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INFLUENCE OF MICRONUTRIENT CONTENT OPTIMIZATION ON THE VEGETABLES QUALITY AND YIELD

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Abstract

Nutritional quality of food is critical role to improving human health. Even mild micronutrient deficiencies in foods have negative health consequences. Finding ways to address micronutrient deficiencies is central to meeting the UN Sustainable Development Goals. The micronutrient content in plant foods depends on their content in the soil. One of the ways to increase the supply of these nutrients (when the content in the soil is low) is to add them when growing the plants. The experiment was carried out in order to investigate the effect of the introduction of micronutrients Zn, Cu and Co in different variants in the cultivation of carrots, beets and cabbage. It was carried out under irrigated conditions. The use of microfertilizers has an ambiguous effect on micronutrient content in vegetables. Zn content slightly increased in cabbage, but almost unchanged in carrots and beets. Cu content increased in cabbage and beets, but almost unchanged in carrots. Co content increased in carrots, beets and cabbage. The use of microfertilizers has increased the yield of vegetables.

***Key words**: hidden hunger, irrigation, micronutrient, soils, vegetables.*

INTRODUCTION

The achievement of most of the 2030 Sustainable Development Goals (SDG) (United Nations, 2015) is impossible without eliminating of hidden hunger. The term "hidden hunger" refers to a chronic lack of micronutrients essential to human health, which can't be synthesized by the body, and need to be obtained from the diet. Micronutrient deficiencies compromise immune systems, hinder child growth and development, and affect human potential worldwide (Stevens et al., 2022). Hidden hunger, experienced by about one in three of the world's total population, is a global trend. Micronutrient inadequacies are not only seen in the developing world, but also in the developed world. At the same time, between 720 and 811 million people in the world faced hunger in 2020: they are chronically hungry, lacking calories or protein (FAO, IFAD, UNICEF, WFP and WHO, 2021). That's why achieving food and nutrition security for all is central to the Sustainable Development Goals (SDGs). Ending hunger in all its forms, including chronic and hidden hunger, requires increasing crop production, and improving crop quality and the nutritional value.

Current approaches to address micronutrient deficiencies include various strategies: by medical supplementation and product fortification; by improving the micronutrient content of crop plants; by increasing micronutrient availability in arable soils; enhancing plant nutrient uptake. In the recent past, food fortification using supplements of vitamins and minerals has been a trend in an attempt to provide health benefits for the consumers (Datta & Vitolins, 2016; Lowe, 2021). Improving the micronutrient content of crop plants and increasing micronutrient availability in soils can be achieved through the use of biotechnology, crop breeding, and fertilization strategies, including microbial biofortification (Garg et al., 2018; Buturi et al., 2021; Alam et al., 2022; Denton-Thompson & Sayer, 2022)

Soil is pivotal in food quality and safety: soil composition determines the composition of food (Cogger & Brown, 2016; Dhaliwal et al., 2022). At the same time, soil properties and conventional agriculture with the application of NPK chemical fertilizers, the use of higher yielding crop cultivars, irrigation etc., along with increased yields, can result in an insufficient micronutrient supply to crops (Silver et al., 2021; Dhaliwal et al., 2022). Strategy with application of fertilizers fortified with micronutrients is the simplest and less expensive method among all biofortification methods (Garg et al., 2018; Prasad & Shivay, 2020; Obaid et al., 2022). When crops are grown in soils, where micronutrients become immediately unavailable, not readily translocated to plants tissues to diminish nutritional deficiencies in crop plants targeted application of soluble inorganic fertilizers to the roots or to the leaves are practiced (Ram et al., 2016; Garg et al., 2018; Ishfaq et al., 2022). Improvement of the soil micronutrient status by their application as fertilizers can contribute to decrease in micronutrient deficiency in humans (Garg et al., 2018).

Vegetable crops are generally grown in agro-systems characterized by a high degree of intensification of the production processes and in which the supply of nutrients is increasingly based on the use of fertigation and foliar fertilization, therefore selecting mineral forms and concentrations may have a relevant importance (Buturi et al., 2021).

However, achieving a balanced supply of micronutrients in soils and crops depends on the properties of soil, plants, and, in irrigation, on the quality of irrigation water. In irrigated agriculture, the problem of micronutrient deficiencies is exacerbated, since irrigation waters act as a factor in increasing their migration. Irrigated water with a high micronutrient content can contribute to the accumulation of these elements in soils and plants to dangerous concentrations, which can harm ecosystems and people (Ahmed et al., 2018; Lu et al., 2016; Zakharova et al., 2021).

Therefore, it is necessary to study the effect of the application of micronutrients Zn, Cu and Co in various ways in the cultivation of carrots, beets and cabbage on the yield and quality of plant products under irrigation when there is a deficiency of micronutrients in the soil. Research objectives consisted in evaluation of:

1) mobile forms of Zn, Cu and Co content in irrigated soils and soil quality;
2) Zn, Cu and Co content in irrigation water and water quality;
3) the effect of the application of micronutrients Zn, Cu and Co on the yield of vegetables;
4) Zn, Cu and Co content in vegetables (carrots, beets and cabbage).

MATERIALS AND METHODS

Experimental site

Site is located in the southern part of the Left-Bank Forest-Steppe of Ukraine, Kharkiv district of Kharkiv region. The studies were conducted in long-term stationary field experience with irrigation of Institute of Vegetable and Melons Growing NAAS. Soil is chernozem typical (Chernozems Chernic, WRB). Vegetables (carrots, beets and cabbage) were grown on the site. Irrigation was carried out with using waters Mzha River (national classification of the irrigation water quality). Duration of irrigation is 50 years. Mineralization of irrigation water during irrigation was 0.6-0.8 g/L. Irrigation norms in experiment were (depending on the crops grown and weather condition): 350-1350 m3/ha. Groundwater depth was more than 11 m.

Soil samples collection

Soil samples were selected on an irregular grid with GPS referencing, taking account of soil and lithological heterogeneity. Soil samples were taken on plots from the boreholes. They were collected from the 0-25 cm, 25-50 cm, 50-75 cm and 75-100 cm depth. More than 4 samples of the experiment every culture (carrots, beets and cabbages) were collected immediately prior to harvest with each variant. Irrigation water samples were tested several times during the growing season.

Soil samples analysis

Mobile forms of micronutrients in soils were determined by extraction with ammonium acetate solution at pH 4.8 for one hour using a 1:5 soil: extractant ratio.

Irrigation water and crops analysis

Water samples were analyzed after drying and dissolving the precipitate in 1M HCl. The micronutrients content of crops was determined by ashing at 550°C for 5 hours and dissolving the ash in 10% HCl.

In all cases, micronutrients were determined by atomic absorption spectroscopy.

Experiment design

The size of each experimental plot was 4 m^2. The experiment was repeated six times, with a systematic stepwise arrangement of 6 variants. Micronutrients were introduced in the form of salts: $ZnSO_4 \cdot 7H_2O$, $CuSO_4 \cdot 5H_2O$, $CoCl_2 \cdot 6H_2O$. Irrigation of the microfield experiment was carried out manually.

The scheme of experiment is presented in Table 1.

Statistical analysis

Statistical processing of the results was performed using Statistica 10 and MapInfo 11.0.

Table 1. Scheme of experiment

Factor	Dose of micronutrients, kg/ha		
	Zn	Cu	Co
Variant 1 - Control, irrigation	-	-	-
Variant 2 - Micronutrients into the soil	3.0	3.0	2.0
Variant 3 - Micronutrients into the soil and foliar nutrition	1.5+1.5	1.5+1.5	1.0+1.0
Variant 4 - Micronutrients foliar nutrition twice during the growing season	1.5+1.5	1.5+1.5	1.0+1.0
Variant 5 - Micronutrients into the soil and fertigation	1.5+1.5	1.5+1.5	1.0+1.0
Variant 6 - Micronutrients fertigation for two irrigations	1.5+1.5	1.5+1.5	1.0+1.0

RESULTS AND DISCUSSIONS

The contents of micronutrients in soil

The average values of the content of mobile form of Zn, Co in the studied soils are slightly lower or at the level of the background soils of Ukraine (Table 2). The average value of the content of mobile Cu in soils is 2.5 times lower than the background, which may be associated with its lower initial content.

The studied soils were characterized by a low supply of plants with Zn mobile forms (Vazhenin, 1976), even if the maximum content of this element in soils is lower than the optimum by 4.2 times. The average Cu content is also insufficient for plants. Plants are provided with Co at an average level.

Table 2. Contents of micronutrients in the 0-30 cm layer of irrigated soils before the experiment, mg/kg

Site		Contents of micronutrients in irrigated soils, mg/kg		
		Zn	Cu	Co
Irrigated soils before the experiment	average	0.99	0.21	0.39
	min/ max	0.72/ 1.18	0.10/ 0.59	0.20/ 0.67
Assessment of soil quality by				
Background[1]		1.00	0.50	0.50
Level of plants micronutrients nutrition[2]	lower	<5.0	<0.5	<0.3
	normal	5.0-10.0	0.5-1.0	0.3-0.7

[1]Authors data

[2]Vazhenin, 1976

Soil contain insufficient amounts of mobile forms of micronutrients necessary for plants, which indicates the need for increasing content of micronutrient in soils. The mobility of micronutrients in the soil, their availability to plants is a very dynamic value, which depends both on internal (chemical properties etc.) and external factors (temperature, acid-base and redox conditions, adsorption properties of the soil etc.) (Kabata-Pendias & Szteke, 2015). Under irrigation, changes in the content of mobile forms of micronutrients in soils, due to more frequent changes in external factors, occur more actively and intensively.

At the same time, Zn, Cu and Co are “potentially toxic elements” and their toxicity manifests itself when the permissible concentrations are exceeded (Kabata-Pendias & Szteke, 2015; Nematollahi, 2020; Raj & Maiti, 2020). It is necessary to study their content in terms of monitoring pollutants and soil, water and crop quality (Baliuk et al., 2017; Malakar et al., 2019; Raj & Maiti, 2020; Zakharova et al., 2021). Therefore, the issues of substantiating the use of micronutrients depending on the levels of micronutrient content in irrigated soils, the provision of them to plants, and determining the most effective ways to use them for specific crops are very important.

The contents of micronutrients in water

The irrigation water used in the experiment is of high quality (Table 3).

Table 3. Content of micronutrients in irrigation water, mg/dm^3 (average ± standard deviation)

Site	Content of micronutrients in irrigation water, mg/dm^3		
	Zn	Cu	Co
river Mzha	0.015 ±0.004	0.004 ±0.001	0.008 ±0.0004
Assessment of water quality by			
Background Forest-steppe of Ukraine[1]	0.016	0.013	0.010
National classification of the irrigation water quality Class1 - Suitable	< 0.5	< 0.08	< 0.02

[1]Authors data

The micronutrients content in water does not exceed the background for the forest-steppe. Irrigation water is of good quality according to the National classification of the irrigation water quality and it is suitable for irrigation. Irrigation water cannot increase the supply of micronutrients to plants and improve their quality.

The impact of micronutrients on vegetable crop yields

Since certain levels of Zn, Co and Cu were quite low in the soil, which could reduce the yields of vegetable crops, and their content in water is low and could not improve the provision of plants with micronutrients during irrigation, we studied the effect of the use of microfertilizers on the quality and yield of crops in a microfield experiment under irrigation conditions.

We explored the impact of the micronutrients use on crop yields (Table 4).

The use of micronutrients for these purposes proved to be effective in all variants and in all crops. Carrot yields increased from 8% (Variant 2) to 47% (Variant 6).

Variants 3, 4 and 5 resulted in yield increases of 41%, 18% and 35%, respectively. Beet yields increased from 11% (Variant 2) to 35% (Variant 3). Variants 4, 5 and 6 resulted in yield increases of 15%, 19% and 23% respectively. Cabbage yields increased from 8% (Variant 2) to 31% (Variant 3). Variants 4, 5 and 6 resulted in yield increases of 10%, 13% and 16%, respectively.

Table 4. The impact of the micronutrients use on crop yields

Factor	Harvest, kg/plot		
	carrot	beet	cabbage
Variant 1 - Control, irrigation	6.8±0.3	10.4±0.4	29.6±0.6
Variant 2 - Zn, Cu, Co into the soil	7.4±0.2,	11.6±0.3	32.0±0.6
Variant 3 - Zn, Cu, Co into the soil and foliar nutrition	9.6±0.2	14.0±0.4	38.8±0.8
Variant 4 - Zn, Cu, Co foliar nutrition twice during the growing season	8.0±0.3	12.0±0.5	32.8±0.7
Variant 5 - Zn, Cu, Co into the soil and fertigation	9.2±0.4	12.4±0.4	33.4±0.7
Variant 6 - Zn, Cu, Co fertigation for two irrigations	10.0±0.4	12.8±0.5	34.4±0.8
LSD_{05}	0.4	0.5	0.9

The most effective, with a significant increase in the yield of carrots, beets and cabbage, was the use of doses of micronutrients twice - fractional application. The best variants were: application of micronutrients with irrigation water for two irrigations; combined use of half doses - into the soil and foliar top dressing; into the soil and application with irrigation water. It draws attention to the fact that the most effective were the options in which the effectiveness of the application of micronutrients (partially or completely in various concentrations) with irrigation water was studied. The least effective, in terms of yield growth, was the variant with the introduction of micronutrients into the soil. Variant using Zn, Cu, Co foliar nutrition twice during the growing season provided an average yield increase.

A large above-ground mass of plants, which is formed during irrigation, causes an increased removal of all nutrients from the soil, therefore, the use of micronutrients in irrigated agriculture and the development of the most effective methods for their application have a significant prospect for development.

The content of micronutrients in tested vegetables

In the conducted microfield experiments, an increase in the content of micronutrients in vegetables was noted (Table 5). The use of microfertilizers had little effect on the Zn content in vegetables. In carrots and beets, an increase in the content of Zn by 1%-3% was noted. The effect in the variant with the use of Zn, Cu, Co foliar nutrition twice during the growing season was better than in the other variants. Cabbage was the most sensitive to the use of Zn microfertilizers in our experiment. In it, the Zn content increased by 10%-15%. The effect in the variant with the use of Zn, Cu, Co fertigation for two irrigations was better than in other variants.

The use of microfertilizers had a greater effect on the Cu content in vegetables. An increase in Cu content by 4%-9% was noted in carrots. The effect in the variants with Zn, Cu, Co foliar nutrition twice during the growing season and Zn, Cu, Co into the soil and fertigation was better than in other variants. In beets, the Cu content increased by 10%-34%. Variants using Zn, Cu, Co into the soil and Zn, Cu, Co foliar nutrition twice during the growing season resulted in an increase in Cu content in beets by 22% and 34%, respectively. An increase in Cu content by 24%-36% was noted in cabbage. The effect in the variants with the use of Zn, Cu, Co foliar nutrition twice during the growing season was better than in the other variants.

Table 5. Content of micronutrients in vegetable (raw vegetables), mg/kg

Factor	Content of micronutrients, mg/kg								
	carrot			beet			cabbage		
	Zn	Cu	Co	Zn	Cu	Co	Zn	Cu	Co
1. Control, irrigation	1.71	0.46	0.07	3.50	0.58	0.12	2.40	0.25	0.08
2. Zn, Cu, Co into the soil	1.75	0.49	0.18	3.54	0.71	0.21	2.65	0.31	0.19
3. Zn, Cu, Co into the soil and foliar nutrition	1.73	0.48	0.17	3.53	0.64	0.28	2.68	0.32	0.19
4. Zn, Cu, Co foliar nutrition twice during the growing season	1.76	0.50	0.18	3.58	0.78	0.28	2.64	0.34	0.20
5. Zn, Cu, Co into the soil and fertigation	1.75	0.50	0.18	3.53	0.68	0.21	2.68	0.32	0.20
6. Zn, Cu, Co fertigation for two irrigations	1.74	0.49	0.22	3.55	0.67	0.23	2.76	0.33	0.19

The use of microfertilizers had the greatest effect on the content of Co in vegetables. The content of Co in carrots increased by 2.43-3.14 times. The maximum increase in the content of this element was noted in the variant with Zn, Cu, Co fertigation for two irrigations. In beets, the content of Co increased by 1.75-2.33 times. The maximum Co content was noted in the following variants: Zn, Cu, Co into the soil and foliar nutrition; Zn, Cu, Co foliar nutrition twice during the growing season. The content of Co in cabbage increased by 2.38-2.5 times. The maximum content of Co was noted in the following variants: Zn, Cu, Co foliar nutrition twice during the growing season; Zn, Cu, Co into the soil and fertigation.

Carrot and beets agronomic biofortification has been carried out with good results – carrot and beets roots have been supplemented with Zn (slightly), Cu (good) and Co (significantly) by application of them as microfertilizers. Cabbage Zn, Cu, Co biofortification has been also carried out with good results after soil agronomic biofortification with an inorganic form of these elements.

The best options providing the greatest increase in micronutrient content in vegetables were the use of half doses of micronutrients: foliar nutrition during the growing season twice; application with irrigation water for two irrigations; application into the soil and application with irrigation water. Attention should be paid to the option with foliar top dressing twice during the growing season. This variant showed an average increase in yield, but it is the leader in the accumulation of micronutrients in vegetables. Application Zn, Cu, Co into the soil (0.5 doses) and foliar nutrition (0.5 doses) was the best option in assessing yield growth, but vegetable quality did not improve significantly.

The experience has shown that it is necessary to constantly monitor the content of micronutrients in soils and irrigation waters, the provision of plants with them. Under the conditions of low and medium supply of plants with micronutrients, the necessity and effectiveness of applying microfertilizers has been proved; with irrigation water. At the same time, it is also necessary to take into account the content of micronutrients in water and their supply with the irrigation rate and adjust the rate of micronutrient fertilizers depending on them. Since different crops have different susceptibility to micronutrient deficiencies, it is necessary to establish and use the most appropriate method of micronutrient application for each crop. The conducted microfield experiment confirmed the possibility of managing the nutritional regime and the possibility of agronomic biofortification of vegetables.

CONCLUSIONS

As a result of the work, the effect of the application of micronutrients Zn, Cu and Co in various ways in the cultivation of carrots, beets and cabbage on the yield and quality of plant products under irrigation when there is a deficiency of micronutrients in the soil was studied.

The average values of the content of mobile form of Zn, Co in the studied soils are slightly lower or at the level of the background soils of Ukraine. Soil contain insufficient amounts of mobile forms of micronutrients necessary for plants, which indicates the need for increasing content of micronutrient in soils.

The micronutrients content in water does not exceed the background for the forest-steppe. Irrigation water is of good quality; it is suitable for irrigation. Irrigation water cannot increase the supply of micronutrients to plants and improve their quality.

The use of micronutrients increased the yield in all variants and in all crops. Carrot yields increased by 8%-47%, beet - by 11%-35%, cabbage - by 8%-31%. The most effective was the use of half doses of micronutrients twice: application of micronutrients with irrigation water for two irrigations; combined use of half doses - into the soil and foliar top dressing; use of half doses - into the soil and application with irrigation water. The variant with the introduction of micronutrients into the soil was the least effective in increasing the yield of all crops. Variant using two foliar nutrition during the growing season provided an average yield increase.

The micronutrient profile of carrot, beets and cabbage has been improved by the application of inorganic microfertilizers. In the conducted microfield experiments, a different increase in the content of micronutrients in vegetables was noted. The use of microfertilizers had little effect on the Zn content in vegetables: in carrots and beets increased by 1%-3%, in cabbage - by 10%-15%. The introduction of microfertilizers had a greater effect on the Cu content in vegetables: in carrots increased by 4% - 9%, in beets - by 10%-34%, in cabbage - by 24%-36%. The use of microfertilizers had the greatest effect on the content of Co in vegetables: in carrots increased by 2.43-3.14 times, in beets - by 1.75-2.33 times, in cabbage - by 2.38-2.5 times.

The best options providing the greatest increase in micronutrient content in vegetables were the use of half doses of Zn, Cu, Co: foliar nutrition during the growing season twice; application with irrigation water for two irrigations; application into the soil and application with irrigation water.

The conducted microfield experiment confirmed the possibility of yeild managment and the possibility of agronomic biofortification of vegetables. Micronutrient biofortification through agronomical practices is an alternative strategy to reduce the Zn, Cu and Co deficiency in carrot, beets and cabbage.

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