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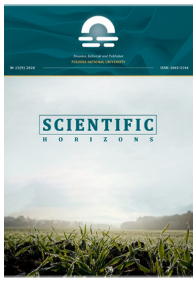

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Formation of the photoassimilation apparatus of pea (*Pisum sativum* L.) crops under biostimulants in arid conditions of the Southern Steppe of Ukraine

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Abstract. The Southern Steppe of Ukraine is characterised by a range of unfavourable agro-climatic conditions, which leads to inhibition of growth processes, disruption of physiological processes and loss of crop yields. The use of environmentally safe bioregulators stimulates growth processes, optimises nitrogen nutrition, increases the adaptability of legumes to adverse conditions and increases yields. The purpose of this study was to find out the specific features of the influence of biostimulants on

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the formation of the photoassimilation apparatus of pea of the Oplot variety in the Southern Steppe of Ukraine. A 3-year small-plot study was conducted to determine the leaf area index, total chlorophyll content, and net photosynthetic productivity in pea crops. The biostimulants were used for pre-sowing and foliar treatment of pea crops in the budding phase at concentrations described in the methodology. It was found that Stimpo (25 ml/t + 20 ml/ha) increased the leaf surface index in different stages of vegetation of pea variety Oplot by 1.12-1.54 times and Regoplant (250 ml/t + 50 ml/ha) increased the leaf surface index by 1.18-1.38 times compared to the control. A significant increase in the chlorophyll content in pea stipules was recorded after foliar treatment of crops with biostimulants and exceeded the value of control plants by 9.0-10.4% in the BBCH stages 61(65) – 75(79). Based on 3-year results, the positive impact of biostimulants on net photosynthetic productivity was proven. Thus, Stimpo and Regoplant increased the net photosynthetic productivity of pea crops by 35% and 22%, respectively, in the budding (BBCH 51-61) and flowering (BBCH 55-65) phases. The obtained scientific results contribute to the widespread use of the studied biostimulants in the technology of pea cultivation in the Southern Steppe zone of Ukraine to increase crop productivity and obtain a high-quality crop

Keywords: legumes; plant growth regulators; Regoplant; Stimpo; net photosynthetic productivity; leaf area index; chlorophyll

INTRODUCTION

Legumes rank third in the global crop production after grains and oilseeds and are an important source of food and feed. Legume protein accounts for 33% of the human diet, and legumes can fix atmospheric nitrogen, increasing soil fertility. Ukraine is distinguished by the fact that peas are the most widespread crop capable of producing high and sustainable grain yields compared to other types of pulses. In 2018, the sown area under peas amounted to 431 thousand hectares and almost half of them are in the steppe zone. In a certain number of farms, its yield is 3-5 t/ha.

Pea (*Pisum sativum* L.) exhibit high requirements for light, moisture, and soil, and therefore they often fail to fully realise their genetic productivity potential under unfavourable environmental conditions, especially in risky farming areas. Abiotic factors are the main factors that limit the yield of crops and cause up to 70% of crop losses. The Southern Steppe zone of Ukraine is characterised by a range of unfavourable abiotic factors that negatively affect the growth and development of crops and considerably reduce their productivity. Therewith, as noted by V. Mazur *et al.* (2021), the introduction of such a high-protein crop as peas into crop rotations contributes to the greening of production and improves the state of agrocenoses. Drought has become one of the most uncontrollable and unpredictable factors that constantly limits crop production and has a negative impact on pulses. M. Nadeem *et al.* (2019) showed that drought conditions reduce seedling emergence, photosynthetic activity, and disrupt the transport of photoassimilates in pulses, and in study M. Kolesnikov *et al.* (2023) showed the inhibition of growth processes in the early stages of plant ontogeny.

Bioregulators play a significant role in plant responses to environmental factors in shaping plant resistance to extreme conditions. In their review studies, B. Kumar (2021) and A. Dubey *et al.* (2020) show the role of biostimulants in the mechanisms of protection of *Fabaceae* plants from abiotic stresses, stimulation of growth processes, nutrient recycling, improvement of grain quality, and increase of crop yields. A lot of evidence has been accumulated that demonstrates the positive results of using growth regulators in soybean (Shepilova *et al.,* 2021), pea (Nebaba, 2023), bean (Pyda *et al.,* 2021), and cereal grains (Lemishko *et al.*, 2022), which contribute to a significant increase in the activity of symbiotic and associative nitrogen fixation and increase yields. N. Khan *et al.* (2020) showed that chickpea plants treated with growth regulators (salicylic acid, putrescine) had a higher height and weight of the aerial parts of plants, increased chlorophyll, protein, and sugar content, and increased yield.

O. Onyshchenko *et al.* (2023) report the effect of an antioxidant-type growth regulator on increasing the leaf surface index, accumulation of dry matter, chlorophyll content in leaves, and growth of photosynthetic potential in sunflower crops. M. Kolesnikov *et al.* (2019) showed that pre-sowing treatment of maize seeds with methyluracil promoted field germination, increased the leaf area index of maize crops, optimised net phototyping performance, and the preparation increased yields by 16-27%. O. Khodanitska *et al.* (2019) showed that the use of treptolem (a complex of auxin, gibberellin, cytokinin compounds) during the budding period of *Linum usitatissimum* L. leads to an increase in the yield of oil flax due to the enhancement of the morphogenesis of vegetative organs with the simultaneous restructuring of the anatomical structure of the stem and leaves. The stimulant enhanced the development of the photosynthetic apparatus: the formation of more leaves, prolongation of their active functioning, increase in the size of chlorenchyma cells and improvement of chloroplastogenesis.

S. Pyda *et al.* (2021) studied the effect of pre-sowing seed treatment with biostimulants Stimpo and Regoplant on the accumulation of oil in seeds and carbohydrates in the leaves of legumes, activation of growth processes and formation of the leaf apparatus of beans. S. Makogonenko *et al.* (2019) and V. Tsygankova *et al.* (2021) found that these biostimulants had bioprotective properties, enhanced growth processes, crop salt tolerance, and contributed to a significant increase in nitrogen fixation by forming a more powerful legume-rhizobial symbiosis. According to H. Kulyk *et al.* (2020), complex pre-sowing and foliar treatments with Stimpo and Regoplant growth regulators intensified the growth and development of sugar beet, increased the weight of roots, which provided an increase in root yields up to 6 t/ha in the central part of Ukraine. In experiments with yellow sorghum, V. Karpenko and S. Shutko (2018) proved that the greatest increase in the concentration of green pigments (a and b chlorophylls) and the increase in the net photosynthetic productivity index in leaves was observed when using the herbicide Pik 75 VG in combination with Regoplant. However, V. Pidlisnyuk *et al.* (2022) found no significant effect of Stimpo and Regoplant on the growth and development of *Miscanthus × giganteus* when grown on depleted soils.

The agrobiological effects of biostimulants Stimpo and Regoplant on the formation of the photoassimilation apparatus of legumes in the arid conditions of southern Ukraine are understudied. Therefore, the purpose of this study was to establish the specific features of the influence of biostimulants (Stimpo, Regoplant) on changes in leaf area index, net photosynthetic productivity, and chlorophyll content in *Pisum sativum* L. Oplot variety under the ecological conditions of the Southern Steppe of Ukraine.

MATERIALS AND METHODS

The study was conducted in 2016-2018 on an experimental field in the Melitopol district of Zaporizhzhia region. Mid-season peas (*Pisum sativum* L.) of the Oplot variety with leafless morphology were sown in the experimental plots. The Oplot pea variety was included in the Register of Plant Varieties of Ukraine in 2011 and recommended for cultivation in the Steppe zone of Ukraine. The originator is the V.Y. Yuriev Institute of Plant Industry of the National Academy of Agrarian Sciences of Ukraine. The territory of Melitopol district is characterised by a temperate continental climate with high temperatures. According to data from the weather station, the average long-term air temperature in the region is 9.9°C. Over the years of the study, during the period of pea cultivation, the average daily air temperatures exceeded the long-term average. Based on the data from the local weather station, Gossen-Walter climadiagrams were constructed in the modification (Cobon *et al.*, 2020), reflecting the hydrothermal regime during the three years of research (Fig. 1).

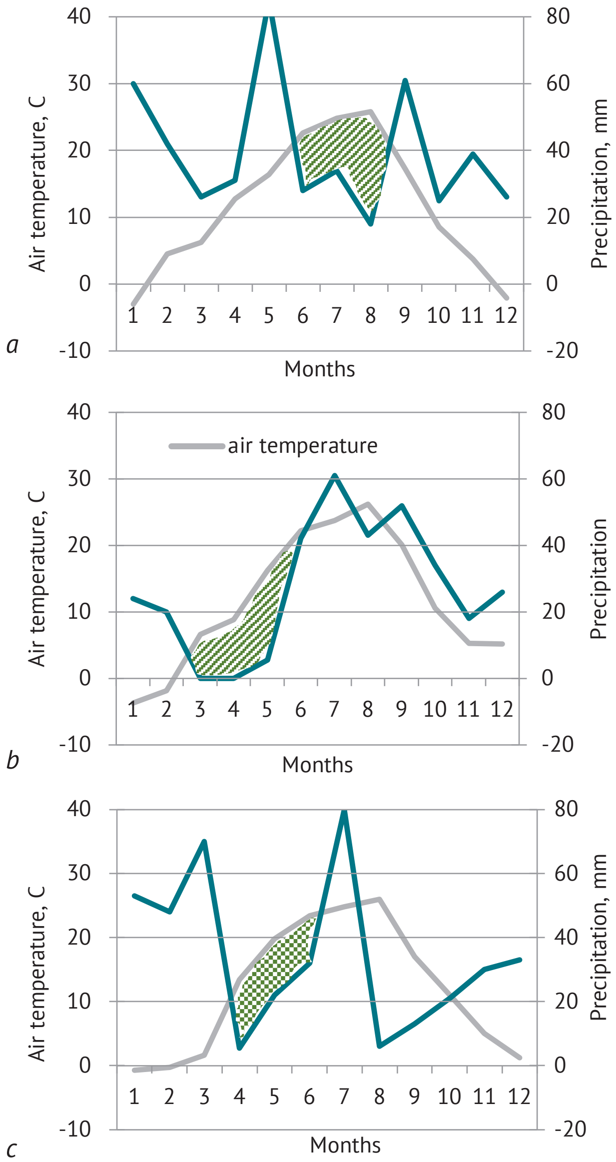

***Figure 1**. Gossen-Walter climate diagrams for 2016 (a), 2017 (b), 2018 (c)*
***Source:** Melitopol weather station data*

During the three years of research, a characteristic precipitation deficit was observed against the background of high temperatures with low hydrothermal potential in spring or summer. According to long-term observations, the annual precipitation in the region was 475 mm, while in 2016, 168 mm fell during the 90-day growing season, in 2017 – 48 mm, and in 2018 – 56 mm. Generally, spring climatic conditions favoured the growth and development of early spring crops, and therefore the efficiency of the production process during the years of research mainly depended on the availability of soil moisture, soil maintenance system, and other agrotechnical methods.

The soil of the experimental plots is a southern alluvial chernozem, characterised by the following indicators: humus content (according to Tyurin) – 2.6%, easily hydrolysable nitrogen (according to Kornfield) – 111.3 mg/kg, mobile phosphorus (according to Chirikov) – 153.7 mg/kg and exchangeable potassium (according to Chirikov) – 255 mg/kg of dry soil. The reaction of the soil solution was neutral (pH water/salt 7.0/7.3). The soil profile was not saline, but was slightly saline (exchangeable sodium 7% of CEC). The soil was of high quality, sufficiently saturated with nutrients and had favourable physical, chemical and agrophysical properties, making it suitable for growing pulses (DSTU 4362:2004, 2006). However, the use of plant growth regulators is justified to obtain high yields of quality products.

Biostimulants Stimpo and Regoplant are complex multicomponent preparations with diverse properties that are explained by the synergistic effect of the interaction of components (a mixture of carbohydrates, polysaccharides, amino acids, antioxidants, and microhormones), fatty acids, amino acids, phytohormones, trace elements) of the vital activity of the microfungus *Cylindrocarpon obtusiucuilum 680*, which is obtained from ginseng roots, and aversectins, which are metabolic products of the soil *Streptomyces avermitilis*. The influence of biostimulants on the formation of photoassimilation apparatus of pea crops in experimental microplots was studied. The seeding rate was 110 pcs/m^2. The variants in the experiment were arranged systematically with four replications. The research design included three variants. The pea seeds of the control group (variant 1) were treated with Liposam solution (5 g/l) before sowing and foliar treatment of crops was carried out with Liposam solution (5 g/l). In variant 2, the following were used: pre-sowing seed treatment – Stimpo (25 ml/t) in Liposam solution (5 g/l); foliar treatment – Stimpo (20 ml/ha) in Liposam solution (5 g/l). The pre-sowing treatment of pea seeds of variant 3 was carried out with Regoplant (250 ml/t) in Liposam solution (5 g/l), and the foliar treatment was carried out with Regoplant (50 ml/ha) in Liposam solution (5 g/l).

Before sowing, the seeds of the experimental variants were treated with biostimulants in the concentrations recommended by the manufacturers, and after drying, they were sown within a day. The first foliar treatment of pea crops was carried out at the stage of 5-6 stipules, and the second foliar treatment was carried out at the stage of budding to flowering. Plant samples were collected during the growing season of pea plants in 5 phases: BBCH 12-13, BBCH 15-16, BBCH 51-55, BBCH 61-65, BBCH 75-79. The working solution consumption was 300 l/ha during foliar treatment of pea crops.

The beginning of each phase of growth and development of pea was established after its onset in 10% of plants, complete phase – in 75% of plants, and the BBCH scale was used (Meier, 2018). At the end of the germination phase (BBCH 09), the field germination of pea seeds was determined. The number of seedlings per 1 m^2 was counted and field germination was calculated in relation to the number of seeds sown in a given area as described in V. Yeshchenko *et al.* (2005). The leaf surface area of pea plants was determined gravimetrically by the notching method. The gravimetric method relates the weight of leaves from 10 plant samples to the weight of leaf cuttings (D = 10 mm). Knowing the area of the leaf notches, the leaf surface area was calculated, and the leaf area index (LAI) was determined in m^2 per 1 m^2 of sown area.

The total chlorophyll content was determined by the fluorometric method using an N-tester (Yara, Japan). The measurement point was chosen in the middle of the first developed leaf. Based on the results of 30 random measurements performed according to the usual "W" scheme, the average value was obtained, and the results were presented in conventional units according to the methodology of I. Rodriguez and G. Miller (2000). The net photosynthetic productivity (NPP) was calculated as the ratio of the growth of plant dry matter mass over a certain period to the half sum of the leaf surface areas at the beginning and at the end of the period. The NPP was calculated using the following formula:

$$NPP = \frac{B_2 - B_1}{0.5(S_1 + S_2)n}, \tag{1}$$

where *NPP* is the net productivity of photosynthesis, g/m^{2}*day; B_1 and B_2 are the dry mass of plants at the beginning and end of the period, g; (B_2-B_1) is the growth of dry weight of plants for n number of days, g; S_1 and S_2 are the leaf surface area at the beginning and end of the period, m^2; 0.5 (S_1+S_2) is the average area of the leaf surface during the experiment; *n* is the period between two observations, days.

The dry mass of the substance was determined gravimetrically according to generally accepted methods (Ram, 2023). In the statistical analysis of the research results, the arithmetic mean, the average error of the arithmetic mean (± m), Student's t-test, and the least significant difference ($LSD_{0.95}$) were determined at a level of confidence of 95% (Yeshchenko *et al.,* 2005). The results were statistically processed using Microsoft Office Excel 2013 and Agrostat. The study 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

The study found that the biostimulants Stimpo and Regoplant during pre-sowing treatment of pea seeds already in the phase of 2-3 stipules increased the LAI of crops by 12% and 17%, respectively, under growing conditions during the study years (Table 1).

***Table 1**. Change in leaf area index (m^2/m^2) of crops of Pisum sativum L. variety Oplot under the effect of biostimulants*

Development phases	Years	Variants			LSD_{05}
		control	Stimpo	Regoplant	
BBCH 12-13	2016	0.10±0.04	0.16±0.05*	0.18±0.05*	-
	2017	0.21±0.01	0.21±0.01	0.22±0.01	-
	2018	0.19±0.01	0.20±0.01	0.19±0.01	-
	mean	0.17	0.19	0.20	0.05
BBCH 15-16	2016	0.39±0.06	0.45±0.05*	0.46±0.07*	-
	2017	0.45±0.01	0.77±0.01*	0.62±0.01*	-
	2018	0.56±0.01	0.83±0.02*	1.03±0.02*	-
	mean	0.47	0.68	0.70	0.21
BBCH 51-55	2016	2.01±0.11	2.30±0.12	2.76±0.13*	-
	2017	2.26±0.07	3.27±0.07*	3.05±0.05*	-
	2018	1.21±0.03	1.30±0.03	1.45±0.03*	-
	mean	1.82	2.29	2.42	0.44
BBCH 61-65	2016	3.80±0.25	5.70±0.31*	5.20±0.35*	-
	2017	4.16±0.04	6.49±0.09*	5.65±0.10*	-
	2018	2.51±0.08	3.93±0.12*	3.58±0.11*	-
	mean	3.49	5.37	4.81	0.75
BBCH 75-79	2016	4.03±0.31	6.10±0.29*	4.95±0.35	-
	2017	5.96±0.04	7.65±0.13*	7.47±0.09*	-
	2018	3.58±0.12	4.78±0.15*	4.20±0.14*	-
	mean	4.52	6.18	5.54	0.88

***Note:** * – difference is significant compared to the control at $P \leq 0.05$*
***Source:** compiled by the author of this study*

The positive effect of biostimulants on the formation of leaf surface during the vegetative phase of pea plants development was established. The LAI value of pea crops under Stimpo and Regoplant increased, respectively, by 15% and 18% in 2016, by 71% and 38% in 2017, and by 48% and 84% in 2018 in the BBCH phase 15-16. During the further vegetative development of pea plants (BBCH phase 15-16), a significant increase in LAI was observed in 1.45 times with Stimpo and in 1.48 times with Regoplant compared to control values.

During the transition to the generative stage of development, an active formation of the leaf surface area of pea plants treated with biostimulants was also noted, as indicated by the growth of LAI in the experimental variants compared to the control values. Thus, in the budding phase, the LAI of pea crops increased on average by 1.26 times under Stimpo and 1.32 times under Regoplant. The most effective increase in the LAI of pea crops was recorded by 1.54 times when using Stimpo (for three years of observations) and by 1.38 times when using Regoplant (for three years of observations) in the flowering phase (BBCH 61-65). The leaf area of pea crops treated with biostimulants stayed significantly increased until the phase of bean formation compared to the control.

The effect of biostimulants on changes in the content of total chlorophyll in pea stipules was characterised by some ambiguity. Thus, at the stages of vegetative development of pea plants, Stimpo led to a slight increase in the chlorophyll content in the stipules, which increased from an average of 1.6% to 2.7% compared to the control. However, during the years of research, a significant increase in chlorophyll content from 4.1% to 10.4% under Stimpo was recorded compared to control values, starting from the budding phase (BBCH 51-55) to the phase of bean formation (BBCH 75-79) (Table 2).

***Table 2**. Changes in the content of total chlorophyll (unit) in the stipules of Pisum sativum L. plants of Oplot variety under the influence of biostimulants*

Development phases	Years	Variants			LSD_{05}
		control	Stimpo	Regoplant	
BBCH 12-13	2016	483±4	505±8*	496±7	-
	2017	402±4	415±2*	405±2	-
	2018	560±5	565±5	568±4	-
	mean	482	495	490	9
BBCH 15-16	2016	459±6	466±5	480±6*	-
	2017	489±7	502±7	480±3	-
	2018	566±6	570±6	579±7	-
	mean	505	513	513	9

Table 2. Continued

Development phases	Years	Variants			LSD_{05}
		control	Stimpo	Regoplant	
BBCH 51-55	2016	549±11	540±10	534±9	-
	2017	489±6	555±8*	562±9*	-
	2018	583±6	590±7	595±8*	-
	mean	540	562	564	15
BBCH 61-65	2016	661±9	676±8	679±9	-
	2017	562±4	619±10*	606±10*	-
	2018	610±9	627±9*	623±9*	-
	mean	611	641	636	18
BBCH 75-79	2016	368±4	385±3*	374±4	-
	2017	624±11	741±12*	721±11*	-
	2018	650±10	685±9*	693±7*	-
	mean	547	604	596	24

Note: ** – difference is significant compared to the control at P⩽0.05*
Source: *compiled by the author of this study*

The biostimulant Regoplant did not have a substantial effect on the chlorophyll concentration in pea stipules at the stages of vegetative growth and plant development. In the experiment conducted in 2016, there were no statistically significant changes in chlorophyll levels under the influence of Regoplant in the generative period of plant growth. At the same time, in 2017, after foliar treatments of crops with Regoplant, an increase in chlorophyll concentration by 7.8-15.5% from the budding phase to the bean formation phase was recorded compared to control values. The same results were obtained in the 2018 research, when the content of total chlorophyll significantly increased by 2.1-6.6% under the influence of Regoplant in the phases of budding, flowering, and bean formation. It was found that the studied biological preparations increased the efficiency of photosynthesis in the initial stages of pea vegetation due to an increase in the net productivity of photosynthesis (Table 3).

Table 3*. Changes in net photosynthetic productivity (g/cm²*day)*
of Pisum sativum L. plants of Oplot variety under the effect of biostimulants

Variants		Interphase periods (according to BBCH)			
		12(13) – 15(16)	15(16) – 51(55)	51(55) – 61(65)	61(65) – 75(79)
control	2016	6.5±0.2	8.4±0.4	8.3±0.4	1.6±0.1
	2017	6.4±0.3	8.8±0.4	11.2±0.5	3.8±0.3
	2018	4.6±0.2	12.7±0.6	15.3±0.7	6.3±0.4
	mean	5.8	10.0	11.6	3.9
Stimpo	2016	5.8±0.3	8.4±0.3	9.4±0.5*	1.7±0.1
	2017	7.3±0.3*	9.2±0.5	12.6±0.8	1.9±0.2*
	2018	5.2±0.3*	12.6±0.7	25.1±0.8*	6.2±0.3
	mean	6.1	10.1	15.7	3.3
Regoplant	2016	6.9±0.2*	8.5±0.3	9.7±0.4*	3.3±0.2*
	2017	7.5±0.4*	9.3±0.5	13.0±0.7*	2.0±0.3*
	2018	5.4±0.3*	13.9±0.6	19.7±0.8*	8.3±0.4*
	mean	6.6	10.6	14.1	4.5
LSD_{05}		0.4	0.6	1.9	0.5

Note: ** – difference is significant compared to the control at P⩽0.05*
Source: *compiled by the author of this study*

From the data presented in Table 3, the NPP exceeded by 6.2% (2016), 17.2% (2017), and 17.4% (2018) its value in the control variant of pea plants between the phases 2-3 and 5-6 stipules under the influence of the biological product Regoplant. Therewith, the NPP was reduced by 10.8% in 2016 when Stimpo was applied and significantly exceeded the NPP value in control crops in 2017 by 14.0% and in 2018 by 13.0% during the periods of vegetative growth. During the next ontogenetic phase of budding, there were no statistically significant changes in the NPP in pea crops under the influence of biostimulants.

During the interphase period of budding – flowering of peas BBCH 51(55) – 61(65), there were substantial changes in the NPP between the experimental and control variants of pea crops. During this period, the average NPP of pea crops over the years of research exceeded the control values by 1.35 times under Stimpo and 1.22 times under Regoplant. The NPP of pea crops treated with the biostimulant Stimpo did not exceed the control values during the period of flowering – bean formation, while under the action of the biostimulant Regoplant, the average NPP value over the years of research exceeded this indicator in control pea crops by 15.4%. Thus, with intensive pea cultivation technologies, the use of plant biostimulants derived from natural raw materials allows for better formation of the leaf surface of crops, stimulation of photosynthetic processes, efficient use of PAR energy and a direct impact on crop yields in the Ukrainian Steppe zone.

The main advantage of modern plant growth regulators, which include a balanced complex of metabolically active substances, is their ability to target key processes of plant growth and development, as well as to effectively implement the potential of a particular variety or hybrid. The organic biological products under study are third-generation plant growth regulators with a broad spectrum of action and bioprotective effect. The mechanism of action of these preparations is based on the synergy of microbial fungi and aversectin, which has a positive effect on the physiological and biochemical parameters of plants and increases their resistance to stress (Medkov *et al.*, 2021). This is confirmed by the findings of studies of the influence of these biostimulants on the formation of the photoassimilation apparatus of different varieties of legumes in the different climate zones of Ukraine (Pyda *et al.,* 2021; Makogonenko *et al.*, 2019).

The analysis of the Gossen-Walter climate diagrams over the years of research shows that during the growing season of peas, there is a steady trend for changes in agroclimatic parameters towards warming and increasing aridity. Weather conditions have a substantial impact on the production process of pea and, specifically, the formation of the photoassimilation surface and its efficiency, such as ambient temperature, amount and uniformity of precipitation, which is confirmed by some researchers (Kolosovskaya, 2019; Vozhegova *et al.*, 2021).

Modern methods of growing crops are based on the concept of crop formation as a photosynthetic system and are developed with the biological characteristics of a particular crop in mind. The size of the assimilation surface of crops directly affects the yield of legumes and is an important diagnostic indicator.

Scientific data shows that the optimum leaf area of crop plants is 40 thsd m^2/ha, which allows for maximum crop productivity. Other studies indicate that for modern varieties and hybrids grown using intensive technologies and widely introduced into agricultural production, the optimum leaf area is within 50-60 thsd m^2/ha (Kim & Narimanov, 2021). The leaf area of pea crops over the 3 years of research increased during the growing season and the LAI reached its maximum values at the stage of bean formation. It was during this period that the most effective effect of the biostimulant Stimpo on the increase in leaf surface was noted, compared to the effect of Regoplant. The positive effect of growth biostimulants on the leaf area of pea crops is confirmed by the findings of K. Nebaba (2020).

Notably, O.S. Titarenko and L.M. Karpuk (2022) confirmed the increase in the efficiency of photosynthesis of grain sorghum hybrids with the foliar application of these biostimulants. The effect of the biostimulants under study on the accumulation of chlorophyll in pea stipules was effective only after the application of foliar treatments carried out in the BBCH phases 51-55. Presumably, according to N.V. Novytska and O.V. Ponomarenko (2022), the improvement of symbiotic nitrogen fixation under biostimulants increased the effective nitrogen assimilation, which had a positive effect on chlorophyll accumulation. The positive effect of the biostimulants under study is associated with the stimulating effect of cytokinins on chlorophyllogenesis (through increased synthesis of its precursor, protochlorophyllide) and on the intensity of photosynthesis and respiration (Khan *et al.*, 2020).

It is well-known that not all the leaf area formed in crops can be effectively used for the synthesis of dry matter. This is mainly due to the different tiering of the leaves and the problems that arise in ensuring efficient access to solar energy. Although it is difficult to estimate the illumination of individual leaves, changes in net photosynthetic productivity can still serve as a basis for some assumptions. The productive process of crops is correlated to a certain extent with photosynthetic parameters (Wu *et al.*, 2019). However, finding a quantitative correlation between plant productivity in agrocenoses and photosynthetic intensity is often difficult, as these aspects are mainly influenced by environmental conditions. The increase in NPP up to the interphase period of BBCH 51(55) – 61(65) was noted in all variants under study and was replaced by a sharp decrease in the interphase period of BBCH 61(65) – 75(79) in pea crops.

During these observations, only pre-sowing treatment of seeds with biostimulants generally did not have a substantial effect on the growth of LAI, while the NPP indicators increased during the vegetative phase of pea plants ontogeny. The biostimulants under study improved the parameters of net photosynthesis of pea plants when applying foliar treatments, which is confirmed by the findings of 3-year studies and the increase in NPP noted in other studies (Kulyk *et al.*, 2020; Pyda *et al.*, 2021; Netwal *et al.*, 2022). The biostimulant Regoplant more effectively contributed to the formation of dry biomass through the photosynthetic activity of the pea leaf apparatus compared to Stimpo during the entire growing season. Thus, the findings of this study confirm the data of other scientists on the influence of growth regulators on the formation of the photosynthetic apparatus of legumes and their effectiveness in the arid conditions of southern Ukraine.

CONCLUSIONS

The findings of the conducted study suggest that the use of biostimulants Stimpo and Regoplant in the cultivation of sowing peas is one of the effective agricultural measures to increase the efficiency of the production process through the influence on the functioning of the photoassimilation apparatus. Thus, based on the obtained 3-year results of the study, it can be concluded that the use of biostimulants Stimpo (25 ml/t + 20 ml/ha) and Regoplant (250 ml/t + 50 ml/ha) increased the leaf area index in different stages of vegetation of pea variety Oplot by 1.12-1.54 and 1.18-1.38 times, respectively, compared to the control.

The biostimulants Stimpo and Regoplant under the conditions of foliar treatments maximally increased the NPP of pea crops by 1.35 and 1.22 times, respectively, during the interphase period budding – flowering. The effect of biostimulants on the concentration of total chlorophyll in pea stipules was ambiguous and varied depending on the years. The probability of changes in the chlorophyll content was observed only after foliar treatment of crops with biostimulants. Thus, the study recorded an average increase in chlorophyll content by 4.0% under the action of biostimulants during the period of budding-flowering (BBCH 51(55) – 61(65)) and by 10.4% under Stimpo and 9.0% under Regoplant during the interphase period of budding-bean formation (BBCH 61(65) – 75(79)).

The data obtained confirm the prospects of further research on the efficiency of legume-rhizobial symbiosis, analysis of the structure of crops, elements of biological yield of peas and other legumes and product quality under the influence of biostimulants in the arid conditions of the Ukrainian Steppe zone, which will provide the population with high-quality food raw materials.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Формування фотоасиміляційного апарату посівів гороху (*Pisum sativum* L.) за дії біостимуляторів в посушливих умовах Південного Степу України

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Анотація. Південний Степ України характеризується рядом несприятливих агрокліматичних умов, що призводить до гальмування ростових процесів, порушення фізіологічних процесів та втрати врожаю сільськогосподарських культур. Застосування екологічно безпечних біорегуляторів стимулює ростові процеси, оптимізує азотне живлення, підвищує адаптивність зернобобових культур до несприятливих умов і збільшує урожайність. Метою роботи було з'ясувати особливості впливу біостимуляторів на формування фотоасиміляційного апарату гороху посівного сорту Оплот в умовах Південного Степу України. Було проведено 3-х річні дрібноділянкові дослідження в ході яких визначали індекс листкової поверхні, вміст загального хлорофілу та чисту продуктивність фотосинтезу в посівах гороху. Біостимуляторами проводили передпосівний та позакореневий обробіток посівів гороху в фазі бутонізації у концентраціях, описаних в методології. Було встановлено, що Стимпо (25 мл/т + 20 мл/га) збільшував індекс листкової поверхні у різних фазах вегетації гороху сорту Оплот в 1,12-1,54 рази та Регоплант (250 мл/т +50 мл/га) збільшував індекс листкової поверхні в 1,18-1,38 рази порівняно з контролем. Вірогідне збільшення вмісту хлорофілу в прилистках рослин гороху було зафіксовано після фоліарної обробки посівів біостимуляторами та перебільшувало значення контрольних рослин на 9,0-10,4 % в період BBCH 61(65) – 75(79). За 3-х річними результатами доведено позитивний вплив біостимуляторів на чисту продуктивність фотосинтезу. Так, Стимпо та Регоплант збільшували чисту продуктивність фотосинтезу посівів гороху на 35 % та 22 % відповідно у фазі бутонізація (BBCH 51-61) і цвітіння (BBCH 55-65). Одержані наукові результати сприяють широкому використанню досліджуваних біостимуляторів в технології вирощування гороху в зоні Південного Степу України з метою підвищення продуктивності культури та отримання врожаю високої якості

Ключові слова: бобові; регулятори росту рослин; Регоплант; Стимпо; чиста продуктивність фотосинтезу; індекс листкової поверхні; хлорофіл