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EFFECTS OF MACRO- AND MICRONUTRIENTS ON THE PRODUCTIVITY OF SOYBEAN (GLYCINE MAX L.) GROWN AS A SECONDARY CROP

Raximova Nodira Odilbek qizi
Lecturer, Urgench State University named after Abu Rayhan Beruni, Urgench, Uzbekistan.
rakhimovanodira1997@gmail.com
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Abstract. This article analyzes the findings of international and local researchers regarding the effects of macro- and micronutrients on the growth, development, and productivity of soybean (Glycine max L.) cultivated as a secondary crop. Soybean is an important leguminous crop characterized by its high protein and oil content, and its productivity largely depends on the level of mineral nutrition. Nitrogen, phosphorus, and potassium play a crucial role in the formation of vegetative and reproductive organs, while micronutrients such as boron, molybdenum, and zinc are essential for enhancing biological nitrogen fixation, photosynthesis, and reproductive processes. The analysis of scientific literature indicates that the integrated application of macro- and micronutrients can significantly increase soybean yield and improve grain quality characteristics.

Keywords: soybean (Glycine max L.), secondary crop, mineral nutrition, macronutrients, micronutrients, boron, molybdenum, zinc, yield.

Introduction. In recent years, the rapid growth of the world's population, the increasing demand for food products, and the limited availability of agricultural land and water resources have necessitated the achievement of higher efficiency in agricultural production. In particular, the rational and efficient use of irrigated lands, the expansion of opportunities to obtain two or more harvests per year, and the increase in agricultural output have become among the most pressing challenges. From this perspective, the scientifically based cultivation of secondary crops and the enhancement of their productivity are of great importance. In the Republic of Uzbekistan, extensive reforms are being implemented to diversify agriculture, improve crop structure, and ensure the supply of high-quality food products to the population. Within this context, crops characterized by high protein and oil content, especially soybean (Glycine max L.), are gaining increasing significance. Soybean is one of the most strategically important leguminous and oilseed crops in global agriculture. Its seeds contain approximately 35–45% protein, 18–25% oil, as well as essential amino acids, vitamins, and minerals required for human nutrition. Therefore, soybean serves as a valuable raw material for the food, livestock, poultry, and pharmaceutical industries. One of the most important biological characteristics of soybean is its ability to biologically fix atmospheric nitrogen through symbiotic root nodules formed by nitrogen-fixing bacteria. As a result, soybean not only produces high-quality yields but also contributes to the accumulation of biologically fixed nitrogen in the soil. This improves the nutritional conditions for subsequent crops, reduces the need for mineral nitrogen fertilizers, and helps maintain soil fertility.

However, achieving high soybean productivity requires the proper management of plant mineral nutrition. Macronutrients such as nitrogen, phosphorus, and potassium play a leading role in plant growth, development, and yield formation. Nitrogen is essential for protein and enzyme synthesis, phosphorus supports energy transfer and root system development, while potassium enhances photosynthetic efficiency, water regulation, and tolerance to environmental

stresses. In addition to macronutrients, micronutrients also have a significant impact on soybean yield and seed quality. Elements such as boron, molybdenum, zinc, manganese, and iron are indispensable for the normal functioning of physiological and biochemical processes. Molybdenum enhances the activity of root nodule bacteria and promotes biological nitrogen fixation. Boron plays an active role in pollination and seed formation, whereas zinc is involved in enzymatic activities and the synthesis of plant growth regulators. Recent studies conducted under various soil and climatic conditions around the world have demonstrated that the combined application of macro- and micronutrients can significantly increase soybean yield, improve seed protein and oil content, and enhance biological nitrogen fixation. Nevertheless, the optimal rates and interactions of macro- and micronutrients in irrigated soils of Uzbekistan, particularly for soybean cultivated as a secondary crop, have not been sufficiently investigated. Therefore, determining the effects of macro- and micronutrients on the growth, development, and productivity of soybean grown as a secondary crop, identifying their effective application rates, and developing scientifically based recommendations are of considerable scientific and practical importance for agricultural production.

Literature Review. Mineral nutrition is one of the key factors determining the growth, development, and productivity of agricultural crops. Plant biological productivity is directly dependent on the availability of macro- and micronutrients, and deficiencies or imbalances of these nutrients can lead to reductions in both yield quantity and quality. According to Marschner (2023) [1], macronutrients such as nitrogen, phosphorus, and potassium are among the most essential elements required by plants, playing critical roles in photosynthesis, respiration, protein synthesis, energy metabolism, and the formation of reproductive organs. As a high-protein crop, soybean (Glycine max L.) is distinguished from many other agricultural crops by its substantial nitrogen requirement. Nitrogen is a fundamental component of proteins, amino acids, nucleic acids, and chlorophyll molecules. Nitrogen deficiency results in leaf chlorosis, reduced photosynthetic activity, and decreased yield. A comprehensive analysis conducted by Salvagiotti et al. (2008) [3] revealed that soybean requires approximately 70–80 kg of nitrogen to produce one ton of grain. The authors emphasized that biological nitrogen fixation is a crucial factor in achieving high soybean productivity. Phosphorus is a key element involved in plant energy metabolism. As a constituent of ATP molecules, it participates in energy generation and transfer processes. In addition, phosphorus promotes root system development and stimulates the formation of reproductive organs. According to Mengel and Kirkby (2001) [5], plants adequately supplied with phosphorus exhibit more vigorous flowering and seed formation processes. Potassium is one of the major elements regulating plant water relations. It controls the osmotic pressure of cell sap, enhances enzyme activity, and improves plant tolerance to drought and other environmental stresses. Studies have shown that soybean plants receiving optimal potassium nutrition demonstrate higher photosynthetic efficiency and increased protein and oil concentrations in the grain.

Although micronutrients are required in relatively small quantities, they play indispensable roles in numerous physiological and biochemical processes. Among these, molybdenum, boron, and zinc are particularly important for leguminous crops. Molybdenum is a structural component of nitrogenase and nitrate reductase enzymes involved in biological nitrogen fixation. Research conducted by Hungria and Vargas (2000) [4] demonstrated that molybdenum supplementation enhances the activity of root nodule bacteria, thereby significantly increasing the assimilation of atmospheric nitrogen. Under molybdenum-deficient conditions, nodule development is impaired and nitrogen metabolism is adversely affected. Boron is especially important for the reproductive development of plants. It participates in cell wall formation, pollen germination, pollen tube growth, and seed development. Boron deficiency can result in flower abortion, reduced pod formation, and lower yield. Several studies have reported that foliar application of boron to soybean plants increases the number of pods and the thousand-seed weight. Zinc is an essential

element regulating the activity of numerous enzymes in plants. It plays a vital role in auxin synthesis, photosynthesis, and carbohydrate metabolism. According to Taiz and Zeiger (2015) [6], plants supplied with adequate zinc exhibit enhanced photosynthetic activity and accelerated biomass accumulation. Consequently, zinc fertilization is considered an important factor for improving both crop productivity and product quality. In recent years, particular attention has been devoted to investigating the relationship between biological nitrogen fixation and mineral nutrition. Studies conducted by Ciampitti et al. (2021) [2] identified a strong positive correlation between soybean yield and biological nitrogen fixation. The authors emphasized that optimal macro- and micronutrient management improves nitrogen-use efficiency and contributes to the formation of higher yields. Overall, the findings of the reviewed literature confirm that macro- and micronutrients exert significant effects on soybean growth, development, biological nitrogen fixation, and productivity. However, under the irrigated soil conditions of Uzbekistan, particularly for soybean cultivated as a secondary crop, the optimal application rates of macro- and micronutrients and their interactions have not been sufficiently investigated. This highlights the need for further scientific research in this area.

Research Object and Methodology. The research was conducted in 2025 at the educational experimental farm of Urgench State University named after Abu Rayhan Beruni, located in Yangibozor district, Khorezm region, Uzbekistan. The experimental site is geographically situated at 41.653695° N latitude and 60.622567° E longitude, with a total area of 2 hectares. The soils of the experimental field belong to the irrigated meadow-alluvial soil group, representing typical soil and climatic conditions of the Khorezm oasis. The region is characterized by a sharply continental climate, with high summer temperatures and low precipitation levels. Soybean (Glycine max L.) cultivated as a secondary crop was selected as the research object. Field experiments were established based on the methodological guidelines of B.A. Dospekhov ("Methodology of Field Experiments"). The study investigated the effects of macronutrients (N, P, K) and micronutrients (B, Mo, Zn) on the growth, development, and yield of soybean plants.

The experimental design included the following variants:

1. Control (without fertilizers);
2. N60P90K60;
3. N60P90K60 + B (boron);
4. N60P90K60 + Mo (molybdenum);
5. N60P90K60 + Zn (zinc);
6. N60P90K60 + B + Mo + Zn.

During the growing season, plant height, number of pods per plant, thousand-seed weight, and grain yield were recorded and subjected to comparative analysis. Soil samples were collected in accordance with GOST 28168-89 standards. Thousand-seed weight was determined according to GOST 12042-80, while seed germination was assessed following GOST 12038-84. All agrotechnical observations were carried out according to the methodologies recommended by V.M. Lukomets, N.M. Tishkov, and S.A. Semerenko.

Results

Table 1. Effects of macro- and micronutrients on biometric indicators and yield of soybean grown as a secondary crop

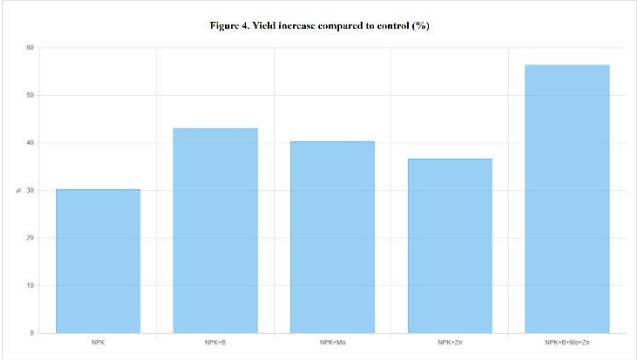
Variant	Fertilization scheme	Plant height, cm	Pods per plant, pcs	1000-seed weight, g	Yield, c/ha
1	Control	72.4	28.3	145.2	21.8
2	N60P90K60	81.7	35.6	156.8	28.4
3	N60P90K60 + B	85.2	39.1	160.4	31.2

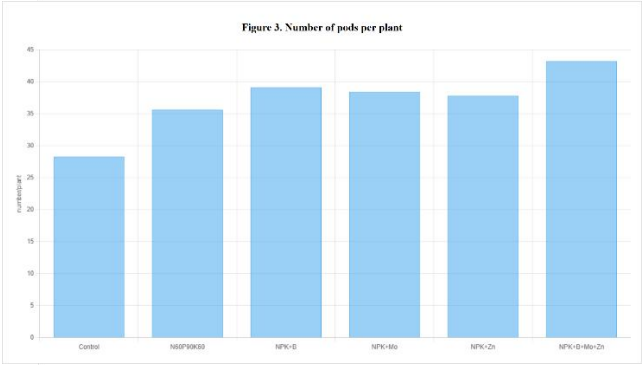
4	N60P90K60 + Mo	84.5	38.4	159.7	30.6
5	N60P90K60 + Zn	83.8	37.8	158.9	29.8
6	N60P90K60 + B + Mo + Zn	89.6	43.2	164.5	34.1

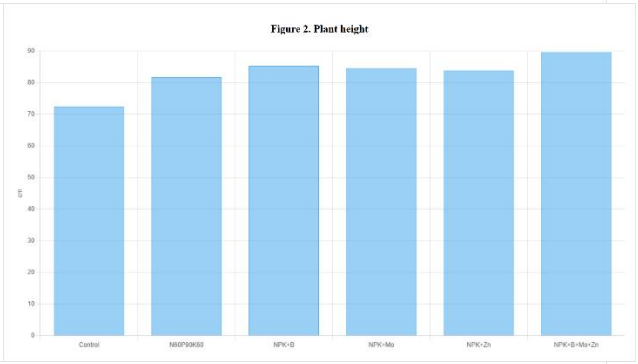
The data presented in Table 1 show that all fertilizer treatments significantly improved plant growth and yield parameters compared to the control variant. In the control treatment, plant height was 72.4 cm, whereas in the N60P90K60 + B + Mo + Zn treatment it reached 89.6 cm, which is 17.2 cm or 23.8% higher than the control. The number of pods per plant increased from 28.3 in the control to 43.2 in the combined micronutrient treatment, representing a 52.7% increase. This indicates a strong positive effect of micronutrients on the formation of generative organs. The 1000-seed weight increased from 145.2 g in the control to 164.5 g in the N60P90K60 + B + Mo + Zn treatment, demonstrating improved seed filling and grain quality. The highest yield was recorded in the combined treatment (N60P90K60 + B + Mo + Zn), reaching 34.1 c/ha, which is 12.3 c/ha or 56.4% higher than the control. The combined application of boron, molybdenum, and zinc on an NPK background improved plant nutrition, enhanced biological nitrogen fixation, and stimulated photosynthetic activity. Overall, the results demonstrate that the integrated application of macro- and micronutrients is highly effective in increasing soybean productivity when cultivated as a secondary crop.

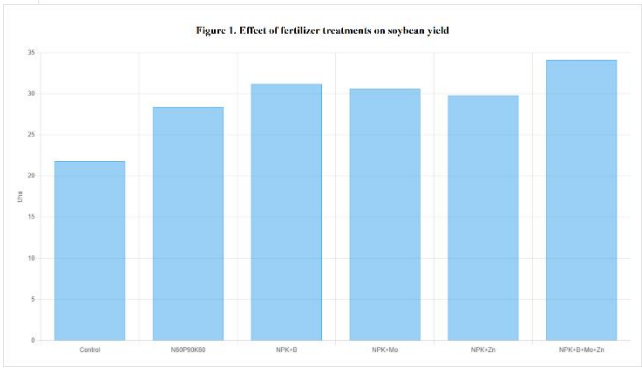
Muhokama

Olib borilgan tadqiqotlar natijalari makro va mikroelementlarning takroriy ekin sifatida parvarishlangan soya o‘simligining o‘sishi, rivojlanishi hamda hosildorligiga sezilarli ta’sir ko‘rsatishini tasdiqladi. Tajriba variantlari orasida eng yuqori natijalar N60P90K60+B+Mo+Zn qo‘llanilgan variantda kuzatildi. Mazkur variantda o‘simlik bo‘yi 89,6 sm ni tashkil etib, nazorat variantiga nisbatan 23,8 % ga yuqori bo‘ldi. Bu holat makroelementlarning vegetativ organlar rivojlanishini jadallashtirishi hamda mikroelementlarning fiziologik jarayonlarni faollashtirishi bilan izohlanadi. Dukkaklar soni bo‘yicha ham eng yuqori ko‘rsatkich kompleks oziqlantirish variantida qayd etilib, bitta o‘simlikda 43,2 dona dukkak hosil bo‘ldi. Bu nazorat variantiga nisbatan 52,7 % ko‘p demakdir. Ayniqsa bor elementining gullash va urug‘ hosil qilish jarayonlariga ijobiy ta’siri ushbu natijalarni shakllantirishda muhim omil bo‘ldi. 1000 dona urug‘ massasi 164,5 g ni tashkil etib, nazorat variantiga nisbatan 13,3 % ga oshdi. Bu esa o‘simliklarning oziqlanish sharoiti yaxshilanganligi sababli donlarning to‘liq shakllanishi va to‘lish darajasi ortganligini ko‘rsatadi. Tadqiqotda eng muhim ko‘rsatkich hisoblangan hosildorlik N60P90K60+B+Mo+Zn variantida 34,1 s/ga ni tashkil etdi. Ushbu ko‘rsatkich nazorat variantidan 12,3 s/ga yoki 56,4 % ga yuqori bo‘ldi. Bor, molibden va ruxning NPK fonida birgalikda qo‘llanilishi biologik azot fiksatsiyasi, fotosintez intensivligi hamda generativ organlar rivojlanishini kuchaytirganligi sababli yuqori hosildorlik shakllangan deb hisoblash mumkin. Olingan natijalar Salvagiotti va hammualliflar (2008) hamda Ciampitti va hammualliflar (2021) tomonidan keltirilgan ma’lumotlar bilan mos keladi.









Their studies also reported that the optimization of mineral nutrition and the application of micronutrients contribute significantly to increasing soybean yield. In addition, the role of molybdenum in biological nitrogen fixation confirms the findings reported by Hungria and Vargas (2000). Thus, it was established that in soybean cultivation as a secondary crop, the combined application of macronutrients together with micronutrients such as boron, molybdenum, and zinc provides a high level of effectiveness in improving plant growth, formation of yield components, and grain productivity.

Conclusion. Based on the conducted research, it was established that the growth, development, and productivity of soybean (Glycine max L.) cultivated as a secondary crop are directly dependent on the level of macro- and micronutrient supply. In all fertilized treatments, a significant increase in biometric and yield parameters was observed compared to the control.

According to the results, the combined application of boron, molybdenum, and zinc on an N60P90K60 background provided the highest efficiency. In this treatment, plant height reached 89.6 cm, the number of pods per plant was 43.2, the 1000-seed weight was 164.5 g, and yield reached 34.1 c/ha. Compared to the control, these indicators increased by 23.8%, 52.7%, 13.3%, and 56.4%, respectively. Macronutrients created an essential nutritional background for the development of vegetative and generative organs, while micronutrients activated physiological and biochemical processes, enhancing biological nitrogen fixation, photosynthetic intensity, and the formation of yield components. In particular, boron played an important role in flowering and seed formation, molybdenum in biological nitrogen fixation, and zinc in enzymatic activity and photosynthesis, all of which significantly contributed to higher yield formation. Thus, under the irrigated meadow-alluvial soil conditions of Khorezm region, the combined application of boron, molybdenum, and zinc on an N60P90K60 background was identified as an effective agronomic practice for obtaining high and quality soybean yields in secondary cropping systems. The obtained results are of important scientific and practical value for improving soybean cultivation technology and optimizing mineral nutrition systems.

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