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Experience in the application of differentiated pre-sowing nitrogen fertilizer placement under the conditions of Kostanay Region, Kazakhstan

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ABSTRACT
The current stage of development of agro-industrial production in the Republic of Kazakhstan highlights one of the most popular and profitable areas in resource-saving technologies, which is developing through modern navigation systems. The introduction of precision farming elements will allow farmers to significantly improve production efficiency. In general, yield increases will be achieved through improvements in agrochemistry, seed production, agricultural science, timeliness and quality of technological operations, use of sensors and weather factors, which together will reduce losses by at least 25%. The studies were conducted at the base farm of Troyana LLP (the first natural-climatic zone of Kostanay Region, ordinary chernozem soils). The cultivation technology was No-till. Soil samples were collected using a mobile sampler according to a technical assignment in a coordinate system, using a tablet or a special GPS receiver. Analysis of the obtained data revealed a deficiency of nitrate nitrogen in the soil; therefore, all subsequent work was aimed at increasing the availability of this element. According to the yield mapping results, the average yield in the unfertilized area was 2.24 c ha^{-1}, whereas in the treatment with the application of 36 kg ha^{-1} active ingredient of urea fertilizer it was 2.49 c ha^{-1}. Therefore, the yield increment from pre-sowing fertilizer application amounted to 0.25 c ha^{-1}.

Key words: Precision agriculture, Fertilizers, Differential application, Digital agrochemical map, NDVI, Yield mapping, Grain quality, Profitability.

Introduction

The primary condition influencing the biological efficiency of plants is the level of nitrogen nutrition (Tenorio *et al.* 2020; Chahal *et al.* 2021, Sarker *et al.* 2023). At the same time, good results are achieved both when fertilizers are applied at sowing and when foliar feeding is carried out during the growing season.
For example, according to researchers from Orenburg, treatment of cereal crops with urea at the tillering stage as a foliar application makes it possible to increase yields by 0.20 c ha^{-1}. Similar results were obtained by other researchers as well (Emam 2010).
At the same time, the efficiency of mineral fertilizers (Bo *et al.* 2025) and other agrochemical products is known to depend largely on the within-field variability of soil fertility and crop conditions. On sites with uniform fertility, differentiation of fertilizer rates is logically unnecessary. Many studies on the effectiveness of differentiated

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fertilizer application, both in our country and abroad, have shown that it is not always economically justified because the degree of within-field variability in soil fertility is not taken into account (Chakraborty *et al.* 2023; Yang *et al.* 2023; Perich *et al.* 2023; Bullock *et al.* 2024).

In particular, the results of long-term studies on differentiated nitrogen fertilizer application for seed potatoes in Idaho, USA, showed that the yield increase compared with conventional fertilizer application was generally small, while the profit from differentiated nitrogen rates did not cover the costs of implementing the new technology. This is not an isolated example (Watkins *et al.* 1998; Afanas' ev 2012). As a result, over the past decade there has been some decline in practitioners' interest in differentiated agrochemical application, which can theoretically be explained by the cyclical development of new agricultural technologies.

It is difficult to identify the relationship between the heterogeneity of agrochemical properties and yield variation. Therefore, to make decisions regarding fertilizer application, it is necessary to study this relationship within individual fields (Gülser *et al.* 2016). This becomes especially important in areas where fertilizer application increases the influence of anthropogenic factors in the formation of heterogeneity, while natural factors that create variability under extensive land use become secondary (Vågen *et al.* 2018; Yamaltdinova *et al.* 2020).

The objective of this study was to determine the effectiveness of differentiated nitrogen fertilizer rates applied at sowing under the conditions of Northern Kazakhstan, based on the results of agrochemical soil surveys using remote sensing and yield mapping.

MATERIALS AND METHODS

The studies were conducted at the base farm of Troyana LLP (the first natural-climatic zone of Kostanay Region, ordinary chernozem soils). The cultivation technology was No-till.

Soil samples were collected using a mobile sampler according to a technical assignment in a coordinate system, using a tablet or a special GPS receiver. The sampling depth, according to methodological recommendations under production conditions, is generally 20-30 cm; however, since the established nutrient availability gradations are linked to the 0-20 cm and 20-40 cm soil layers, the depth of agrochemical surveys should be set at 0-20 cm.

After collecting mixed samples from each elementary plot, soil bags were delivered to an agrochemical laboratory for the relevant analyses.

Differentiated fertilizer application was performed using a Bourgault seeding complex (Canada), which had been additionally equipped with an electric actuator and the AgroNavigator-Dispenser on-board computer system.

The following observations and measurements were carried out during the study:

Ground assessment of field germination and plant density, as well as identification of problem areas using remote monitoring tools.

Determination of nitrate nitrogen ($N\text{-}NO_3$) and available phosphorus (P_2O_5 according to Chirikov or Machigin depending on soil type) in the 0-20 cm soil layer before sowing with coordinate referencing.

Sampling of plant sheaves to determine yield and plant productivity

Yield recording with georeferencing in field plots. Grain samples were taken to determine quality indicators.

Calculation of characteristics reflecting the condition of the land surface based on multispectral remote sensing images was performed in QGIS using cloud-free Sentinel-L2A spectral images.

In QGIS, the vegetation spectral index NDVI (Normalized Difference Vegetation Index) was calculated; short-wave infrared (SWIR) and near-infrared (NIR) imagery were also analyzed, and primary processing of geostatistical data was performed using standard analytical tools.

Delineation of zones with stable year-to-year vegetation index values was carried out using the OneSoil information and analytical service.

Economic efficiency of precision farming elements was calculated, including seed use, yield amount, and grain quality.

RESULTS AND DISCUSSION

The application of mineral fertilizers under the conditions of Northern Kazakhstan is an important prerequisite for obtaining consistently high yields of quality grain. At the same time, fertilizer application should be economically justified, since this cost item increases production costs but does not always increase profitability. Therefore, when planning mineral nutrition for plants, soil nutrient availability must be taken into account.

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Agrochemical studies carried out in the fields of Troyana LLP (Fyodorovsky District, Kostanay Region) were performed using a Wintex 2000 automatic sampler with geographic referencing of samples (Fig. 1). Analysis of the collected samples was carried out by the accredited testing laboratory of Zarechnoye Agricultural Experimental Station LLP.

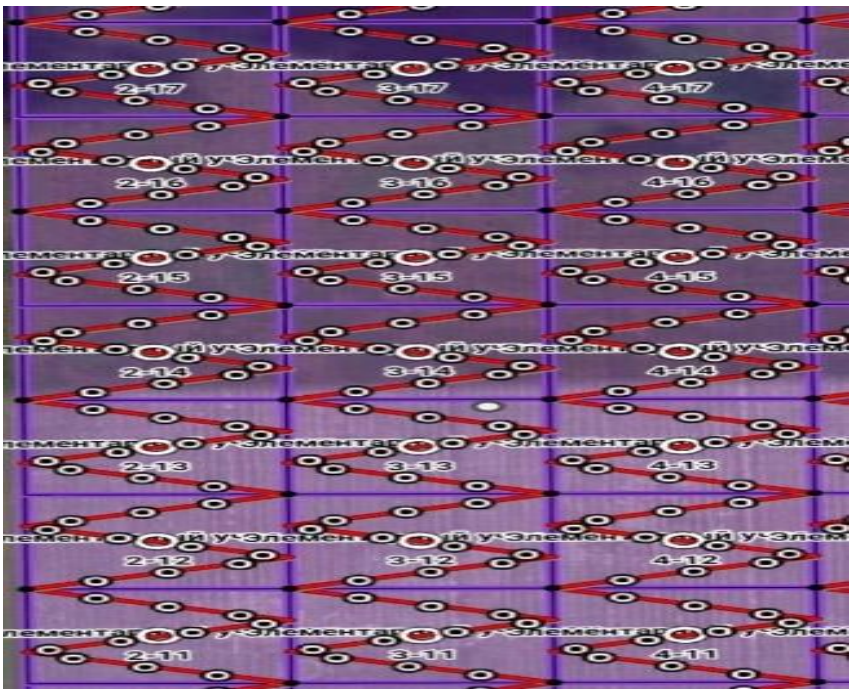

Fig. 1. Schematic map of soil sampling showing 5-ha elementary plots, Troyana LLP

To assess the initial soil condition before sowing in terms of the main mineral nutrients, the contents of nitrate nitrogen ($N\text{-}NO_3$), available phosphorus (P_2O_5), exchangeable potassium (K_2O), available sulfur (S), and humus in the 0-30 cm layer were determined. The analysis results are presented in Table 1.

Table 1. Content of major nutrients in the 0-30 cm soil layer before sowing spring wheat.

Field/ plot	$N\text{-}NO_3$	Availability	P_2O_5	Availability	K_2O	Availability	S	Availability	Humus (%)	Level
U.2-11	4.9	very low	71	medium	380	very high	7.1	medium	4.64	medium
U.2-12	<2.8	very low	76	medium	310	very high	4.3	low	4.36	medium
U.2-13	<2.8	very low	63	medium	264	very high	6.1	medium	4.55	medium
U.2-14	6.5	low	96	medium	264	very high	19.2	very high	4.73	medium
U.2-15	5.6	low	48	low	257	very high	6.8	medium	4.51	medium
U.2-16	8.7	low	65	medium	244	very high	14.0	high	5.27	medium
U.2-17	4.0	very low	66	medium	287	very high	5.9	low	4.61	medium
U.3-11	5.4	low	71	medium	191	very high	6.6	medium	4.35	medium
U.3-12	4.0	very low	72	medium	165	high	7.6	medium	4.38	medium
U.3-13	3.5	very low	70	medium	347	very high	4.4	low	4.85	medium
U.3-14	5.9	low	69	medium	372	very high	5.8	low	4.59	medium
U.3-15	<2.8	very low	56	medium	353	very high	5.3	low	4.88	medium
U.3-16	4.7	very low	70	medium	384	very high	9.7	elevated	5.19	medium
U.3-17	4.2	very low	66	medium	335	very high	5.9	low	4.90	medium
U.4-11	5.2	low	65	medium	337	very high	7.8	medium	4.68	medium
U.4-12	5.2	low	70	medium	387	very high	5.8	low	4.76	medium
U.4-13	5.2	low	67	medium	403	very high	4.3	low	4.90	medium
U.4-14	4.2	very low	55	medium	365	very high	7.2	medium	5.04	medium
U.4-15	4.8	very low	52	medium	322	very high	5.7	low	4.80	medium
U.4-16	5.5	low	56	medium	443	very high	9.0	elevated	5.15	medium
U.4-17	5.9	low	67	medium	458	very high	13.5	high	4.93	medium
V	27.8		14.7		22.8		46.8		5.5	

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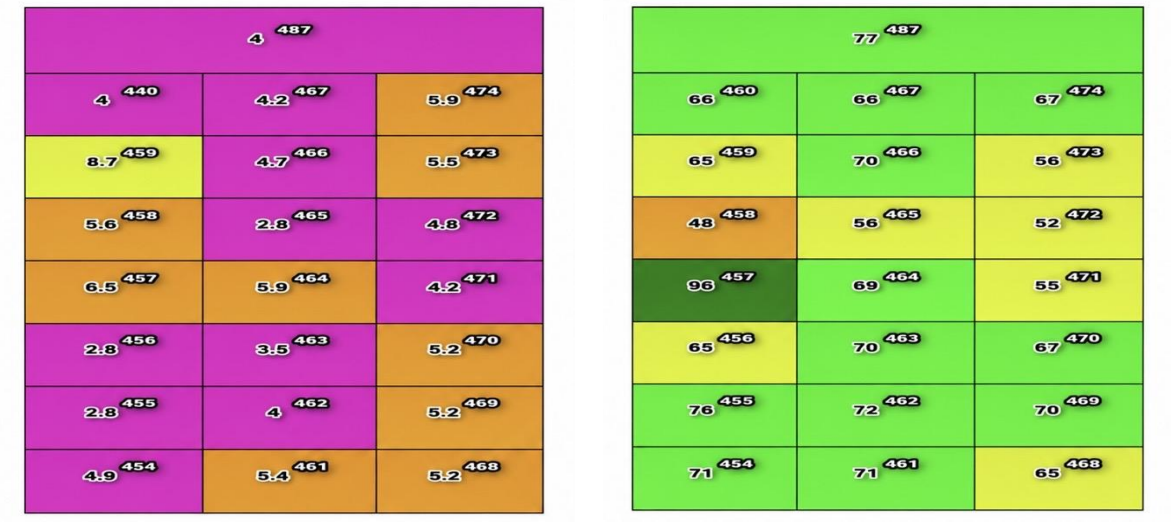
Analysis of the obtained data revealed a deficiency of nitrate nitrogen in the soil; therefore, all subsequent work was aimed at increasing the availability of this element. According to agrochemical analyses, before sowing spring wheat the soil had low nitrate availability ranging from 2.8 to 8.7 mg kg^{-1} of soil in the 0-30 cm layer.
When evaluating the content of available phosphorus in the soil, it should be noted that only 4.8% of the plots had low availability, less than 50 mg kg^{-1} of soil, while the remaining plots had medium availability (Fig. 2).



Distribution map of nitrate nitrogen (mg kg^{-1}). Distribution map of available phosphorus (mg kg^{-1}).

Fig. 2. Digital nutrient availability map in Troyana LLP.

The content of exchangeable potassium in all plots was characterized as very high, meaning that there were no issues with soil availability of this element.
Interesting results were also obtained regarding the content of available sulfur compounds. Sulfur content in 43% of the plots ranged from 4.3 to 5.9 mg kg^{-1}, indicating low availability. The remaining 57% of the study area showed medium to high sulfur availability.
An agrochemical survey at Troyana LLP led to a digital map of nutrient availability for 100 ha before sowing spring wheat. This map guided the agri-navigator's technical assignment, enabling differentiated fertilizer application with control zones for each nutrient level. Consequently, mineral nitrogen fertilizer application rates were calculated (Fig. 3).

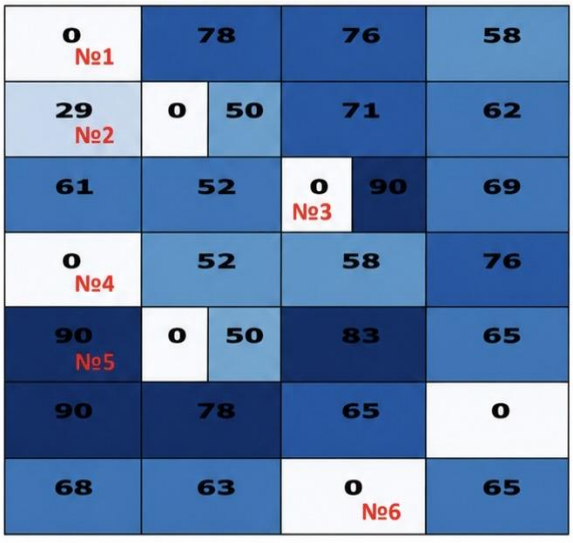


Fig. 3. Schematic map of differentiated fertilizer application with selected control zones for each level of $N\text{-}NO_3$ availability, polygon area 105 ha.

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Our research demonstrates that effective differentiated fertilizer application necessitates more precise mapping of within-field soil fertility variations. This enables the development of a mineral nutrition plan that optimizes plant productivity. We found that within a single field, zones with varying levels of humus, available phosphorus, exchangeable potassium, and available sulfur compounds are unevenly distributed.

During remote sensing of the Earth using satellite images in the experimental field of Troyana LLP, heterogeneity in the distribution of NDVI values was identified (Fig. 4).

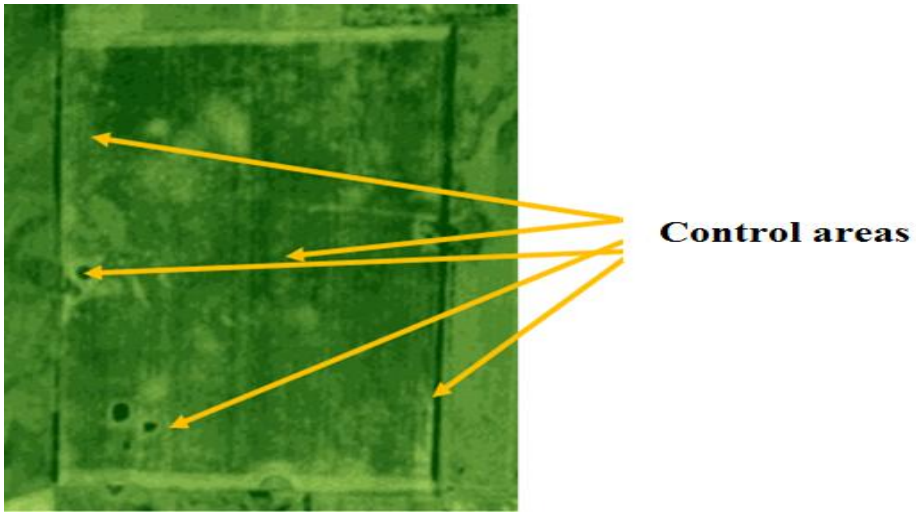

Fig. 4. Assessment of NDVI using remote sensing data.

During the growing season, spring wheat biomass was optimal, with the best plant development observed in nitrogen-fertilized treatments (Fig. 4).

Morphometric parameters at Troyana LLP (Fig. 5) showed that nitrogen fertilizer at 42 kg active ingredient resulted in taller plants (8 cm more than control), a more developed secondary root system, and wider leaf blades, positively impacting yield.

Similar trends were seen in other nitrogen-fertilized treatments. Average spring wheat yield was assessed based on nutrient availability and mineral fertilizer treatments in 2020 (Table 2).

The N_{13} treatment achieved the highest yield at 2.76 c ha^{-1} (a 0.34 c ha^{-1} increase), followed by N24 at 2.70 c ha^{-1} (a 0.17 c ha^{-1} increase), despite both treatments having low nitrate nitrogen availability in the soil.

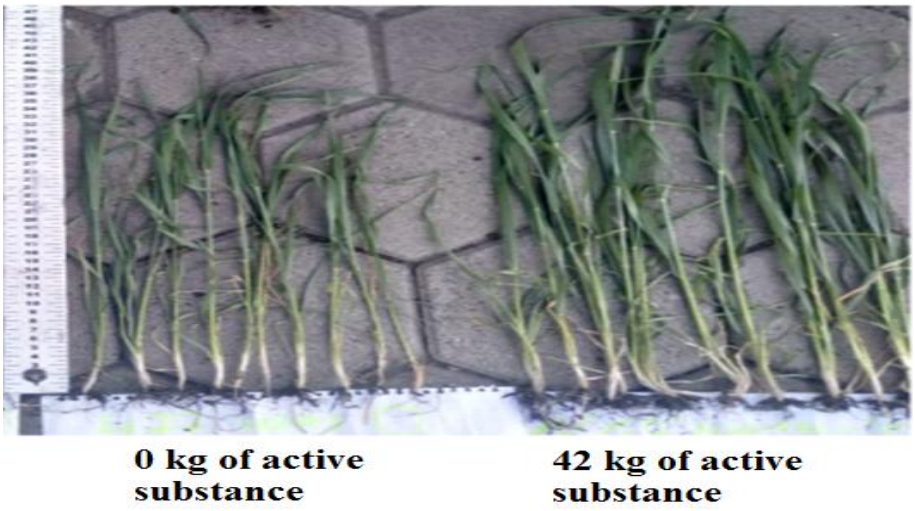

Fig. 5. Intermediate assessment of morphometric indicators when studying the effectiveness of differentiated mineral fertilizer application techniques at Troyana LLP, in 2020.

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Table 2. Spring wheat yield in 2020.

Plot No.	Treatment	Average yield (c ha^{-1})	Yield increase (c ha^{-1})
1	Control	22.4	–
	N_{36}	24.9	2.5
2	Control	24.2	–
	N_{13}	27.6	3.4
	N_{23}	26.9	2.7
3	Control	20.3	–
	N_{23}	21.5	1.2
	N_{42}	23.5	3.2
4	Control	25.3	–
	N_{24}	27.0	1.7
5	Control	16.0	–
	N_{23}	17.6	1.6
	N_{42}	22.8	6.8
6	Control	19.4	–
	N_{30}	20.3	0.9

The maximum yield increase of spring wheat relative to the control was obtained in Plot No. 5 – 0.68 c ha^{-1} with pre-sowing application of nitrogen fertilizer at 42 kg active ingredient.

At the next stage of the study, yield was determined in the experimental field treatments using the yield mapping system of a Case combine harvester (Fig. 6).

Fig. 6 clearly shows that in the control treatment most of the elementary accounting points are colored orange and light shades, corresponding to lower yield, whereas in the fertilized treatment many points are colored green, corresponding to higher yield. Distinct boundaries between treatments and a more uniform color distribution within the nitrogen-fertilized polygon should also be noted. According to the analysis of the obtained data, the average yield in the unfertilized area was 2.24 c ha^{-1}, while in the treatment with the application of 36 kg ha^{-1} active ingredient of urea fertilizer it was 2.49 c ha^{-1}. Therefore, the yield increase from fertilizer application amounted to 0.25 c ha^{-1}.

For further evaluation, grain quality indicators of spring wheat were also studied (Table 3), which made it possible to assess the key economic indicator.

Table 3 shows that the highest grain quality class was obtained in the sixth assessment plot, where mineral fertilizer was applied at the N_{30} rate. The lowest grain quality indicators, corresponding to the fourth class, were obtained in Plot No. 2 – both the control and N_{13} treatments, which is associated with higher yields in these treatments and, accordingly, greater nutrient removal.

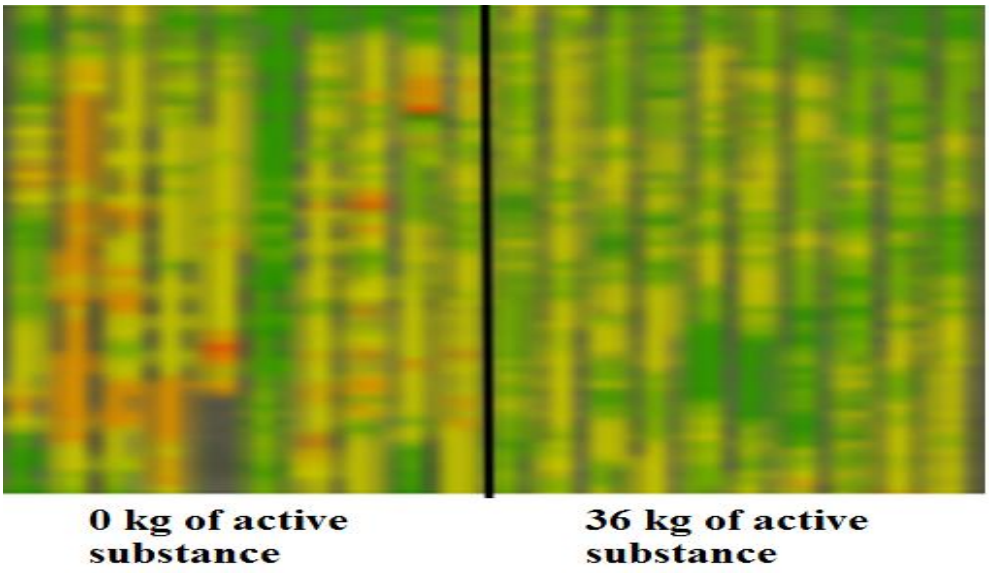

Fig. 6. Yield mapping results using a Case combine harvester.

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Table 3. Wheat grain quality indicators in 2020.

Plot No.	Treatment	Protein (%)	Gluten (%)	Test weight (g L^{-1})	Quality class
1	Control	15.1	29.3	743	II
	N_{36}	16.2	32.3	766	I
2	Control	12.4	19.9	779	IV
	N_{13}	13.3	22.3	755	IV
	N_{23}	14.2	25.3	763	II
3	Control	13.9	24.5	757	III
	N_{23}	14.2	25.0	772	III
	N_{42}	15.9	30.9	758	I
4	Control	13.4	23.0	766	III
	N_{24}	15.3	28.7	771	I
5	Control	14.6	29.0	775	I
	N_{23}	16.1	30.8	756	I
	N_{42}	16.9	33.8	747	II
6	Control	14.9	27.9	748	II
	N_{30}	16.8	34.1	770	Premium

CONCLUSION

The main result of crop cultivation, as is well known, is always assessed at harvest and is ultimately determined by production profitability. Therefore, economic indicators affecting profitability were calculated for the main treatments.

When assessing the economic efficiency of spring wheat production, treatments No. 1, No. 2, and No. 4 should be noted. These treatments showed the highest profit from spring wheat grain production, with production profitability ranging from 316.0% to 374.6%. The lowest profitability was observed in treatment No. 5, where profitability ranged from 217.5% to 226.4%.

Thus, the conducted studies prove the effectiveness of applying scientifically justified nitrogen nutrition rates under the conditions of Northern Kazakhstan.

Practical application

The research results are of practical importance for teachers of higher educational institutions, researchers, managers and specialists of peasant farms and other agricultural enterprises.

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