E3S Web of Conferences **548**, 01019 (2024) https://doi.org/10.1051/e3sconf/202454801019
AGRITECH-X 2024

Optimization of technological cultivation methods as a key to enhancing soybean productivity in the Kursk Region

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Abstract. This study aimed to optimize technological methods for cultivating soybeans in the Kursk region, conducted from 2022 to 2023 at the Federal State Budgetary Institution "Kursk FARC" on typical chernozem. The research involved two field experiments: the first examined the effects of four seed sowing rates on two mineral nutrition backgrounds, while the second investigated the effectiveness of microelement fertilizers when applied to soybean seeds and crops. The results showed that the application of mineral fertilizers significantly increased soybean yields. The highest protein and oil collection rates were achieved at a seeding rate of 0.6 million viable seeds per hectare in the fertilized version. Additionally, the use of microelement fertilizers, specifically MicroFeed Boron, resulted in high soybean yields, protein content, and oil content. Based on the findings, it is recommended that soybeans be cultivated with a seeding rate of 0.6 million viable seeds per hectare, accompanied by the application of mineral fertilizers and MicroFeed Boron during the 2nd and 6th trifoliate leaf phases to achieve maximum soybean yield, protein, and oil collection.

1 Introduction

Soybean is a promising and popular crop in the Central Black Earth Region. The area under crops is increasing every year, but the influence of technological methods on increasing crop yields remains not fully studied [1]. When cultivating soybeans, it is necessary to determine the optimal seed sowing rate and the influence of macro- and microelement fertilizers.

Currently to reduce the economic costs of purchasing seeds, there are recommendations to reduce soybean seed sowing rates [2-4]. It was found that in the conditions of the forest-steppe zone of the Chelyabinsk region, the optimal seed sowing rate for the row sowing method is 0.6–0.8 million pieces. viable seeds/ha [5], a. in the conditions of the southern forest-steppe zone on leached chernozem - 0.5 million pieces. viable seeds/ha. The recommended soybean sowing rate on typical chernozem in the Tambov region is 0.7–0.8 million units of viable seeds/ha [6].

An important element in soybean cultivation technology is the optimization of mineral nutrition using mineral fertilizers. Many researchers have proven the high importance of mineral fertilizers in increasing soybean yields [7, 8]. On podzolized chernozem of the

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Middle Urals, the use of complete mineral fertilizer increased soybean yields more significantly than with fractional application of fertilizers [9]. However, there are also studies where there is no effect of applying mineral fertilizers on soybean productivity [10].

Unlike the main elements of mineral nutrition, microelements are needed in soybeans in small quantities. The application of such fertilizers makes it possible to provide plants with the necessary amount of microelements, which promotes their healthy growth and development, and also increases the yield and quality of products [11-14]. In addition, the use of micronutrient fertilizers can reduce production costs by reducing the need to use other types of fertilizers [15]. Their deficiency, especially during critical periods of growth and development, can significantly reduce the productivity and quality of seeds [16]. In conditions of low supply of soils in the Kursk region with mobile forms of microelements, the role of microelement fertilizers in soybean cultivation increases significantly.

Therefore, the issue of clarifying the rate of seed sowing, applying mineral fertilizers and treating soybean seeds and crops with complex and mono-containing microelement fertilizers when cultivating soybeans in the conditions of the Kursk region remains insufficiently studied and requires further development and clarification.

The purpose of the research is to study the basic technological methods of soybean cultivation (seeding rate, application of mineral fertilizers to the soil, treatment of soybean seeds and crops with complex and mono-containing microelement fertilizers) to increase productivity in the conditions of the Kursk region.

2 Materials and methods

The studies were conducted in 2022–2023 at the Federal State Budgetary Institution "Kursk FARC", Kursk region, Kursk district, Cheryomushki village in field experiments in the laboratory of technologies for cultivating field crops. Soybeans were cultivated in crop rotation with the following alternation of crops: pure fallow; winter wheat; soy; spring barley. Crop rotation unfolds in time and space. The method of sowing soybeans is ordinary. Sowing time is in accordance with the optimal ones in the region. The technology of cultivating the crop in the experiments was generally accepted for the Central Black Earth Region.

The scheme of the first experiment includes the study of four seed sowing rates - 0.4 million pcs. viable seeds/ha; 0.5 million pieces viable seeds/ha; 0.6 million pieces of viable seeds/ha; 0.7 million pieces viable seeds/ha on two backgrounds of mineral nutrition: control without fertilizers and $N_{30}P_{30}K_{30}$. The sown area of the plot is 129.5 m^2 (3.70x35m). The arrangement of variants in the experiment is systematic, repeated 3 times.

In the second experiment, the effectiveness of using microelement complex fertilizers MicroFeed Complex, MicroFeed Zinc, MicroFeed Boron and microelement monofertilizers Reacom-Zinc Chelate and Reacom-Boron Chelate was studied when processing soybean seeds and crops in the 2nd and 6th trifoliate leaf phases. The seeds were treated with an aqueous solution of microfertilizers (water consumption - 15 l/t) 1 day before sowing using a backpack sprayer. Treatment of soybean plants in the 2nd and 6th trifoliate leaf phases was also carried out with a backpack sprayer (water consumption - 250 l/ha). Treatment of seeds with MicroFeed Complex, MicroFeed Zinc and MicroFeed Boron was carried out at a dose of 1.5 l/t, and treatment of crops with 1.5 l/ha, application of Reacom-Chelate Zinc and Reacom-Chelate Boron at a dosage of 1.0 l/t and 1.0 l/ha, respectively. The arrangement of variants in the field experiment is systematic, repeated 3 times. The total area of the experimental plot is 200 m^2, the control plot is 100 m^2. Soybean seeding rate is 0.6 million units of viable seeds/ha.

The soil of the experimental plots is typical thick chernozem of heavy loamy granulometric composition on carbonate loess-like loam. When the field experiment was started, the humus content (according to Tyurin) in the arable layer was 5.5%, alkali hydrolyzable nitrogen 15.4 mg/100 g, mobile forms of phosphorus and potassium (according to Chirikov) -17.5 mg/100 g and 11.3 mg/100 g, reaction of the soil environment slightly acidic – pHKCl – 5.4. The content of mobile forms of microelements: boron – 0.31 mg/kg, copper – 0.29 mg/kg, zinc – 0.34 mg/kg, manganese – 4.3 mg/100 g of soil.

Soybean yield was determined by direct combining using a Sampo-500 combine with data recalculation to standard humidity and purity. The protein content and oil content of the grain were determined by an Infratek 1241 device, which uses IR spectroscopy technology.

Processing of experimental data was carried out using statistical analysis methods [16] using Microsoft Excel and STATGRAP.2_1 programs.

3 Results and discussion

Soybeans have increased requirements for moisture and heat, so they are sown as a late spring crop. Weather is one of the significant factors in crop cultivation [1, 8].

During the research period 2022–2023 the weather conditions varied widely. The average monthly air temperature during the soybean growing season varied from 10.9 to 22.1 ^{0}C. When the crop was sowed and sprouted in May 2022, the average monthly air temperature was slightly lower than the long-term average and amounted to 12.0 ^{0}C (long-term average 13.8 ^{0}C), and during the summer growth period it exceeded the long-term average (by 15.6% in June, by 4.2% in July and 22.1 % in August) (Table 1). In 2023, the average monthly air temperature during the initial periods of growth was within normal limits, gradually increasing towards harvesting compared to long-term average values.

Table 1. Meteorological conditions during the years of research.

Month	Average monthly air temperature, °C			Monthly amount of precipitation, mm		
	average long-term	deviation from the long-term average norm		Perennial	deviation from the long-term average norm	
		in 2022, %	in 2023, %		in 2022, %	in 2023, %
May	13.8	-13.0	2.2	50	69	-78
June	17.3	15.6	1.2	59	-83	11
July	18.9	4.2	6.9	71	-4	77
August	18.1	22.1	16.6	64	-61	-40
September	12.4	-12.1	28.2	44	225	-51

The amount of precipitation during the studied period varied widely by month from 10.1 to 125.7 mm. In May 2022, the amount of precipitation exceeded long-term indicators by 69%. Thus, the sowing and emergence of crop seedlings in 2022 took place under conditions of sufficient moisture supply, but with some heat deficiency. During the period of formation of 1-5 leaves (June), the amount of precipitation was minimal and amounted to 10.1 mm, which is 83% lower than long-term values. In the summer months, the amount of precipitation was below long-term values by 49.0; 2.5 and 39.0 mm in June, July and August, respectively. In September, a very large amount of precipitation fell (125.7 mm), which is 225% higher than the long-term norm.

In the spring of 2023, the least amount of precipitation was recorded for the entire growing season and amounted to 11.1 mm, which is 78% lower than long-term values. Thus, the sowing of the crop and the emergence of seedlings in 2023 took place under optimal temperature conditions, but there was a large lack of precipitation. In June and July, the amount of precipitation exceeded long-term indicators by 11 and 77%, respectively, and in August and September, the lack of precipitation was 40 and 51%, respectively.

The ratio of precipitation to the sum of temperatures above 10 ^{0}C is used to judge the moisture availability of crops. In 2022, the HTC of the growing season was 1.3, which corresponds to the territory of ensured moisture. This figure was obtained due to the large amount of precipitation that fell in September, which compensated for the lack of precipitation in the summer. In 2023, the hydrothermal coefficient was 1.0, which is slightly lower than the long-term average value (1.2). In general, the prevailing weather conditions during the years of the experiment can be characterized as optimal.

In an experiment to study the influence of seeding rates and the application of mineral fertilizers, soybean yield varied from 2.72 to 3.26 t/ha on average over two years of research (Table 2).

Table 2. The influence of seeding rates and the application of mineral fertilizers on the yield and quality of soybeans (average for 2022-2023).

Seeding rate, million pcs. viable seeds/ha	**Application of mineral fertilizers**	**Productivity, t/ha**	**Protein (on dry matter), %**	**Oil content, %**
0.4	$N_0P_0K_0$	2.72	39.7	22.2
	$N_{30}P_{30}K_{30}$	3.01	39.4	22.0
0.5	$N_0P_0K_0$	2.82	40.0	21.9
	$N_{30}P_{30}K_{30}$	3.12	39.9	21.9
0.6	$N_0P_0K_0$	2.99	40.7	21.5
	$N_{30}P_{30}K_{30}$	3.26	40.3	21.8
0.7	$N_0P_0K_0$	2.99	40.7	21.1
	$N_{30}P_{30}K_{30}$	3.17	40.4	21.7
HCP $_{05}$ for factor seeding rate for fertilization factor		0.13 0.09	0.4 0.3	0.3 0.2

When changing seeding rates from 0.4 to 0.5 million pcs. viable seeds/ha, no significant increase in soybean yield was observed, the same as with the shift from 0.6 to 0.7 million pieces. viable seeds/ha. Only increasing the seeding rate from 0.5 to 0.6 million units. viable seeds/ha provided a significant increase in yield by 0.17 and 0.14 t/ha or by 6.0 and 4.5%.

The application of mineral fertilizers had a positive effect on a significant increase in crop yield at all studied seeding rates. Thus, the increase ranged from 0.18 to 0.30 t/ha or 6.0-10.7% compared to unfertilized options. The greatest increase in yield was observed in variants with a seeding rate of 0.4 and 0.5 million pcs. viable seeds/ha, which amounted to 0.29 and 0.30 t/ha or 10.7 and 10.6%.

Using mathematical data processing, it was found that 81% of the variation in yield in the experiment was due to the application of mineral fertilizers and 16% to a change in the seed sowing rate; the interaction of these factors did not have a significant effect.

Indicators of soybean grain quality, such as protein content and oil content, had an inverse relationship with each other, that is, with an increase in protein content, oil content decreased and vice versa. This is confirmed by the inverse high correlation coefficient (r=-0.86 α=0.05).

The change in quality indicators was greatly influenced in the experiment by the factor of seed sowing rate. With an increase in seeding rates, there was a tendency for the protein content in the grain to increase and the oil content to decrease. Thus, the highest protein content was obtained in variants with a seeding rate of 0.6 and 0.7 million pieces of viable seeds/ha and amounted to 40.7%, and the maximum oil content when cultivating soybeans with a seeding rate of 0.4 million pieces of viable seeds/ha – 22.2%. The application of mineral fertilizers did not have a significant effect on the indicators.

An important agricultural task when cultivating soybeans is to obtain not only high yields, but also the maximum collection of oil and protein per unit area. Through research, it was found that the application of mineral fertilizers increased oil collection and protein collection by 5–11% compared to the control option, which is a reliable and significant increase (Fig. 1).

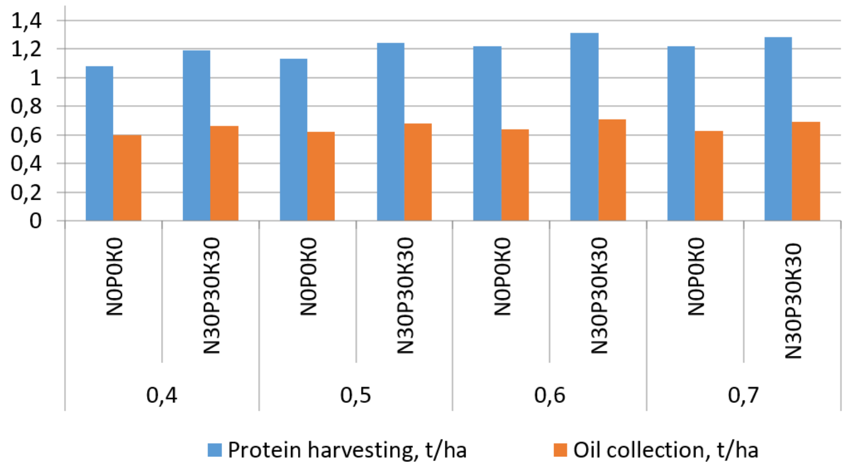

Fig. 1. The influence of seeding rates and the application of mineral fertilizers on protein collection and oil collection (average for 2022-2023).

The maximum rates of protein collection and oil collection were obtained at a seeding rate of 0.6 million pieces. viable seeds/ha in the fertilized version – 1.31 and 0.71 t/ha, respectively. The collection of protein and oil depended on the crop yield (r=-0.98 α=0.05; r=-0.97 α=0.05, respectively). In turn, it increased to a large extent from the application of fertilizers (r=-0.79 α=0.05). Thus, this dependence neutralized the inverse relationship between protein and oil content.

In the second field experiment, seed treatment in combination with double treatment of plants with microelement fertilizers in the phase of the 2nd and 6th trifoliate leaves increased soybean yield by 0.28–0.45 t/ha, which is 11.4–16.5% higher than in the control variant (Table 3).

The highest soybean yields were obtained from the use of complex microelement fertilizers MicroFeed Complex, MicroFeed Boron and MicroFeed Zinc, when treating seeds and double processing of crops in the phase of the 2nd and 6th trifoliate leaves. Compared to the control, the increases in these options were 0.36–0.45 t/ha or 13.2–16.5%. The maximum soybean yield was ensured by treating soybean seeds and crops with the complex microfertilizer MicroFeed Boron - 3.18 t/ha.

The efficiency of seed treatment and double treatment of soybean crops with monocontaining microfertilizers (Reacom-Boron Chelate and Reacom-Zinc Chelate) was lower, the yield increase from their use was 0.28–0.31 t/ha or 10.3–11.4% compared to the control (2.73 t/ha). In variants using microelement monofertilizers, the greatest increase in yield was also provided by the fertilizer containing boron Reacom-Boron Chelate.

The use of microelement fertilizers contributed to obtaining higher grain quality indicators. Thus, the protein content compared to the control variant was higher by 0.9-1.7, and the oil content increased by 0.4-1.0%. Complex microfertilizers (MicroFeed Complex, MicroFeed Zinc and MicroFeed Boron) contributed to an increase in protein in grain by - 1.3-1.7%, oil content by - 0.7-0.9%. The use of monocontaining microfertilizers (Reacom-

Zinc Chelate and Reacom-Boron Chelate), with similar methods of use, showed less efficiency, the protein content increased by - 0.9-1.1%, oil content by - 0.4-0.5, in comparison with the control option.

Table 3. The influence of the combined effect of treating seeds with an aqueous solution of microfertilizers and treating soybean plants in the phases of the 2nd and 6th trifoliate leaves on the yield and quality of soybeans (average for 2022-2023).

Variant	Productivity, t/ha	Protein (on dry matter), %	Oil content, %
1. Control	2.73	35.6	22.7
2. MicroFeed Complex	3.09	37.0	23.8
3. MicroFeed Zinc	3.12	37.1	23.5
4. MicroFeed Bor	3.18	37.4	23.6
5. Reacom-Zinc Chelate	3.01	36.6	23.2
6. Reacom-Boron Chelate	3.04	36.8	23.3
HCP $_{05}$	0.12	0.6	0.3

However, when comparing the reliable influence of individual complex as well as microelement monofertilizers on the quality indicators of soybean grain, no significant difference was obtained, that is, the influence of the studied microfertilizers on the protein content and oil content of soybean was equivalent.

The collection of protein and oil directly depended on the yield and the protein and oil content of soybean seeds. Thus, in the variants using microfertilizers, there was an increase in protein collection by 0.11-0.19 t/ha, and oil collection by 0.06-0.11 t/ha.

The maximum collection of protein and oil was obtained in the variant using the complex microelement fertilizer MicroFeed Boron and amounted to 1.03 and 0.65 t/ha, respectively (Fig. 2).

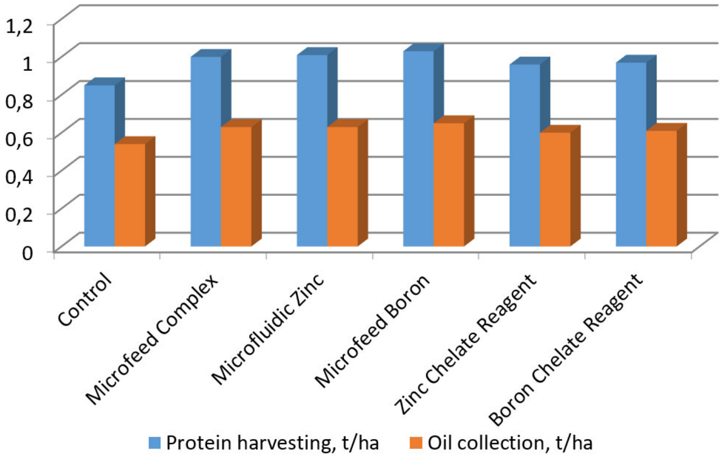

Fig. 2. The effect of the combined effect of treating seeds with an aqueous solution of microfertilizers and treating soybean plants in the phases of the 2nd and 6th trifoliate leaves on protein collection and oil collection (average for 2022-2023).

Based on the results obtained, we can conclude that the use of macro- and microelement fertilizers is an important element of soybean cultivation technology and helps to increase the yield and quality of this valuable agricultural crop.

4 Conclusion

As a result of the research, it was found that 81% of the variation in yield in the experiment was due to the application of mineral fertilizers and 16% to a change in the seed sowing rate; the interaction of these factors did not have a significant effect. The application of mineral fertilizers had a positive effect on a significant increase in crop yield at all studied seeding rates; the increase ranged from 0.18 to 0.30 t/ha. The change in quality indicators was greatly influenced in the experiment by the factor of seed sowing rate. With an increase in seeding rates, there was a tendency for the protein content in the grain to increase and the oil content to decrease. The collection of protein and oil depended on the yield of the crop. The maximum rates of protein collection and oil collection were obtained at a seeding rate of 0.6 million pieces. viable seeds/ha in the fertilized version – 1.31 and 0.71 t/ha, respectively.

The high efficiency of using various types of microfertilizers on soybean crops in the conditions of chernozem soils of the Kursk region has been established. Treatment of seeds and vegetative soybean plants in the 2nd and 6th trifoliate leaf phases with complex fertilizers MicroFeed Complex, MicroFeed Zinc and MicroFeed Boron increased soybean yield by 0.36-0.45 t/ha, or by 13.2-16.5%, grain protein content by 1.3 -1.7%, oil content by 0.7-0.9%, compared to the control option.

Monocontaining microfertilizers Reacom-Zinc Chelate and Reacom-Boron Chelate showed less efficiency. The soybean yield from their use increased by 0.28-0.31 t/ha (10.3-11.4%), the protein content in the grain by 0.9-1.1%, and the oil content by 0.4-0.5%.

Thus, to obtain the maximum soybean yield, protein and oil collection in the conditions of the Central Black Sea Region, it is necessary to cultivate the crop with a seeding rate of 0.6 million pieces. viable seeds/ha with the application of mineral fertilizers in a dose of $N_{30}P_{30}K_{30}$ and the use of microelement complex fertilizer MicroFeed Boron when processing soybean seeds and crops in the phases of the 2nd and 6th trifoliate leaf.

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