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**Abstract**
Durum wheat (*Triticum durum* Desf.) grain is the main raw material for the production of high-quality pasta and cereal products. The research was conducted at Uman National University of Horticulture (Ukraine) in a long-term stationary experiment, founded in 2011. The aim of the work was to study the impact of long-term use of various fertilization systems (with incomplete return of nitrogen, phosphorus and potash fertilizers) on the yield and quality of durum winter wheat grain. The long-term application of nitrogen, nitrogen-potassium, nitrogen-phosphorus and nitrogen-phosphorus-potassium systems in the field crop rotation has a strong impact on the formation of durum winter wheat yield. Long-term use of $N_{150}P_{60}K_{80}$ increases it from 3.6 t $ha^{-1}$ up to 4.9 t $ha^{-1}$ ($p \le 0.05$). The use of half a dose of complete mineral fertilizer provides 4.5 t $ha^{-1}$ ($p \le 0.05$). Variants with incomplete return of phosphorus-potassium fertilizers, as well as paired combinations with a nitrogen component, provide the formation of 4.6–4.8 t $ha^{-1}$ grains. Nitrogen fertilization systems increase grain yield to 4.2–4.5 t $ha^{-1}$ depending on the fertilizer dose. It should be noted that durum winter wheat responds well to the use of nitrogen fertilizers, as the protein content increases from 13.3 to 14.8–15.9 % ($p \le 0.05$), and the gluten content from 28.0 to 31.1–33.4% ($p \le 0.05$) depending on the fertilization system. The protein content was most affected by the application of nitrogen component from complete mineral fertilizer.
**Key words:** durum wheat, long-term fertilization, yield, protein content, gluten content.

## Introduction

According to Eurostat (FAOSTAT data, 2021 June, available at: http://www.fao.org/faostat/en/#data/QC), the world's gross common wheat grain production is about 765 million tonnes, of which durum wheat (*Triticum durum* Desf.) makes up almost 5%. Durum wheat grain is the main raw material for the production of high-quality pasta and cereal products (Panayotova *et al*., 2021). The production of valuable grain products from wheat is possible due to the use of high-protein grain in their production technology (Osokina *et al*., 2020). High-quality pasta requires durum wheat flour, which forms a strong dough with high tear and deformation resistance during cooking. Such flour performance is achieved with high-protein durum wheat grain (Mefleh *et al*., 2018). However, durum wheat is more demanding in terms of growing conditions than common wheat. Therefore, the development of an effective fertilization system ensuring the formation of a heavy yield of grain high in protein is relevant.

Crop productivity is the most variable and integral indicator of their vitality, which accumulates their genetic potential, soil fertility, weather conditions and elements of the cultivation technology (Kiseleva *et al*., 2016). One of the strongest factors leading to the increase in yield and grain quality is application of fertilizers under favourable weather conditions (Novak *et al*., 2019).

Nitrogen, phosphorus, potassium fertilizers (Hospodarenko *et al*., 2019), microfertilizers and a range of organic and organomineral fertilizers are usually used in winter wheat fertilization system (Bezuglova *et al*., 2017). However, the use of nitrogen fertilizers has the greatest impact on wheat crop capacity formation (Litke, Gaile, & Ruža, 2017). Thus, application of $N_{60}$ was found to increase the yield of durum winter wheat grain from 3.77 t $ha^{-1}$ up to 4.19 t $ha^{-1}$, in case of adding $N_{120}$ – up to 4.80 t $ha^{-1}$, while application of $N_{180}$ reduced it to 4.62 t $ha^{-1}$. The effectiveness of nitrogen fertilizers varied depending on the weather conditions of the growing season. Adding $N_{60}$ ensured wheat yield from 3.36 to 4.71 t $ha^{-1}$ depending on the year of the study (Panayotova, Almaliev, & Kostadinova, 2017). In other studies (Pačuta *et al*., 2021) the yield of durum winter wheat grain varied from 2.10 t $ha^{-1}$ in a less favorable year to 5.51 t $ha^{-1}$ in a more favourable year. Initiating a mineral fertilization program increased the yield of durum winter wheat from 2.88-4.61 to 3.46-5.67 t $ha^{-1}$ depending on the weather conditions of the study year (Slamka & Hanáčková, 2014). In these studies, however, the effectiveness of nitrogen fertilizers was explored without phosphorus-potassium fertilizers. In addition, nitrogen is a biogenic element whose content in soil is determined by the activity of its microorganisms and rhizosphere (Karpenko *et al*., 2021).

In the studies (Almaliev, Kostadinova, & Panayotova, 2014) when $N_{120}P_{80}$ was applied, the grain yield increase varied from 21.3 to 40.4 kg depending on the year of a study. However, these studies did not explore the effectiveness of potash fertilizers at all, and the doses of phosphorous and potash fertilizers were high. Moreover, it was a short-term application of a fertiliser, much different from a long-term application in the field crop rotation.

Durum wheat needs nitrogen throughout the entire growth period. Nitrogen nutrition must be balanced with the content of mobile phosphorus and potassium compounds in the soil. Modern durum wheat varieties have a high yield potential yet realize it in conditions of a high agricultural background (Panayotova, Almaliev, & Kostadinova, 2017).

One should point out that long-term use of fertilizers has an advantage over short-term use. With long-term use of fertilizers in low doses, it can be effective at the level of short-term application of high doses. This phenomenon is caused by the aftereffect of fertilizers applied for previous crops in the rotation (Šimansky, 2016).

Usage of mineral fertilizers not only has a positive effect on increasing wheat yield, but also significantly improves grain quality (Hospodarenko & Liubych, 2021). Different elements of plant nutrition have different effects on grain protein content. The mineral fertilization system, which included a nitrogen component, had the greatest impact on the formation of protein content in durum winter wheat grains. Thus, the studies (Slamka & Hanáčková, 2014) found that the protein content increased from 11.1% in the non-fertilized variant to 11.7% after application of a complete mineral fertilizer. Scientists indicate a significant variation in protein content in different weather conditions – from 10.5 to 12.4%.

The analysis of scientific literature confirms the essential role of nitrogen fertilizer use in the agricultural technology of durum winter wheat. A large variation of their effectiveness depending on weather conditions was established. However, studies usually involve the application of nitrogen fertilizers only, which negatively affects the balance of mobile phosphorus and potassium compounds in the soil. In addition, the studies were conducted in short-term experiments, which do not allow us to establish the real yield capacity of durum winter wheat under different soil fertility conditions. Therefore, the analysis of data obtained in stationary experiments on the regularities of the influence of fertilization systems with different return of nutrition elements will allow to develop and put into practice the system of fertilizer application based on protection of soil resources, strengthening of self-regulation processes, restoration of sustainable functioning of agro-ecosystems. In the currently widespread short rotation systems with a significant saturation with grain crops, there has been insufficient research on the impact of predecessors and fertilization systems on the yield and grain quality of durum winter wheat.

The aim of the work was to study the impact of long-term use of various fertilization systems (with incomplete return of nitrogen, phosphorus and potash fertilizers) on the yield and quality of durum winter wheat grain.

**Materials and Methods**

The studies were carried out during 2020-2021. 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 (*Triticum aestivum* L.), maize (*Zea mays* L.), spring barley (*Hordeum vulgare* L.) and soya (*Glycine max* Moench.). The aim of the field experiment is to establish the efficiency of the action of different types, rates and proportions of mineral fertilizers 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 fertilizers including the control variant without fertilizers (Table 1).

In the variant of the experiment with an average rate of nutrients in the crop rotation per hectare $N_{110}P_{60}K_{80}$, the total (100%) compensation with fertilizers of average annual removal of the nutrients by the crops in the crop rotation is planned. The scheme of the experiment was developed in such a way that it could be possible to determine the opportunity to decrease the rates of certain types of mineral fertilizers. 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) fertilizers were applied during fall tillage, nitrogenous fertilizers (ammonium nitrate) during pre-sowing cultivation and fertilizing of winter wheat.

The soil on the experimental plot is the podzolized chernozem heavy loamy soil on loess with 3.8% of humus content, the content of nitrogenous hydrolyzed compounds (by Cornfield method) is low (105 mg $kg^{-1}$), the content of mobile compounds of phosphorus and potassium (by Chirikov method, extraction 0.5 m $CH_3COOH$) is increased (106 mg $kg^{-1}$) and high (132 mg $kg^{-1}$) correspondingly, pH KCl – 5.7.

The grain was harvested by combined harvesters. The protein content and gluten content were determined by the method of infrared spectroscopy using Infratec 1241 (FOSS Analytical, Sweden). The accounting of the harvest of non-marketable produce was conducted with 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 fertilizing.

Table 1

**The design of application of fertilizers in the experiment**

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

Note. * P – $P_2O_5$, K – $K_2O$.

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 during the years of the study differed from the annual average (see Table 2). The amount of precipitation in 2020 was lower compared to the annual average and 2021. There was not enough precipitation to produce sprouts in October 2019. In 2021, there was sufficient precipitation during the growing season to produce a high grain yield. Temperatures in 2020 were higher than the annual average, except for BBCH-stage 10 and BBCH-stage 50.

As a result of the moisture deficit in the fall of 2019, winter durum wheat sprouted in January 2020, which affected the formation of fewer productive stems (Table 3). In addition, the negative impact of frost during the phase BBCH 30 caused the formation of lower grain yield capacity compared with 2021.

Characteristics of 'Andromeda', a durum winter wheat 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 zones. The potential yield is 3.6-6.0 t $ha^{-1}$. Resistance to lodging – 5 points, to shedding – 7, to root rot – 5, to septoria – 9, to fusarium – 7, to brown rust – 8, to

Table 2

**Weather conditions at the experimental site**

| Indicators | Year of research | | | | 1991–2020 | |
|---|---|---|---|---|---|---|
| | 2019/2020 | | 2020/2021 | | | |
| | Precipitation (mm) | Temperature (°C) | Precipitation (mm) | Temperature (°C) | Precipitation (mm) | Temperature (°C) |
| Sowing time | 10.3 | 10.0 | 81.5 | 12.7 | 49 | 8.3 |
| BBCH 10 | 78.9 | -2.1 | 109.7 | -0.2 | 72 | -5.0 |
| BBCH 20 | 38.7 | 7.1 | 44.9 | 9.5 | 77 | 6.1 |
| BBCH 30 | 35.6 | 17.0 | 59.1 | 14.3 | 52 | 15.4 |
| BBCH 50 | 34.3 | 20.4 | 68.0 | 18.7 | 81 | 20.9 |
| BBCH 73 | 35.8 | 21.9 | 58.7 | 23.0 | 49 | 20.1 |

Table 3

**Winter durum wheat sowing, date of the development phase of plants beginning and harvesting time date during trial years**

| Indicators | Year of research | |
|---|---|---|
| | 2019/2020 | 2020/2021 |
| Sowing time | October 17$^{th}$, 2019 | October 30$^{th}$, 2020 |
| BBCH 10 | January 25$^{th}$ | November 20$^{th}$ |
| BBCH 20 | February 25$^{th}$ | April 13$^{th}$ |
| BBCH 30 | May 01$^{th}$ | May 10$^{th}$ |
| BBCH 50 | June 05$^{th}$ | June 06$^{th}$ |
| BBCH 73 | June 20$^{th}$ | June 20$^{th}$ |
| Harvesting time | July 15$^{th}$ | July 22$^{th}$ |

powdery mildew – 6 points. Pasta-making properties are high – 7.4 points (9 is the best, 1 is the worse).

## Results and Discussion

It was established that the yield of durum winter wheat grain with long-term use of $N_{150}P_{60}K_{80}$ increased by 1.4 times (4.9 t ha$^{-1}$) compared to the non-fertilized variant (3.6 t ha$^{-1}$) (Figure 1B). In the variants with incomplete return of phosphorus-potassium fertilizer this indicator was lower by only 2-6% compared to the complete mineral fertilizer, but reliable. Application of $N_{75}P_{30}K_{40}$ increased the yield by 1.3 times (4.5 t ha$^{-1}$) compared to non-fertilized areas. Under this fertilization scenario, the yield was only 9% lower compared to long-term application of $N_{150}P_{60}K_{80}$.

The efficiency of nitrogen-phosphorus and nitrogen-potassium fertilizer systems was at the level of variants with incomplete return of phosphorus-potassium fertilizers. However, the yield was significantly lower compared to the complete mineral fertilizer. Long-term use of 75 kg ha$^{-1}$ of nitrogen fertilizers increased grain yield by 1.2 times compared to non-fertilized areas. This indicator was significantly lower compared to variant $N_{75}P_{30}K_{40}$. The

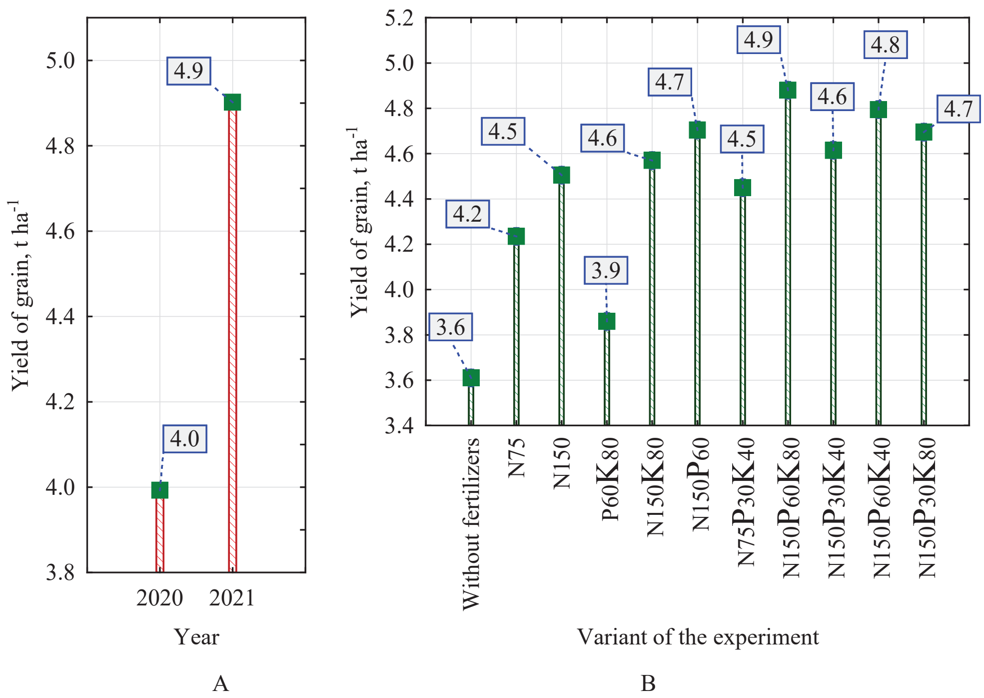


Figure 1. Durum winter wheat grain yields under different fertilisation systems (B) and on average per trial year (A), t ha$^{-1}$

use of 150 kg ha$^{-1}$ of nitrogen fertilizers increased the yield by 1.3 times compared to the test sample. The effectiveness of this fertilizer system was at the level of $N_{75}P_{30}K_{40}$. However, the yield was significantly lower compared with the variants where nitrogen-phosphorus-potassium fertilizers were used.

The yield of durum winter wheat was least affected by the use of phosphorus-potassium fertilizers. With this fertilization system, it increased only by 8% compared to the variant without fertilizers and was significantly less compared to the variants, which included a nitrogen component.

The results of statistical analysis confirm a strong effect of weather conditions on the formation of durum winter wheat yield. Thus, more favourable weather conditions in 2021 ensure a 23% higher grain yield compared to less favourable conditions in 2020 (Figure 1A).

Weather conditions in 2021 were typical for the Right-Bank Forest-Steppe of Ukraine. In 2020, only 187.5 mm of precipitation fell during the growing season, which is 1.5 times less than in 2021 (281.7 mm). This means that durum winter wheat plants in 2020 were under moisture stress conditions, which affected the formation of a smaller grain yield. It has been proved that the reduction in grain yield of durum winter wheat under stress conditions is due to the formation of fewer productive stems, grain mass and grain number per ear (Ruiz *et al.*, 2019). In other studies (Shehab-Eldeen, Khedr, & Genedy, 2021) application of $N_{25–75}$ in a more favourable year, the yield of winter wheat grain increased from 5.97 t ha$^{-1}$ up to 9.62 t ha$^{-1}$. In a less favourable year from 4.52 t ha$^{-1}$ up to 6.89 t ha$^{-1}$. These results confirmed the role of the amount and distribution of precipitation during the growing season for the formation of wheat yields in the conditions of the Right-Bank Forest-Steppe of Ukraine. The efficiency of fertilization systems depended on the nitrogen component of mineral fertilizers, as wheat is a nitrogen-philic crop (Panayotova, Almaliev, & Kostadinova, 2017). Therefore, there was no significant decrease in the yield of durum winter wheat grain from incomplete return of phosphorus-potash fertilizers. Long-term use (since 2011) of $N_{75}P_{30}K_{40}$ was at the level of long-term application of $N_{150}$ in terms of efficiency. This confirmed the conclusions about the high efficiency of low doses of fertilizers when applied for a long time (Šimansky, 2016).

The results of the analysis show that the application of all fertilization programs containing the nitrogen component significantly increased the protein content in grain compared with the test sample (Figure 2 B). The only exception was the phosphorus-potassium fertilizer system, which did not substantially affect the protein content. Long-term use of $N_{75}$ increased protein content by 11% compared to non-fertilized areas. The application of a double dose of nitrogen fertiliser increased it by 18% compared to the test sample and by 6% compared to $N_{75}$. It is worth

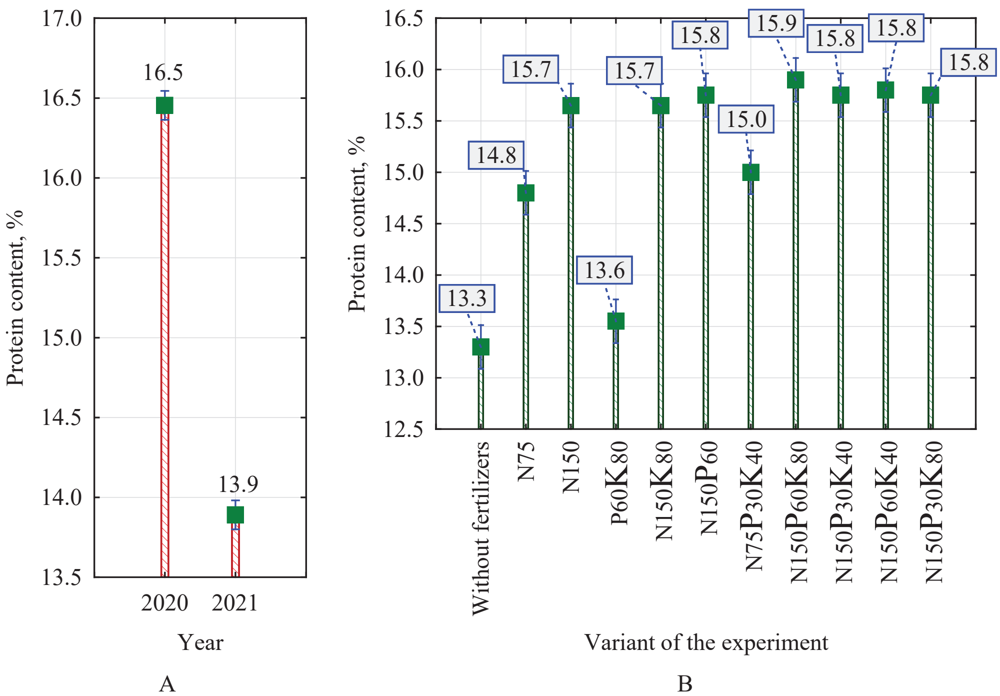


Figure 2. Protein content of durum winter wheat grains under different fertilization systems (B) and on average per trial year (A).

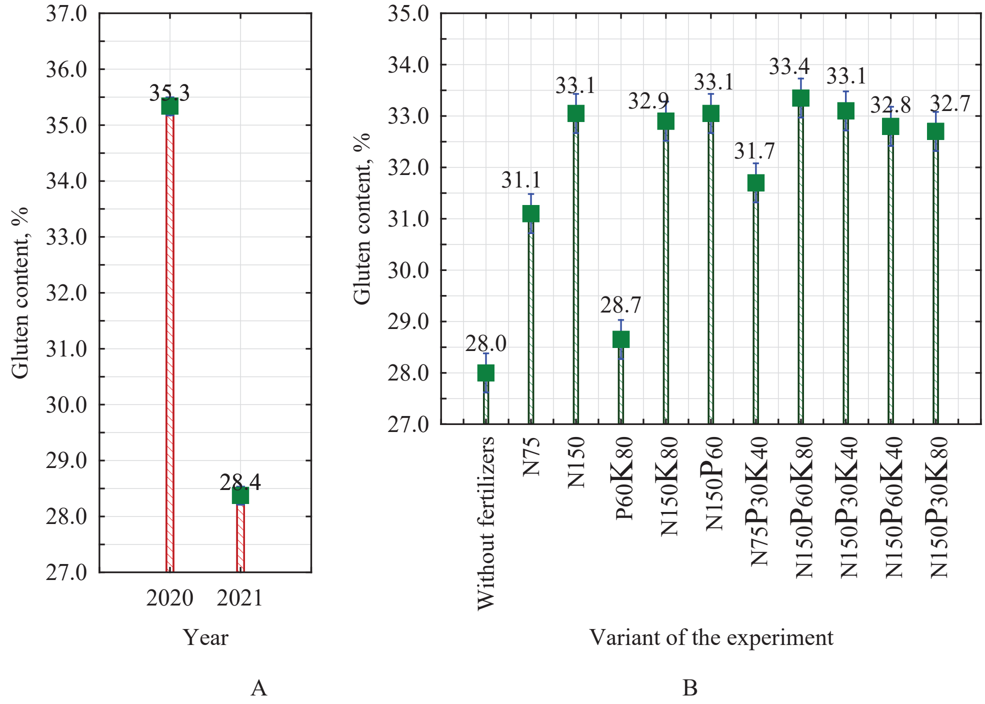


Figure 3. Gluten content of durum winter wheat grains under different fertilization systems (B) and on average per trial year (A).

noting that the use of nitrogen-phosphorus-potassium fertilizers did not significantly increase the protein content compared to nitrogen systems. The impact of weather conditions was also high, as protein content ranged from 13.9% in 2021 to 16.5% in 2020. The protein content in durum winter wheat grain in 2020 was 1.2 times higher compared to the protein content in 2021 (Figure 2A).

The gluten content in durum winter wheat grain with prolonged use of 75 kg ha$^{-1}$ of nitrogen fertilizers increased by 11% compared to the test sample (Figure 3B). Long-term use of $N_{150}$ increased its content by 18% compared to non-fertilized areas and by 6% compared to variant $N_{75}$. Nitrogen-phosphorus-potash fertilization systems had no advantages over the use of nitrogen fertilizers alone. It stands to mention that long-term use of phosphorus-potassium fertilizers did not significantly increase the gluten content. The gluten content of durum winter wheat grain ranged from 28.4 to 35.3%, depending on weather conditions (Figure 3A).

Durum winter wheat grain quality is shaped by the combined effect of abiotic and biotic factors. The protein and gluten content are most dependent on weather conditions during grain maturation and the use of nitrogen fertilizers (Pačuta *et al*., 2021).

Studies (Ruiz *et al*., 2019) confirmed a significant effect of weather conditions on the formation of protein content, which varied from 7.5 to 12.7%. It is noteworthy that in these studies at a yield of 3.60 t ha$^{-1}$ the protein content in durum winter wheat grain was at the level of 9.7%, 3.11 t ha$^{-1}$ – 7.5%, and for 1.37 t ha$^{-1}$ – 12.7%. A decrease in grain yield contributes to an increase in grain protein content. Apparently, this is due to the ability of plants to reutilize nitrogen from the vegetative mass for protein synthesis in grain. In our research, moisture deficiency and high temperature during the BBCH-stage 73 in 2020 contributed to 1.2 times higher protein and gluten content in grain compared to the year 2021.

The factors studied (fertiliser system, year) had a statistically significant ($p \leq 0.05$) effect on yield formation and grain quality of durum winter wheat. The strength of influence was high for both factors. The effects of these factors on yield, protein content and gluten content were almost identical. This indicates that the fertilisation efficiency of durum winter wheat depends on the weather conditions of the growing season and fertilisation. It should be noted that this conclusion applies only to two years of research (2020-2021) or for years with similar weather parameters.

The results obtained can be used for the durum winter wheat variety 'Andromeda' or varieties of this type. In addition, the results obtained can be used for four-field crop rotation, where durum winter wheat is grown after soybeans. In other agricultural technology scenarios, further research is required.

**Conclusions**

The long-term application of nitrogen, nitrogen-potassium, nitrogen-phosphorus and nitrogen-phosphorus-potassium systems in the field crop rotation has a strong impact on the formation of durum winter wheat yield. Long-term use of $N_{150}P_{60}K_{80}$ increases it from 3.6 t ha$^{-1}$ up to 4.9 t ha$^{-1}$ ($p \leq 0.05$). The use of half a dose of complete mineral fertilizer provides 4.5 t ha$^{-1}$ ($p \leq 0.05$). Variants with incomplete return of phosphorus-potassium fertilizers, as well as paired combinations with a nitrogen component, provide the formation of 4.6-4.8 t ha$^{-1}$ grains. Nitrogen fertilization systems increase grain yield to 4.2-4.5 t ha$^{-1}$depending on the fertilizer dose. It should be noted that durum winter wheat responds well to the use of nitrogen fertilizers, as the protein content increases from 13.3 to 14.8-15.9% ($p \leq 0.05$), and the gluten content from 28.0 to 31.1-33.4% ($p \leq 0.05$) depending on the fertilization system. The protein content was most affected by the application of nitrogen component from complete mineral fertilizer. A high influence of the factors of the fertilization system and the year on the yield, protein content and gluten content in durum winter wheat grain was established.

**References**

Ali, S.A., Tedone, L., Verdini, L., Cazzato, E., & De Mastro, G. (2019). Wheat Response to No-Tillage and Nitrogen Fertilization in a Long-Term Faba Bean-Based Rotation. *Agronomy*. 9, 50. DOI: 10.3390/ agronomy9020050.

Almaliev, M., Kostadinova, S., & Panayotova, G. (2014). Effect of fertilizing systems on the phosphorus efficiency indicators at durum wheat. *Agriculture & Forestry*. 60(4), 127–134. DOI: 10.15547/ast.2021.01.010.

Bezuglova, O.S., Polienko, E.A., Gorovtsov, A.V., Lyhman, V.A., & Pavlov, P.D. (2017). The effect of humic substances on winter wheat yield and fertility of ordinary chernozem. *Ann. Agrar. Sci*. 15, 239–242. DOI: 10.1016/j.aasci.2017.05.006.

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, 12-14 May 2021 (pp. 29–35), Vol. 36, Jelgava, Latvia: Latvia University of Life Sciences and Technologies. DOI: 10.22616/rrd.27.2021.004.

Hospodarenko, H., Prokopchuk, I., Nikitina, O., & Liubych, V. (2019). Assessment of the contamination level of a podzolized chernozem with nuclides in a long-term land use. *Agriculture*. 65(3), 128−135. DOI: 10.2478/AGRI-2019-0013.

Karpenko, V.P., Poltoretskyi, S.P., Liubych, V.V., Adamenko, D.M., Kravets, I.S., Prytuliak, R.M., Kravchenko, V.S., Patyka, N.I., & Patyka V.P. (2021). Microbiota in the rhizosphere of cereal crops. *Mikrobiol. Z*., 83(1), 21–31. DOI: 10.15407/microbiolj83.01.021.

Kiseleva, M.I., Kolomiets, T.M., Pakholkova, E.V., Zhemchuzhina, N.S., & Lubich, V.V. (2016). The differentiation of winter wheat (*Triticum aestivum* L.) cultivars for resistance to the most harmful fungal pathogens. *Agricultural Biology*. 51 (3), 299–309. DOI: 10.15389/AGROBIOLOGY.2016.3.299RUS.

Litke, L., Gaile, Z., & Ruža, A. (2017) Nitrogen fertilizer influence on winter wheat yield and yield components depending on soil tillage and forecrop. In Annual 23th International Scientific Conference Research for Rural Development, 17-19 May 2017 (pp. 54–61), Vol. 2, Jelgava, Latvia: Latvia University of Life Sciences and Technologies. DOI: 10.22616/rrd.23.2017.049.

Mefleh, M., Conte, P., Fadda, C., Giunta, F., Piga, A., Hassoun, G., & Motzo, R. (2018). From ancient to old and modern durum wheat varieties: interaction among cultivar traits, management, and technological quality. *J. Sci. Food Agric*. 99, 2059–2067. DOI: 10.1002/jsfa.9388.

Novak, L., Liubych, V., Poltoretskyi, S., & Andrushchenko, M. (2019). Modern Development Paths of Agricultural Production: Trends and Innovations. In V. Nadykto (Eds.), *Technological indices of spring wheat grain depending on the nitrogen supply* (pp. 753–761). Melitopol, Tavria State Agrotechnological University. DOI: 10.31388/2220-8674-2019-1-55.

Osokina, N., Liubych, V., Novikov, V., Leshchenko, I., Petrenko, V., Khomenko, S., Zorunko, V., Balabak, O., Moskalets, V., & Moskalets, T. (2020). Effect of Electromagnetic Irradiation of Emmer Wheat Grain on the Yield of Flattened Wholegrain Cereal. *Eastern European Journal of Enterprise Technologies*. 5(108), 40–51. DOI: 10.15587/1729-4061.2020.217018.

Pačuta, V., Rašovský, M., Michalska-Klimczak, B., & Wyszyňski, Z. (2021). Grain Yield and Quality Traits of Durum Wheat (*Triticum durum* Desf.) Treated with Seaweed and Humic Acid-Based Biostimulants. *Agronomy*. 11, 1270. DOI: 10.3390/ agronomy11071270.

Panayotova, G., Almaliev, M., & Kostadinova, S. (2017). Nitrogen uptake and expense in durum wheat depending on genotype and nitrogen fertilization. *Agricultural Science and Technology*. 9(1), 26–34. DOI: 10.15547/ast.2017.01.005.

Panayotova, G., Kostadinova, S., Stefanova-Dobreva, S., & Muhova, A. (2021). Influence of long-term fertilization and environments on test weight of durum wheat (*Triticum durum* Desf.) grain. *Agriculture and Environment*. 13(1), 52–56. DOI: 10.15547/ast.2021.01.010.

Ruiz, M., Zambrana, E., Fite, R., Sole, A., Tenorio, J.L., & Benavente, E. (2019). Yield and Quality Performance of Traditional and Improved Bread and Durum Wheat Varieties under Two Conservation Tillage Systems. *Sustainability*. 11(17), 4522. DOI: 10.3390/su11174522.

Shehab-Eldeen, M.T., Khedr, R.A., & Genedy, M.S. (2021). Studies on Morphophysiological Traits and their Relationships to Grain Yield and its Components of Six Bread Wheat Genotypes under Four Nitrogen Fertilization Levels. *J. of Plant Production*. 12(1), 11–17. DOI: 10.21608/jpp.2021.152011.

Šimanský, V. (2016). Changes in soil organic matter parameters during the period of 18 years under different soil management practices. *Agriculture*. 62, 149–154. DOI: 10.1515/agri-2016-0015.

Slamka, P., & Hanáčková, E. (2014). Effect of different fertilization on durum wheat (*Triticum durum* Desf.) yield and quality parameters. *Research Journal of Agricultural Science*. 46 (3), 68–78.

Stationary field experiments of Ukraine. (2014). Agrarian Science, Kyiv. 146 p.