

## Analysis of winter wheat yield using land resources

I. Didur<sup>1</sup>, V. Petrychenko<sup>2</sup>, H. Pantsyreva<sup>1\*</sup> , O. Horash<sup>3</sup>,  
N. Zelenchuk<sup>1</sup>, O. Lvovskyi<sup>1</sup>, O. Tsyhanska<sup>1</sup>

<sup>1</sup> Vinnytsia National Agrarian University, Vinnytsia, Ukraine

<sup>2</sup> Institute of Feed Research and Agriculture of Podillya of NAAS, Vinnytsia, Ukraine

<sup>3</sup> Higher Educational Institution, Podillia State University, Kamianets-Podilskyi, Ukraine

\* Corresponding author's e-mail: apantsyreva@ukr.net

### ABSTRACT

Grain farming is a key component of the agro-industrial complex and plays a decisive role in ensuring food security in Ukraine. The aim of the study was to establish the optimal sowing rate of winter wheat depending on the fertilization system on gray forest soils while ensuring the preservation of their fertility. The study covered three factors: variety (Revolver and RZHT DELLO), fertilization rates (no fertilizers and increased fertilization background of 40 t/ha of manure, N<sub>100</sub>P<sub>63</sub>K<sub>112</sub>) and seeding rates (1.5–4 million similar grains/ha). It was found that the interaction of the studied factors forms different conditions for plant growth and development, affecting their tillering, nutrient supply and the level of competition in sowing. The highest productivity indicators are provided by a combination of a high-yielding variety, increased fertilization background and moderate seeding rate. According to the average data for 2023–2025, the yield of winter wheat, depending on the level of intensification, was 4.22–6.97 t/ha. The RZHT DELLO variety demonstrated higher productivity and more efficient use of land resources (98.43%) compared to the Revolver variety (86.65%). The results obtained emphasize the importance of optimization of agrotechnical measures to increase the efficiency of grain production. This has significant practical potential for improving agricultural policy, increasing the competitiveness of the Ukrainian grain sector, and strengthening Ukraine's position on the world market, provided that product quality, storage and processing technologies are improved, and resources are used more efficiently.

**Keywords:** winter wheat, variety, seeding rate, fertilizer, grain farming, cultivation technology, land resources.

### INTRODUCTION

Grain farming occupies a leading place in the structure of the agro-industrial complex and plays a key role in ensuring the food security of the state (Mazur et al., 2022; Brzozowska et al., 2018). The level of its development is an integral indicator of the efficiency of agricultural production, since it is precisely on the stability and volume of grain cultivation that the provision of the population with basic food products, and the processing industry with high-quality raw materials, depends (Bakhmat et al., 2023). In the current conditions of martial law, the importance of the grain sector is growing significantly. Military operations, destruction of infrastructure, complicated logistics and reduced availability of resources create serious challenges

for agricultural production, which, in turn, affects the domestic market and export capabilities of the state. Ensuring the stability of the grain economy is becoming not only an economic, but also a strategic task related to maintaining national stability and food security. Under such conditions, research into the state, development trends and efficiency factors of the grain economy becomes particularly relevant, as the results can be used to improve state policy, support farmers and form a reliable food system of the country (Rogach et al., 2022).

The advantages in the development of winter wheat grain production compared to other grain crops are due to a number of agrobiological and economic factors. Currently, wheat provides food for about two-thirds of the world's population, which emphasizes its exceptional importance in

the global food system. The high value of the crop is explained by the optimal combination of proteins and carbohydrates in the grain, balanced amino acid composition, versatility of use and stability of yield in various soil and climatic conditions. Due to these advantages, winter wheat occupies a leading place in the structure of sown areas and is a strategic crop for the development of agricultural production (Kalenska et al., 2011).

Wheat is primarily a steppe crop, which causes the concentration of more than half of the gross grain harvest in the Steppe and Forest-Steppe zones of Ukraine (Didur et al., 2021). The main grain-growing regions include Odesa, Kherson, Dnipropetrovsk and Zaporizhia, where soil and climatic conditions are most favorable for growing this crop. Despite the existing natural and economic difficulties, in recent years, grain production per capita in Ukraine has averaged 761 kg, which corresponds to one of the highest indicators in the world, including the level of a number of European countries (Malhotra et al., 1997; Patyka et al., 2007).

Ukraine has significant potential for further growth of grain exports provided that key issues are addressed – ensuring high quality of grown products, improving storage and processing technologies, and increasing efficiency and economy of grain resources use. If these tasks are implemented, Ukraine will be able to occupy more confident and competitive positions in the world grain market (Tkachuk et al., 2024; Tkach et al., 2024; Kolisnyk et al., 2025).

Due to their unique biological properties, grain crops are able to accumulate a significant amount of high-calorie organic compounds – proteins, carbohydrates, fats, as well as a wide range of macro- and microelements (Tkachuk et al., 2024). Their important feature is the ability of the grain to retain its nutritional properties and quality indicators for a long time, as well as to acquire high taste characteristics during various technological treatments (Kaletnik, et al., 2024; Okrushko, 2022). This is what makes grain a universal and valuable raw material for the production of high-quality food products and complete animal feed (Dubik et al., 2024; Honcharuk et al., 2024; Butenko et al., 2025).

The total sown area of winter wheat in the world is about 240 million hectares, and the gross harvest is about 560 million tons (2024), which indicates a consistently high role of the crop in the global food system. The demand for wheat

is growing due to its versatility, high nutritional value and importance in the formation of diets of the population of most countries in the world. In Ukraine, the sown area of winter wheat is on average up to 7.6 million hectares, which ensures the country a leading position among the world's producers and exporters of grain (Hnatiuk et al., 2019). The territorial structure of the crop distribution is traditional: about 90% of crops are concentrated in the Steppe (55%) and Forest-Steppe (35%) zones. This is explained by the combination of soil fertility, sufficient heat and the ability to effectively use moisture (Branitskyi et al., 2022). Only 10% of the area falls on Polissya and Transcarpathia, where natural conditions are less favorable for growing winter wheat due to increased soil acidity, insufficient temperature range and excessive moisture. In recent years, the structure of sown areas has undergone certain changes. Martial law, destruction of infrastructure, mining of territories and complication of logistical routes have led to a reduction in cultivated land in some regions, primarily in the southern and eastern regions. Despite this, Ukrainian farmers maintain a relatively stable level of winter wheat production, which emphasizes the high adaptability of the crop and the professionalism of producers.

## MATERIALS AND METHODS

The study used generally accepted methods of conducting scientific and experimental research in the conditions of the Right-Bank Forest-Steppe of Ukraine, which allowed considering varietal agricultural technologies as a multifactorial system that has the main regulated criteria and falls under the regular principles of factorial analysis. The conditions for conducting research and the scheme of the proposed experiment are drawn up taking into account the ecological and agrochemical state of the territory, which are based on the reliable collection of initial data, the systematization of the received information with regard to the subject and object of research.

The purpose of the study was to determine the optimal sowing rate of winter wheat depending on the fertilization system on gray forest soils while ensuring the preservation of their fertility.

The characteristics of hydrothermal conditions of the growing season for 2023–2025 according to the data of the Vinnytsia Regional Center for Hydrometeorology are given in Table 1.

**Table 1.** Characteristics of hydrothermal conditions for 2023–2025

Average daily temperature, °C			Average long-term temperature, °C	Precipitation amount, mm			Average annual precipitation, mm
Years				Years			
2023	2024	2025		2023	2024	2025	
13.7	14.6	17.1	18.4	351	369	125	590

Many years of meteorological observations have shown that in the Right-Bank Forest-Steppe, the transition of the average daily temperature through +5 °C in spring usually occurs in early April, and in autumn – in late October or early November. This determines the duration of the growing season at 200–205 days, which is sufficient for the full formation and ripening of winter wheat and other grain crops. The average annual precipitation in the region is 580–630 mm, of which about 320 mm falls during the growing season, which provides a moderate supply of moisture for plants. The greatest amount of precipitation is observed in the summer months – 80–90 mm per month, while in winter it decreases to 30–35 mm per month. This distribution of precipitation indicates a pronounced seasonal mode of moisture exchange, which directly affects the water regime of soils, the development of the root system of plants and the formation of yield. Taking into account these meteorological indicators is important when planning agrotechnical measures, determining sowing dates and optimal sowing rates for winter wheat, as well as when selecting fertilizer systems to ensure stable crop productivity.

The agrochemical characteristics of the soil of the experimental plot according to soil survey materials are given in Table 2.

The repetition of the research was three times, and the placement of the research plots was consistent. The area of each accounting plot

was 25 m<sup>2</sup>. The research envisaged studying the following factors (Table 3):

The research involved studying the action and interaction of three factors: A – variety (Revolver and RZHT DELLO); B – fertilizer rates (without fertilizers and Increased fertilizer background (40 tons of manure, N 100 P63 K112); C – seeding rate: from 1.5 million pcs./ha to 4 million pcs./ha.

## RESULTS AND DISCUSSION

The influence and interaction of the studied factors – variety (A: Revolver and RZHT DELLO), fertilization rates (B: no fertilizers and increased background fertilization of 40 t/ha of manure, N 100 P 63 K 112) and seeding rates (C: from 1.5 million to 4 million seeds/ha) – created different conditions for the growth and development of winter wheat plants. Thus, the variety (factor A) determined the genetic potential of plants, their resistance to stress conditions and the ability to tiller. Fertilization rates (factor B) influenced the supply of plants with nutrients and the development of the root system, which was reflected in the mass of shoots and plant height. Seeding rate (factor C) regulated the sowing density, competition between plants for resources and the intensity of tillering. The interaction of these three factors showed that optimal productivity and tillering shoot formation was ensured by combining a high-yielding variety, an

**Table 2.** Agrochemical characteristics of gray forest soil

Sampling depth, cm	Humus content, %	Saline pH	Hydrolytic acidity, mg. – eq. per 100 g of soil	Sum of absorbed bases, mg – eq. per 100 g of soil	Degree of saturation with bases, %
0-20	2.12	5,1	3.44	14.38	86
30-40	1.44	4,9	3.48	14.06	88
65-75	0.71	4,6	3.45	13.10	86
95-105	not defined	4,4	3.32	13.63	85
125-135	not defined	4,4	3.37	13.49	88

**Table 3.** Field experiment scheme

Factor A (variety)	Factor B (fertilizer)	Factor C (seeding rate)
1. Revolver	1. No fertilizers	1. 4 million pcs. population / ha 2. 3 million pcs. population / ha 3. 1,5 million pcs. population / ha
2. RZHT DELLO	2. Increased fertilizer background (40 tons of manure, N <sub>100</sub> P <sub>63</sub> K <sub>112</sub> )	1. 4 million pcs. population / ha 2. 3 million pcs. population / ha 3. 1,5 million pcs. population / ha

increased fertilizer background, and a moderate seeding rate, which contributed to the rational use of resources and uniform development of plants in the crop (Fig. 1, Fig. 2).

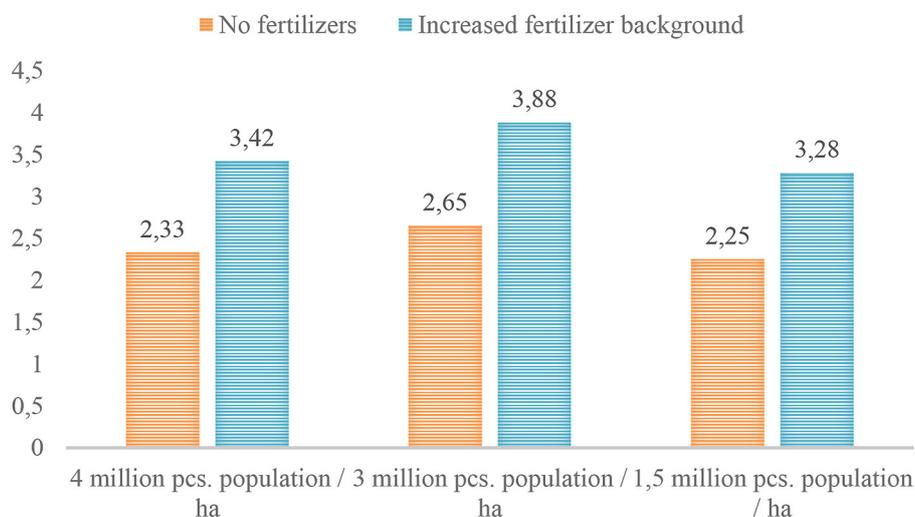
According to the results of the research, it was found that the tillering coefficient and the number of formed nodal roots were significantly influenced by technological methods of cultivation. Average annual data showed that at the end of the autumn vegetation period, the maximum tillering coefficient (3.88) was observed in winter wheat plants of the RZHT DELLO variety, sown with a rate of 3 million seeds/ha on variants with the introduction of an increased fertilizer fund (40 t/ha of manure, N 100 P 63 K 112).

The yield of winter wheat during the research period was determined by the interaction of numerous factors, in particular, the variety, fertilizer rates, seeding rates and weather conditions during the growing season. Thus, according to the average data for 2023–2025, depending on the level of intensification of agricultural techniques, the yield of wheat ranged from 4.22 to 6.97 t/ha (Table 4).

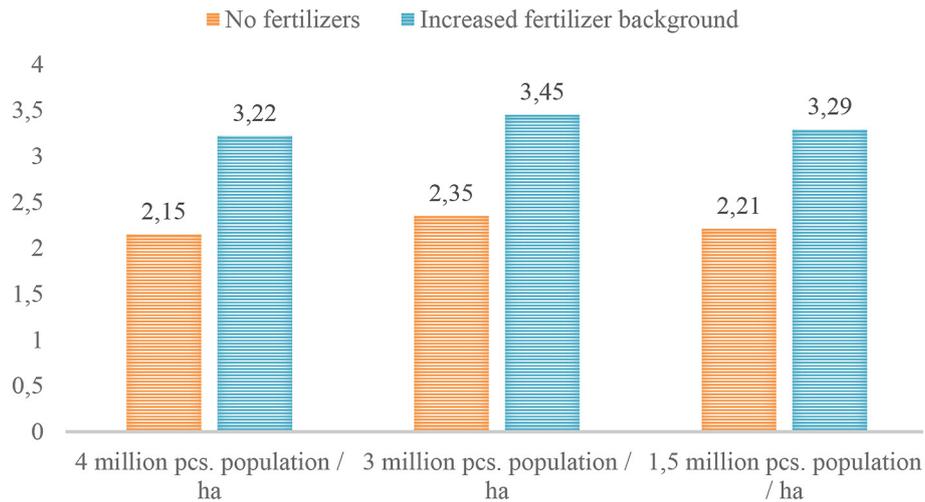
The rate of fertilizer application significantly affected the yield of winter wheat in experiments. Thus, according to the results of the studies, it was established that when growing winter wheat, an increased fertilizer background (40 t/ha of manure, N 100 P 63 K 112) provided a significant increase in yield compared to options without fertilizer application, especially in combination with the RZHT DELLO variety and the optimal seeding rate of 3 million pcs. seeds/ha.

The yield of winter wheat is a complex characteristic that reflects the efficiency of the use of available resources by plants: soil nutrient background, moisture, light and agrotechnical techniques (Kuryata et al., 2019; Razanov et al., 2019; Petrychenko et al., 2024).

The analysis of land resource use showed that the increased fertilization background and optimal seeding density allowed to significantly increase productivity per unit area due to better tillering development, increasing the number of spikelets in the spike and grain mass. At the same time, varieties with high productivity potential more effectively implemented the available soil



**Figure. 1.** Features of the formation of tillering shoots in winter wheat plants at the time of the cessation of autumn vegetation in the RZHT DELLO variety, 2023–2025



**Figure. 2.** Features of the formation of tillering shoots in winter wheat plants at the time of the cessation of autumn vegetation in the Revolver variety, 2023–2025

**Table 4.** Winter wheat yield depending on the studied factors, on average in 2023–2025

Variety	Fertilization	Seed sowing rate, million pcs. of seeds/ha	Average yield, t/ha
Revolver	Without fertilizers	4.0	5.22
		3.0	5.58
		1.5	5.42
RZHT DELLO	Increased fertilizer background	4.0	5.73
		3.0	6.97
		1.5	5.63

*LSD<sub>0,05</sub> t/ha: A-0,02; B-0,04; C-0,03; AB-0,04; AC-0,02; BC-0,11; ABC-0,06*

resources and agrotechnical factors, which was reflected in a higher land use coefficient. The use of differentiated seeding rates allowed to regulate the seeding density and minimize competition between plants for nutrients, which also contributed to increasing yields and rational use of soil resources. The conclusions indicate that maximum land use efficiency is achieved with a complex interaction of the variety, sufficient mineral and organic nutrition, as well as optimal seeding density (Khodanitska et al., 2019; Shevchuk et al., 2019; Mazur, et al., 2021; Lohosha, et al., 2024; Petrychenko et al., 2022; Mostovenko et al., 2022; Hetman et al., 2024; Petrychenko et al., 2018; Vdovenko et al., 2024; Monarkh et al., 2019). Scientists have established that maximum land use efficiency is achieved with a complex interaction of the variety (Khodanitska et al., 2019), sufficient mineral (Shevchuk et al., 2019) and organic nutrition (Mazur, et al., 2021), as well as optimal seeding density (Mostovenko et al., 2022), since only a balanced combination

of these factors ensures the formation of a full-fledged stem, intensive development of the root system and high productivity of each plant (Hetman et al., 2024). Petrychenko et al. note that such a model of technological optimization makes it possible not only to increase the gross grain yield per unit area, but also to increase the efficiency of using photosynthetically active radiation, improve the structural indicators of the crop and minimize losses of crop potential under conditions of variable climatic loads. The established dependence is confirmed by studies by leading Ukrainian scientists (Vdovenko et al., 2024; Monarkh et al., 2019), which show that the realization of the genetic potential of a variety is directly related to adequate nutrition and properly formed sowing density, while the violation of at least one of these elements can significantly reduce the productivity of the agrocenosis.

Analysis of land resource use showed (Table 5) that on gray forest soils, an increased fertilizer

**Table 5.** Analysis of winter wheat yield and land resource use

Variety	Yield, t/ha	Land ball	Produced products for 1 point, kg	Land resource utilization rate, %	Business activity assessment
Revolver	5.58	50	118	86.65	good
RZHT DELLO	6.97		137	98.43	very good

background and optimal seeding density allowed for a significant increase in productivity per unit area due to better tillering development, an increase in the number of spikelets in the spikelet, and grain mass.

The data show that the Patras variety is characterized by higher productivity and more efficient use of land resources compared to the Revolver variety. On gray forest soil, increased yield and better production per 1 land point reflect more rational use of soil and agrotechnical resources. The land resource utilization index for RZHT DELLO reaches 98.43%, which is assessed as «very good», while Revolver realizes soil potential by 86.65% («good»).

## CONCLUSIONS

According to the results of three-year studies (2023–2025), it was found that the average yield fluctuation over the years of research was 4.88–7.07 t/ha, with the maximum values obtained in variants with the RZHT DELLO variety, with a seeding rate of 3 million seeds/ha and the introduction of an increased fertilizer background (40 t/ha of manure, N<sub>100</sub>P<sub>63</sub>K<sub>112</sub>). This confirms the synergistic nature of the interaction of the genetic properties of the variety, optimal nutrient supply and rational crop density. The increased fertilizer background contributed to a more active development of the root system, more intensive tillering and the formation of a larger number of productive shoots, which directly affected the number of grains in the ear and their mass. The highest tillering coefficient – 3.88 was recorded in the RZHT DELLO variety at a seeding rate of 3 million seeds/ha against the background of full fertilization, which confirms the optimality of such a combination of technological elements. Regulation of plant density by correctly selecting seeding rates allowed to reduce intraspecific competition for nutrients, improve the use of soil and light resources and ensure the formation of full-fledged generative organs. A comparative assessment of the use of land resources showed

that varieties with high productivity potential under conditions of sufficient nutrition demonstrated a significantly higher area utilization coefficient. This indicates the ability of intensive genotypes to respond more effectively to agrotechnical factors and convert the obtained resources into a harvest. Thus, optimization of seeding rates in combination with the use of balanced doses of fertilizers is a key direction for increasing yields and stabilizing grain production. Particular effectiveness of these measures was established for the RZHT DELLO variety, which allows us to recommend it for intensive cultivation technologies in conditions similar to experimental ones.

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