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Peculiarities of soybean growth and development on gray forest soils

I. Didur* and H. Pantsyreva

Vinnytsia National Agrarian University, Educational and Scientific Institute of Agrotechnology and Environmental Sciences, Sonyachna Str. 3, UA21008 Vinnytsia, Ukraine, ORCID ID: https://orcid.org/0000-0002-6612-6592
*Correspondence: dim@vsau.vin.ua

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Abstract. The scientific and experimental five-year study highlighted the detailed development of technological techniques for growing soybeans under different hydrothermal growing conditions on gray forest soils. The conducted experimental studies established that under the influence of climatic factors, the duration of the growing season of soybean plants changes, and these factors, as a result, affect the field germination, the conservation factor and, as a result, the yield of plants. It has also been proven that during the ontogenesis of the plant, there are natural changes in linear dimensions depending on varietal characteristics, weather conditions and factors that were investigated. On average, over the years of research, the length of the soybean vegetation period ranged from 110 to 118 days, while the longest vegetation period was recorded on the experimental variants, where seeds were inoculated with the BTU Bioinoculant preparation and two foliar feedings were carried out in phase 3 – the third leaf and budding Helprost soybean. Starting from the flowering phase, soybean plants reacted more intensively to the studied factors. On the options where foliar fertilizing was carried out with Helprost soy mineral fertilizer (2.5 L ha^{-1}) against the background of inoculation with BTU Bioinoculant (2 L t^{-1}), the flowering period lasted 28 ± 3.6 days, which is 3 days more compared to with areas where foliar fertilization was not carried out and for 6 days – compared to the control. This is explained by the influence of a number of factors, in particular, hydrothermal, biotic, soil and anthropogenic. During the period of full ripeness, in connection with the action caused by pests and diseases, certain technological techniques and factors that were put to study, the density of plants according to the experimental options was from 488 ± 28.3 to 552 ± 34.5 thousand ha^{-1}.

Key words: soybean, gray forest soils, productivity, field germination, conservation factor, interphase periods, seed inoculation, foliar fertilization, plant height.

INTRODUCTION

The main criterion for studying the technology of growing soybeans is a detailed analysis of the processes of growth and development of plants in different phases of vegetation (Monarkh & Pantsyreva, 2019; Lutkovska, 2020; Kaletnik & Lutkovska, 2020; Tsyhanskyi, 2021; Bulgakov et al., 2023; Hetman et al., 2024; Tkachuk et al., 2024).

The duration of the growing season of soybean varieties directly depends on the biological characteristics of plant development and climatic conditions. Therefore, the duration of the growing season is influenced by temperature conditions, lighting of crops, availability of sufficient moisture and other factors. Lack of heat in combination with high humidity prolongs the growing season. Relatively dry and warm weather significantly reduces the observed indicators. Increased air temperature shortens the interphase period from sowing to germination and from germination to flowering (Didur et al., 2019; Pantsyreva et al., 2023; Dubik et al., 2024). Favorable conditions for obtaining high soybean yields are formed when 300–350 mm of precipitation falls during the growing season of plants, and the sum of active temperatures is 2,000–2,500 °C. At the same time, crop productivity does not depend on the absolute level of hydrothermal resources, but on their distribution throughout the growing season, especially during critical periods of crop growth and development (Didur et al., 2020; Mazur et al., 2020; Bondarenko et al., 2022). H. Pantsyreva claims that the activity and viability of nodules on the root system in leguminous crops, including soybeans, depends on hydrothermal factors, species and varieties, mineral nutrition and soil moisture in spring and in the first half of summer, soil temperature 22–26 °C, which contribute to the cyclic process of photosynthesis and biological nitrogen fixation (Pantsyreva, 2019). In conditions of reduced soil temperature, there is a significant slowdown in the work of nodule bacteria.

The most balanced ecologically oriented direction is biological agriculture, which promotes the activation of certain soil processes and the improvement of soil fertility, including due to the fixation of atmospheric nitrogen by soil microorganisms. It was established that doses of mineral nitrogen, which do not exceed the physiological optimum for plants, contribute to increasing the activity of nitrogen fixation (Mazur et al., 2018; Puyu et al., 2021; Petrychenko et al., 2022).

It is known that nitrogen is one of the main elements of the formation of indicators of the level of productivity of agricultural crops, as well as an important factor in the reproduction of soil fertility (Alaru et al., 2014; Kaletnik, 2018; Vdovenko et al., 2018; Hnatiuk et al., 2019; Dumpis et al., 2021). Therefore, the problem of its balance and transformations in agroecosystems is an important component of the development of modern energy-saving ecological technologies of cultivation in agricultural production (Mazur et al., 2019). The supply of nitrogen compounds to the soil mainly occurs due to organic substances, symbiotic and non-symbiotic (associative) nitrogen fixation and in the form of organo-mineral fertilizers (Mazur et al., 2021). In traditional cultivation technologies, considerable attention was paid to the quantitative indicators of providing the soil with nitrogen-containing substances.

Whereas in the agronomic systems of feeding agricultural plants, the exclusive role belonged to organic and mineral fertilizers, as well as the cultivation of legumes, in particular soybeans (Zhou et al., 2019; Didur et al., 2021; Petrychenko et al., 2024). This agricultural approach was and remains decisive, as it allows to quickly and extensively influence the yield level (Bulgakov et al., 2014; Kaletnik et al., 2019; Palamarchuk et al., 2021). Therefore, nitrogen fixation due to the use of microorganisms is a process that is closely interconnected with the processes of photosynthesis, equal to it in scale and importance in the environment (Patyka & Petrychenko, 2004; Patyka et al., 2014; Petrychenko et al., 2018). According to many scientists (Mazur & Mazur, 2023): soy belongs to the strategic crops of world crop production and satisfies the most general needs of humanity due to the promotion of balanced nature use.

Today, the issue of studying biological nitrogen, which enters the soil with siderates, by-products, and leguminous crops, has become particularly relevant (Honcharuk et al., 2022; Honcharuk et al., 2024; Pantsyreva et al., 2024) and can be involved due to inoculation or application of microbiological preparations to the soil (Jansson et al., 2019; Bakhmat et al., 2023; Didur et al., 2024; Petrychenko et al., 2024). The relevance of the conducted research is reinforced by tasks of the state theme, which are carried out at the expense of the state budget of Ukraine on the topic: 'Development of ecologically oriented technologies for growing bioenergy crops to ensure energy independence and soil conservation for the formation of climate neutrality'.

MATERIAL AND METHODS

MATERIAL

A two-factor field experiment was conducted during 2017–2021 at the experimental plots of the Agronomichne of Vinnytsia National Agrarian University, whose lands are located in the village of Agronomichne of Vinnytsia district of Vinnytsia region. The soil of the experimental field is gray forest medium loam. The dimensions of the experimental area are 40 m^2, the accounting area is 25 m^2. The repetition is four times, the placement of the plots is systematic. Soybeans of the Madison variety were sown in the experiment (Fig. 1).

Figure 1. Soybeans of the Madison variety.

Culture cultivation technology is recommended for the Forest-Steppe zone of the Right Bank of Ukraine. Accounting was carried out in accordance with methods generally accepted in crop production. The selection of soil samples for agrochemical studies was carried out according to GOST 28168-89, for microbiological ones - according to DSTU ISO 10381-6-2001. The content of alkaline hydrolyzed nitrogen was determined according to the Kornfield method, humus - according to GOST 26213-91. According to the temperature regime and the amount of precipitation in 2017–2021, the studies had some deviations from the average long-term indicators, however, in general, they were favorable for the growth and development of soybean plants.

Field experiment scheme: Factor A – Seed treatment: 1) control, 2) seed treatment with BTU bio-inoculant (2 L t^{-1}), 3) seed treatment with Risoline (2 L t^{-1}) + Rizoseif (2 L t^{-1}), 4) seed treatment with Anderiz (1.5 L t^{-1}). Factor B – Foliar fertilization: 1) control, 2) Biocomplex BTU (1.0), 3) Gummyfriend (1.0 L ha^{-1}), 4) Helprost soybean (2.5 L ha^{-1}).

BTU bioinoculant: liquid from cream to brown color with a specific smell. Composition: viable cells of nodule bacteria Bradyrhizobium japonicum, symbiotic to soybeans, titer from 2.0×109 CFU cm^{-3}, macro- and microelements, biologically active products of bacterial activity (vitamins, heteroauxins, gibberellins, etc.).

Risoline: biopreparation for inoculation of legume seeds. Composition: viable cells of nodule bacteria: Bradyrhizobium japonicum, symbiotic to soybeans, titer (2.0–6.0) × 109 CFU cm^{-3}, macro- and microelements, biologically active products of bacterial activity (vitamins, heteroauxins, gibberellins, etc.).

Anderiz: milky to gray liquid with a specific smell. Composition: viable cells of nodule bacteria Bradyrhizobium japonicum, which have a unique symbiotic relationship with legumes, active metabolites of microorganisms (vitamins, phytohormones, etc.), components of the nutrient medium (sources of nutrition for microorganisms), the total number of viable cells is 2.5×109 CFU cm^{-3}. Component 2 is a phosphorus-mobilizing fungus *Penicillium bilaii*.

Biocomplex BTU: biological preparation for nutrition and disease prevention. liquid from cream to brown color with a weak specific smell. Composition: living bacteria: nitrogen-fixing – provide plants with nitrogen, phosphorus- and potassium-mobilizing – convert difficult-to-dissolve compounds into forms available for plants: phosphorus, potassium, other nutrients, microorganisms with fungicidal properties – protect plants from bacterial and fungal diseases components of the nutrient medium (macro-, trace elements and organic power sources). The total number of viable microorganisms of the producer is not less than 1.0×109 CFU cm^{-3}.

Gummyfriend: Complex fertilizer based on potassium humate with additional content of useful microorganisms and products of their metabolism. Composition: potassium salts of humic and fulvic acids, a complex of microorganisms: *Bacillus subtilis, Bacillus megaterium var. phosphaticum, Bacillus muciloginosus, Bacillus macerans, Paenibacillus polymyxa*, amino acids, peptides; succinic (succinic) acid; polyethylene glycol; trace elements (sulfur, magnesium, zinc, iron, manganese, boron, copper, silicon, molybdenum, cobalt).

Helprost soy: an organo-mineral fertilizer. Contains % to: macroelements (P-2.9; K-3.5), mesoelements (S-1.2; Mg-0.8), trace elements (Fe-0.12; Co-0.01; Mn-0.2; Mo-0.03); biologically active substances: vitamins – 0.02; amino acids – 1.0; peptides – 0.5; polysaccharides – 0.05.

METHODS

The theoretical and methodological basis of research is special and generally accepted methods and techniques in agronomy. The beginning of the phenological phases of plant growth and development was recorded when they occurred in 10% of the plants, and the complete phase in 75% grew. The height was determined by measuring 25 fixed plants in the main phases of growth and development of leguminous crops in two non-adjacent repetitions. Mathematical processing of the obtained results was carried out by the method of dispersion and correlation-regression analysis using Excel, Statistica 10, Agrostat software packages.

RESULTS AND DISCUSSION

On average, over the years of research, the duration of the soybean vegetation period ranged from 110 to 118 days, while the longest vegetation period was recorded on the experimental variants, where seeds were inoculated with BTU Bioinoculant and two foliar feedings were carried out in phase 3 – the third leaf and budding Helprost soybean. In the variants of the experiment, where only pre-sowing inoculation of seeds was carried out, the growing season lasted 112–113 days, while in the control variant the duration of the growing season was 110 days, respectively.

According to the received data on the duration of the period of growth and development of plants in the section of the experimental variants showed that the period from sowing to full germination in the control variant lasted 16 days, and in the experimental variant, where the pre-sowing inoculation of seeds with the preparation Bioinoculant BTU was carried out, the seedlings appeared 2 days earlier than in the control. When seeds were treated with Anderiz or Rizolain + Rizosev composition, seedlings appeared 1 day earlier compared to the control.

The period from germination to the formation of the third triple leaf lasted 23 days in the control, in the variants where pre-sowing inoculation of seeds with the BTU Bioinoculant was carried out for 21 days, and for the rest with the inoculants Anderiz and Rizolain + Rhizosev, respectively, 22 days.

The period from the appearance of the third trifoliate leaf to mass flowering was characterized by intensive linear growth of soybean plants and the formation of its vegetative organs, which required a significant amount of moisture and heat.

After passing the vegetative stages of growth and development, during which the main vegetative mass of plants is formed and generative organs are laid, then the reproductive stages of development occur, which last from flowering to full ripening of seeds.

It is known that the critical period for providing moisture for soybean plants is the flowering period. Over the years of our research, this period was characterized by elevated temperatures and varying amounts of precipitation. Thus, in 2017, the indicators of GTK for this period were 0.55, in 2018 – 0.91, in 2019 – 0.65, and in 2020 and 2021, respectively, 0.41 and 0.73. It was noted that foliar fertilization of soybean plants, carried out in the phase of the third trifoliate leaf and full flowering, had a positive effect on the duration of the generative growth period and extended it (Table 1).

Starting from the flowering phase, soybean plants reacted more intensively to the studied factors. On the options where foliar fertilizing was carried out with helprost soy mineral fertilizer (2.5 L ha^{-1}) against the background of inoculation with BTU Bioinoculant (2 L t^{-1}), the flowering period lasted 28 ± 3.6 days, which is 3 days more compared to with areas where foliar fertilization was not carried out and for 6 days – compared to the control. A similar dependence was recorded against the background of other studied inoculants. So, on the variants where inoculation was carried out with the preparations Rizolain (2 L t^{-1}) + Rhizosev (2 L t^{-1}), the flowering period was 23 ± 2.5 days, for foliar feeding with the biological preparation Biocomplex BTU (1 L ha^{-1}) and complex fertilizer for on the basis of Gummyfriend potassium humate (1 L ha^{-1}), this period was extended to 25 ± 2.8 and 24 ± 2.7 days, respectively, the maximum duration of the flowering period of 26 ± 3.0 days was noted with the use of organic-mineral fertilizer

Helprost soy (2.5 L ha^{-1}). With the use of Anderiz inoculant and foliar top dressing, the duration of the flowering period was the same as when using Risoline (2 L t^{-1}) + Rhizosev (2 L t^{-1}).

Table 1. Duration of interphase periods of soybean plants depending on seed inoculation and foliar fertilization, on average for 2017–2021, days

Processing Seed	Foliar feeding	Phases of growth and development				
		3rd triad leaf	beginning flowering	end flowering	full pouring seed	physiological maturity
No processing	Without feeding (c)	22 ± 1.6	22 ± 2.2	29 ± 1.9	13 ± 1.8	110 ± 3.7
	Biocomplex BTU	21 ± 1.1	23 ± 2.3	30 ± 1.9	14 ± 1.8	112 ± 3.3
	Gummyfriend	21 ± 1.6	23 ± 2.4	30 ± 2.2	14 ± 1.3	111 ± 4.2
	Helprost soy	20 ± 1.5	24 ± 2.5	31 ± 1.8	15 ± 1.9	113 ± 3.9
BTU bio-inoculant	Without feeding	20 ± 1.1	25 ± 2.6	32 ± 2.3	14 ± 1.5	113 ± 3.3
	Biocomplex BTU	19 ± 1.1	27 ± 3.2	34 ± 2.2	15 ± 1.7	117 ± 4.0
	Gummyfriend	20 ± 1.3	26 ± 3.0	33 ± 2.6	15 ± 1.6	115 ± 4.1
	Helprost soy	19 ± 1.3	28 ± 3.6	35 ± 1.8	16 ± 1.7	118 ± 4.3
Risoline + Rhizosev	Without feeding	21 ± 1.1	23 ± 2.5	32 ± 2.1	14 ± 1.6	112 ± 2.9
	Biocomplex BTU	20 ± 1.1	25 ± 2.8	33 ± 1.9	15 ± 1.6	115 ± 3.3
	Gummyfriend	20 ± 1.1	24 ± 2.7	32 ± 1.5	14 ± 1.7	114 ± 3.2
	Helprost soy	20 ± 1.1	26 ± 3.0	33 ± 1.9	15 ± 1.6	115 ± 3.6
Anderiz	Without feeding	21 ± 1.1	24 ± 2.6	32 ± 1.9	14 ± 1.6	112 ± 2.5
	Biocomplex BTU	20 ± 1.1	25 ± 3.0	33 ± 1.9	15 ± 1.6	115 ± 2.9
	Gummyfriend	20 ± 1.5	24 ± 2.8	32 ± 1.8	15 ± 1.3	113 ± 2.9
	Helprost soy	20 ± 1.1	26 ± 3.0	33 ± 1.5	15 ± 1.6	115 ± 3.0

In the years of field research, the density of plants was determined twice during the growing season of soybeans in fixed areas, which were noted after the emergence of seedlings. The first count of plant density was carried out in the full seedlings phase, and the second before harvesting. The first calculation with a known sowing rate made it possible to determine the field germination of seeds, and the second to determine the coefficient of plant preservation (survival). According to scientists, survival is a genetically determined trait, but the level also depends on growing conditions and intensification factors. At the initial stages of soybean organogenesis, seedlings are fed by the plastic substances of the seed, and only after the appearance of cotyledon leaves above the soil surface does the plant begin to absorb carbon dioxide from the atmosphere and nutrients from the soil (Fig. 2).

On average, during the years of research (2017-2021), the indicators of field similarity are, respectively, 86.2 ± 2.5–87.5 ± 2.7%. It was established that the pre-sowing treatment of seeds with inoculants ensured a significant increase in field germination of seeds to 89.4 ± 2.9–91.3 ± 3.7%.

Creating favorable conditions for plant growth and development at the initial stages, especially in the first 30–40 days of vegetation, plays an important role in shaping soybean productivity. The pre-sowing treatment soybean seeds had a positive effect on field germination, while foliar fertilization had a positive effect on the preservation of plants during the growing season (Fig. 3).

Observations during the growing season on the dynamics of plant density of soybean varieties show that it decreases somewhat as they grow and develop, which is a consequence of plants falling from sowing. This is explained by the influence of a number of factors, in particular, hydrothermal, biotic, soil and anthropogenic.

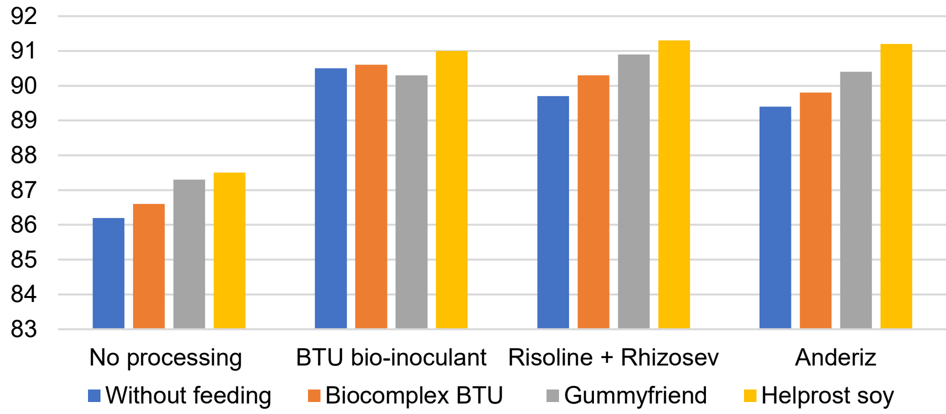

Figure 2. Dynamics of the influence of seed inoculation and foliar fertilization on the field germination of soybean plants, %, on average for 2017–2021.

During the period of full ripeness, in connection with the action caused by pests and diseases, certain technological techniques and factors that were put to study, the density of plants according to the experimental options was from 488 ± 28.3 to 552 ± 34.5 thousand ha^{-1}.

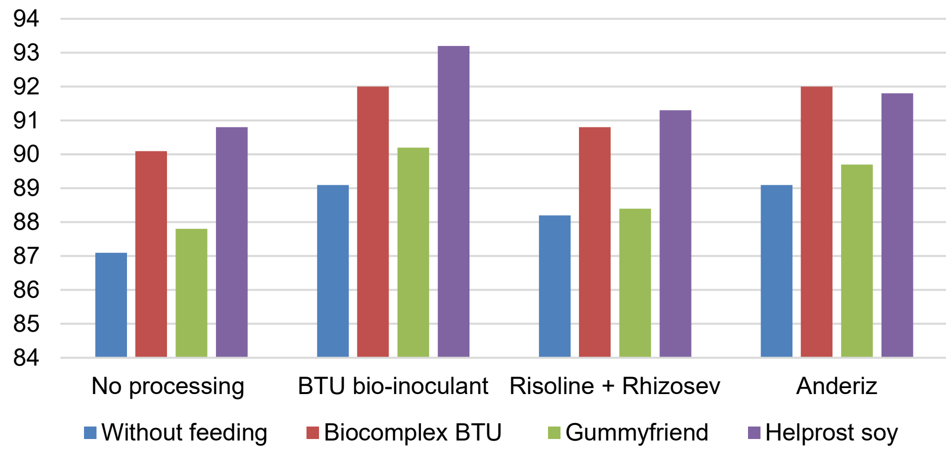

Figure 3. The effect of seed inoculation and foliar fertilization on the ratio of soybean plant survival to the number of seedlings, %, on average for 2017–2021.

On variants of the experiment without inoculation, the density of plants at the time of full maturity was from 488 ± 28.3 to 517 ± 26.2 thousand ha^{-1}. depending on foliar feeding. In the variants where the pre-sowing bacteriization of the seeds with BTU Bioinoculant (2 L t^{-1}) was carried out, 6.7–7.3% (524 ± 30.9–552 ± 34.5 thousand) remained in the phytocenosis, depending on foliar fertilization ha^{-1}) more plants compared to the control, and when using the preparations Rizoline (2 L t^{-1}) + Rhizosev (2 L t^{-1}) and Anderiz (1.5 L t^{-1}), respectively, by 5.0–5.3% (514 ± 30.4–543 ± 31.1 thousand ha^{-1}) and 5.4–6.1% (518 ± 30.0–545 ± 32.3 thousand ha^{-1}).

Thus, it was established that the most favorable conditions for growth and development, and as a result, the greatest survival of soybean plants, were in the variants of the experiment with a combination of seed inoculation with the preparation Bioinoculant BTU (2 L t^{-1}) and foliar fertilizing with the organo-mineral fertilizer Helprost soy (2.5 L ha^{-1}). Under these growing conditions, the share of soybean plant preservation was 93.2 ± 2.8%, while in the absolute control of the experiment this indicator was only 87.1 ± 2.6%.

So, a comprehensive approach to the biologization of the soybean fertilization system, namely its cultivation with seed inoculation with BTU Bioinoculant (2 L t^{-1}) and foliar feeding with the organo-mineral fertilizer Helprost soy (2.5 L ha^{-1}) provides the best conditions for growth, development and preservation of the largest number of plants at the time of full maturity. Survival rates of soybean plants testify to the positive influence of organized factors on the formation of high yields of soybean seeds.

A detailed analysis of the dynamics of the formation of the stem height of soybean plants according to the phases of growth and development shows that the application of the studied intensification factors ensured a fairly significant increase in it. So, in particular, pre-sowing seed inoculation and foliar fertilization contributed to more intensive plant growth, and as a result, to an increase in stem height from the beginning of the growing season of soybean plants (Table 2).

Table 2. Indicators of the height of soybean plants depending on pre-sowing treatment of seeds and foliar fertilization, on average for 2017–2021, see, M ± m

Processing seed	Foliar feeding	Phases of growth and development				
		3rd triad leaf	beginning flowering	end flowering	full pouring seed	physiological maturity
No processing	Without feeding (c)	15.0 ± 2.5	42.5 ± 4.8	55.9 ± 7.3	60.4 ± 7.3	65.0 ± 7.2
	Biocomplex BTU	15.4 ± 2.6	46.0 ± 5.5	60.9 ± 8.1	65.0 ± 8.3	67.8 ± 7.3
	Gummyfriend	15.7 ± 2.6	44.7 ± 5.1	59.0 ± 8.2	63.2 ± 7.7	66.1 ± 7.4
	Helprost soy	15.6 ± 2.4	47.1 ± 5.1	62.7 ± 7.8	66.3 ± 7.8	69.3 ± 7.2
BTU bio-inoculant	Without feeding	16.2 ± 2.8	47.6 ± 5.8	62.8 ± 8.0	67.7 ± 7.5	71.0 ± 6.9
	Biocomplex BTU	16.2 ± 2.7	51.8 ± 5.5	69.2 ± 8.7	73.4 ± 8.1	76.5 ± 7.3
	Gummyfriend	16.6 ± 2.8	50.6 ± 5.1	66.5 ± 8.6	70.8 ± 7.7	75.0 ± 6.9
	Helprost soy	16.2 ± 2.6	53.9 ± 5.0	71.7 ± 7.6	75.7 ± 8.0	78.3 ± 7.4
Risoline + Rhizosev	Without feeding	16.1 ± 2.9	45.2 ± 5.4	59.8 ± 8.1	64.2 ± 7.2	67.7 ± 6.9
	Biocomplex BTU	16.4 ± 2.6	48.8 ± 4.7	64.8 ± 7.4	68.9 ± 7.7	72.3 ± 6.4
	Gummyfriend	16.4 ± 2.8	47.1 ± 5.2	62.3 ± 8.2	67.0 ± 7.7	70.2 ± 7.0
	Helprost soy	17.0 ± 2.6	50.2 ± 4.7	67.0 ± 7.2	70.1 ± 8.3	74.3 ± 6.6
Anderiz	Without feeding	16.5 ± 2.9	45.8 ± 6.0	61.5 ± 8.5	65.9 ± 6.9	68.8 ± 6.3
	Biocomplex BTU	16.9 ± 2.9	50.0 ± 5.3	67.0 ± 7.8	70.4 ± 7.7	73.8 ± 6.7
	Gummyfriend	16.7 ± 2.7	48.8 ± 5.2	64.7 ± 8.8	69.1 ± 7.4	72.2 ± 6.9
	Helprost soy	17.3 ± 2.8	51.9 ± 5.0	69.1 ± 8.1	72.6 ± 7.9	76.1 ± 6.8
V, %		3.8	6.3	6.6	5.9	5.5
Sx, %		0.9	1.6	1.6	1.5	1.4

Thus, in the control variants of the experiment (without inoculation), the height of the plants was, depending on foliar feeding, from 65.0 ± 7.2 to 69.3 ± 7.2 cm, optimization of the mineral nutrition system of soybean plants according to due to inoculation of seeds with BTU Bioinoculant (2 L t^{-1}) contributed to the growth of their height to 71.0 ± 6.9–78.3 ± 7.4 cm, which is by 6.0–9.0 cm (9.2–12.9%) more control.

During the pre-sowing inoculation of seeds with the preparation Risoline (2 L t^{-1}) with the protector Rhizosev (2 L t^{-1}), the height of soybean plants was formed at the level of 67.7 ± 6.9– 74.3 ± 6.6 cm, which is 2 times more than the control. 7.0–5.0 cm (4.1–7.2%). A positive influence of organized factors on plant height indicators was noted. Thus, a higher plant height of 68.8 ± 6.3–76.1 ± 6.8 cm was formed on the variant where Anderiz inoculant (1.5 L ha^{-1}) was used. Growth when compared to options without inoculation was 3.8–6.8 cm (5.8–9.8%).

Depending on the foliar feeding with various researched preparations, the plant height indicators also changed in the direction of growth.

In the version of the experiment with the introduction of Biocomplex BTU biological preparation (2.5 L ha^{-1}), the height of the plants changed depending on the pre-sowing treatment, from 67.8 ± 7.3 to 76.5 ± 7.3, which is by 2.8–5.4 see the option where foliar fertilization was not carried out. In the variant with the use of a complex fertilizer based on Gummyfriend potassium humate (1 L ha^{-1}) for foliar fertilization, the height of the plants was slightly lower, compared to the indicators in the above-mentioned variants, but exceeded the control without fertilization by 1.1–3.9 cm. It was established that that the use of organo-mineral fertilizer Helprost soy (2.5 L ha^{-1}) was more effective. The height of the plants was 69.3 ± 7.2–78.3 ± 7.4 cm, while in the control it was 65.0 ± 7.2–71.0 ± 6.9 cm. variants were 4.3–7.2 cm. With the combined use of pre-sowing seed inoculation and foliar feeding, the height of soybean plants exceeded plants on the variants with the separate use of these technological techniques (Fig. 4).

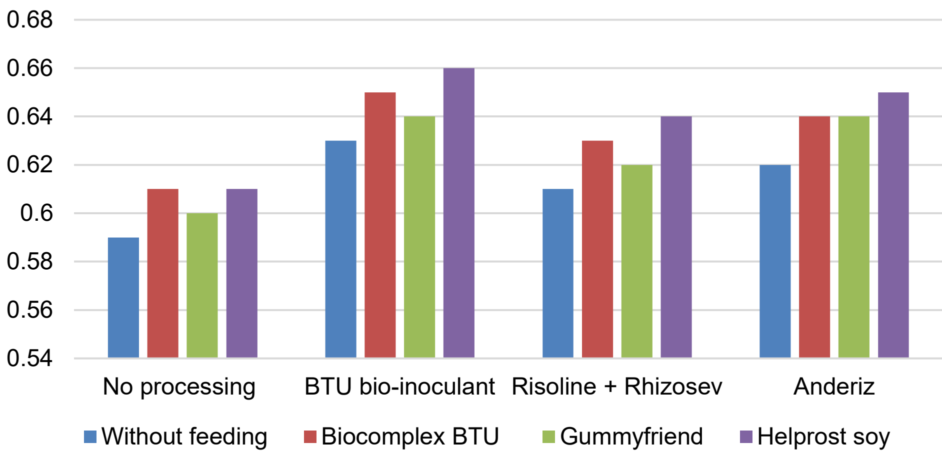

Figure 4. Average daily linear growth of the stem of soybean plants depending on seed treatment with bioinoculants and foliar fertilization (on average for 2017–2021, cm day^{-1}).

Note: 1. without feeding (control); 2. Biocomplex BTU (1 L ha^{-1}); 3. Gummyfriend (1 L ha^{-1}); 4. Helprost soy (2.5 L ha^{-1}).

A close relationship between the height of plants in the phase of physiological maturity and the yield of soybean seeds was established. This also confirms the degree of statistical relationships between the studied indicators, which is characterized by the correlation coefficient (R2). It is known that the closer its value is to one, the stronger the closeness between the indicators. According to statistical data, the value of the correlation coefficient indicator was established (0.936). Therefore, we can conclude that in the dependence presented by us, the degree of closeness of the connection according to the Chaddock scale is very strong.

$$Y = -2{,}630.7 + 0.0774*x$$

where Y – seed yield t ha^{-1}; x – plant height, cm.

Thus, the maximum plant height of 78.3 ± 7.4 cm was formed on the option where seed inoculation with BTU Bioinoculant and foliar fertilizing with Helprost soy was used. Reliable indicators of growth of the height of soybean plants by 13.3 cm or 20.4% were noted when compared with the control variant. The highest average daily linear increases were also noted.

CONCLUSIONS

On the gray forest soils of the Forest-Steppe of Ukraine, the highly plastic soybean variety is Madison, which, when sown at a soil temperature of 12 °C and a seeding rate of 800,000 pieces ha^{-1}, provides optimal growth and development parameters. Therefore, the duration of the growing season is influenced by temperature conditions, lighting of crops, availability of sufficient moisture and other factors. On average, over the years of research, the length of the soybean vegetation period ranged from 110 to 118 days, while the longest vegetation period was recorded on the experimental variants, where seeds were inoculated with the BTU Bioinoculant preparation and two foliar feedings were carried out in phase 3 – the third leaf and budding Helprost soybean. Soybean Pre-sowing treatment seeds had a positive effect on field germination, while foliar fertilizing had a positive effect on the preservation of plants during the growing season. For the period of full maturity, in connection with the effect caused by pests and diseases, certain technological methods and factors were put to study, the density of plants according to the variants of the experiment ranged from 488 ± 28.3 to 552 ± 34.5 thousand ha^{-1}. A comprehensive approach to the biologization of the soybean fertilization system, namely its cultivation with seed inoculation with the preparation Bioinoculant BTU (2 L t^{-1}) and foliar feeding with Helprost soy (2.5 L ha^{-1}) provides the best conditions for growth, development and preservation of the largest number of plants for the time of full maturity. It was established that the use of organo-mineral fertilizer Helprost soy (2.5 L ha^{-1}) was more effective. The same time, the height of the plants was 69.3 ± 7.2– 78.3 ± 7.4 cm, in the control it was 65.0 ± 7.2–71.0 ± 6.9 cm. variants were 4.3–7.2 cm.

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