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The Effect of Saltwater Stress on the Performance of Cherry Tomatoes

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Rising sea levels and saltwater intrusion in aquifers pose significant challenges for South Florida agriculture, leading to increased groundwater salinity and potential crop losses. Utilizing salt-tolerant crop species presents a potential solution for saline soils and regions with active saltwater intrusion. However, the effects of soil salinization through groundwater alone remains less studied. This research investigates the impact of short-term, below-ground saltwater stress on the growth, survival, and overall health of commonly grown cherry tomatoes (Solanum lycopersicum). The objectives of the study are to: 1) determine the impact of saline groundwater on tomato plant health and 2) compare the nutrient content of soil and tomato plant tissue exposed to varying concentrations of saline water. Established cherry tomato plants were exposed to varying concentrations of NaCl solution, simulating saltwater intrusion into groundwater. Over 28 days, plant height, leaf chlorophyll levels, and disease occurrences were monitored. It was found that the NaCl treatments did not significantly affect cherry tomato performance under the parameters of height, chlorophyll levels, or leaf nutrition when compared to the control group. This study suggests that cherry tomatoes can tolerate short-term exposure to NaCl in groundwater. Further exploration of more intense salt stress conditions from groundwater could be beneficial for utilizing this crop in areas with saline soils or polluted groundwater. Identification of salt-tolerant cherry tomato varieties can provide alternative crop options for non-arable land affected by high soil salinity.

Keywords: *salinity, salt tolerance, crop performance, saltwater intrusion, Florida agriculture*

Introduction

Groundwater serves as a crucial source of freshwater for coastal communities throughout the United States, especially in regions like Florida, which has an oceanic peninsular geography (Basack et al., 2022). In Florida, the majority of freshwater used is obtained from groundwater sources (Marella & Fanning, 2011). Agriculture accounts for a significant portion, approximately 39%, of the total water usage. However, this heavy reliance on groundwater has led to a pressing environmental issue: saltwater intrusion within the Florida aquifer system (Haque, 2023).

Saltwater intrusion occurs when seawater infiltrates freshwater aquifers, resulting in increased salinity levels and degradation of water quality (Salam & Sultana, 2022). The main factors contributing to this problem are climate change, human activity, sea-level rise, extreme weather events, and excessive pumping of groundwater (Salam & Sultana, 2022). The inland movement of saltwater not only affects groundwater but also leads to the deposition of salts in coastal soils, causing soil salinization. Coastal regions, such as Florida, heavily rely on groundwater as a vital freshwater source for both anthropogenic and agricultural activities (Marella & Fanning, 2011). Increasing saltwater intrusion into the Florida aquifer system due to climate change and human activities poses a growing environmental challenge as it could lead to soil salinization, adversely affecting crop production in these regions (Haque, 2023). The phenomenon of saltwater intrusion poses a significant challenge for agriculture as high levels of salts in the soil disrupt the nutrient balance, leading to plants absorbing sodium and chloride ions instead of essential nutrients like potassium (Shrivastava & Kumar, 2015). This, in turn, causes nutrient deficiencies and ion toxicity, negatively impacting crop production. Crops such as beans, which are not salt-tolerant, are particularly vulnerable, creating a need for long-term solutions to address the problem of increased soil salinization (Egea et al., 2023).

Global efforts have been underway since the 1950s to develop crops that can thrive in saline conditions, and recent trends have focused on integrated farm management practices tailored to specific environments (Negacz et al., 2021). One potential solution lies in the tomato crop, which exhibits mechanisms to combat salt stress, such as accumulating excess sodium in older leaves (Khelil et al., 2007). Given the substantial economic value of Florida's tomato production, which exceeded $300 million in 2022 (Huang et al., 2022), the development of salt-tolerant tomato varieties holds promise for protecting the state's agricultural industry amid increasing soil salinity.

Tomatoes, especially the cherry tomato variety, hold significant economic value in Florida, making it crucial to understand their responses to short-term below-ground saline water exposure for the development of sustainable agricultural practices in saline environments. Previous research indicates that cherry tomato varieties exhibit better salt tolerance than normal fruit varieties under certain conditions, owing to their ability to regulate osmotic balance and ion transport mechanisms (Khelil et al., 2007). However, the impacts of short-term saltwater exposure on cherry tomato growth and health warrant further investigation, as additional stressors like disease outbreaks could influence plant responses (Roșca et al., 2023). Moreover, exploring how plants adapt to varying salt concentrations and nutrient availability in the root zone could provide valuable insights into enhancing their resilience to salt stress (Negacz et al., 2021).

The goal of this study was to assess how short-term exposure to saltwater intrusion affects the immediate growth and health of cherry tomato plants, a common crop in Florida. The objectives of our study are to monitor the growth and physiology of tomato plants growing under salt stress and evaluate the macro- and micronutrient concentration in the treated soils and plants. The research is significant to South Florida because understanding the effects of salinization on tomato plants will provide valuable insights for developing strategies to enhance their salt tolerance and ensure the continued productivity of Florida's agricultural sector in the face of rising salinity levels.

Materials & Methods

Experimental Setup

Twenty cherry tomato plants were grown from seed for one month within the outdoor shade house of the FIU organic garden. Thirty days after sowing (DAS) the tomato plants were transplanted into three-gallon nursery pots and set on two raised platforms of at least 4 ft in height. Using containers atop platforms allowed us to exert better control over the experimental conditions. The plants were irrigated daily with a mix of rainwater and recycled well water, ensuring consistent hydration.

To simulate saltwater stress resulting from groundwater salinity, we set up 10 greenhouse trays, each capable of accommodating two pots, for a total of 20 pots. The experimental design included one control group and four treatment groups, each consisting of four plants. The treatment groups were exposed to increasing concentrations of salt, achieved by adding different amounts of 99% pure NaCl to the trays, calculated utilizing salinity formulas from the University of California (**Table 1**). The mass of NaCl added for group T2, T3, T4, and T5 was calculated from the ideal electric conductivity of 2 dS/M, 4 dS/M, 6 dS/M, and 8 dS/M, respectively using the formulae below.

- TDS (mg/L) = EC (dS/m) x 640 (EC from 0.1 to 5 dS/m)
- TDS (mg/L) = EC (dS/m) x 800 (EC > 5 dS/m)

Table 1

Electroconductivity of Tray Solutions

Treatment	NaCl Added (g/L)	Total Dissolved Solids (ppm 500 scale)
CT1	0	353.5
T2	128	1810
T3	256	3040
T4	481	3815
T5	64	4435

To ensure homogeneity, the salt solutions were thoroughly mixed until the salt dissolved completely. The electroconductivity (EC) for each tray solution was measured using an EC meter, and the measurements were recorded. The tomato pots were then placed in the trays and allowed to soak for six hours before being removed to drain. This approach, inspired by similar studies on canola crops (Hanley et al., 2020), aimed to mimic short-term below-ground salt exposure, reducing the risk of oxygen-deficiency and contamination across treatment groups. To minimize the impact of soil inundation, the selected trays were shallow, with a height of approximately 2.5 inches. The salt soak treatments were applied once on Week 1 and twice on Week 3, for a total of three salt treatments. At the end of the twenty-eight-day test period, each plant body was harvested for chemical analysis.

Data Collection

Plant Measurements

Before each salt treatment and on every week, the plant height and leaf chlorophyll concentrations of each plant were measured using a measuring tape and a SPAD-502 meter (Spectrum Technologies Inc. Aurora, IL, USA). The SPAD meter provides a quantifiable measure of leaf chlorophyll concentration, which is indicative of nitrogen deficiencies and overall plant health over time. At the beginning and end of the experiment, leaf spectral reflectance for each individual plant was recorded using a spectroradiometer (Spectral Evolution Inc., Haverhill, MA, USA). Leaf spectral reflectance provides valuable information on overall plant health and helps identify water-stressed plants (Sun et al., 2021).

Chemical Analysis

At the end of the experiment period, the entire shoot of each plant was harvested, dried, and ground up for subsequent analysis. Additionally, soil samples were collected from the top two inches of soil in 15 of the 20 pots (3 pots from each experimental group). The soil samples were air dried and sieved using a 2 mm sieve. The soil samples were then analyzed for percentages of essential plant nutrients such as carbon and nitrogen using inductively coupled plasma mass spectrometry (ICP-MS), TCN analyzer. ICP-MS is a powerful technique that enables the identification and measurement of elements within a sample, providing insights into soil quality and nutrient content beyond visual plant performance (Nageswaran et al., 2017).

Statistical Analysis

The collected data was subjected to statistical analysis using Minitab software (version 21). One-way analysis of variance (ANOVA) was conducted to compare the mean values of plant height, leaf chlorophyll concentration, and leaf spectral reflectance among the control group and the treatment groups (T2, T3, T4, and T5) at a 5% confidence level. The Tukey's test was performed for multiple comparisons if the ANOVA results indicated significant differences between the groups. Similarly, ANOVA was applied to assess variations in cation exchange capacity (CEC) and nutrient concentration among the soil samples from different treatment groups, and the Tukey's test was used to identify specific differences.

Results

Plant Measurements

Statistical analysis using Minitab software revealed no significant effect of the saltwater treatments on observed plant height and leaf chlorophyll concentrations (**Figures 1** & **2**). However, during Week 3, there was a sudden decline in plant health while early leaf blight disease, marked by distinct brown, necrotic bull-seye lesions and leaf yellowing occurred.

Figure 1

Effect of Salt Concentration on Plant Height

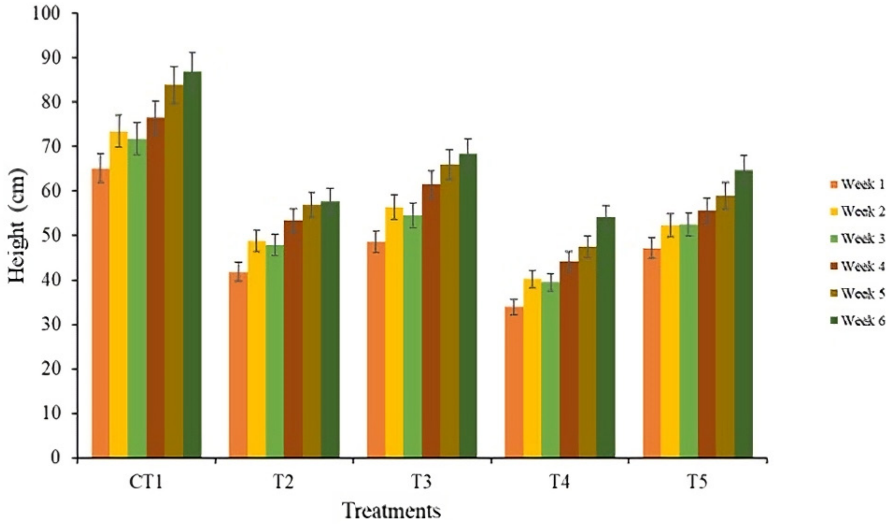


Figure 2

Effect of salt concentration on chlorophyll concentration (SPAD value)

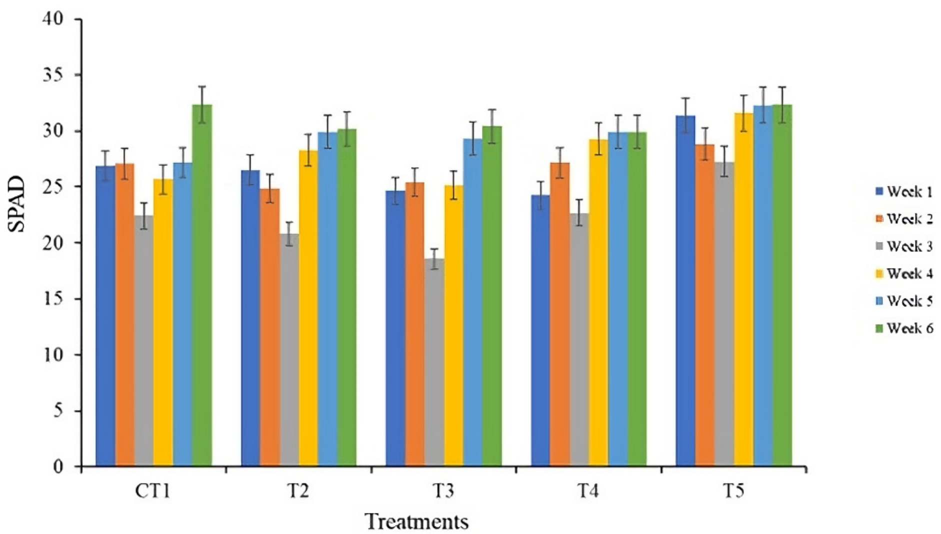


Table 2

Results of the Tukey's Test for plant nutrients

Treatment	N (%)	Ca (%)	K (%)	Mg (%)	P* (%)	S (%)	B* (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Na (%)
CT1	1.76 (±0.12)	1.55 (±0.28)	4.16 (±0.28)	0.55 (±0.03)	0.75 (±0.09) ab	0.38 (±0.04)	26.66 (±3.81) ab	64.53 (±8.89)	17.27 (±1.09)	77.2 (±29.2)	4.74 (±1.129)	0.045 (±0.006)
T2	1.90 (±0.95)	1.44 (±0.127)	3.74 (±0.68)	0.470 (±0.11)	0.63 (±0.16) b	0.28 (±0.05)	19.07 (±3.94) b	60.6 (±33.2)	14.72 (±1.71)	63.22 (±19.87)	4.88 (±1.345)	0.060 (±0.0159)
T3	1.72 (±0.56)	2.37 (±0.66)	3.99 (±0.31)	0.68 (±0.28)	0.83 (±0.36) a	0.47 (±0.20)	31.16 (±8.85) a	54.92 (±9.78)	20.46 (±6.74)	76.8 (±51.3)	6.32 (±2.19)	0.048 (±0.02)
T4	2.29 (±0.17)	2.15 (±0.22)	4.04 (±0.38)	0.754 (±0.04)	0.99 (±0.09) ab	0.52 (±0.06)	26.76 (±1.06) ab	52.65 (±3.3)	21.78 (±1.06)	99.12 (±19.6)	7.4 (±2.74)	0.123 (±0.03)
T5	1.85 (±0.37)	2.47 (±0.41)	4.47 (±0.15)	0.74 (±0.08)	0.89 (±0.04) a	0.46 (±0.06)	26.06 (±3.16) ab	52.04 (±0.79)	17.24 (±2.08)	82.39 (±18.85)	6.93 (±2.88)	0.110 (±0.018)

Note: Elements with asterisk have means that are significantly different.

Table 3

Results for Soil nutrients

Treatment	pH	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)	Zn (ppm)	Na (ppm)	OM (%)	CEC
CT1	7	0.888 (±0.015)	289.08 (±16.72)	671.5 (±116.7)	17469 (±30.1)	1031.5 (±63)	13.98 (±0.71)	132.9 (±23.8)	27.87 (±2.28)	97.661 (±0.966)
T2	7	0.936 (±0.08)	287.45 (±12.79)	690.9 (±61.2)	17480 (±52.3)	1015.1 (±47.5)	13.822 (±0.467)	135.52 (±11.48)	30.51 (±2.48)	97.63 (±0.793)
T3	7	0.948 (±0.10)	287.82 (±7.91)	739 (±106.7)	17506 (±18.5)	1058.6 (±18.4)	14.333 (±0.318)	153.5 (±30.2)	32.01 (±4)	98.244 (±0.32)
T4	7	0.850 (±0.09)	292.88 (±9.21)	701.6 (±100.3)	17551 (±11.9)	1063.6 (±11)	14.4 (±0.531)	163.85 (±13.26)	27.74 (±4.18)	98.419 (±0.35)
T5	7	0.889 (±0.06)	293 (±26.2)	738 (±322)	17534 (±49)	1066.7 (±75.4)	14.188 (±0.284)	174.5 (±81.9)	29.559 (±1.673)	98.452 (±1.499)

Intriguingly, a significant difference in the percentage of phosphorus was found between the T2 test group versus the T3 and T5 test group in plant shoot tissue, as revealed by the Tukey's test (**Table 2**). However, no significant difference was observed in soil nutrient concentration, pH, and other measured parameters among the experimental groups (**Table 3**). Additionally, the plant to soil nutrient ratios were calculated to assess nutrient uptake and adaptation to salt exposure within the root zone, and the nutrient ratio for Ca was found to be less than one for experimental groups CT1 and T2 (**Table 4**).

Table 4

Calculated plant to soil nutrients ratio.

Treatment	N	P	K	Ca	Mg	Na	Zn
CT1	1.98	26.08	62.00	0.89	5.33	3.42	5.52
T2	2.03	22.12	54.22	0.82	4.64	4.45	4.57
T3	1.82	29.12	54.07	1.35	6.42	3.15	5.36
T4	2.70	34.09	57.58	1.23	7.10	7.54	6.88
T5	2.08	30.40	60.63	1.41	6.99	6.35	5.81

Regarding leaf spectral reflectance, the control group exhibited significantly lower reflectance within the range of interest (350-650 nm) compared to the other experimental groups (**Figures 3** & **4**). Further analysis of the Green Normalized Difference Vegetation Index (GNDVI) indicated a significant increase in GNDVI for all experimental groups at the end of the experiment, suggesting an increase in photosynthetic activity despite salt stress. However, no significant relationship was found between water salinity and GNDVI (**Figure 5**).

Figure 3

Spectral Reflectance of Tomatoes Before Salination

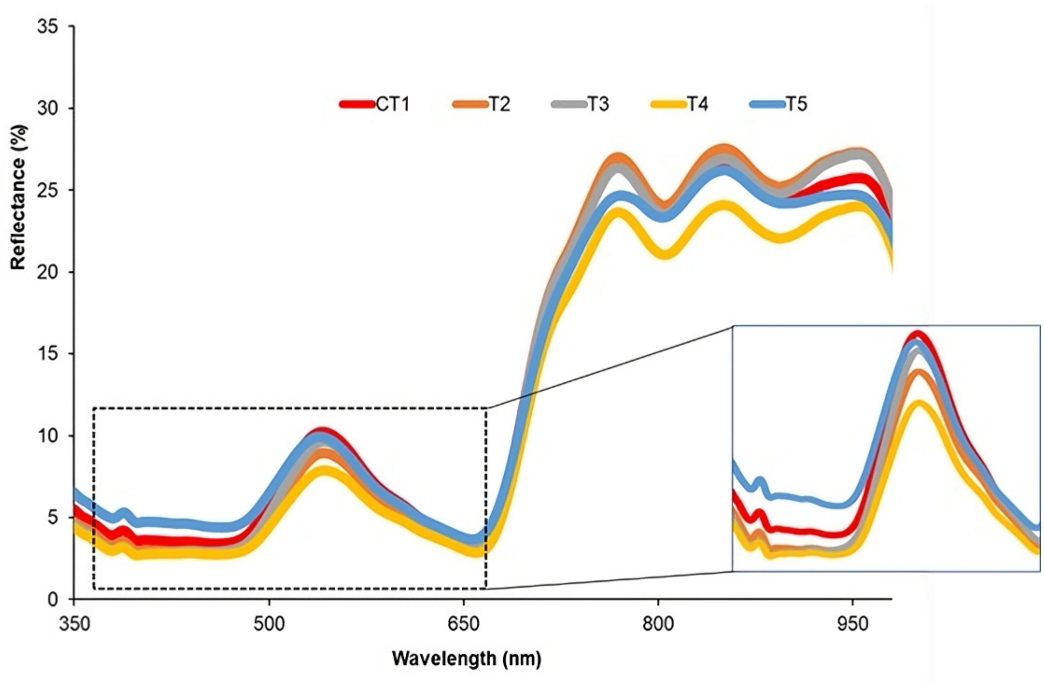


Figure 4

Spectral Reflectance of Tomatoes After Salination

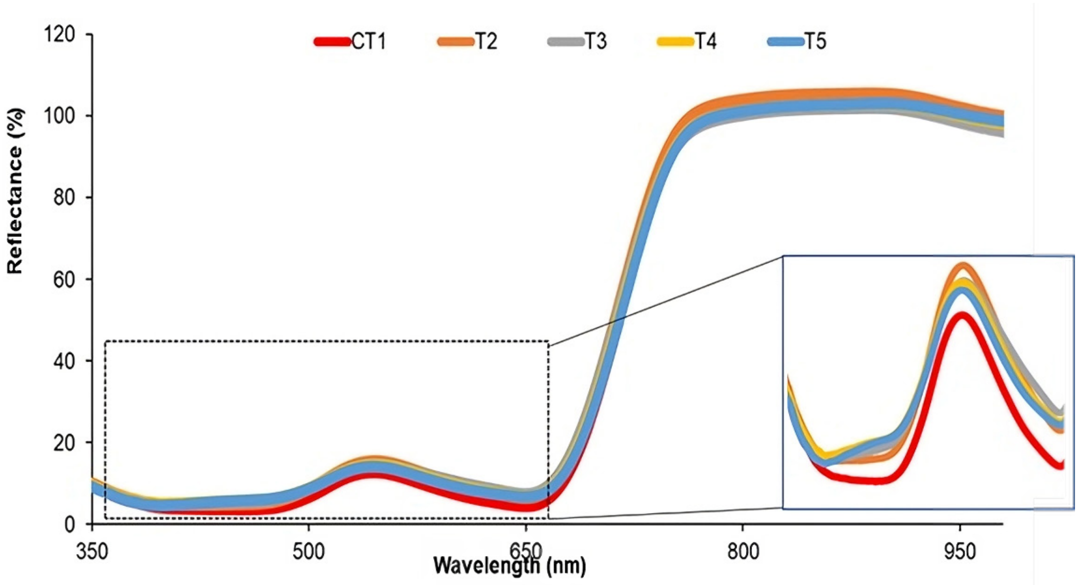
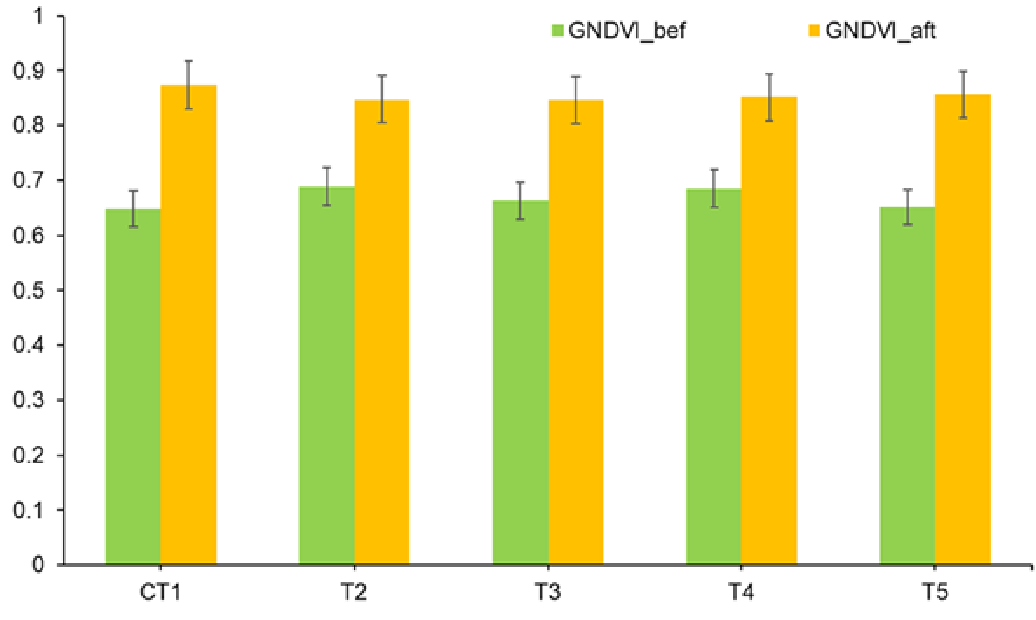


Figure 5

GNDVI Spectral Indices Before and After Salination



Discussion

Plant Measurements

Valuable insights are provided by the findings presented in this study on the impact of short-term below-ground saline water exposure on cherry tomato plants. The observed lack of significant effects on plant height and leaf chlorophyll concentrations suggests that cherry tomato plants exhibit a certain level of tolerance to the tested salt concentrations. This resilience could be attributed to the cherry tomato's ability to regulate osmotic balance and ion transport mechanisms, enabling the plants to maintain their growth and physiological functions under mild salt stress conditions (Munns & Tester, 2008). The findings of this study agree with those of Guo et al. (2022) although Silva et al. (2022) found that salinity affected chlorophyll content and biomass production in cherry tomatoes. However, the unexpected decline in plant health during the third week, coinciding with early leaf blight disease, raises important questions about the interactions between salt stress and disease development (Chourasia et al., 2022). This could be due to the fact that salt stress can possibly weaken the plant's immune system and make it more susceptible to disease (Mustapha et al., 2023). Further research is required to better understand and manage the implications of such interactions on tomato crop management.

Chemical Analysis

The significant difference in phosphorus levels in plant shoot tissue between certain treatment groups highlights the plants' response to the varying salt concentrations. Phosphorus is essential for various biochemical processes, including energy transfer and DNA synthesis, and its altered availability under salt stress may impact plant growth and overall health (Dey et al., 2021). In a study by Loudari et al. (2022), the researchers found that salt stress reduced the uptake and transport of phosphorus in plants, leading to phosphorus deficiency and impaired plant growth; in our study, the phosphorus concentrations increased instead. Therefore, understanding the specific mechanisms underlying this differential response to phosphorus could inform targeted fertilizer application strategies and enhance the plants' nutrient-use efficiency in saline environments.

Interestingly, no significant differences were observed in soil nutrient concentration and other measured parameters among the experimental groups, indicating that short-term saltwater exposure did not exert a pronounced effect on the analyzed soil properties. However, the nutrient ratio results for Calcium revealed differences in nutrient uptake patterns and adaptation strategies among the experimental groups. The plants in groups CT1 and T2 exhibited nutrient ratios below one, indicating that they might have experienced limitations in Calcium uptake under the prevailing salt stress conditions. Calcium is crucial for cell wall integrity, signaling pathways, and enzymatic activities, and its deficiency could affect plant cell functions and overall health (White & Broadley, 2003). Developing tailored soil amendments or calcium application strategies could help improve calcium availability and enhance the resilience of cherry tomato plants to salt stress.

Spectral Reflectance

The observations related to leaf spectral reflectance provide valuable information about the plants' response to salt stress and potential changes in their overall health. The significantly lower reflectance within the range of interest in the control group could be indicative of early stress responses, such as changes in leaf pigments and cellular structures (El-Hendawy et al., 2021). Furthermore, the increase in spectral reflectance with salt concentration as observed in the study agrees with findings by Papadimitriou et al. (2022) and this spectral reflectance can be used as an early indicator of salt stress (Katsoulas et al., 2016; Papadimitriou et al., 2022). This is further evidenced by the significant increase in GNDVI across all experimental groups at the end of the experiment suggests that the plants exhibited vegetative growth despite exposure to saltwater treatments. These findings suggest that cherry tomato plants may possess mechanisms to mitigate the adverse effects of salt stress on their physiological processes.

Conclusion

This study provides insight into the responses of cherry tomato plants to short-term below-ground saline water exposure and its implications for agricultural practices in potentially saline environments. Understanding the mechanisms for short-term salt exposure acts as the foundation for understanding long term exposures and warrants future investigations as tomatoes in field conditions will be exposed to long-term salt concentrations rather than short-term.

The results demonstrate the cherry tomato's tolerance to mild salt stress, as evidenced by the lack of significant effects on plant height and leaf chlorophyll concentrations. However, the unexpected decline in plant health during the third week, coinciding with early leaf blight disease, calls for further investigation into the interactions between salt stress and disease development. The differential response of cherry tomato plants to varying salt concentrations in terms of phosphorus levels highlights their ability to adapt to changing environmental conditions. Understanding these mechanisms could guide targeted nutrient management strategies. The findings emphasize the importance of considering short-term and localized salt stress effects on crop performance and the potential benefits of selecting salt-tolerant cherry tomato varieties for cultivation in saline environments. Ultimately, thisThis research contributes to the broader goal of developing resilient agricultural practices to ensure food security in the face of global climate change.

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