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Features of the soybean photosynthetic productivity indicators formation depending on the foliar nutrition

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ABSTRACT

The three-year research findings prove that foliar nutrition with trace elements influences the dynamics of leaf surface formation, dry matter accumulation, and soybean photosynthetic net productivity under the Western Forest-Steppe conditions of Ukraine. It was found out that foliar nutrition with the particular trace elements could enlarge the soybean leaf surface area, chlorophyll content and dry matter yield. During the experimental studies, a positive effect on increasing the leaf surface area in soybean crops during the end of flowering was found in the variants where copper, iron and molybdenum-containing fertilizer were applied. The leaf surface area in the variant where copper was applied reached 46.3 thousand m^{-2} ha, which confirms the importance of copper in the formation of sugars and protein, direct participation in the process of photosynthesis. On the basis of the conducted researches it is established that in general on the amount of chlorophyll in soybean leaves foliar feeding has a significant effect. The average chlorophyll content in soybean leaves was 1.10 mg^{-2} g of raw weight. The dynamics of dry matter by phases of growth and development of soybeans is established. Soybean produced the maximum amount of dry matter during grain ripening. Thus, 7.59 t^{-1} ha of dry matter was formed during the control.

***Key words**: Soybean, Foliar nutrition, Trace elements, Growing technology, Leaf surface, Dry matter.*

Introduction

Photosynthesis is the basis for the yield organic matter formation. Therefore, the key task of the soybean growing technology is to create optimal conditions for photosynthetic mechanism formation and functioning that will provide its high productivity. Photosynthesis and nitrogen fixation are the most important processes in the life of legumes. Agrotechnologies aimed at ensuring the effective use of environmental factors necessary for plants are mainly subordinated to the regulation of these processes. There is a close correlation between the rate of assimilation of headlights by plants and crop productivity.

It is known that the photosynthesis intensity considerably depends on the plant nutrient system. The point of the positive effect of mineral nutrition is that the plant photosynthetic productivity rises (Vdovenko *et al.*, 2018). The soybean photosynthetic

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mechanism continuously changes from the moment of rising to collection and is at its highest point during the crop «budding-blowing» period. The bigger the leaf surface area of the best soybean density is, the higher the photosynthetic potential per unit of the area (Yanovych *et al.,* 2018 a). Trace elements have a positive effect on the leaf surface area enlargement, photosynthetic net productivity and photosynthetic potential increase. The yield correlates with the soybean photosynthetic net productivity. Foliar nutrition with trace elements considerably influences the photosynthetic net productivity. As Pantsyreva (2019) reports (Boye et al., 2010), the combination of fertilization and foliar nutrition provides better photosynthesis rates and raises the soybean productivity under the forest-steppe conditions of Western Ukraine.

For normal growth and development of crops, it is not enough to meet their basic needs for nitrogen, phosphorus, potassium, calcium, magnesium and sulfur. Trace elements are part of many vitamins, enzymes, activate their work, participate in nitrogen and hydrocarbon metabolism of plants, in redox processes, enhance the process of photosynthesis, affect respiration, as well as the transformation and movement of substances, growth, development and stability plants to various adverse factors and pathogens. The main value of trace elements, and they include iron, molybdenum, copper, manganese, zinc and boron - increase the activity of enzymes. Enzymes are biological catalysts that accelerate chemical processes in the body, which increases the overall tone of the plant and has a positive effect on the dynamics of their growth and development. Lack of micronutrients can cause various deviations in the growth and development of plants, which will reduce yields and impair product quality. That is why trace elements cannot be replaced by any other substances, and their lack can negatively affect the growth and development of plants (Yanovych *et al.,* 2018 b; Ahmadi *et al*., 2010; Honcharuk *et al.,* 2020; Homolka *et al.,* 2012; Hashimi *et al.,* 2019).

Trace elements in plant nutrition allow more complete use of water, light and primary nutrients (nitrogen, phosphorus, potassium), which in turn leads to increased quantitative and qualitative characteristics of the crop. Trace elements and their enzymes promote better tissue repair and significantly reduce the risk of plant disease. Another important factor in the benefits of trace elements is somewhat derived from the previous – they increase the overall immunity of the plant, prevent stress or depressive situations, which are the harbingers of disease.

The system of micronutrient feeding of plants should be developed individually for each crop, taking into account the peculiarities of the geographical location and the level of micronutrient removal by the plant.

Materials and Methods

The investigation was carried out during the 2015-2018 period in the field rotation of the State Agrarian and Engineering University in Podilia testing field. The soil is chernozem that is leaching, deep, low-humus, loamy and is on loess-like loams. The testing area has the following agrochemical indicators (0-30 cm^{-1} soil layer): the content of humus is 4,34%; the content of pH is 6,8%; the content of hydrolysable nitrogen is 124 mg^{-1} per 1 kg^{-1} of soil; the content of floating phosphor is 86 mg per 1 kg of soil; the content of metabolic potassium is 167 mg^{-1} per 1 kg of soil.

Weather conditions in the years of research (2015-2018) during the growing season of soybean plants were characterized by a certain difference from the average long-term indicators in terms of both temperature and rainfall, but were generally favorable for plant growth and development.

The average daily air temperature in the period May-September exceeded the long-term average in 2015 by 2.2 °C, in 2016 – by 2.1 °C, in 2017 – by 1.9 °C, and in 2018 – by 2.8 °C. As for precipitation, they were characterized by uneven precipitation, but their number was at the level of the long-term average. In total, in 2015, 334.3 mm^{-1} of precipitation fell during the soybean growing season, in 2016 – 329.3 mm^{-1}, in 2017 – 265.8 mm^{-1} and in 2018 – 266.8 mm^{-1}.

The investigation also examined how foliar nutrition with trace elements influenced the indicators of soybean photosynthetic productivity. One-element products produced in German by Aglukon were used as foliar feed in the standards recommended by the manufacturer:

Boron – Wuxal Folibor, the content of boron is 150 $g^{-1}l$.

Molybdenum – Wuxal Molybdenum, the content of molybdenum is 73 $g^{-1}l$.

Copper – Wuxal Copper, the content of copper is 70 $g^{-1}l$.

Ferrum – Wuxal Ferro, the content of ferrum is 70 $g^{-1}l$.

Manganese – Wuxal Manganese, the content of manganese is 83 $g^{-1}l$.

Zinc – Wuxal Zn, the content of manganese 109 $g^{-1}l$.

The investigation was carried out in the appropriate sowing period, on the 20th of April. Sowing method is wide-row with 30 ñm $^{-1}$l space between rows and has a sowing limit of 550 thousand similar seeds per 1 $g^{-1}l$. ha. The predecessor is soybean. Agricultural equipment used in the investigation is the one that is generally accepted in the forest-steppe zone of Western Ukraine. The research examined the «Suziria» class. The class creator is The National Academy of Agrarian Sciences of Ukraine (Scientific-methodical and coordination center on scientific problems development of the agroindustrial complex of Ukraine). The soybean class of a restricted growth type was recorded in the Plant Variety Register of Ukraine in 2010.

The testing field sown area is 11 m^{-2}, including 5 m^{-2} of the accounting one. The frequency is four times. All foliar feed was added in the soybean initial flowering stage (R1) using a knapsack sprayer.

All research recordings, findings, and analysis were made per the standard methods.

The leaf surface area was determined using the cutting off method. The leaf surface area in the respective phases of plant growth and development was determined by the method of «cuttings». At the experimental site, 10 plants were selected, all leaves were plucked from them and weighed. The content of chlorophyll in the leaves was selected from 20 plants on one leaf (in the fourth tier on top). Pigments content (chlorophyll a, chlorophyll b, and carotene) was defined according to the «Guidelines on the determination of plant photosynthetic activity indicators». Photosynthetic potential, photosynthetic net efficiency and dry matter were rated by A.O. Nychyporovych methodology (Nychyporovych, 1961).

Results and Discussion

In the process of growth and development of crops a special place is occupied by the dynamics and formation of indicators of photosynthetic productivity of the agrocenosis, as this is the basis of yield of each of the crops. However, it should be noted that the dominant role in the photosynthetic productivity of the crop is played by the rate and size of the formation of the leaf surface of the crop, as this indicator is associated with all others that ensure the production of yields. Thus, in particular, the rate and size of the assimilation surface of the crop determine the intensity of moisture absorption, nutrients and photosynthetically active radiation from the sun. As a result of such a combination, the crop accumulates dry matter, which is the basis of the vegetative mass and the accumulation of assimilation products, which subsequently provide the quantitative formation of the crop and the full value of its quality indicators (Mazur *et al.*, 2020 b; Kim *et al.*, 2010; Pantsyreva, 2019).

The formation of organic matter due to the photosynthetic activity of plants is determined primarily by the size of the leaf surface. Soybean leaf apparatus is formed in a fairly wide range – from 20 to 70 thousand m^{-2} ha, depending on growing conditions. The optimal area of the leaf surface, when a high yield of soybean seeds is formed, is considered to be an area in the range of 40-50 thousand m^{-2} ha. According to A. Nichiporovich, the decisive factor here is not the area of the leaves, but the term of its active work. He considers quite productive crops in which the photosynthetic potential is 2 million m^{-2} days ha in terms of every 100 days of vegetation that actually took place.

The soybean leaf surface area enlarges from the start of the vegetation period to the end of the flowering stage. To get the analysis of the factors influence, we compared the top assimilation values, which were defined at the time the crop stops flowering. It should be mentioned that during the end of the flowering period, the soybean leaf surface area was 39 thousand m^{-2} ha without foliar nutrition with trace elements (Table 1).

Based on the investigation of different crops, it was stated that maximum efficiency was stimulated by the leaf area index of 6 m^{-2} (Yanovych *et al.,* 2018 b.; Kaletnik *et al.,* 2020; Puyu *et al.,* 2021). Therefore the soybean leaf surface area enlargement will provide higher crop productivity. The soybean foliar nutrition with particular elements stimulated slight leaf surface area enlargement.

Therefore, increasing the leaf surface area in experimental soybean crops will contribute to higher crop productivity. The use of foliar feeding of soybeans with individual trace elements contributed to a slight increase in leaf area.

It was noticed that the soybean leaf surface area

Table 1. Dynamics of formation of the leaf surface area of Soybean class «Suziria» depending on foliar fertilizer, thousands of m^{-2} ha, (average in 2015-2018)

Factor A, Foliar nutrition	Phenological stages					
	Start of the flowering stage		End of the flowering stage		Grain forming	
	x	+/-	*x*	+/-	*x*	+/-
Checkout (St)	26.7	-	44.0	-	34.5	-
Boron	26.9	0.3	44.4	0.4	34.5	0.0
Molybdenum	26.5	-0.2	46.1	2.1	34.6	0.2
Copper	27.2	0.5	46.3	2.3	35.8	1.3
Ferrum	27.3	0.6	45.7	1.7	36.0	1.6
Manganese	26.4	-0.3	43.6	-0.4	34.8	0.3
Zinc	26.6	-0.1	43.9	-0.1	34.9	0.4
	x=26.8	LSD_{05}=1.1	x=44.7	LSD_{05}=1.7	x=35,0	LSD_{05}=1.5

increased at the end of the flowering stage in the examples where copper, ferrum, and foliar feed containing molybdenum were added. The leaf surface area with copper added got 46.3 thousand m^{-2} ha. It confirms the significance of copper in sugar and protein creation. And copper also contributes to photosynthesis.

In case ferrum was added the leaf surface area also increased, but not much. The value was 1.7 thousand m^{-2} ha and meant to be more than the slightest considerable difference at the 95% significance level. This very case showed that the leaf surface area was increasing up to the end of the vegetation period. In that way, in the grain forming period the leaf surface area formed 34,5 thousand m^{-2} ha, and in the case, ferrum was added it formed 36,0 m^{-2} ha, which was 1.6 thousand m^{-2} ha as large (LSD_{05}=1,5 thousand m^{-2} ha). It confirms that ferrum plays an important role both in photosynthesis and proteometabolism, and in chlorophyll formation.

It was also noted that adding molybdenum improves soybean foliar nutrition. In this case, the leaf surface area increased to 2.1 thousand m^{-2} ha. There is no molybdenum direct impact on the leaf surface enlargement, but it enables the symbiotic nitrogen fixation of nodule bacteria, that, in turn, can improve the photosynthetic activity of the whole soybean plant.

The statistical analysis of investigation findings indicated a considerable impact on the leaf surface area at the end of the flowering and grain forming stages during the three years of observation.

It was determined that there was a curvilinear correlation between the leaf surface area and the yield. And it can be expressed by the following equation $Y = -37{,}0 + 1{,}9*X - 0{,}02*X^2$.

As the leaf surface area goes up to 45 thousand m^{-2} ha, the soybean yield rises too. Within the leaf surface area of 45-50 thousand m^2/ha, the yield doesn't rise. The regression line extrapolation means that the yield lowers with the next leaf surface area enlargement.

The amount of chlorophyll is a significant internal factor that defines the photosynthesis rate and overall biological efficiency of the plant. The present-day varieties are notable for the higher seed production and more aggressive photosynthetic activity. It is due to high chlorophyll content in leaves and other photosynthetic elements. Mazur V. in her paper mentioned (Mazur et. al, 2019; Mazur et. al, 2020 a) that high-productive barley kinds were characterized by a great amount of chlorophyll in leaves, increased density of pigment set in a photosynthetic membrane, and they also had another type of photosynthetic unit assemblage.

A strong correlation was found between chlorophyll content in leaves, total nitrogen accumulation, and dry matter phytomass in the whole plant. The optimal conditions of soybean watering provided maximum chlorophyll content in the leaves in the flowering stage. During the drought, its content considerably decreased**.** A lot of authors point out that photosynthesis is in direct relation to chlorophyll content (Bandura *et al.,* 2019; Benbouza *et al.,* 2006; Didur *et al.,* 2021; Kaletnik, 2010). However, it is suggested that this relation is more complex, it means the direct relation can be seen at an early stage of ontogenesis only (Didur *et al.,* 2020; Boye *et al.,* 2010; Honcharuk *et al.,* 2021; Roggatz, 1999; Soltani *et al.*, 2001; Oweis, 2004), notably in the process of chlorophyll accumulation. At the time of plant aging, there was a quick photosynthesis intensity decrease, and there was a smaller amount of chlorophyll in the leaves of the soybean flag-shaped leaf. The above-stated information from the scientific documentation confirms that there is a strong correlation between chlorophyll, photosynthesis, and the final output of different crops.

Based on the investigation, it was found out that foliar nutrition generally influences the amount of chlorophyll in the soybean leaves. Within the investigation, the average chlorophyll content in the soybean leaves was 1,10 mg^{-1} g of the raw material (Table 2).

Among the variants examined, added ferrum greatly influenced the chlorophyll content, added copper influenced to a lesser degree, and molybdenum and manganese also increased chlorophyll content.

It is quite important to combine the leaf surface area records with the records of the growth of the biological and economic yield dry matter. In this case, it is possible to get indicators of photosynthetic net productivity.

Table 2. Chlorophyll content in the soybean leaves depending on the foliar nutrition, $mg^{-1}g$ of the raw material, (average in 2015-2018)

Factor A, Foliar nutrition	Phenological stages End of the flowering stage	
	x	+/-
Checkout (St)	0.94	-
Boron	0.92	-0.02
Molybdenum	0.99	+0.05
Copper	1.12	+0.18
Ferrum	1.26	+0.30
Manganese	1.02	+0.08
Zinc	0.95	+0.01
	x=1.3	LSD_{05}=0.04

So, during the investigations, the dry matter dynamics was rated per the soybean growth stage. The biggest amount of soybean dry matter was generated during the period of grain forming. 4,97 t^{-1}ha of dry matter could be seen.

Foliar nutrition with copper and molybdenum provided the increase of the dry matter amount at the soybean end of the flowering stage. It is due to the more intense activity of the photosynthetic surface, both its optimized area and higher chlorophyll concentration.

The variant of foliar nutrition with boron is notable for the dry matter indicator during the grain forming stage. It is the result of better growth of meristematic cells, better fertilization, and fewer abortions of flowers and beans.

Foliar nutrition with molybdenum also provided the increase of the dry matter amount due to a better activity of symbiotic mechanism and better nitrogen feeding afterwards.

To more fully characterize the functioning of the formed leaf surface area of the studied soybean crops in the southwestern part of the Forest-Steppe of Ukraine, we calculated the photosynthetic potential for the experimental variants, which combined the size of the formed assimilation surface of soybean crops with its duration. Photosynthetic potential is an indicator that reflects the quality of the assimilation surface of the crop, as the longer the period of the leaf surface of the crop, the more assimilation products are formed, which has a direct impact on crop yields.

Thus, the results of research showed that the most effective leaf surface area of crops worked during the flowering of soybeans. In particular, the highest indicators of photosynthetic potential in the experiment were determined on the variants with molybdenum treatment – 1.39 million m^{-2} per day ha (Table 3).

As a result of calculations and observations, it was found that the dynamics of photosynthetic potential in soybeans differs depending on the treatment of crops with trace elements. The increase in photosynthetic potential in the period from the beginning to the end of flowering occurs during the treatment of crops with elements such as molybdenum, copper and iron. This is due to the participation of these elements in photosynthetic processes and their activation. In the period of the end of flowering-grain filling there is already a noticeable positive effect on the photosynthetic potential of all options for crop treatment, which contributed to an increase of 0.03-0.06 million m^{-2} per day ha. Especially significant increase in the variant with treatment of crops with iron. The lowest indicators of photosynthetic potential were observed in the variant with the introduction of zinc 1.28 million m^{-2} per day ha, which is 0.04 million m^{-2} per day ha less than the control.

We also calculated the net productivity of photosynthesis of crops. Thus, as a result of the calculations it was found that the largest increase in net

Table 3. Photosynthetic potential of soybean class «Suziria» depending on foliar fertilizer, million m^{-2} per day ha, (average in 2015-2018)

Factor A, Foliar nutrition	Period of development	
	Start of the flowering stage – End of the flowering stage	End of the flowering stage – Grain forming
Checkout (St)	1,32	0,95
Boron	1,33	1,01
Molybdenum	1,39	0,98
Copper	1,37	0,99
Ferrum	1,37	1,10
Manganese	1,31	1,00
Zinc	1,28	0,98

Table 4. Net productivity of photosynthesis of soybean class «Suziria» depending on foliar fertilizer, g m^{-2} per day (average in 2015-2018)

Factor A, Foliar nutrition	Period of development	
	Start of the flowering stage – End of the flowering stage	End of the flowering stage – Grain forming
Checkout (St)	2,06	0,62
Boron	2,60	0,75
Molybdenum	2,19	0,82
Copper	2,02	0,91
Ferrum	2,05	0,87
Manganese	2,11	1,04
Zinc	2,15	0,95

productivity of photosynthesis in the experiment was in the period of "start – end of the flowering" of soybeans. Namely: during this period, the experimental crops produced from 2.02 to 2.60 g m^{-2} per day of dry matter (Table 4).

The effect of foliar fertilization with boron and molybdenum on this integrating indicator was insignificant, but significant in the period between the beginning and end of flowering. For the period from flowering to grain filling, treatment with all nutrients had a significant positive effect on improving the net productivity of soybean crops.

Conclusion

Soybean foliar nutrition with trace elements influences its photosynthetic productivity indicators. The leaf surface area increases if copper, Ferrum, molybdenum, and manganese added. Adding all the elements except zinc increases dry matter accumulation and soybean photosynthetic potential. The effect of foliar fertilizer on the photosynthetic potential of soybean crops and the net productivity of photosynthesis of crops was insignificant, but significant.

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