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Grain yield and protein content in different ripening varieties of soft winter wheat using various types and doses of fertilizers

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Purpose. To study of yield formation and protein content in the grain of different ripening varieties of soft winter wheat under the condition of using various types and doses of fertilizers. **Methods.** Field and laboratory (determination of protein content), calculation (collection of protein), mathematical and statistical. **Results.** It was found that different fertilization systems reliably increased the grain yield of soft winter wheat. The use of N_{75} increased this indicator by 1.2 times and N_{150} by 1.4 times in the varieties studied, compared with the no-fertilizer variant. Yield with incomplete return of phosphorus-potassium fertilizer was only 2–3% lower than with complete mineral fertilizer. With the nitrogen-phosphorus and nitrogen-potassium fertilization systems, the yield was 5–7% higher than with the nitrogen system. At the same time, this indicator was 6% lower than in the full mineral fertilizer version of the trial. The use of 75 kg/ha nitrogen fertilizer per year increased the protein content to 13.5%, or by 10% compared to the control. In the double dose nitrogen fertilizer variant, the protein content increased to 14.2% or by 15%. The use of nitrogen fertilizers with phosphorus-potassium only contributed 2–4% to the increase of this indicator. Cultivation of winter wheat under the condition of application of N_{75} increased the collection of protein up to 724 kg/ha or by 33%, and with a double dose of nitrogen fertilizer – up to 848 kg/ha or by 55% compared to the option without fertilizer. In the $N_{75}P_{30}K_{40}$ variant, protein yield increased by 10% compared to the nitrogen system. The application of a complete mineral fertilizer ($N_{150}P_{60}K_{40}$) increased this indicator by 12%. **Conclusions.** It was found that the use of $N_{75}P_{30}K_{40}$ increased the grain yield of soft winter wheat by up to 5.9 t/ha, or 7%, compared to the option where only 75 kg/ha of nitrogen fertilizer was applied. Yield development in soft winter wheat varies considerably from variety to variety. For example, this indicator was 35% higher in the 'KWS Emil' variety than in the 'Prino' line. In addition, the grain yield of both varieties is reliably influenced by the weather conditions during the growing season. The protein content of soft winter wheat varies considerably depending on the variety and the weather conditions. When growing soft winter wheat varieties, the protein content can vary by 12.8–15.1%. Weather conditions during the growing season can change this indicator by 13.1–14.7%. The protein content index in the grain of the 'Prino' line is significantly higher than that of the 'KWS Emil' variety. According to the protein yield per hectare indicator, the 'KWS Emil' variety (896 kg/ha) has a significant advantage over the 'Prino' line (774 kg/ha).

Keywords: *variety; productivity; weather conditions; fertilizer system; protein collection.*

Introduction

Common wheat is the main raw material for the production of high quality cereal products [1]. According to Eurostat [2], its gross world production is about 765 million tonnes. The optimal dose of fertilizer used in soft wheat cultivation must be determined taking into account the biological characteristics of the variety and the expected yield level, weather conditions and soil fertility, the level of agricultural technologies, the placement of crops in the crop rotation, their saturation with fertilizer and other factors [3].

The productivity of agricultural crops is a variable and integral indicator of their vital activity, which reflects their genetic potential, soil fertility, weather conditions and cultivation technologies [4]. One of the strongest factors for increasing yield and improving grain quality is the application of fertilizer under favorable weather conditions [5].

Nitrogen, phosphorus, potassium fertilizers [6], microfertilizers and a number of organic and organo-mineral preparations [7] are commonly used in the fertilization system of win-

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ter wheat. However, the use of nitrogen fertilizers has the greatest influence on the development of wheat productivity [8].

Studies [9] showed that the efficacy of fertilizer application varies considerably depending on the winter wheat variety. The dose of $N_{150}P_{120}K_{90}$ was effective. Under these fertilization conditions, the yield index of the 'Groma' variety increased from 4.5 to 7.9 t/ha and that of the 'Bezosta 100' variety from 4.0 to 6.8 t/ha. In work [10] the application of $N_{135}P_{20}K_{65}$ was effective: the grain yield of winter wheat was 4.5 t/ha, the protein content increased to 13.4%. However, such doses of fertilizers cannot be recommended for the right bank forest steppe, as their effectiveness has been studied in other soil and climatic conditions.

It should be noted that the effectiveness of fertilizer application is highly dependent on weather conditions. For example, over the period 1985–2020, cereal yield varied from 0.7 to 2.9 t/ha in areas without fertilizer. Under the organic fertilization system (75 t/ha) this indicator was 1.3–6.8 t/ha, mineral ($N_{120}P_{26}$) – 2.3–7.0, organo-mineral ($N_{120}P_{26}$ + 75 t/ha manure) – 1.3–7.8 t/ha. In addition, the reliability of predicting the influence of elements of weather conditions on grain yield was low, as R^2 = 0.22–0.45 [11]. Therefore, different fertilization systems had almost the same effectiveness in development of winter wheat grain yield.

It should be noted that long-term use of fertilizers has an advantage over short-term use. The effectiveness of long-term fertilizer application at low doses can be at the level of short-term application at high doses. This phenomenon is due to the aftereffect of fertilizers applied to previous crop rotations [12].

The use of mineral fertilizers not only has a positive effect on increasing wheat yield, but also significantly improves grain quality [13]. Different elements of plant nutrition have different effects on the protein content of grain. The mineral fertilizer system containing a nitrogen component had the greatest influence on the development of protein content in hard winter wheat grains. For example, research [14] found that the protein content increased from 11.1% in the no-fertilizer version to 11.7% with the introduction of complete mineral fertilizer. The authors note a significant variation in protein content depending on weather conditions – from 10.5 to 12.4%.

The analysis of the scientific literature confirms the important role of the use of nitrogen fertilizers in the agronomy of soft winter wheat. A large variation in their effectiveness has been observed, depending on weather conditions, variety and fertilizer options. However, such studies are mainly focused on studying the effectiveness of nitrogen fertilizers, which negatively affect the balance of mobile compounds of phosphorus and potassium in the soil. In addition, similar studies were carried out in short-term trials, which makes it impossible to determine the true productivity of soft winter wheat under different soil fertility conditions. Therefore, the analysis of the information obtained in the long-term experiments on the patterns of influence of fertilization systems with different nutrient returns will provide an opportunity to develop and implement fertilization systems based on the principles of protecting soil resources, strengthening self-regulation processes and restoring the sustainable functioning of agroecosystems. In the currently widespread short rotations with significant saturation of cereal crops, the influence of precursors and fertilization systems on the yield and grain quality of soft winter wheat has not been sufficiently investigated.

The purpose of the research is to study the development of yield and protein content in the grain of different ripening varieties of soft winter wheat under different types and doses of fertiliser.

Materials and methods

The experimental research was conducted in 2020–2022 in the conditions of the right bank forest steppe of Ukraine in the stationary field experiment of the Department of Agrochemistry and Soil Science of the Uman National University of Horticulture with the geographical coordinates of Greenwich 48° 46' north latitude and 30° 14' east longitude. The trial was established in 2011 at the experimental field of the Uman National University of Science and Technology (NAAS Certificate No. 87). The soil of the experimental field is podozolized chernozem (heavy loam composition on loess) with a humus content of 3.4%, the nitrogen content of easily hydrolysable compounds is low, the mobile compounds of phosphorus and potassium are high, the pH_{KCl} is 5.8.

Weather conditions during the study years were as follows: in 2020, 479 mm of precipitation fell, which is 25% less than the long-term average indicator. Air temperature was higher than the multi-year average and in 2021. The amount of precipitation in 2021 was higher than in 2020 – 655.7 mm and in 2022 – 452.0 mm. The air temperature was within the long-term average, but the distribution of precipitation was different. Thus, in 2020, during the growing season of soft winter wheat, only

187.5 mm of precipitation fell, which is 1.5 times less than in 2021 (281.7 mm) and in 2022 – 280.3 mm. It should be noted that for the sowing of soft winter wheat in 2019, seedlings were received on 20 January 2020. In 2020 the plants overwintered at the stage when the first leaf emerged from the coleoptile (BBCH 10) and in 2022 at the tillering stage when the lateral shoot was in the leaf sheath (BBCH 20). Therefore, the weather conditions in 2022 were more favourable for the formation of the highest yield.

Crop rotation – winter wheat, maize, spring barley, soybean. The trial was repeated three times. The area of the experimental plot is 25 m^2. In the version of the production control experiment ($N_{150}P_{60}K_{80}$), the fertilizer dose is calculated on the basis of the economic removal of the main nutrients by the crop rotation. The design of the experiment is such that, based on the results of the research carried out, it is possible to determine the feasibility of reducing the doses of certain types of mineral fertilizer and to determine their optimum combination.

The fertilizer application scheme in the winter wheat crop rotation included the following options: no fertilizer (control), N_{75}, N_{150}, $P_{60}K_{80}$, $N_{150}K_{80}$, $N_{150}P_{60}$, $N_{75}P_{30}K_{40}$, $N_{150}P_{60}K_{80}$, $N_{150}P_{30}K_{40}$, $N_{150}P_{60}K_{40}$, $N_{150}P_{30}K_{80}$. According to the experimental design, phosphorus (granulated superphosphate) and potassium (potassium chloride) fertilizers are applied under autumn tillage, nitrogen (ammonium nitrate) – as a top dressing, once in spring.

The variety and line of soft winter wheat were studied in the experiment. The 'Prino' line (Uman NUH) was created by hybridization of *Triticum aestivum* L. / *Triticum spelta* L. It is a high-yielding soft winter wheat variety (yield up to 9.0 t/ha), early maturing. 'KWS Emil' (KWS SAAT SE & Co. KGaA) is a high-yielding, late-maturing variety with very good lodging resistance.

The agrotechnology of growing soft winter wheat consisted in peeling the soybean stubble in two tracks after harvesting. According to the design of the experiment, phosphorus and potassium fertilizers were applied for soil tillage and nitrogen fertilizers for top dressing in the II–III decades of January. Seed was sown in the II–III decade of October. In the phase of the beginning of the emergence of the plants in the tube (BBCH 31) the herbicide Granstar® Gold 75 WG with the fungicide Madison 26.3%, SC was used. Harvesting was carried out by direct harvesting at full grain maturity (BBCH 93).

Yield was determined by direct harvesting and protein content was determined according to DSTU 4117:2007 [15]. Statistical processing of the data was carried out by analysis of variance, which confirmed or rejected the null hypothesis. This was done by determining the "p" value, which indicates the probability of the corresponding hypothesis. If $p < 0.05$, the null hypothesis was rejected and the influence of the factor was reliable.

Results and discussion

It was shown that the use of different fertilization systems in our trials reliably increased the yield of soft winter wheat grain (Fig. 1). The application of N_{75} increased this indicator by 1.2 times and N_{150} by 1.4 times compared to the option without fertilizer. The application of phosphorus, potassium and phosphorus-potassium fertilizers significantly increased grain yield compared to the nitrogen fertilization systems. However, the $N_{150}P_{60}K_{80}$ variant only increased the yield index by 10% compared to the nitrogen fertilized system.

Yield with incomplete return of phosphorus-potassium fertilizer was only 2–3% lower than with complete mineral fertilizer. With the nitrogen-phosphorus and nitrogen-potassium fertilization systems, the yield was 5–7% higher than with the nitrogen system. At the same time, this indicator was 6% lower than in the full mineral fertilizer version of the trial.

The phosphorus-potassium fertilization system had the least effect on the grain yield of soft winter wheat. This indicator increased by only 7% compared to the control. At the same time, the influence of the factor was reliable. It should be noted that the yield varied considerably depending on the type of soft winter wheat. For example, this indicator was 35% higher for the 'KWS Emil' variety than for the 'Prino' line.

The weather conditions during the study years also had a significant impact on grain yield. In the more favourable weather year 2022, it was 20% higher than in 2020. The grain yield in 2021 was significantly higher than in 2020, but lower than in 2022.

The studies carried out confirmed the importance of the nitrogen component in the winter wheat fertilization system. The results of other researchers confirm the high efficiency of using nitrogen fertilizers for cereal crops in comparison with phosphorus-potassium fertilizers [16]. It should be noted that the efficiency of fertilizer application depends on the weather conditions during the growing season. In 2020–2022, the yield of common winter wheat varied between 5.3 and 6.6 t/ha. However, this trend is typical of conditions in

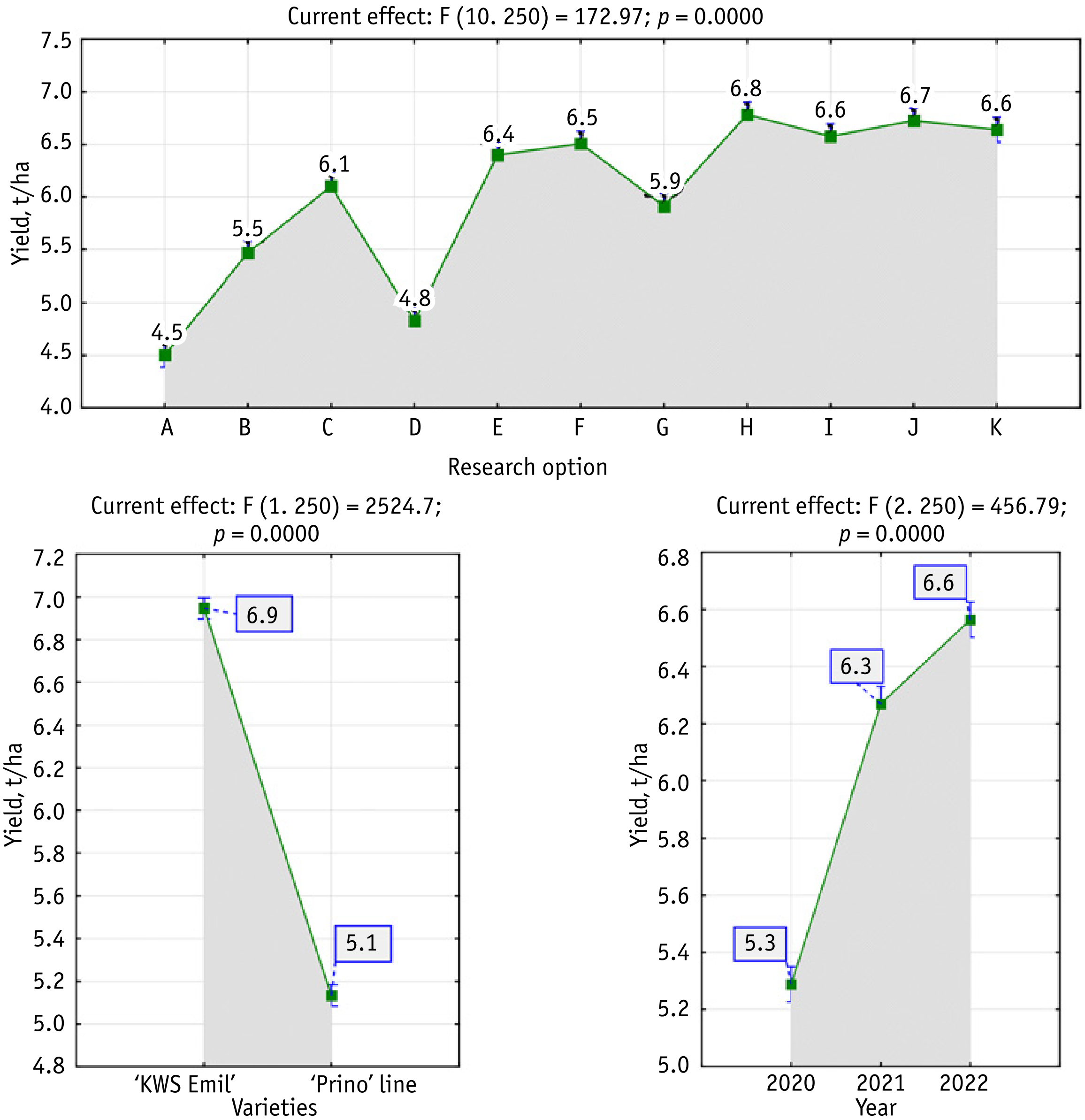

Fig. 1. Yield of different varieties of soft winter wheat as a function of fertilization:
A – No fertilizer (control), B – N_{75}, C – N_{150}, D – $P_{60}K_{80}$, E – $N_{150}K_{80}$, F – $N_{150}P_{60}$, G – $N_{75}P_{30}K_{40}$, H – $N_{150}P_{60}K_{80}$, I – $N_{150}P_{30}K_{40}$, J – $N_{150}P_{60}K_{40}$, K – $N_{150}P_{30}K_{80}$

the Right Bank Forest Steppe. In addition, the grain yield varied according to the winter wheat variety, which is due to the selection and genetic characteristics of the variety. For example, the 'Prino' line was early maturing and the 'KWS Emil' variety was late maturing. It is obvious that plants with a longer vegetation period use more nutrients than plants with a shorter vegetation period.

The use of nitrogen fertilizer had a reliable effect on the protein content of the soft winter wheat grain (Fig. 2). This indicator increased from 12.3 in the case of no fertilization to 14.7% depending on the fertilization system. It should be noted that the phosphorus-potassium system did not affect the protein content. At the same time, the nitrogen fertilizer dose had different effects on this indicator. The application of 75 kg/ha nitrogen fertilizer per year increased the protein content to 13.5%, i.e. by 10% compared to the control. In the double dose nitrogen fertilizer variant, the protein content increased to 14.2%, or by 15%. The use of phosphorus-potassium nitrogen fertilizers only contributed 2–4% to the increase in this indicator.

The results of the statistical processing showed that the protein content varied significantly depending on the variety of soft winter wheat and the weather conditions. When growing winter wheat varieties, the protein content can vary from 12.8 to 15.1%. The weather conditions during the growing season can change this indicator from 13.1 to

14.7%. Therefore, the use of nitrogen fertiliser not only increases the yield of soft winter wheat, but also increases the protein content.

The protein content of winter wheat grains is determined by a number of factors [17]. One of the effective ways to increase its content is the use of nitrogen fertilisers [18]. The studies carried out show that protein content is most dependent on the nitrogen component of the complete mineral fertilizer. In addition, its

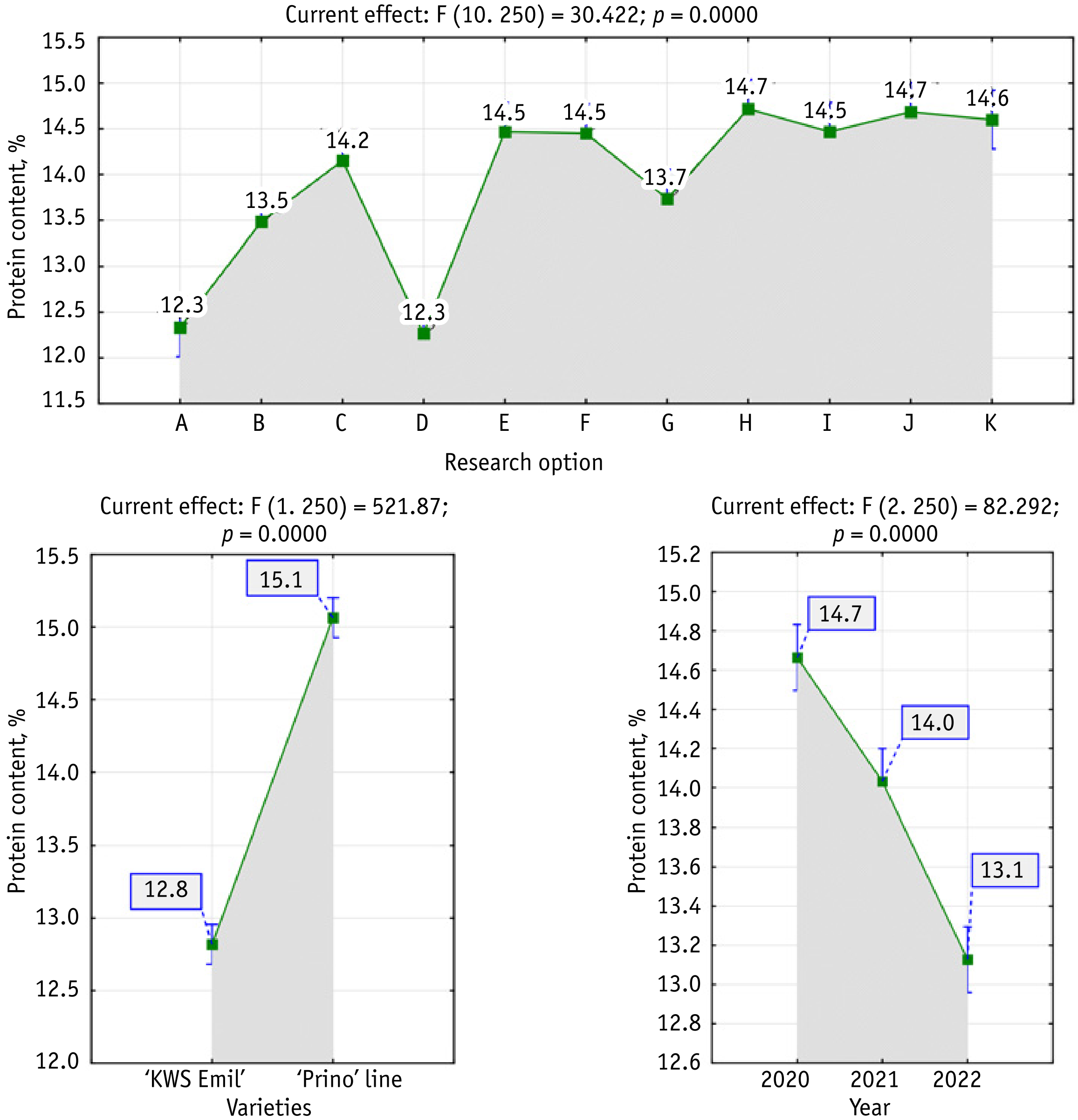

Fig. 2. Protein content in grain of soft winter wheat varieties of different maturity as a function of fertilization:
A – No fertilizer (control), B – N_{75}, C – N_{150}, D – $P_{60}K_{80}$, E – $N_{150}K_{80}$, F – $N_{150}P_{60}$, G – $N_{75}P_{30}K_{40}$, H – $N_{150}P_{60}K_{80}$, I – $N_{150}P_{30}K_{40}$, J – $N_{150}P_{60}K_{40}$, K – $N_{150}P_{30}K_{80}$

effectiveness is determined by weather conditions, especially during the period of grain ripening, and by the characteristics of the winter wheat variety. It should be noted that under the conditions of the Right Bank Forest Steppe, the protein content of soft winter wheat grains varies significantly depending on weather conditions (13.1–14.7%) and variety characteristics (12.8–15.1%). The higher protein content of 'Prino' winter wheat grain is due to the formation of a lower yield level. With the same nitrogen content in the soil and the formation of a lower yield, the proportion used for protein synthesis increases and vice versa.

Different fertilization systems reliably increased the protein yield from the grain harvest of soft winter wheat (Fig. 3). When winter wheat was grown on the N_{75} nitrogen system, this indicator increased to 724 kg/ha, or 33%, and with a double dose of nitrogen fer-

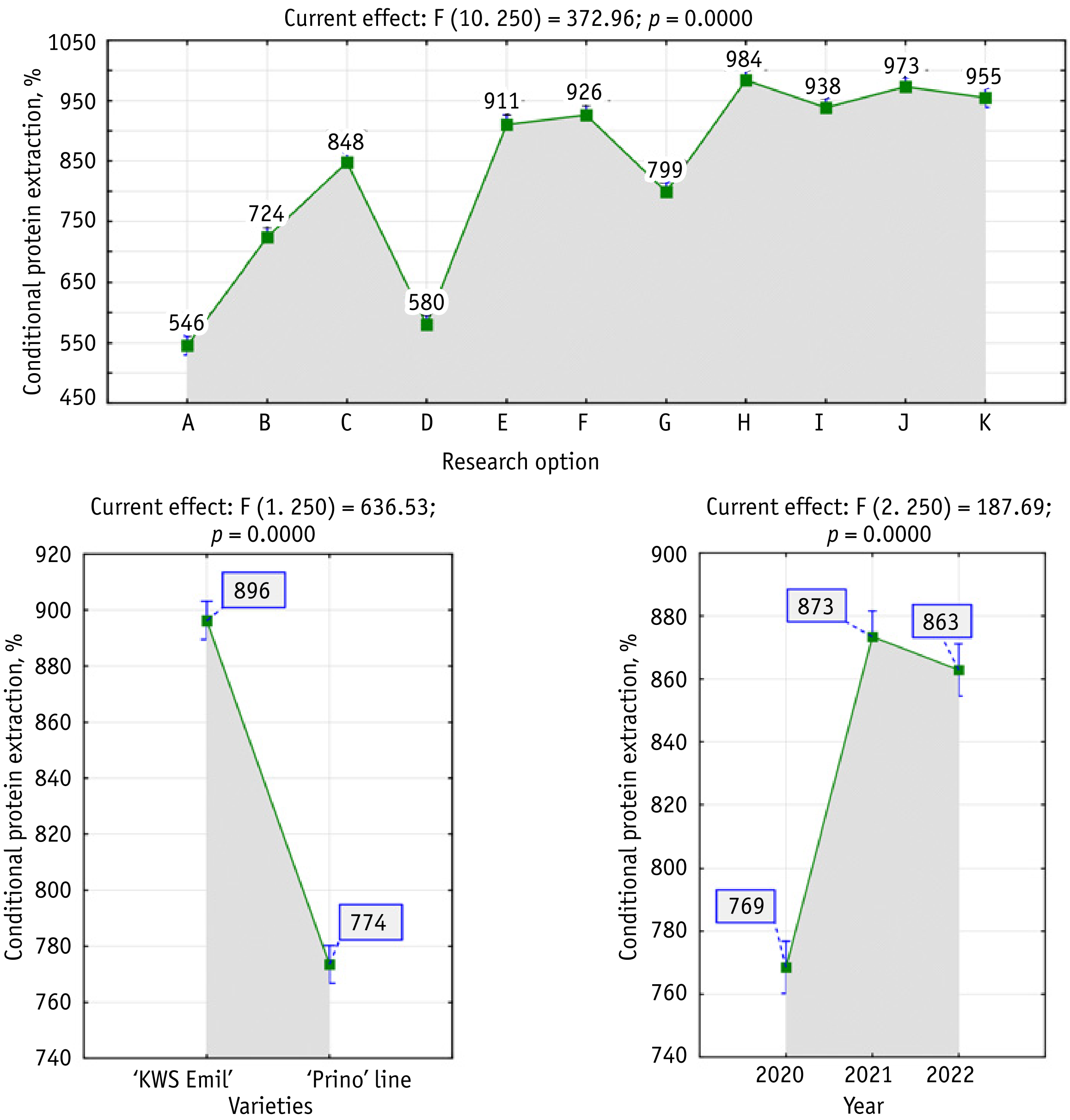

Fig. 3. Protein extraction from the grain harvest of different maturing varieties of common wheat as a function of fertilization, kg/ha:
A – no fertiliser (control), B – N_{75}, C – N_{150}, D – $P_{60}K_{80}$, E – $N_{150}K_{80}$, F – $N_{150}P_{60}$, G – $N_{75}P_{30}K_{40}$, H – $N_{150}P_{60}K_{80}$, I – $N_{150}P_{30}K_{40}$, J – $N_{150}P_{60}K_{40}$, K – $N_{150}P_{30}K_{80}$

tilizer – to 848 kg/ha, or 55%, compared to the no fertilizer option. In the $N_{75}P_{30}K_{40}$ variant, protein yield increased by 10% compared to the nitrogen system. The application of a complete mineral fertilizer ($N_{150}P_{60}K_{40}$) increased this indicator by 12%.

Protein yield under nitrogen-potassium and nitrogen-phosphorus fertilization systems was only significantly increased by 7–9% compared to long-term application of N_{150}. The incomplete phosphorus and potassium return systems gave 1–5% lower protein yields than the full mineral fertilizer systems.

The results of the research carried out show that the effectiveness of fertilisation systems depends on the characteristics of the variety and the weather conditions, which must be taken into account in the agronomy of soft winter wheat.

Conclusions

It was found that the application of $N_{75}P_{30}K_{40}$ increased the yield of soft winter wheat grain by up to 5.9 t/ha, or 7%, compared to the variant with only 75 kg/ha AI. In the complete mineral fertilizer variant ($N_{150}P_{60}K_{80}$), the yield was 11% higher than with long-term use of N_{150}. Nitrogen-potassium and phosphorus-potassium systems and options with incomplete return of phosphorus-potassium fertilizer give 6–7% lower yields compared to full mineral fertilizer.

The yield development of common wheat depends on the variety. In the 'KWS Emil' variety, this indicator was 35% higher than in the 'Prino' line. In addition, the grain yield of both varieties is reliably influenced by the weather conditions during the growing season.

The protein content varies considerably depending on the variety of soft winter wheat and the weather conditions. The protein content can vary from 12.8 to 15.1% during the growing season of the investigated common wheat varieties. The weather conditions during the growing season can change this indicator from 13.1 to 14.7%. In terms of protein content, the grain of the 'Prino' line is reliably superior to the 'KWS Emil' variety.

According to the protein extraction indicator, the 'KWS Emil' variety (896 kg/ha) has a significant advantage over the 'Prino' line (774 kg/ha). The use of a fertilization system with a nitrogen dose of 150 kg/ha per year made it possible to increase this indicator to 848–984 kg/ha. When growing the 'Prino' line, the protein yield increased from 529 to 670–924 kg/ha, depending on the fertilization system.

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Сіліфонов Т. В. Урожайність і вміст білка в зерні різностиглих сортів пшениці м'якої озимої за умови використання різних видів і доз добрив. *Plant Varieties Studying and Protection.* 2022. Т. 19, № 1. С. 44–51. https://doi.org/10.21498/2518-1017.19.1.2023.277770.

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Мета. Вивчити формування врожайності та вмісту білка в зерні різностиглих сортів пшениці м'якої озимої за умови використання різних видів і доз добрив. **Методи.** Польовий і лабораторний (визначення вмісту білка), розрахунковий (збір білка), математично-статистичні. **Результати.** Встановлено, що різні системи удобрення достовірно збільшували врожайність зерна пшениці м'якої озимої. Так, застосування N_{75} підвищувало цей показник у досліджених сортів у 1,2 рази, а N_{150} – у 1,4 рази порівняно з варіантом без добрив. Урожайність з неповним поверненням фосфорно-калійних добрив була лише на 2–3% меншою порівняно з повним мінеральним добривом. За умови застосування азотно-фосфорної та азотно-калійної систем удобрення урожайність була на 5–7% більшою ніж при використанні азотної системи. Водночас цей показник був на 6% меншим порівняно з варіантом досліду, де використовували повне мінеральне добриво. Застосування 75 кг/га д. р. азотних добрив підвищувало вміст білка до 13,5% або на 10% порівняно з контролем. У варіанті з подвійною дозою азотних добрив вміст білка зростав до 14,2% або на 15%. Застосування азотних добрив із фосфорно-калійними сприяло зростанню цього показника лише на 2–4%. Вирощування пшениці озимої за умови застосування N_{75} збільшувало збір білка до 724 кг/га або на 33%, а за подвійної дози азотних добрив – до 848 кг/га або на 55% порівняно з варіантом без добрив. У варіанті $N_{75}P_{30}K_{40}$ збір білка збільшувався на 10% порівняно з азотною системою. Застосування повного мінерального добрива ($N_{150}P_{60}K_{40}$) збільшувало цей показник на 12%. **Висновки.** Встановлено, що застосування $N_{75}P_{30}K_{40}$ збільшує врожайність зерна пшениці м'якої озимої до 5,9 т/га або на 7% порівняно з варіантом, де використовували лише 75 кг/га д. р. азотних добрив. Формування врожайності пшениці м'якої озимої достовірно змінюється залежно від сорту. Так, у сорту 'КВС Еміл' цей показник був на 35% достовірно більший ніж у лінії 'Пріно'. Крім цього, на врожайність зерна обох сортів достовірно впливають погодні умови вегетаційного періоду. Вміст білка достовірно змінюється залежно від сорту пшениці м'якої озимої та погодних умов. При вирощуванні сортів пшениці м'якої озимої вміст білка може змінюватись на 12,8–15,1%. Погодні умови вегетаційного періоду можуть змінювати цей показник на 13,1–14,7%. Показник вмісту білка у зерна лінії 'Пріно' достовірно вищий ніж у сорту 'КВС Еміл'. За показником збору білка з гектара сорт 'КВС Еміл' (896 кг/га) має достовірну перевагу над лінією 'Пріно' (774 кг/га).

Ключові слова: *сорт; продуктивність; погодні умови; система удобрення; збір білка.*

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