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MODULATION OF MORPHOLOGICAL AND PHYSIOLOGICAL TRAITS IN SALT-STRESSED ACID LIME (*CITRUS AURANTIFOLIA* SWINGLE) BY BENEFICIAL MICROBIAL INOCULANTS

Jyoti Sengar[1]*, S. K. Pandey[1], Garima Yadav[1], Anjali Sharma[1] and Pragya Singh[2]

[1]Department of Horticulture, College of Agriculture, JNKVV, Jabalpur (M.P.), India
[2]Department of Horticulture, College of Agriculture, RVSKVV, Gwalior (M.P.), India
*Corresponding author E-mail: jyotisengar0602@gmail.com

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ABSTRACT

Soil salinity imposes a severe threat to the plants and beneficial microbes can be a great choice to manage salt stress in acid lime (*Citrus aurantifolia* Swingle). Inoculation of *Bacillus subtilis*, *Pseudomonas fluorescens* and *Trichoderma viride* were used to evaluate their effect on different attributes of acid lime under artificially induced salt stress. Stress reduced shoot, root, seedling length. On the other hand, the root/shoot decreased due to salt stress as compared to non-inoculated seeds. *Pseudomonas fluorescens* followed by *Bacillus subtilis* and *Trichoderma viride* improved these different attributes and maintained a better growth and development of the acid lime plants. Salt stress also influenced the shoot, root and leaf fresh and dry weight too. The weight got decreased, while microbes still maintained a better shoot, root and leaf fresh and dry weight. Our findings suggest that these different microbial inoculants have the potential to manage salt stress in acid lime (*Citrus aurantifolia* Swingle).

***Key words*: Acid lime, growth, microbes, salinity.**

Introduction

In spite of the technological innovations in agriculture, which dramatically increased food production in the past few decades (Godfray *et al.*, 2010), food security globally is being challenged by several factors including climate change. Large tracts of land have become unproductive or less productive due to soil salinization alone. A worldwide and ever-changing issue, soil salinization is expected to worsen in the future due to climate change scenarios, such as rising sea levels and their effects on coastal regions, rising temperatures and increased evaporation, etc. There are no precise statistics on the most recent estimates of the global extent of soils damaged by salt, and the information provided by various data sources varies (Shahid *et al.*, 2018). India's salt-affected soils are on the rise, endangering both the country's economic growth and food security. Being citrus is one of the most important fruit crops in the world and India as well, are going to be affected adverse heavily because citrus is one of the most sensitive crops to soil salinity. So, there is a need to consider the problem of soil salinity in terms of citrus. Cations (sodium (Na^+), calcium (Ca^{+2}), and magnesium (Mg^{+2}) and anions (chloride (Cl^-), sulfate (SO_4^{-2}), and bicarbonate (HCO_3^-) are among the inorganic dissolved salts found in saline soils. These ions create an electrical field in the solution, which causes the salt concentration and the water's electrical conductivity (EC) to correlate linearly (Grattan *et al.*, 2015). Fruit yields is dropped by almost 13% for every 1.0 dS m^{-1} increase in ECs above the previous records of the threshold for EC (saturated-soil, ECs) in citrus, which was approximately 1.4 dS m^{-1} (Maas *et al.*, 1993). It is common for hazardous concentrations of Na^+ and Cl^- ions to build up inside plant cells. Cl^- ions contribute to the harmful effects of leaf abscission, growth halt, and necrosis in citrus (Li *et al.*, 2020). Fruit yield is dropped by almost 13% for every 1.0 dS m^{-1} increase in ECs above the previous records of the threshold for EC (saturated-soil, ECs) in citrus, which was approximately 1.4 dS m^{-1} (Maas *et al.*, 1993). In order to minimize leaf ion toxicity and preserve leaf water, turgor, and photosynthesis, plants react to salt stress by raising the root/canopy ratio, chlorophyll content, and causing changes in the leaf anatomy (Acosta-Motos *et al.*, 2015). One of the sustainable methods for enhancing acid lime seedling health under salt stress is the use of beneficial microbes. PGPR participates in the following activities:

(i) soil nutrient mobilization;

(ii) plant growth regulator production;

(iii) phytopathogenic attack control;

(iv) systemic resistance induction;

(v) soil structure improvement; and

(vi) remediation of polluted soil.

Endophytic fungi have been shown to enhance plant growth under stress, in addition to the well-known mycorrhizal fungi and plant-growth-promoting rhizobacteria. Through improved root growth, nutrient uptake, and protection against oxidative damage, *Trichoderma* strains (endophytic fungi) increase a plant's resistance to biotic and abiotic conditions such drought and salinity (Mastouri *et al.*, 2010; Shoresh *et al.*, 2010). So, the aim of this study is to understand the effect of beneficial microbes on the different attributes of acid lime seedling under various levels of salt stress.

Material and Methods

At the College of Agriculture, Jabalpur, JNKVV, Jabalpur (M.P.), the experiment was conducted in 2023. The experiment was designed using a two-factorial, totally randomized design. The effectiveness of *Trichoderma viride*, *Pseudomonas fluorescens*, and *Bacillus subtilis* in managing salt stress in acid lime was evaluated. The microbial cultures were taken from Microbe Research & Production Centre situated at JNKVV, Jabalpur (M.P.). The design of the experiment was 2 factorial completely randomized design (CRD). The polyethylene bags of 6×8 inch was filled with a general composition soil, vermicompost and sand. The growing mixture weighed one kg in each bag. The sterilized seeds were dipped for nine hours in the different microbial cultures then sowed in the polyethylene bags in the net house. 2 months old seedlings with equal health and height were chosen for further experiment from every microbial inoculated pot. These pots were then treated with different salt solutions. The concentration of salt solution was gradually increased to avoid sudden osmotic shock. Then ultimately the plants were watered with 0, 3 and 6 dS m^{-1} EC. The doses were applied for 8 weeks. The plants were watered twice in a week with 150ml solution. Then the plants were evaluated for different traits.

The total 12 different treatments were applied, which are as follows: T_1- 0 dS m^{-1}EC× No inoculation, T_2- 3 dS m^{-1}EC × No inoculation, T_3- 6 dS m^{-1}EC × No inoculation, T_4- 0 dS m^{-1}EC ×*B. subtilis*, T_5- 3 dS m^{-1}EC × *B. subtilis*, T_6- 6 dS m^{-1}EC × *B. subtilis*, T_7- 0 dS m^{-1}EC × *P. fluorescens*, T_8- 3 dS m^{-1}EC × *P. fluorescens*, T_9- 6 dS m^{-1}EC × *P. fluorescens*, T_{10}- 0 dS m-1EC ×*T. viride*, T_{11}- 3 dS m^{-1}EC ×*T. viride*, T_{12}- 6 dS m^{-1}EC ×*T. viride*

Shoot length

The shoot length was observed at the end of the experiment. After carefully removing the seedlings from the polyethylene bags, extra water was blotted out with tissue paper. The seedlings were then put on the sterile laboratory bench. For the purpose of measuring shoot length, five seedlings were selected from each replication of each treatment. Thus, it is possible to measure shoot length at the same time. The 30-cm ruler was used to measure the shoot's length. It was measured from the shoot's base, or cotyledon node, to its tip. Centimetres (cm) were used to measure the shoot length.

Root length

The same plants were utilized to measure the root length after the shoot length was determined. On the lab bench, the roots were spread out completely—not coiled

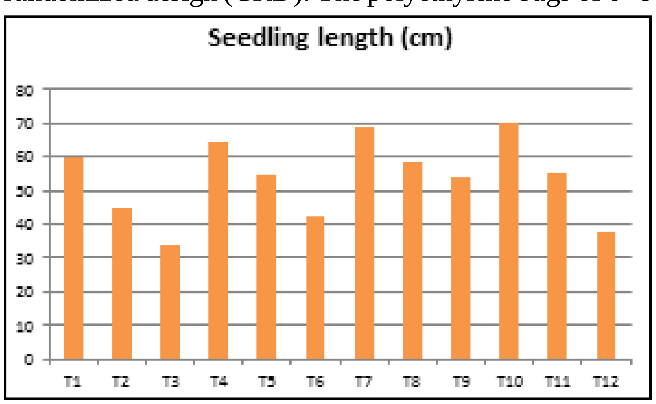

Fig. 1: Effect of different treatments on seedling length.

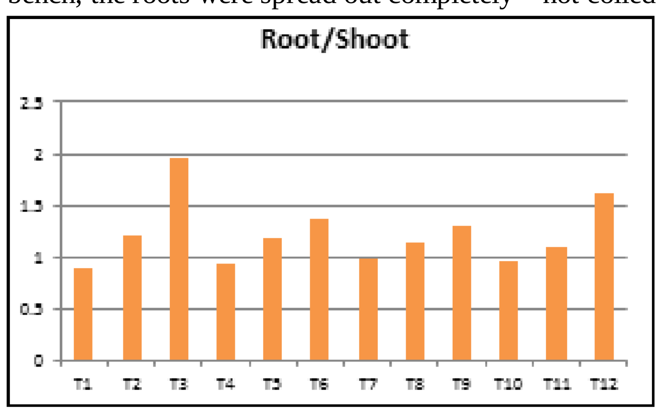

Fig. 2: Effect of different treatments on Root/Shoot.

or knotted. From the collar, where the shoot and root meet and the tip of the longest root were used to measure the root's length. Centimeters (cm) were used to measure the root length.

Root/Shoot

Root/shoot was calculated by dividing the root length by shoot length.

Seedling length

Seedling length was calculated by measuring the overall length including shoot and root length. The unit of seedling length is also cm.

Shoot, Leaf & Root Fresh weight

By separating root and shoot of the plant, the shoot and root was measured individually through using weighing balance in the lab. The leaves were plucked from the shoot and weighed. The fresh weight was noted in g.

Shoot, Leaf & Root Dry weight

After taking the shoot, root & leaves fresh weight, the samples were kept in different envelops. These envelops were kept in the hot air oven at 60–70°C until the plants weight became constant. Then the samples were weighed on a weighing balance.

Staistical analysis

The collected data are presented as the means of the three replicates. One way analysis of variance (ANOVA) was used to determine significantly significant differences between the means of treatments according to Least significance difference test. The statistical analysis was done by using excel.

Results

Shoot length

Shoot length decreased significantly when the stress increased. *T. viride* had longest shoot (35.58 cm) under no stress, followed by *P. fluorescens* (34.75 cm) and *B. subtilis* (33.28 cm). The plants which were not treated with microbes had shortest shoot length (31.40 cm) even under no stress situation. Then shoot length further reduced to 20.43 cm at moderate stress and ultimately to 11.40 cm at highest stress and were the shortest shoot length at every level of salt stress. Where, microbes outperformed even at highest EC. The results show that the microbes especially, *P. fluorescens* was able to maintain the shoot length at highest EC in acid lime, resulting in a shoot length almost double that of the un-inoculated control (T_3). The stem growth was also found to be enhanced by the use of *P. fluorescens* under salinity in pomegranate (Ahmadi *et al.*, 2024). *B. subtilis* (T_6) also showed a good improvement, while *T. viride* (T_{12}) provided some benefit but less than the other two inoculants at this stress level.

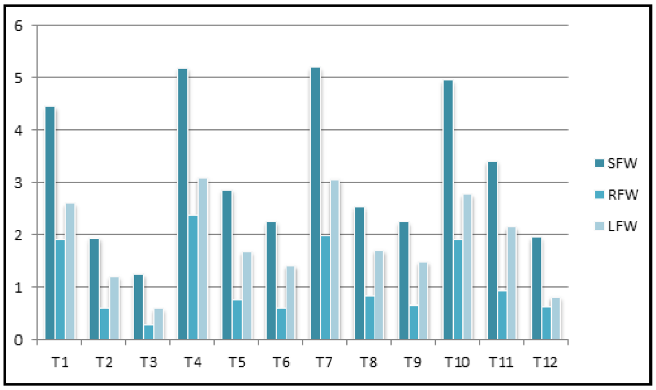

Fig. 3: Effect of different treatments on shoot, root and leaf fresh weight in acid lime.

Table 1: Effect of different treatments on shoot, root, seedling length and Root/Shoot in acid lime.

Treatments	A	B	C	D
T_1	31.40	28.21	59.61	0.90
T_2	20.43	24.53	44.95	1.20
T_3	11.40	22.28	33.68	1.96
T_4	33.28	31.32	64.60	0.94
T_5	25.25	29.53	54.78	1.18
T_6	17.80	24.4	42.20	1.37
T_7	34.75	34.14	68.89	0.99
T_8	27.30	31.36	58.66	1.15
T_9	23.50	30.32	53.82	1.29
T_{10}	35.58	34.32	69.91	0.96
T_{11}	26.40	28.76	55.16	1.10
T_{12}	14.50	23.2	37.70	1.61
SE(m)±	**0.68**	**0.99**	**1.31**	**0.05**
C.D. (P=0.05)	**1.93**	**2.83**	**3.72**	**0.13**
C.D. (P=0.01)	**2.57**	**3.77**	**4.97**	**0.18**

A: Shoot length (cm); **B:** Root length (cm); **C:** Seedling length (cm); **D:** Root/Shoot

Root length

Similar to shoot length, root length generally decreased with increasing salinity, though the reduction was less drastic in some inoculated treatments. All

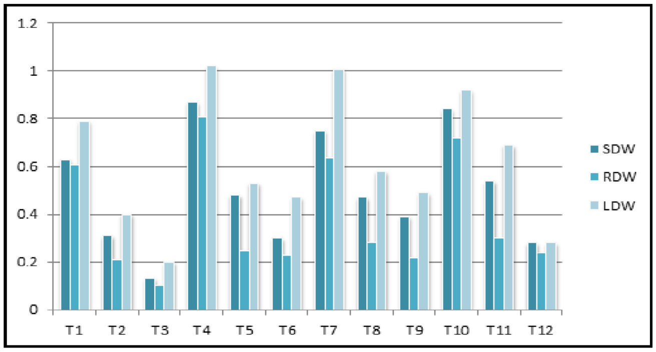

Fig. 4: Effect of different treatments on shoot, root and leaf dry weight in acid lime.

Table 2: Effect of different treatments on shoot, root and leaf fresh weight in acid lime.

Treatments	Shoot fresh weight (g)	Root fresh weight (g)	Leaf fresh weight (g)
T_1	4.45	1.90	2.60
T_2	1.94	0.61	1.22
T_3	1.26	0.29	0.60
T_4	5.19	2.39	3.09
T_5	2.87	0.76	1.69
T_6	2.26	0.60	1.42
T_7	5.20	1.98	3.07
T_8	2.54	0.83	1.72
T_9	2.25	0.65	1.49
T_{10}	4.95	1.92	2.78
T_{11}	3.42	0.924	2.16
T_{12}	1.95	0.626	0.82
SE(m)±	**0.10**	**0.03**	**0.05**
C.D. (P=0.05)	**0.28**	**0.08**	**0.16**
C.D. (P=0.01)	**0.38**	**0.10**	**0.21**

Table 3: Effect of different treatments on shoot, root and leaf dry weight in acid lime.

Treatments	Shoot dry weight (g)	Root dry weight (g)	Leaf dry weight (g)
T_1	0.63	0.61	0.79
T_2	0.31	0.21	0.40
T_3	0.13	0.10	0.20
T_4	0.87	0.81	1.02
T_5	0.48	0.25	0.53
T_6	0.30	0.23	0.47
T_7	0.75	0.64	1.01
T_8	0.47	0.28	0.58
T_9	0.39	0.22	0.49
T_{10}	0.84	0.72	0.92
T_{11}	0.54	0.30	0.69
T_{12}	0.28	0.24	0.28
SE(m)±	**0.02**	**0.01**	**0.02**
C.D. (P=0.05)	**0.04**	**0.04**	**0.05**
C.D. (P=0.01)	**0.06**	**0.05**	**0.79**

inoculations significantly promoted root growth under non-saline conditions, with *P. fluorescens* (T_7) (34.32 cm) and *T. viride* (T_{10}) (34.14 cm) showing the most significant enhancement. Under moderate salinity, all inoculants considerably improved root length compared to the control (T_2). *P. fluorescens* (T_8) (31.36 cm) and *B. subtilis* (T_5) (29.53 cm) were particularly effective in maintaining root growth. At high salinity, *P. fluorescens* (T9) (30.32 cm) demonstrated a remarkable ability to sustain root length, showing the highest root length under severe stress conditions. *B. subtilis* (T_6) (24.4 cm) and *T. viride* (T_{12}) (23.2 cm) also provided some protection, but to a lesser extent than *P. fluorescens*.

Seedling length

Seedling length, being the sum of shoot and root length, followed a similar pattern of decrease with increasing salinity. *P. fluorescens* (T_7) and *T. viride* (T_{10}) significantly enhanced total seedling growth in non-saline conditions. All inoculants significantly improved seedling length under moderate salinity, with *P. fluorescens* (T_8) being the most effective in promoting overall growth. Under high salinity, *P. fluorescens* (T_9) provided the most substantial improvement in seedling length, demonstrating its strong potential in mitigating severe salt stress. *B. subtilis* (T_6) also offered considerable protection.

Root/shoot

Root/shoot continuously increased with the increase in salt concentration increases. It shows that the shoot length was more affected by the salt than the root length, which ultimately leads to higher root/shoot. Under moderate stress, non-inoculated plants had the most root/shoot (1.20) while, *T. viride* had the least (1.10), showing least change as compared to *T. viride* (0.96) inoculated plants in non-saline conditions. The uninoculated plants had the highest root/shoot (1.96) at 6 ds $m^{-1,}$ while *P. fluorescens* showed the least root/shoot showing more balanced growth under severe stress. The results show that microbes helped plants to maintain better resource allocation.

Shoot fresh weight

Shoot fresh weight significantly declined with increasing salinity, but microbial inoculation mitigated this effect. The highest shoot fresh weight was observed in T_7 (*P. fluorescens*, 0 dS m^{-1}) at 5.20 g, followed very closely by T_4 (*B. subtilis*, 5.19 g) and T_{10} (*T. viride*, 4.95 g). These values were all higher than the uninoculated control T_1 (4.45 g), indicating a growth-promoting effect of microbial inoculation even under non-saline conditions. At 3 dS m^{-1}, T_5 (*B. subtilis*: 2.87 g), T_8 (*P. fluorescens*: 2.54 g), and T_{11} (*T. viride*: 3.42 g) outperformed the uninoculated saline treatment T_2 (1.94 g). Similarly, at 6 dS m^{-1}, T_6 (B. subtilis: 2.26 g), T_9 (*P. fluorescens*: 2.25 g), and T_{12} (*T. viride*: 1.95 g) showed much better performance than the uninoculated T3 (1.26 g), with values nearly doubled.

Root fresh weight

Root fresh weight followed a similar pattern. The highest root fresh weight (2.39 g) was recorded in T_4 (*B. subtilis*, 0 dS m^{-1}), followed by T_7 (*P. fluorescens*: 1.98 g), and T_{10} (*T. viride*: 1.92 g). These values were significantly higher than T_1 (1.90 g), suggesting that beneficial microbes enhance belowground biomass even under optimal conditions. At 3 dS m⁻¹, root fresh weight improved in inoculated treatments (T_5: 0.76 g, T8: 0.83 g, T_{11}: 0.924 g) compared to T_2 (0.61 g). At 6 dS m^{-1}, while a general decline was observed, T_6 (0.60 g), T9 (0.65 g), and T_{12} (0.626 g) performed better than the uninoculated control T_3 (0.29 g).

Leaf fresh weight

Leaf fresh weight was also influenced by both salinity and microbial treatment. The maximum leaf fresh weight was recorded in T_4 (*B. subtilis*, 3.09 g) and T_7 (*P. fluorescens*, 3.07 g), followed by T_{10} (*T. viride*, 2.78 g), all higher than the uninoculated control T_1 (2.60 g). Under 3 dS m^{-1}, inoculated treatments (T_5: 1.69 g, T_8: 1.72 g, T_{11}: 2.16 g) were significantly better than the uninoculated T_2 (1.22 g). At 6 dS m^{-1}, microbial inoculation again helped retain higher leaf fresh weight—T_6 (1.42 g), T_9 (1.49 g), and T_{12} (0.82 g) all performed better than T_3 (0.60 g).

Shoot dry weight

Shoot dry weight was significantly influenced by salinity levels and microbial inoculation. The highest shoot dry weight (0.87 g) was recorded in T_4 (0 dS m^{-1} × *B. subtilis*), followed closely by T_{10} (0.84 g; 0 dS m^{-1} × *T. viride*), and T_7 (0.75 g; 0 dS m^{-1} × *P. fluorescens*), all of which were significantly superior to the uninoculated control (T_1: 0.63 g). As salinity increased to 3 and 6 dS m^{-1}, shoot dry weight declined across all treatments. At 6 dS m^{-1}, microbial inoculation still provided mitigation: T_6 (*B. subtilis*) and T_9 (*P. fluorescens*) showed higher shoot dry weights (0.30 g and 0.39 g, respectively) compared to the non-inoculated control T_3 (0.13 g). *Trichoderma viride* at 6 dS m^{-1} (T_{12}) was less effective, yielding only 0.28 g.

Root dry weight

Root dry weight followed a similar trend. The maximum root dry weight (0.81 g) was again observed in T_4 (*B. subtilis*, 0 dS m^{-1}), followed by T_{10} (*T. viride*, 0.72 g), and T_7 (*P. fluorescens*, 0.64 g). Under salt stress, microbial inoculants improved root dry weight compared to non-inoculated treatments. At 3 dS m^{-1}, inoculated treatments like T_5 (*B. subtilis*: 0.25 g), T_8 (*P. fluorescens*: 0.28 g), and T_{11} (*T. viride*: 0.30 g) outperformed the non-inoculated T_2 (0.21 g). At 6 dS m^{-1}, *B. subtilis* (T_6) and *T. viride* (T_{12}) had similar root dry weights (0.23–0.24 g), while *P. fluorescens* (T_9) showed slightly lower performance (0.22 g) but was still better than the uninoculated T_3 (0.10 g).

Leaf dry weight

The pattern of leaf dry weight mirrored that of shoots and roots. The highest leaf dry weight was observed in T_4 (*B. subtilis*, 1.02 g), followed closely by T_7 (*P. fluorescens*, 1.01 g) and T_{10} (*T. viride*, 0.92 g). In contrast, T_3 (6 dS m^{-1} without inoculation) recorded the lowest value (0.20 g). Microbial inoculation helped retain leaf biomass under salt stress. At 3 dS m^{-1}, T_5 (0.53 g), T_8 (0.58 g), and T11 (0.69 g) all performed better than T_2 (0.40 g). At 6 dS m^{-1}, *P. fluorescens* (T_9: 0.49 g) and *B. subtilis* (T_6: 0.47 g) were more effective than *T. viride* (T_{12}: 0.28 g), though all were superior to the uninoculated control (T_3: 0.20 g).

Discussion

According to reports, plants under salt stress have nutritional and osmotic imbalances, which lower photosynthesis and ultimately impede plant development (Pandit *et al.*, 2024). Studies have already shown that salinity, not only reduce shoot length, it reduces root biomass too in citrus (Al-Yassin *et al.*, 2004). Significant morphological changes in the responses of plant development can result from excessive salt in the soil also. The escalation in osmotic stress and decreased cell water content can be the reason for the reduction in the shoot length (Souri *et al.*, 2021). Xi *et al.*, 2022 found the same effect of salt stress on root dry weight, shoot dry weight and root/shoot in *Juglans microcarpa* L. Different salinity dosages were found to have a substantial effect on tomato plant height (Madugundu *et al.*, 2023). Higher concentrations of sodium chloride (NaCl) significantly reduced the number of sprouts, plant height, root weight, plant weight, and leaf weight of aloe vera plants too (Moghbeli *et al.*, 2012). Improved root development and more efficient nutrient uptake can be the reasons behind microbes helping seedlings grow well under different levels of salinity. *P. fluorescens*-treated plants showed a marked increase in stem length and shoot fresh weight of soybean under salinity (Abulfaraj *et al.*, 2021). Lastochkina *et al.*, 2017 also reported that in comparison to non-saline settings, wheat plant growth (seedling length, and fresh and dry weights) was reduced following salt stress treatment. The growth parameters of wheat seedlings subjected to salt stress are protected when seeds were treated with *B. subtilis* prior to sowing. In comparison to the control plant, salt concentrations inhibited the tomato plants' shoot height, root length, and the fresh and dry weight of their shoots and roots but compared to plants treated with *T. viride*, plants not treated with the fungi exhibited a larger decrease in these parameters (Metwally *et al.*, 2023).

Conclusion

In conclusion, this research unequivocally demonstrates the significant potential of microbial interventions in mitigating salt stress in acid lime (*Citrus aurantifolia* Swingle). Our findings highlight that specific microbes, when applied to acid lime plants under saline conditions, effectively enhance various growth parameters. The study revealed that inoculated plants exhibited improved morphological traits. While this study provides compelling evidence for the efficacy of microbial applications, further research is warranted to elucidate the precise molecular interactions between the selected microbes and acid lime under saline conditions. Future investigations could also focus on optimizing application methods, exploring the long-term effects of microbial inoculation in field conditions, and assessing the economic viability of such interventions for large-scale acid lime production in salt-affected regions. Nevertheless, the present work lays a strong foundation for developing sustainable and eco-friendly strategies for salt stress management in acid lime, contributing significantly to enhancing agricultural resilience in challenging environments.

References

Acosta-Motos, J.R., Ortuño M.F., Bernal-Vicente A., Diaz-Vivancos P., Sanchez-Blanco M.J. and Hernandez J.A. (2017). Plant responses to salt stress: adaptive mechanisms. *Agronomy*, **7(1)**, 18.

Ahmad, F., Ahmad I. and Khan M.S. (2008). Screening of free-living rhizospheric bacteria for their multiple plant growth promoting activities. *Microbiological research*, **163(2)**, 173-181.

Al-Kharusi, L., Al-Yahyai R. and Yaish M.W. (2019). Antioxidant response to salinity in salt-tolerant and salt-susceptible cultivars of date palm. *Agriculture*, **9(1)**, 8.

Ali, Baber, Xiukang Wang, Muhammad Hamzah Saleem, Sumaira, Aqsa Hafeez, Muhammad Siddique Afridi and Shahid Khan *et al*., (2022). "PGPR-mediated salt tolerance in maize by modulating plant physiology, antioxidant defense, compatible solutes accumulation and bio-surfactant producing genes." **Plants 11, no. 3**, 345.

Amirjani, Mohammad R. (2011). "Effect of salinity stress on growth, sugar content, pigments and enzyme activity of rice." 73-81.

Asada, K. (1999). The water-water cycle in chloroplasts: scavenging of active oxygens and dissipation of excess photons. *Annual review of plant biology*, **50(1)**, 601-639.

Asensi-Fabado, M.A., Amtmann A. and Perrella G. (2017). Plant responses to abiotic stress: the chromatin context of transcriptional regulation. *Biochimica et Biophysica Acta (BBA)-Gene Regulatory Mechanisms*, **1860(1)**, 106-122.

Ashraf, M., Shahzad S.M., Imtiaz M. and Rizwan M.S. (2018). Salinity effects on nitrogen metabolism in plants–focusing on the activities of nitrogen metabolizing enzymes: A review. *Journal of Plant Nutrition*, **41(8)**, 1065-1081.

Bhat, Mujtaba Aamir, Vijay Kumar, Mudasir Ahmad Bhat, Ishfaq Ahmad Wani, Farhana Latief Dar, Iqra Farooq, Farha Bhatti, Rubina Koser, Safikur Rahman, and Arif Tasleem Jan (2020). "Mechanistic insights of the interaction of plant growth-promoting rhizobacteria (PGPR) with plant roots toward enhancing plant productivity by alleviating salinity stress." *Frontiers in microbiology*, **11**, 1952.

Cui, Jinyu, Tao Sun, Shubin Li, Yaru Xie, Xinyu Song, Fangzhong Wang, Lei Chen, and Weiwen Zhang (2020). "Improved salt tolerance and metabolomics analysis of Synechococcus elongatus UTEX 2973 by overexpressing Mrp Antiporters." *Frontiers in Bioengineering and Biotechnology*, **8**, 500.

Damam, M., Kaloori K., Gaddam B. and Kausar R. (2016). Plant growth promoting substances (*phytohormones*) produced by rhizobacterial strains isolated from the rhizosphere of medicinal plants. *International Journal of Pharmaceutical Sciences Review and Research*, **37(1)**, 130-136.

Darshan, D., Prasad Pandey H., Pathak R.K., Pandey S.B. and Singh V. (2022). Impact of Soil Salinity on Citrus: A Review. *International Journal of Plant & Soil Science*, **34(12)**, 57-65.

De Sousa, Sylvia Morais, Christiane Abreu de Oliveira, Daniele Luiz Andrade, Chainheny Gomes de Carvalho, Vitória Palhares Ribeiro, Maria Marta Pastina, Ivanildo Evódio Marriel, Ubiraci Gomes de Paula Lana, and Eliane Aparecida Gomes (2021). "Tropical Bacillus strains inoculation enhances maize root surface area, dry weight, nutrient uptake and grain yield." *Journal of Plant Growth Regulation*, **40(2)**, 867-877.

Etesami, H. and Beattie G.A. (2017). Plant-microbe interactions in adaptation of agricultural crops to abiotic stress conditions. *Probiotics and plant health*, 163-200.

Etesami, H. and Beattie G.A. (2018). Mining halophytes for plant growth-promoting halotolerant bacteria to enhance the salinity tolerance of non-halophytic crops. *Frontiers in microbiology*, **9**, 148.

FAO (2023). Food And Agriculture Organizations of the United Nations [Internet]. 2023. Available from: http://www.fao.org/faostat/en/#data. [Accessed: June 2, 2023]

Ferguson, L. and Grattan S.R. (2005). How salinity damages citrus: osmotic effects and specific ion toxicities. *Tree Physiol*, **12**, 195-216.

Fouda, A., Hassan S.E.D., Eid A.M. and El-Din Ewais E. (2019). The interaction between plants and bacterial endophytes under salinity stress. *Endophytes and secondary metabolites*, 1-18.

García-Sánchez, F. and Syvertsen J.P. (2006). Salinity tolerance of Cleopatra mandarin and Carrizo citrange citrus rootstock seedlings is affected by CO2 enrichment during growth. *Journal of the American Society for Horticultural Science*, **131(1)**, 24-31.

Giannelli, G., Potestio S. and Visioli G. (2023). The contribution of PGPR in salt stress tolerance in crops: Unravelling the molecular mechanisms of cross-talk between plant and bacteria. *Plants*, **12(11)**, 2197.

Gómez-Cadenas, A., Iglesias D.J., Arbona V., Colmenero-Flores J.M., Primo-Millo E. and Talon M. (2003). Physiological and molecular responses of citrus to salinity.

Grattan, S.R., Díaz F.J., Pedrero F. and Vivaldi G.A. (2015). Assessing the suitability of saline wastewaters for irrigation of Citrus spp.: Emphasis on boron and specific-ion interactions. *Agricultural Water Management*, **157**, 48-58.

Hasanuzzaman, M., Bhuyan M.B., Zulfiqar F., Raza A., Mohsin S.M., Mahmud J.A. and Fotopoulos V. (2020). Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator. *Antioxidants*, **9(8)**, 681.

Krishan, G. (2019). Groundwater salinity. *Current World Environment*, **14(2)**, 186.

Li, X., Li S., Wang J. and Lin J. (2020). Exogenous abscisic acid alleviates harmful effect of salt and alkali stresses on wheat seedlings. *International Journal of Environmental Research and Public Health*, **17(11)**, 3770.

López-Climent, M.F., Arbona V., Pérez-Clemente R.M. and Gómez-Cadenas A. (2008). Relationship between salt tolerance and photosynthetic machinery performance in citrus. *Environmental and experimental botany*, **62(2)**, 176-184.

Maas, E.V. (1993). Salinity and citriculture. *Tree physiology*, **12(2)**, 195-216.

Mittler, R. (2002). Oxidative stress, antioxidants and stress tolerance. *Trends in plant science*, **7(9)**, 405-410.

Molassiotis, A. and Fotopoulos V. (2011). Oxidative and nitrosative signaling in plants: two branches in the same tree?. *Plant Signaling & Behavior*, **6(2)**, 210-214.

Nagpal, B. (2024, February 10). Saline soil could double by 2050, affect crop production:CSSRI. *Hindustan times*.

Shultana, Rakiba, Ali Tan Kee Zuan, Umme Aminun Naher, AKM Mominul Islam, Md Masud Rana, Md Harun Rashid, Israt Jahan Irin, Shams Shaila Islam, Adiba Afrin Rim and Ahmed Khairul Hasan (2022). “The PGPR mechanisms of salt stress adaptation and plant growth promotion.” *Agronomy*, **12(10)**, 2266.

Storey, R. and Walker R.R. (1998). Citrus and salinity. *Scientia horticulturae*, **78(1-4)**, 39-81.

Tanou, G., Ziogas V., Belghazi M., Christou A., Filippou P., Job D. and Molassiotis A. (2014). Polyamines reprogram oxidative and nitrosative status and the proteome of citrus plants exposed to salinity stress. *Plant, cell & environment*, **37(4)**, 864-885.

Van Zelm, E., Zhang Y. and Testerink C. (2020). Salt tolerance mechanisms of plants. *Annual review of plant biology*, **71(1)**, 403-433.

Ying-Ning, Z.O.U. and Qiang-Sheng W.U. (2011). Sodium chloride stress induced changes in leaf osmotic adjustment of trifoliate orange (*Poncirus trifoliata*) seedlings inoculated with mycorrhizal fungi. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, **39(2)**, 64-69.

Ziogas, V., Tanou G., Filippou P., Diamantidis G., Vasilakakis M., Fotopoulos V. and Molassiotis A. (2013). Nitrosative responses in citrus plants exposed to six abiotic stress conditions. *Plant Physiology and Biochemistry*, **68**, 118-126.

Ziogas, V., Tanou G., Morianou G. and Kourgialas N. (2021). Drought and salinity in citriculture: Optimal practices to alleviate salinity and water stress. *Agronomy*, **11(7)**, 1283.