

Qualitative composition and dynamics of soybean varieties of various ecological groups during pre-sowing treatment with trace elements

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Abstract. The article presents the results of studies on the effect of trace elements on the qualitative composition and development of varieties of different ecological groups of soybeans (*Glycine max* (L.) Merrill). The purpose of the work was to evaluate the effectiveness of various trace elements in the pre-sowing treatment of seeds. The experiments were conducted in 2022-2024 on experimental plots of the department of leguminous crops of the Kazakh Scientific Research Institute of Agriculture and Crop Production (KSRIACP, Almaty region) in light chestnut, loamy, and rarely sandy loam soils. The study used microelements of balanced complexes (Mo+ "B" + "Zn" + "Co"). It was found that the use of trace elements had a positive effect on field germination, physiology, phenology and grain quality indicators. Kazakh (Zhansaya, Ivushka) and North American (Dawson, Supra) ecotypes are the most adaptive and responsive to pre-sowing microelement treatment in the foothill zone of southeastern Kazakhstan (KSRIACP). Treatment with trace elements ensures a steady increase in grain productivity by 16.0–18.0% due to an increase in the mass of 1000 seeds and lacustrine content, as well as increases the protein content of grain by 1.5–2.1%. Thus, pre-sowing treatment with trace elements has shown high efficiency and can be recommended for integrated environmentally friendly soybean cultivation technologies.

Keywords: soybeans, microelements, pre-sowing seed treatment, phenology, germination, flowering, yield

Introduction

Soybeans are one of the most important leguminous crops in the world, including in Kazakhstan. The Government of the Republic of Kazakhstan has recently attached great importance to it as a strategic crop, and a significant phased expansion of its acreage has been planned and launched. So, in the early 2000s, soybeans occupied 40 thousand hectares in the republic, and by 2030 it is planned to expand soybean crops to 500 thousand hectares to ensure production of up to 1 million tons. In this regard, the task has been set to promote soybeans to the North and East of the country. For the introduction of new crops into new growing conditions, targeted scientific research is needed to identify the most adapted varieties and lines [1,2,3,4].

Pre—sowing treatment of soybean seeds with trace elements is one of the most effective and economically justified elements of agricultural technology. Since the seed is in direct contact with nutrients from the moment of swelling, trace elements stimulate metabolism at the earliest stages of ontogenesis [5,6,7].

Soybean (*Glycine max* (L.) Merrill) is a culture with high sensitivity to the daily photoperiod and temperature regime. The ecological adaptability of varieties of various geoclimatic origin determines the reaction of their genotype to growing conditions. In the foothill zone of southeastern Kazakhstan, the key limiting factors are the continentality of the climate and the deficiency of mobile forms of trace elements (boron, molybdenum, zinc, cobalt) in the soil during the initial phases of organogenesis [8,9,10,11,12,13].

Pre-sowing treatment of seeds with trace elements is a catalyst for physiological and biochemical processes. However, the nature of the impact of trace elements on the pace of individual development (ontogenesis), the establishment of generative organs, and the formation of elementary productivity varies significantly among representatives of different ecotypes [14].

The purpose of the study: To study the qualitative composition of various ecological and geographical groups of soybeans and to evaluate the effect of pre-sowing treatment with a complex of trace elements on their growth dynamics, the passage of phenological phases, morphogenesis, and seed productivity at the Kazakh Scientific Research Institute of Agriculture and Crop Production LLP hospital.

Materials and research methods

The research was conducted in 2022-2024 at the experimental field of Kazakh Scientific Research Institute of Agriculture and Crop Production LLP (KSRIACP, Almalybak village, Almaty region). The soil is light chestnut, with a humus content of 2.2–2.5%, pH 7.4–7.6 [15].

Objects of research (Qualitative composition by ecological groups): Varietal material systematized into 5 ecological and geographical groups (ecotypes) was studied as an object:

1. Kazakhstan group (Domestic ecotypes): Varieties Zhansaya, Ivushka, Almaty, Perizat. They are characterized by high drought resistance and adaptability to the local hydrothermal regime.

2. North American ecological ecotype: Varieties Dawson, Supra, Evans, Meridian. They are characterized by high technological efficiency, determinant and semi-determinant growth types, and high attachment of the lower bean.

3. Eastern European ecological ecotype: Varieties Harmony, Romance, Podyaka, Smena. They are characterized by high cold resistance at the germination stage and plasticity.

4. Western European ecological ecotype: Varieties Rana, Sepia, Estofita, Turijskaja masnaja. They belong to the precocious and ultra-ripe groups (000, 00) with a short growing season.

5. East Asian ecological ecotype: Varieties of local breeding in China and the Far East. They are characterized by an indeterminate type of growth, high foliage, and responsiveness to moisture supply (Figure 1).

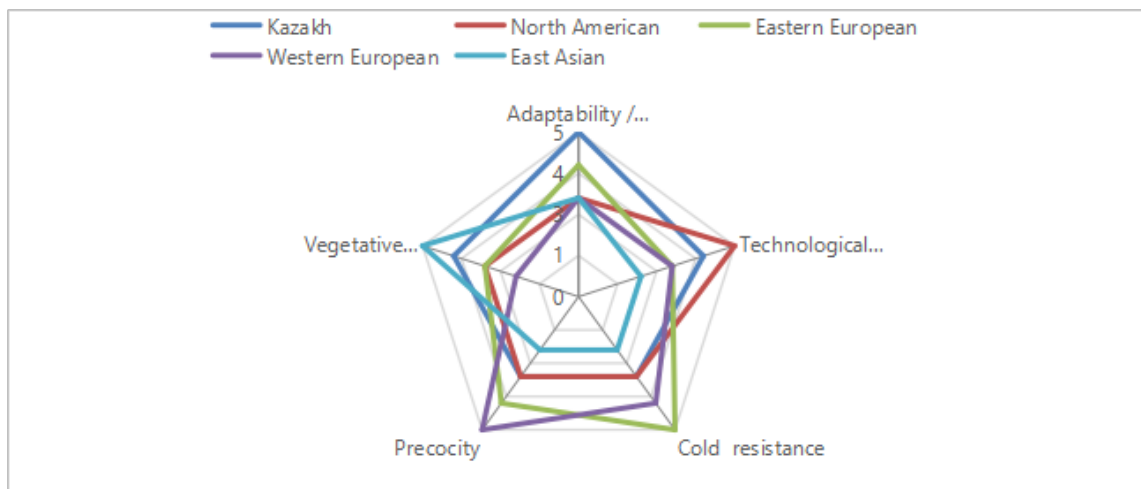


Figure 1. Qualitative characteristics of ecological and geographical soybean groups at the KSRIACP hospital

The experimental scheme:

Option 1 (Control): Sowing without treatment with trace elements.

Option 2 (Pre-sowing treatment): Soaking seeds with a solution of trace elements (Mo-0.05%, B-0.02%, Co-0.01%, Zn-0.02%) 24 hours before sowing.

Sowing is in the first decade of May; the sowing method is wide—row (row spacing 25 cm), three-fold repetition. The calculations were carried out according to the international classifier of the Fehr & Caviness Scale (VE–R8) [16,17,18].

Results

The analysis and evaluation of the main features of adaptivity (flowering time, bean formation time, bean filling time, ripening time), morphophysiology (plant height, attachment height of the lower bean, number of lateral branches), yield components (number of productive nodes, number of beans per plant, weight of 1000 seeds, weight of seeds per plant and weight of seeds from the plot) and seed quality (protein and fat content).

The flowering time is one of the key agronomic signs for soybeans, as it directly affects the duration of the growing season and the adaptation of the plant to various climatic conditions. Proper flowering time can promote better pollination and ripening of beans, which increases yields and improves seed quality. It is important for breeders to take this trait into account when developing new varieties so that they are adapted to specific climatic conditions, demonstrating stable results in different growing regions [18]. A comparative analysis of the cultivation results showed that the samples of the studied collection of varieties with pre-seed priming bloomed faster than those without treatment, which confirms the influence of trace elements on plant growth and development.

Pre-sowing treatment of seeds with trace elements had a significant stimulating effect on germination and the initial phases of development (ND-v2) in all ecological groups. Molybdenum

and zinc activated respiratory enzymes, which accelerated the emergence of seedlings by 2-3 days (Table 1).

Table 1

**Duration of interphase periods in varieties of different ecological groups
(KSRIACP, on average for 2022-2024)**

Ecological group	Experience variant	Sowing – Germination (VE), days	Germination – Flowering (V1–R1), days	Flowering – Ripening (R1–R8), days	Total growing season, days
Kazakhstan	Control	11,2	38,9	67,4	117,5
	With treatment	8,9	36,1	68,2	113,2
North American	Control	12,0	36,2	64,3	112,5
	With treatment	9,4	33,9	65,1	108,4
Eastern European	Control	10,5	34,6	58,1	103,2
	With treatment	8,1	32,1	59,0	99,2
Western European	Control	10,8	36,8	55,2	102,8
	With treatment	8,5	34,5	56,0	99,0
East Asia	Control	12,8	45,0	72,5	130,3
	With treatment	10,1	42,8	73,1	126,0

The greatest reduction in the “Germination– Flowering” period was observed in the Kazakh (-2.8 days) and Eastern European (-2.5 days) groups. This allowed the plants to form a powerful layer of leaves before the onset of the summer air drought (July).

Plant height is one of the key characteristics of soybeans. The optimal height of the plant is important for efficient harvesting; it is in the range of 95-105 cm, since plants that are too low can complicate mechanized harvesting, leading to grain losses. At the same time, plants that are too tall may be prone to lodging, which reduces their stability and makes harvesting more difficult [19,20,21].

In this regard, plant breeders strive to find the optimal balance between plant height and other important characteristics, such as lodging resistance, drought resistance, and the ability to maintain high productivity in a variety of climatic conditions [21]. Plant height is a critically important parameter that directly affects yield, ease of harvesting, and resistance to mechanical stress.

Studies conducted as part of the analysis of collection samples for 2022-2024 have shown that the lowest plant heights are observed in the ultra-ripe group of varieties, which indicates the genetic characteristics of these samples, which are adapted to a short growing season. As the length of the growing season increases, there is a regular increase in plant height, which is confirmed by the growth of both average and extreme (maximum and minimum) values of this parameter.

As a result of a comprehensive analysis of the soybean collection for 2022-2024, varieties with optimal plant height indicators were identified, which combine high resistance to lodging, good productivity, and adaptation to the conditions of the region, which makes them promising for further use in breeding programs (Table 2).

Table 2

Changes in the morphological parameters of varieties under the influence of trace elements

Ecological group	Height of the plant (Control), cm	Height of the plant (with treatment), cm	Height of attachment of the lower bean (Control), cm	Height of attachment of the lower bean (with treatment), cm	Number of lateral branches (Control), pcs.	Number of lateral branches (with treatment), pcs.
Kazakhstan	88,1	97,4 (+9,3)	14,2	17,1 (+2,9)	2,4	3,1
North American	82,2	89,5 (+7,3)	13,1	15,4 (+2,3)	1,8	2,2
Eastern European	66,9	74,3 (+7,4)	11,2	13,8 (+2,6)	1,5	1,9
Western European	89,6	96,1 (+6,5)	14,5	16,8 (+2,3)	2,1	2,5
East Asian	85,4	92,0 (+6,6)	13,8	15,9 (+2,1)	3,2	3,8

The development of the vegetative sphere (height of plants, branching) under the influence of boron and cobalt, it became more active due to increased symbiotic nitrogen fixation.

The Kazakhstan group showed the maximum growth response to trace elements: the height of plants increased by 9.3 cm, and the height of attachment of the lower bean reached a technologically optimal 17.1 cm.

The number of seeds per plant is an important indicator of soybean productivity and one of the key factors determining the overall yield. This feature has a direct impact on the economic profitability of growing a crop, since a larger number of seeds from a plant leads to an increase in gross yield per unit area. In addition to the overall increase in yield, the number of seeds per plant affects the quality of the final product, including seed size, protein, and oil content. More productive plants can compensate for possible fluctuations in external factors such as drought or stressful conditions. This feature is also important for breeding, as it allows us to develop varieties that will be more resistant to adverse conditions and at the same time maintain a high level of yield [22,23,24].

An analysis of the results of the phenotypic assessment based on the number of seeds per plant revealed that the samples of the studied collection showed the highest rates with pre-seed priming of seeds with trace elements. I would especially like to note the year 2023, when the entire collection averaged more than 60 seeds per plant (Figure 2). Also, with pre-seed priming,

there was strong variability depending on the year of cultivation, while without treatment, the average values for the collection were more stable (Table 3).

Table 3

Elements of productivity and quality of soybean grain by ecological groups

Ecological group	Number of beans per plant, pcs. (Control/ Priming)	Weight of 1000 seeds, g (Control/ Priming)	Protein content, % (Control/ Priming)	Oil content, % (Control/ Priming)	Yield from the plot, g (Control/ Priming)
Kazakhstan	28,4 / 34,1	175,0 / 186,4	40,2 / 42,3	19,8 / 19,5	165,4 / 195,2 (+18,0%)
North American	26,1 / 30,8	182,0 / 190,1	39,0 / 40,5	20,5 / 20,3	152,0 / 178,0 (+17,1%)
Eastern European	21,5 / 25,6	183,3 / 191,5	38,5 / 40,1	21,0 / 20,8	128,5 / 150,3 (+17,0%)
Western European	29,1 / 33,5	175,3 / 184,2	39,2 / 41,0	20,2 / 20,1	144,1 / 168,6 (+17,0%)
East Asian	25,8 / 29,9	188,5 / 196,0	40,1 / 41,8	19,2 / 19,0	138,2 / 160,3 (+16,0%)

The weight of 1000 seeds reflects the completeness of the ripening and filling of the beans. Although it does not always have a direct correlation with yield, with the same number of seeds per plant, preference is given to samples with larger seeds [25]. The importance of this feature also lies in its effect on nutritional value, since larger seeds often have a higher protein and fat content, which makes them more in demand in the food and feed industry [26,27].

In general, in 2022-2024, samples grown with pre-sowing seed priming had higher rates than samples without treatment (Figure 2).

Pre-sowing treatment with boron contributed to better ovary preservation (reducing flower abortion in phases r3-r4), and molybdenum stimulated protein accumulation in seeds.

Treatment with trace elements resulted in an increase in the weight of 1,000 seeds in all ecological groups by 7.5–11.4 g and an increase in protein content by 1.5–2.1%.

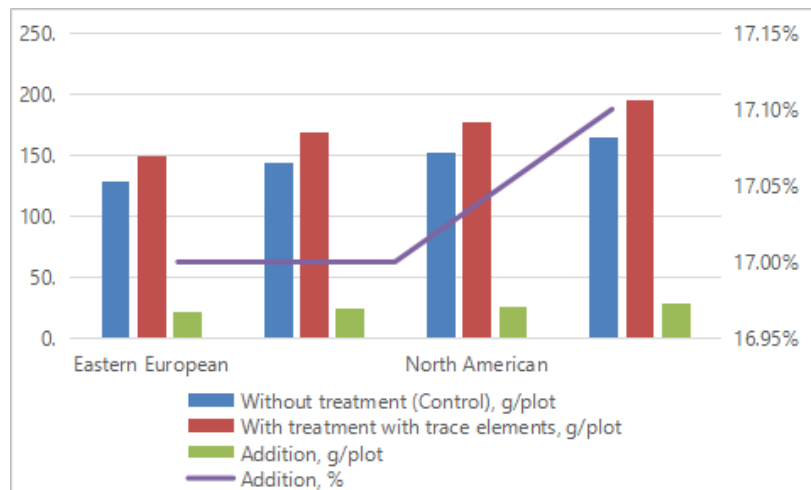


Figure 2. Comparative yields of ecological and geographical soybean groups during pre-sowing seed treatment

An analysis of the seeds of the 2022-2024 harvest in the Almaty region revealed high parameters in samples grown with pre-sowing seed priming. Thus, in the first two years of the study (2022-2023), the average protein content with pre-seed priming exceeded 40%.

The protein content in soybean seeds is one of the key agronomic features that determine the value of this plant for the food and feed industry. The high protein content makes soy an important source of plant protein for humans and animals, which is especially important in the context of global demand for healthy and sustainable food sources. The protein content is associated with the commercial attractiveness of soy products, as the protein component affects their nutritional value and market value [28]. The oil content in soybean seeds is also one of the key qualitative, economic and technological indicators that determine the value of the crop and the direction of its processing [29,30].

Discussion

Seed treatment with trace elements directly accelerates and stabilizes the passage of vegetative and reproductive stages:

1. Sowing phase — Germination (VE):

- Increases germination energy and laboratory/field germination (by 3-8%).
- Seedlings appear 2-4 days earlier, forming an even and friendly stem.

2. Vegetative growth (V1–V4):

- The formation of a powerful root system and the primary formation of nodules are accelerated (already by the phase of 1-2 triple leaves).
- Plants pass the critical period faster when the supply of nutrients in the seed is exhausted, and the root system has not yet begun to fully feed from the soil.

3. Flowering and bean formation (R1–R4):

- Due to boron and molybdenum, the shedding of buds and ovaries is reduced.

The active flowering phase is more intense and coordinated.

4. Maturation (R7–R8):

- The grain filling process is carried out evenly. Depending on the composition of micro-fertilizers (for example, with a high content of boron and zinc), the growing season can be shortened by 3-6 days, which is critically important for the northern regions of soybean cultivation.

Pre-sowing treatment with trace elements builds productivity potential at the germination stage (Table 4).

Table 4**Impact on structural elements and overall yield**

Elemental structure yield	Effect of the use of trace elements
Parking lot	The survival rate of plants for harvesting increases by 5-10%.
Number of beans per plant	It increases by 12-25% due to a decrease in abortivity of the ovaries.
Weight of 1000 seeds	It increases by 4-8% due to a more active outflow of assimilates.
Product Quality	The protein content in seeds increases by 1.0–2.5%, and the oil content increases by 0.5–1.2%.

The use of complex micro fertilizers (especially combinations of Mo+B+Co) for seed treatment ensures stable yield growth in the range of 2.0–5.5 kg/ha (10-20% of the control, depending on the initial availability of soil).

Two—factor analysis of variance showed that the contribution of the “Genotype (Ecological group)” factor to the variation in yield was 54.2%, and the “Pre-sowing treatment” factor was 32.8% at $p < 0.001$.

The high responsiveness of the varieties in the Kazakh group (Zhansaya, Ivushka) and the North American group (Dawson, Supra) was revealed. They demonstrated the greatest increases in the number of beans and the weight of seeds per plant, which is explained by the better synergy of trace elements with local conditions of insolation and agricultural technology.

Practical recommendations for use compatibility with inoculants. Molybdenum and cobalt are synergistic with bacterial preparations (*Bradyrhizobium*). However, tank mixtures should be prepared immediately before sowing, or specialized forms of micro-fertilizers should be used that are pH-neutral so as not to inactivate live bacterial strains. Follow the regulations for use — excess trace elements (especially boron and copper) on seeds can cause toxicity and delay germination. Microelements are successfully combined with fungicidal and insecticidal seed protectants.

Conclusion

In the course of the analysis, the interrelation of the main features of adaptivity, morphophysiology, components of yield and quality of soybean seeds with pre-sowing seed priming was evaluated. Promising varieties and lines for breeding in the southeastern and northern regions have been identified. Significant negative correlations were observed between yield characteristics and seed quality, which emphasized the need for careful selection of varieties in order to achieve a balance between quantity and quality of harvest. These results underline the importance of breeding work aimed at creating varieties adapted to specific climatic conditions and having high potential both in terms of yield and quality characteristics of seeds.

Thus, the study of the qualitative composition of soybean varieties of 5 ecological and geographical groups showed differences in the dynamics of development: the shortest growing season is typical for the Western European and Eastern European groups (99-103 days), the

longest — for the East Asian group (126-130 days).

Pre-sowing treatment with trace elements (Mo, B, Co, Zn) optimizes the rate of ontogenesis: it accelerates the appearance of seedlings by 2-3 days and shortens the period before flowering by 2.2-2.8 days.

Under the influence of trace elements, the varieties of the Kazakh group showed a maximum increase in plant height (+9.3 cm) and the height of attachment of the lower bean (+2.9 cm), which increases their suitability for mechanized harvesting.

Treatment with trace elements ensures a steady increase in grain productivity by 16.0–18.0% due to an increase in the mass of 1000 seeds and the lacustrine content, as well as an increase in the protein content of grain by 1.5–2.1%.

Kazakh (Zhansaya, Ivushka) and North American (Dawson, Supra) ecotypes are the most adaptive and responsive to pre-sowing microelement treatment in the foothill zone of south-eastern Kazakhstan (KSRIACP).

These results are characterized by high scientific novelty, as the soybean collection was simultaneously studied for the first time in the field with pre-seed priming, with the ultimate goal of studying patterns of increasing soybean yields.

Author Contributions

A.Z., S.D. – concept and supervision of the work; **G.K.** – conducting the experiments; **Sh.A.** – discussion of the research results; **B. Sh.** – writing the text; **G.Kh.** and **N.A.** – editing the text of the article.

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Conflicts of Interest

The authors declare no conflicts of interest.

Compliance with ethical standards

This article does not contain a description of studies performed by the authors involving people or using animals as objects.

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Микроэлементтермен себу алдындағы өңдеу кезінде әртүрлі экологиялық топтардың соя сорттарының сапалық құрамы мен даму динамикасы

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Аңдатпа. Мақалада сояның әртүрлі экологиялық топтарының (*Glycine max* (L.) Merrill) сорттарының сапалық құрамы мен дамуына микроэлементтердің әсерін зерттеу бойынша нәтижелері келтірілген. Жұмыстың мақсаты тұқым себу алдындағы өңдеу кезінде әртүрлі микроэлементтердің тиімділігін бағалау болды. Тәжірибелер 2022-2024 жылдары «Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институты» ЖШС, дәнді-бұршақты дақылдар бөлімінің (ҚазЕӨҒЗИ, Алматы облысы) тәжірибелік учаскелерінде ашық каштан, сазды, сирек құмды сазды топырақтарда жүргізілді. Зерттеуде теңдестірілген кешендердің микроэлементтері қолданылды (Мо+»В»+»Zn»+»Со»). Микроэлементтерді қолдану далалық өңгіштікке, физиологияға, фенологияға және астық сапасының көрсеткіштеріне оң әсер еткені анықталды. Қазақстанның оңтүстік-шығысындағы тау бөктеріндегі аймақ (ҚазЕӨҒЗИ) жағдайында егіс алдындағы микроэлементтерді өңдеуге барынша бейімделген және жауап беретін қазақстандық (Жансая, Ивушка) және Солтүстік Америка (Dawson,

Supra) экотиптерінің сорттары болып табылады. Микроэлементтермен өңдеу астық өнімділігінің 1000 тұқым массасын және өнімділігін ұлғайту есебінен 16,0–18,0% тұрақты өсуін қамтамасыз етеді, сондай-ақ астық ақуызын 1,5-2,1% - ға арттырады. Осылайша, микроэлементтерді егу алдындағы өңдеу жоғары тиімділікті көрсетті және соя өсірудің интеграцияланған экологиялық таза технологиялары үшін ұсынылуы мүмкін.

Түйін сөздер: соя, микроэлементтер, тұқым себу алдындағы өңдеу, фенология, өну, гүлдену, өнімділік

Качественный состав и динамика развития сортов сои различных экологических групп при предпосевной обработке микроэлементами

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Аннотация. В статье представлены результаты исследований по изучению влияния микроэлементов на качественный состав и развитие сортов разных экологических групп сои (*Glycine max* (L.) Merrill). Цель работы заключалась в оценке эффективности различных микроэлементов при предпосевной обработке семян. Эксперименты проводились в 2022-2024 гг. на опытных участках отдела зернобобовых культур КазНИИ Земледелия и Растениеводства (КазНИИЗиР, Алматинская область) в условиях светлокаштановых, суглинистых, реже супесчаных почв. В исследовании использовались микроэлементы балансированных комплексов (Мо+»В»+»Zn»+»Со»). Установлено, что применение микроэлементов оказывало положительное влияние на полевую всхожесть, физиологию, фенологию и показатели качества зерна. Наиболее адаптивными и отзывчивыми на предпосевную микроэлементную обработку в условиях предгорной зоны юго-востока Казахстана (КазНИИЗиР) являются сорта Казахстанского (*Жансая*, *Ивушка*) и Североамериканского (*Dawson*, *Supra*) экотипов. Обработка микроэлементами обеспечивает устойчивый рост зерновой продуктивности на 16,0–18,0% за счет увеличения массы 1000 семян и озерненности, а также повышает белковость зерна на 1,5–2,1%. Таким образом, предпосевная обработка микроэлементами показала высокую эффективность и может быть рекомендована для интегрированных экологически безопасных технологий возделывания сои.

Ключевые слова: соя, микроэлементы, предпосевная обработка семян, фенология, всхожесть, цветение, урожайность

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