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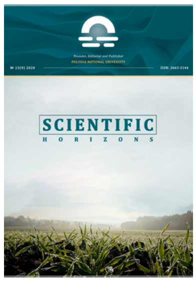

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Fertilisation system influence on the main agrochemical indicators of soil and productivity of white cabbage

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Abstract. The research relevance is determined by the need to study the long-term use of various fertilisers and their effect on the soil nutrient regime, yield, and quality of white cabbage. The research aims to determine the effect of different nutrition optimisation systems on the yield and quality of late-ripening white cabbage in irrigated vegetable-fodder crop rotation. Field, statistical, calculation-analytical and laboratory methods were used to conduct the research. It was established that the use of a mineral fertilizer system ($N_{550}P_{260}K_{370}$ + "NutriVant Plus Universal") led to an

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increase in the level of supply of the topsoil with mobile nitrogen, phosphorus, and potassium compounds, and had a positive effect on the biometric parameters and productivity of white cabbage plants. All fertilisation systems, except for the application of microbial preparations only provided a significant increase in yields in the range of 21.6-71.8%. However, a significant increase in the content of vitamin C in cabbage heads was observed for all fertilisation systems studied, except for the use of 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$ and $N_{550}P_{260}K_{370}$ + "NutriVant Plus Universal". The nitrate content in the heads did not increase significantly after fertilisation. The ineffectiveness of using the system of microbial preparations, including seed treatment with *Azotobacter chroococcum*, and soil treatment before pre-sowing cultivation with Roundfix, to optimise the nutrition of white cabbage plants was noted. (*Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, Bacillus subtilis*) and five foliar fertilisers Organic Balance (*Bacillus subtilis, Azotobacter chroococcum, Paenibacillus polymyxa*). The practical value is determined by obtaining results for adjusting fertiliser doses when planning their application in crop rotations of farms of different forms of ownership

Keywords: *Brassica oleracea* var. *capitata* L.; fertilisation systems; soil; crop rotation; irrigation; cultivation

INTRODUCTION

Ukraine, possessing fertile soils and a favourable climate, could become one of the world's future food suppliers, according to the Food and Agriculture Organisation (n.d.). However, it is worth noting that the use of soil resources in Ukraine is not always rational, which causes various degradation processes. This includes a decrease in the level of organic matter (humus), an increase in erosion processes, deterioration of soil agrophysical properties (increased dispersion, density, deterioration of structure and filtration capacity), changes in the acid-base state of the soil, signs of salinity, toxicity, and allopathy. All of this leads to a decrease in yields, deterioration in the quality of agricultural products, indicators of natural and effective soil fertility, and deterioration of the ecological state of the environment (Lykhovyd *et al.*, 2022).

Degradation processes are particularly intense in vegetable production due to the specifics of vegetable growing technologies. Thus, an urgent need arises to develop and implement vegetable-growing technologies that, in addition to increasing yields, also help to preserve or restore soil fertility. The key aspects of this approach include choosing the right crop rotation, optimising tillage, and improving plant nutrition. According to L. Zhang *et al.* (2022), the introduction of even short-term crop rotations (e.g., beans – mustard – rice) in combination with the use of calculated fertiliser rates contributes to a significant increase in yields, maintaining yield stability and sustainability of the crop production system.

Sustainable agricultural biocenosis relies on a sufficient amount of soil organic matter, the main sources of which are organic and green manure fertilisers. The use of organic fertilisers not only increases the humus content in the soil but also contributes to the stability of soil aggregates due to the binding effect of humic substances and microbial waste products (Reichert *et al.*, 2018). The combination of organic and mineral fertilisers leads to an increase in carbon sequestration, which is explained by the increase in the amount of plant residues due to the increase in plant productivity. However, without organic fertilisers, even high rates of mineral fertilisers cannot change the humus content. In their research, G. Xiapu *et al.* (2018) noted that the use of organic-mineral fertilisation systems provide the maximum impact on crop yields and soil C and N reserves, but the use of high manure rates can lead to an increased risk of nitrogen losses in the environment.

The introduction of a scientifically based system for optimising the nutrition of vegetable plants should ensure not only a sustainable increase in yields but also an increase in fertility by improving its parameters (agrochemical, microbiological, water and physical) (Stoessel *et al.,* 2018). This has become especially relevant in the context of martial law and the energy crisis. O. Zhernova *et al.* (2022) believe that under such conditions in Ukraine, the volume of fertiliser application has decreased sharply and, as a result, the yield of crops, including white cabbage, has decreased.

X.W. Cui *et al.* (2022) determined that the combined application of mineral and organic fertilisers increased the marketable yield and quality of white cabbage. The most effective was the replacement of 30% of organic fertilisers with mineral fertilisers, which increased the yield by 32.2%, the vitamin C content by 14.9%, the soluble sugar content by 5.5%, the efficiency of nitrogen absorption from fertilisers by 97% and the overall agronomic efficiency of fertilisers by 55.6%. According to L. Jin *et al.* (2022), a 30% reduction in the rate of mineral fertilisers when used in combination with organic fertilisers not only increases yields but also improves the physical and chemical composition of the soil, the number and diversity of beneficial bacteria and fungi in it.

It is worth noting that significant reductions in mineral fertiliser rates also have negative consequences for cabbage yields. Nitrogen fertiliser rates are particularly carefully controlled (Gonzaga *et al.*, 2021). A combination of organic and mineral fertilisers with green manure is also effective. For example, in studies on chernozem soils in Kazakhstan, the maximum level of cabbage yield and vitamin C content in heads is ensured by the application of 60 t/ha of manure + 3 t/ha of straw and N_{30} (Boteva *et al.*, 2019).

Therefore, it is necessary to study the long-term use of fertilisers in crop rotations and their aftereffects on soil nutrient regime, the productivity of vegetable plants (especially white cabbage), and soil fertility, which will allow adjusting fertiliser doses when planning their application in farm crop rotations. The research aims to determine the effect of different nutrition optimisation systems on soil nutrition, biometric parameters of plants, yield, and quality of late-ripening white cabbage in irrigated vegetable-fodder crop rotation.

MATERIALS AND METHODS

The research was carried out in 2020-2022 in a stationary long-term experiment of the Institute of Vegetable and Melon Growing of the National Academy of Agrarian Sciences of Ukraine. The experimental plots are located in the southeastern part of the Left-Bank Forest-Steppe of Ukraine, which is characterised by unstable moisture. During the years of research, the average amount of precipitation was 471 mm, with the highest amount of precipitation (57-73 mm) observed in June and July. The spring and autumn months were dry, with productive moisture reserves in the soil layer up to one metre ranging from 116 to 138 mm in April, and from 39 to 77 mm in July (Archive of meteorological data, n.d.).

The experiment site is located on land with typical chernozem, which is low-humus, heavy and loamy, with signs of forest loam. The agrochemical state of the topsoil has the following indicators: the sum of absorbed bases – 26.0 mg-eq per 100 g of soil; pH of the salt extract – 5.7; hydrolytic acidity – 2.8 mg-eq per 100 g of soil; humus content – 4.3%; hydrolysable nitrogen – 139 to 144 mg/kg; exchangeable potassium – 91 to 266 mg/kg; mobile phosphorus – 140 to 430 mg/kg of soil. The experiments were conducted on long-term stationary plots as part of a 9-year cycle of vegetable and fodder crops, including the following successive crops: barley with grass – alfalfa (first and second year of use) – cucumber – winter wheat – onion – tomato – white cabbage – table beetroot. Stationary trials were started in 1968. The experimental design included 12 different variants of fertiliser application systems: mineral, organic, organo-mineral, resource-saving (with local use of mineral fertilisers), and complex using a calculated dose of mineral fertilisers and microelements (Table 1).

***Table 1**. Fertilisation systems for white cabbage in crop rotation*

Fertilisation system in crop rotation	Fertilisation system for white cabbage
1. Without fertilizer	Without fertilizer
2. Green manure with a complex of microbial chemicals	Complex microbial chemicals
3. Manure 14 t/ha + NPK	Manure 60 t/ha + $N_{120}P_{120}K_{90}$
4. Manure 21 t/ha	Manure 90 t/ha
5. NPK	$N_{120}P_{120}K_{90}$
6. Manure 14 t/ha	Manure 40 t/ha
7. Manure 14 t/ha + ½ NPK	Manure 40 t/ha + $N_{60}P_{60}K_{45}$
8. Manure 21 t/ha + ½ NPK	Manure 60 t/ha + $N_{60}P_{60}K_{45}$
9. NPK (calculated) + microfertilisers	$N_{550}P_{260}K_{370}$+ foliar dressing “NutriVant Plus universal” at 2 kg/ha in 3 terms
10. Manure 14 t/ha + ½ NPK (locally)	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)
11. Manure 21 t/ha + 1/4 NPK (locally)	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)
12. Biological (organic fertilisers + green manure + microbial preparations)	Manure 40 t/ha + complex of microbial preparations

***Source:** compiled by the authors*

In the experiments, organic fertilisers were applied in the form of cattle manure, and mineral fertilisers (in all experimental variants, except for variants 10 and 11, where fertilisers were applied locally) – in the form of nitroammophoska, ammonium nitrate and potassium chloride. The microbial application system included seed treatment with Azotophyte (1 l/t), soil treatment with pre-sowing cultivation with Groundfix (5 l/ha), foliar feeding with Organic Balance (2 l/ha) five times (3-4 true leaves, 6-7 true leaves, rosette formation, beginning of head formation, 25-30 days after the previous application).

NutriVant Plus Universal is a fertiliser designed for foliar application to crops outside the root zone. Its composition includes the following components: nitrogen (N) – 19%, phosphorus (P2O5) – 19%, potassium (K_2O) – 9%, magnesium (MgO) – 2%, manganese (Mn) – 0.04%, zinc (Zn) – 0.02%, copper (Cu) – 0.005%, iron (Fe) – 0.08%, molybdenum (Mo) – 0.005% (ICL Specialty Fertilizers Logo Vector, n.d.). This fertiliser is used for foliar feeding of plants at three stages: at the stage of 3-4 true leaves, during rosette formation and at the initial stage of head formation.

Azotophyt-p is a formula containing live cells of the rhizosphere bacterium Azotobacter chroococcum, which is capable of fixing nitrogen from the environment and transferring it to plants. This bacterium also synthesises vitamins, amino acids, and phytohormones and produces antifungal substances. The number of live microorganisms of the bacterium Azotobacter chroococcum is at least 1x109 CFU/g (Brochure about AZOTOPHYT, n.d.).

Organic-Balance-P is a biological product designed to stimulate the growth and development of plants of various crops and increase resistance to diseases, pests, and stress. The composition of the product includes live bacteria that perform the following functions: fix nitrogen, mobilise phosphorus and potassium, have an antagonistic effect on fungi, produce biologically active substances such as vitamins, phytohormones, fungicides, antibiotics, amino acids, enzymes, and contain organic food sources and macro- and microelements. The product is used for foliar feeding and seed treatment (Brochure about ORGANIC-BALANCE (vegetation), n.d.).

Groundfix is a biofertilizer containing cells of the bacteria Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, and Bacillus subtilis. The total number of live cells ranges from 0.5 to 1.5 × 109 CFU/cm3. This product increases phosphorus mobility and potassium availability from soil and mineral fertilisers, prolongs the availability of nutrients, improves soil biological activity, and limits the development of phytopathogens (Brochure about GROUNDFIX, n.d.).

The experimental plot area was 58.3 m^2 (8.33 m × 7.0 m), with a recording area of 36.4 m^2 (5.6 m × 6.5 m). The experiment was conducted four times, placing the plots in a systematic arrangement on two levels. The technology of growing white cabbage corresponded to the conditions of the forest-steppe of Ukraine and included the use of drip irrigation. The methodology of the experiment and observation was developed following the "Methodology of experimental work in vegetable and melon growing" (Bondarenko & Yakovenko, 2001).

The following methods were used to determine the content of nutrients in the soil from the topsoil: nitrate determination according to State Standards of Ukraine (hereinafter DSTU) 4729:2007 (2008), determination of mobile phosphorus and potassium compounds in the modification of CINAO by Chirikov, and phosphorus was analysed by colorimetric method, and potassium – by photometer (DSTU 4115:2002, 2003). Biometric measurements at the stage of technical ripeness, harvest accounting and determination of the chemical composition of cabbage heads, including dry matter content according to DSTU 7804:2015 (2016), vitamin C content according to DSTU 7803:2015 (2016), total sugar according to DSTU 4954:2008 (2009), and nitrates according to DSTU 4948:2008 (2009) were carried out. During the research, the authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

Analysing the changes in the nitrate nitrogen content in the upper soil layer at a depth of 0-30 cm, it was observed that in the initial period of growth of white cabbage, an increase in this indicator was observed when using mineral fertilisers or combined application of organic and mineral fertilisers (in the range from 66 to 127 mg/kg dry soil). At the time when a complex of microbial preparations was used, or after the application of organic fertilisers alone, the nitrate nitrogen content ranged from 29 to 49 mg/kg dry soil (Fig. 1).

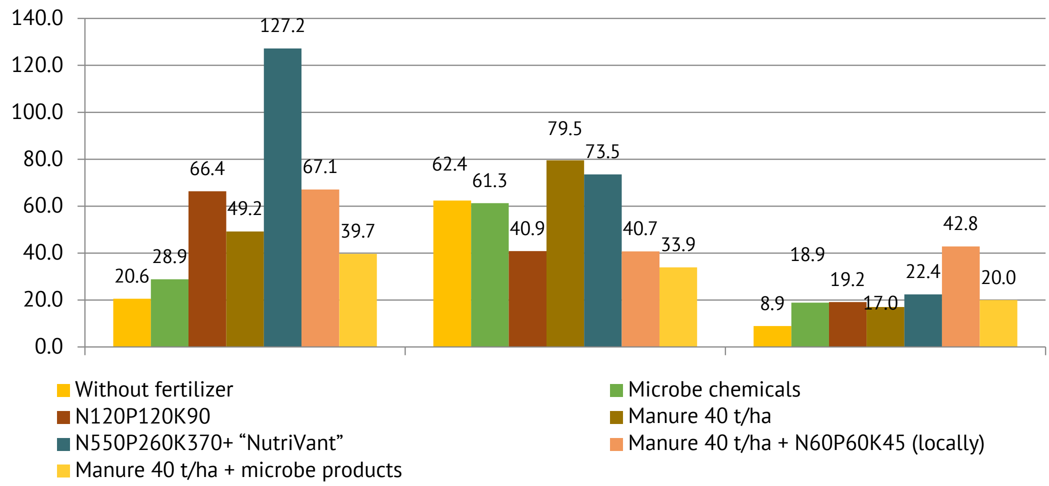

Figure 1. *Dynamics of nitrate nitrogen content in the soil layer 0-30 cm depending on the fertilisation system of white cabbage (average for 2020-2022)*

Source: *compiled by the authors*

The content of nitrate nitrogen in the soil decreased regardless of the fertilisation system, which indicates its active use by cabbage plants and migration in the soil profile. It is also worth noting that the highest level of nitrate nitrogen in the soil was recorded at the beginning of the growing season, at the stage of 3-4 true leaves – the beginning of the formation of the leaf rosette, when the use of mineral fertilisers was most effective. Instead, at the end of the growing season, a high value of this indicator was observed in the system of resource-saving fertilisation, where mineral fertilisers were applied locally.

A high level of mobile phosphorus in the upper soil layer at a depth of 0-30 cm was observed when both mineral and organic fertilisers were applied, both separately and together (in the range of 324 to 435 mg/kg dry soil, see Fig. 2). The level of mobile phosphorus remained stable throughout the entire growing season of white cabbage. However, it is worth noting a significant increase in mobile phosphorus in the soil when applying microbial preparations, where the content was 290 mg/kg of dry soil. Similar results were obtained in studies conducted by D. Sarkar *et al.* (2021), where the use of beneficial microorganisms (*Trichoderma harzianum, Pseudomonas fluorescens and Bacillus subtilis*) contributed to the activation of phosphorus and potassium in the soil and the uptake of these macronutrients by cabbage plants.

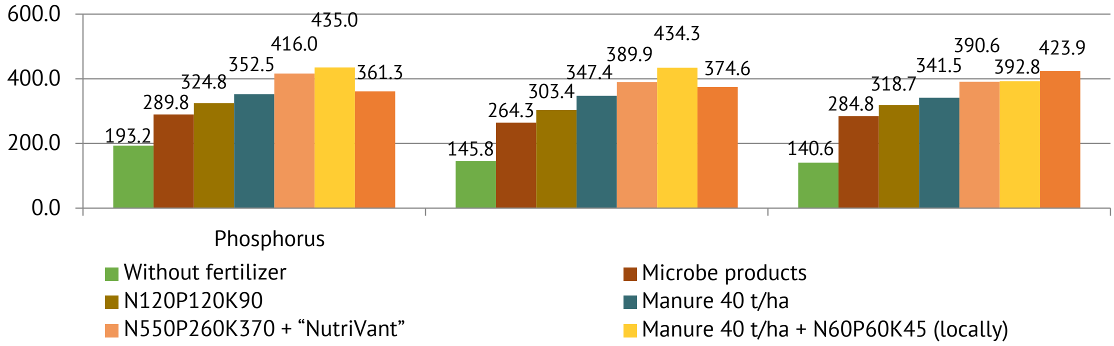

Figure 2. *Dynamics of mobile phosphorus content in the soil layer 0-30 cm depending on the fertilisation system of white cabbage (average for 2020-2022)*

Source: *compiled by the authors*

A significant content of mobile phosphorus forms in the soil at the beginning of the growing season was ensured by the use of an organic-mineral fertilisation system and mineral fertilisers locally (435 mg/kg of dry soil). The effectiveness of localised fertilisation in terms of increasing the content of mobile phosphorus in the topsoil was confirmed in the research of L.O. Duarte *et al.* (2019), where the introduction of this technological measure led to an increase in the phosphorus uptake coefficient from fertilisers from 30.0% to 60.4%. All fertilisation systems led to an increase in the content of exchangeable potassium in the 0-30 cm soil layer. The use of the calculated dose of mineral fertilisers ($N_{550}P_{260}K_{370}$) provided the maximum values of the indicator during the entire vegetation period of white cabbage (213-266 mg/kg). Thus, during the phase of 3-4 true leaves – the beginning of the formation of a rosette of leaves, a high level of exchangeable potassium content was provided by the resource-saving fertilizer system (213-215 mg/kg), and at the end of the growing season – with the application of 40 t/ha of manure (233 mg/kg) (Fig. 3).

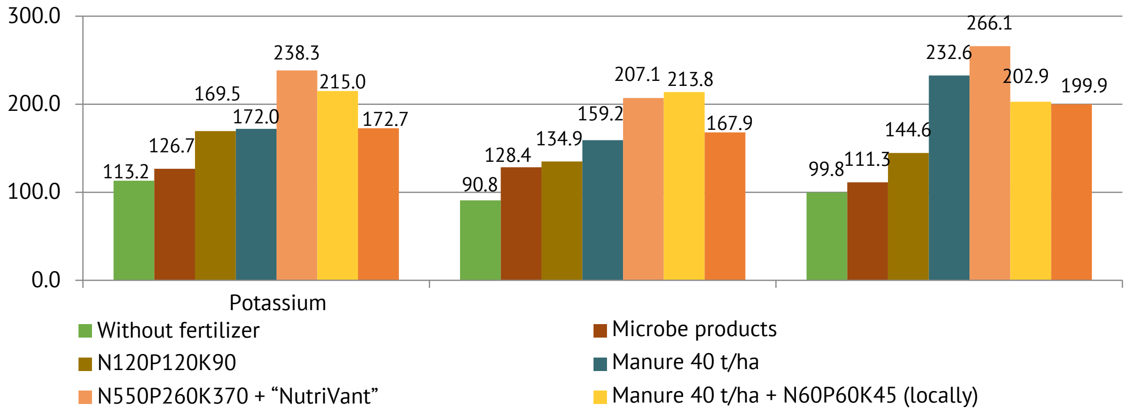

Figure 3. *Dynamics of exchangeable potassium content in the soil layer 0-30 cm depending on the fertilisation system of white cabbage (average for 2020-2022)*

Source: *compiled by the authors*

The use of a complex of microbial products proved to be effective, which ensured an increase in the content of exchangeable potassium in the soil by 11.5-40.6% compared to the control. That is, microbial preparations with phosphorus and potassium mobilising agents have the prospect of being used in technological schemes for growing vegetable plants, which is confirmed by the research of S. Shanmugam *et al.* (2022). The use of fertilisers improved the development of white cabbage plants, especially under organic-mineral fertilisation systems (Table 2). It was noted that under organic-mineral fertilisation systems, the height of plants ranged from 43-46 cm, under mineral fertilisation – 42.6-46.0 cm, under a combination of organic fertilisers and microbial preparations – 43 cm, while the value of this indicator in the control was 35 cm. Separate application of only organic fertilizers, as well as the use of a complex of microbial preparations caused only a positive trend in the growth of the height of white cabbage plants (increase in the value of the indicator relative to the control by 7.4-17.7%).

Table 2. *Biometric parameters of white cabbage plants under different fertilisation systems (average for 2020-2022)*

No.	Fertilisation system	Biometric parameters			
		Plant height, cm	Diameter of the leaf rosette, cm	Diameter of the leaf rosette, cm	Average head weight, kg
1	No fertilisers (control)	35.1	32.1	17.8	1.43
2	Microbial products	37.7	35.8	17.6	1.88
3	Manure 60 t/ha + $N_{120}P_{120}K_{90}$	43.1	32.7	16.9	1.83
4	Manure 90 t/ha	41.3	34.8	21.0	1.80
5	$N_{120}P_{120}K_{90}$	42.6	36.2	17.6	1.88
6	Manure 40 t/ha	41.3	38.3	17.9	1.75
7	Manure 40 t/ha + $N_{60}P_{60}K_{45}$	44.3	41.6	19.7	1.96
8	Manure 60 t/ha + $N_{60}P_{60}K_{45}$	45.8	42.8	20.2	2.03
9	$N_{550}P_{260}K_{370}$+ foliar dressing "NutriVant Plus universal"	46.0	37.8	17.9	2.25
10	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)	39.7	35.4	18.1	1.90
11	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)	45.8	39.1	19.1	1.92
12	Biological (organic fertilisers + microbial preparations)	43.0	41.1	20.2	2.06
	$HIP_{0.95}$	7.5	5.6	2.1	0.38

Source: *compiled by the authors*

The influence of fertilisers on the diameter of the rosette of leaves of white cabbage had the same tendencies as on the height of plants. There was a significant increase in the diameter of the cabbage head when using organo-mineral fertilisation systems, $N_{550}P_{260}K_{370}$ + foliar feeding with NutriVant plus universal, a combination of organic fertilisers and microbial preparations by 17.8-33.3%. A significant increase in the head diameter was typical for the application of 90 t/ha of manure, 60 t/ha of manure + $N_{60}P_{60}K_{45}$ and a combination of organic fertilisers and microbial preparations (20.2-21.0 cm). Thus, the use of fertilisers contributed to an increase in the average weight of the head of white cabbage by 22.4-57.3%. This growth was not significant in the variants of 90 and 40 t/ha of manure. Improving the soil nutritional regime and biometric parameters contributed to the growth of the yield of white cabbage. On average, over three years in irrigated vegetable-fodder crop rotation, the use of different fertilisation systems provides an increase in the yield of white cabbage by 9.9-33 t/ha or 21.6-71.8% compared to the control with a yield of 45.9 t/ha (Table 3).

Table 3. *Effect of different fertilisation systems on the yield of white cabbage in irrigated vegetable-fodder crop rotation (2020-2022)*

	Crop rotation fertilisation system	Cabbage fertilisation system	Overall yield, t/ha				Increase in comparison to control		Marketability, %
			2020	2021	2022	average	t/ha	%	
1	No fertilisers (control)	Without fertilizer	36.5	31.3	70.0	45.9	-	-	87.7
2	Green manure with a complex of microbial chemicals	Microbial products	38.2	33.4	71.5	47.7	1.7	3.8	89.5

Table 3, Continued

	Crop rotation fertilisation system	Cabbage fertilisation system	Overall yield, t/ha				Increase in comparison to control		Marketability, %
			2020	2021	2022	average	t/ha	%	
3	Manure 14 t/ha + NPK	Manure 60 t/ha + $N_{120}P_{120}K_{90}$	40.2	40.5	88.9	56.5	10.6	23.0	88.7
4	Manure 21 t/ha	Manure 90 t/ha	44.8	41.0	85.4	57.1	11.1	24.2	89.3
5	NPK	$N_{120}P_{120}K_{90}$	39.4	43.3	87.1	56.6	10.7	23.2	91.5
6	Manure 14 t/ha	Manure 40 t/ha	40.8	45.7	81.1	55.9	9.9	21.6	91.0
7	Manure 14 t/ha + ½ NPK	Manure 40 t/ha + $N_{60}P_{60}K_{45}$	42.1	46.3	98.0	62.1	16.2	35.3	89.5
8	Manure 21 t/ha + ½ NPK	Manure 60 t/ha + $N_{60}P_{60}K_{45}$	45.2	46.0	103.9	65.0	19.1	41.6	91.3
9	NPK (calculated) + fertilisation with complex fertilisers	$N_{550}P_{260}K_{370}$ + "NutriVant Plus universal"	41.0	50.7	105.2	78.9	33.0	71.8	91.9
10	Manure 14 t/ha + ½ NPK (locally)	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)	44.4	49.1	98.7	64.1	18.2	39.5	89.8
11	Manure 21 t/ha + 1/4 NPK (locally)	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)	39.0	51.7	101.7	64.1	18.2	39.6	94.2
12	Biological (organic fertilisers + green manure + microbial preparations)	Manure 40 t/ha + microbial chemicals	44.6	46.1	93.4	61.4	15.4	33.6	88.6
	$HIP_{0.95}$		4.96	5.65	10.85				

Source: *compiled by the authors*

Favourable weather conditions for the growth and development of cabbage plants were formed in 2022, which allowed for a yield higher than in previous years by 107-154%. The most noticeable difference was for organic-mineral fertilisation systems (130-150%). The most efficient is the use of an organic-mineral fertiliser system (60 t/ha of manure + $N_{120}P_{120}K_{90}$, 30 t/ha of manure + $N_{60}P_{60}K_{45}$ and 40 t of manure + locally $N_{60}P_{60}K_{45}$) and mineral ($N_{120}P_{120}K_{90}$ and $N_{550}P_{260}K_{370}$ + "NutriVant Plus universal"), which provided yields of 56.5-78.9 t/ha. A similar pattern is noted in the studies of other scientists. According to O. Ponjičan *et al.* (2021), the use of organic and mineral fertilisers in a complex ensures an increase in cabbage yield by 73.3%, while the yield of barley increased by 21.2-60.6% when applied separately.

The calculated dose of mineral fertilisers ($N_{550}P_{260}K_{370}$ + NutriVant Plus universal), which was planned to obtain a cabbage yield of 100 t/ha, provided an average of 78.9 t/ha over the years of research, although in 2022, with this fertilisation system, the yield level was 105.2 t/ha. The use of a complex of microbial preparations to optimise the nutrition of cabbage plants did not provide a significant increase in yield. It can be assumed that the system of their application selected for the research (Azotophyte for seed treatment, Groundfix for pre-sowing cultivation and Organic Balance for foliar feeding) did not ensure optimal saturation of the root rhizosphere with beneficial microorganisms and a low stimulating effect, since the effectiveness of using microbial preparations for growing cabbage has been proven in various studies. For example, in Kazakhstan, the use of organic fertilisers and a complex of biological products increases crop yields by 15.2-47.2% (Aitbayev *et al.*, 2018).

The marketability of products increases with the use of organic and mineral fertilisers; without fertilisation, this figure was 87.7%, and with different fertilisation systems – 88.6-94.2%. The use of fertilisers has a different effect on the change in the quality indicators of white cabbage products. On average, over the years of research, the content of total sugar and mono sugars in the heads of white cabbage did not change significantly. When applying 60 t/ha of manure + $N_{60}P_{60}K_{45}$, a decrease in these indicators was observed compared to the control to the level of 3.54 and 3.25%, respectively (Table 4).

Table 4. *Effect of fertilisers on the biochemical composition of white cabbage products (average for 2020-2022)*

No.	Fertilisation system	Mass fraction			
		of overall sugar, %	mono sugars, %	vitamin C, mg/100g	nitrates, mg/kg
1	No fertilisers (control)	4.23	4.02	10.4	85.5
2	Microbial products	4.33	4.14	12.6	79.6

Table 4, Continued

No.	Fertilisation system	Mass fraction			
		of overall sugar, %	mono sugars, %	vitamin C, mg/100g	nitrates, mg/kg
3	Manure 60 t/ha + $N_{120}P_{120}K_{90}$	4.05	3.89	13.6	75.2
4	Manure 90 t/ha	4.12	3.96	18.2	54.3
5	$N_{120}P_{120}K_{90}$	4.00	3.71	19.2	41.8
6	Manure 40 t/ha	4.09	3.70	16.2	40.9
7	Manure 40 t/ha + $N_{60}P_{60}K_{45}$	3.89	3.59	9.43	57.1
8	Manure 60 t/ha + $N_{60}P_{60}K_{45}$	3.54	3.25	10.8	80.6
9	$N_{550}P_{260}K_{370}$ + foliar fertilisation "NutriVant Plus universal" 2 kg/ha (100 t/ha)	3.75	3.33	11.9	83.1
10	Manure 40 t/ha + $N_{60}P_{60}K_{45}$ (locally)	4.20	3.94	18.6	93.1
11	Manure 60 t/ha + $N_{30}P_{30}K_{22,5}$ (locally)	4.09	3.88	17.0	104.7
12	Biological (organic fertilisers + green manure + microbial preparations)	3.82	3.68	16.8	71.4
	$HIP_{0.95}$	0.52	0.56	2.9	10.8

Source: *compiled by the authors*

All fertilisation systems studied, except for 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$ and the use of $N_{550}P_{260}K_{370}$ with foliar fertilisation "NutriVant plus universal", showed a significant increase in the content of vitamin C in cabbage heads to the level of 13.6-19.2 mg/100 g, while the value of this indicator in the control was 10.4 mg/100 g. The research of L. Rempelos *et al.* (2023) noted a positive effect on the content of sugars, vitamins C, B_9 and carotene in cabbage heads only in cases where organic fertilisers were used. The biochemical composition of cabbage products did not change significantly when mineral fertilisers were used. The nitrate content in the heads of cabbage did not increase significantly, except for the variant of 60 t/ha of manure + locally applied $N_{30}P_{30}K_{22.5}$ (104.7 mg/kg). However, this indicator was lower than the maximum permissible level (MPL) for white cabbage production (500 mg/kg of raw weight). This pattern is somewhat inconsistent with the research of other scientists. According to the results of X. Jun *et al.* (2023), the introduction of organo-mineral fertilisation systems does not lead to the accumulation of excess nitrogen in cabbage plants at different stages of growth compared to other fertilisation systems.

Thus, according to our research and the results of other scientists, the use of organic fertilisers has a significant impact on plant biometric parameters, yield, and vitamin C content in products, while the application of mineral fertilisers increases the content of nitrate nitrogen and partially the content of mobile phosphorus and potassium compounds in the topsoil, yield and vitamin C content. The introduction of an organo-mineral fertilisation system using mineral fertilisers locally improves the soil's nutritional regime, increases plant biometric parameters, yields and product quality, and reduces the nitrate content in the heads. The use of a complex of microbial preparations as an alternative to organic fertilisers improves the soil nutritional regime, and increases the content of vitamin C, but does not affect the level of yield, while other studies have shown that this effect is significant, indicating the inefficiency of the developed system of using microbial preparations.

CONCLUSIONS

Conducting research in long-term stationary experiments allows us to thoroughly investigate the impact of different fertilisation systems not only on the yield and quality of products but also on the soil condition and the supply of plants with basic nutrients. It is noted that a high level of soil supply with mobile nitrogen, phosphorus and potassium compounds during the growing season is ensured by the use of mineral ($N_{550}P_{260}K_{370}$ + NutriVant plus universal) and resource-saving fertilisation systems (spreading manure in autumn of 40 t/ha + locally in spring $N_{60}P_{60}K_{45}$). These fertilisation systems resulted in a 152-517% increase in nitrate nitrogen in the 0-30 cm soil layer compared to the control, a 116-197% increase in mobile phosphorus, and a 90-166% increase in exchangeable potassium.

The maximum effect on the biometric parameters of cabbage plants was found to be achieved by using the calculated dose of mineral fertilisers (spread in autumn $N_{550}P_{260}K_{370}$), organo-mineral systems (scattered in autumn 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$), resource-saving (scattered in autumn 60 t/ha of manure + locally in spring $N_{30}P_{30}K_{22.5}$) and biological fertilisation systems (scattered in autumn 40 t/ha of manure + a complex of microbial preparations). There was an increase in plant height by 22.5-31.3%, leaf rosette diameter by 21.8-32.1%, head diameter by 10.7-13.5%, and head weight by 32.9-57.3%. All fertilisation systems, except for the application of microbial preparations only, provide a significant increase in the yield of white cabbage within 21.6-71.8%. The maximum yield level (78.9 t/ha) was recorded when using a mineral fertiliser system ($N_{550}P_{260}K_{370}$+ "NutriVant plus universal").

The ineffectiveness of using the system of microbial preparations for optimising the nutrition of white cabbage plants, including seed treatment with Azotophyte (*Azotobacter chroococcum*), soil treatment before pre-sowing cultivation with Groundfix (*Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, Bacillus subtilis*) and five foliar applications of Organic Balance (*Bacillus subtilis, Azotobacter chroococcum, Paenibacillus polymyxa*). Under all fertilisation systems studied, except for the use of 40-60 t/ha of manure + $N_{60}P_{60}K_{45}$ and $N_{550}P_{260}K_{370}$ with foliar application of NutriVant plus universal, a significant increase in the content of vitamin C in cabbage heads to the level of 13.6-19.2 mg/100 g was observed, while fertilisers had no significant effect on other biochemical parameters of the product (total sugar and mono sugar content, nitrate content).

Determination of the mechanisms of influence on soil fertility and productivity of vegetable crop rotations of alternative nutrition optimisation systems with a complex of green manure, humic fertilisers and microbial preparations remains relevant in further research. At the same time, it is necessary to expand the range of beneficial microorganisms that saturate the soil rhizosphere and plan their additional introduction, for example, with irrigation water.

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CONFLICT OF INTEREST

None.

REFERENCES

[1] Aitbayev, T.E., Mamyrbekov, Z.Z., Aitbayeva, A.T., Turegeldiyev, B.A., & Rakhymzhanov, B.S. (2018). The influence of biorganic fertilizers on productivity and quality of vegetables in the system of "Green" vegetable farming in the conditions of the South-East of Kazakhstan. *Online Journal of Biological Sciences*, 18(3), 277-284. doi: 10.3844/ojbsci.2018.277.284.
[2] Archive of meteorological data. (n.d.). Retrieved from https://meteopost.com/weather/archive/.
[3] Bondarenko, G.L., & Yakovenko, K.I. (Ed). (2001). *Methodology of research work in vegetable growing and melon growing*. Kharkiv: Osnova.
[4] Boteva, H., Turegeldiyev, B., Aitbayev, T., Rakhymzhanov, B., & Aitbayeva, A. (2019). The influence of biofertilizers and organic fertilizers on productivity, quality and storing of cabbage (*Brassica oleracea* var. *capitata* L.) in the South-East of Kazakhstan. *Bulgarian Journal of Agricultural Science*, 25(5), 973-979.
[5] Brochure about AZOTOPHYT. (n.d.). Retrieved from https://btu-center.com/en/industrial-sector/crop-production/b-oaktivatori/azotofit-r/.
[6] Brochure about GROUNDFIX (n.d.). Retrieved from https://btu-center.com/en/industrial-sector/crop-production/nutrition/groundfix/.
[7] Brochure about ORGANIC-BALANCE (vegetation). (n.d.). Retrieved from https://btu-center.com/en/industrial-sector/crop-production/nutrition/organic-balance/.
[8] Convention on Biological Diversity. (n.d.). Retrieved from https://www.cbd.int/convention/.
[9] Convention on International Trade in Endangered Species of Wild Fauna and Flora. (n.d.). Retrieved from https://cites.org/eng/disc/what.php.
[10] Cui, X.W., Lu, H.L., Lu, Y.X., Gao, P., & Peng, F.Y. (2022). Replacing 30% chemical fertilizer with organic fertilizer increases the fertilizer efficiency, yield and quality of cabbage in intensive open-field production. *Ciencia Rural*, 52(7), 1-13. doi: 10.1590/0103-8478cr20210186.
[11] DSTU 4115:2002. (2003). *Soils Determination of mobile phosphorus and potassium compounds by the modified Chirikov method*. Retrieved from http://online.budstandart.com/ru/catalog/doc-page?id_doc=58863.
[12] DSTU 4729:2007. (2008). *Soil quality. Determination of nitrate and ammonium nitrogen in the modification of the NSC IHA named after O.N. Sokolovskyi*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=72836.
[13] DSTU 4948:2008. (2009). *Fruits, vegetables and their processing products. Methods of determination of nitrate content. With correction*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=83097.
[14] DSTU 4954:2008. (2009). *Products of fruit and vegetable processing. Methods of determination of sugars*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=74270.
[15] DSTU 7803:2015. (2016). *Products of fruit and vegetable processing. Methods of determination of vitamin C*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=80801.
[16] DSTU 7804:2015. (2016). *Fruit and vegetable processing products. Methods of determining dry substances or moisture*. Retrieved from http://online.budstandart.com/ua/catalog/doc-page?id_doc=80802.
[17] Duarte, L.O., de Aquino, L.A., Caixeta, I.A.B., Gonçalves, F.A.R., & Dos Reis, M.R. (2019). Rates and methods of phosphorus application in cabbage crop. *Pesquisa Agropecuaria Tropical*, 496, article number e54191. doi: 10.1590/1983-40632019v4954191.

[18] Food and Agriculture Organization (n.d.). Retrieved from https://www.fao.org/statistics/en/.

[19] Gonzaga, A.B., Gonzaga, N.R., Pepito, S.L.A., Octavio, R.I., & Harper, S.M. (2021). Growth, yield, and postharvest quality of cabbage (*Brassica oleracea* L.) in response to different levels of nitrogen fertilizer. *Acta Horticulturae*, 1312, 393-399. doi: 10.17660/ActaHortic.2021.1312.57.

[20] ICL Specialty Fertilizers Logo Vector. (n.d.). Retrieved from https://icl-growingsolutions.com/en-us/agriculture/

[21] Jin, L., Jin, N., Wang, S., Li, J., Meng, X., Xie, Y., Wu, Y., Luo, S., Lyu, J., & Yu, J. (2022). Changes in the microbial structure of the root soil and the yield of chinese baby cabbage by chemical fertilizer reduction with bio-organic fertilizer application. *Microbiology Spectrum,* 10(6), article number e01215-22. doi: 10.1128/spectrum.01215-22.

[22] Jun, X., Blagodatskaya, E., Yu, Z., Jie, W., Yu, W., & Xiao-Jun, S. (2023). Fertilization strategies to improve crop yields and N use efficiency depending on soil pH. *Archives of Agronomy and Soil Science*, 69(10), 1893-1905. doi: 10.1080/03650340.2022.2126457.

[23] Lykhovyd, P., Vozhehova, R., Lavrenko, S., & Lavrenko, N. (2022). The study on the relationship between normalized difference vegetation index and fractional green canopy cover in five selected crops. *The Scientific World Journal*, 2022, article number 8479424. doi: 10.1155/2022/8479424.

[24] Ponjičan, O., Kiss, F., Ilin, Ž., Adamović, B., Sabadoš, V., Sedlar, A., & Višacki, V. (2021). Influence of plastic mulch and fertilization on the environmental impact of spring cabbage production. *European Journal of Agronomy*, 122, article number 126170. doi: 10.1016/j.eja.2020.126170.

[25] Reichert, J.M., Mentges, M.I., Rodrigues, M.F., Cavalli, J.P., Awe, G.O., & Mentges L.R. (2018). Compressibility and elasticity of subtropical no-till soils varying in granulometry organic matter, bulk density and moisture. *Catena*, 165, 345-357. doi: 10.1016/j.catena.2018.02.014.

[26] Rempelos, L., *et al.* (2023). Effect of climatic conditions, and agronomic practices used in organic and conventional crop production on yield and nutritional composition parameters in potato, cabbage, lettuce and onion; Results from the Long-Term NFSC-Trials. *Agronomy*, 13(5), article number 1225. doi: 10.3390/agronomy13051225.

[27] Sarkar, D., Sankar, A., Devika, O.S., Singh, S., Shikha, Parihar, M., Rakshit, A., Sayyed, R.Z., Gafur, A., Ansari, M.J., Danish, S., & Fahad, S. (2021). Optimizing nutrient use efficiency, productivity, energetics, and economics of red cabbage following mineral fertilization and biopriming with compatible rhizosphere microbes. *Scientific Reports,* 11, article number 15680. doi: 10.1038/s41598-021-95092-6.

[28] Shanmugam, S., Hefner, M., Labouriau, R., Trinchera, A., Willekens, K., & Kristensen, H.L. (2022). Intercropping and fertilization strategies to progress sustainability of organic cabbage and beetroot production. *European Journal of Agronomy*, 140, article number 126590. doi: 10.1016/j.eja.2022.126590.

[29] Stoessel, F., Thomas, S., Peter, B., & Stefanie, H. (2018). Assessing the environmental impacts of soil compaction in Life Cycle Assessment. *Science of the Total Environment*, 630, 913-921. doi: 10.1016/j.scitotenv.2018.02.222.

[30] Xiapu, G., Hongbin, L., Jian, L., Limei, Z., Bo, Y., Shuxia, W., Tianzhi, R., Qiuliang, L., & Hongyuan, W. (2018). Long-term benefits of combining chemical fertilizer and manure applications on crop yields and soil carbon and nitrogen stocks in North China Plain. *Agricultural Water Management*, 208, 384-392. doi: 10.1016/j.agwat.2018.07.002.

[31] Zhang, L., Yuan, J., Zhang, M., Zhang, Y., Wang, L., & Li, J. (2022). Long term effects of crop rotation and fertilization on crop yield stability in southeast China. *Scientifc Reports*, 12, article number 14234. doi: 10.1038/s41598-022-17675-1.

[32] Zhernova, O., Dehtiarov, Y., & Kuts, O. (2022). Soil-saving technologies and their influence on agrophysical and colloid-chemical parameters of chernozem. *Scientific Papers. Series A. Agronomy*, 65(2), 157-166.

Вплив систем удобрення на основні агрохімічні показники ґрунту та продуктивність капусти білоголової

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Анотація. Актуальність проведених досліджень полягає у необхідність вивчення тривалого застосування різних добрив та їх післядію на поживний режим ґрунту, формування урожайності та якості капусти білоголової. Метою роботи було встановлення впливу різних систем оптимізації живлення на урожайність і якісні продукції капусти білоголової пізньостиглої в зрошуваній овоче-кормовій сівозміні. Для проведення досліджень використовувалися польові, статистичні, розрахунково-аналітичні та лабораторні методи. Встановлено, що використання мінеральної системи удобрення ($N_{550}P_{260}K_{370}$ + «Нутрівант плюс універсальний») призвело до підвищення рівня забезпеченості орного шару ґрунту рухомими сполуками азоту, фосфору та калію, забезпечувало позитивний вплив на біометричні показники та продуктивність рослин капусти білоголової. Всі системи удобрення, окрім внесення тільки мікробних препаратів, забезпечує істотне підвищення урожайності в межах 21,6-71,8 %. Однак, істотне зростання вмісту вітаміну С в головках капусти зазначено для всіх досліджуваних систем удобрення, окрім використання 40-60 т/га гною + $N_{60}P_{60}K_{45}$ та $N_{550}P_{260}K_{370}$ + «Нутрівант плюс універсальний». Вміст нітратів в головках від внесення добрив зростав не істотно. Зазначено неефективність використання для оптимізації живлення рослин капусти білоголової системи внесення мікробних препаратів, що включає обробку насіння Азотофіт (*Azotobacter chroococcum*), обробка ґрунту до передпосівної культивації Граундфікс (*Paenibacillus polymyxa, Bacillus megaterium var. phosphaticum, Enterobacter, Azotobacter chroococcum, Bacillus subtilis*) та п'ять позакореневих підживлень Органік баланс (*Bacillus subtilis, Azotobacter chroococcum, Paenibacillus polymyxa*). Практична цінність полягає у отриманні результатів для корегування доз добрив за планування їх внесення в сівозмінах господарств різних форм власності

Ключові слова: *Brassica oleracea* var. *capitata* L.; системи удобрення; ґрунт; сівозміна; зрошення; вирощування