**Effect of Halotolerant Microbial Inoculants on Growth and Yield Attributes of Groundnut (*Arachis hypogaea* L.) under dry land Saline Soil Conditions**

**Abstract**

A pot culture experiment was conducted to assess the influence of microbial bio-stimulants CSR-GROW-SURE (collected from CSSRI, Karnal) and TNAU culture (*Bacillus subtilis*) on the growth, nodulation, and no. of pods plant-1 of groundnut (var. CO7) under saline soil conditions (EC: 4.03, 5.01, and 6.02 dS m-1) maintained at 75 % field capacity (FC). The microbial cultures were applied at 1, 2, and 3 L ha-1. The results revealed that both bio-inoculants significantly enhanced plant growth attributes, with higher values observed at the post-harvest stage. Comparing treatments, the maximum values are recorded in CSR-GROW-SURE and TNAU cultures with 3 L ha-1. The interaction of microbial cultures with salinity levels indicated that CSR-GROW-SURE and TNAU cultures with 3 L ha-1 under 4.03 dS m-1 produced the most pronounced improvements in plant growth and yield attributes, recorded the highest germination (94.47 %), root length (10.83 cm), number of nodules plant-1 (15.67) and number of pods plant-1 (17.00). The TNAU culture with 3 L ha-1 is statistically on par with germination percentage (94.02 %), root length (10.78 cm), nodules plant-1 (15.67) and pods plant-1 (17.00). Furthermore, comparing, all salinity levels, the 4.03 dS m-1 soil recorded maximum values compared to 5.01 and 6.02 dS m-1 soils in all parameters. The observed benefits are due to microbial production of phytohormones (IAA, gibberellins), ACC deaminase, siderophores, nitrogen fixation, and zinc solubilization. These findings strongly support the application of halotolerant microbial bio-stimulants as a sustainable strategy to mitigate salinity stress and enhance groundnut productivity in dryland saline agro-ecosystems.

**Key words: *Bacillus* *spp*., CSR-GROW-SURE, Dry land, Groundnut, Growth &Yield, Saline soil**

**1. Introduction**

Groundnut (*Arachis hypogaea* L.) is a nutritionally and economically important legume crop widely cultivated in arid and semi-arid regions (Pokhrel *et al*., 2025) for its rich content of edible oil, protein, and dietary fiber (Aremu *et al*., 2025). India’s agricultural sector is predominantly dependent on rainfed farming. Out of the total net cultivated area of approximately 140 million hectares, around 70 million hectares constituting nearly 50% are under rainfed conditions. is categorized as dryland (Andimuthu et al., 2025). Crops like groundnut, sorghum, maize, sunflower, cotton, and pulses are mostly grown in dryland ecosystems (Sahoo et al., 2025). Although dryland agriculture holds considerable potential for enhancing food grain production and sustaining rural livelihoods, its productivity is frequently limited by two key challenges: inadequate soil moisture and soil salinity (Kundu et al., 2025).

 Salinity is a growing global concern, affecting nearly 20% of irrigated agricultural lands (Demo et al., 2025). In saline soils, high concentrations of soluble salts disrupt the osmotic balance, restrict water and nutrient uptake, and induce toxicity from ions such as sodium, chloride, and sulfate (Saleem et al., 2025, Kaur et al., 2025). Moreover, salinity reduces microbial diversity and soil enzymatic activities, further impacting crop performance (Li *et al*., 2025). In groundnut, saline conditions lead to reduced germination, poor root and shoot growth, decreased nodulation, and ultimately lower pod yield. (Yunusa *et al*., 2025)

To address these challenges, the use of halotolerant plant growth-promoting rhizobacteria (PGPR) has emerged as a promising eco-friendly strategy (Santhosh *et al*., 2025). These beneficial microbes enhance plant growth through multiple direct and indirect mechanisms. They synthesize phytohormones such as indole-3-acetic acid (IAA), gibberellic acid, and cytokinins, produce siderophores and exopolysaccharides, solubilize phosphorus, and possess ACC deaminase activity that helps reduce ethylene stress in plants (Anwar et al., 2025; Ghosh et al., 2025 and Mohamed et al., 2025).

Several bacterial genera, including *Achromobacter, Arthrobacter, Bacillus, Chryseobacterium, Enterobacter, Ochrobactrum,* and *Pseudomonas*, have been isolated from saline environments and reported to improve soil fertility and crop resilience without negative environmental effects (Jha and Subramanian, 2014; Bhise *et al*., 2017; Sarkar  *et al*., 2018). Among these, *Bacillus spp.* is the most effective PGPRs due to their ability to form spores, withstand harsh environmental conditions, and maintain a long shelf life makes them well-suited for use in dryland and saline agricultural systems. (Leser *et al*., 2008; Abd-Allah *et al*., 2018).

*Bacillus licheniformis*, a facultative anaerobic species, is particularly well-suited to the rhizosphere under drought and salinity conditions because of its capacity for fermentative metabolism and anaerobic respiration (Clements et al., 2002). These bacteria not only enhance germination and root growth but also improve nodulation and pod development in legumes under stress conditions. Studies by Verma *et al*., (2010), Anitha and Punith Kumar (2013), Sandhya *et al*., (2009), Damodaran *et al*., (2014), and Bhatt and Maheshwari (2019) have consistently revealed the positive effects of *Bacillus* and other PGPRs on groundnut and other crops, particularly in saline soils. The present study aims to evaluate the impact of halotolerant microbial inoculants on growth and yield parameters of groundnut grown under saline soil conditions.

**2. Materials and methods**

**2.1. Collection of soil samples and microbial inoculants**

To assess the efficacy of microbial inoculants under saline stress, soil samples were collected from Adivalli village in Udumalpet Taluk, Coimbatore district, Tamil Nadu, representing three distinct salinity levels with electrical conductivity (EC) values of 4.03, 5.01, and 6.02 dS m-1. The corresponding geographical coordinates for these sites were 10°41'44" N and 77°09'21" E, 10°41'33" N and 77°09'18" E, and 10°41'29" N and 77°09'04" E, respectively.

A halotolerant microbial consortium, CSR-GROW-SURE, collected from the ICAR–Central Soil Salinity Research Institute (ICAR–CSSRI), Karnal, Haryana, was included in the study. This microbial formulation contains three bacterial strains *Lysinibacillus fusiformis* (CSR-A-11), *Lysinibacillus sphaericus* (CSR-A-16), and *Bacillus licheniformis* (CSR-M-16) are tolerant to dry land saline conditions. Furthermore, a microbial culture developed at Tamil Nadu Agricultural University (TNAU), Coimbatore, was evaluated. The bacterial strain in this formulation was later identified as *Bacillus subtilis*, a species known for its salt tolerance and plant growth-promoting attributes. Both microbial inoculants were selected based on their potential to mitigate the adverse effects of salinity on soil properties and crop performance.

**2.2. Experimental details**

A pot culture experiment was carried out at the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University (TNAU), Coimbatore, to assess the impact of microbiological technologies on the growth performance of groundnut (*Arachis* *hypogaea* L.) and associated soil properties under saline stress conditions. The groundnut variety used for this study was CO 7, a drought-tolerant cultivar obtained from the Department of Oilseeds, TNAU. The experiment was conducted for a duration of 110 days, with three seedlings maintained per pot, to evaluate the effect of different microbial treatments across three levels of soil salinity 4.03, 5.01, and 6.03 dS m-1. Soil samples were air-dried, sieved (2 mm), and 10 kg of soil was filled into each pot. The pots were arranged in a Completely Randomized Design (CRD) with three replications, and soil moisture was maintained uniformly at 75% of field capacity to simulate dryland conditions. The treatment structure included: T1 – Control (no inoculant) with three salinity levels; T2 – TNAU Culture @ 1 L ha-1; T3 – TNAU Culture @ 2 L ha-1; T4 – TNAU Culture @ 3 L ha-1; T5 – CSR-GROW-SURE @ 1 L ha-1; T6 – CSR-GROW-SURE @ 2 L ha-1; and T7 – CSR-GROW-SURE @ 3 L ha-1. Observations on plant growth and related parameters were recorded at three critical crop growth stages: vegetative, flowering, and post-harvest, to capture the influence of treatments throughout the crop lifecycle.

**2.3. Preparation and application of bio-inoculants and fertilizers**

To prepare the microbial inoculants for pot culture, 10 ml of either the TNAU or CSR-GROW-SURE culture was mixed with 1 liter of water, supplemented with 2 grams of jaggery liter-1 and incubated overnight to enhance the population of viable microbes (CFUs). Prior to sowing, groundnut seeds were treated with the respective inoculants at a concentration of 1% per kilogram of seed. Additionally, soil drenching was performed during the germination phase using the same inoculants at rates of 1, 2, and 3 L ha-1 to ensure effective root zone colonization.

To maintain uniform nutrient availability across all treatments, fertilizers were applied at the recommended rate of NPK (25:50:75 kg ha-1). Nutrients were supplied through standard chemical sources: urea for nitrogen, single super phosphate (SSP) for phosphorus, and muriate of potash (MOP) for potassium. This baseline fertilization ensured that differences in plant response were primarily due to the microbial treatments and salinity levels.

**2.4. Methodology for the determination of soil properties**

The various physical and physico-chemical properties of soil were analyzed using standard procedures. Soil texture was determined by the International Pipette Method as described by Piper (1966), while field capacity was analysed using Pressure Plate Apparatus following the method of Dakshinamurthi and Gupta (1968). The soil reaction (pH) and electrical conductivity (EC) were measured by potentiometry and conductometry, respectively (Jackson, 1973). Available nitrogen (N) was estimated through the alkaline permanganate method as proposed by Subbiah and Asija (1956), whereas available phosphorus (P) in alkaline soils was extracted using 0.5 M NaHCO₃ as per Olsen (1954). Exchangeable calcium (Ca2+) and magnesium (Mg2+) were determined by the versenate titration method, Exchangeable sodium (Na+) and potassium (K+) were quantified using a flame photometer (Richards 1954). The concentrations of bicarbonates (HCO3-) and chlorides (Cl-) were estimated by titration methods (Richards 1954), while sulphate content was measured using the turbidimetric method as suggested by (Tandon 2005).

**Table 1. Initial Soil Properties**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No** | **Particulars** | **Soil EC****4.03 dS m-1** | **Soil EC****5.01 dS m-1** | **Soil EC****6.02 dS m-1** |
|  | Soil Texture | Sandy clay | Sandy clay | Sandy clay |
|  | pH | 8.00 | 8.10 | 8.20 |
|  | Available N (kg ha-1) | 168.12 | 155.01 | 147.28 |
|  | Available P (kg ha-1) | 6.76 | 5.99 | 5.91 |
|  | Exchangeable Calcium (meq kg-1) | 10.34 | 12.64 | 14.58 |
|  | Exchangeable Magnesium (meq kg-1  ) | 5.48 | 6.98 | 8.58 |
|  | Exchangeable Sodium (meq kg-1) | 15.27 | 19.10 | 23.76 |
|  | Exchangeable Potassium (meq kg-1) | 7.99 | 9.89 | 12.04 |
|  | Bicarbonates | 3.34 | 3.67 | 3.91 |
|  | Chloride (meq kg-1) | 22.10 | 27.00 | 35.15 |
|  | Sulphate (meq kg-1) | 13.56 | 17.85 | 19.83 |

**2.5. Assessment of plant growth and yield attributes under salinity stress**

Root length was assessed at vegetative, flowering and postharvest stage. Nodule development was recorded by gently uprooting the groundnut plants and rinsing the roots to remove adhering soil without dislodging the nodules. The nodules were then separated from the roots, and the mean number of effective nodules was determined based on observations from five plants per treatment. Pod formation was evaluated at harvest by counting the number of pods produced per plant. Germination percentage is a critical parameter used to assess the ability of seeds germinate under salt stress conditions. It is as an indicator to evaluate the influence of microbial inoculants germination and establishment of groundnut seedlings in different salinity levels of soil. Germination percentage was calculated by the formulae given (1).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Germination percentage | = | Total no. of seeds germinated | X | 100 | (1) |
| Total no. of seeds sown |

**2.6. Statistical analysis**

By using Gomez and Gomez (1984) statistical analysis method the present data of the pot culture was analysed. F- Test was used for the level of significance and variance analysis
P = (0.05). As well as the critical difference with probability level of 5 % was also analysed.

**3. Results and discussion**

**3.1. Impact of microbial inoculants on germination percentage of ground nut crop**

The germination percentage linearly increased with increasing rate of application of cultures. Among the cultures CSR-GROW-SURE with 3 L ha-1 was observed significantly highest percentage of germination with mean value of 91.01% and it was on par with the TNAU culture with 3 L ha-1 with mean value of 90.58 % and least mean value was detected in the control with 71.89 %. Comparing the soils, the per cent germination decreased with increase in soil EC levels. Significantly maximum per cent of germination was observed 4.03dS m-1 soil with the mean per cent germination of 89.25 % followed by 5.01, 6.03 dS m-1 soils with 85.98 and 82.72 % respectively (Table 2). Celluloses, xylanases and mannasnase also help bacteria to sustain to salt tolerance (Govender *et al.,* 2009). These enzymes are help for increasing germination percentage of the plant by providing energy and by improving metabolic processes of in the embryo (Joshi 2018).

 In the interaction of cultures with soils showed a significant variation where the highest value 94.47 % germination was observed in CSR-GROW-SURE with 3L ha-1 under 4.03dS m-1 soil and it was at with TNAU culture with 3 L ha-1 with germination percentage of 94.02 %, followed by 5.01 and 6.02 dS m-1 soils of the same treatments. The control (without microbial inoculation) recorded least per cent germination of 74.62, 71.89 and 69.16 in 4.03, 5.01, 6.03 dS m-1 soils respectively. Menasria (2020) found that *Bacillus* spp. was able to produce the enzymes like lipase, protease, amylase, gulutaminase, catalase which make the bacteria to survive under high salt conditions to improve per cent of germination. *Bacillus* can also produce the gibberellins which makes the increase of germination of the seed reported by (Perrig *et al.,* 2007).

**3.2. Impact of microbial inoculants on Root length (cm) of ground nut crop**

The root length of the groundnut variety (CO 7) was assessed at three critical growth stages-vegetative, flowering, and post-harvest to evaluate the impact of microbial treatments across the crop’s developmental phases. Among the cultures, CSR-GROW-SURE with 3 L ha-1 showed the uppermost root length with mean values 5.83, 7.40 and 10.43cm. It was comparable to TNAU Culture with 3 L ha-1 with mean values of 5.80, 7.36 and 10.38cm, and the control exhibited the lowest mean values of 4.61, 5.84 and 8.24cm during the vegetative, flowering and harvest respectively. Tank and Saraf (2010) reported that with increase in activity of the ACC deaminase, reduction in effect of ethylene content by reducing ACC concentration in the plant Glick *et al*., (2007) will be done by bacillus results in increase of the root length of the plant.

The maximum length of the root was observed in all the 4.03 dS m-1 soil with mean value of 5.72, 7.25 and 10.23 cm and in 5.01 and 6.02 dS m-1 of soil showed the mean values of 5.51, 6.99 & 9.85cm and 5.30, 6.72 and 9.48cm at vegetative, flowering and harvest stages respectively. However, among all the stages the length of the root was observed more at the stage of harvest. Vivas *et al*., (2003) reported that phosphorus content in plant increased after inoculation of the *Bacillus* spp. will improve the root length of the plant. Also Kayin *et al.,* (2015) attributed that nitrogen fixation stimulation by *Bacillus spp*. will improve the formation of root.

 The interaction between the soils and culture showed the significantly different were highest root length was observed in all the stages with treatment of CSR-GROW-SURE @ 3-1 root length for groundnut CO7 in 4.03 dS m-1 with values of 6.05, 7.68 and 10.83cm at vegetative, flowering and harvest stages respectively. And it was on par with TNAU culture with 3 L ha-1 root length for groundnut CO7 with 4.03 dS m-1 with values of 6.02, 7.64 and 10.78 cm respectively (Table 3). And similar trend was observed in 5.01 and 6.02 dS m-1 of saline soil. Arkhipova *et al.,* (2007), reported that cytokinins produced by *Bacillus spp*. will also increase the root growth. Further, Rana *et al.,* (2012)substantiated that solubilisation of zinc through *Bacillus spp*. will improve the root growth of the plant.

**3.3. Impact of microbial inoculants on No. of Nodules per plant-1 of ground nut crop**

The application of cultures in groundnut crop improved the number of nodules per plant at all the doses and salinity levels and it was increased linearly with increasing rate of application microbes and decreased with increasing levels of salinity reveals the no. of nodules per plant of all the treatments including control. The cultures improved the no. of nodules per plant at all the rates. Whereas maximum mean value of 15.67 (54.01 %) observed in treatment CSR-GROW-SURE with 3 L ha-1 and it was on par with TNAU culture with 3 L ha-1 with mean value of 15.67 (54.01 %) (Table 4).

Among the soils with different EC levels showed the highest no. of pods at 4.03 dS m-1 of soil with mean value of 15.43 followed by 13.42 in 5.01 dS m-1 and 13.00 in 6.02 dS m-1 of soil. Verma *et al*., (2010) stated that no. of nodules per plant were increased due to IAA and ammonia production and nitrogen fixation. Similar results was also reported by Bahadur and Tiwari (2014).

After inoculating the treatment CSR-GROW-SURE with 3 L ha-1 and it was on par with the 3 L ha -1 dose of TNAU Culture with 3 L ha-1 in 4.03, 5.01, 6.03 dS m-1 of saline soils. The highest no.of nodules were observed in 4.03 dS m-1 of saline soil with percentage of 34.49 in both the treatments CSR-GROW-SURE with 3 L ha-1 and TNAU culture with 3 L ha-1. Kumawat *et al*., (2009) reported that due to raise in phosphorus content in soil after PSB inoculation will increase the no. of nodules per plant. Similar studies was also testified by Anandham *et al*., (2007) and Argaw (2012).

**3.4. Impact of microbial inoculants on no. of pods plant-1 of ground nut crop**

The effect of microbial cultures on No. of pods plant-1 at vegetative, flowering and harvest stages under varied saline soils were represented in the table 5. Among the cultures CSR-GROW-SURE with 3 L ha-1 was showed significantly highest plant height with mean values of 15.67 and it was on par with the TNAU culture with 3 L ha-1 with mean values of 15.67 and the less mean value was detected in the control with 10.33. Comparing the soils, the highest no. of pods was recorded in the 4.03 dS m-1 soil with mean values of 15.57 followed by 5.01 and 6.02 dS m-1 with mean values of 13.86 and 13.43 respectively.Esitken *et al.,* (2002) revealed that increase in pod number due to N2 fixation and auxin production and siderophores.

The interaction between the cultures and salinity levels, more number of pods per plant was observed in the treatment CSR-GROW-SURE with 3 L ha-1 with 17.00 pods in 4.03 dS m-1 of soil and it was on par with TNAU culture with 3L ha-1 showed the 17.00 no. of pods plant-1 in 4.03 dS m-1 of soil. Similar trend was verified in 5.01 and 6.02 dS m-1 soils with values of 15.00 and 15.00 respectively with CSR-GROW-SURE with 3 L ha-1 of treatment (Figure 1). 15.00 and 15.00 pods plant-1 with treatment of TNAU culture with 3 L ha-1 and control showed the less no. of pods in all the three saline soils of 4.03, 5.01 and 6.02 dS m-1 with values of 11.00, 10.00 and 10.00 respectively. IAA production will also improve the no. of pods of plant-1 (Pradhan *et al*., 2017).

**4. Conclusion**

The study highlights the significant potential of halotolerant microbial inoculants, particularly CSR-GROW-SURE and TNAU *Bacillus subtilis*, in enhancing groundnut growth and yield under saline conditions. Their application improved germination, root development, nodulation, and pod formation, especially at higher doses and in soils with lower salinity. The observed positive interactions between salinity levels and inoculant application emphasize their adaptive efficacy under stress conditions. These results affirm the role of microbial bio-inoculants as a sustainable and eco-friendly solution for managing saline soils. Going forward, field-level validation, formulation development, and integration with nutrient management practices are essential to scale up their use. Further research on microbial consortia and their synergistic interactions with crops under multi-stress environments can enhance their resilience-building capacity, contributing to sustainable and climate-smart agriculture

**7. Reference**

1. Abd\_Allah, Elsayed Fathi, Abdulaziz A Alqarawi, Abeer Hashem, Ramalingam Radhakrishnan, Asma A Al-Huqail, Fatma Olyan Naser Al-Otibi, Jahangir Ahmad Malik, Raedah Ibrahim Alharbi, and Dilfuza Egamberdieva. 2018. "Endophytic bacterium Bacillus subtilis (BERA 71) improves salt tolerance in chickpea plants by regulating the plant defense mechanisms." *Journal of Plant Interactions* 13 (1):37-44
2. Anandham, R, R Sridar, P Nalayini, S Poonguzhali, and M Madhaiyan. 2007. "Potential for plant growth promotion in groundnut (Arachis hypogaea L.) cv. ALR-2 by co-inoculation of sulfur-oxidizing bacteria and Rhizobium." *Microbiological research* 162 (2):139-153.
3. Anitha, M., & Kumar, C. H. P. (2013). Effect of organic and inorganic seed priming on soybean germination and yield parameters. *Biolife, 1*(4), 223–230.
4. Anwar, H., Jamil, M., Hussain, A., Dar, A., Ahmad, M., Salmen, S. H., ... & Iqbal, R. (2025). Zinc-coated urea and zinc-solubilizing microbes: synergistic strategies for improving zinc bioavailability in dry region soils. *Asian Journal of Agriculture and Biology*, *2025*(01).
5. Argaw, Anteneh. 2012. "Evaluation of co-inoculation of Bradyrhizobium japonicum and Phosphate solubilizing Pseudomonas spp. effect on soybean (Glycine max L. Merr.) in Assossa Area." *Journal of Agricultural Science and Technology* 14 (1):213-224.
6. Arkhipova, TN, E Prinsen, SU Veselov, EV Martinenko, AI Melentiev, and GR Kudoyarova. 2007. "Cytokinin producing bacteria enhance plant growth in drying soil." *Plant and soil* 292 (1):305-315.
7. Bhatt, K., & Maheshwari, D. K. (2019). Decoding multifarious role of cow dung bacteria in mobilization of zinc fractions along with growth promotion of C. annuum L. Scientific Reports, 9(1), 1–10.
8. Bhise, K. K., Bhagwat, P. K., & Dandge, P. B. (2017). Synergistic effect of Chryseobacterium gleum sp. SUK with ACC deaminase activity in alleviation of salt stress and plant growth promotion in Triticum aestivum L. 3 Biotech, 7(2), 1–13.
9. Dakshinamurthi, C., & Gupta, R. P. (1968). *Practicals in soil physics*. Indian Agricultural Research Institute (IARI), New Delhi.
10. Damodaran, T., Rai, R. B., Jha, S. K., Kannan, R., Pandey, B. K., Sah, V., Mishra, V. K., & Sharma, D. K. (2014). Rhizosphere and endophytic bacteria for induction of salt tolerance in gladiolus grown in sodic soils. *Journal of Plant Interactions, 9*(1), 577–584.
11. Demo, A. H., Gemeda, M. K., Abdo, D. R., Guluma, T. N., & Adugna, D. B. (2025). Impact of soil salinity, sodicity, and irrigation water salinity on crop production and coping mechanism in areas of dryland farming. *Agrosystems, Geosciences & Environment*, *8*(1), e70072.
12. Esitken, AHMET, HÜSEYİN Karlidag, Sezai Ercisli, and FİKRETTİN SAHIN. 2002. "Effects of foliar application of Bacillus subtilis Osu-142 on the yield, growth and control of shot-hole disease (Coryneum blight) of apricot." *Gartenbauwissenschaft* 67 (4).
13. Ghosh, S. K., Pal, P., Mondal, S., Mondal, T., Soren, T., Ghosh, P. K., & Maiti, T. K. (2025). Halotolerant Plant Growth Promoting Rhizobacteria: The Hidden Gem. In *Plant-Microbe Interactions: A Comprehensive Review* (pp. 197-222). Bentham Science Publishers.
14. Glick, Bernard R, Biljana Todorovic, Jennifer Czarny, Zhenyu Cheng, Jin Duan, and Brendan McConkey. 2007. "Promotion of plant growth by bacterial ACC deaminase." *Critical Reviews in Plant Sciences* 26 (5-6):227-242.
15. Gomez, Kwanchai A, and Arturo A Gomez. 1984. *Statistical procedures for agricultural research*: John wiley & sons.
16. Govender, Lucretia, Lureshini Naidoo, and Mathabatha Evodia Setati. 2009. "Isolation of hydrolase producing bacteria from Sua pan solar salterns and the production of endo-1, 4-bxylanase from a newly isolated haloalkaliphilic Nesterenkonia sp." *African Journal of Biotechnology* 8 (20).
17. Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.
18. Jha, Y., & Subramanian, R. B. (2014). PGPR regulate caspase-like activity, programmed cell death, and antioxidant enzyme activity in paddy under salinity. Physiology and Molecular Biology of Plants, 20(2), 201–207.
19. Joshi, Renu. 2018. "Role of enzymes in seed germination." *International Journal of Creative Research Thoughts* 6 (2):1481-1485.
20. Kaur, H., Kumar, S., Ali, S., Kaushik, R., Ravi, K., Saroha, A., ... & Rashid, B. Salinity Stress Alleviation in Fenugreek. In *Fenugreek* (pp. 177-206). Apple Academic Press.
21. Kayin, Günsu Barişik, Sencer Öztüfekçi, Hasan Fatih Akin, Ekin Ulaş Karaata, A Vahap Katkat, and Murat Ali Turan. 2015. "Effect of Bacillus subtilis Ch-13, nitrogen and phosphorus on yield, protein and gluten content of wheat (Triticum aestivum L.)." *Uludağ Üniversitesi Ziraat Fakültesi Dergisi* 29 (1):19-28.
22. Kumawat, Narendra, R Kumar, and OP Sharma. 2009. "Nutrient uptake and yield of mungbean [Vigna radiata (L.) Wilczek] as influenced by organic manures, PSB and phosphorus fertilization." *Environ Ecol* 27 (4B):2002-2005.
23. Li, W., Zhong, M., Wang, H., Shi, X., Song, J., Wang, J., & Zhang, W. (2025). Exogenous carbon inputs alleviated salt-induced oxidative stress to cotton in salinized field by improving soil aggregate structure and microbial community. *Frontiers in Plant Science*, *16*, 1522534.
24. Menasria, Taha. 2020. "Biodiversité microbienne dans les milieux extrêmes salés du Nord-Est Algérien." Université de Batna 2.
25. Olsen, S. R. (1954). *Estimation of available phosphorus in soils by extraction with sodium bicarbonate* (Circular No. 939). U.S. Department of Agriculture.
26. Pradhan, Madhusmita, Chinmay Pradhan, and Santanu Mohanty. 2017. "Effect of P-solubilizing bacteria on microbial biomass P and phosphatase activity in groundnut (ArachishypogaeaL) rhizosphere." *Int J Curr Microbiol App Sci* 6 (4):1240-1260.
27. Perrig, D, ML Boiero, OA Masciarelli, C Penna, OA Ruiz, FD Cassán, and MV Luna. 2007. "Plant-growth-promoting compounds produced by two agronomically important strains of Azospirillum brasilense, and implications for inoculant formulation." *Applied microbiology and biotechnology* 75 (5):1143-1150.
28. Piper, CS. (1966). Soil and plant analysis.,(Hans Publishers: Bombay, India).
29. Rana, Anuj, Monica Joshi, Radha Prasanna, Yashbir Singh Shivay, and Lata Nain. 2012. "Biofortification of wheat through inoculation of plant growth promoting rhizobacteria and cyanobacteria." *European Journal of Soil Biology* 50:118-126.
30. Richards, L. A. (1954). *Diagnosis and improvement of saline and alkali soils* (Vol. 78). U.S. Department of Agriculture.
31. Saleem, M. A., Khan, A., Tu, J., Huang, W., Liu, Y., Feng, N., ... & Xue, Y. (2025). Salinity Stress in Rice: Multilayered Approaches for Sustainable Tolerance. *International Journal of Molecular Sciences*, *26*(13), 6025.
32. Salma Santhosh, S., Meena, S., Baskar, M., Karthikeyan, S., Vanniarajan, C., & Ramesh, T. (2025). Transformative strategies for saline soil restoration: Harnessing halotolerant microorganisms and advanced technologies. *World Journal of Microbiology and Biotechnology*, *41*(5), 1-41.
33. Sarkar, A., Ghosh, P. K., Pramanik, K., Mitra, S., Soren, T., Pandey, S., Mondal, M. H., & Maiti, T. K. (2018). A halotolerant Enterobacter sp. displaying ACC deaminase activity promotes rice seedling growth under salt stress. Research in Microbiology, 169(1), 20–32.
34. Subbiah, B. V., & Asija, G. L. (1956). Alkaline method for determination of mineralizable nitrogen. *Current Science, 25*(2), 259–260.
35. Tandon, H. L. S. (2005). *Methods of analysis of soils, plants, waters, fertilisers & organic manures*. Fertiliser Development and Consultation Organisation.
36. Tank, Neelam, and Meenu Saraf. 2010. "Salinity-resistant plant growth promoting rhizobacteria ameliorates sodium chloride stress on tomato plants." *Journal of Plant Interactions* 5 (1):51-58.
37. Verma, J. P., Yadav, J., & Tiwari, K. N. (2010). Application of Rhizobium sp. BHURC01 and plant growth promoting rhizobacteria on nodulation, plant biomass and yields of chickpea (Cicer arietinum L.). International Journal of Agricultural Research, 5(3), 148–156.
38. Verma, JP, J Yadav, and Kavindra Nath Tiwari. 2010. "Application of Rhizobium sp. BHURC01 and plant growth promoting rhizobactria on nodulation, plant biomass and yields of chickpea (Cicer arietinum L.)." *International Journal of Agricultural Research* 5 (3):148-156.
39. Vivas, Astrid, Adriana Marulanda, Juan Manuel Ruiz-Lozano, José Miguel Barea, and Rosario Azcón. 2003. "Influence of a Bacillus sp. on physiological activities of two arbuscular mycorrhizal fungi and on plant responses to PEG-induced drought stress." *Mycorrhiza* 13 (5):249-256.
40. Yunusa, A. Y., Hayatu, M., Sani, L. A., Babura, S. R., Aminu, M. A., Namadina, M. M., & Phoebe, A. O. (2025). Impact of Salinity Stress on Ion Homeostasis of Some Selected Groundnut (Arachis hypogaea L.) Varieties. *Sahel Journal of Life Sciences FUDMA*, *3*(2), 198-204.

**Table 2. Effect of microbial inoculants on germination percentage (%) of ground nut crop (CO 7) at various salinity levels**

|  |  |
| --- | --- |
|  **Treatments**  | **Germination percentage (%)** |
| **4.03 dS m-1** | **5.01 dS m-1** | **6.02 dS m-1** | **Mean** |
| T1 - Control | 74.62 | 71.89 | 69.16 | 71.89 |
| T2 -TNAU Culture @ 1 L ha-1 | 89.54 | 86.27 | 82.99 | 86.27 |
| T3 - TNAU Culture @ 2 L ha-1 | 91.04 | 87.71 | 84.38 | 87.71 |
| T4 - TNAU Culture @ 3 L ha-1 | 94.02 | 90.58 | 87.14 | 90.58 |
| T5 - CSR-GROW-SURE @ 1 L ha-1 | 89.69 | 86.41 | 83.13 | 86.41 |
| T6 - CSR-GROW-SURE @ 2 L ha-1 | 91.33 | 87.99 | 84.65 | 87.99 |
| T7 - CSR-GROW-SURE @ 3 L ha-1 | 94.47 | 91.01 | 87.56 | 91.01 |
| Mean | 89.25 | 85.98 | 82.72 |   |
|   | Cultures (C)  | Soils (S) | C × S |
| SEd |  0.24 |  1.02 |  1.26 |
| CD @ 5 % |  0.48  |  2.04  |  2.52  |

**Table 3. Effect of microbial inoculants on root length (cm) in all growth stages of ground nut crop (CO 7) at various salinity levels**

|  |  |  |  |
| --- | --- | --- | --- |
| Treatments | Vegetative stage | Flowering stage | Post- Harvest stage |
| 4.03dS m-1 | 5.01dS m-1 | 6.02dS m-1 | Mean | 4.03dS m-1 | 5.01dS m-1 | 6.02dS m-1 | Mean | 4.03 dS m-1 | 5.01 dS m-1 | 6.02 dS m-1 | Mean |
| T1 – Control | 4.78 | 4.61 | 4.43 | 4.61 | 6.07 | 5.84 | 5.62 | 5.84 | 8.55 | 8.24 | 7.93 | 8.24 |
| T2 -TNAU Culture @ 1 L ha-1 | 5.74 | 5.53 | 5.32 | 5.53 | 7.28 | 7.01 | 6.75 | 7.01 | 10.26 | 9.89 | 9.51 | 9.89 |
| T3 - TNAU Culture @ 2 L ha-1 | 5.83 | 5.62 | 5.41 | 5.62 | 7.40 | 7.13 | 6.86 | 7.13 | 10.43 | 10.05 | 9.67 | 10.05 |
| T4 - TNAU Culture @ 3 L ha-1 | 6.02 | 5.80 | 5.58 | 5.80 | 7.64 | 7.36 | 7.08 | 7.36 | 10.78 | 10.38 | 9.99 | 10.38 |
| T5 - CSR-GROW-SURE @ 1 L ha-1 | 5.75 | 5.54 | 5.33 | 5.54 | 7.29 | 7.02 | 6.76 | 7.02 | 10.28 | 9.90 | 9.53 | 9.90 |
| T6 - CSR-GROW-SURE @ 2 L ha-1 | 5.85 | 5.64 | 5.42 | 5.64 | 7.42 | 7.15 | 6.88 | 7.15 | 10.47 | 10.09 | 9.70 | 10.09 |
| T7 - CSR-GROW-SURE @ 3 L ha-1 | 6.05 | 5.83 | 5.61 | 5.83 | 7.68 | 7.40 | 7.12 | 7.40 | 10.83 | 10.43 | 10.04 | 10.43 |
| Mean | 5.72 | 5.51 | 5.30 |  | 7.25 | 6.99 | 6.72 |  | 10.23 | 9.85 | 9.48 |  |
|  | Cultures (C) | Soils (S) | C × S | Cultures (C) | Soils (S) | C × S | Cultures(C) | Soils (S) | C × S |
| SEd | 0.05 | 0.06 | 0.09 | 0.04 | 0.06 | 0.10 | 0.05 | 0.05 | 0.10 |
| CD @ 5 % | 0.09 | 0.11 | 0.19 | 0.08 | 0.12 | 0.20 | 0.10 | 0.10 | 0.20 |

**Table 4. Effect of microbial inoculants on no. nodules plant-1 in groundnut crop (CO 7) at various salinity levels**

|  |  |
| --- | --- |
| Treatments  | No. of nodules per plant  |
| 4.03 dS m-1 | 5.01 dS m-1 | 6.02 dS m-1 | Mean |
| T1 – Control | 10.00 | 9.00 | 8.00 | **9.00** |
| T2 -TNAU Culture @ 1 L ha-1 | 13.00 | 13.00 | 12.00 | **13.33** |
| T3 - TNAU Culture @ 2 L ha-1 | 14.00 | 14.00 | 14.00 | **14.67** |
| T4 - TNAU Culture @ 3 L ha-1 | 15.00 | 15.00 | 15.00 | **15.67** |
| T5 - CSR-GROW-SURE @ 1 L ha-1 | 13.00 | 13.00 | 13.00 | **13.67** |
| T6 - CSR-GROW-SURE @ 2 L ha-1 | 15.00 | 15.00 | 14.00 | **15.00** |
| T7 - CSR-GROW-SURE @ 3 L ha-1 | 15.00 | 15.00 | 15.00 | **15.67** |
| Mean | **15.43** | **13.42** | **13..00** |   |
|   | Cultures (C) | Soils (S)  | C × S |
| SEd |  0.19 |   0.05 |  0.26 |
| CD @ 5 % |  0.38 |  0.10 | 0.48  |

****

**Figure 1. Influence of microbial inoculants on no. nodules plant-1 in groundnut crop (CO 7) at various salinity levels**