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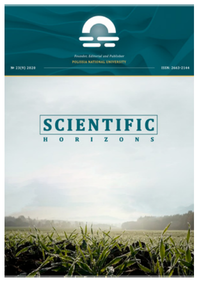

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Influence of sowing dates and fertilisation on yield and quality of winter wheat grain

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Abstract. New wheat varieties exhibit a high adaptive potential for productivity. The question of improving cultivation technologies, specifically sowing dates, optimised fertilisation systems, and micronutrient application, remains relevant to fully realise the genetic potential of these varieties under specific soil and climatic conditions. The aim of this study was to determine the influence of sowing dates, fertilisation, and foliar application of micronutrients on the yield and quality parameters of winter wheat grown in the Western Forest-Steppe zone. A field experiment was conducted on grey forest surface-gleyed soils during 2021-2023. The study evaluated the yield formation parameters and quality indicators of the winter wheat varieties Estafeta myronivska, Dovira odeska, and Akhim under sowing dates of 20 September, 5 October, and 20 October. It was determined that the yield and grain quality of the studied wheat varieties varied under the influence of sowing dates, fertilisation, and foliar micronutrient application. Sowing winter wheat on 5 October resulted in the highest yields over the years of the study: on average, 5.29 t/ha for the Estafeta myronivska, 4.78 t/ha for Dovira odeska, and 5.05 t/ha for Akhim. The highest productivity (5.83 t/ha) was achieved by sowing Estafeta myronivska with $N_{120}P_{90}K_{90}$ fertilisation and foliar application of the Aidamin complex. Across all wheat varieties, protein content, gluten content, and vitreousness increased from the earliest to the latest sowing dates. The findings of this study can be applied to enhance the productivity of winter wheat agroecosystems and produce high-quality grain under production conditions

Keywords: winter wheat; yield; 1,000-grain weight; protein content

INTRODUCTION

The introduction of new winter wheat varieties into production is directly linked to the improvement of existing cultivation technologies. Under conditions of changing weather and climate, the development of measures to mitigate the negative impact of changing temperature regimes and soil moisture deficits on the productivity of grain crops is becoming increasingly important. Researchers L. Wilson *et al.* (2021) note an increase in temperature of 2.0°C since the beginning of the 20th century and 1.2 degrees since the 1990s. According to scientists' forecasts, this trend will affect the growing conditions of all crops. O. Tarariko *et al.* (2022) also indicate that the shift of soil-climatic zones northward in the next 20-50 years may cause significant changes in agricultural production in general. Already, there is an observed lengthening of the growing season of winter crops by 10-20 days due to an increase in the frost-free period in winter and a shortening of the spring vegetation period, which necessitates changes in some elements of the cultivation technology, in particular, a review of the sowing dates of winter crops.

Researchers B. Bliznyuk *et al.* (2019) highlight that optimal sowing dates vary in different soil and climatic conditions and depend on preceding crops, soil moisture reserves, and other factors. Only by adhering to optimal sowing dates can high grain yields with corresponding quality indicators be achieved. According to observations by S. Poltoretskyi *et al.* (2020), the increase in average daily air temperatures during the autumn growing season causes a shift of optimal sowing dates towards later terms. According to V. Petrychenko and O. Korniychuk (2018), the warming in the first half of November is 1.8°C, which significantly reduces the impact of late sowing on overwintering conditions and allows them to be shifted to later dates.

O.L. Ulich (2018) indicates a shift towards later sowing dates for winter wheat: by 30 days compared to the 1950s, and by 10 days compared to the 1990s. V. Polovyi *et al.* (2018) in their research also highlight that, compared to the late 20th century, at the beginning of the 21st century, optimal sowing dates shifted from 15-25 September to 25-5 September-October. The increase in seed productivity of plants when sowing dates are shifted from the second decade of September to the first decade of October is confirmed by the research of R.A. Vozhegova and V.M. Bily (2019). When sowing at later dates, the 1,000-grain weight increased by 31.0%, 24.6%, and 15.7% compared to the first sowing date.

Currently, applying macronutrients alone is insufficient to achieve high yields of quality grain. Micronutrients are also essential for normal plant growth as they enhance enzyme efficiency and influence plant growth and development processes. Researchers O. Markovska and T. Grechishkina (2020), and V. Hanhur *et al.* (2021) note the high effectiveness of applying nitrogen fertilisers and foliar applications of micronutrients. V. Yamkoviy *et al.* (2021) also confirm the positive impact of micronutrients on the quality indicators of winter wheat grain. For instance, the application of micronutrients contributed to an increase in grain protein content by 3.4-8.8%, and the 1,000-grain weight increased by 4.4-8.1% compared to the control.

The question of determining the optimal technological components to ensure the realisation of the genetic potential of new varieties under the influence of various weather conditions remains relevant today. Therefore, this study aimed to determine the specific features of the formation of yield components and overall yield of winter wheat varieties depending on mineral fertilisation and foliar application of micronutrients under different sowing dates.

MATERIALS AND METHODS

The research was conducted from 2021 to 2023 at the experimental fields of the Institute of Agriculture of the Carpathian Region, National Academy of Agrarian Sciences of Ukraine, on grey forest surface-gleyed, coarse-silty, light loamy soil. The agrochemical parameters (before the experiment was set up) were as follows: pH (in salt extract) – 4.8-5.2, humus content 1.97-2.2% (determined by Tyurin's method, DSTU 7855:2015), easily hydrolysable nitrogen 99.0-114.2 mg/kg soil (by Kjeldahl's method, DSTU 7863:2015), mobile phosphorus 95.2-101.1 and exchangeable potassium 107.1-112.0 mg/kg soil (by Kirsanov's method, DSTU 4405:2005).

Factor A (varieties): 1. Estafeta myronivska; 2. Dovira odeska; 3. Achim;

Factor B (sowing dates): first sowing date (20.09), second sowing date (5.10), third sowing date (20.10). Years of the study: 2021–2023.

Factor C (fertilisation):

1. $N_{60}P_{60}K_{60}$;
2. $N_{120}P_{90}K_{90}$;
3. $N_{120}P_{90}K_{90}$ + foliar application of Aydamin complex (1.0 L/ha).

Plot size: sown area – 40.8 m^2, accounting area – 25 m^2, replicates – 4 times. The protection system included seed treatment with Vitavaks 200 FF at 34% active substance (3.0 L/t) and the application of the herbicide Grodyl Maxi at 37.5% active substance (0.09–0.11 L/ha). Field experiments were established according to the methodology of V. Ushkarenko *et al.* (2019). Harvesting of the plots was performed using a Sampo-130 combine harvester. Yield calculations were carried out based on standard grain moisture content. Statistical analysis of the results was conducted using the software "Statistica 6.0" and "Excel 2003".

Grain quality assessment for 1,000-grain weight, test weight, and vitreousness was conducted according to DSTU 3768:2019 (2019). The content of crude protein and gluten was determined using an IR analyser, Spectran-119 M. Weather conditions during the study years were characterised by elevated temperatures during the winter wheat growing season, except for April 2021 and 2022, when the average daily air temperature was below normal (7.4°C) by 1.2 and 0.9°C, respectively. Precipitation in individual months differed significantly from long-term averages: either excess or insufficient precipitation was observed. The distribution by decades was extremely uneven, with no precipitation in some decades. The highest amount of precipitation fell in September 2020 (173% of the norm) and 2022 (236% of the norm), while the lowest amount was recorded in October 2021 (14% of the norm).

All experimental research involving plants, both cultivated and wild, including plant material collection, adhered to institutional, national, or international guidelines. The authors complied with the standards set by the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

In the cultivation of cereal crops, agronomic practices play a crucial role in significantly improving seed yield and quality. Climate change necessitates a reevaluation of certain aspects of winter wheat cultivation, particularly the timing of sowing. As is well-known, sowing dates and fertilisation systems throughout the winter wheat growing season are pivotal components of the overall cultivation system.

The results of the study indicate that among all the varieties, the agrocenosis of winter wheat of the Estafeta myronivska variety achieved the highest average yield (5.29 t/ha) when sown on 5 October (Table 1). The yield under the $N_{60}P_{60}K_{60}$ fertilisation treatment was 4.37 t/ha. Increasing the mineral fertiliser rate to $N_{120}P_{90}K_{90}$ resulted in a significant yield increase of 1.29 t/ha compared to the control, while the application of the Aidamin complex contributed an additional 0.17 t/ha. Sowing Estafeta myronivska on 20 October led to a decrease in average yield by 0.69 t/ha (to 4.6 t/ha) compared to the second sowing date (5 October), and sowing on 20 September resulted in a decrease of 0.45 t/ha (to 4.84 t/ha). In all experimental variants and years, the variety Estafeta myronivska consistently produced the highest yields when sown on 5 October. For the varieties Dovira odeska and Achim, the highest yields were observed in 2021 and 2022 when sown on 5 October, but in 2023, the highest yield was achieved with a sowing date of 20 September.

Table 1. *Winter wheat yield depending on technology elements, 2021-2023, t/ha*

Variants	Yield, t/ha											
	First sowing date (20 September)				Second sowing date (5 October)				Third sowing date (20 October)			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
1	2	3		4	5	6		7	8	9	10	11
Estafeta myronivska variety												

Table 1. Continued

Variants	Yield, t/ha											
	First sowing date (20 September)				**Second sowing date (5 October)**				**Third sowing date (20 October)**			
	2021	**2022**	**2023**	**Avg.**	**2021**	**2022**	**2023**	**Avg.**	**2021**	**2022**	**2023**	**Avg.**
1	**2**	**3**		**4**	**5**	**6**		**7**	**8**	**9**	**10**	**11**
$N_{60}P_{60}K_{60}$	4.09	4.00	4.01	4.0	4.45	4.32	4.35	4.37	3.75	4.15	3.31	3.73
$N_{120}P_{90}K_{90}$	5.04	5.03	5.38	5.15	5.75	5.54	5.69	5.66	4.76	5.18	4.99	4.97
$N_{120}P_{90}K_{90}$ + Aidamin	5.26	5.27	5.49	5.34	6.0	5.65	5.84	5.83	4.93	5.30	5.10	5.11
Average	4.8	4.77	4.96	4.84	5.42	5.17	5.26	5.29	4.48	4.88	4.46	4.6
Dovira odeska variety												
$N_{60}P_{60}K_{60}$	3.56	3.23	4.26	3.68	4.36	3.79	3.93	4.02	3.47	3.26	3.5	3.41
$N_{120}P_{90}K_{90}$	4.51	4.07	5.59	4.72	5.35	4.81	5.2	5.12	4.66	4.35	5.04	4.68
$N_{120}P_{90}K_{90}$ + Aidamin	4.68	4.24	5.62	4.84	5.47	4.92	5.27	5.22	4.78	4.45	5.14	4.79
Average	4.25	3.85	5.15	4.41	5.06	4.51	4.8	4.78	4.30	4.02	4.56	4.29
Achim variety												
$N_{60}P_{60}K_{60}$	4.08	3.54	4.52	4.04	4.26	4.13	4.31	4.23	3.54	3.68	4.16	3.79
$N_{120}P_{90}K_{90}$	5.13	4.57	6.34	5.35	5.29	5.07	5.89	5.41	4.68	4.81	5.32	4.93
$N_{120}P_{90}K_{90}$ + Aidamin	5.28	4.70	6.41	5.46	5.47	5.18	5.95	5.53	4.89	4.96	5.46	5.1
Average	4.83	4.27	5.75	4.95	5.0	4.79	5.38	5.05	4.37	4.48	4.94	4.59
$HIP_{0.5}$, t/ha A (sowing dates)		0.058	0.061	0.061								
B (fertilisation)		0.058	0.064	0.062								
C (varieties)		0.058	0.061	0.063								
ABC (interaction)		0.173	0.190	0.188								

Source: *developed by the authors*

On average, during the years of the study (2021-2023), the winter wheat varieties Dovira odeska and Achim also achieved their highest yields with the second sowing date (5^{th} October), producing 4.78 and 5.05 t/ha, respectively. The yield increase due to fertilisers was 1.1 and 1.18 t/ha, and from foliar application, it was 0.1 and 0.12 t/ha. The Dovira odeska variety showed a lower average yield when sown on 20 September, with a decrease of 0.37 t/ha compared to the 5 October sowing, and the yield decreased by 0.49 t/ha when sown on 20 October. A significant yield reduction compared to the second sowing date was also observed in the Achim variety, with an average decrease of 0.1 t/ha when sown on 20 September and 0.46 t/ha when sown on 20 October. When $N_{120}P_{90}K_{90}$ fertilisation was applied, the yield increase for the wheat varieties compared to the control was 1.04-1.31 t/ha for the 20 September sowing, 1.1-1.29 t/ha for the second sowing date, and 1.14-1.27 t/ha for the third sowing date. Foliar application with micronutrients provided a significant yield increase within the range of 0.1-0.17 t/ha.

The highest yield (5.83 t/ha) was achieved by sowing the winter wheat variety Estafeta myronivska on 5 October, combined with the application of $N_{120}P_{90}K_{90}$ mineral fertiliser and foliar application with the Aidamin complex. In contrast, the control treatment ($N_{60}P_{60}K_{60}$) yielded 4.37 t/ha. Increasing the rate of mineral fertiliser resulted in a significant yield increase of 1.29 t/ha, while the application of the Aidamin complex contributed an additional 0.17 t/ha. High grain yields do not always correspond to high quality. Often, the grain quality is poor and does not meet the requirements of the food industry. The results of the conducted research have established that sowing dates have a direct impact on the quality indicators of the grain, including 1000-grain weight, test weight, and vitreousness.

In 2021, the winter wheat variety Estafeta myronivska achieved the highest 1,000-grain weight when sown on 20 September. Sowing on 5 October and 20 October resulted in a decrease in 1,000-grain weight by 0.77 g and 1.99 g, respectively (Table 2). For the winter wheat varieties Dovira odeska and Achim, the highest 1,000-grain weight was recorded with the second sowing date (5 October). Deviations from this sowing date, either earlier or later, resulted in a decrease in 1,000-grain weight by 0.51 and 1.11 g for early sowing and 0.89 and 2.91 g for late sowing, respectively.

Table 2. *The 1000-grain weight and quality indicators of winter wheat grain depending on sowing dates and nutrition backgrounds, 2021-2023*

No. Var.	1000-grains weight, g				Test weight, g/L				Vitreousness, %			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
Estafeta myronivska variety – first sowing date												
1	41.16	42.64	39.4	41.07	790.2	800.2	781.5	790.63	47	69.25	49.75	55.3
2	42.15	43.91	40.58	42.21	804	809.7	784	799.23	56	73	72.5	67.2
3	43.22	44.04	41.64	42.97	804.7	810.6	784.5	799.93	63	76.5	72.75	70.8
Avg.	42.2	43.5	40.5	42.1	799.6	806.8	783.3	796.6	55.3	72.9	65.0	64.4
Estafeta myronivska variety – second sowing date												
1	41.11	44.26	40.69	42.0	789.5	798	783.2	790.2	51	73.5	53.25	59.3
2	41.5	44.51	40.89	42.3	802.5	811.5	792	802.0	59.5	79.5	76	71.7
3	41.62	45.17	41.27	42.7	806.2	813.8	793.2	804.4	65.5	81.25	79.5	75.4
Avg.	41.4	44.6	41.0	42.3	799.4	807.8	789.5	798.9	58.7	78.1	69.6	68.8
Estafeta myronivska variety – third sowing date												
1	39.95	42.58	39.42	40.7	790	801.5	776.2	789.2	58.75	70.25	57.75	62.3
2	40.26	42.85	40.76	41.3	805.8	807.9	792.5	802.1	60.5	80.75	75	72.1
3	40.37	43.56	41.37	41.8	806.3	810.8	793.3	803.5	63	81.5	77.5	74.0
Avg.	40.2	43.0	40.5	41.2	800.7	806.7	787.3	798.3	60.8	77.5	70.1	69.4
Dovira odeska variety – first sowing date												
1	37.69	38.25	38.5	38.1	740.7	798	736.2	758.3	22.75	42	16	26.9
2	39.68	40.76	40.34	40.3	754.7	804.3	769	776.0	24.5	53.75	37.75	38.7
3	40.2	41.41	41.18	40.9	757.3	805.8	772.3	778.5	27.25	57.5	39	41.3
Avg.	39.2	40.1	40.0	39.8	750.9	802.7	759.2	770.9	24.8	51.1	30.9	35.6
Dovira odeska variety – second sowing date												
1	39.28	40.01	40.96	40.1	745.3	795.2	761	767.2	23.5	38.5	26.75	29.6
2	39.23	41.61	41.24	40.7	745.7	804.4	776.7	775.6	28	62.25	33	41.1
3	40.59	41.91	41.27	41.3	749.5	804.5	777.3	777.1	29	63.5	36.25	42.9
Avg.	39.7	41.2	41.2	40.7	746.8	801.4	771.7	773.3	26.8	54.8	32.0	37.9
Dovira odeska variety – third sowing date												
1	37.82	38.65	36.55	37.7	730.2	795	749.2	758.1	28.25	48.25	21.25	32.6
2	39.13	40.29	39.62	39.7	739	803.8	765.7	769.5	31	64.75	31	42.3
3	39.47	41.43	39.74	40.2	741.8	804	767.2	771.0	31.25	76.25	31.75	46.4
Avg.	38.8	40.1	38.6	39.2	737.0	800.9	760.7	766.2	30.2	63.1	28.0	40.4
Achim variety – first sowing date												
1	37.11	38.63	43.73	39.8	765	769.3	759.8	764.7	41.25	11	49.75	34.0
2	41.59	42.11	44.38	42.7	768.7	777.9	776	774.2	50.75	43	58	50.6
3	42.42	42.39	44.78	43.2	772	787.2	776.7	778.6	53	53.5	59	55.2
Avg.	40.4	41.0	44.3	41.9	768.6	778.1	770.8	772.5	48.3	35.8	55.6	46.6
Achim variety – second sowing date												
1	39.94	42.8	41.35	41.4	768	769.6	762.7	766.8	46.25	17.5	45.25	36.3
2	41.71	42.94	42.39	42.3	744.7	772.4	777.7	764.9	58.25	38.25	68	54.8
3	42.79	43.07	42.9	42.9	756.7	787.4	780.5	774.9	58.75	47.75	72.75	59.8
Avg.	41.5	42.9	42.2	42.2	756.5	776.5	773.6	768.9	54.4	34.5	62.0	50.3
Achim variety – third sowing date												
1	37.46	33.64	38.52	36.5	752.2	767.9	762.7	760.9	56	26	46.5	42.8
2	38.53	37.44	39.96	38.6	745.2	770.8	775.5	763.8	59.75	49.75	78.5	62.7
3	39.71	37.7	39.92	39.1	755.3	787.3	775.7	772.8	61	51.75	79	63.9
Avg.	38.6	36.3	39.5	38.1	750.9	775.3	771.3	765.8	58.9	42.5	68.0	56.5

Source: *developed by the authors*

The test weight of the winter wheat variety Estafeta myronivska ranged from 799.6 to 800.7 g/L, Dovira odeska from 737.0 to 750.9 g/L, and Achim from 750.9 to 768.57 g/L. The 1,000-grain weight of Estafeta myronivska was not significantly affected by sowing dates, while for Dovira odeska and Achim, this parameter decreased from the earliest to the latest sowing dates. Vitreousness increased from the earliest to the latest sowing dates for all wheat varieties. Estafeta myronivska had the highest vitreousness, ranging from 55.3% to 60.75%. Dovira odeska had a vitreousness of 24.83% to 30.17%, and Achim had a vitreousness of 48.33% to 58.92%. In 2022, the highest 1,000-grain weight (42.58-45.17 g), test weight (800.2-813.8 g/L), and vitreousness (58.1-73.4%) were observed in the Estafeta myronivska wheat variety. For the Dovira odeska variety, the 1,000-grain weight was 38.25-41.91 g, test weight 795.0-805.8 g/L, and vitreousness 38.5-76.25%; for Achim, the corresponding values were 38.63-43.07 g, 767.9-787.3 g/L, and 26.13-56.38%. The protein and gluten content in winter wheat varied depending on the sowing date. These indicators increased from early to optimal and late sowing dates (Table 3).

Table 3. *Selected quality indicators of winter wheat grain, 2021-2023*

No. Var.	Protein, %				Crude gluten, %				Ash content, %			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
Estafeta myronivska variety – first sowing date												
1	11.7	12.8	11.4	12.0	17.1	26.1	20.5	21.2	1.2	1.3	1.3	1.3
2	14.3	13.9	14.5	14.2	25.3	27.8	28.3	27.1	1.3	1.3	1.3	1.3
3	14.7	14.5	15.1	14.8	25.5	29.9	30.3	28.6	1.3	1.3	1.3	1.3
Estafeta myronivska variety – second sowing date												
1	11.7	12.8	11.4	12.0	17.4	24.7	20.5	20.8	1.3	1.3	1.3	1.3
2	14.4	13.9	14.8	14.4	25.8	28.2	31.7	28.5	1.3	1.3	1.3	1.3
3	14.8	14.4	15.1	14.8	26.4	29.9	31.9	29.4	1.3	1.3	1.3	1.3
Estafeta myronivska variety – third sowing date												
1	12.0	12.5	13.7	12.7	17.9	23.4	27.6	23.0	1.3	1.3	1.3	1.3
2	14.6	14.3	14.8	14.6	26.2	29.5	31.9	29.2	1.3	1.3	1.3	1.3
3	15.0	14.4	15.4	14.9	26.7	29.4	33.3	29.8	1.3	1.3	1.3	1.3
Dovira odeska variety – first sowing date												
1	11.3	11.4	10.2	11.0	15.9	20.8	17.3	18.0	1.3	1.3	1.3	1.3
2	12.5	11.6	11.8	12.0	20.2	21.5	22.6	21.4	1.3	1.3	1.3	1.3
3	13.0	12.8	12.6	12.8	21.1	24.7	24.5	23.4	1.3	1.3	1.3	1.3
Dovira odeska variety – second sowing date												
1	11.6	11.2	12.5	11.8	16.1	20.5	23.9	20.2	1.3	1.3	1.3	1.3
2	12.8	13.0	13.0	12.9	21.4	25.5	25.7	24.2	1.3	1.3	1.3	1.3
3	13.5	13.5	13.6	13.5	22.1	27.3	27.2	25.5	1.3	1.3	1.3	1.3
Dovira odeska variety – third sowing date												
1	12.7	11.8	12.0	12.2	19.6	21.9	22.7	21.4	1.3	1.3	1.3	1.3
2	13.4	13.5	13.3	13.4	21.6	26.4	26.3	24.7	1.3	1.3	1.3	1.3
3	13.9	13.6	13.5	13.7	22.3	27.2	26.7	25.4	1.3	1.3	1.3	1.3
Achim variety – first sowing date												
1	12.1	10.3	10.9	11.1	17.8	17.4	19.4	18.2	1.3	1.3	1.3	1.3
2	12.9	11.9	12.0	12.3	19.9	21.8	22.0	21.2	1.3	1.3	1.3	1.3
3	13.5	13.0	13.5	13.3	20.7	25.1	26.7	24.2	1.3	1.3	1.3	1.3
Achim variety – second sowing date												
1	12.3	10.5	11.0	11.3	18.2	18.8	20.1	19.0	1.3	1.3	1.3	1.3
2	13.1	12.4	13.8	13.1	20.6	22.7	27.9	23.7	1.3	1.3	1.3	1.3
3	13.7	13.1	14.0	13.6	21.2	24.9	28.7	24.9	1.3	1.3	1.3	1.3
Achim variety – third sowing date												
1	12.6	10.5	12.3	11.8	18.6	18.8	22.7	20.0	1.3	1.3	1.3	1.3
2	13.4	12.4	13.3	13.0	20.8	23.1	25.9	23.3	1.3	1.3	1.3	1.3
3	13.9	13.1	14.0	13.7	21.5	25.0	28.6	25.0	1.3	1.3	1.3	1.3

Source: *developed by the authors*

In 2021, regardless of sowing dates (except for the control plots), the winter wheat variety Estafeta myronivska, based on its protein content, crude gluten, vitreousness, and test weight, belonged to the 2nd quality class, while the control plots were classified as the 4th class (DSTU 3768:2019). The variety Dovira odeska, when sown on 20 September 2021 and 05 October 2021, produced grain of the 4th quality class on the control plots. However, with fertilisation at the $N_{120}P_{90}K_{90}$ rate and foliar application of micronutrients (Aidamin complex foliar application), the grain was classified as the 3rd quality class. The grain sown on 20 October 2021 also belonged to the 3rd class. The winter wheat variety Achim, when sown on 20 October 2021, had 4th class quality on the control variant, while on other variants, the grain belonged to the 3rd class.

In 2022, under all sowing dates, the Estafeta myronivska variety, when fertilised with $N_{120}P_{90}K_{90}$ and supplemented with a micronutrient feed, produced 1st class-quality grain. The same quality was achieved for the third sowing date when only $N_{120}P_{90}K_{90}$ fertiliser was applied. Other treatments resulted in 2nd class grain. The Dovira odeska variety produced 3rd class grain on control plots for all sowing dates and the $N_{120}P_{90}K_{90}$ fertilised plot for the first sowing date. Other treatments resulted in 2nd class grain. The Achim variety had the lowest grain quality, 4th class, on all control plots regardless of sowing date. Fertilisation with $N_{120}P_{90}K_{90}$ improved the quality to the 3rd class, while other treatments resulted in 2nd class grain.

In 2023, the Estafeta myronivska variety produced 1st class-quality grain when fertilised with $N_{120}P_{90}K_{90}$, and third-class quality grain on control plots for all sowing dates. The Akhim wheat variety produced first-class quality grain when sown in the second and third periods and treated with $N_{120}P_{90}K_{90}$ fertiliser and foliar application of the Aidamin complex. On other treatments, the grain quality ranged from 2nd to 3rd class. The Dovira odeska variety produced 2_{nd} and 3_{rd} class quality grain.

The yield and quality of grain are directly influenced by a range of factors including soil and climatic conditions, the genetic characteristics of the variety, and agricultural practices such as sowing dates and fertilisation (Oliinyk *et al.,* 2018; Jaisi *et al.,* 2021). Maximum yields are achieved when there is an optimal balance of all these factors (Kovalenko & Kiriyak, 2018). The question of optimal sowing dates and fertilisation systems for winter wheat is not new and has been studied extensively. Researchers such as U. Madhu *et al.* (2018) and A. Siroshtan *et al.* (2021) have investigated the impact of these factors on the yield and quality of winter wheat. However, the emergence of new varieties and changing climatic conditions necessitate continuous adjustments.

According to O.A. Zaima *et al.* (2024), adhering to optimal sowing dates (the third decade of September and the first decade of October) ensures maximum yields for the studied varieties. L. Gandjaeva (2019) highlights the reduction in crop productivity when sowing dates deviate from the optimal ones. In the Polissia region, sowing on 10 October resulted in a yield of winter wheat 1.02 t/ha lower compared to sowing on 10 September (3.56 t/ha). However, the question of optimal sowing dates remains controversial. Specifically, G. Gutsol and I. Ovcharuk (2023) recommend sowing 11 days later in the Right-bank Forest-Steppe, and in some years, these dates can be further adjusted. H. Chuhrii (2019) also found increased yields when sowing was delayed to 10 October compared to 10 September.

According to A. Kryvenko *et al.* (2019), sowing on 5 October resulted in a 25.5% higher yield compared to sowing on 25 September. However, further delaying sowing to 15 October decreased the grain yield by 37.6%, and to 25 October by 53.2%. Sowing on 5 and 15 October resulted in the highest quality grain in terms of weight and the weight of 1,000 grains. R. Vozhegova and V. Bily (2019) found that the highest number of productive stems and grains per ear were obtained with later sowing dates. Many researchers have noted an improvement in grain quality with later sowing dates. S. Shakaliy *et al.* (2020) observed an increase in the protein content of winter wheat grain when sowing on 10 October, reaching 12.8-12.6%, compared to earlier sowing on 10 September (11.3-12.0%).

The most effective factor in increasing the yield and quality of winter wheat is the application of mineral fertilisers. Research has confirmed that the use of mineral fertilisers increases the yield of grain crops. According to V. Ivanina and I. Korotenko (2022), the use of fertilisers increased crop yields regardless of sowing date. The application of $N_{80}P_{60}K_{60}$ to winter wheat in a crop rotation with peas increased grain yield by 1.02 t/ha compared to the control without fertilizers, reaching 5.42 t/ha. Scientists believe that a significant reserve for increasing crop productivity lies in the application of micronutrients (Vozhegova & Kryvenko, 2019). Their application effectively influences growth processes, as well as yield and grain quality. The use of micronutrients for seed treatment or foliar application is an effective agronomic measure to provide plants with micronutrients during the growing season. V. Petrychenko and V. Lykhochvor (2020) observed a 14.5% increase in grain yield compared to the control when using seed treatment with the growth stimulator Vimpel-K and foliar application of Vimpel-2 in combination with Oracle micronutrients. V. Hanhur *et al.* (2021) noted a trend toward increased 1,000-grain weight and gluten content in treatments where seeds were pre-sown treated with the micronutrient Vuksal and followed by foliar application of micronutrients.

In conclusion, based on the findings presented above, it is clear that established crop production practices, particularly sowing dates, are influenced by weather conditions and require adjustments. To achieve high yields and grain quality, it is essential to use not only mineral fertilisers but also micronutrients for foliar application.

CONCLUSIONS

Research findings indicate that, under the soil and climatic conditions of the Western Forest-Steppe, the highest yields of winter wheat crops were achieved with the first sowing date (5 October). For this sowing date, the studied varieties – Dovira odeska, Achim, and Estafeta myronivska – produced average yields of 4.78 t/ha, 5.05 t/ha, and 5.29 t/ha, respectively. Shifting the sowing dates either earlier (20 September) or later (20 October) resulted in lower yields. For Estafeta myronivska, the deviations from the optimal yield were 0.45 t/ha and 0.69 t/ha, respectively, for Dovira odeska – 0.37 t/ha and 0.49 t/ha, and for Achim – 0.1 t/ha and 0.46 t/ha.

Although, on average, the second sowing date (5 October) was the most effective during the years of the study, the varieties exhibited varying yields in different years of observation. Of all the varieties studied, only Estafeta myronivska consistently produced the highest yields when sown on 5 October. Dovira odeska and Achim achieved their highest yields in 2021 and 2022 when sowed on 5 October, but in 2023, their highest yields were obtained with a sowing date of 20 September. The lowest yields for all wheat varieties were observed when sown on 20 October.

Increasing the application rate of mineral fertilisers to $N_{120}P_{90}K_{90}$ led to an increase in grain yield for all sowing dates. Depending on the variety and experimental variant, the increase was 1.04–1.31 t/ha. Foliar application of the micronutrient Aidamin complex provided an additional yield increase of 0.11–0.19 t/ha. Among the varieties, the highest yield (5.83 t/ha) was obtained from winter wheat cultivar Estafeta myronivska sown on 5 October, with the application of mineral fertilisers at the rate of $N_{120}P_{90}K_{90}$ and foliar application of the micronutrient Aidamin complex. The increase from mineral fertilisers was 1.29 t/ha and from the application of micronutrients – 0.17 t/ha. The application of mineral fertilisers and foliar application with micronutrients improved grain quality in all experimental variants. On average, over the years of the study, the 1,000-grain weight was highest for all varieties with the second sowing date (5 October), while the test weight was highest for Estafeta myronivska and Dovira odeska with the second sowing date, and for Achim with the first sowing date. The vitreousness increased from the first to the third sowing dates.

Future research could focus on the evaluation of new winter wheat varieties and the identification of effective micronutrients and growth stimulators that can mitigate the impact of negative biotic and abiotic factors during the growing season and ensure stable high-quality grain yields.

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CONFLICT OF INTEREST

None.

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Анотація. Нові сорти пшениці відзначаються високим адаптивним потенціалом продуктивності. Актуальним залишається питання удосконалення елементів технології їх вирощування в конкретних ґрунтово-кліматичних умовах, зокрема строків сівби, оптимізації системи удобрення, застосування мікроелементів, за рахунок яких можна суттєво вплинути на реалізацію генетичного потенціалу сортів. Метою роботи було встановити вплив строків сівби, удобрення і фоліарного підживлення мікроелементами на врожайність і якісні показники зерна пшениці озимої за вирощування в зоні Лісостепу західного. У процесі виконання роботи були застосовані польовий метод, лабораторний (визначення якісних показників зерна) та статистичний (оцінка достовірності даних). Польові дослідження проводили на сірих лісових поверхнево оґлеєних ґрунтах впродовж 2021-2023 рр. Було встановлено параметри формування продуктивності і якісні показники пшениці озимої сорту Естафета миронівська, Довіра одеська і Ахім за сівби 20.09; 05.10; 20.10. Визначено, що показники врожайності і якість зерна досліджуваних сортів змінювалися під впливом строків сівби, удобрення та листкового підживлення мікродобривом. Сівба пшениці озимої 05.10 забезпечила найвищу врожайність за роки дослідження: в середньому у сорту Естафета миронівська – 5,29 т/га, Довіра одеська – 4,78, Ахім – 5,05 т/га. Максимальну продуктивність (5,83 т/га) сформував посів сорту Естафета миронівська за внесення $N_{120}P_{90}K_{90}$ і листкового підживлення мікродобривом Айдамін-комплексний листкове підживлення. У всіх сортів пшениці озимої зафіксовано зростання вмісту білку, клейковини і скловидності зерна від першого до третього строку сівби. Отримані результати можуть бути застосовані для підвищення продуктивності агроценозів пшениці озимої і отримання продукції високої якості у виробничих умовах

Ключові слова: пшениця озима; врожайність; маса 1000 зерен; вміст білку