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The effectiveness of the use of trace elements in foliar feeding of soybeans in the conditions of the western Forest Steppe

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Goal. To determine the effect of the use of microelements in the form of highly concentrated liquid fertilizers in foliarfeeding on the dynamics of the formation of the leaf surface area, photosynthetic and symbiotic potential, indicators of individual productivity and yield of soybean seeds. **Methods.** Field, laboratory, quantitative, comparative calculation, mathematical and statistical. **Results.** Weather conditions during the years of research (2021–2022) were marked by significant deviations from the average long-term values fccording to the indicator "average daily air temperature" - in the direction of excess, according to the amount precipitation - a deficit of precipitationwas obserwed in some monts, in some - their excessive amount, which had a significant impact on the growth and development of soybean plants, the formation of the seed yield of its researched varieties. The effect of microelements on the mentioned indicators varied significantly over the years of research. On average, over the years of research, 2-time treatment of crops in the phase of 4–5 trifoliate leaves and the beginning of flowering with trace elements tonsured an increase in the leaf surface area in the Siverka variety by 3.9–21.7%, the Pallada variety by 3.7–20.6%, photosynthetic potential by 2.4–15.3% and 2.7–16.0%, respectively, and total symbiotic potential by 32.1–74.3% and 22.6–59.3% compared to the control. The number of beans per 1 plant of the Siverka variety increased compared to the control by 6.5–21.2%, the number of seeds per 1 plant – by 13.8–31.0%, the weight of seeds per 1 plant – by 11.1–27.8%, the mass of 1000 seeds – by

1.8–6.3%. In the Pallada variety, the number of beans and seeds per1 plant increased by 5.9–29.0% and 8.4–30.5%, the weight of seeds from 1 plant and 1000 seeds increased by 7.5–41.8% and 2.1–9.0%, respectively. The seed yield increased in the Siverka variety from 2.73 t/ha in the control to 2.79-2.98 t/ha in the tested variants, in the Pallada variety – from 2.57 t/ha to 2.62–2.81 t/ha or respectively by 2.2–9.2% and 1.9–9.3%. **Conclusions.** The use of trace elements in the form of highly concentrated liquid fertilizers in foliar feeding of soybeans in the phase of 4–5 leaves and the beginning of flowering had a positive effect on the formation of the leaf surface area, indicators of photosynthetic and symbiotic potential, individual productivity and seed yield. Among the investigated options, the most efficiency for foliar fertilization was the use of highly concentrated liquid fertilizer Khimik Bor, the least effective was the uze of Khimik Manganese or Khimiк Copper.

***Key words** : variety, nutrition, photosynthetic and symbiotic potential, individual productivity, productivity.*

Modern intensive soybean varieties (Glizine hispida Maench) when grown according to improved and adaptive technologies are able to form consistently high yields of high-quality seeds. One of the ways to increase the yield of soybeans is to improve the conditions of its nutrition by introducing macro- and microelements into the soil or foliarly. Mineral nutrition is one of the main regulated factors that are used for purposeful management of plant growth and development during the growing season in order to obtain the maximum high-quality harvest [1–3].

Optimizing plant mineral nutrition is the most important means of regulating physiological processes that determine the formation of the crop of any agricultural crop, including soybeans. However, it is worth noting that soybean is quite picky about nutrients, and for crop formation it consumes more nutrients than other grain and leguminous crops and unevenly absorbs nutrients according to the phases of plant growth and development [4, 5]. Phosphorus, calcium, cobalt and molybdenum are needed during the period of germination - budding of soybeans for better development of roots, nodules and aerial mass. In the period of flowering - the formation of

beans, the maximum need for nitrogen, phosphorus, sulfur and magnesium is manifested. The lack of at least one of the elements leads to the abortiveness of flowers, ovaries and the formation of a small number of insufficiently developed seeds [6–9].

Studies in different soil and climate zones have established that fertilization and foliar fertilization with complex chelated microfertilizers effectively affect the stand density and survival of soybean plants [10], chlorophyll biosynthesis in soybean plants, leaf surface area, and photosynthetic potential [11, 12], contribute to reducing the abortiveness of flowers and beans [13], increasing the productivity of soybeans [14–17] and improving the quality of seeds [18, 19].

For the cultivation of soybeans in the Western Forest Steppe of Ukraine, the issues of development and implementation of modern technologies, which would be based on the rational use of the genetic potential of the productivity of the variety and the optimization of mineral nutrition conditions according to the stages of organogenesis, are important.

The purpose of the research is to determine the effect of the use of micronutrients in the form of highly concentrated liquid fertilizers in foliar feeding on the dynamics of the formation of the leaf surface area, photosynthetic and symbiotic potential, indicators of individual productivity and productivity of soybean seeds.

Materials and methods of research. Field research was conducted at the Khmelnytskyi State Agricultural Experimental Station of the Institute of Feed Research and Agriculture of Podillya of NAAS on podzolized, medium loamy chernozems in 2021–2022. The soil is sufficiently saturated with bases – 39.8–42.0 mg equiv. per 100 g, hydrolytic acidity 1.8–2.7 mg equiv. per 100 g of soil. The content of humus (according to Tyurin) is 3.2%. It is moderately supplied with forms of nutrients: the content of easily hydrolyzed nitrogen – 14.4–16.6 mg, mobile phosphorus – 11.0–12.0 mg, exchangeable potassium – 7.8–8.0 mg per 100 g of soil.

The subject of research is soybean varieties and their response to foliar fertilization with trace elements in the form of highly concentrated liquid fertilizers.

Soybean varieties Siverka (originator – of the NSC «Institute of Agriculture of NAAS») and Pallada (originator – Institute of Feed Research and Agriculture of

Podillya of NAAS) were studied. The registered area of the site is 24 m^2, the total is 32 m^2. The experiment was repeated three times. Variants in repetitions were laid by a systematic method. Foliar feeding of crops was carried out twice during the growing season - in the phase of 3–5 trifoliate leaves and the beginning of flowering.

In the years of the research (2021–2022), the weather conditions were characterized by significant deviations from the average long-term values according to the "average daily air temperature" indicator - in the direction of excess, according to the amount of precipitation - a deficit of precipitation was observed in some months, in some - their excess the amount that significantly influenced the growth and development of soybean plants, the formation of the yield of soybean seeds of the studied varieties.

It is worth noting that significant differences in the weather conditions during the period of intensive growth of vegetative mass and the formation of the soybean seed crop in the years of research, in particular in terms of moisture availability of the seed layer, led to different effectiveness of the studied agromeasure. As a result, indicators of photosynthetic and symbiotic potential, individual productivity and seed yield of both soybean varieties were better in 2021 than in 2022 (table 1).

1. Weather conditions for the 2021-2022 growing season.

Years of research	Months					During the growing season
	may	june	july	august	september	
Average daily air temperature, ^oC						
2021 p.	15,8	22,0	25,2	20,7	13,8	19,5
2022 p.	16,2	22,4	22,0	22,1	13,6	19,3
Average for 1960-2020.	13,6	18,4	19,3	18,6	13,4	16,7
Total amount of precipitation, mm						
2021 p.	188,6	58,2	349,2	166,5	71,2	833,7
2022 p.	55,4	63,1	93,2	153,2	206,8	571,7
Average for 1960-2020.	70,1	107,4	129,9	89,8	62,4	459,6
Hydrothermal coefficient						
2021 p.	3,84	0,88	4,48	2,59	2,72	2,90
2022 p.	1,10	0,94	1,36	2,24	5,08	2,14
Average for 1960-2020.	1,61	1,93	2,16	1,58	1,56	1,77

Planning, conducting field experiments, observation, accounting and statistical processing of research results were carried out according to generally accepted methods [20, 21]. Leaf surface area and photosynthetic potential were determined according to the method [Nychiporovich A. O., 1982], evaluation of the work of the symbiotic apparatus - according to the method [Posypanov G. S., 1991].

Research results. Optimum leaf surface area and photosynthetic activity are the basis of soybean crop formation. According to the results of research, the leaf surface reached its maximum size during the periods of flowering and the beginning of the formation of beans and was up to 56.78–68.14 thousand m2/ha in Siverka varieties, Pallada – up to 59.02–71.15 thousand m2/ha. Two-time treatment of crops in phases 4–5 of trifoliate leaves and the beginning of flowering with trace elements ensured an increase of this indicator in Siverka varieties by 3.9–21.7%, Pallada – by 3.7–20.6% compared to the control.

The photosynthetic potential of the period of 4–5 leaves – bean formation increased in Siverka varieties from 1023.49 thousand m2 days/ha in the control to 1048.55–1179.78 thousand m2 days/ha in the studied variants, Pallada – from 1194.86 thousand m2 days/ha to 1227.59–1386.37 thousand m2 days/ha. Compared to the control, the photosynthetic potential of Siverka varieties increased by 2.4–15.3%, Pallada – by 2.7–16.0% (table 2).

2. The effect of foliar feeding on the formation of the assimilation surface, photosynthetic and symbiotic potential of Siverka and Pallada soybean plants

Variant of foliar top dressing	Siverka			Pallada		
	Leaf surface area, thousand m^2/ha	Photosyn-thetic potential, thousand m^2 days/ha	Symbiotic potential, thousand kg d/ha	Leaf surface area, thousand m^2/ha	Photosyn-thetic potential, thousand m^2 days/ha	Symbiotic potential, thousand kg d/ha
Control	56,80	1023,49	9,30	59,02	1194,86	12,12
Khimik Bor	68,14	1179,78	16,21	71,15	1386,37	19,31
Khimik Zinc	64,45	1129,36	15,26	67,23	1324,56	17,68
Khimik Molybdenum	66,58	1160,10	15,84	69,36	1358,64	18,71
Khimik Copper	58,71	1048,55	12,29	61,21	1227,59	14,86
Khimik Manganese	59,88	1059,43	13,56	62,36	1246,03	15,69

Foliar top dressing with trace elements had a positive effect on the formation of the symbiotic potential of soybeans. It was established that the number of active nodules on the roots of each variety varied according to the phases of soybean development, foliar fertilizing options, and years of research. On average, over the years of research, the maximum number of active nodules on one plant and their weight was noted in the phase of formation of beans of Siverka varieties – 32.2–38.6 pieces. and 0.68–1.24 g, Pallas – 41.8–52.0 pcs. and 0.83–1.41 g. Compared to the control, the number of active nodules increased by 2.2–19.9% in Siverka varieties, Pallada – by 4.3–24.4%, and their mass increased by 36.8 –82.3% and 28.9–69.9%.

Indicators of active symbiotic potential in the period of flowering - formation of beans increased in the investigated variants in Siverka varieties up to 9.38–12.31 thousand kg d./ha or by 33.6–76.0%, Pallada – up to 12.08– 16.16 thousand kg per day/ha or by 25.4–68.1% against 6.94 and 9.52 thousand kg per day/ha, respectively, in the control.

The total symbiotic potential of soybeans over the entire observation period (4–5 leaves – formation of beans) increased in Siverka varieties from 9.30 to 12.29–16.21 thousand kg d./ha or by 32.1–74.3% , Pallada – from 12.12 thousand kg per day/ha in the control to 14.86–19.31 thousand kg per day/ha or by 22.6–59.3% in variants of foliar fertilizing with microfertilizers.

The main criterion for evaluating the effectiveness of the processes of photosynthesis, biological nitrogen fixation and the formation of plant productivity are indicators of individual plant productivity and the amount of soybean yield. The results of the conducted research indicate a positive effect of the use of trace elements in foliar feeding of soybeans on the formation of individual productivity indicators. On average, over the years of research, with 2-time treatment of soybean crops with microfertilizers, the number of beans per 1 plant of the Siverka variety increased by 6.5–21.2%, compared to the control, the number of seeds per 1 plant – by 13.8–31.0 %, the weight of seeds from 1 plant – by 11.1–27.8%, the weight of 1000 seeds – by 1.8–6.3% (table 3). In the Pallada variety, the number of beans and seeds per 1 plant increased by 5.9–29.0% and 8.4–30.5%, and the weight of seeds from 1 plant

and 1000 seeds increased by 7.5–41.8% and 2.1–9.0%, respectively.

3. The effect of foliar feeding on the structural parameters of the yield of Siverka and Pallada soybean varieties

Variant of foliar top dressing	number of beans, units/ plant	number of seeds, units/plant	seed weight, grams/plant	weight of 1000 seeds, g
Siverka				
Control	17,0	35,5	7,2	180,8
Khimik Bor	20,6	46,5	9,2	192,2
Khimik Zinc	18,5	42,5	8,8	190,8
Khimik Molybdenum	19,5	43,7	9,0	191,5
Khimik Copper	18,7	40,7	7,7	187,8
Khimik Manganese	18,1	40,4	8,0	184,0
Pallada				
Control	16,9	47,5	6,7	143,3
Khimik Bor	23,8	62,0	9,5	156,2
Khimik Zinc	21,0	56,9	8,8	150,0
Khimik Molybdenum	21,2	60,4	9,0	150,1
Khimik Copper	17,9	51,5	7,2	146,3
Khimik Manganese	19,2	54,0	7,7	143,9

Yield is the most important indicator of the economic value of soybean plants, which combines individual plant productivity, environmental conditions and elements of cultivation technology. According to the research results, two-time treatment of soybean crops in the phases of 4–5 leaves and the beginning of flowering with concentrated microfertilizers helped to increase the yield of Siverka varieties from 2.73 t/ha in the control to 2.79–2.98 t/ha in the investigated variants, Pallada - with 2.57 t/ha to 2.62–2.81 t/ha, respectively (table 4).

4. The effect of foliar fertilization on seed yield of Siverka and Pallada soybean varieties

Variant of foliar top dressing	Siverka			Pallada		
	2021	2022	Average	2021	2022	Average
Control	2,97	2,48	2,73	2,81	2,32	2,57
Khimik Bor	3,25	2,71	2,98	3,08	2,54	2,81
Khimik Zinc	3,20	2,64	2,92	3,03	2,47	2,75
Khimik Molybdenum	3,22	2,67	2,95	3,05	2,50	2,78
Khimik Copper	3,03	2,54	2,79	2,85	2,38	2,62
Khimik Manganese	3,10	2,57	2,84	2,91	2,41	2,66
LSD_{05}	2021	A – 0,17	B – 0,12	AB – 0,23		
	2022	A – 0,10	B – 0,15	AB – 0,21		

According to the results of mathematical processing, it was established that a significant increase in the seed yield compared to the control was provided by options of foliar fertilizing with the use of highly concentrated liquid fertilizers: Khimik Bor, Khimik Zinc, Khimik Molybdenum. In Siverka varieties, this indicator was 0.19–0.25 t/ha or 7.0–9.2%, Pallada – 0.18–0.24 t/ha or 7.0–9.3%. The seed yield of soybean varieties Siverka (0.25 t/ha or 9.2%) and Pallada (0.24 t/ha or 9.3%) increased the most due to the use of highly concentrated liquid fertilizer Chemik Bor in foliar feeding. Within the statistical error in Siverka (0.06–0.12 t/ha or 2.2–4.4%) and Pallada (0.05–0.12 t/ha or 1.9–4.7%) varieties) the yield of soybean seeds increased in the variants where Khimik Manganese or Khimik Copper fertilizers were used for foliar feeding.

Conclusions. Foliar feeding of soybeans in the phases of 4–5 leaves and flowering with trace elements in the form of highly concentrated liquid fertilizers has a positive effect on the formation of the leaf surface area, indicators of photosynthetic and symbiotic potential, individual productivity and seed yield. Among the studied options, the greatest increase was noted for the use of highly concentrated liquid fertilizer Himik Bor: the leaf surface area increased in Siverka varieties by 20.0%, Pallada - by 20.6%, the number of active nodules - by 19.9 and 24.4%, their mass is 82.3 and 69.9%, respectively. Indicators of photosynthetic potential increased in Siverka varieties by 15.3%, Pallada - by 16.0%, symbiotic potential - by 74.3 and 59.3%, respectively. The number of beans per 1 plant of the Siverka variety increased by 21.2% compared to the control, the number of seeds from 1 plant - by 31.0%, the weight of seeds from 1 plant - by 27.8%, the weight of 1000 seeds - by 6.3% . In the Pallada variety, the number of beans and seeds per 1 plant increased by 29.0% and 30.5%, the weight of seeds from 1 plant and 1000 seeds increased by 7.5–41.8% and 2.1–9.0%, respectively.

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