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YIELD AND GRAIN QUALITY OF WINTER WHEAT SOWN AFTER SUNFLOWER DEPENDING ON THE DATES AND RATES OF AUTUMN AND EARLY SPRING NITROGEN FEEDINGS

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Topicality. *In the context of rapid climatic and economic changes, conventional soft wheat cultivation technology requires optimisation; therefore the dates and rates of nitrogen fertiliser application are of paramount importance.* ***Purpose.*** *To determine indicators of the grain yield and quality for soft winter wheat depending on the dates and rates of early spring feedings after sunflower as a predecessor.* ***Materials and Methods.*** *The research was conducted in the field grain-fallow-row crop rotation system at the Yuriev Institute of Plant Production of NAAS in 2020–2022 and in 2023–2024. The experiment included five variants of autumn and early spring feedings of soft winter wheat (Zdobna variety) with ammonium nitrate at rates of* N_{30}, N_{60}, N_{90}, *and* N_{120} *after sunflower as a predecessor by dates: 1) control (no fertilisers), 2) at sowing, 3) seedling stage, 4) 1–2 leaf stage, 5) on frozen-thawed soil.* ***Results.*** *On average over three years, the maximum yield of 4.56 t/ha was obtained with a rate of* N_{120} *applied to frozen-thawed soil. The content of protein, gluten and grain hardness increased due to the increase in nitrogen rate during feeding in the 2–3 leaf stage of winter wheat, reaching its maximum at* N_{120} *and amounted to 12.7 %, 22 % and 69 %, respectively. The gluten deformation index (GDI), on the contrary, decreased with increasing nitrogen rate for feeding, with the highest GDI value being 48 units at a nitrogen rate of* N_{30} *in the 2–3 leaf stage of winter wheat. The dates and rates of nitrogen feeding had no significant effect on the grain test weight, which ranged from 808 to 822 g/l.* ***Conclusions****. The study found that the yield of soft winter wheat is primarily dependent on the fertiliser rate rather than the date of nitrogen fertiliser application. No clear correlation between grain quality indicators and the rate and date of nitrogen feeding was observed. The date and rate of nitrogen application had various effects on wheat grain quality indicators: increasing the nitrogen rate resulted in higher protein and gluten content, grain hardness, while GDI decreased. Grain test weight did not depend on the date and rate of feeding.*

Key words: *nitrogen fertilisers, autumn feeding, winter wheat, yield, sunflower as a predecessor, ammonium nitrate, phenological stage, protein content, gluten content, GDI, test weight, grain hardness.*

Introduction. Wheat (*Triticum aestivum* L.) is one of the ancient crops, which is of the greatest importance for food production on a global scale and ranks first among agricultural crops in terms of acreage.

The main purpose of wheat is to provide the population with bread. The advantageous chemical composition of the grain enhances the value of wheat bread. Among grain crops, wheat grain has the highest protein content. Depending on the variety and growing conditions, the protein content in soft wheat grain ranges from 9% to 24%. Wheat grain contains a large amount of carbohydrates, including 62 to 74 % starch, vitamins B_1, B_2, PP, E and provitamins A, D, up to 2 % ash minerals [1].

Wheat proteins are complete in terms of amino acid composition and contain all essential amino acids. Therefore, growing high-protein wheat is an important task.

A rich harvest of high-quality grain will not be achieved without fertilisers. The fertilisation system for production, developed and recommended 15–20 years ago, no longer meets modern cultivation technology requirements. As a rule, existing recommendations for the applications of fertilisers for winter wheat are aimed at obtaining the highest possible yield without sufficient economic justification. In a market economy, the parameters of the rates and types of fertilisers should be determined by the greatest economic effect they can have in order to obtain such yields [2–6].

The yield and grain quality of winter wheat largely depend on compliance with certain requirements in crop cultivation technology. Since the growing season for winter crops is significantly longer than for spring crops, more attention should be paid to performing the necessary technological operations during different

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periods of plant growth and development. The longest (in terms of time) phenological stage for winter wheat is the tillering stage. During the tillering stage, plants enter and emerge from winter dormancy, remaining in this state for an average of three to six months, depending on many growing factors [7–9].

The most important nutrient that, to a certain extent, determines the highest yield increases and improves the biochemical quality of grain is nitrogen, which in agronomic practice is referred to as a growth nutrient [10]. According to research, modern wheat varieties can produce high grain yields of good quality only on fertile soils and with sufficient fertiliser application. The main reason for low grain quality is a nitrogen deficiency in wheat agrocenoses, so without sufficient nitrogen application, obtaining a high-quality grain yield is largely impossible [11, 12].

Modern nitrogen management strategies for winter wheat in arid regions are based on studies that show that all fertilisers can be applied to winter wheat in autumn when annual precipitation does not exceed 480 mm. Conversely, it is recommended to divide the nitrogen rate between autumn and spring feeding in areas where precipitation exceeds 650 mm [13].

According to a number of studies, wheat responded significantly better to autumn application of nitrogen fertilisers. The highest yield of winter wheat was achieved with application of N_{120}, and when the nitrogen rate was increased to N_{180} in autumn, not only was there no increase in yield, but on the contrary, the yield decreased significantly. The above-mentioned results confirm the conclusion that the effectiveness of nitrogen fertilisation is reduced when the amount of nitrogen is increased beyond the optimal level, which leads to an increase in its losses to the environment. This is a typical response confirmed by studies on wheat [14].

Long-term research by various institutions has shown that the grain quality of field crops depends primarily on soil and climatic conditions, biological characteristics of the variety, and cultivation technology. For soft wheat, the most important quality indicators are protein content, as well as gluten content and quality in the grain [15].

The grain quality of wheat is influenced by genetic and environmental factors and their interaction [16–18]. Nitrogen fertilisers used in cultivation technology also affect the quality of the grain obtained, primarily in terms of protein content and composition. The protein content, including its gluten fraction, increases with higher nitrogen application rates [19].

In fact, increasing nitrogen during feeding does not always affect the level of gluten proteins, where the genetic factor is crucial [20].

An important indicator of winter wheat grain quality is its test weight, which depends on many factors: variety, climatic conditions, and soil fertility. According to V. P. Murygina, the test weight of grain increases by 5 g/l when applying a nitrogen rate of 30 kg a. i./ha and by 8 g/l when applying a rate of 60 kg a.i./ha, compared to the control variant [21].

At this stage of research, information on the relationship between yield and quality indicators of winter wheat depending on the development stage of the plants and the application rate of autumn nitrogen fertiliser is insufficient; therefore this issue requires further study.

The research was aimed at determining the yield and grain quality indicators of soft winter wheat depending on the development stage and application rates of autumn and early spring feeding after sunflower as a previous crop.

Materials and Methods. The research was conducted in the field grain-fallow-row crop rotation experiment of the V. Ya. Yuriev Institute of Plant Production of NAAS of Ukraine in 2020–2022 and 2023/2024. The object of the study was the Zdobna variety of winter wheat. Wheat was sown after sunflower in the second and third ten days of October. The experiments included five variants of pre-spring feeding with ammonium nitrate in rates of N_{30}, N_{60}, N_{90}, and N_{120} after sunflower by dates: 1 – control (no fertilisers); 2 – at sowing; 3 – seedling stage ; 4 – 2–3 leaf stage; 5 – in frozen-thawed soil. Total number of experimental variants was 17.

The variants were placed using the split-plot method according to a multifactorial scheme. The area of the registration plot was 25 m^2, with 4 repetitions. The soil of the experimental plot was typical powerful medium-humus chernozem. After harvesting the predecessors, disc harrowing was carried out with a BDT-7 unit in two passes. Before sowing, cultivation was carried out using KPS-4 to a depth of 5–6 cm. The seeds were dressed with Pascal (1 l/t) and sown with an SN-16M seeder at a rate of 4.5 million germinated seeds per hectare. After sowing, the field was rolled with sprocket packers. The plant protection strategy for 2021 and 2024 involved spraying winter wheat crops with the Ahent herbicide (2,4-D 2-ethylhexyl ester, 452 g/l + florasulam, 6.25 g/l) – 0.5 l/ha + Mastak (clopyralid, 300 g/l) – 0.3 l/ha during tillering stage. For crop protection against disea-ses, the Dezaral Extra fungicide (carbendazim, 250 g/l + flutriafol, 125 g/l) was used, as well as the insecticide Antikolorad Max (imidacloprid, 300 g/l + lambda-cyhalothrin, 100 g/l) was used to protect crops from pests.

In spring 2022, due to intense fighting in the research area, no plant protection treatments were applied, resulting in a significant reduction in winter wheat yields compared to 2021. The decrease in crop yield in 2022 was primarily associated with the spread of yellow leaf spot in the late stages of plant growth and development [22]. The harvest was collected directly using a Sampo-130 combine harvester. Generally accepted methods and recommendations were used during the research [23].

Weather conditions varied during the years of research. In 2020, autumn was warm and dry. In August, precipitation was 40 mm below the norm, and rains fell only in the second ten days of October (30.4 mm). The average daily air temperature in September and October was higher than the long-term average by 4.3 °C and 5.2 °C, respectively. The autumn growing season for winter crops ended in the first ten days of November. In 2021, growth resumption of wheat began in the first ten days of April. Spring and summer were moderately warm, at the level of long-term averages. May and June were wet, while July and August were abnormally dry. The autumn period of 2021 was less wet compared to long-term data, with temperatures at the level of long-term indicators. Autumn vegetation ceased in the first ten days of November. Crops overwintered under favourable hydrothermal conditions. Resumption of their vegetation began in the first ten days of April. Spring and summer were warm, at the level of long-term averages, and very wet [22]. Autumn 2023 was generally warm and wet, with insufficient rainfall in September (66 % of the norm) compensated for by wet October and November (289 % and 141 %, respectively). Autumn vegetation ceased in the second ten days of November. The resumption of vegetation was abnormally early in the spring of 2024, beginning in the second ten days of March. March and April were dry and warm, and in May there was a frost of -5 °C on the soil surface, which caused significant damage to winter wheat plants in the stem elongation stage. The summer was dry and hot, which also had a negative impact on yield formation. Over the three years, seedlings appeared on average on the 8^{th}–9^{th} day [24]. Thus, the conditions for growing winter wheat varied greatly over the years of research, which made it possible to obtain objective results and evaluate them.

Results and Discussion. The experiments showed that winter wheat responded differently to nitrogen feeding with ammonium nitrate in different phenological stages after sunflower as a predecessor. Thus, an increase in nitrogen rate resulted in higher yields, regardless of the phenological stage at the time of feeding. During the years of research in 2021, 2022 and 2024 the highest yield was obtained with feeding at a rate of N_{120} – an average of 6.98 t/ha (on frozen-thawed soil), 3.17 t/ha (seedling stage), and 3.79 t/ha (at sowing), respectively, for each year. On average over three years, the maximum yield was obtained with feeding on frozen-thawed soil – 4.56 t/ha with an increase of 61 % compared to the control.

It was found that when winter wheat was grown after sunflowers, the yield depended more on the rate of nitrogen feeding than on the date of application. Thus, against the background of nitrogen feeding, regardless of the rates of ammonium nitrate, there was no significant difference between different dates of nitrogen application on average over the years. Only when feeding with rates of N_{30} and N_{60}, the highest yield (3.63 t/ha and 4.12 t/ha, respectively) with an increase of 28 % and 46 % over the control was obtained when nitrogen was applied in the 2–3 leaf stage, compared to other periods. On average for all fertiliser rates, the difference between the application dates was insignificant, with increases to the control of 43–47 % (Table 1).

The effect of ammonium nitrate feeding during phenological stages with different nitrogen rates on grain quality indicators was determined. Thus, the protein content increased significantly when crops were fertilised with nitro-

Table 1. Winter wheat yield depending on the dates and rates of early spring nitrogen feeding after sunflower as a predecessor, t/ha; 2021, 2022 and 2024

Rate (A)	Application date/ phenological stage (B)	Year (C)				Increase to control	
		2021	2022	2024	average	t/ha	%
Control	no fertilisers	4.16	1.92	2.42	2.83	–	–
N_{30}	at sowing	5.16	2.11	3.11	3.46	0.63	22
	seedling stage	5.14	2.40	3.06	3.53	0.70	25
	2–3 leaf stage	5.07	2.72	3.09	3.63	0.80	28
	in frozen-thawed soil	5.15	2.47	2.91	3.51	0.68	24
	average	5.13	2.43	3.04	3.53	0.70	25
N_{60}	at sowing	5.76	2.59	3.44	3.93	1.10	39
	seedling stage	5.99	2.61	3.33	3.98	1.15	41
	2–3 leaf stage	5.78	3.16	3.41	4.12	1.29	46
	in frozen-thawed soil	5.92	2.82	3.24	3.99	1.16	41
	average	5.86	2.80	3.36	4.01	1.18	42
N_{90}	at sowing	6.13	3.04	3.64	4.27	1.44	51
	seedling stage	6.48	3.01	3.68	4.39	1.56	55
	2–3 leaf stage	6.58	3.12	3.55	4.42	1.59	56
	in frozen-thawed soil	6.50	3.06	3.36	4.31	1.48	52
	average	6.42	3.06	3.56	4.35	1.52	54
N_{120}	at sowing	6.76	3.05	3.79	4.53	1.70	60
	seedling stage	6.67	3.17	3.65	4.50	1.67	59
	2–3 leaf stage	6.89	3.12	3.57	4.52	1.69	60
	in frozen-thawed soil	6.98	3.13	3.57	4.56	1.73	61
	average	6.82	3.12	3.65	4.53	1.70	60
average	at sowing	5.95	2.70	3.49	4.05	1.22	43
	seedling stage	6.07	2.80	3.43	4.10	1.27	45
	2–3 leaf stage	6.08	3.03	3.40	4.17	1.34	47
	in frozen-thawed soil	6.14	2.87	3.27	4.09	1.26	45
	average	6.06	2.85	3.40	4.10	1.27	45
$LSD_{0.5}$	A – 0.21; B – 0.12; C – 0.24; AB – 0.36; BC – 0.39; AC – 0.44; ABC – 0.75						

gen rates of N_{90} and N_{120}, averaging 11.4 % and 12.2 %, respectively. No significant difference in rates was found between the autumn fertilisation variants in the stages: during sowing, the seedling stage and at 2–3 leaf stage of wheat, the protein content was 11.2 %, 11.6 % and 11.5 %, respectively. Under nitrogen feeding in frozen-thawed soil, the protein content was lower than when feeding in other phenological stages of winter wheat development – 11.0 %. Grain hardness increased significantly with increasing nitrogen rate, starting from N_{30}, and reached maximum at a rate of N_{120} during the seedling stage and at 2–3 leaves stage – 69 %. On average in terms of application rates, the highest values of grain hardness were obtained at feeding during the seedling stage and at the 2–3 leaf stage of the crop – 55 % and 54 %, respectively.

The factors of application rate and date had no significant effect on test weight indicators. The gluten content increased with an increasing nitrogen rate compared to the control. The maximum gluten content was obtained by feeding at a rate of N_{120} during the seedling stage and 2–3 leaves stage – 22 %, but no significant difference between the various stages of spring feeding was observed on average, and the gluten content varied within the range of 18.5–19.2 %.

The gluten deformation index decreased with increasing nitrogen rate; the maximum was obtained with feeding in the 2–3 leaf stage with a rate of N_{30} – 48 p.p., on average, the feeding period in the 2–3 leaf stage stood out by the rate, where the GDI was 44 p.p. (Table 2).

Table 2. Winter wheat grain quality indicators depending on the dates and rates of early spring nitrogen feeding after sunflower as a predecessor, average for 2021, 2022 and 2024

Rate (A)	Application date/ phenological stage (B)	Protein content %	Grain content, %	Test weight, g/l	Gluten content, %	GDI, p.p.
control	no fertilisers	10.5	46	814	15.8	40
N_{30}	at sowing	10.9	44	816	17.6	40
	seedling stage	10.7	35	808	16.6	45
	2–3 leaf stage	10.8	43	826	17.2	48
	in frozen-thawed soil	10.8	52	814	19.0	45
	average	10.8	43	816	17.6	44
N_{60}	at sowing	10.8	43	814	17.8	40
	seedling stage	11.4	60	820	19.2	38
	2–3 leaf stage	11.0	44	818	17.8	40
	in frozen-thawed soil	10.4	41	820	16.8	43
	average	10.9	47	818	17.9	40
N_{90}	at sowing	11.6	61	810	19.2	35
	seedling stage	11.8	57	822	19.1	40
	2–3 leaf stage	11.6	62	816	19.6	43
	in frozen-thawed soil	10.8	52	816	18.2	33
	average	11.4	58	816	19.0	38
N_{120}	at sowing	11.5	56	806	19.2	38
	seedling stage	12.5	69	808	22.0	43
	2–3 leaf stage	12.7	69	816	22.0	45
	in frozen-thawed soil	12.0	65	815	21.8	40
	average	12.2	65	811	21.3	41
Average	at sowing	11.2	51	812	18.5	38
	seedling stage	11.6	55	815	19.2	41
	2–3 leaf stage	11.5	54	819	19.1	44
	in frozen-thawed soil	11.0	52	816	19.0	40
	average	11.2	53	815	18.9	41
$LSD_{0.5}$		A – 0.10; B – 0.07; AB – 0.22	A – 1.9; B – 0.8; AB – 0.25	A – 32; B – 26; AB – 68	A – 0.16; B – 0.11; AB – 0.30	A – 1.6; B – 0.7; AB – 0.21

Conclusions. The results of three-year studies show that feeding soft winter wheat with ammonium nitrate after sunflower cultivation at different dates and with different nitrogen rates did not significantly affect yield, which increased due to higher nitrogen rates during feeding. Over the three years of research, the average increase to the control ranged from 22 % to 61 %. In terms of grain quality indicators, no clear dependence on the rate and date of nitrogen feeding was observed. Thus, protein content and grain hardness increased significantly at rates of N_{90} and N_{120}, and the highest values of these indicators by rates were obtained with feeding in the seedling stage and at the 2–3 leaf stage. The gluten content grew with the increase in the nitrogen rate, reaching its maximum when feeding was carried out during the seedling stage and the 2–3 leaf stage. The gluten deformation index decreased with increasing nitrogen rates. On average, a significant rise in the GDI among nitrogen application dates was only observed when nutrition was provided during the 2–3 leaf stage. Test weight did not vary significantly under the influence of different nitrogen rates and different nutrition dates.

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Актуальність. В умовах стрімких кліматичних та економічних змін традиційна технологія вирощування м'якої пшениці потребує оптимізації, саме тому терміни та дози азотних добрив при підживленні мають першочергове та ключове значення. **Мета досліджень.** Визначити урожайність та показники якості зерна пшениці м'якої озимої залежно від строку та доз довесняного підживлення після попередника соняшник. **Матеріали та методи.** Дослідження проводили в польовій зерно-паро-просапній сівозміні Інституту рослинництва ім. В.Я. Юр'єва НААН у 2020–2022 рр. та у 2023/2024 рр. Досліди передбачали п'ять варіантів осіннього та раньовесняного підживлення пшениці м'якої озимої сорту Здобна аміачною селітрою у дозах N_{30}; N_{60}; N_{90}; N_{120} після попередника соняшник: 1 – контроль (без добрив); 2 – при посіві; 3 – фаза проростків; 4 – фаза 2–3 листків; 5 – по мерзлоталому ґрунту. **Результати.** В середньому за три роки максимальна урожайність отримана при дозі N_{120} – 4,56 т/га за підживлення по мерзлоталому ґрунту. Вміст білка, клейковини та скловидність зростали зі збільшенням дози азоту при підживленні набуваючи свого максимуму при N_{120} у строк 2–3 листків пшениці і становили 12,7%; 22% та 69% відповідно. Індекс деформації клейковини навпаки – зменшувався при збільшені дози азоту при підживленні, найбільше значення ІДК становило 48 од. пр. за дози азоту N_{30} у фазі 2–3 листків пшениці. На натуру зерна строк і доза азоту при підживленні не мали істотного впливу, – її показник коливався в межах 808–822 г/л. **Висновки.** Встановлено, що на урожайність пшениці м'якої озимої найбільший вплив має доза підживлення, а не строк внесення азотних добрив. Щодо показників якості зерна, то їх чіткої залежності від дози та строку азотного підживлення не спостерігали. Строк та доза внесення азоту мали різний вплив на показники якості зерна пшениці: зі збільшенням дози азоту вміст білка, скловидність та вміст клейковини зростали, а ІДК зменшувався. Натура зерна не залежала від строку та дози при підживленні.

Ключові слова: *азотні добрива, осіннє підживлення, пшениця озима, урожайність, попередник соняшник, аміачна селітра, фенологічна фаза, вміст білку, вміст клейковини, ІДК, натура зерна, скловидність*