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Simulation of High–Product Soy Crops Based on the Application of Foliar Fertilization in the Conditions of the Right Bank of the Forest Steppe of Ukraine

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ABSTRACT

The article highlights experimental and field studies of the scientific problem of increasing the yield of soybean seeds by optimizing the main elements of growing technology. Improved standards for the depletion of major biological nutrients during the formation of units in soybean crops make it possible to specify the standards of foliar fertilization to obtain the planned levels of yield and removal of these elements from the soil. The obtained results are of practical importance, as they contribute to optimizing the nutrition of soybean plants due to the use of foliar fertilizers Ecoline Legume. This helps to increase seed yield to the level of 2.0–2.5 tons per hectare. The researchers also conducted a generalization and analysis of scientific results in the field of soybean yield management through foliar feeding. In addition, scientific publications on the influence of liming, application of organic, mineral and microfertilizers on the physicochemical and agrochemical properties of the soil were analyzed. The cultivation of soybeans and the rational application of foliar fertilization are economically beneficial methods, and in this case, the use of foliar fertilization Ecoline Legume to approximately neutral reaction of the soil environment contributed to obtaining the highest levels of conditional net profit and profitability. This confirms the high energy efficiency of soybean cultivation.

Keywords: soybean, foliar fertilization, ecoline legume, seed yield, seed quality, energy efficiency, microfertilizer.

INTRODUCTION

Soybeans play a key role in agriculture for food, feed or technical purposes. Soybeans have unique characteristics because plants are capable of biological nitrogen fixation and photosynthesis. This means that soybeans can provide themselves with nitrogen and simultaneously increase soil fertility [Babich et al., 2011; Petrychenko et al., 2016; Bakhmat et al., 2017; Hryhoriv et al., 2022; Kovalenko et al., 2024a]. The dynamic improvement of soybean cultivation technologies is of great importance, as it affects both the general trends of crop production and the achievement of maximum yields in specific soil and climatic conditions of Ukraine. In recent years, the agro–climatic conditions of Western Polissia have become favorable for the cultivation of precocious soybean varieties that have adapted to local conditions [Heatherly et al., 2003; Babich et al., 2011; Didur et al., 2019; Sousa et al., 2021; Silva et al., 2022; Tsyuk et al., 2022].

However, the effect of soil acidity on soybean yield on sod–podzolic soils of different acidity remains practically unstudied. A decrease in the level of soil acidity can worsen its nutritional regime and the availability of nutrients for plants. Soil liming primarily affects the reduction of acidity, and therefore it is important to establish how soybeans react to gradual changes in soil acidity, moving from highly acidic to nearly neutral soil, and to determine the optimal conditions [Palamarchuk et al., 2010; Bakhmat et al., 2017; Ivanov et al., 2019; Kolisnyk et al., 2020; Kovalenko et al., 2024b].

MATERIAL AND METHODS

The research was carried out in 2022–2023 in the conditions of the Vinnytsia National Agrarian University training field, which is based on the Agronomichne state–owned enterprise in the village of Agronomichne, Vinnytsia district. In the study of foliar fertilization, Ecoline Legume was used, and the Legenda variety, which belongs to early maturing varieties, was studied.

Thus, together with the increase of sown areas and production of soybeans, scientific substantiation of the cultivation technology of this crop in the conditions of the Forest Steppe becomes relevant. This involves the use of optimal doses of mineral and organic fertilizers and increasing their effectiveness by liming the soil. The purpose of the study was to determine the effectiveness of the use of foliar fertilization and quality indicators of the soybean crop. To achieve this goal, the following tasks were set:

- to determine the influence of foliar feeding on the physico–chemical and agrochemical properties of sod–podzolic soil;
- to study the peculiarities of the formation of the assimilation surface, the symbiotic apparatus of soybeans and the dynamics of the growth of the above–ground mass of soybean plants depending on the application of foliar fertilization;
- to evaluate the content of the main nutrients in plants and their supply at different stages of organogenesis using different systems of foliar fertilization.
- establish the standards of consumption of biogenic nutrients necessary for the formation of a unit of soybean crop.
- to determine the effect of nutritional conditions on the yield and quality of soybean seeds.
- to establish the efficiency of using foliar fertilizers for growing soybeans at different levels of soil acidity.

RESULTS AND DISCUSSION

It is known that achieving high productivity in soybean crops depends on the optimal density of plants per unit area and their individual productivity. Soybeans, as a crop, have a high demand for light and moisture, so to realize their yield potential, it is important to have adequate plant density, as well as an adequate supply of moisture and nutrients. This, in turn, affects the formation of leaves, the intensity of photosynthesis and the quality of the harvest [Petrychenko and Lykhochvor, 2014; Kolisnyk et al., 2019a; Kolisnyk 2019b; Kolisnyk et al., 2020; Naik et al., 2020; Karbivska et al., 2020; Palamarchuk et al., 2023].

The results of our research showed that the density of the arrangement of plants during germination depended on the conditions of soybean nutrition. Application of straw as fertilizer contributed to an increase in the number of plants by 3.5 plants per square meter in the option without foliar feeding and by 4.1 plants in the option with foliar feeding compared to the control option, where 73.3 plants per square meter were found. Increasing the acidity of the soil to the level of pH_{KCl} 4.2 in the variant with the introduction of mineral fertilizers according to the $N_{40}P_{60}K_{60}$ norm, against the background of the use of by–products, led to a slight decrease in plant density compared to the system of organic fertilizer supply.

The use of an organo–mineral fertilizer system to reduce potential acidity contributed to an increase in the number of plants from 7.5% to 13.5% in the plots where no foliar fertilization was carried out, and from 7.9% to 14.1% in the plots with foliar fertilization compared to control. In general, this means an increase in he number of plants by 3.4% to 9.2% compared to the use of a similar fertilizer on high acidity soil, where the plant density was 76.2 and 76.3 plants per square meter, respectively. The density of standing soybean plants depending on the application of foliar fertilization in Table 1.

During the soybean growing season, the number of plants decreased, reaching at full maturity from 64.7% to 75.8 plants per square meter without the use of microfertilizers and from 66.4% to 77.5 plants per square meter with their application, depending on variant of fertilizers. The least preservation of plants (in the range from 87.5% to 88.3%) was noted in variants with a strongly acidic reaction of the soil solution on untreated soil without foliar fertilization. However, due to the reduction of potential acidity, this indicator increased by 1.8% to 3.6% to the limit of 89.3% to 91.1%, depending on the level of reaction of the soil solution.

Table 1. The density of standing soybean plants depending on the application of foliar fertilization (units/m^2), average for 2022–2023

Application phase	Research option	Number of beans per plant, pcs./plant	Number of seeds per plant, pcs.	Seed weight per plant, g	Weight of 1000 seeds, g
VVSN 54-59	No fertilizers (control)	9.5	17.7	1.71	96.1
	Ecoline Legume 1 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	11.2	23.3	2.49	106.4
	Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	11.5	24.2	2.64	108.8
	Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	11.8	24.9	2.82	112.7
VVSN 70-79	No fertilizers (control)	9.8	18.3	1.82	98.9
	Ecoline Legume 1 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	11.5	23.8	2.60	108.9
	Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	11.8	24.9	2.79	111.9
	Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	12.2	25.5	2.97	116.0

Two–time application of microfertilizers Ecoline Legume and Ecoline Molybden 1 l·ha^{-1} by foliar fertilization led to an increase in plant survival by 1.0–2.3%, compared to areas without microfertilizers. An important morphobiological indicator that reflects how plants react to changes in growing conditions is their height [Khodanitska & Kolisnyk, 2020; Kolisnyk et al., 2020; Palamarchuk et al., 2020; Kerubo et al., 2021].

On the basis of the conducted research, it was established that the height of soybean plants varied depending on the phase of growth and development, increasing in areas without foliar fertilization from 25.9–45.1 cm at the beginning of flowering to 44.1–82.5 cm during the seed pouring phase. This is 70.3–82.9% more than at the beginning of flowering and 15.1–22.4% more than during the bean formation phase. Determining the peculiarities of the formation of the height of soybean plants depending on fertilizers and the level of potential acidity made it possible to establish the positive effect of improving nutritional conditions on this indicator in all phases of soybean growth and development.

During the years of research, the height of the plants increased by 8.9–10.9% in the version with straw plowing, depending on the phase of growth and development of soybeans, compared to the version without fertilizers (control). The height of soybean plants depending on the application of foliar fertilizers in Table 2. The use of an increased rate of foliar fertilization in the seeding phase led to an increase in the height of soybean plants by 3.0–4.9 cm, compared to the option where Ecoline Legume was applied in the amount of 1 l·ha^{-1} + Ecoline Molybden in the amount of

Table 2. The height of soybean plants depending on the application of foliar fertilizers (cm), average for 2022–2023

Implementation phase	Research option	Phase and period of growth and development of plants		
		Beginning of flowering	Formation of beans	Filling of seeds
VVSN 54-59	No fertilizers (control)	25.9	38.3	44.1
	Ecoline Legume 1 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	36.2	54.1	66.2
	Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	39.9	59.7	72.5
	Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	44.1	67.0	80.2
VVSN 70-79	No fertilizers (control)	27.7	41.1	47.4
	Ecoline Legume 1 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	38.2	57.4	69.8
	Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	42.1	63.5	76.8
	Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	46.9	71.6	85.5

1 l·ha^{-1}, here it ranged from 39.9 cm to 72.5 cm, depending on the phase of growth and development of soybeans.

The use of two foliar fertilizers for soybean crops, Ecoline Bean and Ecoline Molybdenum, led to a significant increase in plant height during the growing season. In different phases of soybean growth and development, plant height increased as follows: at the beginning of flowering, from 8.3% to 73.6% compared to control indicators; in the phase of bean formation from 9.5% to 78.8%; and in the phase of pouring seeds from 9.6% to 86.1%. In the control, the height of the plants was 27.7 cm, 41.1 cm and 47.4 cm, respectively, in different phases of soybean growth and development.

The greatest positive effect on the improvement of plant growth and development was observed when applying foliar top dressing simultaneously with Ecoline Legume and Ecoline Molybdenum. In this case, the height of plants in different phases of soybean growth and development was, respectively: 44.1–46.9 cm at the beginning of flowering, 71.6–73.5 cm in the phase of bean formation, and 85.5–80.2 cm in the phase pouring seeds. This corresponds to an increase of 36.1–38.1% compared to control values.

One of the objective factors that affects the identification of soybean productivity potential is the level of individual productivity of each individual plant. This factor is important for calculating the biological yield of crops and is a key aspect in crop yield management. The results of our research show that different methods of applying foliar fertilizers significantly affect the conditions of growth and development of soybeans. These factors play an important role in plant nutrition in crops and affect the structural characteristics of the soybean crop and its overall productivity.

According to the average indicators during the research, the introduction of foliar fertilization at the rate of Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1} caused an increase in the number of beans on each plant to 10.6 pieces, the number of seeds to 21.3 pieces and the weight of seeds, or individual performance, up to 2.25 grams. This corresponds to an increase of the respective indicators by 11.6%, 20.3% and 31.6% compared to the variant without fertilizers (control), where they were 9.5 pieces, 17.7 pieces and 1.71 grams, respectively. Thus, there was an increase in the number of beans by 0.9 pieces (9.3%), the number of seeds by 2.8 pieces (15.1%) and the weight of seeds by 0.41 grams (22.3%) compared to straw plowing. Indicators of soybean crop structure elements depending on the application of foliar fertilization in Table 3.

Under conditions of application of foliar fertilization at the rate of Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}, a slight improvement in structural indicators was observed compared to the control. However, the mass of seeds per plant was 0.21 grams less than when using a lower rate of foliar fertilization, and only a downward trend was noted for other structural indicators. One of the main and generalizing indicators that determines the yield of leguminous crops is the weight of 1000 seeds [Petrychenko et al., 2016; Snitynskyi et al., 2023; Palamarchuk et al., 2022; Kolisnyk, 2019b; Tsvei et al., 2020; Karbivska et al., 2022a; Radchenko et al., 2024].

The use of foliar fertilizers in the norm Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1} contributed to the increase of this indicator to 106.4 grams, which corresponds to an increase of 9.5% compared to the control and 6.9% compared to the organic fertilization system. After applying different doses of foliar fertilizers, such as Ecoline Bean and Ecoline Molybdenum 1 l·ha^{-1}, in the amount of 2 l·ha^{-1} each, a further increase in the weight of 1000 seeds to the range of 106.4–111.9 g was found, which exceeds the weight in the range of 10.3–12.7 g (or 10.7–20.4%) compared to non–entered variants. It is important to note that only an increase in the rate of foliar fertilization to 3.0 l·ha^{-1} led to a noticeable increase in this indicator (112.7–116.0 g) compared to the option without foliar fertilization (control), where the mass of 1000 seeds was 96.1–98.9 g.

On the basis of the conducted research, the positive effect of the use of foliar fertilizers, such as Ecoline Legume and Ecoline Molybdenum 1 l·ha^{-1}, on the structural components of the soybean crop has been confirmed. In particular, a two–time application of foliar fertilization in the form of Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1} increased the number of beans per plant by 1.9–3.4%, the number of seeds per plant by 1.6–3.4%, the mass of seeds from a plant by 3.6–6.4% and the mass of 1000 seeds by 1.4–2.9% compared to similar options without foliar fertilization. It is important to note that this improvement in structural indicators indicates the effectiveness of using microfertilizers in this version of fertilization. Thus, all elements of the crop structure participated in its formation and

Table 3. Indicators of soybean crop structure elements depending on the application of foliar fertilization, average for 2022–2023

Application phase	Research option	Number of beans per plant, pcs./plant	Number of seeds per plant, pcs.	Seed weight per plant, g	Weight of 1000 seeds, g
VVSN 54-59	No fertilizers (control)	9.5	17.7	1.71	96.1
	Ecoline Legume 1 $l \cdot ha^{-1}$ + Ecoline Molybdenum 1 $l \cdot ha^{-1}$	11.2	23.3	2.49	106.4
	Ecoline Legume 2 $l \cdot ha^{-1}$ + Ecoline Molybdenum 1 $l \cdot ha^{-1}$	11.5	24.2	2.64	108.8
	Ecoline Legume 3 $l \cdot ha^{-1}$ + Ecoline Molybdenum 1 $l \cdot ha^{-1}$	11.8	24.9	2.82	112.7
VVSN 70-79	No fertilizers (control)	9.8	18.3	1.82	98.9
	Ecoline Legume 1 $l \cdot ha^{-1}$ + Ecoline Molybdenum 1 $l \cdot ha^{-1}$	11.5	23.8	2.60	108.9
	Ecoline Legume 2 $l \cdot ha^{-1}$ + Ecoline Molybdenum 1 $l \cdot ha^{-1}$	11.8	24.9	2.79	111.9
	Ecoline Legume 3 $l \cdot ha^{-1}$ + Ecoline Molybdenum 1 $l \cdot ha^{-1}$	12.2	25.5	2.97	116.0

changed under the influence of foliar fertilization. As a result of the research, it was established that the best indicators of the crop structure, in particular, 12.2 beans per plant, 25.5 seeds per plant, 2.97 g of seeds per plant and the weight of 1000 seeds in the amount of 116.0 g, were provided thanks to foliar feeding

The use of fertilizers and foliar fertilization in soybean cultivation technology is one of the most effective measures to increase its yield. Experiments have shown that an optimal fertilizer system that takes into account the nutrient needs of plants at different stages of growth can contribute to obtaining the best yield for that crop. Of particular importance are trace elements, which can increase productivity by 15–24% [Petrychenko et al., 2016; Khodanitska and Kolisnyk, 2020; Karbivska et al., 2022b; Mazur et al., 2024]. The use of only mineral fertilizers, especially nitrogen fertilizers in physiologically acidic forms, can lead to the deterioration of the physical and chemical properties of the soil and its increased acidity, as confirmed by scientific research. Therefore, the addition of lime is an important factor for the intensification of agricultural production on acidic soils, increasing the efficiency of mineral fertilizers and the yield of agricultural crops.

Summarizing the results of the research, it was established that the use of Ecoline Legume in the amount of 3 liters per hectare plus Ecoline Molybdenum 1 $l \cdot ha^{-1}$ in the amount of 3 liters per hectare ensured soybean yields at the level of 3.10 and 3.32 tons per hectare, respectively, in areas without the use of microfertilizers. This indicates that the yield decreased by 0.98 and 1.08 tons per hectare respectively compared to the control plots. Application of Ecoline Legume in the amount of 3 liters per hectare plus Ecoline Molybdenum 1 $l \cdot ha^{-1}$ in the phase of VVSN 54–59 led to a significant increase in soybean yield. Variants without microfertilizers showed the highest yields, namely 3.20 and 3.29 tons per hectare more compared to the control plots, the increase was 0.97 and 0.99 tons per hectare, respectively.

The research has established that the application of foliar fertilization significantly increases the productivity of soybeans, while the maximum yield of 3.32 tons per hectare was achieved when applying Ecoline Bean in the amount of 3 liters per hectare plus Ecoline Molybdenum in the amount of 1 $l \cdot ha^{-1}$ in the amount of 3 liters per hectare in the VVSN phase 54–59. The yield of soybean seeds depending on the application of foliar fertilizers in Table 4.

The experiments also showed that soybean productivity (y) has a close direct dependence (correlation) with the level of soil acidity (x). This dependence is expressed by the following equation: $y = 1.3704x + 2.7876$. The corelation between exchangeable soil acidity and soybean yield in Figure 1.

A decrease in acidity to a slightly acidic level (pH_{KCl} 5.1), which was achieved after applying 1.0 dose of chemical meliorant, led to an increase in yield when applying Ecoline Legume 3 liters per hectare plus Ecoline Molybdenum 1 $l \cdot ha^{-1}$ in the amount of 3 liters per hectare to 2.23 and 2.30 tons per hectare, respectively. Such an increase is

Table 4. The yield of soybean seeds depending on the application of foliar fertilizers, t·ha^{-1}

Application phase (A)	Research option (B)	Year		Average
		2022	2023	
VVSN 54-59	No fertilizers (control)	2.12	2.24	2.18
	Ecoline Legume 1 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	2.68	2.70	2.69
	Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	2.96	3.01	2.99
	Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	3.10	3.32	3.22
VVSN 70-79	No fertilizer (control)	2.23	2.30	2.27
	Ecoline Legume 1 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	2.82	2.90	2.86
	Ecoline Legume 2 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	3.10	3.19	3.15
	Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}	3.20	3.29	3.25
$LSD_{0.5}$ factor A		0.02	0.03	0.25
$LSD_{0.5}$ factor B		0.08	0.09	0.85
$LSD_{0.5}$ interaction of factors		0.11	0.13	0.12

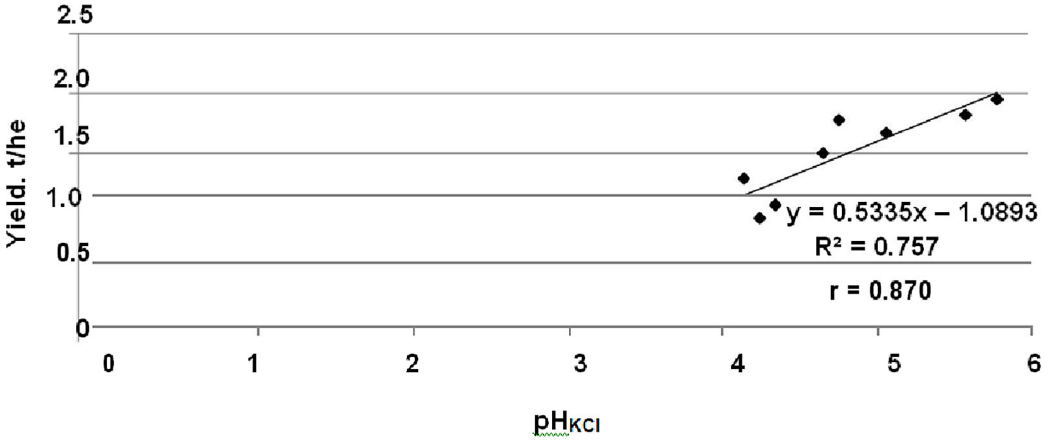

Figure 1. The corelation between exchangeable soil acidity and soybean yield

16.3 and 17.6% compared to the application of the same doses of fertilizers on acidic soils (pH_{KCl} 4.2), where the yield was 2.23 and 2.30 tons per hectare, respectively, on plots without foliar fertilization.

The introduction of an increased rate of Ecoline Bean in the amount of 3 liters per hectare plus Ecoline Molybdenum 1 l·ha^{-1} (pH_{KCl} 4.8), although it led to an increase in soybean yield by 0.99 tons per hectare, but this happened on soils with close to neutral acidity. Application of foliar fertilization of soybean crops with microfertilizer Ecoline Legume in the amount of 3 liters per hectare plus Ecoline Molybdenum 1 l·ha^{-1} in the phase of budding and formation of beans led to an increase in soybean productivity by 0.97–0.99 tons per hectare (5.4–8.2%) compared to similar options without foliar feeding, where the yield was 2.12–2.24 tons per hectare. The greatest increases in seed yield – 0.97–0.99 tons per hectare – were achieved in the variants with application of Ecoline Legume in the amount of 3 liters per hectare plus Ecoline Molybdenum 1 l·ha^{-1}.

Importance of the quality of agricultural products: The text states that one of the most important criteria for evaluating the effectiveness of fertilization systems is their impact on the quality of agricultural products. Product quality is considered as a comprehensive indicator, which includes the content of organic compounds, proteins, carbohydrates, fats and vitamins, as well as balance in terms of macro– and microelements and technological quality of products. The role of nitrogen in the formation of soybean seeds: The text emphasizes that nitrogen plays a key role in the formation of high–protein soybean seeds. Soy consumes nitrogen both from the soil and from the air. Increasing the protein content of soybean seeds through nitrogen nutrition: By changing the conditions of nitrogen nutrition of plants, it is possible to significantly increase the protein content of soybean seeds by 20–50%. This can be important for improving product quality and nutritional value.

In general, the text indicates the importance of nitrogen nutrition for obtaining high–quality agricultural products, in particular, for ensuring a high protein content in soybean seeds, which affects its nutritional value and quality [Babich et al., 2011; Khanna et al., 2019; Mazur et al., 2021; Radchenko et al., 2023; Kovalenko et al., 2024c].

Effect of soil reaction on soybean protein content: Studies have shown that soil reaction, measured by pH_{KCl} in the range of 5.4–5.6, contributed to the highest soybean protein collection of 0.97 tons per hectare. Effect of fertilizers and liming on protein content in soybean seeds: Application of fertilizers, such as Ecoline Bean and Ecoline Molybdenum 1 $l·ha^{-1}$ on strongly acidic and moderately acidic soil (pH_{KCl} 4.2–5.1) led to a slight increase in protein content in seeds up to level of 38.4–38.8%, compared to the option without fertilizers, where this indicator was 37.7%.

According to the results of research, it was established that the application of foliar fertilization to soils with a slightly acidic and close to neutral reaction contributed to a significant increase in the protein content of seeds to the level of 39.2–40.1%, which was higher by 1.5–2.4% compared to the control, and 0.6–1.5% more than when foliar fertilization was applied. The effect of foliar fertilization and soil acidity on soybean seed quality indicators in Table 5.

Overall, this piece of text demonstrates the importance of optimal fertilizer and soil management to increase protein content in soybean seeds, which can positively impact crop quality and nutritional value. The introduction of an increased dose of foliar feeding, depending on hydrolytic acidity, led to an increase in protein content by 2.0%, which was higher than in the control variant. Double foliar fertilization of soybean crops with microfertilizers Ecoline Legume 3 $l·ha^{-1}$ and Ecoline Molybdenum 1 $l·ha^{-1}$ led to an increase in protein content to the level of 38.7–41.2%, which was 0.8–1.1% more than in similar versions without the use of microfertilizer. The maximum protein content, namely 40.7–41.2%, was achieved in variants with the introduction of foliar fertilizers in areas with a close to neutral reaction of the soil solution, as well as when using an increased dose of foliar fertilizers Ecoline Legume on moderately acidic soil.

The results of the conducted research indicate an inverse relationship between the content of protein and oil (correlation coefficient r = –0.916. In particular, the highest oil content in soybean seeds (23.2%) was recorded in the control variant. The improvement of mineral nutrition conditions led to a decrease of this indicator by 0.3–1.9%,

Table 5. The effect of foliar fertilization and soil acidity on soybean seed quality indicators, average for 2022–2023

Phase of application (A)	Research option (B)	pH_{KCl}	Protein content, %	Oil content, %
VVSN 54-59	No fertilizers (control)	4.4	38.4	22.9
	Ecoline Bean 1 $l·ha^{-1}$ + Ecoline Molybdenum 1 $l·ha^{-1}$	4.7	38.8	22.5
	Ecoline Bean 2 $l·ha^{-1}$ + Ecoline Molybdenum 1 $l·ha^{-1}$	5.3	39.2	22.3
	Ecoline Bean 3 $l·ha^{-1}$ + Ecoline Molybdenum 1 $l·ha^{-1}$	5.8	40.1	21.8
VVSN 70-79	No fertilizer (control)	4.4	39.3	23.6
	Ecoline Bean 1 $l·ha^{-1}$ + Ecoline Molybdenum 1 $l·ha^{-1}$	4.7	39.6	23.1
	Ecoline Bean 2 $l·ha^{-1}$ + Ecoline Molybdenum 1 $l·ha^{-1}$	5.3	40.1	23.0
	Ecoline Bean 3 $l·ha^{-1}$ + Ecoline Molybdenum 1 $l·ha^{-1}$	5.8	41.2	22.7
$LSD_{0.5}$ factor A			0.6	0.4
$LSD_{0.5}$ factor B			1.2	0.7
$LSD_{0.5}$ interaction of factors			1.7	1.0

depending on the fertilizer option and the level of soil acidity compared to the control. However, significant changes in this indicator were observed only in the variants where Ecoline Bean 3 l·ha^{-1}and Ecoline Molybdenum 1 l ha^{-1} were used, taking into account hydrolytic acidity, and when the doses of foliar fertilization were increased with the use of a chemical meliorant, where the amount of oil decreased by 0.9–1.9% compared to the control.

The double application of Ecoline Legume 3 l·ha^{-1} and Ecoline Molybdenum 1 l·ha^{-1} led to an increase in the oil content in soybean seeds to 22.1–24.0%, which exceeds the indicators of similar options without foliar fertilization by 0.5–0.9%. One of the important indicators is the gross production of protein and oil per unit area. By analyzing the productivity and content of protein and oil in soybean seeds, we calculated the collection of these components according to different research options.

With the improvement of plant mineral nutrition conditions, a decrease in the level of potential acidity and an increase in the protein content, the collection of protein increased by 0.49–4.24 centners per hectare (13.6–117.8%), depending on the fertilizer option in areas without foliar fertilization top dressing, and by 0.5–4.66 centners per hectare (12.4–116.0%) – with it, compared to the control option, where the harvest was 3.60 and 4.02 centners per hectare, respectively. The highest collection of protein and oil, respectively 8.68 and 4.78 centners per hectare, was obtained under the condition of joint application of foliar fertilization Ecoline Legume 3 l·ha^{-1} and Ecoline Molybdenum 1 l·ha^{-1}. The increase compared to the control was 4.66 and 2.29 centners per hectare, respectively, or 115.9 and 92.2%, respectively.

The studied factors had a significant impact on the indicators of the structure of the soybean crop of the Hallek variety. The largest number of beans per plant (12.4 pcs.), the number of seeds per plant (26.6 pcs.), the weight of seeds from one plant (3.17 g) and the weight of 1000 of seeds (116.0 g) was achieved with a two–time application of foliar fertilization Ecoline Legume and Ecoline Molybdenum 1 l·ha^{-1}.

CONCLUSIONS

In this qualification work, the theoretical justification and practical results regarding the optimization of soybean plant nutrition during its cultivation on sod–podzolic soil in the conditions of Vinnytsia region were presented.

It was determined that foliar fertilization has the greatest positive effect on the growth and development of soybeans. In particular, the introduction of microfertilizer Ecoline Legume together with Ecoline Molybdenum 1 l·ha^{-1} contributed to the maximum preservation of protein content in soybean seeds at the level of 40.8–41.2%. Two–time foliar fertilization with microfertilizer also had a positive effect on the protein and oil content of seeds, increasing them by 0.8–1.7% and 0.5–0.9%, respectively, compared to plots without microfertilizer application. The study showed that growing soybeans on the gray forest soils of Vinnytsia with rational fertilization is economically beneficial.Application of foliar top dressing with microfertilizer Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1} led to high levels of conditional net profit and profitability, ranging from 143% to 183% depending on the research options.

This testifies to the high energy efficiency of soybean cultivation using foliar fertilizing with microfertilizers Ecoline Legume 3 l·ha^{-1} + Ecoline Molybdenum 1 l·ha^{-1}.

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