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NITROGEN NUTRITION OF CROP PLANTS IN THE PRECISION FARMING SYSTEM IN THE SOUTH AND SOUTHEAST KAZAKHSTAN

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SUMMARY

South and Southeast Kazakhstan underwent soil nitrogen forecasting and diagnosing for nutrition to establish the requirement of nitrogen fertilizers for field crops. The study established the possible use of alkaline hydrolyzable nitrogen as an indicator to provide field crops with available soil nitrogen. Managing the soil organic matter more accurately as the main source of nitrogen helps determine the spatial and temporal variability of its content in each specific field and to use a narrower (oriented to the prevailing soil types) scale of humus availability. The recent studies began in several stages, during 2014–2016, 2015–2017, and 2020–2021, on the irrigated light chestnut calcareous medium loamy non-saline and non-alkaline soil formed at the foothill loess plain of the Zailiyskiy Alatau, Kazakhstan. The nitrogen content of nitrates varied significantly over the years of research. In the control variants (without fertilizers), the recording of the minimum content of $N\text{-}NO_3$ took place in 2016 compared with 2014 and 2015. In two consecutive years (2020–2021), 2,816 ha of arable land underwent testing in Almaty, Zhambyl, and Zhetysu regions, Kazakhstan. A total collection of 1,015 soil samples went through analysis, revealing a close correlation between the content of humus and alkaline hydrolyzable nitrogen in the upper soil layer of 0-30 cm. The hydrothermal conditions from a long multi-factorial field experiment data largely affected the intensity of mineralization and immobilization processes of the available nitrogen compounds. The rational use of nitrogen fertilizers makes it possible to increase the field crop yield with good quality and enhance the payback of applied fertilizers, maintaining and improving soil fertility.

Keywords: Light chestnut soil, humus, alkaline hydrolyzable nitrogen, the need for nitrogen fertilizers, the planned harvest

Key findings: Rational use of nitrogen fertilizers and the determination of spatial and temporal variability of nitrogen fertilizer consumption fully control the state of provision of plants.

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INTRODUCTION

Precision agriculture is an approach to farm management that ensures soil and crops receive exactly what they need for optimum health and productivity (Tilman *et al*., 2011). The goal of precision farming centers on profitability, sustainability, protection of the environment, and optimizing returns on inputs while preserving resources (Whelan and McBratney, 2003; McBratney *et al*., 2005). Precision agriculture defines a farming management concept based on observing, measuring, and responding to inter and intra-field variability in crops. The first conceptual work on precision farming and its practical applications goes back to the late 1980s (Schnug and Haneklaus, 2006).

One of the fundamental components of precision farming consists of complete control over the state of provision of plants with mineral nutrition elements, which takes place both in the form of a periodic survey of the territories used and in the form of operational diagnostics of problem areas. Optimal soil nutrient provides effective sources fueling the crop plant's management activities, including growth and development and final yield. The most common concept of agricultural production today is based on 'equalizing' land use systems that do not take into account the spatial and sequential variability of the fertility factors of each specific field (Konstantinov, 2015; Bhat *et al*., 2018).

Mineral fertilizers are used in spring in calculated doses for the planned yield, depending on the agrochemical characteristics of the soils. An important condition for the effective use of mineral fertilizers is their differentiated application, taking into account the planned harvest and the level of soil fertility (Bastaubayeva *et al*., 2022). The content and transformation of nitrogenous compounds in the soil and their distribution by profile, in connection with the use of various doses and forms of fertilizers, need extensive study to establish a forecast of the effectiveness of nitrogen fertilizers and calculate their doses when planning yields in various soil and climatic conditions (Proberzh and Janis, 2008; Swailam *et al*., 2021).

Nitrogen is a mobile macronutrient in the soil and plant through its efficient application and management (Lea and Morot-Gaudry, 2001). Nitrogen, being a major component of the chlorophyll molecule and also found in nucleic acids and amino acids and component of protein and enzymes, enables the plant to capture sunlight energy by photosynthesis, motivating plant growth and grain yield (Masclaux-Daubresse *et al*., 2010; Leghari *et al*., 2016). Nitrogen serves as the primary limiting nutrient after carbon, hydrogen, and oxygen for the photosynthetic process, phytohormone and proteomic changes, and development in the growth of plants to complete their lifecycle and productivity in most cropping systems (Dilz, 1988; Socolow, 1999; Anas *et al*., 2020). Excessive and inefficient use of nitrogen fertilizer results in increased crop production costs, extreme vegetative growth and lodging, and atmospheric pollution (Zhu and Chen, 2002).

The diagnostics of the prerequisites of field crops with soil nitrogen and the prediction of their availability to determine the need for nitrogen fertilizers is the most complex, in contrast, to the soil diagnostics of phosphorus and potassium nutrition (Schimel and Bennett, 2004; Rochester *et al*., 2007). A reason consists of the high mobility of mineral nitrogen compounds and the impossibility, on their basis, of compiling not only long-term but also short-term (vegetation period) agrochemical cartograms (Gamzikov, 2000, 2013; Shafran, 2000). The research purpose seeks to establish the most effective method of soil diagnostics for nitrogen supply and determine the field crop requirements for nitrogen fertilizers in the environmental conditions of South and Southeast Kazakhstan.

MATERIALS AND METHODS

Study locations and procedure

The series of studies took place in several stages, during 2014–2016 (Figures 1, 2, and 3), 2015–2017 (Figure 4), and 2020–2021 (Figures 5 and 6), on the irrigated light chestnut calcareous medium loamy non-saline and non-alkaline soil, formed at the foothill loess plain of the Zailiyskiy Alatau, Kazakhstan. The Soil Science and Agro-Chemistry Laboratory, Kazakh Research Institute of Agriculture and Plant Growing, Almaty Region, Kazakhstan, mostly used the said area for long-term experiments. The establishment of the actual provision of soils with nitrogen and humus proceeded based on the random agrochemical survey of the three main types of soils, i.e., light chestnut, gray soils, and meadow-marsh, in South and Southeast Kazakhstan.

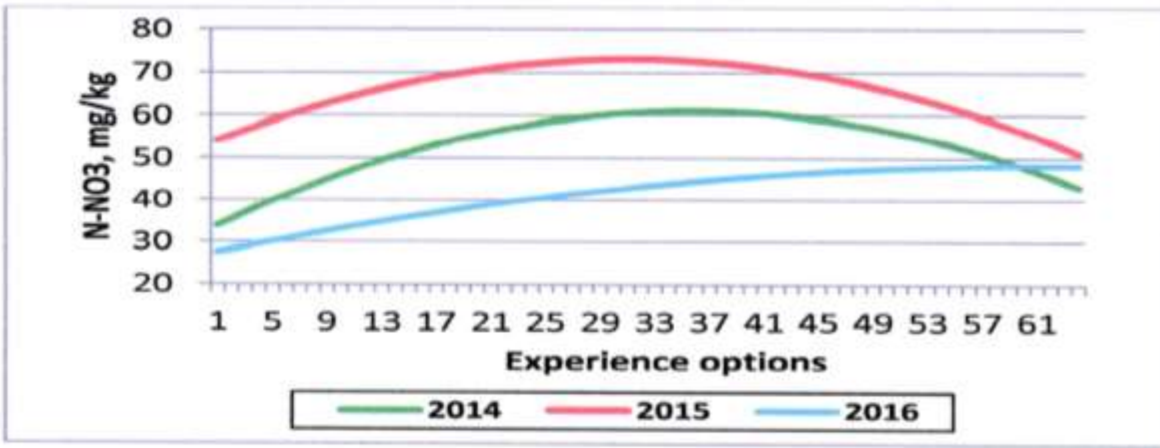

Figure 1. Average content of $N\text{-}NO_3$ in 0-30 cm soil layer in different years of research**.**

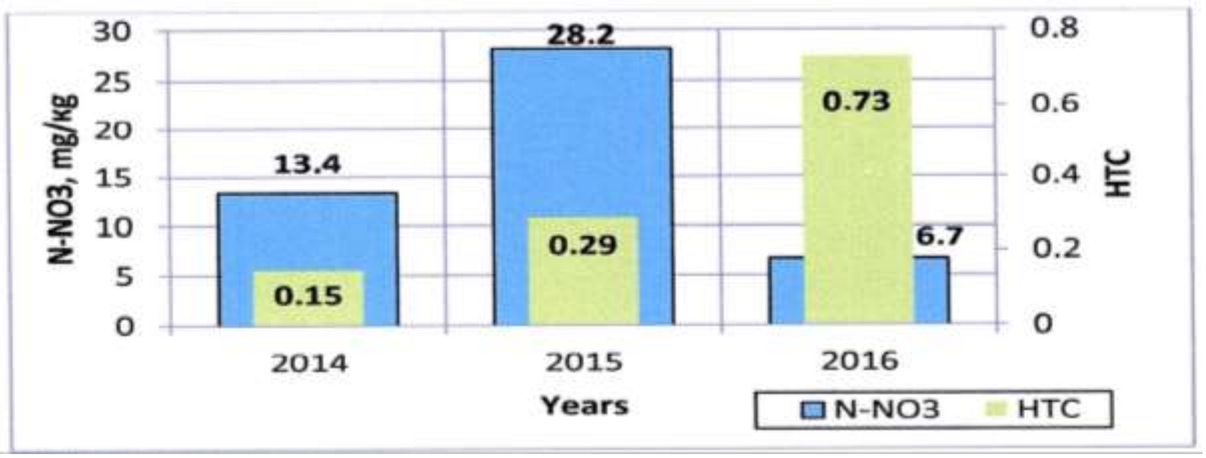

Figure 2. The value of the hydro-thermal coefficient and the nitrogen content of nitrates in 0-30 cm soil layer.

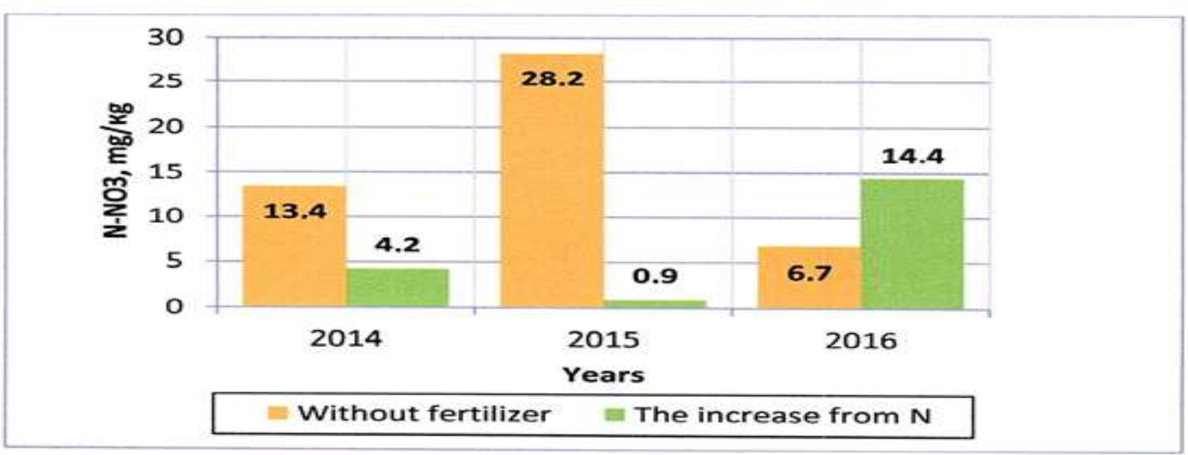

Figure 3. The effect of nitrogen fertilizers on the nitrogen content of nitrates in 0-30 cm soil layer.

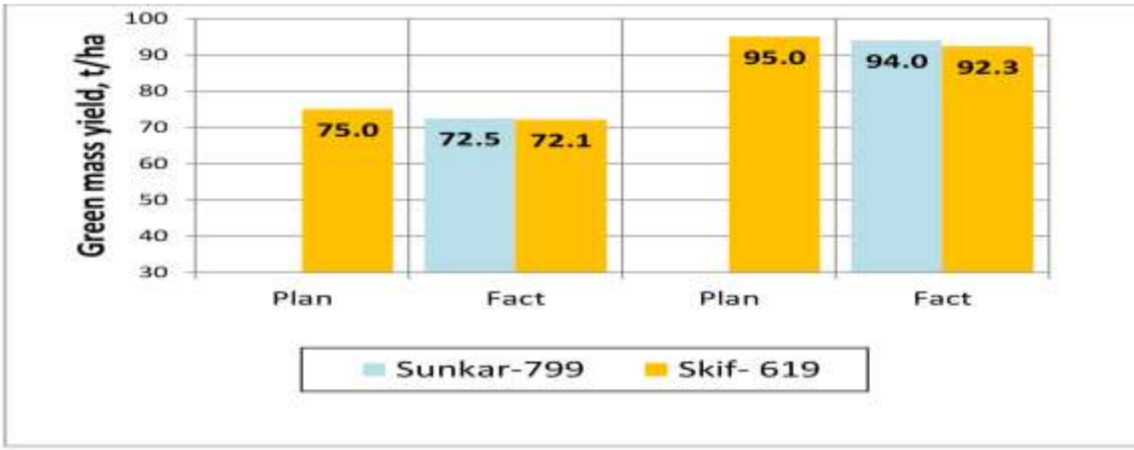

Figure 4. Planned and actual yield of green mass of corn, t/ha (average for 2015–2017).

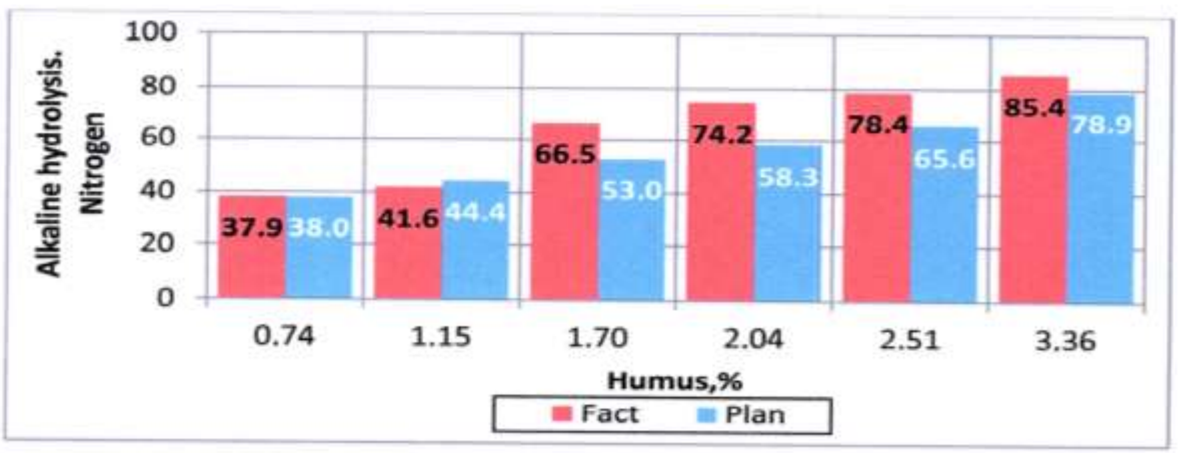

Figure 5. Actual and calculated content of alkaline hydrolyzable nitrogen in 0-30 cm soil layer (2020).

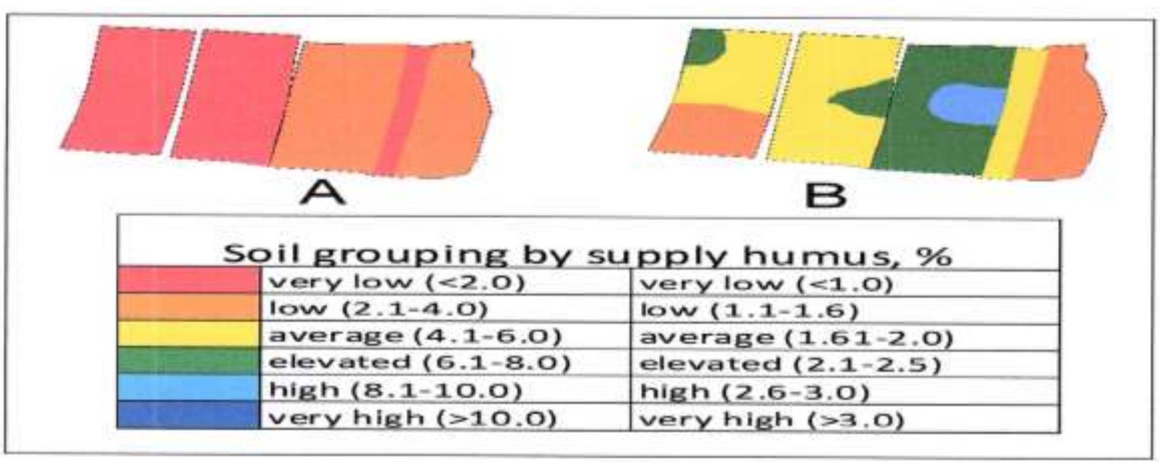

Figure 6. Cartograms of humus content in 0-30 cm layer of light chestnut soil performed for various groups of soil availability.

Statistical analysis

In soil, content determination of key nutrients followed the methods, i.e., GOST 26213-91, GOST 26490-85, GOST 26423-85, and GOST 26951-86, mostly used in agrochemical studies. Statistical analysis of the recorded data took place using the analytical program STATISTICA-6.

RESULTS AND DISCUSSION

Nitrogen nitrate and hydra thermal conditions in 2014–2016

The soils of South and Southeast Kazakhstan are characterized by the predominant distribution of low levels of natural fertility. In comparison with other soil types, soil poverty exudes in organic matter, resulting in minimum reserves for mineral nitrogen. In the soil, the bulk of nitrogen shows in organic form, and only a small part (about 1%) displays mineral compounds available for absorption by plants. These include nitrate and ammonia forms of nitrogen, characterized by high mobility and content changes under the influence of temperature, aeration, and humidity (Vanek *et al*., 1995, 1997). However, these predominantly inorganic forms of nitrogen show relevance only at the time of soil sampling. It becomes hard for one to judge the amount of available nitrogen in the soil during the growing season. In addition, the long period of high temperatures in the annual cycle further complicates the diagnosis of soil nitrogen supply to the crop plants (Kochergin and Gamzikov, 1972; Ermohin, 1995). The period of increased temperatures for the environmental conditions of Southeast Kazakhstan averaged 220 days, with fluctuations from 190 to 240 days, but in South Kazakhstan, this figure is even higher. Therefore, the cartogram for the content of mobile forms of nitrogen ($N\text{-}NO_3$ and $N\text{-}NH_4$) was not compiled (Ponomareva, 1968).

The hydrothermal conditions from a long multi-factorial field experiment data mainly determine the intensity of the processes of mineralization and immobilization of the available nitrogen compounds (Figure 1). To establish the general relationship between the nitrogen content of nitrates (in the upper soil layer of 0-30 cm) under winter wheat based on the hydrothermal conditions of the study year, the study used the averaged data for all 99 variants of the experiment. The construction of a polynomial 3-power trend line averaged the said variants. The presented data cannot characterize the actual content of $N\text{-}NO_3$ in the soil, yet, reflect the average level and the deviation of its content in one or another direction under various hydrothermal conditions of the year of research (Vanek *et al*., 2003; Schimel and Bennett, 2004).

The nitrogen content of nitrates varied significantly over the years of research. In the control variants (without fertilizers) of the experiment, the lowest content of $N\text{-}NO_3$ (6.7 g kg^{-1}) occurred in 2016, when the hydrothermal coefficient (HTC) ratio (the ratio of the amount of rainfall during the period with air temperatures above 10°C, to the sum of above active temperatures for the same period) amounted to 0.73. The increase in the HTC, from 0.29 (in 2015) to 0.73 (in 2016), changed the natural content of nitrate nitrogen to 28.2 and 13.4 mg kg^{-1}, respectively. The changes were not linear, and the fluctuations in the content of $N\text{-}NO_3$ over the years also oscillated relative to its maximum content of 28.2 mg kg^{-1} (2015) from 23.8% to 47.5% in 2016 and 2014, respectively (Figure 2). Past studies reported that mineral nitrogen content in soils from two different sites indicates weather conditions, field crops, and the type of organic fertilizers used influenced the values for each site (Rausch, 1989; Vanek *et al*., 1995, 1997).

The general natural level of soil supply with nitrate nitrogen also determines the strength of the action of mineral nitrogen introduced with fertilizers (Kochergin and Gamzikov, 1972; Gamzikov, 2018). The higher the availability of soil with it, the lower the effect of fertilizers on this indicator. Thus the introduction of 70 kg ha^{-1} of the active ingredient of ammonium nitrate into the top dressing of winter wheat in the tillering phase increased the content of nitrate nitrogen by 14.4, 4.2, and 0.9 mg kg^{-1} against the background of its content in the soil, 6.7, 13.4, and 28.2 mg kg^{-1}, respectively (Figure 3). The soils and crops supplied with mobile nitrogen can define nitrification capacity. However, this method has not been sufficiently tested in the field and does not give reliable results for authentication based on the doses of nitrogen fertilizers.

Interestingly, the use of a simple, precise, and rapid alkaline hydrolysis method can determine the nitrogen availability index of South and Southeast Kazakhstan. It includes the determination of nitrogen in mineral and organic compounds easily hydrolyzed upon the cultivation of the soil with weak solutions of acids and alkalis. The methodology is based on the assumption that these solvents extract (mineralize) nitrogen-containing organic compounds in the soil, easily subjected to mineralization in natural conditions, then the crop plants use the closest sources of replenishment of mineral nitrogen compounds. In essence, these methods are empirical and cannot often be used to know if the plants need nitrogen fertilizers. These processes capture well the genetic characteristics of soils concerning nitrogen and are widely used for these purposes (Sokolova, 1975; Dodor and Tabatabai, 2007). Nevertheless, these methods can serve as one of the components to forecast the supply of field crops with nitrogen under the environmental conditions of South and Southeast Kazakhstan.

Alkaline hydrolyzable nitrogen as an indicator for nitrogen fertilizers in 2015-2017

The soil content of alkaline hydrolyzable nitrogen can serve as an objective indicator to establish the nitrogen fertilizer requirements for field crops, as shown in Figure 4. In the recent results, the planned (75.0-95.0 t ha^{-1}) and obtained green mass yields of two corn Kazakh-Serbian selected hybrids (Sunkar-799 and Skif-619) have been compared. Calculating fertilizer rates (NPK) used the elemental balance method, based on the actual provision of the soil with the main elements of mineral nutrition, including alkaline hydrolyzable nitrogen, as also described in past findings (Stanford and Smith, 1972; Mulvaney, 1996; Dodor and Tabatabai, 2019). The study results revealed that the irrigated light chestnut soil showed characteristics of low humus content (2.62%), very low alkaline hydrolyzable nitrogen (72.2 mg kg^{-1}), medium mobile phosphorus (22.6 mg kg^{-1}), and the highest content of exchangeable potassium (467 mg kg^{-1}). The obtained crop yields practically corresponded to the planned levels of productivity. The average differences were 2.5% for both corn hybrids.

The provision of soils with mobile nitrogen is its total (gross) content and the presence of humus, which also determine the soil type, and the more total nitrogen and humus in the soil, the more mobile forms of nitrogen in it. Therefore, the dose of nitrogen fertilizers increases with the transition from chernozems to chestnut and gray soils by about 15%–25%. These results were in analogy with the past findings as reported close correlation between nitrogen mineralization and total N and organic C in meadow soils (Simard and N'dayegamiye, 1993; Dodor and Tabatabai, 2007, 2019). However, it contradicts Groot and Houba (1995), who reported a poor correlation between N mineralization rates and soil organic matter and N contents. According to past findings, upper soil layer of 0-20 cm, the alkaline hydrolyzable nitrogen content exceeded 100 mg, while no such increase showed in this form of nitrogen with increasing doses of nitrogen fertilizer (Proberzh and Janis, 2008).

Soil availability with humus in precision farming in 2020-2021

The latest studies were unable to establish any provable actual relationship between the content of organic matter and mineral forms of nitrogen on low-humus soils (light chestnut and gray soils) in Southeast Kazakhstan. On the other hand, a certain relationship occurred between the humus content and the provision of soil with alkaline hydrolyzable nitrogen.

In two consecutive years (2020–2021), 2,816 ha of arable land underwent testing in Almaty, Zhambyl, and Zhetysu regions, Kazakhstan. A total of 1,015 soil samples, collected and analyzed, revealed a close correlation (r = 0.64) between the content of humus and alkaline hydrolyzable nitrogen in the upper soil layer of 0-30 cm, described by the straight-line regression equation: $Y = 26.7 + 15.5*G$. The significance of the obtained model received confirmation with the help of random variables F, using the Fisher-Snedekor distribution (F observation > F critical; 19.77 > 1.96). Consequently, an increase in the humus content in the soil for every 0.1% also increases the content of alkaline hydrolyzable nitrogen by 1.55 mg kg^{-1}. Figure 5 shows the actual and calculated (obtained by the equation) indicators of the content of alkaline hydrolyzable nitrogen in the soil. The coefficient of determination (R^2) between the actual and calculated content of alkaline hydrolyzable nitrogen was 0.90%, which indicates an almost functional relationship between the variables, making it possible to determine the content of alkaline hydrolyzable nitrogen with a sufficient degree of reliability by the content of humus in the upper soil layer of 0-30 cm. The latest results agree with past findings about the estimation of mineral nitrogen in the humus content of soil through the soil alkaline hydrolysis method (Stanford and Smith, 1972; Vanek *et al*., 2003; Schimel and Bennett, 2004).

Undoubtedly, the determination of alkaline hydrolyzable nitrogen content in the soil according to humus content, as an indicator for nitrogen fertilizer needs in crops, proves possible than practical expediency, and the use of said method during the non-availability of soil content data on the farm suffices. The existing and widely used soil grouping in agrochemical surveys, which characterizes the content of humus in the soil, does not fully provide information about the soil content of the spatial variability of these indicators and requires some adjustment (Shafran, 2000; Gamzikov, 2000).

Soil humus availability scale (up to two and more than 10%) covers all the soil-climatic differences of the republic as a whole and focuses more on high-humus soil types (chernozems, dark chestnut, and chestnut soils). Therefore, it cannot objectively characterize the soils of poorer organic matter in South and Southeast Kazakhstan (light chestnut and gray soils), where the natural content of organic matter levels ranges from 1%–3%, which is the maximum possible for these types of soils. Figure 6 shows the results of an agrochemical survey and mapping of a soil plot for humus content using the existing availability of scale-A and scale-B, which more objectively assessed the spatial variability of soil content in an area of 3.5 ha at the Experimental Field of the Institute, Almaty region, Kazakhstan.

In all the weighted samples, the average humus content in the light chestnut soil showed 2.08%, with fluctuations from 1.13% to 2.93%, indicating a high heterogeneity of the surveyed area. In the classical grouping of soils, grouping A cannot ensure the detection of this heterogeneity and reflects the weighted average of the humus content in the soil (Table 1). Grouping B and the cartogram made on its basis provides a more detailed picture of the spatial variability of this indicator and allows for a differentiated and more efficient use of available resources (organic and nitrogen fertilizers, perennial grasses, and tillage) to control and reproduce the content of organic matter and nitrogen in the soil. The data given in Table 1 confirmed these results, which shows a survey of about 2000 ha with main types of soils in Zhetysu, Almaty, Zhambyl, Kyzylorda, and Turkestan regions of South and Southeast Kazakhstan.

Along with chemical methods of soil diagnostics of nitrogen nutrition, the so-called agrotechnical method is an obligatory component of the forecast of soil nitrogen supply. Despite its somewhat conventional nature, it gives an obvious idea of the possible situation with the nitrogen nutrition of plants (Gamzikov, 2018). Using these two major components allows focusing on the content of organic matter and alkaline hydrolyzable nitrogen in the upper soil layer of 0-30 cm, the precursors in the crop rotation, the main tillage types, and the intensity of inter-row cultivation of row crops, to determine the need of nitrogen fertilizers in the crop fields.

Table 1. Coverage levels of humus content in the soils of South and Southeast Kazakhstan, depending on the level of gradation of the scales used.

Content levels	Soil types		
	Light chestnut	Grey soil	Meadow-swamp*
The existing scale of security			
<2			
2-4			
4-6			
6-8			
8-10			
>10			
Proposed endowment scale			
<1.00			
1.1-1.5			
1.6-2.0			
2.1-2.5			
2.6-3.0			
>3			
Actual Content Boundaries	1.29-3.25	0.74-2.10	0.99-4.5

*: The district of rice cultivation in Kyzylorda region.

CONCLUSIONS

In South and Southeast Kazakhstan, the prevailing distribution of soils exhibit characteristics of a low level of natural fertility. Hence, using the $N\text{-}NO_3$ content in the soil as an indicator of its need for nitrogen fertilizers is not possible. This is explained by the high nitrogen mobility determined by various hydrothermal conditions during the growing season. The study proposes to use an indicator, such as, the alkaline hydrolyzable nitrogen content to determine the need for nitrogen fertilizers for various field crops. Using this indicator ensured the harvest of green mass of corn following the planned levels, and the differences did not exceed 2.5%. For more effective control and reproduction of soil organic matter and determination of the spatial and temporal variability of its content in each specific field, the study advises using a narrower (oriented to the prevailing soil types) scale of humus availability (<1 – >3) instead of the used one (<2 – >10). This will allow differentiated and more efficient use of available resources (organic and nitrogen fertilizers, crops of perennial grasses, and tillage) to control and reproduce the content of organic matter and nitrogen in the soil.

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