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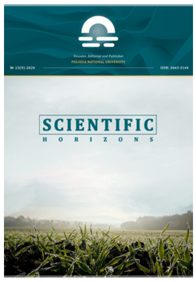

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The influence of different fertilization regimes on the yield and nutrient content of the sugar beet crop

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Abstract. Sugar beet is one of the crops with high industrial significance, the reduction of the area of its crops in Ukraine in recent years actualizes the development of technologies for increasing yield and technological indicators of the crop. The research aims to study different regimes of applying mineral fertilizers on productivity, and the content of soluble sugars and proteins in sugar beet. The field study was conducted in the period of April-September 2023. The pre-sowing treatment was carried out using a hybrid of the productive and sugary direction Oleksandria employing deep ploughing up to 30 cm deep, the seeding density was 100 thousand/ha. The fertilization scheme provided for the introduction of a combination of complex fertilizers in one of two concentrations: $N_{180}P_{150}K_{200}$ or $N_{250}P_{200}K_{280}$ and a growth stimulator based on amino acids and trace elements Quantum. The application was carried out separately or in combination, the frequency of fertilization was one or two times. It has been demonstrated that the most pronounced positive effect on the increase in biomass

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and sugar content of beets is caused by the combined application of mineral macro fertilizers with the drug Quantum. In the case of the combined application option, the increase in the biomass of the root crop compared to the control was 120.8±8.5%-143.0±14.3%; the increase in the content of soluble sugars – in the range from 4.23±0.6% to 5.3±0.45%. An increase was also observed in comparison with the variants of separate applications of fertilizers. There was no significant difference between the two applied fertilizer concentrations, as well as when individual fertilizers and their combinations were re-applied. The content of proteins in terms of dry weight increased depending on the concentration and frequency of application of complex fertilizers. The obtained data on the increase in biomass of sugar content indicate the expediency of increasing these indicators is the use of a combination of mineral fertilizers containing macro- and microelements, so it is advisable to recommend a similar mode of fertilization. The data can become the basis for the development of recommendations for implementation in the industrial cultivation of sugar beet. Such techniques are economically feasible, as they allow for a reduction in the number of treatments and the consumption of fertilizer to obtain a harvest with high indicators

Keywords: trace elements; macronutrients; growth stimulant; agrotechnical characteristics; sowing treatment

INTRODUCTION

Sugar beet is one of the crops of strategic industrial and national importance. In recent years, Ukraine has seen a significant and progressive reduction in sugar beet acreage: from 318,000 hectares in 2017 to 220,000 hectares in 2023. Irrational use of soils, lack of proper crop rotation planning, reduction of areas under perennial grasses and legumes, as well as climatic factors, lead to a decrease in the fertility of black soil (Gamajunova *et al*., 2021). Another unpredictable factor in soil erosion is the full-scale Russian invasion of Ukraine, which caused a reduction in the area available for agricultural cultivation, with some soil areas experiencing erosion and loss of fertility due to explosions and demining (Drobitko *et al*., 2023). Under the current circumstances, it is particularly important to make the most efficient use of the available areas to obtain the highest possible yield. Although beet cultivation technologies have been known and used for a long time, there is a need to improve them due to the peculiarities of changing climatic conditions, soil composition, and peculiarities of changing plant varieties (Hospodarenko & Martyniuk, 2020). Among the known ways to increase yields are the application of organic and mineral fertilisers, as well as the use of growth stimulants. For most macro- and microelements, the concentrations required to obtain a certain yield weight are set, so their application is the key to obtaining the predicted weight of the beet crop (Tyrus, 2018). The dependence of yield and sugar content is shown in many modern studies, while the selection of the amount of fertiliser, conditions and method of application should be selected considering the specific conditions of cultivation: soil characteristics and climatic conditions in the area of cultivation.

The experience of international authors can be useful in developing beet cultivation schemes, but soil and climatic conditions require adaptation, so it is important to consider the experience of Ukrainian scientists. M. Tyrus (2018) studied the influence of tillage methods and different regimes of nitrogen, potassium and phosphate fertilisation and demonstrated that, regardless of the tillage method, the application of higher fertiliser concentrations led to an increase in root crop weight. O.V. Pismennyi (2012) demonstrated the importance of using micro fertilisers containing phytohormones and trace elements to increase the yield of table beet. S. Shahini *et al.* (2023) in their study of the quality of agricultural soils indicate that there is a reverse problem with the use of mineral fertilisers: the accumulation of some elements and products of their transformation in the soil, and increased eutrophication. M.O. Lukyaniuk *et al.* (2021) describe the problem of the negative effects of excess nitrogen in the soil, especially when it is accompanied by a lack of potassium and phosphorus. The authors draw attention to the need to select fertiliser doses since despite the importance of nitrogen for increasing sugar content, high doses (over 120 kg/ha) have the opposite effect: a decrease in yield and sugar yield. In this regard, the use of fertilisers should be as rational as possible, ensuring maximum absorption by plants, so it is important to monitor soil agrochemical parameters and study the needs of individual crops.

The main industrially valuable component of sugar beet raw materials is soluble sugars, namely sucrose. However, production wastes, in particular sugar pulp, can be a valuable source of other nutrients for feed production (Türk & Arslanoglu, 2023). Therefore, it is also important to determine the protein value of the resulting crop. The research aims to determine the influence of fertilisation regime on the increase of root biomass and soluble sugars and protein content in sugar beet crops.

MATERIALS AND METHODS

The field study was conducted in April-September 2023. Pre-sowing cultivation was carried out by deep ploughing up to 30 cm deep. The soil belongs to the type of ordinary low-humus dusty light clay soil. Before sowing the seeds, the agrochemical characterisation of the soil of the experimental area was carried out, using the following methods: humus content – according to Tyurin; alkaline hydrolysable nitrogen – according to the Kornfield method; mobile forms of phosphorus and potassium – determination by Chirikov (Ovcharuk *et al*., 2019). pH was determined ionometrically.

The study of the effect of mineral fertilisers on beet yields was conducted using the yield-sugar beet hybrid Alexandria, which has been included in the State Register of Varieties and Hybrids since 1997. The planting density was 100 thousand/ha. The following concentrations were used as the baseline level of mineral fertilisers in terms of the main elements: $N_{180}P_{150}K_{200}$, with higher concentrations used as a second option: $N_{250}P_{200}K_{280}$. The Quantum growth stimulator, which is a mixture of amino acids and trace elements, was also used separately. According to the manufacturer's instructions: N – 9.5% (95 g/l); CaO – 2.0% (20 g/l); MgO – 1.5% (15 g/l); Fe – 1.2% (12 g/l); Zn – 1.2% (12 g/l); Cu – 0.7% (7 g/l); SO3 – 1.8% (18 g/l); Mn – 0.7% (7 g/l); B – 0.5% (5 g/l); Mo – 0.01% (0.1 g/l); amino acids – 5% (50 g/l). The stimulant was applied at a concentration of 1.5 litres/ha. Each of the mineral fertilisers was applied separately once: during pre-sowing cultivation, or twice: the second fertilisation was applied 30 days after sowing. In variants with combined micro fertiliser application, they were applied simultaneously with mineral fertilisers, 30 days after sowing. In case of repeated application, micro fertilisers were applied 30 days after the first application. All fertiliser application options are presented in Table 1.

Table 1. *Fertiliser options and combinations*

Control	-	No treatment
One-time treatment	1	$N_{180}P_{150}K_{200}$
	2	$N_{250}P_{200}K_{280}$
	3	Quantum
	4	$N_{180}P_{150}K_{200}$+ Quantum
	5	$N_{250}P_{200}K_{280}$+Quantum
Two-time treatment	1	$N_{180}P_{150}K_{200}$
	2	$N_{250}P_{200}K_{280}$
	3	Quantum
	4	$N_{180}P_{150}K_{200}$+Quantum
	5	$N_{250}P_{200}K_{280}$+Quantum

The size of each plot was 35 m_2, and each trial was replicated three times. Thus, a total of 31 experimental plots were laid out. The crop was harvested and weighed separately from each plot, and only the weight of the roots was considered, after separating the green mass of the tops. The weight was recalculated per 1 ha of sown area.

Sugar content was determined individually for each plot and averaged for each experimental variant. The sugar content was determined in the laboratory by the acid inversion method, and the soluble carbohydrate content was measured spectrophotometrically. Protein content was determined by the Lowry method with photocolourimetric measurement of optical density. To make the data on protein and carbohydrate content comparable and to compare their relative increase in total biomass, the resulting amounts of sugars and proteins were converted into percentages of dehydrated biomass. The measurement results were compared using a one-way ANOVA analysis of variance. The statistical significance of the data was assessed using the F-criterion.

The experimental studies of plants (both cultivated and wild), including the collection of plant material, were in accordance with institutional, national or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

Analysing the agrochemical parameters, the following characteristics were obtained, as shown in Table 2. The methods used to determine the agrochemical characteristics are also shown in Table 2. These indicators are quite typical for typical chernozem soils and are favourable for sugar beet cultivation.

Table 2. *Agrochemical parameters of the soil of the experimental area*

Characteristic	Humus content (by Tyurin)	Alkali-hydrated nitrogen, mg/kg (by Grandval-Lajoux)	Mobile phosphorus forms, mg/kg (by Chirikov)	Mobile potassium forms, mg/kg (by Chirikov)	pH
Indicator	4±0.3%	97±7.5	115±8.7	160±12	6±0.2

The results of the study indicate that the application of mineral fertilisers contributes to a significant increase in the biomass of sugar beet roots. The average biomass of root crops harvested in the control variant without fertilisation was 23.50±1.32 t/ha. In the experiment where fertilisers were applied once, during sowing, a significant increase in weight was observed. In the variant with the use of average doses of mineral fertilizers $N_{180}P_{150}K_{200}$, the harvested biomass of the root crop was 40±3 t/ha, which is an increase of 70.9±10.54% compared to the control without treatment. In the variant where the pre-sowing treatment with $N_{250}P_{200}K_{280}$ was applied, the yield weight was 45±2.5 t/ha, which is 91.66±5.04% more than in the control. In the sowing treatment with Quantum micro fertiliser, the weight of harvested roots was 34.50±1.50 t/ha, which is 41.94±5.55% higher than without treatment. Thus, these data indicate a significant impact of mineral fertilisers on the increase of sugar beet biomass, which is also well-known from previous experience. At the same time, the combination of microelements is more effective for biomass growth compared to micro fertilisers. The generalised data on biomass growth in all variants of the experiment are presented graphically in Figure 1.

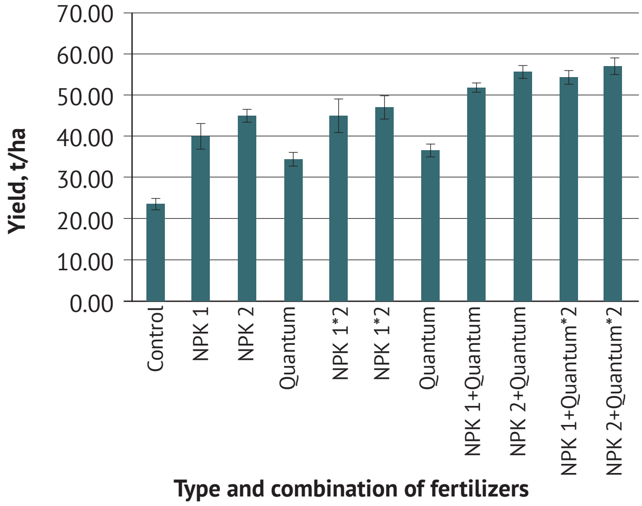

Figure 1. *Yield of sugar beet harvested from plots with different fertilisation regimes, t/ha*

Note: *NPK1 – $N_{180}P_{150}K_{200}$; NPK2 – $N_{250}P_{200}K_{280}$*

The biomass growth compared to the control variant without treatment is shown in Table 3. The second fertilisation, which was carried out 30 days after sowing, coincided with the phase of 4-6 leaf formation. The harvested yield was as follows: with the second application of $N_{180}P_{150}K_{200}$ – 45±4 t/ha (92.35±12.4% higher than in the control). With the application of mineral fertilisers in increased concentrations of $N_{250}P_{200}K_{280}$ – 47±2.65 t/ha (100.2±11% higher than in the control). Re-application of micro fertilisers allowed for a harvest of 36.5±4 t/ha, which is 55.43% higher compared to the untreated control. As you can see, repeated fertilisation did not significantly affect biomass growth compared to a single application, there was some tendency to increase biomass, but it was not significant (Table 3). The data obtained cast doubt on the need for repeated application of mineral fertilisers, it can be assumed that pre-sowing treatment with the applied combinations sufficiently saturates the soil with the necessary elements for the full growth of root crops when sowing beetroot at this density. However, these data may not be relevant for other agrochemical parameters of the soil or an increase in sowing density.

Table 3. *Relative weight gain of sugar beet under different fertilisation schemes*

Fertiliser application rate	Fertiliser type	Mass increase in comparison to control
One-time treatment	$N_{180}P_{150}K_{200}$	70.9±10.54
	$N_{250}P_{200}K_{280}$	91.7±5.0
	Quantum	46.9±5.5
Two-time treatment	$N_{180}P_{150}K_{200}$	92.3±12.4
	$N_{250}P_{200}K_{280}$	100.2+11.3*
	Quantum	55.4±3
One-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	120.8±8.5*
	$N_{250}P_{200}K_{280}$+Quantum	137±14.8*
Two-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	131.8±16.5*
	$N_{250}P_{200}K_{280}$+Quantum	143.0±14.3*

Note: ** – significant compared to the control ($p \leqslant 0.05$)*

At the next stage of the study, the effectiveness of the use of a combination of mineral fertilisers containing trace elements with micro fertilisers was analysed. In the case of pre-sowing one-time treatment with fertilizer containing $N_{180}P_{150}K_{200}$ in combination with Quantum, the harvested weight of root crops was 51.83±1.05 t/ha, which is 120.88±8.48% higher than in the untreated control and more than in each of the variants of individual fertilizer application. The combination of $N_{250}P_{200}K_{280}$ with Quantum allowed to harvest of a root crop weighing 55.67±1.05 t/ha, which is 137.37±14.84% more than in the untreated control and higher than in each of the variants of individual fertilisation. It should be noted that the difference between the two concentrations of mineral fertilisers – standard and increased, in this treatment variant, was 16.49% on average, which is not a statistically significant difference. The second treatment with the fertiliser combination also did not lead to a significant increase in yield compared to the single treatment, similar to the separate application of fertilisers. Repeated treatment with the combination $N_{180}P_{150}K_{200}$ – Quantum allowed to harvest a yield of 54.33±1.53 t/ha (131.77% more compared to the untreated control). Double fertilisation with a higher concentration of macro-mineral fertiliser $N_{250}P_{200}K_{280}$ with Quantum increased the yield to 57±2 t/ha (142.2±14.32% more than the untreated control). As you can see, the double application of an increased dose of complex mineral fertiliser in combination with micro fertiliser allowed us to collect the highest yield, but the difference between a single pre-sowing treatment and a double treatment was on average 22.11%. As can be seen from the data in Table 3, the best effect on the growth of sugar beet biomass is provided by the use of a combination of complex fertilisers and micro fertilisers, which proves the feasibility of using such a combination.

Biomass growth is an important indicator of fertiliser efficiency. However, the crop must not lose its industrial characteristics, the main of which for sugar beet is the sugar content. Therefore, in the second stage of the study, the soluble sugar content of the roots harvested from all plots was compared. The sugar content was converted to a percentage of dry biomass. The content of soluble sugars in the control variant of the experiment was 14.03±0.25%, which is the average for this variety, the maximum sugar content for which is 18-20% (Fig. 2). The sugar content in beetroot harvested from the plot fertilised with $N_{180}P_{150}K_{200}$ was 15.83±0.58%, which is 1.8±0.66% higher than in the control variant. With the application of increased doses of mineral fertiliser $N_{250}P_{200}K_{280}$, the sugar content in the root crop increased to 3.60±0.26%, an increase over the control of 2.23±0.25%. When applying the micro fertiliser Quantum, the sugar content in the biomass was 16.97±0.64%, which is 2.93±0.45% higher compared to the control. This increase in sugar content compared to the control is quite significant and correlates with the effect of macro-mineral fertilisers, which indicates various possible mechanisms for increasing the content of simple carbohydrates in sugar beet.

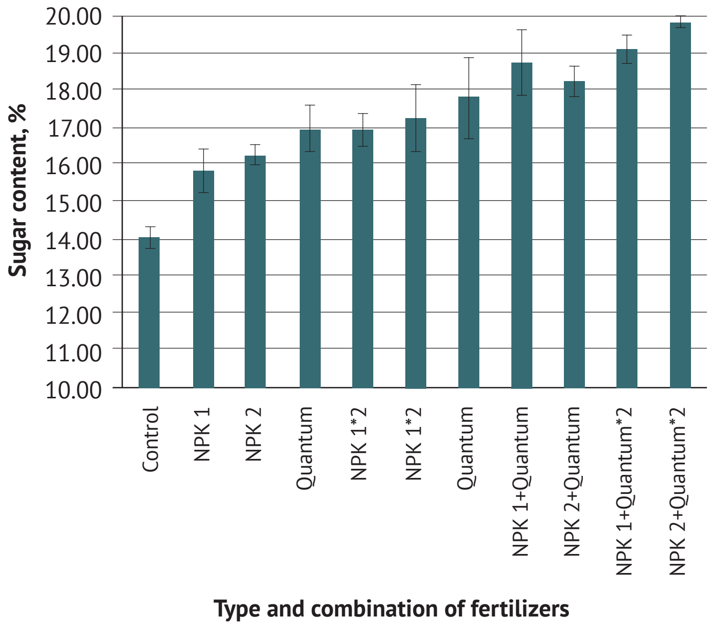

Figure 2. *Sugar content in beetroot harvested from plots with different fertilisation regimes, % of dry weight*
Note: *NPK1 – $N_{180}P_{150}K_{200}$; NPK2 – $N_{250}P_{200}K_{280}$*

Repeated fertilisation affected sugar content as follows. In the variant with the introduction of an average dose of mineral fertiliser $N_{180}P_{150}K_{200}$, this indicator was 16.93±0.4% (2.9±0.66% higher than in the control variant). With the repeated application of a higher concentration of fertiliser $N_{250}P_{200}K_{280}$, the sugar content was 17.27±0.87% (3.23±0.95% higher than in the control). In the variant with the introduction of micro fertiliser, the sugar content was 17.80±1.08%, which is 3.77±1.25% higher than in the control. Thus, it can be seen that there is some tendency to increase sugar content after the second treatment with individual complex fertilisers, but this difference is not significant compared to a single application of these types of fertilisers. All the data on sugar content in the dry weight of sugar beet in different variants of the experiment are shown graphically in Figure 2, and the increase in the indicator relative to the control is given in Table 4.

Table 4. *Sugar increase relative to the control in sugar beet harvested from plots with different fertilisation regimes, %*

Fertiliser application rate	Fertiliser type	Increase in sugar content relative to control
One-time treatment	$N_{180}P_{150}K_{200}$	1.8±0.65
	$N_{250}P_{200}K_{280}$	2.23±0.25
	Quantum	2.93±0.45
Two-time treatment	$N_{180}P_{150}K_{200}$	2.9±0.66
	$N_{250}P_{200}K_{280}$	3.23±0.95
	Quantum	3.8±1.1
One-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	4.7±0.64*
	$N_{250}P_{200}K_{280}$+Quantum	4.23±0.6
Two-time treatment	$N_{180}P_{150}K_{200}$+ Quantum	5.0±0.2*
	$N_{250}P_{200}K_{280}$+Quantum	5.3±0.45*

Note: ** – significant compared to the control ($p \leqslant 0.05$)*

A comparison of the results of the combined use of fertilizers indicated the presence of a cumulative effect on sugar content. In the variant with sowing treatment with a combination of fertilizers in the usual concentration of $N_{180}P_{150}K_{200}$ and Quantum, the sugar content in root crops was 18.77±0.87% (an increase over the control of 4.7±0.64%). When applying an increased concentration of complex fertiliser $N_{250}P_{200}K_{280}$ with Quantum, the studied indicator was 18.27±0.87% (an increase compared to the control of 4.23±0.6%). The increase in sugar content was even more pronounced when the fertiliser combination was applied again. The treatment with $N_{180}P_{150}K_{200}$ and Quantum led to an increase in the sugar content in root crops to 19.9±0.36% (an increase over the control of 5±0.2%). At the same time, the increased concentration of mineral fertilizers $N_{250}P_{200}K_{280}$ in combination with Quantum increased the sugar content to 19.83±0.45%, which is 5.8±0.4% more than in the control. As can be seen from the above data, the combination of mineral fertilisers containing macronutrients with micronutrient fertilisers leads to a pronounced cumulative effect of application that exceeds the effect of each fertiliser separately. Thus, the use of the combination is advisable, especially given that the combination of fertilisers leads to a more pronounced increase in biomass and sugar content than the repeated application of mineral fertilisers based on nitrogen, potassium, and phosphorus.

The protein content can be an important indicator in terms of the nutritional value of the pulp, which can be used as animal feed – both directly and for the production of mixed fodder. The determination of protein content in the control variant showed its content at the level of 9.40±0.36%, which is a standard average for sugar beet. The application of mineral fertilisers on pine needles increased the protein content to 10.60±0.37% and 11.50±0.5% – when applying standard and increased concentrations, respectively. The application of micro fertiliser did not significantly affect this indicator – 9.73±0.25%.

Two-time treatment with complex fertiliser resulted in a slight increase in protein content both in comparison with the control and in comparison, with a single treatment: 12.3±0.36% and 12.40±0.56% and at medium and high doses, respectively. In the variant with repeated application of micro fertilisers, no significant differences were observed: 9.67±0.29%. The result of combined fertilisation was equivalent to the results of macro fertilisation: 11.73±0.21% and 11.43±0.29 when combining medium and high doses with Quantum. Repeated application of the fertiliser combination slightly increased the protein content: 12.53±0.45% and 12.74±0.15%, respectively. The data on protein content are shown graphically in Figure 3. As can be seen, the greatest impact on the protein content of sugar beet is made by the application of fertilisers containing nitrogen, potassium, and phosphorus, with a certain effect of repeated application. The combination with micro fertilisers in the experimental conditions did not have a significant effect on the protein content of sugar beet. It can be assumed that the increase in biomass observed in the experiment was mainly due to the accumulation of carbohydrates in plants, rather than an increase in the protein part.

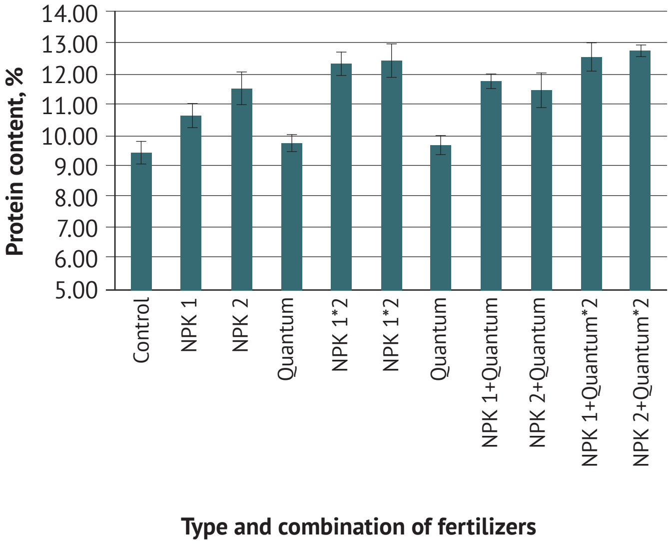

Figure 3. *Protein content in beetroot harvested from plots with different fertilisation regimes, % of dry weight*
Note: *NPK1 – $N_{180}P_{150}K_{200}$; NPK2 – $N_{250}P_{200}K_{280}$*

In general, the aggregate data on biomass growth and sugar content indicate that under the existing growing conditions, the most appropriate way to increase yields is to use a combination of mineral fertilisers containing macro- and microelements. The relative effect of other technological methods, such as increasing the concentration of the main elements per unit area and repeated fertilisation, does not have such a pronounced positive effect. Therefore, it is advisable to recommend such a fertilisation regime, which can reduce the cost of growing and harvesting sugar beet. The results of the study may be useful for the development of large-scale fertilisation technologies for sugar beet cultivation on an industrial scale, but the economic component of the process should be considered.

DISCUSSION

The study shows that the nature of the increase in biomass and soluble sugar content in sugar beet largely depends on the presence of macro- and microelements in the soil. The data are confirmed in numerous studies by colleagues. M. Abbas *et al.* (2018) studied the effect of nitrogen fertiliser deficiency on the sugar content of sugar beet when grown under drought conditions on sandy soils, showing that nitrogen fertiliser deficiency significantly reduces yields, but maintains and increases the sugar content. Y.E. El-Ghobashi and A.E.M. Eata (2020) in their studies emphasise the leading role of nitrogen fertilisers in increasing sugar beet yields when grown on depleted soils. H.A. Aslanov *et al.* (2023) investigated the effect of phosphate and potassium fertilisers in combination with different planting regimes, concluding that additional fertilisation and sparse planting (increased access to nutrients) increased yield quality. J. Chen *et al.* (2023) point out the importance of mineral fertilisation for satisfactory yields even when using organic fertilisers.

A combination of macro fertilisers, including nitrogen, phosphate, and potash, is essential for sugar beet growth. Usually, half of the fertiliser is applied in autumn and the other half during ploughing. In this study, the soil was not fertilised beforehand, so the background average recommended dose of fertiliser was applied during sowing. As a result, yields increased significantly compared to the control, and sugar content approached the maximum values for this variety. The most important mineral element that stimulates biomass growth is nitrogen. It is a component of building proteins, enzymes, vitamins, and chlorophyll, which together are essential for plant growth. K. Steinke & C.A. Bauer (2017) emphasise the leading role of nitrogen in increasing beet biomass and the problems that arise in the natural denitrification of soils. M. Tyrus (2018) cites data according to which about 4-5 kg of nitrogen, 1.5-2 kg of phosphorus, and 5-6 kg of potassium are removed from the soil to produce one tonne of sugar beet, so the introduction of these mineral fertilisers is the key to ensuring proper soil productivity. M. Tyrus demonstrated a dose-dependent increase in root crop weight with increasing fertiliser doses, the author uses 3 fertiliser concentrations: $N_{180}P_{135}K_{210}$, $N_{240}P_{180}K_{280}$, and $N_{300}P_{225}K_{350}$. As a result, it is possible to achieve biomass growth rates of 200 to 300% compared to the unfertilised variant. However, similarly to the results of this study, the amount of growth increases only slightly with increasing fertiliser concentration. Thus, it is necessary to calculate the amount of fertiliser based on the expected yield and the economic feasibility of increasing fertiliser concentrations. X. Xie *et al.* (2022) studied the combination of different fertiliser concentrations under different irrigation regimes. Among the fertilisers, the best growth and sugar content indicators were provided by the fertiliser concentration of $N_{229.5}P_{180}K_{202.5}$ kg/ha.

Both lower and higher concentrations of fertilisers showed worse growth-stimulating performance. At the same time, it was the potassium content that was recognised as a factor limiting the growth of biomass and sugar content. The study also demonstrated that irrigation is important and has a cumulative effect on yields along with fertilisation, which confirms the importance of considering the water regime of a particular growing area to determine optimal fertiliser concentrations.

A.M. Ali *et al.* (2023) demonstrate the limiting role of nitrogen fertiliser deficiency in increasing sugar beet fertility on depleted soils, with the best results obtained when using the maximum nitrogen fertiliser concentration of 215 kg/ha. M. Abbas *et al.* (2018) studied the effect of reducing the dose of nitrogen fertilizers from 288 to 216 kg/ha against the background of water deficit. It was shown that a decrease in soil nitrogen led to a decrease in yield and sugar content, but the relative sucrose content was higher, however, this did not increase the sugar level to control values. Thus, the availability of this element is a basic condition for the realisation of the growth potential of the crop, which is confirmed by the significantly lower yield of the control, unfertilised variant in this study. A. Salarian and A. Salari (2021) in his experiment compares the effect of fertilisation with nitrogen, potassium and phosphorus on such indicators as dry weight, sugars, proteins, and carbohydrates. The variants with background concentrations ($P_{120}K_{90}$) and N_{90} are compared with the unfertilised control. It is demonstrated that each of the application options leads to an increase in all these indicators. Reducing the planting density, i.e., greater availability of substances, leads to a similar effect of increasing the nutrient content of the crop.

The study by A. Panfilova and V. Gamayunova (2019) demonstrated that the second fertilisation did not have a significant effect on the growth of biomass and sugar content compared to the single fertilisation. This can be explained by the low absorption of substances, including microelements, from the soil in the initial phase of growth – up to 40-45 days of growth, before the first 10 leaves appear. However, as L. Kolaric *et al.* (2015) points out, the crop is very sensitive to soil nutrient deficiencies during this period, especially in the period of 4-6 pairs of leaves, during the period of secondary cambium establishment, so fertilisation is mandatory. Since most of the nutrients were not absorbed from the soil, the addition of the second portion of fertiliser did not significantly affect the yield and sugar content. As shown in the study, the weight of beetroot was significantly lower in the control variant, so the lack of mineral fertilisation may have played a limiting role in increasing biomass. K. Bürcky *et al.* (2018) present the results of long-term studies of the extraction of nutrients from the soil by sugar beet, which were conducted over 19 years. These studies demonstrate that the extraction of trace elements such as nitrogen, potassium, and sulphur is gradually decreasing. The authors attribute this phenomenon to the development of more optimised varieties with high productivity and lower absorption of trace elements from the soil. These studies emphasise the importance of reviewing soil cultivation methods and selecting fertilisation methods that are optimal for a given natural zone and period.

One of the most important results of this study is the identification of the cumulative effect of the combination of complex fertiliser and micro fertiliser. Many researchers have reached similar results when cultivating sugar beet in different climatic conditions. A. Salarian and A. Salari (2021) in their study demonstrated that the use of micro fertilisers together with fertilisers containing trace elements significantly increases the sugar content in sugar beet roots, especially when it is accompanied by a decrease in nitrogen in fertilisers. They managed to achieve a sugar content of 19.16-20.01% when combined with micro fertilisers. The main elements that influenced the sugar content were iron, zinc, manganese, and magnesium. These elements are also present in the Quantum preparation used in this study. M.Z. Aghdam and R. Valilue (2023) studied the effect of the interaction of micro fertilisers containing iron, zinc, and boron on the technological parameters of sugar syrup obtained from beetroot. The maximum growth of root crops and the purity of raw syrup were obtained with the combined use of $Zn_{100}B_{20}$. O.V. Pismennyi (2012) studied the effect of micro fertilisers in different concentrations on yield and sugar content and demonstrated an increase in yield by 17 – 94% when applying different types and concentrations of micro fertilisers. It should be noted that in this study, even higher yields were achieved by applying a combination of fertilisers at medium doses of macro fertilisers and the lowest doses of micronutrients recommended by the manufacturer. Thus, numerous studies by Ukrainian and international colleagues point to the need to use mineral fertilisers, with due regard to climatic conditions and soil agrochemical parameters. With a competent and planned approach to cultivation and the use of reasonable combinations of different types of mineral fertilisers, it is possible to achieve a crop with high technological indicators and reduce economic costs. Further research should be aimed at studying the effect of the proposed fertiliser combinations on other technological indicators of sugar beet, such as juice purity, sugar extraction, and concentration of reducing substances. It is also advisable to analyse the effect of different concentrations and combinations of micro fertilisers to increase yield and sugar content.

CONCLUSIONS

The influence of different fertilisation regimes on the yield, and accumulation of sugars and proteins in the roots of sugar beet of the Alexandria hybrid was studied. The data obtained confirm the need for mineral fertilisers in the cultivation of beet to realise the growth potential of the variety. The most effective for increasing biomass growth was the application of a combination of complex mineral fertiliser containing nitrogen, sodium, and phosphorus in combination with micro fertiliser Quantum: the biomass growth compared to the untreated control was 120.8±8.5-143.0±14.3%, depending on the amount and frequency of fertilisation. The difference between the concentrations of fertilisers $N_{120}P_{90}K_{180}$ and $N_{150}P_{110}K_{300}$ was more pronounced at a single application (about 20%), with repeated application it was reduced to 10%, so the concentration in the soil reached a certain saturation, and further increase in fertilisers did not affect the biomass growth.

The combined fertiliser application also had the best effect on the sugar content of beetroot, the increase in soluble sugars ranged from 4.23±0.6 to 5.3±0.45% under different combined fertiliser application schemes and reached the maximum values for this hybrid, about 20%. Increasing the concentration of fertilisers when used separately, as well as the frequency of their application, did not significantly affect the increase in the sugar content of beet (no significant difference).

The most significant effect on the protein content of biomass was exerted by the concentration of combined fertilisers containing nitrogen, potassium, and phosphorus. The addition of mineral micronutrient fertilisers did not make a significant contribution to the increase in this indicator. Probably, these macronutrients are the main limiting components for protein synthesis. Thus, the increase in biomass observed in the experiment was mainly due to the accumulation of carbohydrates in plants.

Based on the study, it can be concluded that it is advisable to use a combination of fertilisers containing macro- and microelements. From the point of view of improving the commercially valuable qualities of sugar beet, this is more appropriate than repeated processing. Implementation of the proposed measures can reduce fertiliser costs and allow for achieving high yields and sugar content. Further research should be aimed at deepening the influence of micro fertilisers on the yield, sugar content, and other technological parameters of sugar beet.

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CONFLICT OF INTEREST

None.

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Вплив різних режимів удобрення на врожайність і вміст поживних речовин у врожаї цукрового буряка

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Анотація. Цукровий буряк є однією з сільськогосподарських культур з високою промисловою значущістю, скорочення площ його посівів в Україні останніми роками актуалізує розвиток технологій підвищення врожайності та технологічних показників культури. Метою роботи було дослідження різних режимів внесення мінеральних добрив на урожайність, вміст розчинних цукрів та білків у цукровому буряку. Польове дослідження проведене в період квітня-вересня 2023 року. Передпосівна обробка проводилась з використанням гібриду урожайно-цукристого напрямку Олександрія шляхом глибокої оранки глибиною до 30 см, щільність висіву становила 100 тис/га. Схема удобрення передбачала внесення комбінації комплексних добрив у одній з двох концентрацій: $N_{180}P_{150}K_{200}$ або $N_{250}P_{200}K_{280}$ та стимулятору росту на основі амінокислот та мікроелементів Квантум. Внесення відбувалось окремо або в комбінації, кратність удобрення – одно- чи двократна. Продемонстровано, що найбільш виражений позитивний ефект на приріст біомаси та цукристості буряка чинить комбіноване застосування мінеральних комбінованим макродобрив з препаратом Квантум. При комбінованому варіанті внесення приріст біомаси коренеплоду стосовно контролю склав 120.8±8.5 %-143.0±14.3 %; приріст вмісту розчинних цукрів – в межах від 4.23±0.6 % до 5.3±0.45 %. Також спостерігався приріст в порівнянні з варіантами роздільного внесення добрив. Значущої різниці між двома застосованими концентраціями добрив, а також при повторному внесенні окремих добрив та їхньої комбінацій, виявлено не було. Вміст білків у перерахунку на суху масу збільшувався в залежності від концентрації та кратності внесення комплексних добрив. Отримані дані щодо приросту біомаси вмісту цукру, вказують на доцільність підвищення зазначених показників є застосування комбінації мінеральних добрив, що містять макро- та мікроелементи, тож доцільно рекомендувати подібний режим удобрення. Дані можуть стати основою для розробки рекомендацій для впровадження в промисловому вирощуванні цукрового буряку. Подібні прийоми мають економічну доцільність, оскільки дозволяють скоротити кількість обробок та розхід добрива для отримання урожаю з високими показниками

Ключові слова: мікроелементи; макроелементи; стимулятор росту; агротехнічні характеристики; припосівна обробка