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Effect of fertilizer treatments on sugar beet cultivars: A comprehensive study on crop yield and nutrient contents of soil and plant in chestnut soil of Kazakhstan

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Abstract

This study aimed to investigate the effects of different fertilizer treatments on the growth, yield, and nutrient content of two sugar beet cultivars, Aksu (Kazakhstan) and Yampol (Poland), cultivated in the Almaty region of Kazakhstan. The experiment was conducted using a complete randomized block design with three replicates, comprising six treatments: control (without fertilizer), $N_{120}P_{120}K_{90}$, and $N_{130}P_{130}K_{130}$ for both cultivars. The soil's physical and chemical properties were analyzed, revealing a foothill light chestnut soil with favorable nutrient levels. Results indicated that the $N_{130}P_{130}K_{130}$ treatment significantly increased soil available nitrogen, phosphorus, and potassium contents, leading to enhanced sugar beet growth, nutrient uptake, and yield. Both cultivars responded positively to the increased nutrient levels, with the $N_{130}P_{130}K_{130}$ treatment showing the highest yield of 785.6 tons/ha for Aksu and 802.5 tons/ha for Yampol. Furthermore, nutrient content in tubers and leaves was significantly higher in the $N_{130}P_{130}K_{130}$ treatment compared to other treatments. These findings underscore the importance of balanced nutrient management tailored to specific cultivars for optimizing sugar beet productivity and soil fertility in diverse agro-climatic conditions. Adopting balanced mineral nutrient management approaches could offer promising solutions to enhance sugar beet productivity and sustainability. Future research should focus on exploring long-term effects and integrated nutrient management strategies for sustainable sugar beet cultivation.

Keywords: Sugar beet, fertilizer treatments, mineral fertilizers, crop yield, nutrient contents.

Introduction

Sugar beet (Beta vulgaris L.) is an essential crop cultivated worldwide, predominantly for sugar production but also as a source of bioenergy and feedstock (Haankuku et al., 2015). Sugar beet cultivation spans across 41 countries worldwide, encompassing approximately 8.1 million hectares (Mall et al. 2011). Among these, the top ten sugar beet-producing countries include the Russian Federation, France, Germany, the United States of America, Turkey, Poland, China, Egypt, Ukraine, and the United Kingdom, as reported by FAO in 2019. Kazakhstan, with its diverse agro-climatic zones, holds significant potential for sugar beet cultivation due to its favorable soil and climatic conditions (Zhaksybayeva et al., 2022). Almaty, Zhetysu, and Zhambyl regions includes 14.5 thousand hectares of the fields for sugar beet cultivation, it is 99 per cent of all sugar beet sowing fields in Kazakhstan (Khusnitdinova et al., 2023). The Almaty region, in particular, offers suitable conditions for sugar beet growth, with its temperate climate and fertile soils.

Climatic factors, particularly temperature and precipitation, significantly influence sugar beet growth and

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development (Sánchez-Sastre et al., 2018). Adequate temperature and water availability during the growing season are crucial for achieving optimal yields (Huang et al., 2022). Therefore, monitoring and understanding the climatic conditions during the crop's growth stages are essential for implementing appropriate irrigation and management practices (de Oliveira e al., 2015).

Soil fertility plays a pivotal role in determining the success of sugar beet cultivation (Tayyab et al., 2023). Understanding the physical and chemical properties of the soil is essential for implementing effective management practices that optimize soil health and crop productivity (Gülser et al., 2017; Onyegbule et al., 2023). The soil at the study site, characterized as a foothill light chestnut soil, was analyzed for its physical and chemical properties to provide insights into its fertility status and nutrient availability (Saparov, 2014; Ospanbayev et al., 2023).

Fertilization is a key management practice that significantly impacts sugar beet yield and quality (Pogłodziński et al., 2021; Kamzina et al., 2022). Proper nutrient management, including nitrogen (N), phosphorus (P), and potassium (K) application, is essential for promoting vigorous growth, improving yield, and enhancing sugar content in sugar beet plants. However, excessive or inadequate nutrient application can lead to nutrient imbalances, affecting crop health and productivity (El-Geddawy et al., 2008).

The choice of sugar beet cultivars is critical in determining the crop's performance and yield under specific environmental conditions (Taleghani e al., 2023). In this study, two sugar beet cultivars, Aksu (Kazakhstan) and Yampol (Poland), were selected to assess their performance under varying fertilizer treatments. These hybrids have been chosen based on their adaptability to the local climatic conditions and their potential to deliver high yields. Given the importance of soil fertility, climatic conditions, and fertilization practices in determining sugar beet yield and quality, this study aims to investigate the effects of different fertilizer treatments on the growth, yield, and nutrient content of two sugar beet hybrids (Aksu and Yampol) cultivated in the Almaty region of Kazakhstan. The findings from this study will contribute to the existing knowledge base on sugar beet cultivation practices in the region and provide valuable insights for farmers and researchers aiming to enhance sugar beet productivity and sustainability in similar agro-climatic conditions.

Material and Methods

Study site and Soil Properties

During the spring and summer of 2022, the current research was conducted at Kazakh Research Institute of Agriculture and Plant Growing located in Almalybak village, Karasai district, Almaty region, Kazakhstan on a foothill light chestnut soil. The sugar beet hybrids used in the experiment were Aksu (Kazakhstan) and Yampol (Poland). A soil sample was collected from the experimental field at the beginning of the experiment. Physical and chemical properties of the experimental soil were determined Kazakh National Agrarian Research University according to the Rowell (1996).

Climatic data

Based on meteorological data collected during the study period, temperature conditions for sugar beet crops were relatively consistent across the growing seasons. The most favorable temperature conditions were observed during the growing season, with an average temperature of approximately 17°C. Optimal distribution of heat and water resources was observed, attributed to consistent and favorable natural moisture supply during the sugar beet sowing period. Specifically, precipitation levels were 35.6 mm in April, 145.4 mm in May, 35.9 mm in June, 15.1 mm in July, 8.2 mm in August, and 2.1 mm in September and the first ten days of October. Overall, the total precipitation during the growing season closely aligned with the long-term average. The least precipitation was recorded during the sowing period, with a negative water balance observed during the period of intensive growth and development of sugar beet. To mitigate the moisture deficit, vegetative irrigations were implemented to ensure adequate water supply for the sugar beet crops.

Soil Preparation, Experimental design and Cultivation

As per standard commercial cultural practice for light chestnut soil. The field was plowed using a chisel plow. Thereafter, the experimental field was divided into 180 cm wide strips. For each fertilizer treatment described below. Total plot area was 288 m^2 (12 m x 4 m) to which mineral fertilizers. Fertilizers were then incorporated into the soil using a rotavator. Fertilizer treatments were arranged in a complete randomized block design with three replicates.

Sugar beet (*Beta vulgaris* L.) cultivar Aksu and Yampol were mechanically planted on 12 April 2022, with a planting density of 4kg/ha or 1.7 p.u./ha of dried seed in the 3.75-4.75 mm fraction using a four-row-planter in all plots.

The experiment consisted of six treatments as follows:

T1-Aksu	Control (without fertilizer)
T2-Aksu	$N_{120}P_{120}K_{90}$
T3-Aksu	$N_{130}P_{130}K_{130}$
T4-Yampol	Control (without fertilizer)
T5-Yampol	$N_{120}P_{120}K_{90}$
T6-Yampol	$N_{130}P_{130}K_{130}$

Fertilizers were applied at a rate of $N_{120}P_{120}K_{90}$ and $N_{130}P_{130}K_{130}$ for Aksu and Yampol cultivar. All amounts of phosphorus and potassium were applied manually during soil preparation in the form of Ammophos (46%P_2O_5, 10%N) and potassium sulfate (50% K_2O), while nitrogen was divided into two equal portions, and applied during soil preparation and 6 weeks after planting in the form of ammonium nitrate (33% N).

Harvesting of the crop was done treatment-wise on 15 October 2022. Firstly one border row from both sides and two plants from both ends were harvested to eliminate the border effect from each plot. Harvesting was done by digging of plants.

Agronomic Activities

Throughout the experimental period, a comprehensive set of agronomic activities was meticulously executed at the experimental site to optimize conditions for sugar beet growth and ensure accurate data collection. The soil was carefully prepared for planting, followed by furrow irrigation with a total water requirement of 600-700 m^3/ha, divided into four applications. Cultivation and weed control measures were consistently applied to maintain soil health and manage weed growth. During the active growth phase, disease and pest control strategies were implemented using systemic fungicides like Impact and Skor for powdery mildew and cercosporosis, and insecticides such as Kinmix, Rovikurt, Arrivo, and Cymbush for beet fleas, beet weevils, and leaf-eating moths. Harvesting was conducted at the optimal maturity stage to ensure maximum yield and quality, with all activities performed in strict adherence to recommended practices, highlighting the importance of ecological and agronomic parameters in the experimental setup.

Data collection

Soil Sampling and Analyses

After harvest, the soil samples collected from depth of 20 cm were naturally air-dried, milled and passed through 2.0 mm sieve. Available nitrogen (NH_4+NO_3) by the modified Kjeldahl method, available Phosphorus was determined by the 0.5M $NaHCO_3$ extraction method, available Potassium content were determined by the 1N NH_4OAc extraction method according to the Rowell (1996) and Jones (2001).

Plant Sampling and Analyses

After harvesting, tubers of sugar beet were separated according to the treatment and weighed on double pan balance for each treatment separately. After this, total tuber yield was calculated as the sum of the weights of tubers from the net plot area and transformed to ton per hectare. Leaves of sugar beet samples were analyzed for dry weight and nutrient (N, P and K) content in leaves and sugar beet tubers according to the Jones (2001).

Results and Discussion

The experimental site was characterized by foothill light chestnut soil formed on loess-like loams, presenting a well-defined fertile profile. The surface soil exhibited an organic matter content of 2.02%, total nitrogen (N) at 0.135%, a C/N ratio of 8.7, and a total carbonate content of 2.73%. Exchangeable cations were measured with Ca at 10.24 meq/100 g, Mg at 1.49 meq/100 g, and Na at 0.30 meq/100 g. Additionally, the soil contained 82.4 mg/kg of Available nitrogen (NH_4+NO_3), available P_2O_5 at 25 mg/kg, available K_2O at 442 mg/kg, with a soil pH of 8.2.

The study aimed to investigate the effects of different fertilizer treatments on the growth, yield, and nutrient content of two sugar beet cultivars, Aksu and Yampol, cultivated in the Almaty region of Kazakhstan. The results obtained shed light on the intricate relationship between fertilizer treatments, soil nutrient content, and crop yield. The application of different fertilizer treatments had a significant impact on the nutrient content of the soil. For the Aksu cultivar, the highest NH_4+NO_3 content was observed in the N130P130K130 treatment with 19.4 mg/kg, followed by the $N_{120}P_{120}K_{90}$ treatment with 16.7 mg/kg and the control with 11.7 mg/kg (Table 1). Similarly, the highest available P content was recorded in the $N_{130}P_{130}K_{130}$ treatment with 45.9 mg/kg, whereas the control had the lowest P content at 12.8 mg/kg. Regarding available K, the $N_{130}P_{130}K_{130}$ treatment led with 415 mg/kg, followed by $N_{120}P_{120}K_{90}$ with 378 mg/kg, and the control with 331 mg/kg. For the Yampol cultivar, the trend was consistent with the Aksu cultivar. The $N_{130}P_{130}K_{130}$ treatment resulted in the highest NH_4+NO_3 content at 20.2 mg/kg, available P at 47.7 mg/kg, and available K at 422 mg/kg. The control treatment showed the lowest nutrient content across all parameters (Table 1).

Table 1. Effects of fertilizer treatments on soil nutrient content

Treatment	Aksu cultivar			Yampol cultivar		
	NH_4+NO_3, mg/kg	Available P, mg/kg	Available K, mg/kg	NH_4+NO_3, mg/kg	Available P, mg/kg	Available K, mg/kg
Control	11,7	12,8	331	12,0	13,1	342
$N_{120}P_{120}K_{90}$	16,7	27,2	378	17,7	28,5	382
$N_{130}P_{130}K_{130}$	19,4	45,9	415	20,2	47,7	422

The sugar beet plant's nutrient content, particularly in tubers and leaves, was significantly influenced by the fertilizer treatments. For the Aksu cultivar, the $N_{130}P_{130}K_{130}$ treatment exhibited the highest N, P, and K content in both tubers and leaves. The control treatment showed the lowest nutrient content across all parameters. Similarly, for the Yampol cultivar, the $N_{130}P_{130}K_{130}$ treatment had superior nutrient content, with higher N, P, and K values in both tubers and leaves compared to other treatments (Table 2).

Table 2. Effects of fertilizer treatments on sugar beet yield and plant nutrient content

Treatment	Yield, ton/ha	Tubers			Leaves		
		N, %	P, %	K, %	N, %	P, %	K, %
Aksu cultivar							
T1-Control	345,0	0,75	0,30	4,65	3,1	0,22	4,67
T2- $N_{120}P_{120}K_{90}$	634,2	1,52	0,32	4,22	4,3	0,47	5,55
T3-$N_{130}P_{130}K_{130}$	785,6	1,72	0,36	3,88	4,22	0,61	5,22
Yampol cultivar							
T4-Control	389,0	0,77	0,36	4,78	3,22	0,31	4,85
T5-$N_{120}P_{120}K_{90}$	683,5	1,55	0,34	4,36	4,4	0,52	5,62
T6-$N_{130}P_{130}K_{130}$	802,5	1,77	0,42	4,11	4,38	0,56	5,14

Soil nutrients play a pivotal role in determining plant growth, development, and yield productivity. The present study aimed to evaluate the effects of different mineral fertilizer treatments on soil agrochemical properties and sugar beet nutrient content, in line with the literature. In the current study, the application of mineral fertilizers at different rates significantly improved the soil's available nutrient contents. The treatment of $N_{130}P_{130}K_{130}$ notably increased available nitrogen, phosphorus and potassium compared to the control treatment. These findings are consistent with previous studies by Jabborova et al. (2019, 2020), McDowell et al. (2004), Fang et al. (2009), Monaco et al. (2008), and Wang et al. (2008), highlighting the positive impact of inorganic fertilizers on soil nutrient contents and other agrochemical properties. Dinesh et al. (2012) observed an enhancement in total N content of rainfed ginger soil with chemical nutrient management. Similarly, Yanthan et al. (2010) reported increased N, P, and K content in soil with NPK applications, corroborating our findings. However, it's noteworthy to mention the findings from Srinivasan et al. (2019), indicating that high mineral fertilizer decreased several nutrient contents in the soil, emphasizing the need for balanced fertilizer management. Furthermore, the mineral elements in soil, particularly N, P, and K, significantly influence plant growth, development, and yield. The present study found that the $N_{130}P_{130}K_{130}$ application rate significantly enhanced the sugar beet's nutrient content, including N, P, and K, in both tubers and leaves. These results align with the studies of Egamberdieva et al. (2018), and Thakur and Sharma (1997), emphasizing the positive effect of mineral fertilizers on nutrient uptake by plants. Interestingly, our study revealed high levels of NPK in sugar beet tubers and leaves, which underscores the plant's potential as a rich source of essential nutrients. These findings are in agreement with Ayaji et al. (2013), who reported the richness of ginger in various essential minerals.

The effects of fertilizer treatments on sugar beet yield varied significantly between the two cultivars, Aksu and Yampol. The yield data presented in Table 2 clearly demonstrate the substantial influence of nutrient management on sugar beet productivity. For the Aksu cultivar, the control group without fertilizer application yielded 345.0 tons/ha. However, with the application of $N_{120}P_{120}K_{90}$, the yield increased to 634.2 tons/ha, marking a significant improvement. The highest yield was observed with the $N_{130}P_{130}K_{130}$ treatment, reaching 785.6 tons/ha, indicating that the additional nutrients further enhanced sugar beet growth and yield. In contrast, the Yampol cultivar exhibited a different response to the fertilizer treatments. The control group yielded 389.0 tons/ha, which was surpassed by the $N_{120}P_{120}K_{90}$ treatment with a yield of 683.5 tons/ha. The highest yield for this cultivar was recorded with the $N_{130}P_{130}K_{130}$ treatment at 802.5 tons/ha, suggesting that the increased nutrient levels positively impacted the growth and yield of Yampol sugar beets. These results highlight the importance of selecting appropriate fertilizer treatments tailored to specific sugar beet cultivars to maximize yield potential. The variability in yield responses between Aksu and Yampol cultivars underscores the necessity for cultivar-specific nutrient management strategies to optimize sugar beet production in diverse agro-climatic conditions. To further contextualize the findings of this study, a comparative analysis was conducted with recent researches focusing on the effects of different nutrient management practices on sugar beet cultivars. El-Mageed et al. (2022) explored the physio-biochemical and agronomic changes in two sugar beet cultivars (Romulus and Francesca) grown in saline soil under varying potassium (K) rates. The study found that a high potassium rate of 144 kg K/ha significantly enhanced cell membrane stability, relative water content, and performance index under high salinity conditions. Additionally, the maximum improvements in sugar yield and quality were observed at this potassium rate, emphasizing the importance of potassium fertilization in mitigating the adverse effects of saline soils and enhancing sugar beet productivity. Similarly, Demirbaş (2021) investigated the impact of different phosphorus (P) doses on sugar beet yield and nutrient uptake. The study reported that increasing phosphorus doses led to a significant yield increase, with the highest yield recorded at 30 kg P/ha. Furthermore, elevated concentrations of nitrogen, phosphorus, and potassium were observed at this phosphorus dose, highlighting the crucial role of phosphorus fertilization in optimizing sugar beet yield and nutrient uptake. In another study by Marajan et al. (2021), the combined application of compost and phosphorus fertilizer was assessed for its effect on sugar beet growth and yield components. The results revealed that the combination of compost and phosphorus fertilizer significantly increased various agronomic traits, including leaf number, leaf area index, leaf dry weight, root diameter, and root fresh weight. This suggests that integrating organic and mineral fertilizers can synergistically enhance sugar beet growth and yield. Comparing these studies with the current research, it is evident that nutrient management plays a pivotal role in determining sugar beet productivity across different environmental conditions. While the current study primarily focused on nitrogen (N), phosphorus (P), and potassium (K) fertilization, the aforementioned studies highlighted the importance of potassium in saline soils and the synergistic effects of combining compost with mineral fertilizers. In conclusion, these comparative insights emphasize the need for tailored nutrient management strategies based on soil conditions, cultivar characteristics, and environmental factors to optimize sugar beet yield and quality. Adopting integrated nutrient management approaches that combine organic and mineral fertilizers could offer promising solutions to enhance sugar beet productivity and sustainability in diverse agro-climatic conditions.

Conclusion

In conclusion, the present study provides comprehensive insights into the effects of different fertilizer treatments on the growth, yield, and nutrient content of two sugar beet cultivars, Aksu and Yampol, cultivated in the Almaty region of Kazakhstan. The results underscore the significant impact of nutrient management on sugar beet productivity and soil fertility, highlighting the importance of tailored fertilizer applications in optimizing crop performance. The application of mineral fertilizers, particularly the $N_{130}P_{130}K_{130}$ treatment, significantly enhanced the soil's available nitrogen, phosphorus, and potassium contents, leading to improved sugar beet growth, nutrient uptake, and yield. Both sugar beet cultivars responded positively to the increased nutrient levels, with the $N_{130}P_{130}K_{130}$ treatment demonstrating superior performance in terms of yield and nutrient content in tubers and leaves. The findings from this study corroborate previous research highlighting the positive effects of balanced nutrient management on crop productivity. Moreover, the variability in yield responses between the Aksu and Yampol cultivars underscores the necessity for cultivar-specific nutrient management strategies to maximize sugar beet production under diverse agro-climatic conditions. It is essential to emphasize the significance of soil fertility in determining crop yield and quality. The foothill light chestnut soil of the Almaty region exhibited favorable physical and chemical properties, emphasizing the region's potential for sugar beet cultivation. However, continuous monitoring and effective soil management practices are crucial to maintaining soil health and ensuring sustainable crop production.

Future research should focus on exploring integrated nutrient management approaches that combine organic and mineral fertilizers to enhance soil fertility, improve nutrient use efficiency, and promote sustainable sugar beet cultivation practices. Furthermore, investigating the long-term effects of different fertilizer regimes on soil health, microbial communities, and crop resilience will provide valuable insights for developing holistic and sustainable agricultural strategies. In conclusion, the findings from this study contribute to the existing knowledge base on sugar beet cultivation practices in Kazakhstan and offer practical recommendations for farmers and researchers aiming to enhance sugar beet productivity, soil fertility, and sustainability in similar agro-climatic conditions. Adopting science-based nutrient management strategies is imperative for achieving sustainable agricultural intensification and ensuring food security in the face of changing climatic conditions and increasing demand for agricultural products.

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