**Impact of Microbial Inoculants on Soil Exchangeable Cations in Salinity-Affected Dryland Soils**

**Abstract**

 A laboratory incubation study was conducted at Tamil Nadu Agricultural University, Coimbatore (2021-2022), to evaluate the efficacy of salt-tolerant microbial inoculants for the biological remediation of saline soils with an electrical conductivity (EC) of 4.03, 5.01, and 6.02 dS m-1 under dry land conditions (75 % field capacity). Two microbial consortia CSR-GROW-SURE [contained halo-tolerant strains including Lysinibacillus fusiformis (CSR-A-11), Lysinibacillus sphaericus (CSR-A-16), and Bacillus licheniformis (CSR-M-16)] and the TNAU culture (*Bacillus subtilis*) were applied at three dosage levels: 1, 2, and 3 L ha-1. Soil samples were collected at 30, 60, and 90 days after incubation (DAI) to assess changes in soil exchangeable cations. The application of CSR-GROW-SURE at 3 L ha-1 significantly reduced the levels of exchangeable calcium (Ca2+), magnesium (Mg2+), and sodium (Na⁺) in saline soils with EC levels of 4.03, 5.01, and 6.02 dS m-1 at 90 days after incubation (DAI), compared to the control. The percentage reductions observed were (8.11, 4.27 and 5.69%) for Ca2+; (8.01%, 4.29%, and 5.59%) for Mg2+; and (26.45, 26.04 and 25.64%) for Na+, respectively. In contrast, exchangeable potassium (K⁺) showed the highest percentage increase of (15.44, 17.03, and 14.72%) at the same EC levels. These results were statistically on par with those recorded for the TNAU culture applied at 3 L ha-1 at the same incubation period, indicating similar efficacy in improving soil chemical properties under similar salinity levels. These findings suggest that halo-tolerant microbial inoculants, particularly CSR-GROW-SURE and TNAU culture with 3 L ha-1, hold considerable potential for the reclamation of saline soils. Their application enhances nutrient mobilisation, mitigates salinity-induced stress, and contributes to sustaining soil health in salt-affected dry land ecosystems.

***Key Words***: *Bacillus spp.*, CSR-GROW-SURE, Dry land, Exchangeable cations, Saline soils

**Introduction**

Salt-affected soils are mainly found in arid and semi-arid regions where evaporation exceeds rainfall, leading to salt accumulation (Mwesige *et al.,* 2025). These include salts like calcium (Ca2+), magnesium (Mg2+), sodium (Na+) and potassium (K+), chlorides, carbonates, and bicarbonates (Singh *et al.,* 2025). Saline soils are defined by EC > 4.0 dS m⁻¹ (Richards, 1954), ESP < 15, SAR < 13, and pH < 8.5 (Gupta and Abrol, 1990). Natural factors like rock weathering, wind deposition, and runoff, along with human activities, cause salinity (Shrivastava and Kumar, 2015). In saline soils carbonates are absent and pH generally remains below 8.2 (Abrol *et al.,* 1980).

Though saline soils have good structure due to flocculation (Reid et al., 1950), leaching can cause dispersion, reducing permeability (Abrol *et al*., 1988 and Saleem *et al.*, 2025). Salinity impairs osmotic potential, limiting water and nutrient uptake and microbial activity, reducing productivity (Gupta and Abrol, 1990 ad Goszez *et al*., 2025). Reclamation involves leaching and drainage (Chen *et al*., 2025). In drylands, salinity suppresses organic matter decomposition and nutrient cycling (Tripathi *et al.,* 2006; Elmajdoub and Marschner, 2013 and Sahoo *et al.,* 2025). In such areas, microbes offer an alternative to ineffective chemical amendments (Saqib *et al.,* 2017; Shultana *et al.,* 2020).

Microbes like *Bacillus*, *Pseudomonas*, and *Arthrobacter* enhance soil properties (Jha and Subramanian, 2014; Bhise et al., 2017 and Sarkar et al., 2018). *Bacillus* *spp*. are stress-tolerant and effective PGPRs (Abd-Allah *et al.,* 2018 and Leser *et al.,* 2008). They improve stress tolerance by producing IAA, gibberellins, cytokinins, ACC deaminase (Dey *et al.,* 2004), and exopolysaccharides (Upadhyay *et al.,* 2009). They solubilize nutrients using organic acids and siderophores (Shanware *et al.,* 2014 and Egamberdieva *et al.,* 2019), bind Na+ (Chen *et al.,* 2007), and conserve nutrients (Kaiser *et al.,* 2015). Microbial management reduces fertilizer use (Damodaran *et al.,* 2011; Saharan and Nehra, 2011; Glick, 2012), improves soil fertility and enhances soil properties (Damodaran *et al.,* 2013). In India, 57% of agricultural land is dryland; in Tamil Nadu, it is 65%, growing crops like sorghum, maize, groundnut, and pulses. Though rainfed farming holds high potential, salinity and moisture stress must be managed microbial to improve productivity (Shaw *et al.,* 1976). The present study is aimed at reclaiming the saline soils by using microbial cultures which are halophilic in nature that is *Bacillus* *spp*. through incubation experiment for 30, 60 and 90 days.

1. **Materials and Methods**

**2.1 Collection of soil samples**

Soil samples with an EC of 4.03, 5.01, and 6.02 dS m-1 were collected from three sites in Adivalli village, Udumalpet taluk, Coimbatore district, Tamil Nadu. The sampling locations were situated at latitudes 10°41′44″ N, 10°41′33″ N, and 10°41′29″ N, and longitudes 77°09′21″ E, 77°09′18″ E, and 77°09′04″ E, respectively.

**2.2 Collection of Microbial Consortia**

In this study, microbial consortia comprising salt-tolerant bacterial strains were applied to evaluate their efficacy under saline soil conditions. The commercial bio-stimulant CSR-GROW-SURE, obtained from the Central Soil Salinity Research Institute (CSSRI), Karnal, Haryana, contained halo-tolerant strains including Lysinibacillus fusiformis (CSR-A-11), Lysinibacillus sphaericus (CSR-A-16), and Bacillus licheniformis (CSR-M-16). In addition, a salinity-resistant strain of Bacillus subtilis, collected from Tamil Nadu Agricultural University (TNAU), Coimbatore, was characterized and included as a comparative treatment to assess performance relative to CSR-GROW-SURE under saline soil dry land conditions.

**2.3. Details of Incubation Experiment**

For this incubation experiment, 250 g of air-dried and 2 mm sieved 4.03, 5.01 and 6.02 dS m-1 saline soil were used. The soil was treated with microbial inoculants with three different doses @ 1, 2 and 3 L ha-1 on a weight basis, following the Factorial Completely Randomized Design (FCRD) with three replications. Three separate sets were maintained for destructive sampling. The microbial formulations included the TNAU Culture (*Bacillus subtilis*) containing 2.8 × 10⁷ CFU mL-1 and the CSR-GROW-SURE bio-stimulant with 1.0 × 10⁷ CFU mL-1, both of which were applied to the soil. The incubation was carried out under this moisture condition for a period of 90 days, based on the weight loss distilled water was added once in two days to the container to maintain a uniform moisture content throughout the incubation period. Destructive sampling was done at intervals *viz.,* 30, 60 and 90 days after incubation and analysed for soil cations. Moisture factor was calculated and applied to express the results on an oven dry basis.

**2.4. Treatment details**

An incubation experiment was conducted to evaluate the reclamation potential of two microbial inoculants applied at varying doses under saline soil conditions. The study involved three levels of soil electrical conductivity (EC: 4.03, 5.01, and 6.02 dS m-1), maintained at 75% field capacity. The treatments included: Control (T1), TNAU Culture at 1 L ha-1 (T2), 2 L ha-1 (T3), and 3 L ha-1 (T4), and CSR-GROW-SURE at 1 L ha-1 (T5), 2 L ha-1 (T6), and 3 L ha-1 (T7). The experiment was conducted over a 90-day incubation period and each treatment was replicated three times.

**2.5 Methodology**

**2.5.1. Soil Analysis**

In soil the EC was analyzed by the 1:2.5 Soil water extract method (Jackson 1973) and theexchangeable Ca2+ and Mg2+ cations were determined using the Versenate method, which uses EDTA-based complex metric titration to calculate divalent cations. Exchangeable Na+ and K+ was analyzed using a flame photometer, allowing accurate measurement through emission intensity following the procedure outlined by Richards (1954). The initial soil cations in the incubation experiment was presented in the (Table 1).

**Table 1. Initial soil cation properties**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **S. No** | **Soil Parameter** | **Soil EC****(4.03 dS m-1)** | **Soil EC****(5.01 dS m-1)** | **Soil EC****(6.02 dS m-1)** |
| 1. | Exchangeable Ca2+(meq kg-1) | 10.34 | 12.64 | 14.6 |
| 2. | Exchangeable Mg2+ (meq kg-1) | 5.48 | 6.98 | 8.58 |
| 3. | Exchangeable Na+ (meq kg-1) | 15.27 | 19.10 | 23.8 |
| 4. | Exchangeable K+ (meq kg-1) | 7.99 | 9.89 | 12.04 |

**2.6. Statistical Analysis**

The data acquired from the experiment were subjected to statistical analysis using AGRESS software version 7.01. Critical Difference (CD) values were calculated for the P < 0.05 whenever “F” test was found significant Gomez and Gomez (1984). For clear visual interpretation a heat map was created using “pheatmap” package in R software following data normalization and hierarchical clustering to enhance pattern recognition across variables.

**3. Results and discussion**

**3.1. Impact of microbial inoculants on soil exchangeable calcium in saline soil**

 Irrespective of soil EC levels (4.03, 5.01, and 6.02 dS m-1), a reduction in exchangeable Ca2+ was consistently observed following the application of CSR-GROW-SURE at 3 L ha-1, which recorded mean values of 9.74, 12.3, and 14.0 meq kg-1, respectively, under 75 % FC conditions. These values were statistically comparable to those obtained with TNAU culture at 3 L ha-1, which showed similar mean values of 9.77, 12.3, and 14.0 meq kg-1. In contrast, the highest exchangeable Ca2+ concentrations were observed in the control treatment, with mean values of 10.35, 12.65 and 14.59 meq kg-1 under the respective EC levels (Table 2). Across all treatments and EC levels, a general decline in exchangeable Ca2+ was noted with increasing incubation duration: from 10.0 to 9.70 meq kg-1 (4.03 dS m-1), 12.5 to 12.2 meq kg-1 (5.01 dS m-1), and 14.3 to 13.9 meq kg-1 (6.02 dS m-1). This reduction in exchangeable Ca2+ content is likely attributed to the production of organic acids particularly carbonic acid by *Bacillus* *spp*., which enhances the solubilisation and displacement of Ca2+ions in the soil matrix (Macias-Benitez *et al*., 2020).

 The interaction effect between microbial inoculants and incubation period further revealed that the greatest reduction in exchangeable Ca2+ occurred under CSR-GROW-SURE at 3 L ha-1 at 90 DAI, with corresponding values of 9.52, 12.12, and 13.76 meq kg-1 showing percentage reduction of 8.11, 4.27 and 5.69 % in soils with EC levels of 4.03, 5.01, and 6.02 dS m-1, respectively, than control treatment. This trend was on par with the TNAU culture at 3 L ha-1, which recorded values of 9.57, 12.14, and 13.78 meq kg-1 under the same conditions with percentage decrease of 7.63, 4.11 and 5.55 % respectively. This was supported by the findings of Chen *et al*., (2000), who confirmed that organic acids produced by *Bacillus* *spp*. promote the dissolution of calcareous minerals, thereby influencing soil exchangeable Ca2+ dynamics. Similarly, Neina (2019) reported that the production of organic acids led to alterations in soil pH, which subsequently contributed to a reduction in exchangeable Ca2+content in the soil.

**3.2. Impact of microbial inoculants on soil exchangeable magnesium** in **saline soil**

With respect to exchangeable Mg2+, the application of CSR-GROW-SURE at 3 L ha-1 resulted in a notable reduction, with mean values of 5.17, 6.77, and 8.23 meq kg-1 observed under soil EC levels of 4.03, 5.01, and 6.02 dS m-1, respectively (Table 3). This reduction was statistically comparable to that observed with the TNAU culture at 3 L ha-1, which recorded mean exchangeable Mg2+ concentrations of 5.18, 6.78, and 8.24 meq kg-1 under the corresponding EC levels. In contrast, the control treatment exhibited higher exchangeable Mg2+ levels, with values of 5.48, 6.99, and 8.58 meq kg-1 at 75% FC across the respective EC conditions.

The most pronounced reduction in exchangeable Mg2+ was observed at 90 DAI, with mean values decreasing from 5.33 to 5.14 meq kg-1 (EC 4.03 dS m-1), 6.89 to 6.75 meq kg-1 (EC 5.01 dS m-1), and 8.42 to 8.18 meq kg-1 (EC 6.02 dS m-1). This decline is attributed to soil acidification driven by microbial activity, particularly the production of organic acids, which alters soil pH and facilitates the reduction of exchangeable Mg2+ (Stamford et al., 2007).

The interaction between microbial inoculants and incubation period revealed that the greatest reduction in exchangeable Mg2+ occurred under CSR-GROW-SURE at 3 L ha-1 at 90 days of incubation, with percentage reduction of 8.01, 4.29 and 5.59% over control at EC levels of 4.03, 5.01, and 6.02 dS m-1, respectively. These results were statistically on par with those recorded under the TNAU culture at 3 L ha-1, with decrease in percentage of 7.83, 4.14 and 5.48 % than control under the similar salinity levels of soil. These findings are supported by Thomas *et al*., (2014), who reported that cation binding by *Bacillus* *spp*. contributes to the reduction of exchangeable Mg2+ in soil.

**3.3. Impact of microbial inoculants on soil exchangeable sodium in saline soil**

The exchangeable Na+ content decreased progressively with the application of microbial inoculants across varying dosages, and this reduction intensified with increasing incubation duration. Application of CSR-GROW-SURE at 3 L ha-1 resulted in a mean reduction of exchangeable Na+ to 12.3, 15.5, and 19.5 meq kg-1 under soil EC levels of 4.03, 5.01, and 6.02 dS m-1, respectively (Table 4). These values were statistically comparable to those observed with the TNAU culture at 3 L ha-1, which recorded exchangeable Na+ concentrations of 12.5, 15.6, and 19.6 meq kg-1 under the respective salinity conditions. In contrast, the control treatment exhibited the highest mean exchangeable Na+ contents, measuring 15.3, 19.2, and 23.9 meq kg-1 at the corresponding EC levels. This reduction is likely due to Na+ displacement facilitated by organic acids such as sulfuric acid produced by *Bacillus* *spp*. during microbial activity (Stamford *et al*., 2007).

The application of CSR-GROW-SURE and TNAU culture at 3 L ha-1 resulted in 20-22% and 20-21% reductions in exchangeable Na+, respectively, compared to the untreated control. With increasing incubation time, a continuous decrease in Na+ content was observed up to 90 days: from 13.9 to 12.0 meq kg-1 (EC 4.03 dS m-1), 17.4 to 15.1 meq kg-1 (EC 5.01 dS m-1), and 21.9 to 18.8 meq kg-1 (EC 6.02 dS m-1), under 75% field capacity. Damodaran *et al*., (2013) further demonstrated that *Bacillus subtilis* and *Bacillus pumilus* could reduce soil Na⁺ content through active uptake, with reported values of 1.271 and 1.122 meq L-1, respectively, under 1 M NaCl conditions.

The interaction between microbial inoculant type, dosage, and incubation period was found to significantly influence exchangeable Na+ concentrations. At 90 DAI, the most pronounced reductions were recorded in soils treated with CSR-GROW-SURE at 3 L ha-1, with Na+ levels showed percentage reduction of 8.01, 4.29 and 5.59% over control at EC levels of 4.03, 5.01, and 6.02 dS m-1, respectively. These reductions were statistically on par with those observed under TNAU culture at 3 L ha-1, with decrease in percentage of 7.83, 4.14 and 5.48 % than control under the similar conditions. The efficacy of microbial inoculants in lowering soil exchangeable Na+ has also been substantiated by previous studies (Sarathambal & Ilamurugu, 2013; Arora *et al*., 2016), highlighting their role in improving soil chemical properties under saline stress.

**3.4. Impact of microbial inoculants on exchangeable potassium in saline soil**

An increase in exchangeable K+ was observed in soils treated with the microbial inoculant CSR-GROW-SURE at 3 L ha-1, with mean values of 8.96, 11.3, and 13.5 meq kg-1 under soil EC levels of 4.03, 5.01, and 6.02 dS m-1, respectively. These values were statistically comparable to those obtained with the TNAU culture at the same application rate, which recorded mean values of 8.91, 11.3, and 13.4 meq kg-1 across the corresponding EC levels. In contrast, the control treatment recorded the lowest mean exchangeable K+ content, with values of 7.96, 9.86, and 12.0 meq kg-1 under the respective salinity levels at 75% field capacity (Table 5). This enhancement in K+ levels is attributed to the solubilization of native soil K⁺. Similar findings have been reported by Parmar *et* *al*., (2016), confirming the effectiveness of this process.

Exchangeable K+ content increased progressively with the duration of incubation, ranging from 8.34 to 9.12 meq kg-1 (EC 4.03 dS m-1), 10.5 to 11.5 meq kg-1 (EC 5.01 dS m-1), and 12.6 to 13.7 meq kg-1 (EC 6.02 dS m-1). This enhancement in K+ availability may be attributed to the microbial solubilisation of native soil K+ through the production of organic acids such as citric and gluconic acids (Velivelli *et al*., 2014).

The interaction between microbial inoculant type and incubation duration revealed a significant increase in exchangeable K+ content compared to the control. The highest percentage increase in exchangeable K+ was recorded in soils treated with CSR-GROW-SURE at 3 L ha-1 at 90 days of incubation with 15.44, 17.03 and 14.72 % over control treatment in soils with EC level of 4.03, 5.01, and 6.02 dS m-1, respectively. These values were statistically on par with TNAU culture at the same dose, recorded percentage increase of 14.99, 16.54 and 14.48% than control under the similar conditions. The increase in exchangeable K+ availability is likely due to the action of organic acids such as lactic, pyruvic, and butyric acids secreted by *Bacillus* *spp*., which facilitate the solubilisation of non-exchangeable soil potassium (Styriakova *et al*., 2003).

**4. Conclusion**

The results of the incubation experiment demonstrated that the concentrations of exchangeable cations such as Ca2+, Mg2+, and Na+ decreased significantly following the application of both microbial inoculants, irrespective of dosage and incubation duration, across all salinity levels (4.03, 5.01, and 6.02 dS m-1) under 75% field capacity. The percentage reduction in these cations increased linearly with higher application rates and longer incubation periods. Among the cations, the most pronounced reduction was observed in exchangeable Na⁺ levels. In contrast, the application of both microbial inoculants led to a consistent increase in exchangeable K+ across all treatments and incubation period. The concentration of increase in exchangeable K+ was positively correlated with both the dosage of bio inoculants and the duration of incubation.

Among the treatments, CSR-GROW-SURE applied at 3 L ha-1 resulted in the greatest reductions in exchangeable Ca2+, Mg2+, and Na+ across all salinity levels, which were statistically comparable to those achieved with TNAU culture at the same dose under 75% FC at 90 DAI. Similarly, CSR-GROW-SURE at 3 L ha-1 also recorded the highest levels of exchangeable K⁺ at 90 DAI and the results were on par with the TNAU culture at 3 L ha-1 under all EC levels at 90 DAI. These findings highlight the efficacy of both microbial inoculants particularly at higher application rates in modulating the ionic composition of saline soils. Their ability to reduce harmful cations while enhancing exchangeable K+ availability enhances their potential in ameliorating saline soils and promoting sustainable soil health.

**5. Competing Interests**

 The authors declared that they have no conflicts of interest to disclose.

**6. Acknowledgement**

 The authors gratefully acknowledge the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, for providing the requisite laboratory infrastructure that facilitated the scientific execution of the incubation studies. The contribution of Dr. T. Damodaran and the ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI), Karnal, in providing the CSR-GROW-SURE halotolerant microbial bio-inoculant, which played a crucial role in this research.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, manuscript.

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**Table 2. Effect of microbial cultures on soil exchangeable Ca2+ (meq kg-1) under various salinity levels**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments**  | **4.03 dS m-1** | **5.01 dS m-1** | **6.02 dS m-1** |
| **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** |
| **T1 – Control** | 10.34 | 10.36 | 10.36 | 10.35 | 12.63 | 12.66 | 12.66 | 12.65 | 14.58 | 14.59 | 14.59 | 14.59 |
| **T2 -TNAU Culture @ 1 L ha-1** | 10.04 | 9.79 | 9.64 | 9.83 | 12.47 | 12.29 | 12.17 | 12.31 | 14.33 | 14.02 | 13.82 | 14.06 |
| **T3 - TNAU Culture @ 2 L ha-1** | 10.02 | 9.77 | 9.61 | 9.80 | 12.45 | 12.27 | 12.15 | 12.29 | 14.31 | 14.01 | 13.81 | 14.04 |
| **T4 - TNAU Culture @ 3 L ha-1** | 9.99 | 9.75 | 9.57 | 9.77 | 12.44 | 12.26 | 12.14 | 12.28 | 14.27 | 13.99 | 13.78 | 14.01 |
| **T5 - CSR-GROW-SURE @ 1 L ha-1** | 10.02 | 9.77 | 9.61 | 9.80 | 12.45 | 12.27 | 12.15 | 12.29 | 14.31 | 14.01 | 13.81 | 14.04 |
| **T6 - CSR-GROW-SURE @ 2 L ha-1** | 9.99 | 9.75 | 9.57 | 9.77 | 12.44 | 12.26 | 12.14 | 12.28 | 14.27 | 13.99 | 13.78 | 14.01 |
| **T7 - CSR-GROW-SURE @ 3 L ha-1** | 9.97 | 9.73 | 9.52 | 9.74 | 12.42 | 12.23 | 12.12 | 12.26 | 14.25 | 13.98 | 13.76 | 14.00 |
| **Mean** | 10.05 | 9.85 | 9.70 |   | 12.47 | 12.32 | 12.22 |   | 14.33 | 14.08 | 13.91 |   |
|  | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D |
| **SEd** |  0.02 |  0.0 |  0.05 |  0.01 |  0.03 |  0.04 |  0.01 |  0.05 |  0.06 |
| **CD @ 5 %** |  0.04 | 0.06  |  0.10 |  0.03 | 0.06  |  0.09 |  0.02 | 0.10  | 0.12  |

**Table 3. Effect of microbial cultures on soil exchangeable Mg2+ (meq kg-1) under various salinity levels**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments**  | **4.03 dS m-1** | **5.01 dS m-1** | **6.02 dS m-1** |
| **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** |
| **T1 – Control** | 5.48 | 5.48 | 5.49 | 5.48 | 6.98 | 7.000 | 7.000 | 6.99 | 8.58 | 8.58 | 8.58 | 8.58 |
| **T2 -TNAU Culture @ 1 L ha-1** | 5.32 | 5.19 | 5.10 | 5.21 | 6.89 | 6.79 | 6.72 | 6.80 | 8.42 | 8.25 | 8.13 | 8.27 |
| **T3 - TNAU Culture @ 2 L ha-1** | 5.31 | 5.18 | 5.09 | 5.19 | 6.88 | 6.78 | 6.71 | 6.79 | 8.41 | 8.24 | 8.12 | 8.26 |
| **T4 - TNAU Culture @ 3 L ha-1** | 5.30 | 5.17 | 5.06 | 5.18 | 6.87 | 6.77 | 6.71 | 6.78 | 8.39 | 8.23 | 8.11 | 8.24 |
| **T5 - CSR-GROW-SURE @ 1 L ha-1** | 5.31 | 5.18 | 5.09 | 5.19 | 6.88 | 6.78 | 6.71 | 6.79 | 8.41 | 8.24 | 8.12 | 8.26 |
| **T6 - CSR-GROW-SURE @ 2 L ha-1** | 5.30 | 5.17 | 5.06 | 5.18 | 6.87 | 6.77 | 6.71 | 6.78 | 8.39 | 8.23 | 8.11 | 8.24 |
| **T7 - CSR-GROW-SURE @ 3 L ha-1** | 5.29 | 5.16 | 5.05 | 5.17 | 6.86 | 6.76 | 6.70 | 6.77 | 8.38 | 8.22 | 8.10 | 8.23 |
| **Mean** | 5.33 | 5.22 | 5.14 |   | 6.89 | 6.81 | 6.75 |   | 8.42 | 8.29 | 8.18 |   |
|  | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D |
| **SEd** |  0.01 |  0.03 |  0.04 |  0.01 |  0.01 |  0.02 |  0.005 |  0.03 |  0.04 |
| **CD @ 5 %** |  0.02 | 0.06  | 0.08  |  0.02 | 0.03 | 0.05 | 0.01  | 0.06 | 0.07  |

**Table 4. Effect of microbial cultures on soil exchangeable Na+ (meq kg-1) under various salinity levels**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments**  | **4.03 dS m-1** | **5.01 dS m-1** | **6.02 dS m-1** |
| **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** |
| **T1 - Control** | 15.27 | 15.39 | 15.39 | 15.35 | 18.99 | 19.24 | 19.24 | 19.16 | 23.76 | 23.91 | 23.91 | 23.86 |
| **T2 -TNAU Culture @ 1 L ha-1** | 13.86 | 12.57 | 11.64 | 12.69 | 17.34 | 15.86 | 14.70 | 15.96 | 21.78 | 19.66 | 18.16 | 19.87 |
| **T3 - TNAU Culture @ 2 L ha-1** | 13.76 | 12.43 | 11.52 | 12.57 | 17.18 | 15.70 | 14.55 | 15.81 | 21.64 | 19.51 | 18.03 | 19.73 |
| **T4 - TNAU Culture @ 3 L ha-1** | 13.64 | 12.31 | 11.42 | 12.46 | 17.01 | 15.53 | 14.40 | 15.65 | 21.52 | 19.38 | 17.90 | 19.60 |
| **T5 - CSR-GROW-SURE @ 1 L ha-1** | 13.76 | 12.43 | 11.52 | 12.57 | 17.18 | 15.70 | 14.55 | 15.81 | 21.64 | 19.51 | 18.03 | 19.73 |
| **T6 - CSR-GROW-SURE @ 2 L ha-1** | 13.64 | 12.31 | 11.42 | 12.46 | 17.01 | 15.53 | 14.40 | 15.65 | 21.52 | 19.38 | 17.90 | 19.60 |
| **T7 - CSR-GROW-SURE @ 3 L ha-1** | 13.53 | 12.17 | 11.32 | 12.34 | 16.86 | 15.36 | 14.23 | 15.48 | 21.40 | 19.23 | 17.78 | 19.47 |
| **Mean** | 13.92 | 12.80 | 12.03 |   | 17.37 | 16.13 | 15.15 |   | 21.89 | 20.08 | 18.82 |   |
|  | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D |
| **SEd** |   0.06 |   0.12 |   0.18 |   0.12 |   0.18 |   0.28 |   0.09 |   0.09 |   0.16 |
| **CD @ 5 %** |   0.14 |   0.24 |   0.38 |   0.25 |  0.32 |  0.52  |   0.18 |   0.18 |   0.36 |

**Table 5. Effect of microbial cultures on soil exchangeable K+ (meq kg-1) under various salinity levels**

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatments**  | **4.03 dS m-1** | **5.01 dS m-1** | **6.02 dS m-1** |
| **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** | **30 DAS** | **60 DAS** | **90 DAS** | **Mean** |
| **T1 - Control** | 7.99 | 7.94 | 7.94 | 7.96 | 9.89 | 9.84 | 9.84 | 9.86 | 12.04 | 11.99 | 11.99 | 12.00 |
| **T2 -TNAU Culture @ 1 L ha-1** | 8.35 | 8.86 | 9.23 | 8.81 | 10.55 | 11.16 | 11.65 | 11.12 | 12.63 | 13.39 | 13.93 | 13.32 |
| **T3 - TNAU Culture @ 2 L ha-1** | 8.37 | 8.93 | 9.29 | 8.86 | 10.62 | 11.23 | 11.72 | 11.19 | 12.69 | 13.44 | 13.97 | 13.37 |
| **T4 - TNAU Culture @ 3 L ha-1** | 8.42 | 8.97 | 9.34 | 8.91 | 10.69 | 11.29 | 11.79 | 11.26 | 12.74 | 13.49 | 14.02 | 13.42 |
| **T5 - CSR-GROW-SURE @ 1 L ha-1** | 8.37 | 8.93 | 9.29 | 8.86 | 10.62 | 11.23 | 11.72 | 11.19 | 12.69 | 13.44 | 13.97 | 13.37 |
| **T6 - CSR-GROW-SURE @ 2 L ha-1** | 8.42 | 8.97 | 9.34 | 8.91 | 10.69 | 11.29 | 11.79 | 11.26 | 12.74 | 13.49 | 14.02 | 13.42 |
| **T7 - CSR-GROW-SURE @ 3 L ha-1** | 8.46 | 9.02 | 9.39 | 8.96 | 10.75 | 11.38 | 11.86 | 11.33 | 12.78 | 13.53 | 14.06 | 13.46 |
| **Mean** | 8.34 | 8.80 | 9.12 |   | 10.55 | 11.06 | 11.48 |   | 12.62 | 13.25 | 13.71 |   |
|  | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D | Cultures(C) | Duration(D) | C × D |
| **SEd** |  0.05 |  0.11 |  0.15 |  0.05 |  0.10 |  0.15 |  0.03 |  0.13 |  0.16 |
| **CD @ 5 %** |  0.09 | 0.22 | 0.31  | 0.09  | 0.20 | 0.29  | 0.06  | 0.25 |  0.31  |