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Productivity and economic efficiency of winter wheat (*Triticum aestivum* L.) cultivation depending on preceding crops and sowing dates

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Abstract It was found that the most effective factor influencing yield indicators was preceding crop, with increased in winter wheat grain yield of 1.23 t ha^{-1} for soybean as a predecessor in favorable years and +0.71 t ha^{-1} in other years. In unfavorable years for the crop, delaying the sowing dates of winter wheat did not significantly affect grain yields when grown after sunflower, while after soybean as preceding crop, a significant yield increase was observed, ranging from 5.14 to 5.47 t ha^{-1}. Late sowing dates in optimal vegetative conditions led to decrease in crop yield, especially affected soybean as preceding crop: -0.64 t ha^{-1} and -1.12 t ha^{-1}. It is advised to sow winter wheat on September 15th after sunflower and on September to 15th trom 30th after soybean as preceding crop. The research results indicated a significantly increased in productivity of winter wheat after soybean compared to sunflower as preceding crop, regardless of the sowing date. The yield of grain units from the main and by-products of winter wheat averaged 11.66 t ha^{-1} after soybean as preceding crop and 9.78 t ha^{-1} after sunflower; feed units were 10.05 t ha^{-1} and 8.43 t ha^{-1}, digestible protein units were 1.97 t ha^{-1} and 1.65 t ha^{-1}, respectively. The yield increased in grain units after soybean preceding crop ranged from 1.61 to 2.15 t ha^{-1}; feed units – 1.39-1.85 t ha^{-1}; digestible protein units – 0.27-0.36 t ha^{-1}. Delaying the sowing dates of winter wheat to later dates had a negative impact on crop productivity, with the most significantly decreased which observed after sunflower as a predecessor. Higher economic indicators were achieved when growing winter wheat after soybean and sowing on September 15: the value of the produced goods increased to 33540 UAH ha^{-1}, net profit reached 15489 UAH ha^{-1} with profitability of 85.8 %.

Keywords: Economic efficiency, Preceding crop, Productivity, Sowing dates, Winter wheat, Yield

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Introduction

Wheat is one of the most valuable food crops in the world. Food products based on wheat contain a number of important and beneficial components for human nutrition, including protein (Shiferaw *et al.*, 2013; Shewry and Hey, 2015; Abdalla *et al.*, 2023; Reynolds and Braun, 2022; Cheremisina and Rossokha, 2021; Bazaluk *et al.,* 2020).

Among the agronomic practices that are part of modern technologies, the most important are sowing dates and proper placement of varieties after different predecessors in crop rotation. According to scientific research, the potential of modern winter wheat varieties is only realized to 30-40 % (Bazaliy *et al.*, 2022; Korkhova *et al.*, 2021; Kyrylenko *et al.*, 2023). The main reason for this situation is that the application of one technology or another in the cultivation of modern varieties does not fully allow the biological properties of plants to be realized, which ultimately affects the productivity levels of crops and sharp decreases in yield in unfavorable weather conditions.

The weather-climatic conditions and soils of the northern Steppe of Ukraine contribute to the cultivation of winter wheat and allow for obtaining high yields of quality products. However, due to rapid climate changes on the planet, including in Ukraine, the northern Steppe is now considered a risky agricultural zone where plants are most affected by stress factors in the environment (Adamenko, 2014; Bilousova *et al.*, 2020; Mostipan *et al.*, 2021).

Among the natural factors, precipitation and temperature have the most significant impact on the growth and development of agricultural crops (Gourdji *et al.*, 2013; Argha and Ahmed, 2019; Mostipan *et al.*, 2019). A lack of moisture in the soil during seed germination damages future yields, reduces stem density during tillering, overall and later productive stem numbers per plant, grain number in the spike during flowering, and the weight of 1000 grains during grain ripening. The temperature regime during the vegetative period of winter wheat affects the photosynthetic capacity of plants, determining the level of assimilation product accumulation in the grain after the flowering phase.

Among the key factors influencing winter wheat productivity, preceding crops play a crucial role. Predecessors affect the water, air, and nutrient regimes of the soil, which in turn influence plant growth and development. Their impact on yield and biometric indicators of winter wheat plants is not uniform. Due to the trend of a continuous decrease in fallow land, leguminous crops, and perennial grasses, particular attention is needed to find predecessors that provide favorable conditions for winter wheat cultivation (Shakaliy *et al.*, 2021; Shcherba *et al.*, 2021; Kyrylenko *et al.*, 2023; Gamayunova *et al.*, 2022; Kudria *et al.*, 2021; Hanhur and Kotliar, 2023).

Long-term research has shown that the most productive potential of winter wheat varieties in the Steppe region is realized after fallow predecessors. However, due to the reduction in fallow land and the expansion of sunflower crops, studying the growth and development characteristics of winter wheat plants after these non-fallow predecessors has become highly relevant (Kholmurzaev, 2022; Mashchenko and Sokolovska, 2023).

For achieving consistently high yields of winter cereals, studying and adhering to optimal sowing dates is crucial. According to numerous studies, sowing dates have a significant impact on plant growth and development, survival, frost resistance, winter hardiness, productive stem density, productivity, and product quality. The duration of the optimal sowing period is limited, and deviations from it lead to yield reductions (Tkachuk and Tymoshchuk, 2020; Shakaliy *et al.*, 2020; Korkhova, 2019; Sobko *et al.*, 2023; Oleksiak, 2014; Spanic *et al.*, 2023).

The importance of determining optimal sowing dates for winter wheat has increased significantly in recent years due to global climate changes. Furthermore, this agronomic practice is not associated with additional costs and is considered the most cost-effective way to increase plant productivity. The variety, as one of the biological means of production, significantly influences land use efficiency, with its potential yield depending on its harvest level (Mostipan and Umrykhin, 2022; Liu *et al.*, 2023).

Based on aggregated data from research institutions and the state variety testing system, recommended optimal sowing dates for winter crops are continually being developed. However, these dates are closely related to agronomic and soil conditions, they need to be clearly established in each natural-climatic zone of a region, district, or even in individual farms.

Materials and methods

Experimental site

Field research was conducted in the Laboratory of Bio-Adaptive Technologies at the Institute of Agriculture of the Steppe NAAS. The geographic location of the institute is expressed by 48°34' north latitude and 32°19' east longitude.

The territory of the Institute is located on the left bank of the Ingul River, 8 km away from its bed, on the watershed between two ravines. The relief of the area where the Institute operates is moderately undulating with a wide plateau and fairly deep ravines. The schemes of ravines and valley bottoms are small, mostly steep, and gentle in the upper part.

Soil parameters

The soils of the research area correspond to the chernozem zone of the northern Right-Bank Steppe of Ukraine in the subzone of ordinary chernozems transitioning to deep ones. These soils formed as a result of the settlement of meadow-steppe vegetation on loamy rock. The main feature of the soil cover is ordinary chernozem transitioning to deep, which lies on the plateau on gentle slopes of various exposures and has a heavy loamy mechanical composition. According to the soil monitoring data of the Kirovohrad branch of the State Institution «State Soil Protection» (Soil monitoring materials, 2021), the arable soil layer contains an average of 3.70 % humus, 117 mg of easily hydrolyzable nitrogen, 92 mg of available phosphorus, and 137 mg kg^{-1} of soil of exchangeable potassium per, mobile forms of manganese, zinc, and boron – respectively 9.60, 0.65, and 1.51 mg per kilogram of soil. Chernozems mainly have a neutral to slightly alkaline reaction of the soil solution and do not require chemical amelioration.

General technology for growing winter wheat

The technology for growing winter wheat, except for the studied issues, is generally accepted for the Northern Steppe zone of Ukraine. The main soil tillage began with plowing the stubble to a depth of 8-10 cm. Two disc harrowings were carried out: the first one to a depth of 8-10 cm, the second one to 5-6 cm without cultivation. Before sowing winter wheat, cultivation was carried out to a depth of 5 to 8 cm. In spring, nitrogen fertilizers (ammonium nitrate) were applied to the crops at a rate of 30 kg ha^{-1} of active substance. The seeding rate for winter wheat was 5.0 million ha^{-1}.

Layout plan

The research was conducted using a two-factor plan with the use of one variety of winter wheat. Factor A – preceding crop (sunflower and soybean). Factor B – sowing dates (September 15th – optimal, September 30th – late-optimal, October 15th – late).

In the experiments, the Katrusia Odeska winter wheat variety was sown (*Triticum aestivum* L.): bred by Ukrainian breeders (Breeding and Genetics Institute – National Center for Seed Science and Variety Research) and included in the State Register of plant varieties suitable for distribution in Ukraine in 2016, of a high-intensity type, universally used on high and medium agro-sites, recommended for the Steppe zone).

Meteorological conditions during the research period

The weather conditions during the years of the research were variable, differing from the average multi-year indicators and from each other, which allowed for a comprehensive assessment of the reaction of the winter wheat variety to the studied factors.

The autumn of 2020 (the first year of sowing winter wheat for the 2021 harvest) turned out to be very warm. The average air temperature for the calendar autumn was 12.8 °C, which was 4.8 °C above the norm. Autumn precipitation exceeded the norm, with a total of 127.3 mm, which is 27 % above normal. The winter of 2020-2021 was characterized by contrasting mostly warm and rainy weather. The average air temperature for the calendar winter was 1.9 °C, which was 2.3 °C above the norm. The total precipitation for the winter period was 147.5 mm, exceeding the norm by 140 %. Wintering of winter wheat plants occurred under satisfactory weather conditions.

The spring of 2021 was cool and rainy. The average temperature for the calendar spring was 9.5 °C, which was 1.2 °C above the norm. Precipitation during the spring exceeded the climatic norm, reaching 154 mm. Moderate temperature conditions were observed with average vegetation recovery and sufficient soil moisture reserves in the soil during the spring and summer periods.

The weather conditions in the autumn of 2021 were cold and rainy, with an average air temperature of 15.4 °C in September, which was 0.7 °C below the norm. The total precipitation for the month was 73.5 mm, exceeding the monthly norm by 93 %.

Wintering of winter crops occurred under satisfactory weather conditions. During the coldest periods, the minimum soil temperature at the depth of plant node formation decreased to -7 °C, remaining above the critical freezing temperature for winter wheat plants. No weather anomalies were observed in spring. The weather conditions during the vegetation period of 2021-2022 were mostly favorable for winter wheat.

The autumn period of 2022 was mostly rainy with excessive precipitation compared to the average multi-year indicators. The winter period was predominantly warm, with occasional sharp fluctuations in temperature. There were no threatening phenomena observed for their wintering. Wintering occurred under satisfactory weather conditions.

The weather conditions during the vegetation period of 2022-2023 were mostly favorable for winter wheat. Moderate temperature conditions were observed with early vegetation recovery in spring, moderate increases in air temperature, and sufficient soil moisture reserves during the spring period.

Results

The results of the three-year research showed that the winter wheat yield indicators significantly varied depending on the factors, with yield ranges of 3.79-7.97 t ha^{-1} (Figure 1).

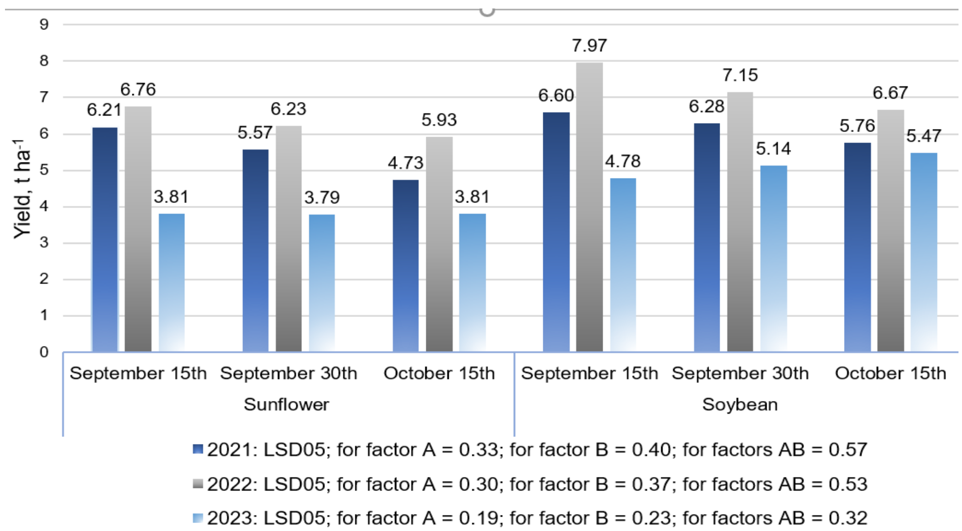

Figure 1. Winter wheat yields depending on preceding crops and sowing dates

The complex of weather and climatic conditions significantly mitigated the impact of agronomic practices in growing winter wheat, especially during the vegetation periods of autumn and spring-summer of 2022/2023. In these conditions, the predecessor factor still contributed to yield increase (average yield after soybean predecessor was 5.03 t ha^{-1}, after sunflower predecessor 3.80 t ha^{-1}), while sowing dates did not significantly affect crop productivity. Particularly, the effect of sowing date factor was mitigated when growing wheat after sunflower.

The lower winter wheat yields in our research were obtained in 2021, 3.81 t ha^{-1} when grown after sunflower. The activity of soybean rhizobia bacteria in the previous year contributed somewhat to increased plant metabolism in wheat, resulting in yield increases (+1.23 t ha^{-1}, LSD05 for factor B = 0.40 t ha^{-1}, 2021) after the soybean predecessor. The grain yield of winter wheat this year did not exceed 5.47 t ha^{-1}, with the highest yield obtained from sowing on October 15th. The extended vegetation period in autumn and early spring vegetation recovery promoted higher winter wheat yields, especially when sown later.

Weather conditions during the growing season of winter wheat during the 2020/2021 and 2021/2022 research years, characterized by moderately warm temperatures and excessive moisture, were quite favorable for achieving high winter wheat productivity. However, the highest wheat yield indicators were obtained in 2022.

The overwintering conditions of winter wheat plants in the 2021/2022 season were the most favorable for crop productivity formation during the years of the study. The winter temperature regime did not reach critical levels, and the absence of weather anomalies during the spring vegetation period with even rainfall in the spring-summer period at air temperatures close to optimal for the crop all contributed to winter wheat yields ranging from 5.93-7.97 t ha^{-1}. This wide range of yield variations was determined by the active effect of agronomic practices that we studied.

The highest winter wheat yields were obtained sown after a soybean predecessor (average yield of 7.26 t ha^{-1}). Due to the predecessor factor, a significant yield increase of 0.96 t ha^{-1} was achieved (LSD05 = 0.30 t ha^{-1}). When growing winter wheat after sunflower in the conditions of that year, the average crop yield was 6.30 t ha^{-1}.

Special attention should be paid to the factor of sowing dates. Under favorable vegetation conditions, delays in sowing winter wheat led to significant grain yield losses. Higher yield indicators were obtained with early sowing dates, on September 15th, 7.97 t ha^{-1} after a soybean predecessor and 6.76 t ha^{-1} after a sunflower predecessor (the predecessor factor provided a significant yield increase of 1.21 t ha^{-1}, LSD05 = 0.30 t ha^{-1}). It is important to note that yield losses due to late sowing dates were less significant after a sunflower predecessor compared to a soybean predecessor. For example, in the case of sowing on September 30th, the yield of winter wheat in our studies decreased by 0.53 t ha^{-1} (compared to the September 15th sowing date), and sowing on October 15th resulted in an additional decrease of 0.30 t ha^{-1}; after soybean predecessor, the difference between the indicators was much greater – 0.82 t ha^{-1} and 0.48 t ha^{-1} respectively.

Therefore, it can be concluded that under optimal favorable vegetation conditions for winter wheat, the predecessor factor has the most significant impact on yield formation, and delays in sowing by 15 days and 30 days compared to the early sowing date of September 15th led to a decrease in winter wheat yield. We observed the reverse effect of sowing dates compared to the results of the 2021 research year when conditions for the crop were unfavorable, especially after a soybean predecessor, where later sowing dates allowed for a higher yield.

The weather conditions in 2020/2021, on average (as in 2022/2023), were favorable for winter wheat, but frequent and sharp fluctuations in temperature during the winter and cool, rainy weather in the spring resulted in lower crop productivity compared to 2023. Yield indicators ranged from 4.73-6.60 t ha^{-1}. It should be noted that the variability of these indicators was determined by a complex of growing conditions, with the greatest impact being from the weather and climatic conditions: in 2021, the yield fluctuation range was 1.87 t ha^{-1}, in 2022 – 2.04 t ha^{-1}, and in 2023 – 1.68 t ha^{-1}. Favorable weather conditions allow winter wheat plants to most effectively utilize their genetic potential and field potential.

The difference in winter wheat yield in 2021 due to the predecessor factor was 0.71 t ha^{-1} with LSD05 = 0.30 t ha^{-1} (the average yield indicator for the sunflower predecessor was 5.50 t ha^{-1}, and for the soybean predecessor was 6.21 t ha^{-1}). The highest yield in this year was obtained when growing winter wheat after soybeans with an early sowing date of September 15th, at 6.60 t ha^{-1}. In this scenario, a significant increase of +0.84 t ha^{-1} was achieved compared to the late sowing date of October 15th (LSD05 factors AB = 0.57 t ha^{-1}). Delaying the sowing date by 15 days compared to the early sowing date did not significantly affect the yield of winter wheat, with a decrease of only 0.32 t ha^{-1}. However, yield losses for winter wheat with a sunflower predecessor were much greater with delayed sowing dates: for late-optimal sowing on September 30th, the yield decreased by 0.64 t ha^{-1}, and for late sowing on October 15th, this indicator was lower by 1.48 t ha^{-1}.

Thus, favorable weather conditions throughout the entire growth period significantly determined the level of winter wheat crop yields. The highest indicators under the most optimal weather conditions were in 2022 with the widest fluctuation range of 5.93-7.97 t ha^{-1}, slightly lower in 2021 at 4.73-6.60 t ha^{-1}. The predecessor factor had the greatest impact on yield, with a yield increase of 1.23 t ha^{-1} after soybeans in 2022 (LSD05 = 0.33 t ha^{-1}) and +0.71 t ha^{-1} (LSD05 = 0.30 t ha^{-1}) in 2021. Delaying winter wheat sowing dates in these years resulted in a decrease in grain yield, with the most significant impact observed with a sunflower predecessor. Under unfavorable weather conditions for growing winter wheat in 2023, its yield ranged from 3.79-5.47 t ha^{-1}. The potential of the previous soybean crop allowed for a higher grain yield of winter wheat at 5.03 t ha^{-1}, while with a sunflower predecessor it was 3.81 t ha^{-1}. Later sowings of winter wheat in this year, especially after soybeans, resulted in significant yield increases, +0.36 t ha^{-1} and 0.69 t ha^{-1} compared to the overall significant difference of 0.32 t ha^{-1}.

It is known that to maximize the genetic potential of winter wheat varieties and achieve a stable level of yield, it is necessary to determine optimal sowing dates for each soil-climatic zone and pay significant attention to the choice of predecessor. The results of conducted research, characterizing the average yield indicators of winter wheat, indicate that from 2021 to 2023, it ranged from 4.82 t ha^{-1} for sowing on October 15th after sunflower to 6.45 t ha^{-1} for sowing on September 15th after soybeans (Table 1).

Table 1. Winter wheat yield depending on the predecessor and sowing date, average for 2021-2023

Preceding crops, factor A	Sowing dates, factor B	Yield, t ha^{-1}	Difference, factor A		Difference, factor B	
			t ha^{-1}	%	t ha^{-1}	%
Sunflower	September 15th	5.59	–	–	–	–
	September 30th	5.20	–	–	-0.40	-7.1
	October 15th	4.82	–	–	-0.77	-13.7
Soybean	September 15th	6.45	0.86	15.4	–	–
	September 30th	6.19	0.99	19.1	-0.26	-4.0
	October 15th	5.97	1.14	23.7	-0.48	-7.5
LSD05 (t ha^{-1})	for factor A = 0.25; for factor B = 0.30; for factors AB = 0.43					

The research was shown that the predecessor factor played a significant and decisive role in shaping the yield of winter wheat. Comparing the effect of the predecessor, we found significant yield increases when growing winter wheat after soybeans compared to those grown after sunflowers. The smallest but significant yield increase for winter wheat with a soybean predecessor was for sowing on September 15, amounting to 0.86 t ha^{-1} (15.4 %). There was a difference of almost one ton of grain (0.99 t ha^{-1}) for sowing on September 30, and winter wheat responded most significantly with a yield increase of 1.14 t ha^{-1} (23.7 %) for sowing on October 15.

Comparing sowing dates after a sunflower predecessor, the best seeding date for winter wheat was September 15th, which showed a significant difference of 0.40 t ha^{-1} (7.1 %) compared to the October 30 date and 0.77 t ha^{-1} (13.7 %) compared to the October 15th date. A significant yield increase was also observed for sowing on September 15 after soybeans compared to sowing on October 15, amounting to 0.48 t ha^{-1} (7.5 %). Soybeans were the most favorable predecessor among those studied, as delaying the sowing of winter wheat by 15 days (from September 15 to September 30) did not have a significant impact on its yield.

Therefore, a significant increase in winter wheat yield after a soybean predecessor compared to a sunflower predecessor was established, regardless of the sowing date. It is advisable to sow winter wheat on September 15 after a sunflower predecessor and on September 15-30 after a soybean predecessor. The highest yield of winter wheat, on average for 2021-2023, was obtained for sowing on September 15 after soybeans, reaching 6.45 t ha^{-1}.

The productivity of winter wheat to yield indicators of grain units, feed units, and digestible protein units output from main and by-products is determined by a complex of agronomic factors that influence the intensity of plant growth and development, as well as the direction of physiological and biochemical processes. In our research, the effect of the predecessor crop and sowing dates of winter wheat determined the variation in productivity indicators.

The yield of grain units, as well as grain yield, averaged over three years of research, was higher when growing winter wheat after soybeans (Figure 2).

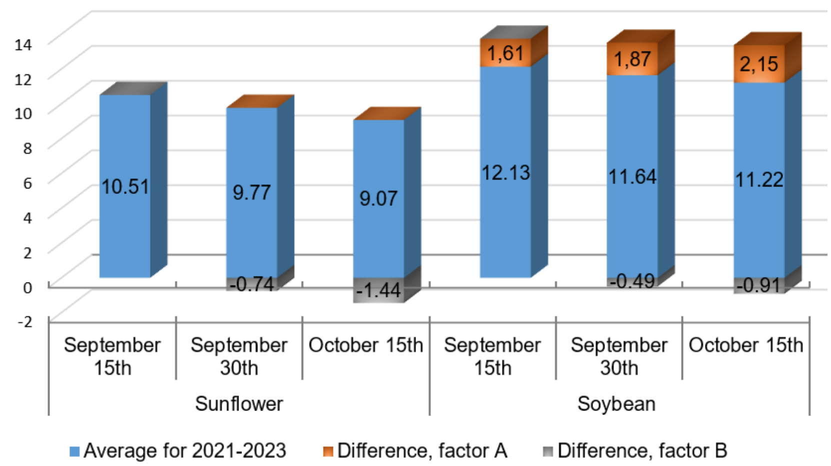

Figure 2. Yield of grain units from the main and by-product production of winter wheat depending on the predecessors and sowing dates, t ha^{-1}

For the optimal sowing date of September 15, the grain units yield was highest at 12.13 t ha^{-1}. Delaying the sowing of winter wheat to later dates, by 15 days and 30 days, resulted in a decrease in crop productivity by this indicator by 0.49 t ha^{-1} (4.0 %) and 0.91 t ha^{-1} (7.5 %) respectively.

However, it should be noted that the loss of grain units when growing winter wheat after sunflowers was more significant. When sown on September 30th, the crop productivity in terms of grain units yield decreased by 0.74 t ha^{-1} (7.1 %) compared to the early sowing date, and when sown at a later date, October 15, there was a loss of 1.44 t ha^{-1} of grain units, which constituted 13.7 % of the main and by-product output (LSD05 = 0.57 t ha^{-1}).

The greatest effect of the predecessor factor was observed with a late sowing date, October 15. The yield increase of grain units in this variant was 2.15 t ha^{-1} (23.7 %).

A similar trend was observed when analyzing the yield indicators of feed units. Wheat crops planted after the preceding soybern culture showed higher productivity in terms of feed unit output. Depending on the sowing dates, yields ranged from 9.67-10.45 t ha^{-1}, while with sunflower as a predecessor, these indicators varied from 7.82-9.06 t ha^{-1} (Figure 3).

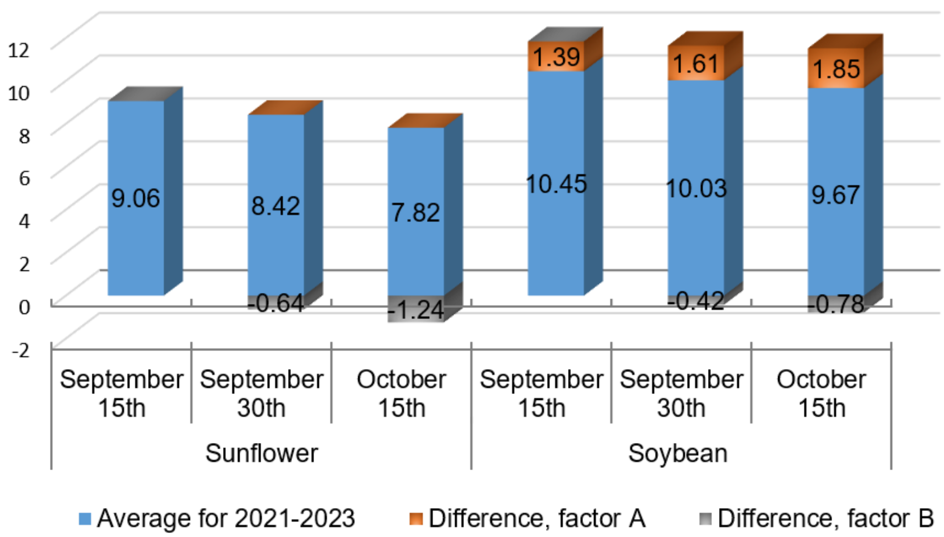

Figure 3. Yield of feed units from the main and by-product production of winter wheat depending on the predecessors and sowing dates, t ha^{-1}

Sowing winter wheat in optimal-late and late dates negatively affected the yield of feed units from production, and the crop productivity significantly decreased, especially after sunflower as a predecessor. When sowing winter wheat on October 30th, the yield of feed units decreased by 0.64 t ha^{-1} (7.1 %), on October 15th – by 1.24 t ha^{-1} (13.7 %), LSD05 = 0.49 t ha^{-1}. Choosing the previous crop, even considering delays in sowing dates of this crop, allowed us to reduce feed unit losses by almost one and a half times. And after soybern as a predecessor, the decrease in feed unit yield with a late sowing date on October 15th did not exceed 0.78 t ha^{-1} (7.5 %), which was within the significant difference compared to the optimal-late date with sunflower as a predecessor. However, it should be noted that even with the latest sowing date with soybern as a predecessor, the feed unit yield reliably exceeded this indicator with sunflower as a predecessor.

Harvesting digestible protein is an important indicator not only for determining the productivity of agricultural crops but also for land area and determining the efficiency of agronomy, especially in regions with risky agriculture. A significant increase in digestible protein yield was provided by the predecessor factor, and with LSD05 = 0.08 t ha^{-1} with soybern as a predecessor, it ranged from 0.27-0.36 t ha^{-1} (Figure 4).

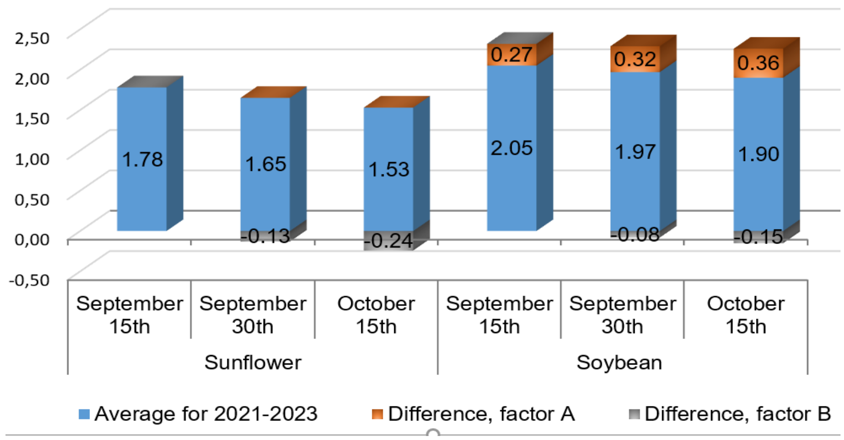

Figure 4. Yield of digestible protein from the main and by-product production of winter wheat depending on the predecessors and sowing dates, t ha^{-1}

Moreover, delaying the sowing date by 15 days later than the optimal date, September 15th, in this variant did not have a significant impact on reducing the digestible protein yield, -0.08 t ha^{-1} (LSD05 = 0.10 t ha^{-1}), which was not observed with sunflower as a predecessor. A significant decrease in the yield of digestible protein was observed specifically after sunflower as a predecessor at later sowing dates of winter wheat. When sowing on September 30th, the crop productivity decreased by 0.13 t ha^{-1}, and with a further delay in sowing by 15 days, the reduction was within 0.24 t ha^{-1}, resulting in the lowest protein yield in our studies, 1.53 t ha^{-1} from the main and by-product production. The final stage of evaluating the study of various factors is determining the economic efficiency of conducting scientific research, which is valuable for both science and production.

Economic efficiency indicators were determined using price calculations for the first quarter of 2024. It was found that to achieve the highest yield, which was achieved with the winter wheat variety Katrusia Odeska after soybern as a predecessor with a sowing date of September 15th, averaging 6.45 t ha^{-1} over three years of research, it is necessary to increase production costs to the maximum level – 18051 UAH ha^{-1} (Table 2).

The increase in costs for the same technology can be explained by the high cost of fuel and lubricants for transporting the additional harvest. However, in this scenario, the highest gross production value was obtained – 33540 UAH ha^{-1}, leading to the maximum reduction in the difference between costs and achieving the highest net profit – 15489 UAH ha^{-1}.

Table 2. Economic efficiency of winter wheat cultivation of the Katrusia Odeska variety depending on the predecessors and sowing dates, average 2021-2023

Preceding crops, factor A	**Sowing dates, factor B**	**Yield, t ha^{-1}**	**Production costs. UAH ha^{-1}**	**Cost of gross production, UAH ha^{-1}**	**Notional profit, UAH ha^{-1}**	**Profitability, %**
Sunflower	September 15th	5,59	17600	29068	11468	65,2
	September 30th	5,20	17396	27040	9644	55,4
	October 15th	4,82	17197	25064	7867	45,8
Soybean	September 15th	6,45	18051	33540	15489	85,8
	September 30th	6,19	17915	32188	14273	79,7
	October 15th	5,97	17799	31044	13245	74,4

Comparing the impact of predecessors, it has been shown that cultivating winter wheat after soybern, regardless of the sowing date, contributed to an increase in economic efficiency indicators. The worst results were obtained when growing winter wheat after sunflower as a predecessor with an optimally late sowing date of October 15th, which led to a decrease in net profit by 1.97 times compared to growing the crop after soybern with a sowing date of September 15. It was also noted that the level of profitability was the lowest for winter wheat sown after sunflower, ranging from 45.8 % for sowing on October 15th to 65.2 % for sowing on September 15th. The highest profitability was achieved under the conditions of growing winter wheat after soybern with a sowing date of October 15th, reaching 85.8 %.

Therefore, the choice of predecessor and sowing date is crucial for winter wheat cultivation to achieve higher yields and high economic indicators. If cultivating winter wheat after sunflower or soybern, the optimal sowing date would be September 15th. However, among пo-fallow predecessors, soybern is the best choice for winter wheat cultivation with a sowing date of September 15th, leading to a higher yield (6.45 t ha^{-1}), increased production value (33540 UAH ha^{-1}), maximum net profit (15489 UAH ha^{-1}), and highest profitability (85.8 %).

Discussion

The increase in stressful weather conditions requires constant study of the impact of environmental factors on plants. Research has shown that weather conditions during the vegetation period significantly affect the yield formation of winter wheat. Their contribution exceeds the influence of agronomic elements and reaches almost 61% (Bilousova *et al.*, 2020). In the conditions of the Forest-Steppe of Ukraine, the average yield of winter wheat varieties was higher when sown on September 25th after soybean – 6.24 t ha^{-1}, compared to after sunflower – 5.52 t ha^{-1}. The factors that most influenced the yield level of winter wheat were found to be the growing season conditions and the previous crop, accounting for 67.8 % and 20.9 % respectively (Kyrylenko *et al.*, 2023). In studies by Hanhur and Kotliar (2023), sunflower and sugar beets were identified as poorer predecessor crops. When sown after these predecessors, the grain yield of winter wheat was lowest at 5.17 t ha^{-1} and 5.23 t ha^{-1} respectively.

Research conducted in the central part of Polissya, Ukraine from 1999-2018, demonstrates that the highest level of realization of the biological potential of winter wheat productivity (3.56 t ha^{-1}) was achieved when sown on September 10th, which was 28.7 % higher compared to sowing on October 10th (Tkachuk and Tymoshchuk, 2020). In the conditions of the Eastern Polissya region, the difference in yield of winter wheat depending on sowing dates, according to Sobko *et al.* (2023), was as follows: when sown on September 1st – 5.72 t ha^{-1}, September 10th – 5.54 t ha^{-1}, September 20th – 5.41 t ha^{-1}, October 1st – 5.45 t ha^{-1}, October 10th – 4.87 t ha^{-1}, October 20th – 5.11 t ha^{-1}, November 1st – 5.06 t ha^{-1}.

Results of studies conducted in the Kharkiv region, located in the Forest-Steppe zone of Ukraine with pronounced continental weather conditions, confirm a significant increase in winter wheat yield after predecessor crops such as peas, soybeans, and beans. The lowest yield was observed after sunflower and maize. Intensive use of sunflower in short rotation cropping systems (40 %) led to a significant decrease in winter wheat yield to 3.75 t ha^{-1} (Kudria *et al.*, 2021).

The optimal sowing period for winter wheat in the southern regions of the northern Steppe of Ukraine (2013-2018) on fallow land is considered to be from September 30th to October 10th. Under favorable weather conditions during the growing season, yields reach 6.27 t ha^{-1}, while under unfavorable conditions it drops to 4.43 t ha^{-1} (Korkhova, 2019). According to our research conducted in the central part of the Steppe zone of Ukraine during 2021-2023, a significant increase in productivity, yield, and economic efficiency of winter wheat cultivation after soybean as a predecessor compared to sunflower as a predecessor was established regardless of the sowing date. It is advisable to sow winter wheat on September 15th after sunflower and September 15-30th after soybean. Higher productivity winter wheat can be obtained when sown on September 15th after soybean with an increase in the yield of grain units by 1.61-2.15 t ha^{-1}; feed units – 1.39-1.85 t ha^{-1}; digestible protein units – 0.27-0.36 t ha^{-1}. Delaying the sowing dates for winter wheat, especially after sunflower as a predecessor, leads to reduced yields and productivity levels when grown in the conditions of the northern Steppe of Ukraine.

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