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IMPACT OF NUTRIENT MANAGEMENT ON PHYSIOLOGICAL PROCESSES, BIOCHEMICAL PROPERTIES, AND PRODUCTIVITY OF TABLE BEETROOT (*BETA VULGARIS* L.)

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Aim. The purpose of the study was to determine the effect of different fertilizers and their aftereffects on the biometric and biochemical parameters of plants, the formation of yield, and the quality of beetroots. **Methods**. Field, statistical, calculation, analytical, and laboratory research methods were used in the study (dry matter (thermogravimetric method), total sugar (titration with red blood salt), ascorbic acid (according to Tillmans), nitrates (potentiometric method using nitrate-selective electrodes)). **Results**.The use of microbial preparations both separately and in the aftereffect of organic fertilizers led to an increase in the chlorophyll content in beetroot leaves (up to 7.36–9.14 mg/kg). The yield of table beetroots at the level of 52.6–57.6 t/ha is provided by mineral and organo-mineral fertilization systems, the aftereffect of 21 t/ha of manure, and a combination of organic fertilizers and microbial preparations. Using a complex of microbial preparations (Groundfix, Azotophyte, Organic Balance) to optimize the nutrition of beetroot plants increased the yield by 19 %. The values of most biochemical parameters in the products decreased with the increase in their yield. The use of high norms of mineral fertilizers or the localization of their administration conditioned the increase in the content of nitrates (1,490–2,349 mg/kg). With the increase in yield, a decrease in some biochemical parameters of beetroots (dry matter, total sugar, and ascorbic acid content) was observed. The use of high rates of mineral fertilizers or localization of their application led to an increase in the content of nitrates (1,490–2,349 mg/kg). Different fertilization systems for table beetroot provided the additional profit at the level of UAH 46.4–142.9 thousand/ha and the profitability of 42.6–69.6 % while reducing production costs to UAH 4.72–5.61 per one kg. **Conclusions.** The practical value of the research was determining the effect of different fertilization systems on a number of physiological processes and productivity of beetroot plants, the biochemical composition of root crops, and accumulation of nitrates in them, which allowed us to recommend the organo-mineral and biological fertilization systems with a complex of microbial preparations. In further research, it is important to establish the efficiency of alternative nutrition optimization systems with the combined use of humic and green manure fertilizers, and microbial preparations of various directions.

Key words: *Beta vulgaris* var. conditiva Alef., nutrition optimization, chlorophyll, peroxidase, productivity, content of nitrates.

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INTRODUCTION

Table beetroot (*Beta vulgaris* var. conditiva Alef) is a valuable vegetable cultivated in Ukraine. Its roots contain a high content of anthocyan substances, micro- and macroelements, and vitamins, which make this crop valuable for dietetic nutrition. In addition, this is a valuable raw material for the processing industry, where it is used to produce juices, borshch, preserves, natural food dyes (betanin), etc. (Food and Agriculture Organization, n.d.).

Beetroot consumes much more nutrients than other vegetables. Plants consume their significant amount in the period of intense growth of leaves and at the beginning of beetroot formation. In the period of beetroot ripening, they receive nutrients from the leaves, and the total consumption of nutrients decreases rapidly (Enchev, Bozhanska, 2022a).

The issue of the impact of fertilization efficiency on the quality and yield of beetroot is still urgent in modern literature. Many studies demonstrate that the increase in the dose of nitrogen fertilizers promotes the increase in both total and tradable yield of roots (Lopes et al, 2015; Reid et al, 2020). In particular, it was determined that on the loamy soils of New Zealand, the increase in the dose of nitrogen fertilizers for this crop from N_{160} to N_{480} led to the rise in the weight of raw substance of the roots from 80 to 111 t/ha (Reid et al, 2020). It was found that the optimal dose for high yields on such soils was nitrogen $N_{320,}$ which promoted high yields and low content of nitrates in the roots and was sufficient for a considerable amount of mineral nitrogen not to remain in the soil. The impact of different doses of phosphorus fertilizers on the yield of table beetroot was also studied, for instance, under drought conditions (Gerlani et al, 2019) and under salinization conditions (Ben-Ari et al, 2021). It is believed that the optimal norms of potassium on soils with a sufficient level of this element content are $K_{120\text{-}160}$ (Passos et al, 2020). At the same time, in the southern regions of Ukraine, smaller norms of potassium fertilizers are recommended to cultivate table beetroot – $K_{30\text{-}45}$ (Honcharenko et al, 2015). Optimal doses of mineral fertilizer complexes were determined for different zones of Ukraine. In particular, on the sod-podzolic and gray forest soils of Ukrainian Polissia, an effective dose of fertilizer for table beetroot is $N_{60\text{-}90}P_{60\text{-}90}K_{90}$, on typical chornozem of the Forest-Steppe – $N_{60}P_{60}K_{120}$, scattered, or $N_{30}P_{30}K_{60}$ locally, on usual chornozem of the Steppe – $N_{60}P_{90}K_{90}$, scattered, or $N_{30}P_{45}K_{45}$ locally (Honcharenko and Kornienko, 2015).

An important component of the quality and yield of table beetroot is the use of not only mineral fertilizers, but also other types of fertilizers. A number of scientists have shown the positive impact of microfertilizers on the quality indices of table beetroot: the nitrate content is reduced by the use of molybdenum and boron (Al-Khuzae et al, 2020), the damage to the roots by heart rot and the loss of dry matter, sugar, and ascorbic acid during storage of root crops with boron (Enchev et al, 2022b). It has also been shown that the combined use of mineral and organic fertilizers had a positive effect on the growth, quality, and yield of beetroot and improved soil properties. Organo-mineral fertilization systems decrease industrial expenses and danger to agrocenoses considerably (Ali et al, 2023).

Recently, various microbial preparations have been actively used to optimize the nutrition of vegetable plants. Microorganisms provide stimulation of plant growth processes and increase their productivity through various mechanisms: nitrogen fixation, solubilization of nutrients (phosphorus, potassium, etc.), production of phytohormones (auxins, cytokinins, gibberellins, etc.), iron sequestration through the production of siderophores, inhibition of phytopathogens through the synthesis of hydrolytic enzymes, siderophores, antibiotics, and cyanides (Ahemad & Kibret, 2014; de Souza et al, 2015). The effectiveness of using a complex of microbial preparations for the cultivation of table beetroot on chornozem soils of the Left Bank (Kuts et al, 2023) and Right Bank Forest-Steppe of Ukraine (Vdovenko et al, 2018) has been proven.

The identification of the patterns of table beetroot yield formation under the influence of mineral and organic fertilizers is an important condition for the development of a scientifically based fertilizer application system, which will allow for the selection of rational doses of fertilizers and time for their application. Thus, the purpose of the study was to investigate the effect of different fertilization systems on the biometric and biochemical parameters of plants, the formation of yield, and the quality of table beetroots.

MATERIALS AND METHODS

The research work was carried out in 2021–2023 in the conditions of the Left-Bank Forest-Steppe of Ukraine in long-term stationary experiments in a 9-field irrigated vegetable-fodder crop rotation of the Laboratory of Agrochemical Research and Product Quality of the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine. The material for the study was Bordo Kharkivskyi, a table beetroot cultivar.

The soil of the experimental field was presented by typical low-humus, heavy-loamy chornozem (pH of the salt extract – 5.8; the amount of absorbed alkali – 27.0 mg-eq. per 100 g of soil; hydrolytic acidity – 2.9 mg-eq. per 100 g of soil; humus content – 4.2 % nitrogen, which is hydrolyzed – 140.0 mg/kg; mobile phosphorus – 106–119 mg/kg and exchange potassium – 93 mg/kg of soil).

The average annual amount of precipitation in the zone of the studies is 471 mm. The most humid months in all the districts of the region are June and July, with 57–73 mm of precipitation. Relatively dry months are in early spring and autumn. The reserves of productive moisture in the 0–100 cm soil layer are 116–138 mm in April, and 39–77 mm in July (Archive of meteorological data, n.d.).

During the years of studies, the weather conditions of the beetroot vegetation period had some deviations from the average perennial indices. The HTC was noted at the level of 0.91 in 2021, 1.46 – in 2022, and 1.03 – in 2023 (the average perennial value – 1.05). In 2021, there was a considerable increase in the average daily air temperature starting from the second decade of June till the third decade of August (by 1.7–5.8 ^{o}C). In 2022, there was a considerable increase in the average daily air temperature compared to the perennial values in May–July (by 1.0–3.1 ^{o}C). In 2023, the decrease in the average daily air temperature was noted in June, while in July–August, this index exceeded the perennial values.

The scheme of a single-factor experiment covered twelve fertilization systems: organo-mineral, mineral, the aftereffect of organic fertilizers under different levels of their saturation (14 and 21 t/ha of the crop rotation area), resource-saving (using mineral resources locally), complex with the application of the estimated dose of mineral fertilizers and microelements (foliar application of "Nutrivant plus universal" (2 kg/ha) in three terms), green manure (the combination of plowing green manure for intermediate crops in case of cultivating beetroot predecessors and a complex of biopreparations), biological (aftereffect of organic fertilizers, green manure, and a complex of biopreparations) (**Table 1**). The estimated dose of mineral fertilizers ($N_{390}P_{100}K_{210}$) was determined for the yield level of 80 t/ha based on the indices of the removal of the main nutrients with the crop yield, coefficients of using the nutrients from fertilizers and soil.

The system of introducing microbial preparations for the beetroot cultivation covered seed processing with Azotophyte-r (2 l/t), soil processing under pre-sowing cultivation using Groundfix (5 l/ha), foliar nutrition with Organic balance-r (0.5 l/ha) + Azotophyte-r (0.3 l/ha) in the phase of 2–4 real leaves, foliar nutrition using Organic balance-r (1 l/ha) in three terms (the third-fourth pair of real leaves, the third-fourth pair of real leaves, the beginning of the root formation, 25–30 days after the previous introduction).

The following biological fertilizers and microbiological preparations were used during the study:

Azotophyte-r – a component of the preparation are the cells of rhizosphere bacterium *Azotobacter chroococcum* (1 × 10^9 CFU/g), which is capable of fixing nitrogen from the environment and deliver it to the plants. (Brochure about AZOTOPHYT, n.d.).

Organic-balance-r – composed of nitrogen-fixing, phosphorus- and potassium-mobilizing bacteria, and the microorganisms with fungicide properties and the products of their life activity. The preparation for fo-

Table 1. Fertilization systems for beetroot in vegetable-fodder crop rotation

The system of fertilization in the crop rotation	The system of fertilization for beetroot
No fertilizers	No fertilizers
Green manure with a complex of microbial preparations	Microbial preparations
Manure 14 t/ha + NPK	Aftereffect of 14 t/ha of manure + $N_{60}P_{60}K_{120}$
Manure 6 t/ha	Aftereffect of 21 t/ha of manure
NPK	$N_{60}P_{60}$K120
Manure 14 t/ha	Aftereffect of 14 t/ha of manure
Manure 14 t/ha + ½ NPK	Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$
Manure 21 t/ha + ½ NPK	Aftereffect of 21 t/ha of manure + $N_{30}P_{30}K_{60}$
NPK (estim.) + microfertilizers	$N_{390}P_{100}K_{210}$ + foliar fertilization with Nutrivant plus universal, 2 kg/ha in 3 terms (yield of 80 t/ha)
Manure 14 t/ha + ½ NPK (loc.)	Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)
Manure 21 t/ha + 1/4 NPK (loc.)	Aftereffect of 21 t/ha of manure + $N_{15}P_{15}K_{30}$ (locally)
Biological (manure 9 t/ha + green manure + microbial preparations)	Aftereffect of 9 t/ha of manure + microbial preparations

Source: composed by the authors.

liar nutrition and seed processing (Brochure about ORGANIC-BALANCE (vegetation), n.d.).

Groundfix – a biofertilizer, containing the cells of bacteria *Bacillus subtilis, Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum* (0.5–1.5) × 10^9 CFU/cc). It impacts phosphorus mobility and potassium availability from soil and mineral fertilizers (Brochure about GROUNDFIX, n.d.).

The total area of the plot was 58.3 sq.m. (8.33 m × × 7.0 m), the registration plot – 36.4 sq.m. (5.6 m × × 6.5 m), there were four repeats, the plots were located systematically in two layers. The technology of table beetroot cultivation covered ploughing for 25–25 cm, spring tillage and cultivation for 5–6 cm; cultivation of early-maturity cultivar of universal purpose, Bordo Kharkivskyi; wide rows with the row spacing of 70 cm and the density of 290–350 thousand plants/ha; precision irrigation with the irrigation norm of 300–450 cc/ha (4–5 irrigations).

The experiments and observations were planned and conducted according to the method of experimental work in vegetable and melon growing (Bondarenko & Yakovenko, 2001). The content of chlorophylls *a* and *b* and carotenoids was determined by the non-maceration method of extracting pigments according to Wellburn (Wellburn et al, 1994), the peroxidase activity – using the colorimetric method (Krasilnikova et al, 2007). The samples were taken in two terms: the phase of 5–6 real leaves and the beginning of the beetroot formation.

The product quality was determined visually using the standardized methods: dry matter – by the thermogravimetric method, total sugar – by the titration with red blood salt, ascorbic acid – according to Tillmans, nitrates – by the potentiometric method using nitrate-selective electrodes (Prytulska et al, 2007; Prysedskyi, 2022).

The statistical processing of the study results was done using the method of dispersion analysis, using the years as repeats (Rozhkov et al, 2016).

During the study, the authors adhered to the standards of the Convention on Biological Diversity (Convention on Biological Diversity, n.d.) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (Convention on International Trade in Endangered Species of Wild Fauna and Flora, n.d.).

RESULTS

On average, in three years of the study, the content of chlorophyll *a* in the leaves of table beetroot in the phase of 5–6 leaves in the control variant was 4.88 mg/g of dry matter but it increased considerably only in the variant with the aftereffect of 9 t/ha of manure with microbial preparations (5.41 mg/g of dry matter) (**Table 2**). The increase in the content of chlorophyll *b* in this phase under the effect of different fertilization systems compared to the control (2.71 mg/g of raw substance) was observed in most variants (3.44–3.86 mg/g of raw substance), except for the aftereffect of manure and mineral fertilization system. The total content of chlorophyll in the leaves of the table beetroot in the phase of 5–6 leaves exceeded the values in the control considerably (7.59 mg/ g of raw substance), in the variant with the aftereffect of 9 t/ha of manure with microbial preparations (9.14 mg/g of raw substance). There were no reliable differences in the content of total carotenoids between the control and the experimental variants.

In the phase of the root formation, there was a noted positive impact of the introduction of microbial preparations, $N_{390}P_{100}K_{210}$ + “Nutrivant plus universal”, and the aftereffect of 9 t/ha of manure with microbial preparations on the content of chlorophyll *a,* and the total chlorophyll in the leaves of the table beetroot (Table 2). The content of chlorophyll *b* in this phase was increasing compared to the control, and in case of the introduction of the fertilization system $N_{390}P_{100}K_{210}$+ “Nutrivant plus universal”, the aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally) and the aftereffect of 9 t/ha of manure with microbial preparations. Similar to the previous phase, no fertilization system had a considerable effect on the content of total carotenoids.

Redox potential characterizes the course of biochemical processes in a plant. One of the indicators to characterize it is the activity of redox enzymes, in particular, peroxidase. The changes in its activity are used as markers of plant resistance to stress factors, since, along with the antioxidant function, the peroxidase system is involved in ensuring the course of many other reactions (Kolupaev and Kokorev, 2019).

In our studies, the activity of peroxidase in the phase of 5–6 leaves was high in the control and after the aftereffect of 14 t/ha of crop rotation area of manure: 14.13–14.37 mmol/g per second (**Table 3**). At the same time, the activity of the enzyme in all other variants was much lower: 2.83–9.03 mmol/g per sec. In the phase of the beginning of the root formation, the peroxidase activity was lower than in the control after the introduction of $N_{60}P_{60}K_{120}$ and the aftereffect of 9 t/ha of manure with microbial preparations. Lower values of this enzyme activity may demonstrate better nutrition conditions in these variants, in particular, the ones caused by the decrease in the reactive oxygen intermediaries, the occurrence of which is related to the effect of stresses and in the inactivation of which the peroxidase takes part.

The analysis of the impact of the fertilization systems demonstrated that the introduction of $N_{60}P_{60}K_{120}$, the fertilization system $N_{390}P_{100}K_{210}$ + "Nutrivant plus universal", and the aftereffect of organic fertilizers in combination with the mineral fertilizers increased the yield of the table beetroot considerably (on average for three years): by 13.1–21.1 t/ha compared to the control (**Table 4**). The alternative way of optimizing the nutrition for the beetroot plants under the deficit of organic and mineral fertilizers is the use of a complex of microbial preparations (Groundfix, Azotophyte, Organic Balance) did not result in a considerable yield increase. In the variant with the dose of mineral fertilizers, estimated to obtain a yield of 80 t/ha, the mentioned yield index was not achieved. The yield of beetroot under this fertilization system was 54.7 t/ha, which demonstrates the inefficiency of this approach under the formation of the crop fertilization systems (Table 4).

A decrease in some biochemical indices of the products was noted with the increase in the beetroot yield (**Table 5**). In case of the aftereffect of 21 t/ha of manure, the aftereffect of 14 t/ha of manure with the introduction of $N_{30}P_{30}K_{60}$ and in case of the aftereffect of 21 t/ha of manure with the local introduction of $N_{15}P_{15}K_{30}$, there was a notable increase in dry matter content in the roots, up to 12.54–13.12 %. In case of the aftereffect of 14 t/ha of manure + $N_{60}P_{60}K_{120}$, the aftereffect of 14 t/ha of manure + local introduction of $N_{30}P_{30}K_{60}$, and the mineral fertilization systems, there was a considerable decrease in the index level (9.22–10.25 %).

Under all the fertilization systems, except for the aftereffect of 14 t/ha of manure, the aftereffect of 21 t/ha of manure with the introduction of $N_{30}P_{30}K_{60}$ and in case of the aftereffect of 21 t/ha of manure with the local introduction of $N_{15}P_{15}K_{30}$, there was a considerable decrease in the content of total sugar in the beetroot, down to the level of 7.31–9.80 %. The yield of sugar in all the fertilization systems, except for the introduction of $N_{390}P_{100}K_{210}$ + "Nutrivant plus universal", was higher than in the control, and

Table 2. The impact of different fertilization systems on the content of photosynthetic pigments in the leaves of the table beetroot, cultivar Bordo Kharkivskyi, mg/g of raw substance (on average in 2021–2023)

The system of introducing fertilizers	The content of chlorophyll and carotenoids in the leaves, mg/g			
	Chl *a*	Chl *b*	Chl (*a*+*b*)	Carotenoids
Phase of 5–6 leaves				
No fertilizers (control)	4.88	2.71	7.59	2.07
Microbial preparations	4.46	3.86*	8.32	1.78
$N_{60}P_{60}K_{120}$	4.81	3.07	7.88	1.89
Aftereffect of 14 t/ha of manure	4.40	2.48	6.88	1.63
$N_{390}P_{100}K_{210}$ + "Nutrivant plus universal"	4.79	3.44 *	8.23	1.71
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)	4.25	3.57 *	7.82	1.88
Aftereffect of 9 t/ha of manure + microbial preparations	5.41 *	3.73 *	9.14 *	2.28
Phase of the beginning of root formation				
No fertilizers (control)	3.18	2.84	6.02	2.03
Microbial preparations	4.04 *	3.32	7.36*	2.12
$N_{60}P_{60}K_{120}$	3.56	2.79	6.35	1.78
Aftereffect of 14 t/ha of manure	2.88	2.73	5.61	1.84
$N_{390}P_{100}K_{210}$ + "Nutrivant plus universal"	4.02 *	3.39 *	7.41*	1.80
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)	3.72	3.44 *	7.01	2.18
Aftereffect of 9 t/ha of manure + microbial preparations	4.69 *	4.08 *	8.77*	2.36
LSD_{05}	0.54	0.48	1.03	0.40

Note. * – the difference from the corresponding control variant is significant at $p < 0.05$. Source: composed by the authors.

Table 3. The impact of different fertilization systems on the peroxidase activity in the leaves of the table beetroot, cultivar Bordo Kharkivskyi (2021–2023), mmol/g per s

The system of introducing fertilizers	Peroxidase activity, mmol/g per s.							
	Phase of 5–6 leaves				Phase of the beginning of root formation			
	2021	2022	2023	Average	2021	2022	2023	Average
No fertilizers (control)	11.90	17.10	13.40	14.13	12.26	11.79	12.40	12.15
Microbial preparations	8.63	8.55	8.81	8.66 *	12.60	11.77	12.00	12.12
$N_{60}P_{60}K_{120}$	9.03	8.99	9.07	9.03 *	9.07	8.31	9.01	8.80
Aftereffect of 14 t/ha of manure	12.60	15.8	14.70	14.37	12.07	12.09	12.20	12.12
$N_{390}P_{100}K_{210}$+ “Nutrivant plus universal”	5.09	5.08	6.04	5.40 *	13.90	12.77	13.70	13.46
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)	2.58	2.78	3.12	2.83 *	11.07	11.09	11.40	11.19
Aftereffect of 9 t/ha of manure + microbial preparations	6.29	6.63	5.94	6.29 *	10.67	10.27	11.10	10.67
LSD_{05}	1.20	1.39	1.29	1.30	1.75	1.67	1.75	1.73

Note: * – the difference from the corresponding control variant is significant at $p < 0.05$. Source: composed by the authors.

fluctuated within 4.60–6.18 t/ha, which confirmed the fact of the “dilution effect” (the decrease in the sugar content in the roots) after the introduction of fertilizers.

Also, in most fertilization systems, except for the use of microbial preparations, the aftereffect of 14 t/ha of manure + $N_{60}P_{60}K_{120}$, the aftereffect of 14 t/ha of manure + local introduction of $N_{30}P_{30}K_{60}$, conditioned

Table 4. The impact of different fertilization systems on the beetroot yield, cultivar Bordo Kharkivskyi (2021–2023)

The system of introducing fertilizers	Yield, tons/ha				Gain	
	2021	2022	2023	average	t/ha	%
No fertilizers	39.1	41.1	38.3	39.5	0.0	0
Microbial preparations	39.9	53.1	48.2	47.1	7.6	19
Aftereffect of 14 t/ha of manure + $N_{60}P_{60}K_{120}$	45.2	78.2	48.8	57.4	17.9	45
Aftereffect of 21 t/ha of manure	41.7	77.2	54.0	57.6	18.1	46
$N_{60}P_{60}K_{120}$	41.5	59.8	56.5	52.6 *	13.1	33
Aftereffect of 14 t/ha of manure	43.1	44.1	56.7	48.0	8.4	21
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$	42.7	89.6	51.7	61.3	21.8	55
Aftereffect of 21 t/ha of manure + $N_{30}P_{30}K_{60}$	37.6	81.8	63.2	60.9	21.4	54
$N_{390}P_{100}K_{210}$ + foliar nutrition using “Nutrivant plus universal”, 2 kg/ha in 3 terms	42.3	64.5	57.3	54.7 *	15.2	38
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)	45.8	74.1	45.9	55.3	15.8	40
Aftereffect of 21 t/ha of manure + $N_{15}P_{15}K_{30}$ (locally)	47.4	82.4	51.8	60.6 *	21.1	53
Aftereffect of 9 t/ha of manure + microbial preparations	46.7	59.0	62.6	56.1 *	16.6	42
LSD_{05}	6.52	10.21	7.84	8.09		

Note. * – the difference from the corresponding control variant is significant at $p < 0.05$. Source: composed by the authors.

Table 5. The impact of different fertilization systems on the quality of beetroot products, cultivar Bordo Kharkivskyi (average in 2021–2023)

The system of introducing fertilizers	Mass content				sugar yield, t/ha
	dry matter, %	total sugar, %	ascorbic acid, mg/100 g	nitrates, mg/kg	
No fertilizers	11.51	10.45	12.90	499	4.13
Microbial preparations	11.87	9.80*	12.67	505	4.62
Aftereffect of 14 t/ha of manure + $N_{60}P_{60}K_{120}$	10.25*	8.01*	13.26	1223*	4.60
Aftereffect of 21 t/ha of manure	13.12*	9.78*	10.34*	801*	5.63
$N_{60}P_{60}K_{120}$	9.97*	8.89*	10.71*	798*	4.65
Aftereffect of 14 t/ha of manure	11.30	9.97	10.39*	724*	4.79
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$	12.54*	9.58*	9.34*	706*	5.87
Aftereffect of 21 t/ha of manure + $N_{30}P_{30}K_{60}$	11.95	10.15	8.70*	756*	6.18
$N_{390}P_{100}K_{210}$ + foliar nutrition using “Nutrivant plus universal”	9.22*	7.31*	11.77*	2349*	4.00
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)	10.47*	8.35*	12.32	1490*	4.70
Aftereffect of 21 t/ha of manure + $N_{15}P_{15}K_{30}$ (locally)	12.60*	9.98	10.97*	1245*	6.05
Aftereffect of 9 t/ha of manure + microbial preparations	11.02	9.56*	12.71	871*	5.36
LSD_{05}	0.62	0.52	0.98	72.4	

Note: * – the difference from the corresponding control variant is significant at $p < 0.05$. Source: composed by the authors.

Table 6. The economic indices of cultivating beetroot under different fertilization systems (average in 2021–2023)

The system of introducing fertilizers	Yield,tons/ha	Expenses for cultiva-tion, UAH thousand/ha	Profit, UAH thousand/ha	Profit from the fertili-zation systems, UAH thousand/ha	Cost of products, UAH/ kg	Profitability, %
No fertilizers	39.5	247.6	68.4	–	6.27	27.6
Microbial preparations	47.1	257.9	118.9	50.5	5.48	46.1
Aftereffect of 14 t/ha of manure + $N_{60}P_{60}K_{120}$	57.4	291.5	167.7	99.3	5.08	57.5
Aftereffect of 21 t/ha of manure	57.6	284.8	176.0	107.6	4.94	61.8
$N_{60}P_{60}K_{120}$	52.6	273.2	147.6	79.2	5.19	54.0
Aftereffect of 14 t/ha of manure	48.0	269.2	114.8	46.4	5.61	42.6
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$	61.3	289.1	201.3	132.9	4.72	69.6
Aftereffect of 21 t/ha of manure + $N_{30}P_{30}K_{60}$	60.9	295.8	191.4	123.0	4.86	64.7
$N_{390}P_{100}K_{210}$ + foliar nutrition using “Nutrivant plus universal”	54.7	292.1	145.5	77.1	5.34	49.8
Aftereffect of 14 t/ha of manure + $N_{30}P_{30}K_{60}$ (locally)	55.3	283.8	158.6	90.2	5.13	55.9
Aftereffect of 21 t/ha of manure + $N_{15}P_{15}K_{30}$ (locally)	60.6	292.5	192.3	123.9	4.83	65.7
Aftereffect of 9 t/ha of manure + microbial preparations	56.1	275.0	173.8	105.4	4.91	63.2

Source: composed by the authors

the decrease in the ascorbic acid content in the roots (8.70–11.77 mg/100 g).

The content of nitrates increased after the introduction of high norms of mineral fertilizers or the localization of their introduction. The content of nitrates, exceeding the maximal permissible level, was noted after the introduction of $N_{390}P_{100}K_{210}$ (2,349 mg/kg) and in case of the aftereffect of 14 t/ha of manure with the local introduction of $N_{30}P_{30}K_{60}$ (1,490 mg/kg). Under other fertilization systems, the index value did not exceed that of the maximal permissible level (1,400 mg/kg).

The use of different fertilization systems in beetroot cultivation is economically reasonable (**Table 6**). The profit after the introduction of mineral fertilizers and the aftereffect of organic fertilizers was UAH 46.4–132.9 thousand/ha, after the introduction of microbial preparations – UAH 50.5 thousand/ha, after the combination of low norms of organic fertilizers (up to 9 t/ha of crop rotation area) and the combination of microbial preparations – UAH 105.4 thousand/ha. High profit is ensured by the aftereffect of organic fertilizers with the norm of 21 t/ha of the crop rotation area, and the introduction of mineral fertilizers – scattered $N_{30}P_{30}K_{60}$ and local $N_{15}P_{15}K_{30}$ (additional profit of UAH 107.6–132.9 thousand/ha) after the aftereffect of 14–21 t/ha of manure. Under these fertilization systems, the cost of the products was the lowest in the experiment, fluctuating within UAH 4.72–4.94 per one ha when the control value was UAH 6.27/kg.

When different fertilization systems were used, the profitability level of beetroot cultivation increased from 27.6 % in the control to 46.1–69.6 %. A high profitability rate was ensured by the aftereffect of 21 t/ha of organic fertilizers and the use of mineral fertilizers – scattered $N_{30}P_{30}K_{60}$ and local $N_{15}P_{15}K_{30}$ after the aftereffect of 14–21 t/ha of manure.

DISCUSSION

In general, chlorophyll content in leaves is a crucial indicator of plant health. The concentration of the pigment, which can serve as a measure of both photosynthetic capacity and yield, is closely related to the nitrogen status of the plant. Chlorophyll affects the use of light energy in photosynthesis and the carbon cycle. Since the chlorophyll content is influenced by the nitrogen supply of the plant, there is always a strong relationship between the chlorophyll and nitrogen content of the plant leaves. As a result, the chlorophyll content in leaves is considered a potential bioindicator for monitoring the growth and development of crops, as well as determining the nitrogen nutrition status of the crop. High nitrogen application rates increase chlorophyll concentration in the leaves, while low nitrogen levels in the leaves result in pale green leaves due to low chlorophyll concentration. In our studies, we found a positive effect of high rates of mineral fertilizers and a combination of organic fertilizers and microbial preparations on chlorophyll content.

A positive aspect of using fertilizers in the cultivation of beetroot is a decrease in the peroxidase activity in the plant leaves. No significant difference compared to the control was observed in the aftereffect of low rates of organic fertilizers, using green manure and estimated mineral fertilization systems, which may indicate an increase in stress factors in the plant.

Improving the conditions of mineral nutrition through different fertilization systems leads to an increase in the beetroot yield. At the same time, the maximum effect on the level of crop yield was observed with the introduction of organic-mineral fertilization systems, where organic fertilizers were used for the predecessor, which is confirmed by studies of other scientists in different soil and climatic zones of the world (Zhakashbaeva et al, 2015; Sapkota et al, 2021). It was noted that the use of high rates of mineral fertilizers (for example, the estimated rate of $N_{390}P_{100}K_{210}$) did not provide a significant increase in the yield compared to the introduction of the recommended norm ($N_{60}P_{60}K_{120}$), which, in our opinion, is due to the incomplete use of nutrients from fertilizers by beetroot plants under these soil, climatic, and technological conditions of cultivation.

It is also possible to note the positive response of beetroot plants to the aftereffect of high rates of organic fertilizers (21 t/ha of crop rotation area). With this approach, a sufficient number of mobile forms of nutrients remains in the soil after harvesting the predecessor to form the optimal level of crop yield (18.1 t/ha). In the research of Wolna-Maruwka et al (2017) on the aftereffect of 35 t/ha of cattle manure, the maximum level of beetroot yield and high values of the main indicators of soil fertility were noted. In these studies, the use of $N_{90}P_{40}K_{180}$ also provided a high yield, but was inferior to the specified system of using only organic fertilizers in terms of the impact on the microbiological parameters of the soil (Biological Index of Fertility; higher number of pathogenic microflora, *Fusarium* sp. and *Alternaria* sp.)

Our studies did not confirm the fact of improving the quality indicators of beetroot with the use of mineral fertilizers, which was determined in the studies of Al-Khuzae et al (2020). At the same time, according to Zhakashbaeva et al (2015), different systems of optimizing the nutrition of beetroot plants did not provide a significant positive effect on the biochemical composition of root crops. In other studies, the introduction of nitrogen fertilizers in the dose of 0.6 g N/plant reduced the betanin content by 25 % from 352 to 258 mg/kg, while root crop yields increased (Sitompul and Zulfati, 2019). According to our assumption, the decrease in the content of biochemical indicators in root crops is associated with the "dilution effect", when, due to a sharp increase in yield, the relative content of biochemical components decreases, despite their higher synthesis in plants. This fact is confirmed by the positive impact of different fertilization systems on sugar yield, which increases significantly compared to the control, except for the use of $N_{390}P_{100}K_{210}$.

High rates of mineral fertilizers lead to an increase in the content of nitrates in root crops, which exceeds the maximum permissible level. Most of all, this problem is associated with a high rate of nitrogen fertilizers; in our studies, it was N_{390}. Lower rates of nitrogen fertilizers will not ensure the excess in the nitrate content compared to the maximum permissible level, which is confirmed in studies by New Zealand scientists with the introduction of N_{320} (Reid et al, 2020) and Lithuanian researchers using N_{90+30} (Bundiniene et al, 2009).

Thus, our research has determined the possibility of using a complex of microbial preparations as a certain alternative to classical fertilizers to optimize the nutrition conditions of beetroot plants. However, it is interesting to investigate how microbial preparations affect changes in soil fertility in irrigated crop rotations in the long term (agrochemical, water-physical, and microbiological parameters). In the future, it is also planned to determine the factors that limit the achievement of the planned level of crop yields when using the calculated rate of mineral fertilizers, to establish the coefficients of nutrient absorption from fertilizers and soil when applying high rates of fertilizers on chornozem soils.

CONCLUSIONS

The use of a complex of microbial preparations (both separately and after the effect of organic fertilizers) leads to an increase in the chlorophyll content in the table beetroot leaves (up to 7.36–9.02 mg/kg). Higher peroxidase activity was noted in the first stages of plant development (the phase of 5–6 leaves) only in case of the aftereffect of 14 t/ha of the crop rotation area of manure (14.37 mmol/g per s), in the phase of the beginning of the root formation, and also under the green manure fertilization and the use of the estimated dose of mineral fertilizers (12.12–13.46 mmol/g per s). The beetroot yield at the level of 52.6–57.6 t/ha is provided by mineral and organo-mineral fertilization systems, the aftereffect of 21 t/ha of manure, and a combination of organic fertilizers and microbial preparations. The dose of mineral fertilizers, estimated to obtain a yield of 80 t/ha, does not help achieve the corresponding yield level. The use of a complex of microbial preparations (Groundfix, Azotophyte, Organic Balance) to optimize the nutrition of beetroot plants increased the yield by 19 %. The values of most biochemical parameters in the products decreased with the increase in their yield. The use of high norms of mineral fertilizers or the localization of their administration conditioned the increase in the content of nitrates (1,490–2,349 mg/kg). Different fertilization systems for table beetroot provided the additional profit at the level of UAH 46.4–142.9 thousand/ha and the profitability of 42.6–69.6 % while reducing production costs to UAH 4.72–5.61 per one kg.

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Adherence to ethical principles. No experiments, described in this article, involved the use of animals

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Вплив застосування поживних речовин на фізіологічні процеси, біохімічні показники й продуктивність буряка столового (*Beta vulgaris* L.)

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Мета. Встановлення впливу різних добрив та їх післядії на біометричні та біохімічні показники рослин, формування врожайності та якості коренеплодів буряка столового. **Методи.** Для проведення досліджень використовували польові, статистичні, розрахунково-аналітичні та лабораторні методи досліджень (суха речовина термогравіметричним методом, загальний цукор – титруванням з червоною кров'яною сіллю, аскорбінова кислота – за Тільмансом, нітрати – потенціометрично з використанням нітрат-селективних електродів). **Результати.** Застосування мікробних препаратів як окремо, так і післядії органічних добрив зумовлювало підвищення в листках буряка столового вмісту хлорофілу (до рівня 7,36–9,14 мг/кг). Урожайність буряка столового на рівні 52,6–57,6 т/га забезпечують мінеральні, органо-мінеральні системи удобрення, післядія 21 т/га гною та поєднання органічних добрив і мікробних препаратів. За використання для оптимізації живлення рослин буряка столового комплексу мікробних препаратів (Граундфікс, Азотофіт, Органік баланс) урожайність зростає на 19 %. З підвищенням урожайності коренеплодів більшість біохімічних показників продукції знижується. Використання високих норм мінеральних добрив або локалізації їх внесення зумовлює зростання вмісту нітратів (1490–2349 мг/кг). З підвищенням рівня урожайності відмічається зниження деяких біохімічних показників коренеплодів буряка столового (вміст сухої речовини, загального цукру та аскорбінової кислоти). З використання високих норм мінеральних добрив й локалізацією їх внесення зумовлюють зростання вмісту нітратів (1490–2349 мг/кг). Різні системи удобрення буряка столового забезпечують отримання додаткового прибутку на рівні 46,4–142,9 тис. грн/га та рен-табельності 42,6–69,6 % за зниження собівартості продукції до 4,72–5,61 грн/кг. **Висновки**. Практична цінність досліджень полягає у визначенні впливу різних систем удобрення на ряд фізіологічних процесів і продуктивність рослин буряка столового, біохімічний склад коренеплодів та накопичення в них нітратів, що дає змогу рекомендувати органо-мінеральну та біологічну системи удобрення з комплексом мікробних препаратів. У подальших дослідженнях актуальним залишається встановлення ефективності альтернативних систем оптимізації живлення із спільним застосуван-ням гумінових і сидеральних добрив, мікробних пре-паратів різного спрямування.

Ключові слова: *Beta vulgaris* var. conditiva Alef., оптимізація живлення, хлорофіл, пероксидаза, урожайність, вміст нітратів.

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