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## Research Article

# Growth, Yield and Ionic Response of Spinach (*Spinacia oleracea* L.) to Saline Water in Open-air Hydroponics

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## ABSTRACT

Salinity is an increasing global concern, as rising salinity levels are reducing crop productivity and threatening agricultural sustainability, particularly in arid and semi-arid regions. We investigated the influence of canal and saline waters on the growth, yield, and ion content of English spinach (*Spinacia oleracea* L.), in an open-air hydroponic system. The study was arranged in a completely randomized design, comprising four irrigation treatments, viz. canal water (control), and saline waters with EC of 2.0, 4.0, and 6.0 dS m<sup>-1</sup>, repeated thrice. Our findings revealed that the increasing salinity levels of irrigation water significantly reduced spinach growth and yield. The maximum plant height (36.3 cm), number of leaves per plant (20.2), fresh weight per plant (42.2 g), and dry weight per plant (6.2 g) was observed under canal water irrigation treatment. While potassium (K<sup>+</sup>) ion concentration of plants was found highest under both canal water (4.13%) and salt-water of EC 2.0 dS m<sup>-1</sup> (4.05%), respectively. Sodium (Na<sup>+</sup>) ion concentration increased linearly with the increasing EC levels. The maximum Na<sup>+</sup> concentration was recorded under salt-water of 6.0 dS m<sup>-1</sup> (2.72%). The study concluded that using saline water in hydroponics can reduce the growth, yield and K<sup>+</sup> ion concentration of spinach, while increasing its Na<sup>+</sup> concentration. However, spinach may tolerate saline water of an EC level up to 4.0 dS m<sup>-1</sup> with less than 21.6% reduction in fresh weight (yield) compared to canal water irrigation. Future research is warranted for the validation of these results under field conditions.

**Keywords:** Hydroponics, Saline Water, Spinach, Growth, Yield, Electrical Conductivity.



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## INTRODUCTION

Soil and water salinity are increasingly recognized as major threats to global agricultural productivity, particularly in arid and semi-arid regions where evapotranspiration exceeds precipitation and irrigation practices are common (Majeed and Muhammad, 2019). About one-third of global irrigated lands are moderately to severely saline (FAO, 2021). Nearly ~20% of Pakistan's agricultural land (37 m ha) is also salt-affected (Zia-ul-hassan and Arshad, 2006), with high heavy metal concentration (Bux et al., 2022, 2023). Salinity stress impacts plants through both osmotic and ionic mechanisms. Osmotically, it reduces water uptake, while ionically, the excessive accumulation of sodium (Na<sup>+</sup>) and chloride (Cl<sup>-</sup>) ions leads to nutritional imbalances, oxidative stress, and disruption of metabolic processes (Mehra and Bennett, 2022; Suthar et al., 2025).

Among the key ions affected by salinity, potassium (K<sup>+</sup>) plays a central role in maintaining osmotic balance, enzyme activation, protein synthesis, and stomatal

Regulation (Saddiq et al., 2021). Sodium competes with K at the uptake sites in roots due to their similar physicochemical properties, often resulting in a decreased  $K^+/Na^+$  ratio - a critical indicator of plant salinity tolerance (Suthar et al., 2018; Zahra et al., 2022). Managing the uptake and distribution of these ions is crucial for improving plant resilience under saline conditions. Spinach (*Spinacia oleracea* L.) is one of the most important fast-growing leafy vegetables. The nutritional quality of spinach, particularly its mineral composition, is highly essential for humans (Massa et al., 2018).

Hydroponic systems have been widely used to study plant responses to salinity stress due to their precise control over nutrient and salt levels (Hirst et al., 2024). Unlike soil-based systems, hydroponics enables precise control over nutrient concentrations, salinity levels, pH, and environmental conditions, minimizing confounding variables (Zia-ul-hassan et al., 2011; Machado et al., 2018). This allows researchers to isolate the effects of salinity on growth, physiology, and nutrient dynamics more accurately. Moreover, hydroponic studies are instrumental in developing strategies for urban and peri-urban agriculture where water quality and land resources are limited (Rothwell et al., 2016; Sapkota et al., 2019).

Spinach production in soilless culture is under cultivation using different substrates all over the world (Machado et al., 2018; Leal et al., 2020). While hydroponics can enhance plant growth, yield, and quality, its success relies on various factors including nutrient supply, genetic traits of crops, and the cultivation technique used (Sapkota et al., 2019). Salinity negatively affects spinach production by reducing growth, and yield due to osmotic stress and ionic imbalance. High sodium levels interfere with potassium uptake, lowering the  $K^+/Na^+$  ratio essential for plant functions (Bhatti et al., 2021). This experiment was conducted in an open-air hydroponic system to evaluate the impact of canal and saline water irrigations involving varying EC levels, on growth, yield, and ion ( $Na^+$  &  $K^+$ ) concentration of spinach. It was hypothesized that spinach plants may show moderate tolerance when exposed to different salinity levels under a hydroponic system.

## MATERIALS AND METHODS

### Experimental site

This open-air hydroponic experiment was conducted at the Soil Salinity and Reclamation Institute, Agriculture Research Centre, Tandojam, Pakistan at the Integrated Waterlogging and Salinity Component (IWSC) Greenhouse of Sindh Water and Agriculture Transformation Project (SWAT).

### Experimental details

The hydroponic system was locally fabricated using PVC pipes. It consisted of four separate compartments, each with a capacity to hold 50 liters of solution. The system followed a nutrient film technique, in which plant roots remained suspended in the nutrient solution. Aeration was provided through pipes connected with an aeration system. The other environmental factors, including light, temperature, and humidity, were natural, as the experiment was conducted in an open-air hydroponic system. Healthy seeds of English spinach were grown in germination boxes for two weeks before they were transplanted to hydroponics system (five seedlings per unit). The experiment was arranged in a completely randomized design (CRD), consisting of four irrigation treatments: Canal water (control) with an EC value of  $0.3 \text{ dS m}^{-1}$ , and saline waters with EC of 2.0, 4.0, and  $6.0 \text{ dS m}^{-1}$ , repeated thrice. The canal water was collected from field, while saline waters solutions were prepared using pure analytical grade sodium chloride (NaCl). The pH of the solution was monitored on a weekly basis and maintained within an optimal range (pH 5.5 to 6.5). Nutrient solution was provided to plants for balanced nutrition (Arnon and Hoagland, 1944; Zia-ul-hassan et al., 2011). Fresh saline water treatments and nutrient solutions were supplied to hydroponics every seven days to ensure consistent salinity and nutrient availability.

### Collection of data

Growth and yield traits of spinach plants were recorded after 60 days of growth, followed by laboratory analysis of plant  $Na^+$  and  $K^+$  concentration. The growth and yield traits were recorded from five randomly selected plants from each replication, including plant height (cm), number of leaves per plant, and fresh & dry weight per plant (g). For the determination of plant  $Na^+$  and  $K^+$  ion concentration, fully expanded mature leaves of spinach were selected and processed for laboratory analysis. Plant samples were oven-dried at  $68^\circ\text{C}$  until constant weight, followed by their grinding into fine powder. Sodium and  $K^+$  ions in plant samples were determined following wet digestion method (Nawaz et al., 2006; Vishandas et al., 2006; Zia-ul-hassan et al., 2014) using a flame photometer.

### Statistical analysis

The ANOVA was performed using Statistix ver. 8.1 statistical software package. Treatment means were separated using the Least Significant Difference (LSD) test at  $P < 0.05$ .

## RESULTS

### Effect of saline waters on growth and yield traits of spinach

#### Plant height (cm)

The results showed that plant height of spinach was significantly ( $P < 0.05$ ) decreased in relation to the increasing EC levels in hydroponic culture (Figure 1). It was observed that plant height was overall better under the canal water irrigation compared to the salt-water irrigation treatments. The maximum plant height (36.3 cm) was recorded under the treatments receiving canal water irrigation. While minimum plant height (23.2 cm) was observed with saline water of  $6.0 \text{ dS m}^{-1}$ . The EC level of  $2.0 \text{ dS m}^{-1}$  obtained a plant height of (32.5 cm). Plant height of (28.7 cm) was noticed under the saltwater irrigation at  $4.0 \text{ dS m}^{-1}$ .

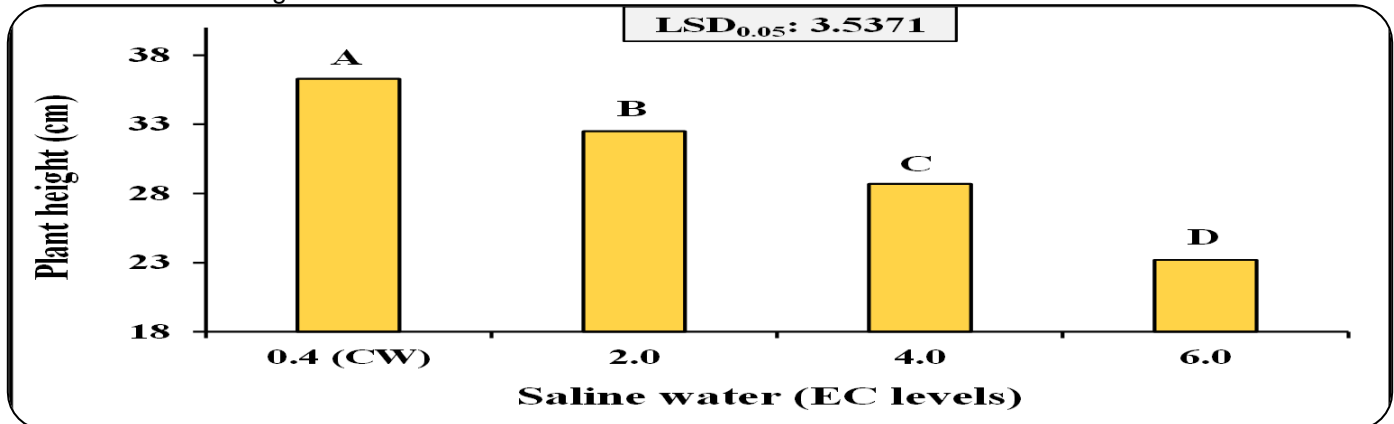


Figure 1. Plant height of spinach as influenced by canal and saline water irrigations in hydroponics. CW: Canal water (control).

#### Number of leaves per plant

Effects of varying EC levels on spinach grown in hydroponic culture were significant ( $P < 0.05$ ) as presented in Figure 2. The maximum number of leaves per plant (20.2) were recorded under canal water irrigation treatment (control), while minimum number of leaves (12.2) were observed under salt-water irrigation of  $6.0 \text{ dS m}^{-1}$ . Salt-water irrigation of  $2.0 \text{ dS m}^{-1}$  yielded the number of leaves per plant of (18.4), outperforming the EC level of  $4.0 \text{ dS m}^{-1}$ , which achieved (16.1) number of leaves per plant.

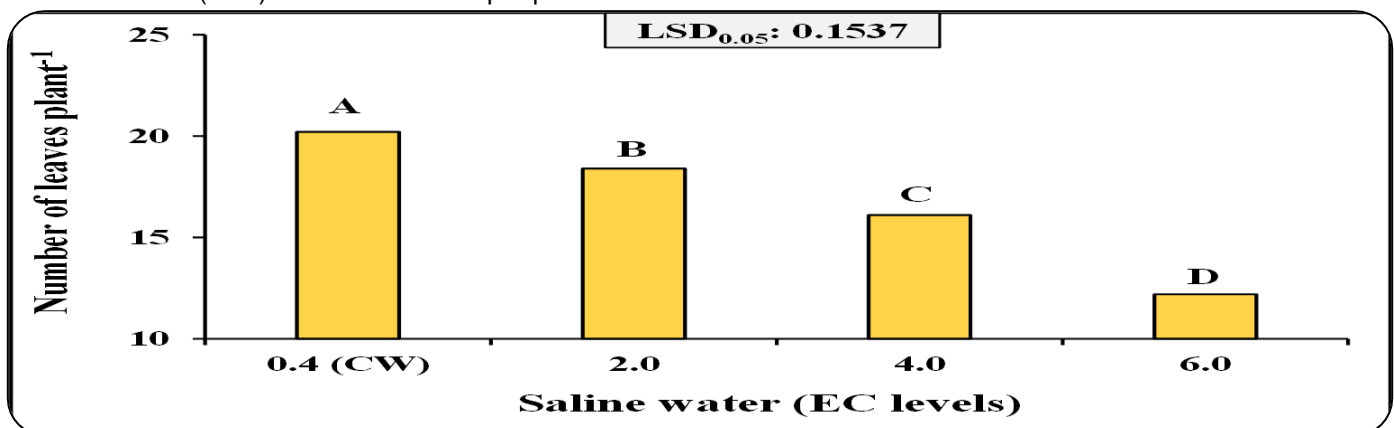


Figure 2. Number of leaves per plant of spinach as influenced by canal and saline water irrigations in hydroponics. CW: Canal water (control).

#### Fresh weight per plant (g)

The data related to the fresh weight per plant of spinach as affected by different salinity levels under hydroponic conditions is presented in Figure 3. The data revealed that the effects of varying EC levels on fresh weight of spinach were significant ( $P < 0.05$ ). The maximum fresh weight per plant (42.2 g) was recorded under the canal water irrigation treatment (control). The culture irrigated with salt-water of  $2.0 \text{ dS m}^{-1}$  achieved the fresh weight per plant of (38.2 g), outyielded the higher EC levels of  $4.0 \text{ dS m}^{-1}$  and  $6.0 \text{ dS m}^{-1}$ , which recorded (33.1 g) and (26.1 g) fresh weight per plant of spinach, respectively.

### Dry weight per plant (g)

Dry weight per plant of spinach was significantly ( $P < 0.05$ ) affected by the varying EC levels in hydroponic conditions (Figure 4). The overall performance of spinach plants in producing the dry weight was significantly better under canal water irrigated treatment (control). The same treatment obtained the maximum dry weight per plant of (6.2 g). The application of salt-water of  $2.0 \text{ dS m}^{-1}$  acquired the dry weight of (5.5 g), outweighing the higher EC levels of  $4.0 \text{ dS m}^{-1}$  and  $6.0 \text{ dS m}^{-1}$ , which obtained the dry weights of (4.7 g) and (2.8 g) per plant, respectively.

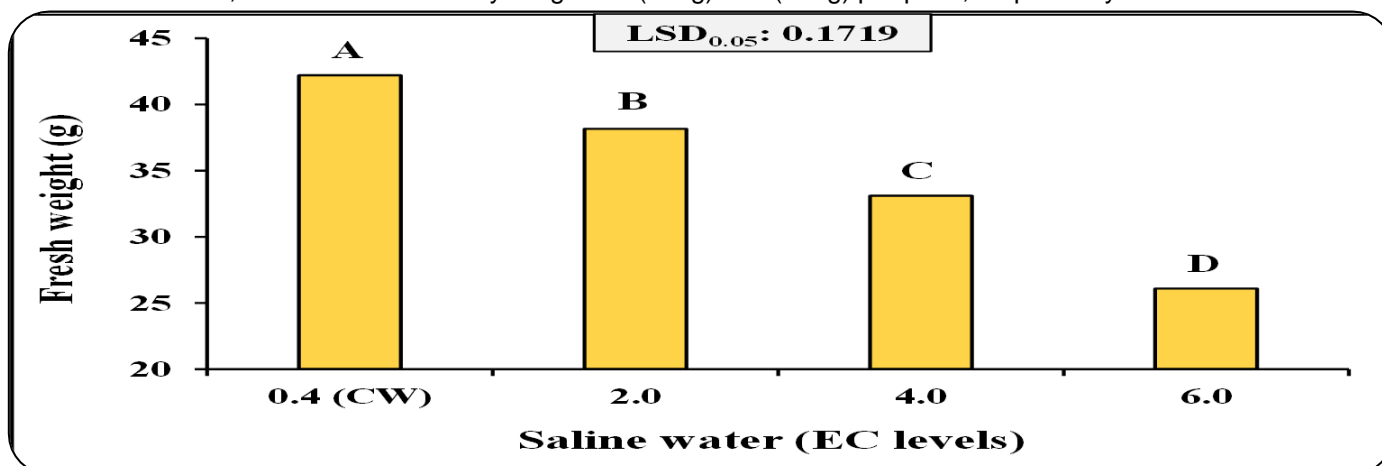


Figure 3. Fresh weight per plant of spinach as influenced by canal and saline water irrigations in hydroponics. CW: Canal water (control).

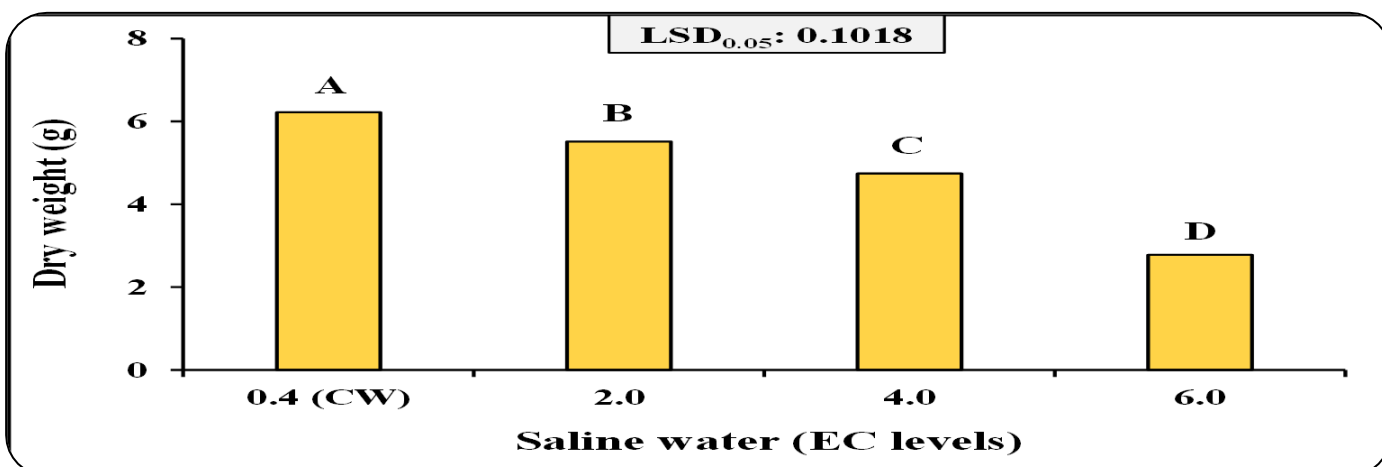


Figure 4. Dry weight per plant of spinach as influenced by canal and saline water irrigations in hydroponics. CW: Canal water (control).

### Effect of saline waters on sodium and potassium concentration of spinach

#### Sodium concentration (%)

The application of salt waters showed a significant ( $P < 0.05$ ) effect  $\text{Na}^+$  ion concentration of spinach plants (Figure 5). The  $\text{Na}^+$  in plants increased linearly with respect to increasing salinity levels (EC 0.3 to  $6.0 \text{ dS m}^{-1}$ ). Irrigation with canal water (control) with an EC of  $0.3 \text{ dS m}^{-1}$  showed the minimum  $\text{Na}^+$  ion concentration (0.93%). While maximum  $\text{Na}^+$  concentration (2.72%) was observed under the treatment of highest EC level ( $6.0 \text{ dS m}^{-1}$ ). The moderate ( $4.0 \text{ dS m}^{-1}$ ) and low ( $2.0 \text{ dS m}^{-1}$ ) EC levels attained the  $\text{Na}^+$  ion concentration of (2.10%) and (1.25%), in spinach plants, respectively.

#### Potassium concentration (%)

Potassium ion concentration of spinach plants varied significantly ( $P < 0.05$ ) across canal and salt-water irrigation treatments (Figure 6). The maximum  $\text{K}^+$  concentration was observed with canal water (control) and EC  $2.0 \text{ dS m}^{-1}$  salt-water irrigation with (4.13%) and (4.08%), respectively. The application of salt-waters with an EC level higher than  $2.0 \text{ dS m}^{-1}$  did not further increase plant  $\text{K}^+$  concentration. The minimum  $\text{K}^+$  concentration (2.09%) was recorded with highest EC level of  $6.0 \text{ dS m}^{-1}$ . While the moderate EC level ( $4.0 \text{ dS m}^{-1}$ ) showed  $\text{K}^+$  ion concentration of (3.16%).

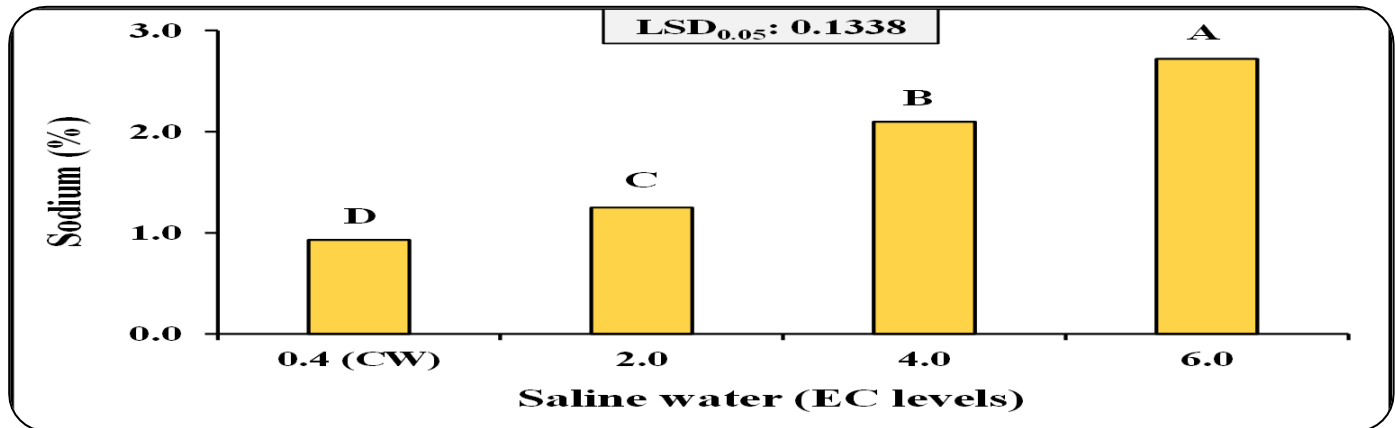


Figure 5. Sodium ion concentration of spinach as influenced by canal and saline water irrigations in hydroponics. CW: Canal water (control).

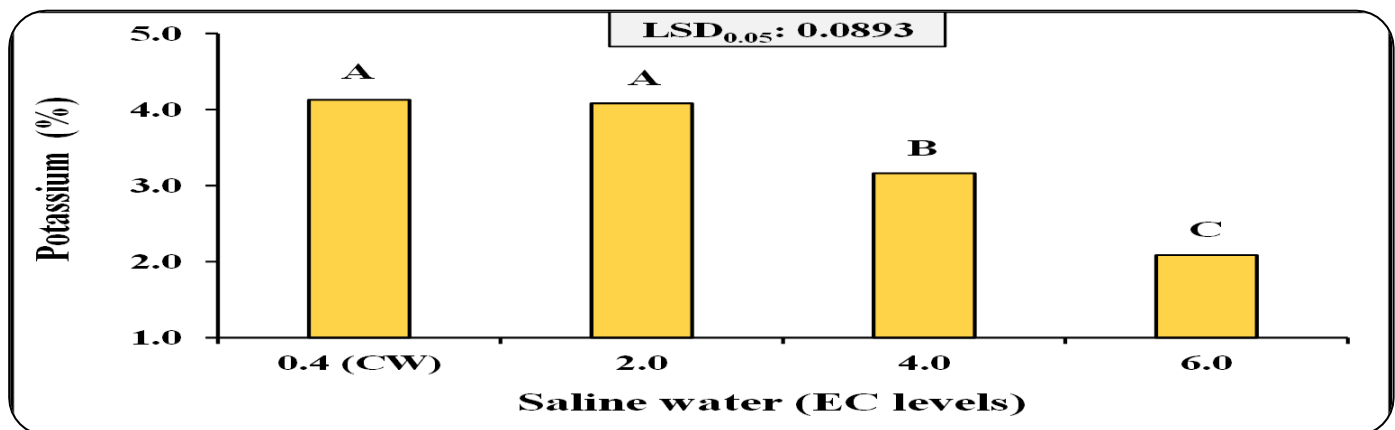


Figure 6. Potassium ion concentration of spinach as influenced by canal and saline water irrigations in hydroponics. CW: Canal water (control).

## DISCUSSION

Abiotic stressors are becoming a major concern to agricultural sustainability as these stressful conditions considerably decline plant growth, yield and quality (Jamali and Zia-ul-hassan, 2025; Suthar et al., 2025). Among various abiotic stresses, salinity is considered the most damaging to agriculture. It significantly hampers plant growth and crop productivity, especially in arid and semi-arid regions where water scarcity and poor irrigation practices exacerbate the problem (Hafeez et al., 2021; Suthar et al., 2025). The quality of irrigation water has been endorsed as the key driving force for enhanced growth, biomass production and nutrient accumulation, leading towards improved crop yields (Tareen et al., 2025). Globally, around 20% of irrigated areas have been severely affected by salinity, posing a significant threat to global food security. If this persists, this figure could rise to nearly 50% within the next 25 years (FAO, 2021), emphasizing the urgent need for sustainable and innovative strategies to manage and mitigate soil salinization. Salinity disrupts plant water uptake and causes ion toxicity, particularly from excessive sodium and chloride. It leads to reduced germination, stunted growth, chlorosis, and lower yields, making it a critical barrier to successful crop production (Saddiq et al., 2021). Hydroponics offers an effective method for cultivating short-duration crops without soil. By precisely managing water and nutrients, this soilless system allows for consistent plant growth even in regions with saline or degraded soils (Sharma et al. 2018; Agarwal et al., 2020). The outcomes of the present study revealed that on per plant basis maximum plant height, number of leaves, and fresh & dry biomass were highest under canal water application. The highest  $K^+$  concentration was recorded under both canal and salt-water of  $2.0 \text{ dS m}^{-1}$ . Whereas maximum  $Na^+$  concentration ( $2.72\%$ ) was noted where salt-water of highest concentration ( $6.0 \text{ dS m}^{-1}$ ) was applied. Suthar et al. (2018) reported that increasing salinity levels in guar straw and seed was directly related to the increased  $Na^+$  concentration and decreased  $K^+$  concentration and  $K^+/Na^+$  ratio. These results agree with various previous studies investigating the physiological, biochemical, and yield response of spinach to saline irrigation in hydroponic and soil-based systems. In a pot experiment, it was reported that salt stress considerably reduces spinach growth, yield and ionic response. Spinach can survive salinity stress up

to 4.0 dS m<sup>-1</sup> with an acceptable decrease of approximately one-fourth of its yield (Bhatti et al., 2021).

The spinach grown in a hydroponic system demonstrated a notable resilience to increased salinity, with some studies reporting a linear increase in fresh leaf weight as salinity rose, suggesting that hydroponic systems can buffer the negative impacts of saline irrigation more effectively than soil-based cultivation. This is likely due to improved osmotic adjustment and increased leaf succulence, which help maintain water status and growth under saline conditions (Leal et al., 2020). However, other researchers highlighted that although moderate salinity levels may not significantly reduce growth, higher salinity levels can drastically reduce plant height and overall growth (Suthar et al., 2025), though the number of leaves may remain unaffected (Dlamini and Masarirambi, 2020). These findings suggest that spinach can tolerate moderate salinity in a hydroponic system, but higher levels may restrict its growth.

Salinity not only affects growth but also alters the nutritional quality of spinach. Higher salt levels in irrigation water can decrease the concentrations of essential nutrients, beneficial metabolites, including flavonoids, amino acids, sugars, and phenolic compounds, which are important for both plant health and human nutrition (Kim et al., 2021; Suthar et al., 2025). While moderate salinity increases leaf Na<sup>+</sup> increases, K<sup>+</sup> remains relatively stable. Nonetheless, K<sup>+</sup> may also start declining at the higher concentrations.

## CONCLUSION

We conclude that saline water irrigation of up to an electrical conductivity value of 4.0 dS m<sup>-1</sup> may be suitable for spinach cultivation in hydroponic systems with a meager reduction in biomass. We recommend further studies to validate these findings.

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## AUTHOR CONTRIBUTIONS

JNJ conducted experiment and collected data; HSR designed and executed the study; LAB provided funding and logistic support; AHM and MAS processed data, developed graphs and validated results; IAJ analyzed data, reviewed literature and wrote first draft of the paper, ASR reviewed literature, formatted paper and done proof reading, ZHN: provided technical support and edited all drafts of manuscript as corresponding author.

## COMPETING OF INTEREST

The authors declared no conflicts of interest.

## REFERENCES

- Agrawal, R. K., Tripathi, M. P., Verma, A., Sharma, G. L., & Khalkho, D. (2020). Hydroponic systems for cultivation of horticultural crops: A review. *Journal of Pharmacognosy and Phytochemistry*, 9(6), 2083–2086.
- Arnon, D. I., & Hoagland, D. R. (1944). The investigation of plant nutrition by artificial culture methods. *Biological Reviews*, 19(2), 55–67.
- Bhatti, S. M., Gadehi, A. K., Rajpar, I., Kandhro, M. N., Soothar, M. K., & Bughio, Z. U. R. (2021). Effect of saline water on growth, yield and ions content in spinach genotypes. *Journal of Innovative Sciences*, 7, 78–87.
- Bux, R. K., Batool, M., Shah, S. M., Solangi, A. R., Shaikh, A. A., Haider, S. I., & Zia-ul-hassan. (2023). Mapping the spatial distribution of soil heavy metals pollution by principal component analysis and cluster analyses. *Water, Air, & Soil Pollution*, 234(6), 330.
- Bux, R. K., Haider, S. I., Batool, M., Solangi, A. R., Zia-ul-hassan, Karimi-Maleh, H., & Sen, F. (2022). Assessment of heavy metal contamination and its sources in urban soils of district Hyderabad, Pakistan using GIS and multivariate analysis. *International Journal of Environmental Science and Technology*, 19, 7901–7913.
- Dlamini, M. V., & Masarirambi, M. T. (2020). The response of fordhook giant / swisschard (*Beta vulgaris* var. *Cicla*) and mustard (*Brassica juncea*) spinach vegetables to irrigation with saline water. *Asian Journal of Advances in Agricultural Research*, 14(3), 20–26.
- FAO. (2021). *The State of the World's Land and Water Resources for Food and Agriculture – Systems at breaking point*. Food and Agriculture Organization of the United Nations.
- Hafeez, M. B., Raza, A., Zahra, N., Shaukat, K., Akram, M. Z., Iqbal, S., & Basra, S. M. A. (2021). Gene regulation in halophytes in conferring salt tolerance. In *Handbook of bioremediation* (pp. 341–370). Academic Press.
- Hirst, A. K., Anee, S. A., Housley, M. J., Qin, K., & Ferrarezi, R. S. (2024). Selected beneficial microbes alleviate salinity stress in hydroponic lettuce and pak choi. *HortTechnology*, 34(3), 345–352.

- Jamali, I. A., & Zia-ul-hassan. (2025). Zinc-induced plant resilience against abiotic stresses: Physiological, biochemical and molecular insights—A review. *Pakistan Journal of Agriculture*, 2(1), 27–36.
- Kim, B., Lee, H., Song, Y., & Kim, H. (2021). Effect of salt stress on the growth, mineral contents, and metabolite profiles of spinach. *Journal of the Science of Food and Agriculture*, 101(9), 3787-3794.
- Leal, L., Souza, E., Júnior, J., & Santos, M. (2020). Comparison of soil and hydroponic cultivation systems for spinach irrigated with brackish water. *Scientia Horticulturae*, 274, 109616.
- Machado, R. M. A., Alves-Pereira, I., & Ferreira, R. M. A. (2018). Plant growth, phytochemical accumulation and antioxidant activity of substrate-grown spinach. *Heliyon*, 4(8), e00751.
- Majeed, A., & Muhammad, Z. (2019). Salinity: a major agricultural problem—causes, impacts on crop productivity and management strategies. *Plant abiotic stress tolerance: Agronomic, molecular and biotechnological approaches*, 83-99.
- Massa, D., Incrocci, L., Botrini, L., Carmassi, G., Diara, C., Ili De Paoli, P., Incrocci, G., Maggini, R., & Pardossi, A. (2018). Modelling plant yield and quality response of fresh-market spinach (*Spinacia oleracea* L.) to mineral nitrogen availability in the root zone. *Italian Journal of Agronomy*, 13(3), 1120.
- Nawaz, I., Zia-ul-hassan, Ranjha, A.M., & Arshad, M. (2006). Exploiting genotypic variation among fifteen maize genotypes of Pakistan for potassium uptake and use efficiency in solution culture. *Pakistan Journal of Botany*, 38, 1689-1696.
- Mehra, P., & Bennett, M. J. (2022). A novel Ca<sup>2+</sup> sensor switch for elevated salt tolerance in plants. *Developmental Cell*, 57(17), 2045-2047.
- Rothwell, A., Ridoutt, B., Page, G., and Bellotti, W. (2016). Environmental performance of local food: trade-offs and implications for climate resilience in a developed city. *Journal of Cleaner Production*, 114, 420-430.
- Saddiq, M. S., Afzal, I., Iqbal, S., Hafeez, M. B., & Raza, A. (2021). Low leaf sodium content improves the grain yield and physiological performance of wheat genotypes in saline-sodic soil. *Pesquisa Agropecuária Tropical*, 51, e67663.
- Sapkota, S., Sapkota, S., & Liu, Z. (2019). Effects of nutrient composition and lettuce cultivar on crop production in hydroponic culture. *Horticulturae*, 5(4), 72.
- Sharma, N., Acharya, S., Kumar, K., Singh, N., & Chaurasia, O. P. (2018). Hydroponics as an advanced technique for vegetable production: An overview. *Journal of Soil and Water Conservation*, 17(4), 364-371.
- Suthar, J. D., Rajpar, I., Ganjegunte, G. K. & Zia-ul-hassan. (2018). Evaluation of Guar (*Cyamopsis tetragonoloba* L.) genotypes performance under different irrigation water salinity levels: Growth parameters and seed yield. *Industrial Crops and Products*, 123, 247-253.
- Suthar, J. D., Rajpar, I., Zia-ul-hassan, Ganjegunte, G. K., & Grover, K.K. (2025). Seedling emergence of guar (*Cyamopsis tetragonoloba* L.) genotypes and their growth under irrigation water salinity. *Agrosystems, Geosciences & Environment*, 8(2), e70130.
- Tareen, G. S., Shahid, T., Bibi, S., Hayee, A. A., & Shahzadi, A. K. (2025). Impact of Different Water Qualities on Germination and Seedling Growth of *Triticum aestivum*, *Hordeum vulgare*, *Coriandrum sativum*, and *Raphanus sativus*. *Pakistan Journal of Agriculture*, 2(1), 22-26.
- Vishandas, Zia-ul-hassan, Arshad, M., & Shah, A. N. (2006). Phosphorus fertigation at first irrigation due to its unavailability at sowing time prevents yield losses in (*Triticum aestivum* L.). *Pakistan Journal of Botany*, 38(5), 1439-1447.
- Zahra, N., Al Hinai, M. S., Hafeez, M. B., Rehman, A., Wahid, A., Siddique, K. H., & Farooq, M. (2022). Regulation of photosynthesis under salt stress and associated tolerance mechanisms. *Plant Physiology and Biochemistry*, 178, 55-69.
- Zia-ul-hassan & Arshad, M. (2006). Land degradation in Pakistan: A serious threat to environments and economic sustainability. *ECO Services International*. <https://www.eco-web.com/edi/060715.html>
- Zia-ul-hassan, Arshad, M., & Khalid, A. (2011). Evaluating potassium-use-efficient cotton genotypes using different ranking methods. *Journal of Plant Nutrition*, 34(13), 1957-1972.
- Zia-ul-hassan, Arshad, M., Basra, S. M. A., Rajpar, I., Shah, A. N., & Galani, S. (2014). Response of potassium-use-efficient cotton genotypes to soil applied potassium. *International Journal of Agriculture and Biology*, 16, 771-776.