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NITROGEN FERTILIZERS ROLE IN GRAIN CROPS PRODUCTIVITY IN SOUTH-EAST KAZAKHSTAN

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SUMMARY

Seeking to improve the efficiency of nitrogen fertilizers for grain crops led to conducting this study on developing methods using 15N in 2015–2017 at the Kazakh Research Institute of Agriculture, Almalybak Village, Almaty Region, Southeastern Kazakhstan. Nitrogen use efficiency using the stable isotope 15N in microfield experiments revealed that the assimilation of nitrogen fertilizers by grain crops largely depends on the norms, timing, fertilization method, and varietal parameters of the concerned crop. Based on morphophysiological methods of monitoring plant development conditions, the nitrogen fertilizers' role based on the development has been affirmative, with the optimal timing of their application also determined. Results show that grain crops use nitrogen productively with partial application at the beginning of tillering and tubing, respectively, and stages III and V of organogenesis. With the use of nitrogen fertilizers, the significant varietal differences were evident. The help of an isotope label established the accurate nitrogen utilization coefficients of fertilizers based on the options ranging from 14.7% to 32.2%. Using the isotope method provides an opportunity for further development of practicing the most efficient techniques of applying fertilizers, which is an imperative method for determining the effectiveness of nitrogen fertilizers.

Keywords: grain crops, microfield experience, stable nitrogen isotope, light chestnut soil, morphophysiology, utilization factor

Key findings: The effect of nitrogen fertilizers on the plant height of grain crops planted on light chestnut soils of Southeast Kazakhstan was distinguishable by a low level of natural fertility. The help of morphophysiological observation methods determined the reasonable period needing nitrogen through nitrogen fertilizers by grain crops nitrogen fertilization. With the help of a stable isotope ^{15}N, the coefficients of nitrogen use from fertilizers (11.7%–31.7%) attained establishment, which vary based upon the time and methods of application and the varietal characteristics of the grain crops.

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INTRODUCTION

Nitrogen is a primary component of the chlorophyll molecule, enabling the plant to capture sunlight energy by photosynthesis for plant growth and grain yield. Nitrogen is also critical within the plant to ensure energy availability and where the plant needs it to optimize harvests. Back in the last middle century, based on agriculture development in Western Europe, past findings enunciated that the chief condition determining an average plant height in different eras was the nitrogen supply to crop plants (Pryanishnikov, 1965). In Southeast Kazakhstan, a broader part of the arable land was characteristic of a low level of natural fertility, and yet, the area is necessary for agricultural use. These soils were also usable in developing new high-yielding varieties and hybrids and disseminating modern, advanced technologies. These processes have covered various countries worldwide, and as a result, the average global yield of grain crops by the beginning of the new century crossed the threshold of 3.0 t/ha, and in advanced European countries widely engaged in the strategy of crop productivity management, reached 8.0 t/ha. Therefore, it was noteworthy that in these countries, the yield level directly depended on the fertilizer intensity (Mineev and Bychkova, 2000).

The use of modern high-precision methods is increasing to assess the effectiveness of various modes of fertilizer application, including isotopic nitrogen indication (Utebayev *et al.,* 2022; Kushanova *et al*., 2023; Makenova *et al.,* 2023). Thanks to the help of nitrogen-containing compounds with a heavy isotope, it became possible to determine the absolute size of nitrogen consumption from fertilizers by plants and its share in forming the crop (Turchin, 1964; Korenkov, 1975; Smirnov and Kidin, 1980). It made it possible to regulate the fertilizer doses and their application timing considering the soil fertility and planned yield. It has been customary that as the timing of nitrogen fertilizers' application approaches the period of maximum crop demand, the effectiveness of nitrogen fertilizers significantly intensify due to synchronization of their application in time with crop need (Andreeva and Shcheglova, 1966; Korenkov and Lavrova, 1973; Smirnov, 1973; Smirnov *et al*., 1979; Tilman *et al*., 2002; Kidin *et al.*, 2009; Vernichenko, 2010; Zavalin and Sokolov, 2016).

For a specific agroclimatic region, employing biological methods determined the critical period of crop demand for nitrogen fertilizers based on the obtained data, technologies for the fertilizer use gained development during the plants' demand period (Patnaik, 1965; Zadoks *et al*., 1974; Kuperman *et al*., 1980; Fuertes-Mendizábal *et al.*, 2013; Wallace *et al.*, 2020). Using the stable isotope of nitrogen 15N, it was also noticeable that with fractional application, plants highly used nitrogen fertilizers valuably than with one-time application. Therefore, a single high-dose fertilizer application is not only a fertilizer waste but also reduces the grain yield. With the introduction of increasing rates of fertilizers labeled by a stable nitrogen isotope in the prescribed time, an adequate increase in plants' nitrogen content, grain yield, grain protein, and an enhanced nitrogen utilization rate of fertilizers were evident. Therefore, it is crucial to note that nitrogen fertilizer application needs integration with the crop need for nitrogen at this particular time (Haile *et al*., 2012; Zhao *et al*., 2015; Chen *et al*., 2016; Fuertes-Mendizábal *et al*., 2018).

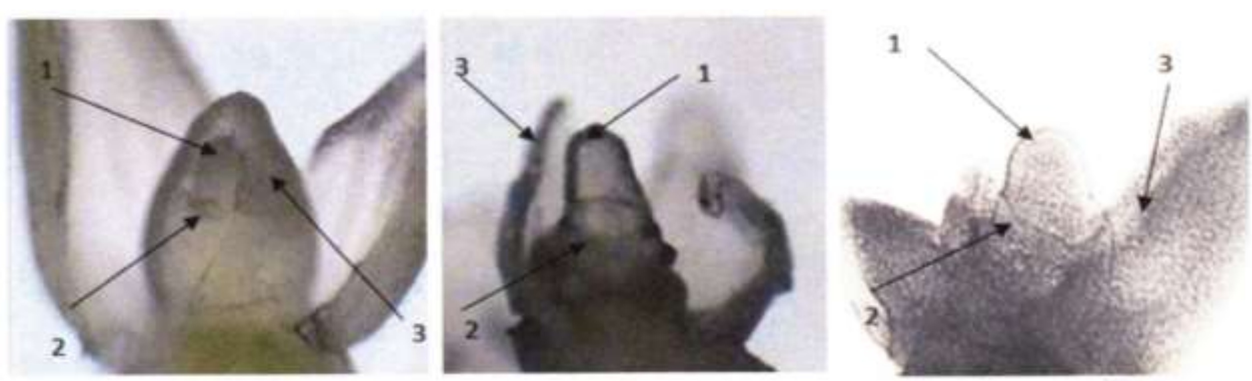
During the research, the implementation of morphophysiological methods observed the growth and development of plants. All plant types have patterns and sequences of organ-forming processes common to the genus and family. With significant differences in the organogenesis of life form structures, there were characteristics of surprising uniformity. In the life cycle of grain crops, there are 12 stages of organogenesis, at which specific organs develop. When conducting systematic observations of the formation of organs, elements of productivity, and scientifically based and timely technological operations, it is possible to purposefully stimulate the crop plants' growth, development, and productivity (Kuperman, 1977; Kuperman *et al.,* 1980).

In the presented study, using nitrogen fertilizer labeled by 15N allowed scientists to determine the nitrogen role in the formation of grain crops in South and Southeast Kazakhstan, to establish the accurate coefficients of nitrogen fertilizer use and to assess the varietal differences. The pertinent study presents some past findings of authors' long-term research on the investigation of the effectiveness of nitrogen fertilizers applied to cereals, carried out using 15N labeled fertilizers (Petinov and Brovtsina, 1963; Nichiporovich, 1972; Ramazanova, 1982; Kenenbaev *et al*., 2008a, b; Ramazanova *et al*., 2023).

Tapping isotopic indication and morphophysiological research methods, it was also visible that the maximum number of productivity elements of grain crops emerged after nitrogen fertilizers application before the differentiation of the main axis of the rudimentary inflorescence began. Nitrogen fertilizers applied during this period stimulate the laying of twigs and flowers – the primary elements of the potential productivity of grain crops (Ramazanova, 1982; Kenenbaev *et al*., 2008a, b; Ramazanova *et al*., 2023).

The formation of crop yields closely depended on the leaves' surface assimilation area, duration, and productivity (Nichiporovich, 1972; Ramazanova, 1984). In grain crops, stem leaves are not equivalent in their participation in forming the grain harvest. The leading role in this process belongs to the two upper flag leaves, younger and physiologically active, with high-intensity rates and productivity of photosynthesis, as well as, the rate of assimilated outflow into the forming grains (Petinov and Brovtsina, 1963).

The related studies have established an increase in the assimilation surface of the grain crops' leaves, mainly of the upper tier, when applying nitrogen fertilizers at the beginning of stage III of organogenesis compared with their application before and after the specified period. Notably, after laying off the penultimate sub-flag and the last flag leaves, the growth cone (a) stretches, increases in size, and proceeds to the differentiation of the main axis of the rudimentary inflorescence. The rudiment of the last leaf – flag is in this period in the phase of the roller-collar primordia (b), and the rudiment of the penultimate leaf-pod flag in the stage of the cap primordia (c) (Figure 1).



Almaly wheat variety | Arna barley variety | Rice variety Kuban 3

Designations: 1. the rise of the cone; 2. the rudiment of the last sheet of the flag; 3. the rudiment of the sub-flag sheet.

Figure 1. The cone of grain crops growth at the beginning of stage III of organogenesis, before differentiation of the main axis of the rudimentary inflorescence according to the scale of Kuperman *et al*. (1980).

The assimilation surface of the two upper leaves of the main shoot, fertilizing at the third stage of organogenesis, ranged in rice varieties (46.6–47.2 cm^2), in winter wheat at earing phase (59.7–62.0 cm^2) and exceeded that options with an application of nitrogen fertilizers before and after this period in rice (1.1–1.7 times) and winter wheat (1.5–2.4 times). An increase in the assimilation surface associated with the large size of the upper leaves contributes to a better supply of the panicle and ear with assimilates, increases the number of grains, and provides higher grain yield (Kenenbaev *et al*., 2008a, b). However, when applying nitrogen fertilizers at the fifth stage of organogenesis of grain crops (the phase of entering the tube), a decrease in dying (reduction) and an increase in the preservation of already laid elements of grain yield occurred (Zhao *et al*., 2015). The presented study hopes to develop techniques for improving the efficiency of nitrogen fertilizers used for grain crops using 15N.

MATERIALS AND METHODS

This study ran in 2015–2017 at the Kazakh Research Institute of Agriculture (Almaty Region, Almalybak Village), Southeastern Kazakhstan. Microfield experiments laid out in bulk vessels without a bottom had a volume of 20.5 cm × 20.5 cm, with a capacity of 11 kg of soil. Soil from the field available from the Kazakh Research Institute of Agriculture and Crop Production filled the vessels. During vessel filling, a simultaneous application of phosphorus-potassium fertilizers transpired. Introducing ammonium nitrate (N30) labeled in ammonium form ensued before sowing. During the growing season, adding N60 to the top dressing followed at the beginning of stage III (tillering phase). N30 introduction was at the fifth stage (exit phase into the tube) on the Kuperman scale (1977). The ammonium nitrate introduced had 15NH4NO3 with an initial enrichment of 20 atomic%. The scheme of experiments is available in the tables. Agrochemical indicators of light chestnut soil were characteristic of a slightly alkaline reaction of the medium, low humus content (2.74% ± 0.06%), alkaline hydrolyzable nitrogen (57.4.7 ± 13.5mg/kg), average content of mobile phosphorus (29.8 ± 0.85mg/kg), and a high content of exchangeable potassium (602.0g ± 12.5mg/kg).

Domestic zonal wheat cultivars, i.e., Almaly, Kazakhstanskaya 10, and newly developed cultivars, viz., Matai and Arap, were samples studied. The analysis of the above-ground part of plants (grain, straw) for nitrogen content and its enrichment with the 15N isotope started on the DELTA-V Advantage isotope mass spectrometer in the laboratory of nitrogen fertilizers of the D.N. Pryanishnikov All-Russian Research Institute of Agrochemistry. In plants (grain and straw), the total nitrogen determination used the Kjeldahl method. Identifying the agrochemical parameters of the soil ran according to generally accepted approaches, i.e., humus by Tyurin, alkaline hydrolyzable nitrogen by Cornfield, and mobile phosphorus and exchangeable potassium by Machigin (Mineev, 2001).

According to years of research and based on climatic and meteorological conditions, the research area has a continentality characteristic, with daily fluctuations in air temperature. The average annual precipitation was 414.4 mm, with a maximum in spring (about 200 mm), while the average yearly air temperature was +7.5 °C. In study years, the meteorological conditions differed somewhat from the long-term average data. During the autumn-winter period of 2015–2016, precipitation was 1.7 times more in 2016–2017 (2.6 times) compared with the long-term data. The temperature in the spring period was characteristic of an excess of the average daily air temperature in April by 3.1 °C and in May by 0.2 °C. Generally, the prevailing meteorological conditions over the years of research were favorable for the growth and development of winter wheat.

Statistical analysis

The statistical analysis and its further compilation proceeded according to Dospekhov (1985) to determine the significant differences among the doses of nitrogen fertilizers and the wheat cultivars yield.

RESULTS AND DISCUSSION

The use of labeled fertilizer made it possible to determine the nitrogen role in forming winter wheat grain yield to show varietal differences and recognize the exact coefficients of its use under the environmental conditions of Southeast Kazakhstan. Microfield experiments proceeded during the fall of 2015. The scheme of the trial included options with applying nitrogen fertilizers before sowing (15N30) and in top dressing at the beginning of the third (15N60) and fifth (15N30) stages of organogenesis according to the scale of Kuperman (1977).

Before leaving for winter, the collected plant samples from all the experimental variants underwent analysis to determine the content and consumption of total nitrogen and stable isotope 15N by winter wheat plants. An observation showed the winter wheat plants utilized according to the experimental variants ranging from 9.0–12.6 mg/vessel of total nitrogen, including labeled nitrogen ranging from 1.8–3.5 mg/vessel. The total amount of nitrogen the plants used, the share of isotope-enriched nitrogen, reached 19.6%–27.5%. The coefficient of nitrogen use of fertilizers applied before sowing was 1.3%–2.6% of the applied dose. However, the maximum amount of nitrogen fertilizer usage resulted from the plants of the newly developed winter wheat cultivar Matai (Table 1).

By the full ripening phase, the biomass of cultivar Almaly in the variant without nitrogen fertilizers was 51.7 g/vessel; however, after applying nitrogen fertilizers, it increased to 57.9–91.9 g/vessel. Grain yield was 21.1 g/vessel on the variant without nitrogen fertilizers, and in the variants with nitrogen fertilizers, it rose to 23.4–36.9 g/vessel. At the same time, the total nitrogen removal increased by 45.0%–97.0%, depending on the norm, time, and method of applying nitrogen fertilizers (Table 2).

According to the experimental variants, the total amount of labeled nitrogen fertilizers applied to the wheat plants varied from 14.7 to 104.1 mg/vessel. However, fertilizer efficiency depends on the norms, timing, and application method. By applying N30 before sowing winter wheat, no reliable increase occurred in the wheat grain yield. The nitrogen fertilizers applied in the autumn had winter wheat plants used only 14.7 mg/vessel of labeled nitrogen (Table 2). With an increased nitrogen fertilizer application rate, the winter wheat plants' total nitrogen consumption enhanced by 45.0%–97.0%. Grain accounted for up to 83.0%–85.9% of fertilizer nitrogen (^{15}N) supplied to plants (Table 2).

The nitrogen utilization coefficient of fertilizers, established using an isotope label (15N), fluctuated according to the experimental variants ranging from 11.7% to 27.6% and was maximum when adding 2/3 of the nitrogen norm to the top dressing at the tillering stage and 1/3 in the tubing phase at the third and fifth stages of organogenesis, according to Kuperman (1977). In the 2017 experiments, in wheat cultivar Almaly, applying N30 onto the top dressing at the beginning of the tillering phase (at stage III of organogenesis) proved more effective. The accumulation of total biomass with the influence of nitrogen fertilizers increased by 25.0%, and the grain yield was 29.3 g/vessel, with 24.3 g/vessel in the variant without nitrogen fertilizers. Hence, a reliable increase appeared in wheat grain yield (Table 3).

The total nitrogen uptake by winter wheat plants improved by 38.6% compared with the option without nitrogen fertilizers. The amount of nitrogen fertilizers used by plants was 26.5 mg/vessel, with 68.3% accounting for the formation of grains. The nitrogen utilization rate of fertilizers was 20.8% (Table 3). With an increase in nitrogen fertilizer application and their fractional applications, the accumulation of biomass by winter wheat plants increased, and the grain yield rose by 45.7% compared with the control (without nitrogen fertilizers). Concurrently, the total nitrogen uptake was 828 mg/vessel, with the nitrogen obtained from fertilizers was 81.2 mg/vessel, with 64.8% accounting for grain formation. The nitrogen utilization rate of the fertilizers was 21.5% (Table 3).

Table 1. Winter wheat cultivars' use of fertilizers labeled with 15N nitrogen applied before sowing during 2015.

Options	Cultivars	Plant biomass (g/vessel)	Nitrogen removal (mg/vessel)		KIU* (%)
			General N	Nitrogen fertilizers, ^{15}N	
N30-before sowing	Almaly	0.208	9.0±0.65	1.8±0,30	1.4
	Matai	0.300	12.6±0.73	3.5±0,92	2.8
	Arap	0.250	10.9±0.86	2.3±0,27	1.8

*- fertilizer utilization rate

Table 2. Nitrogen consumption of fertilizers by winter wheat cultivar Almaly depending on the time and method of application during 2016.

Options	Biomass (g/vessel)	Yield (g/vessel)		General uptake of N (mg/vessel)	Plant consumption ^{15}N (mg/vessel)		KIU* (%)
		Grains	±		in total	grain	
RK- background	51.7	21.1	-	506	-	-	-
N30 - before sowing	57.9	23.4	2.3	734	14.7	12.2	11.7
N30 + N60 III stage	69.4	27.3	6.2	759	78.7	68.0	20.8
N60III+ N 30 V stage	91.9	36.9	15.9	997	104.1	89.4	27.6
NSR_{05}			5.2				
$S_{x\ \%}$			4.6				

*- fertilizer utilization rate

Table 3. Nitrogen consumption of fertilizers by winter wheat cultivar Almaly based on the norms and method of application during 2017.

Options	Biomass (g/vessel)	Grain yield (g/vessel)		General uptake of N (mg/vessel)	Plant consumption ^{15}N (mg/vessel)		KIU* (%)
		Seed	±		in total	grain	
RK- background	65.9	24.3	-	648	-	-	-
N30. Stage III	82.4	29.3	5.0	898	26.5	18.1	20.8
N30 p/pic + N 60 stage III	91.7	35.4	11.1	828	81.2	52.6	21.5
NSR_{05}			4.0				
$S_{x\%}$			4.5				

*- fertilizer utilization rate

The introduction of N60 in the top dressing proved effective in the winter wheat cultivar Kazakhstanskaya 10. The biomass accumulation in the variant without fertilizers was 52.6 g/vessel, and the grain yield was 20.2 g/vessel. With the influence of nitrogen fertilizers applied against this background, plant biomass increased by 74.9%–96.45%, and grain yield enhanced by 65.9%. The total uptake of nitrogen increased by 1.7 times. The nitrogen fertilizers used by winter wheat plants were 55.2 mg/vessel, utilizing 70.5% for grain formation. The nitrogen utilization rate of the fertilizers was 21.9%.

An increase in the application of nitrogen fertilizers and their fractional options - at the third and fifth stages of organogenesis - proved the most effective. However, an upsurge was evident in the total plant biomass, grain yield, and nitrogen consumption from fertilizers. The nitrogen utilization rate of fertilizers was high, amounting to 27.4% (Table 4). It is also a fact that each wheat cultivar has a particular specificity of nitrogen consumption of the fertilizers. The study of varietal characteristics of mineral nutrition of plants provides for the reaction of the genotype to fertilizers according to the type of

Table 4. Nitrogen consumption of fertilizers by winter wheat cultivar Kazakhstanskaya 10 based on the norms and method of application during 2017.

Options	Biomass (g/vessel)	Grain yield (g/vessel)		General Uptake of N (mg/vessel)	Plant consumption ^{15}N (mg/vessel)		KIU* (%)
		Seed	±		in total	Grains	
PK- background	52.6	20.2	-	433	-	-	-
N60 III Stage	92.0	33.5	13.3	740	55.2	38.9	21.9
N60III Stage +N 30V Stage	103.3	38.5	18.3	977	103.8	68.6	27.4
HCP_{05}			3.7				
$S_{x\%}$			3.0				

*- fertilizer utilization rate

Table 5. Nitrogen consumption of fertilizers by various winter wheat cultivars during 2016.

Options	Biomass (g/vessel)	Grain yield (g/vessel)	Total uptake of N (mg/ vessel)	Used by plants ^{15}N (mg/vessel)		KIU* (%)
				in total	Grains	
Winter wheat Almaly variety						
N30 before sowing + N 60 stage III	69.4	27.3	759	78.7	68.0	30.1
Winter wheat Matai variety						
N30 before sowing + N 60 stage III	102.9	39.9	1170	118.3	94.1	31.3
Winter wheat Arap variety						
N30 before sowing + N 60 stage III	111.3	45.3	1230	122.6	92.2	32.2

*- fertilizer utilization rate

growth, the nature of use, the distribution of nutrients by organs, and the size and quality of the crop (Klimashevsky, 1984; Vose, 1984).

In the presented study, using the 15N-labeled ammonium nitrate allowed researchers to establish the varietal features of fertilizer nitrogen consumption during crop formation and determine the exact coefficients of its use. The results showed that winter wheat varieties used nitrogen fertilizers differently and effectively. The zonal wheat cultivar Almala grain yield was 69.4 g/vessel after applying N30 before sowing and N60 in the tillering phase (stage III of organogenesis). The total nitrogen uptake was 759 mg/vessel. Nitrogen uptake of the fertilizers 15N was 78.7 mg/vessel, with 86.4% utilized by grains and 14.0% by wheat straw. The nitrogen utilization rate of fertilizers was 20.8% (Table 5).

Against the same background, the grain yield of newly developed wheat cultivars Matai and Arap exceeded the wheat zonal cultivar Almaly by 46.2%–65.9%. The coefficient of nitrogen use of fertilizers in the zonal wheat cultivar Almaly was 20.8%, while in the newly developed wheat cultivars (Matai and Arap), the values were 33.3% and 32.4%, respectively. However, the portion of nitrogen use of fertilizers by the commercial part of the plants of the zonal cultivar was higher (86.4%); but, in the newly developed cultivars, Matai and Arap, the values were 79.5% and 75.2%, respectively.

CONCLUSIONS

Application of nitrogen fertilizers labeled by the stable nitrogen isotope 15N to the soil depended on the norms, timing, application methods, and varietal characteristics to enhance the winter wheat yield by 11.7% to 33.1%. The introduction of nitrogen fertilizers stimulates the development of plant biomass and promotes greater consumption of nutrients, leading to an increased grain yield in winter wheat. Nitrogen fertilizers applied at the beginning of stage III of organogenesis stimulate the development of leaves of the grain crops' upper tier and productivity elements. The high efficiency of nitrogen fertilizers has been successful by applying nitrogen fertilizers at the beginning of tillering and in the tubing phase. The efficiency of new winter wheat cultivars Matai and Arap with a high coefficient of nitrogen fertilizer use has also been affirmative.

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