



Effect of Halotolerant Microbial Inoculants on Growth and Yield Attributes of Groundnut (*Arachis hypogaea* L.) under Varying Soil Salinity Levels in Dry Land Condition

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A pot culture experiment was conducted to assess the influence of microbial bio-stimulants CSR-GROW-SURE 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

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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, and while 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. Furthermore, the interaction of treatments with various salinity levels of soil indicated that the treatments CSR-GROW-SURE with 3 L ha⁻¹ and TNAU cultures with similar dosage at 4.03 dS m⁻¹ produced the increase in percentage of plant growth and yield attributes than treatment control. The treatment CSR-GROW-SURE with 3 L ha⁻¹ recorded the percentage increase of germination (94.47 %), root length (10.83 cm), number of nodules plant⁻¹ (15.67) and number of pods plant⁻¹ (17.00) over control. And the treatment 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) compared to control. 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.

Keywords: *Bacillus* spp.; CSR-GROW-SURE; dry land, groundnut; growth & yield; saline soils.

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 (Parmar et al., 2022). 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 it is categorized as dryland (Ganapathy 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 mostly limited by inadequate soil moisture and soil salinity (Osman et al., 2025 and Srinivasrao et al., 2025; Eşitken et al., 2002).

Salinity is a growing global problem, 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 (Kaur et al., 2025 and Saleem et al., 2025). Moreover, salinity reduces microbial diversity and soil enzymatic activities, further impacting crop performance (Li et al., 2025). In groundnut, saline conditions cause decrease in germination percentage, root and shoot growth,

nodulation, and eventually lower pod yield (Yunusa et al., 2025).

To address these challenges, the use of halotolerant plant growth-promoting rhizobacteria (PGPR) has emerged as an eco-friendly strategy (Santhosh et al., 2025). These beneficial microbes enhance plant growth through 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 and Ghosh 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 and Sarkar et al., 2018). Among these, *Bacillus* spp. is the most effective PGPRs due to their ability to form spores, withstand severe environmental conditions, and maintain a long shelf life makes them well-suited for use in dryland and saline agricultural systems (Abd-Allah et al., 2018; Srinivasrao et al., 2021).

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 (Zeiger et al., 2021). 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 different salinity levels of soil.

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 growth.

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 6.02 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 observe the influence of treatments.

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.

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

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
1.	Soil Texture	Sandy clay	Sandy clay	Sandy clay
2.	pH	8.00	8.10	8.20
3.	Available N (kg ha ⁻¹)	168.12	155.01	147.28
4.	Available P (kg ha ⁻¹)	6.76	5.99	5.91
5.	Exchangeable Calcium (meq kg ⁻¹)	10.34	12.64	14.58
6.	Exchangeable Magnesium (meq kg ⁻¹)	5.48	6.98	8.58
7.	Exchangeable Sodium (meq kg ⁻¹)	15.27	19.10	23.76
8.	Exchangeable Potassium (meq kg ⁻¹)	7.99	9.89	12.04
9.	Bicarbonates	3.34	3.67	3.91
10.	Chloride (meq kg ⁻¹)	22.10	27.00	35.15
11.	Sulphate (meq kg ⁻¹)	13.56	17.85	19.83

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). The initial soil properties were given in the (Table 1).

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 to 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).

$$\text{Germination percentage} = \frac{\text{Total no. of seeds germinated}}{\text{Total no. of seeds sown}} \times 100 \quad (1)$$

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 recorded in the treatment control with 71.89 % mean value. Comparing the soils, the per cent germination decreased with increase in soil EC levels. Significantly maximum per cent of germination was observed 4.03 dS m⁻¹ soil with the mean per cent germination of 89.25 % followed by 5.01, 6.02 dS m⁻¹ soils with 85.98 and 82.72 % respectively (Table 2). Celluloses, xylanases and mannanase also help

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
T ₁ - Control	74.62	71.89	69.16	71.89
T ₂ -TNAU Culture @ 1 L ha ⁻¹	89.54	86.27	82.99	86.27
T ₃ - TNAU Culture @ 2 L ha ⁻¹	91.04	87.71	84.38	87.71
T ₄ - TNAU Culture @ 3 L ha ⁻¹	94.02	90.58	87.14	90.58
T ₅ - CSR-GROW-SURE @ 1 L ha ⁻¹	89.69	86.41	83.13	86.41
T ₆ - CSR-GROW-SURE @ 2 L ha ⁻¹	91.33	87.99	84.65	87.99
T ₇ - 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	

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).

The interaction between microbial cultures and soil salinity levels showed significant differences in germination rates. The highest germination percentage (94.47%) was observed in the CSR-GROW-SURE treatment at 3 L ha⁻¹ under 4.03 dS m⁻¹ soil, with 20.63% increase compared to the control. This was on par with the treatment TNAU culture at the same application rate, which achieved a 94.02% germination rate an increase of 21.01% over the control. In contrast, the control treatment (without microbial inoculation) recorded the lowest germination percentages in 4.03, 5.01, 6.02 dS m⁻¹ saline soils. 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. Among the cultures, CSR-GROW-SURE with 3 L ha⁻¹ showed increase in root length with mean values 5.83, 7.40 and 10.43cm at vegetative, flowering, and post-harvest stage respectively. It was on par with treatment 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 post-harvest stage 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 root length was observed in the 4.03 dS m⁻¹ soil with mean values of 5.72, 7.25 and 10.23 cm and followed by 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 soil salinity and microbial cultures resulted in significant variations in root length at different growth stages. The highest root lengths for groundnut CO 7 were observed with the application of CSR-GROW-SURE at 3 L ha⁻¹ in soil with 4.03 dS m⁻¹ salinity, measuring 6.05 cm, 7.68 cm, and 10.83 cm at the vegetative, flowering, and harvest stages, respectively. These values represent an increase of 20.60 20.55 and 20.69% over the control. A similar performance was noted with the TNAU culture at the same application rate and salinity level, which produced root lengths of 6.02 cm, 7.64 cm, and 10.78 cm showing respective

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				
	4.03 dS m ⁻¹	5.01 dS m ⁻¹	6.02 dS m ⁻¹	Mean	4.03 dS m ⁻¹	5.01 dS m ⁻¹	6.02 dS m ⁻¹	Mean	4.03 dS m ⁻¹	5.01 dS m ⁻¹	6.02 dS m ⁻¹	Mean
T ₁ – 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
T ₂ -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
T ₃ - 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
T ₄ - 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
T ₅ - 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
T ₆ - 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
T ₇ - 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
T ₁ – Control	10.00	9.00	8.00	9.00
T ₂ -TNAU Culture @ 1 L ha ⁻¹	13.00	13.00	12.00	13.33
T ₃ - TNAU Culture @ 2 L ha ⁻¹	14.00	14.00	14.00	14.67
T ₄ - TNAU Culture @ 3 L ha ⁻¹	15.00	15.00	15.00	15.67
T ₅ - CSR-GROW-SURE @ 1 L ha ⁻¹	13.00	13.00	13.00	13.67
T ₆ - CSR-GROW-SURE @ 2 L ha ⁻¹	15.00	15.00	14.00	15.00
T ₇ - 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	

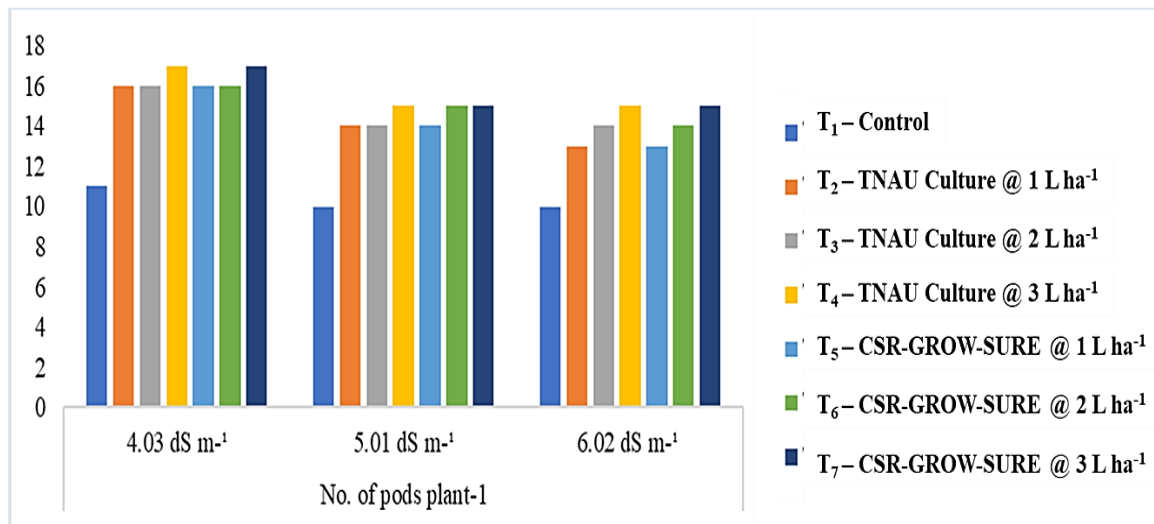


Fig. 1. Influence of microbial inoculants on no. nodules plant⁻¹ in groundnut crop (CO 7) at various salinity levels

increases of 20.99, 20.96% and 21.05% compared to the control (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

In groundnut, the application of microbial cultures enhanced the number of nodules plant⁻¹ across all doses and salinity levels. The nodule count increased gradually with higher microbial application rates but declined with increasing salinity levels across all treatments, including the control. The number of nodules per plant increased with the application of microbial cultures at all treatment levels. The highest mean value of 15.67 nodules was observed with both CSR-GROW-SURE and TNAU cultures applied at 3 L ha⁻¹, representing a 54.01% improvement over the control (Table 4). Among the different soil salinity levels, the maximum nodule count was recorded in soil with 4.03 dS m⁻¹ EC, with mean value of 15.43 nodules, followed by 13.42 at 5.01 dS m⁻¹ and 13.00 at 6.02 dS m⁻¹. Verma *et al.*, (2010) stated that no. of nodules per plant were increased due to IAA and ammonia production and nitrogen fixation. The maximum number of nodules per plant was recorded in saline soil with an EC of 4.03 dS m⁻¹,

where both CSR-GROW-SURE and TNAU cultures applied at 3 L ha⁻¹ showed a 34.49% increase in nodule formation compared to the control. 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 yield potential of groundnut is directly impacted by no. of pods plant⁻¹. Beneficial microbes in the soil will increase nutrient uptake and overall plant health, which improves the pod development. Among the cultures CSR-GROW-SURE with 3 L ha⁻¹ showed significantly highest no. of pods plant⁻¹ with mean value of 15.67 and it was on par with the TNAU culture with 3 L ha⁻¹ with mean value of 15.67 and the less mean value was observed in the treatment control with 10.33. Comparing the soils, the highest no. of pods plant⁻¹ was recorded in the 4.03 dS m⁻¹ soil with mean value of 15.57 followed by 5.01 and 6.02 dS m⁻¹ with mean value of 13.86 and 13.43 respectively. Hou *et al.*, (2021) revealed that increase in pod number due to N₂ fixation and auxin production and siderophores.

The interaction between microbial cultures and salinity levels significantly influenced the number of pods per plant. The highest number of pods (17.00) was observed with the CSR-GROW-SURE treatment at 3 L ha⁻¹ under 4.03 dS m⁻¹

salinity, with 35.29% increase over the control. This result was statistically on par with the TNAU culture applied at the same rate, which also produced 17.00 pods per plant under the same salinity level, showing an identical percentage (35.29 %) increase. A similar trend was seen at higher salinity levels (5.01 and 6.02 dS m⁻¹), where both treatments (CSR-GROW-SURE and TNAU culture at 3 L ha⁻¹) recorded 15.00 pods per plant. In contrast, the control treatment constantly showed lower pod numbers, with 11.00, 10.00, and 10.00 pods per plant under 4.03, 5.01, and 6.02 dS m⁻¹ salinity levels, respectively (Fig. 1). Indole Acetic Acid production by beneficial microbes enhances root growth and nutrient uptake, will prove the plant vigour. This, in turn, promotes flower and pod development, resulting in an increased number of pods plant⁻¹ (Pradhan *et al.*, 2017).

4. CONCLUSION

The study highlights the significant potential of halotolerant microbial inoculants, particularly CSR-GROW-SURE and TNAU culture (*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 confirm the role of microbial bio-inoculants as a sustainable and eco-friendly solution for managing saline soils. Furthermore, field-level evaluation, formulation development, and integration with nutrient management practices are essential. Moreover, 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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