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MINERAL FERTILIZERS IMPACT ON SUGAR BEET PRODUCTIVITY IN SOUTHEAST KAZAKHSTAN

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SUMMARY

Determining the influence of various levels of mineral fertilizers to obtain the optimum productivity of two sugar beet (*Beta vulgaris* L.) hybrids was the prime goal of the pertinent research. The sugar beet responsiveness' identification and their payback by enhanced yield to increasing fertilizer rates was effective. The fertilizers' role in managing the variations in the primary indicators of efficient soil fertility has also been evident. Regression analysis described the relationship among the fertilizer intensity, soil agrochemical indicators, and the productivity of sugar beet. It allowed, with a high degree of reliability, to predict the sugar beet yield of the two hybrids (Aksu and Yampol) at different levels of fertilizer strength. The data characterizing the state of sugar beet sowing in Kazakhstan over the past 10 years are accessible.

Keywords: Sugar beet (*Beta vulgaris* L.), hybrids, mineral fertilizers, elements of mineral nutrition, productivity, payback

Key findings: Characterizing the potential of two sugar beet (*Beta vulgaris* L.) hybrids (Aksu and Yampol) with high root yield revealed that both crossbreeds have significantly higher yields (83.7–85.2 t/ha). The hybrid Yampol showed some advantages over the other hybrid Aksu. In the hybrid Yampol, responsiveness to increased fertilizer rates occurs in the entire range of standards used, and, presumably, an increase in the fertilizer application rate (above 540 kg/ha) will increase root yield. The high responsiveness of the hybrid Aksu was notable in a narrower range of fertilizer norms (330–420 kg/ha). However, with an increased fertilizer rate (above 420 kg/ha), there was no similar increase in the sugar beet root yield.

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INTRODUCTION

Sugar beet (*Beta vulgaris* L.) occupies an exceptional position in Kazakhstan's agriculture. It is one of the most important industrial crops and the only source of white sugar production in the Republic (Bastaubayeva *et al.,* 2021). In industrial processing, the sugar beet byproducts, such as pulp and molasses, are also of sizable value. The total feed value of all byproducts obtained during the processing of the sugar beet roots (25–30 t/ha) and leaves (10–15 t/ha) is about 5000 feed units. Sugar beet leaves are also equal in fodder value to the green mass of seeded grasses (Egorova *et al*., 2010).

Sugar beet cultivation occurs on irrigated lands of Southeast Kazakhstan. Over the last decade (2012–2021), the sown area of the crop increased by 35.4%, and the beetroot yield enhanced by 92.0%, amounting to 30.9 t/ha in 2021, compared with 16.0 t/ha in 2012. At the same time, the gross harvest of roots reached 33,200 t (Bureau of National Statistics, 2022). Analyzing the current sugar beet production shows that the average crop yield over the past decade was 26 t/ha, indicating the non-achievement of the valuable crop's fullest potential. The reason may be due to the low level of its cultivation technology, including the existing volume of mineral fertilizers' application. The average use of mineral fertilizers was only 45.5 kg of the active substance of NPK per hectare of sown area (Bureau of National Statistics, 2022).

The process of agriculture intensification has covered almost all countries. However, its effectiveness depends upon the states' scientific and technological progress and economic development. At the same time, in all countries, the yield was directly proportional to the fertilizer application, which confirms the thesis "Scientific and technical inventions may remain invalid until conditions for their application appear" (Kiryushin, 2018a, 2018b; Kenenbayev *et al*., 2023). Using the recommended dose of mineral fertilizers is an essential part of almost any agricultural technology. It is also a fact that the correct formulation of the fertilizer dose is the most critical task (Yakushev, 2013; Nemeata-Alla and Helmy, 2022). At present, especially for row crops, one of the most effective ways of using mineral fertilizers is their differentiated application, which is an integral part of the precision farming system (Afendulov and Lantukhova, 2005; Shpaar *et al.,* 2009). Therefore, complete control is reliable in providing plants with various elements of mineral nutrition. The optimal residual content in the soil was also a consideration as a concrete basis for crop management activities.

Nowadays, scientific institutions of Kazakhstan have established fertilizer standards that ensure the production of 65–70 t/ha of root crops with a sugar content of 16%–17% (Kenenbayev *et al*., 2023). For more effective management and reproduction of the soil fertility elements and determination of the spatial and temporal variability of its content in each specific field, enhancing the levels of soil supply with humus and the main constituents of mineral nutrition has ensued (Gusev *et al.,* 2022a). The issues of soil diagnostics of nitrogen nutrition in the precision agriculture system in Southeast Kazakhstan were also ponderable (Gusev *et al.,* 2022b). The influence of irrigation and fertilizers on the variations in the physical parameters of light chestnut soil during the cultivation of sugar beet is illustrative (Bastaubayeva *et al*., 2023). Based on this phenomenon, it is possible to effectively develop modern fertilizer systems designed for various levels of intensification to ensure optimal yields with high quality. Of considerable scientific and practical interest are developing fertilizer systems for modern cultivars and hybrids that provide a high economic effect and the additional harvest obtained for each kilogram of minerals spent.

MATERIALS AND METHODS

Study location and procedure

Field studies on sugar beet (*Beta vulgaris* L.) transpired in 2021–2022 under irrigation conditions at the LLP - Kazakh Research Institute of Agriculture and Plant Growing (KazRIAPG) in Southeast Kazakhstan. The research area belongs to the foothill desert-steppe zone with absolute elevations of 800–900 masl. The experimental site soil was light chestnut and medium loamy, with humus content (2.0%–2.2%), alkaline hydrolyzable nitrogen (82.7 mg/kg), mobile phosphorus (52.1), and exchangeable potassium (320 mg/kg). The climatic conditions of the research site were characteristic of sharp continentality, with large daily fluctuations in air temperature. The average annual precipitation was 414.4 mm, with a maximum in spring (about 200 mm). The average annual air temperature was +7.50 °C.

The sugar beet (*Beta vulgaris* L.) hybrids included in the study were Aksu (Kazakhstan) and Yampol (Poland). The scheme of the experiment comprised four variants of differentiated application of mineral fertilizers:

a. Without fertilizers – 0 kg/ha

b. $N_{120}P_{120}K_{90}$ (N^{I}_{0} + N^{II}_{60} + N^{III}_{60}) - for the sugar beet root yield up to 50 t/ha - 330 kg/ha

c. $N_{150}P_{150}K_{120}$ (N^{I}_{30} + N^{II}_{60} + N^{III}_{60}) - for the sugar beet root yield up to 65 t/ha - 420 kg/ha

d. $N_{180}P_{180}K_{150}$ (N^{I}_{60} + N^{II}_{60} + N^{III}_{60}) - for the sugar beet root yield up to 90 t/ha - 510 kg/ha

At the same time, introducing the nitrogen fertilizers also had different times:

N^{I}_{0} - for pre-sowing cultivation

N^{II}_{60} - for fertilizing sugar beet plants in the phase of 2–3 pairs of real leaves

N^{III}_{60} - for fertilizing sugar beet plants in the phase of 4–5 pairs of real leaves

The mineral fertilizers applied were: nitrogen - for pre-sowing cultivation - carbamide (N - 46%), ammonium nitrate (N - 34%), phosphorus - ammophos (N - 11% and P_2O_5 - 52%), and potassium - potassium chloride (K_2O - 60%). Phosphoric and potash fertilizers introduction began for the chief tillage. The area of the experimental plot was 399 m^2 (7 m × 57 m), with four repetitions.

Determining primary elements (NPK) of nutrition in the soil started according to the relevant GOST standards and generally accepted methods. In the ground, the alkaline hydrolyzable nitrogen detection followed Cornfield (Sokolov, 1975), mobile phosphorus and exchangeable potassium by Machigin, modified by TSINAO (GOST 26205-91) (GOST - 26205-91), humus content (GOST - 26213-91), and sugar content in sugar beet root (GOST - 53036-2008). The data analysis and processing ran according to Dospekhov (1985) using the analytical program STATISTICA-6.

RESULTS AND DISCUSSION

Fertilization effects on soil content

The introduction of fertilizer norms formulated for various crop productivity levels showed the achievement of crucial quantitative indicators of soil available with primary elements of fertility, which provided the soil culture with sufficient mineral nutrition. Notably, variations in the provision of the earth with mineral nutrition elements were not due to varietal differences of the sown sugar beet hybrids, and the presented results have the basis of weighted averages. Figure 1 shows the influence of differentiated (depending on the planned yield levels) nitrogen fertilizer norms on the formation of the nitrogen reserve of the soil.

The hydrolyzable nitrogen content between the organic matter and readily available forms of nitrogen in the soil practically did not change and was at the same level. Nitrogen fertilizers had a significant effect only on the nitrogen content of nitrates (the accessible form of nitrogen for plants) and almost straightforwardly enhanced its content. If, in the control variant (without fertilizers), the amount of N-NO3 was 11.1 mg/kg, then in the variant with the introduction of 120-150-180 kg of nitrogen, it increased by 33%, 59% and 120%, amounting to 14.8, 17.6, and 24.7 mg/kg of soil, respectively.

A regression analysis helped determine the strength and action of nitrogen fertilizers on the nitrogen content of nitrates in the soil. The probe showed that nitrogen fertilizers had a significant effect (R-0.74) on the ground's available mobile nitrogen. The established dependence, with a sufficient reliability degree (D-54, 8%), has a regression model

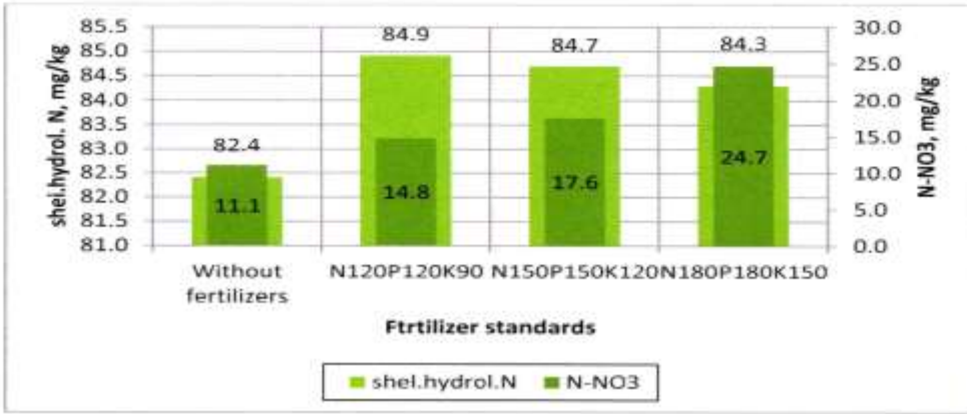

Figure 1. The effect of fertilizers on the average seasonal content of nitrate (N-NO_3) and alkaline hydrolyzable nitrogen in the 0-30 cm soil layer (on average for two varieties).

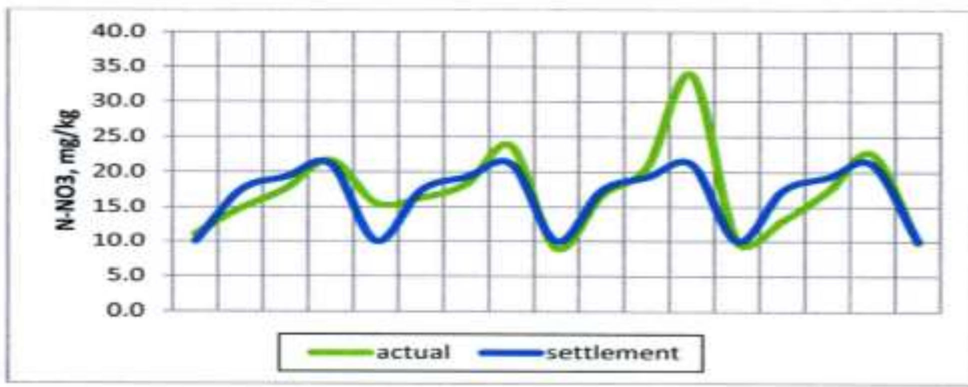

Figure 2. Actual and calculated N-NO_3 content in the soil under sugar beet depending on the nitrogen fertilizer burrow.

description – y =9.968+0.06198 *N (N is the norm of nitrogen fertilizer applied). The same is also valid in the data in Figure 2, which shows the regression equation results on the nitrogen content of nitrates in diverse variants of the experiment in the context of four repetitions.

With fertilizer application, the availability of mobile forms of phosphorus and potassium in the soil has also increased relative to the control variant (Figure 3). Mobile phosphorus increases were by 21.8 – 37.2 mg/kg (42%–72%), exchangeable potassium by 65.4 – 92.6 mg/kg (22.7%–32.2%), respectively, with the introduction of increasing rates of the same fertilizers. An increase in the rate of phosphorus application to the soil for every 10 kg/ha significantly (R-68.0) increased the content of phosphorus pentoxide by 2.1 mg/kg and the exchange of potassium by 6.3 mg/kg of soil. Thus, with calculated doses of fertilizers, it was possible to achieve a significant increase in the availability of mobile phosphorus and exchangeable potassium in the ground. Partial application of nitrogen fertilizers made it possible to maintain the content of mobile (N-NO3) and easily hydrolyzable forms of nitrogen at enhanced levels exceeding their initial content in the soil.

Figure 3. The effect of fertilizers on the average seasonal content of mobile phosphorus (P_2O_5) and exchangeable potassium (K_2O) in the 0-30 cm soil layer (average over two hybrids).

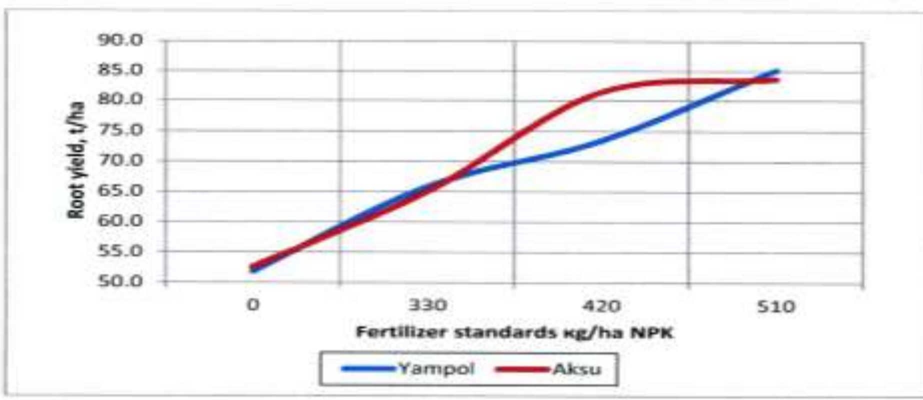

Figure 4. The effect of increasing fertilizer rates on the yield of sugar beet root crops.

Regression equations, describing the strength and direction of variations in the chief indicators of soil fertility (NPK) by applying the same fertilizer, cannot serve as normative indicators. Since obtaining these were in a narrow time and spatial framework and were also relevant for a particular experiment. Thus, with calculated doses of fertilizers, it was possible to achieve a significant enhancement in the availability of mobile phosphorus and exchangeable potassium in the soil. Partial application of nitrogen fertilizers also maintained the mobile (N-NO3) and easily hydrolyzable forms of nitrogen during the growing season of sugar beet at levels exceeding their initial content found in the earth.

Fertilizers' effect on productivity

Characterizing the potential of the two studied sugar beet hybrids (Aksu and Yampol) to produce sufficiently high root yield, it was notable that both crossbreeds have a moderately good productivity potential. Relatively high harvests (51.9–52.6 t/ha) were available in the variants without fertilizers. The advantage of the hybrid Yampol was almost straightforward responsiveness to higher fertilizer rates (510 kg/ha). The effective responsiveness of the hybrid Aksu with an increase in the fertilizer rate (above 420 kg/ha) was practically without a provable increase in the root yield (Figure 4).

Both sugar beet hybrids more or less showed better responses to enhanced fertilizer rates (Figure 4). Based on data analysis, the regression equations revealed a sufficient degree of reliability (D = 79.8%–80.7%) to characterize the response of both hybrids to diverse levels of mineral nutrition (Y = 43.6 + 0.07054*Y – for the hybrid Aksu and Y = 48.1 + 0.06456*Y - for the hybrid Yampol, with Y as the fertilizer norm). An analysis further indicated that equations disclosed that an increase in the fertilizer rate for the sugar beet hybrid Aksu by 1% (1 kg/ha) led to an upsurge in the beetroot yield by 0.388% (0.082 t/ha); however, the hybrid Yampol showed lower root yield, i.e., 0.297% (0.064 t/ha), respectively.

However, a good response of the hybrid Aksu was evident in a narrower range of fertilizer norms (330–420 kg/ha). With an increase in the fertilizer rate above 420 kg/ha, there was no similar increase in the sugar beet root yield. In the hybrid Yampol, response to increased fertilizer rates occurred in the entire range of standards used, and, presumably, an increase in the fertilizer application rate above 540 kg/ha will increase root yield. Consequently, the hybrid Yampol has somewhat better plasticity than the hybrid Aksu. However, the weighted average root yield increase for all the fertilizer variants was approximately the same, amounting to 44%–46%. Generally, it was possible to achieve the planned yield levels using increased fertilizer rates. Although reaching the maximum level (90 t/ha) had 93%–95% rates relative to the planned ones.

In the sugar beet hybrids, the root sugar content had no significant change with different fertilizer application intensities, as evidenced by the low coefficient of variation. For the hybrid Yampol, the coefficient of variation for the sugar content was 12.7%, with a standard deviation of 1.72, while for hybrid Aksu, the values were 11.0% and 1.37, respectively. However, on average, the sugar content in the roots of hybrids Yampol and Aksu for all the variants, including control, was 13.5% and 12.5%, respectively. Various researchers reported that increasing rates of mineral fertilizers do not lead to an increase in the sugar content of root crops, with the sugar yield more determined by an upsurge in crop yield (Napkinnikov and Zinchenko, 2005; Smurov *et al*., 2008; Uvarov *et al*., 2007; Minakova *et al*., 2021, 2022).

The two-factor regression model also established the strength and direction of the influence of the crop and the root sugar content on the sugar beet harvest. The obtained correlation coefficients for two-factor features (root yield and percent sugar) showed that the productive attribute (sugar harvest), as determined by the root yield (r = 0.938), had the coefficient of determination at 88.1%. Consequently, the average sugar harvest (88.1%) has the root yield of the sugar beet crop determining it, and the sugar content had no significant effect on the resulting trait (r = 0.036). Therefore, to build a regression model, discarding this indicator was necessary, and the regression model took the form: y = 0.793 + 0.1178 *Y (Y is the crop of root crops). Testing the null hypothesis using random variables F having a Fischer-Snedecor distribution, the study found F nab. = 103.4, and F was critical (0.05, 1, 14) = 4.6. Thus, with Fn. > F was unfavorable, leading to rejecting the null hypothesis, and the regression model proved significant. Hence, an increase in the root yield by one ton (1%) increases the sugar harvest by 117.8 kg/ha (0.909%). Figure 5 shows the actual and calculated indicators of sugar harvesting, depending on the size of the resulting crop, for the variants of different intensities of fertilizer application.

The results further indicated that by the size of the harvest, with 88% confidence, it was possible to predict the amount of sugar harvested. One of the objective indicators characterizing the effectiveness of fertilizers and the responsiveness of various varieties and hybrids to them was the payback indicator of fertilizers, manifesting as an additional unit of production due to an introduced unit of mineral fertilizers (Table 1).

The sugar beet hybrid Yampol showed better plasticity to the increasing rates of mineral fertilizers and demonstrated an increase in their payback. Although indirectly, it may indicate that the fertilizer rate of 510 kg/ha has only partially realized its potential,

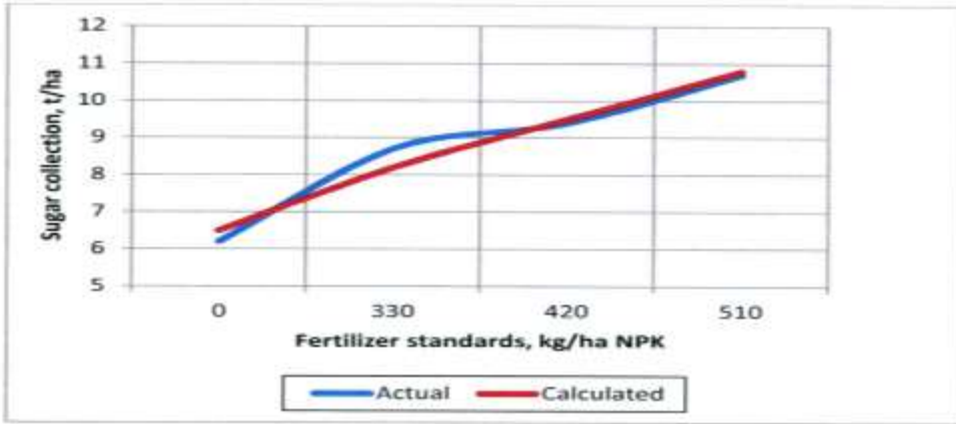

Figure 5. Actual and calculated sugar collection from one hectare with different intensities of fertilizer application (average over two hybrids).

Table 1. The payback of fertilizers additionally obtained by the harvest of sugar beet crops during 2021–2022.

NPK fertilizer norm (kg/ha)	Hybrid Aksu			Hybrid Yampol		
	Root yield (t/ha)	Increase (t/ha)	Payback of 1 kg NPK by additional harvest (kg)	Root yield (t/ha)	Increase (t/ha)	Payback of 1 kg NPK by additional harvest (kg)
0	52.0	-	-	51.9	-	-
330	65.1	12.5	37.9	65.9	14.0	42.4
420	81.5	28.9	68.8	73.5	21.6	51.4
510	83.7	31.1	60.9	85.2	33.3	65.3

and, with an increase in the fertilizer rate, the productivity of the hybrid may increase. The hybrid Aksu effectively increased its yield, and the payback of fertilizers applied only to the dose of 420 kg/ha. However, a further increase in fertilizer intensity led to a negligible increase in root yield, and their payback decreased.

CONCLUSIONS

Differentiated (depending on the availability of soil and the planned yield level) application of mineral fertilizers allows for obtaining 65–85 t/ha of root yield with a sugar content of 12%–13% and a sugar yield of about 8–10 tons. Partial application of 120-150-180 kg of active substance N, as part of a complete mineral fertilizer, made it possible to increase and maintain the content of nitrate nitrogen in the soil at the levels of 14.8, 17.6, and 24.7 mg/kg, which was, on average, 70% higher than its content for variants without the fertilizers. The introduction of every 10 kg/ha of mobile phosphorus and exchangeable potassium increases (R 68.0) the content of phosphorus pentoxide and potassium dioxide in the soil by 2.1 and 6.3 mg/kg, respectively. Regression analysis revealed a sufficient degree of reliability (D = 79.8%–80.7%) to characterize the responsiveness of sugar beet hybrids to various levels of mineral nutrition ($Y = 43.6 + 0.07054*Y$ - for the Aksu hybrid and $Y = 48.1 + 0.06456*Y$ - for the hybrid Yampol, with Y - the fertilizer application rate). The hybrid Yampol demonstrated superior rectilinear plasticity in the range of all studied fertilizer application rates, which may indicate its higher potential.

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