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THE EFFECT OF SALINITY ON THE GROWTH AND DEVELOPMENT OF SOYBEAN VARIETIES

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Abstract
Salinity is among the most critical abiotic stress factors that adversely affect the physiological and morphological development of crops, particularly in arid and semi-arid regions. This study investigates the impact of different soil salinity levels on the growth and development of several soybean (*Glycine max* L.) varieties, which are strategically important leguminous crops in the global food and protein supply chain. The objective of the research was to assess how salinity influences specific agronomic traits, such as plant height and leaf surface area expansion, which are key indicators of plant health and productivity. Controlled experiments were conducted under varying salinity regimes, and a comparative analysis of the growth responses among the soybean varieties was carried out. The findings demonstrate that soil salinity significantly affects the growth rate and leaf morphology of soybean plants. Notably, genotypic variability was observed among the tested varieties in their tolerance to salinity stress. Some varieties showed relatively stable growth under moderate salinity levels, indicating potential for cultivation in marginal and salt-affected soils. The correlation between salinity levels and biomass development revealed that both physiological adaptability and genetic resistance play crucial roles in plant performance. This study provides valuable insights for breeding programs aimed at improving salt tolerance in soybean and highlights the necessity of integrating

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molecular, physiological, and agrotechnical approaches to ensure sustainable production under stress-prone conditions. The results also contribute to the broader field of plant stress biology and legume crop resilience under changing environmental conditions.

Keywords: Abiotic stress, salinity stress, soybean varieties, physiological response, morphological traits, leaf surface area, leguminous crops, breeding, sustainable agriculture, soil management.

Introduction

In recent years, significant attention has been paid to expanding the cultivation of soybean (*Glycine max* L.) in Uzbekistan as part of broader efforts to increase domestic food production and meet the growing demand for plant-based protein sources. National strategies have prioritized the development and introduction of new soybean varieties adapted to the diverse soil and climatic conditions of the country, with a focus on achieving high yields, selecting optimal genotypes, and understanding the physiological and biochemical processes involved in ontogenesis.

To ensure stable crop production, it is essential to cultivate varieties that are well-suited to specific agroecological zones. For instance, a study conducted at the experimental fields of Korea National University (Suwon Province) tested 80 local and 4 foreign soybean lines from China, Japan, Korea, and Vietnam. Correlation analysis of the data revealed significant variability in agronomic traits such as biomass accumulation, flowering time, vegetation duration, and maturation phase. A positive correlation was identified between total biomass and the number of seeds and pods, suggesting the potential of these lines for further use in genetic improvement and breeding programs [1].

Salinity stress is one of the major abiotic factors that negatively affects multiple physiological aspects of plant development. High salinity levels reduce shoot growth and dry matter accumulation while increasing the root-to-shoot ratio. Salinity impairs seed germination by decreasing water absorption, creating unfavorable osmotic conditions, and exposing the embryo to toxic ions. It also

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interferes with cell division and elongation at growth points, further inhibiting shoot development.

Halophytes are known to survive in saline environments due to specialized physiological mechanisms that enable them to adapt. Therefore, studying valuable halophytes and understanding the physiological mechanisms underlying salt stress tolerance is of great importance [2].

Salinity reduces plant growth and significantly decreases crop productivity under stress conditions. Many agricultural lands are affected by soil salinization, posing a threat to soybean cultivation. Thus, developing salt-tolerant soybean varieties is a critical task. The number and quality of root nodules play a key role in determining the overall nutritional status of the plant. Salinity stress impairs nodulation, reduces nitrogen fixation efficiency, and limits both the number and biomass of root nodules. While the effects of salinity on crop yield have been extensively studied, there is still limited information on the specific physiological responses of soybean to salt stress [3].

Traditional soybean breeding programs in Uzbekistan have historically focused on improving traits such as yield potential, early maturity, adaptability to local environments, and resistance to diseases and pests. In recent years, however, breeding priorities have expanded to include stress tolerance and seed quality traits—particularly oil and protein content. The Ministry of Agriculture has developed a unified national strategy, referred to as the “Roadmap,” for the breeding and genetic improvement of leguminous crops. This includes defining short- and long-term parameters for future soybean varieties, promoting seed production specialization among farms, and mechanizing seed propagation to improve efficiency. Accordingly, the number of seed-producing farms is gradually being reduced, while the acreage under seed production in specialized farms is increasing, leading to a higher share of certified seed production within the private farming sector [4].

Soybean (*Glycine max* L.) is a globally important multipurpose oilseed crop. In addition to producing edible oil, soybeans provide essential food products for human consumption and high-protein feed for animals. Despite their wide agroecological adaptability, soybeans remain sensitive to a range of abiotic

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stresses, including salinity, drought, heavy metal toxicity, and temperature extremes. Among these, soil salinization poses one of the most significant threats to soybean cultivation, with salinity stress being a major limiting factor in achieving high yields. Salinity adversely affects seedling growth, physiological processes, metabolic activity, final yield, and grain quality.

In response to this, researchers have explored various physiological, molecular, and agrotechnical strategies to improve salt tolerance in soybeans. However, these initiatives are still in the early stages and require further advancement and integration [5].

Environmental stressors such as salinity, drought, waterlogging, toxic metals, and extreme temperatures have become a global concern for ecologists and botanists, as they negatively affect food security worldwide. Salt stress is considered one of the most detrimental abiotic factors due to its combined osmotic and ionic effects on plants. Soybeans are classified as moderately salt-sensitive, and depending on the severity of salinity, yield losses can reach up to 40%. Excessive salt accumulation in the rhizosphere significantly affects seed germination, seedling vigor, nodulation, and overall plant development [6].

Salt stress also disrupts key physiological and metabolic functions in plants, including protein synthesis, water and nutrient uptake, translocation of assimilates, as well as cytosolic and mitochondrial reactions. These disruptions lead to reduced biomass accumulation and compromised reproductive development [7].

In the context of global food insecurity and undernutrition, ensuring adequate nutrition for populations requires the promotion of nutrient-dense crops. Soybean, due to its high protein and oil content, stands out as a versatile and resilient crop that should remain at the forefront of agricultural development efforts. However, despite a notable increase in global production over the past decade, yield per unit area has not increased proportionally. A key limitation is the lack of comprehensive understanding of the physiological and architectural traits that contribute to yield. Unlike cereals, soybeans possess complex plant architecture, making it more challenging for breeders to optimize canopy integration and biomass partitioning. For example, increasing plant height alone

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does not guarantee higher yields, while dwarf varieties may also yield less due to shorter internodes and reduced light interception [8].

Salinity-Induced Osmotic Stress and Agrotechnical Management in Soybean Cultivation

One of the primary effects of soil salinity on plants is osmotic stress. Under saline conditions, a deficiency of energy and the imbalance between solute concentrations in the soil solution and plant cells lead to reduced water uptake. As a result, plant cells lose turgor pressure, which is a direct manifestation of osmotic stress. It has been observed that water consumption decreases progressively as salinity levels increase. Consequently, the water content in the leaves declines, accompanied by a loss of tissue turgidity [9].

As in many other crops, agronomic management strategies can significantly improve soybean stability under stress conditions. These practices primarily include the optimization of sowing time, mulching, water management, tillage, soil amendments, fertilizer application, and other related measures. The effectiveness of such approaches depends on environmental variables such as temperature, precipitation, humidity, and local salinity gradients. Studies have shown that increased soil moisture enhances resistance to salinity by suppressing Na^+ ion uptake, improving root activity, and enhancing stomatal conductance, which is a key factor in plant resilience [10].

Challenges related to plant tolerance to external stress factors, especially salinity, have long been the subject of physiological and agronomic studies. To achieve high and stable yields, and to efficiently utilize irrigation water, it is critical to ensure adequate water supply based on the specific varietal traits of each plant. This enhances physiological and biochemical activity by activating water exchange processes within plant tissues. Understanding the physiological and biochemical effects of salinity is essential for identifying and developing salt-tolerant soybean varieties adapted to diverse conditions.

Given the biological characteristics of soybean varieties, the application of region-specific agrotechnical measures at the appropriate time and quality level is essential to ensure high and stable yields. Each province of Uzbekistan has

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unique soil and climatic conditions, making it necessary to study the impact of salt stress on both local and imported varieties. On the basis of such scientific experimentation, it is possible to develop new agrotechnical practices tailored to the natural environment of each region and to provide practical recommendations to local farming communities.

Materials and Methods

The object of the research consisted of selected soybean (*Glycine max* L.) varieties. The experiments were carried out on soils with varying levels of salinity. Leaf surface area was measured using the cross-sectional (cutting) method, a widely accepted approach in plant morphology studies [11]. Growth parameters of the plants were assessed using standard agronomic procedures. The methods of sowing and agrotechnical treatments were implemented in accordance with the experimental design and based on regionally accepted cultivation practices and soybean production technologies.

Results and Discussion

Plant growth processes are significantly altered under the influence of unfavorable environmental conditions. Salinity, in particular, inhibits the growth of plants and the formation of their organs. The decline in biological and economic yield under saline conditions is directly related to the slowdown of physiological growth processes. Soil salinity not only reduces the quality of agricultural produce but also adversely affects all stages of plant development.

Among the key parameters affected by salinity are leaf size and surface area, which are critical for light interception and photosynthesis. Under salt stress, leaf area is markedly reduced, which directly influences chlorophyll biosynthesis and the production of photosynthetic pigments. Additionally, the availability of calcium and iron ions in leaves decreases, further impairing photosynthetic efficiency.

One of the primary effects of salinity is osmotic stress. The imbalance between the concentration of dissolved substances in the soil solution and plant cells restricts water uptake, causing a loss of turgor in plant tissues. As salinity levels

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increase, water uptake declines, leading to reduced leaf water content and diminished turgor pressure [12].

Experimental observations showed that, depending on the biological characteristics of the soybean varieties, initial growth after germination to the formation of the first trifoliate leaves occurred slowly under saline conditions. In general, germination vigor was found to be influenced by several abiotic factors, including the degree of soil salinity. A negative correlation between salinity level and plant height was recorded for all soybean varieties studied. Maximum plant height was reached during the pod formation stage. The average height of plants grown in non-saline soil ranged from 76.4 to 97.5 cm, whereas in moderately saline soils it dropped to 75.6–88.4 cm, and in highly saline soils it was further reduced to 71.5–78.7 cm.

During the early bud formation stage, differences in plant height among varieties were negligible. However, as ontogenesis progressed, these differences widened, peaking during the pod formation stage. Salinity was shown to decrease the water potential and create ionic toxicity, both of which disrupt cellular metabolism. While soybean plants are relatively sensitive to salinity in their early developmental stages, they exhibit a degree of resilience as growth progresses. Ensuring proper water balance in early growth stages can mitigate the damaging effects of salt.

The leaf surface area is a vital parameter for effective dry matter accumulation. Experimental data confirmed that under non-saline conditions, soybean leaves developed broader assimilation areas compared to those under saline stress. On average, leaf surface area under moderately saline conditions was reduced by 9.8%, and by approximately 16% under high salinity, compared to the control group.

Leaf area expansion varied not only with soil salinity levels but also across the stages of ontogeny. The smallest assimilation surface area was observed during bud initiation, and it increased progressively until pod development, where the maximum values were recorded. This aligns with the period of maximal dry matter accumulation in soybean.

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However, in addition to measuring total leaf area, it is also essential to evaluate the rate of leaf development to better understand the crop's potential for biomass formation and yield. The differences observed in leaf area among varieties reflected their inherent biological characteristics and the degree of environmental influence—primarily the soil's salinity level.

The variability in primary adaptive responses across soybean varieties highlights that stress resistance is highly dependent on genotype, developmental dynamics, and the interaction of activating and inhibiting factors at specific growth stages. Overall, adaptation is a complex and multilevel process, encompassing the entirety of physiological mechanisms that increase plant stress tolerance.

Conclusion

Based on the scientific evidence presented above, it is clear that, regardless of whether soybean (*Glycine max* L.) is cultivated under favorable or unfavorable environmental conditions, the achievement of expected yields requires the implementation of either stress-avoidance or stress-adaptation mechanisms. Numerous studies have investigated soybean's physiological responses to abiotic stress—particularly its tolerance to salt stress.

However, the precise physiological, molecular, and genetic mechanisms underlying salinity resistance in soybean remain to be fully elucidated. Comprehensive research is essential to identify and characterize these mechanisms and to develop salt-tolerant varieties through evidence-based breeding strategies.

Salinity represents one of the most limiting environmental factors affecting soybean growth and development. It significantly suppresses plant height, biomass accumulation, and overall yield potential. In the context of climate change and declining water availability, it becomes increasingly important to explore the ecophysiological effects of salt stress across different growth stages—particularly its impact on both seed yield and green biomass production.

Future efforts should prioritize the development of adaptive soybean genotypes capable of maintaining productivity under saline conditions. This will require integrative approaches that combine physiological studies, stress-responsive gene

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identification, and region-specific agrotechnical interventions. Understanding the multifaceted responses of soybean to salt stress is vital for ensuring sustainable crop production in salt-affected regions.

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