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Effect of Halophilic Bio-formulations on Soil Fertility and Productivity of Salt Tolerant Variety of Paddy in Sitapur District

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ABSTRACT

Background: Soil salinity and sodicity significantly hinder agricultural productivity, particularly in regions with salt-affected soils. Halophilic bio-formulations, which employ salt-tolerant microorganisms, offer a sustainable approach to improving soil fertility and crop yield. This study evaluates the effects of such bio-formulations-Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix-on the growth of the salt-tolerant rice variety CSR-43 in sodic and normal soils of the Parsendi block, Sitapur district, Uttar Pradesh.

Methods: The experiment employed a randomized block design with five treatments and four replications. Rice seeds and seedlings were treated with halophilic bio-formulations before sowing and transplantation. Growth parameters (plant height, tillers, panicle length, grains per panicle, test weight and grain yield) and soil chemical properties (pH, electrical conductivity, organic carbon and macronutrients) were analyzed pre-and post-harvest using standard methods.

Result: Bio-formulations significantly enhanced growth parameters and yield in both sodic and normal soils. The highest improvements in plant height (7.50%), panicle length (33.48%), tillers per hill (12.38%), test weight (16.59%) and grain yield (7.57%) were observed with Halo-Mix treatment in sodic soil. Soil fertility metrics, such as nitrogen, phosphorus and potassium levels also improved, with Halo-Mix showing the highest efficacy. Sodic soil pH was slightly neutralized and organic carbon content increased.

Key words: Grain yield, Halophilic bio-fertilizers, Rice (CSR-43), Sodic soil, Soil fertility.

INTRODUCTION

Agriculture focused on non-food purposes often produces bio-energy. This leads to withdrawing of large amounts of biomass, resulting in the degradation and depletion of soils. As an alternative to mineral fertilization, there is currently a growing interest in exploring the benefits and opportunities as well as the limitations in the use of organic amendments, as compost and biochar to enhance plant nutrition, crop yield and quality, protect soil fertility and ensure environmental sustainability of crop production (Rao *et al.*, 2023). Returning the organic matter in the form of biochar back to soils presents an effective solution for this issue where half of the carbon can be returned to the soil while improving the soil fertility (Joseph *et al.*, 2007), which is the main factor of agriculture profitability. Increasing soil salinity and sodicity are serious worldwide land degradation issues and may even increase rapidly in the future (Wong *et al.*, 2009). In India, about 6.9 million hectares of sodic soils are found, of which 1.63 million hectares occur in Uttar Pradesh only which is the largest area found in any single state in the country. Only a negligible portion of soils in UP is saline, the bulk suffering from alkalinity, associated with excess of available sodium, poor porosity, low nutrient content, indifferent drainage and high water-table (Pandey *et al.*, 2011).

Rice (*Oryza sativa* L.) is a staple food for over half the global population and serves as a crucial crop for many small-scale farmers, providing both income and food security. In India, approximately 8 million hectares (Mha) are affected by salinity, with 3.1 million hectares located in coastal regions. Rice is the dominant crop in these saline soils, but the challenges are significant. Effective management strategies are essential to sustain rice production and ensure food security for the local population. The microbial strains available as bio-fertilizers for different crops do not perform effectively under salt stress and their activity decreases when used in salt affected soils due to osmolysis (Arora *et al.*, 2014). The soils of vast areas of country are sodic or saline sodic and these soils have low productivity due to poor physical and bio-chemical properties including low nutrient status. Physical and

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chemical methods of their reclamation are not cost-effective and also the availability of gypsum or other chemical amendments is a problem. The advanced microbial technology for bioremediation of salt affected soils through salt tolerant (halophilic) bacterial strains of N fixers, P and Zn solubilizing bacteria have been developed by ICAR CSSRI, RRS, Lucknow. These strains were characterized for plant growth promotion and tested for their efficacy under different levels of salt stress. To enable the seed application of these promising selected strains of beneficial soil microorganisms, these were made available as liquid bio-formulations *viz*. Halo Azo, Halo-PSB and Halo-Zinc. These can be used either for seed treatment or soil application. Application of these bio-formulations helps to improve the availability of plant nutrients like N, P and Zn through their activities in the soil or rhizosphere in a gradual manner under salt stress (Arora, 2020). These have been effective in improving yield of rice, wheat, mustard, vegetables and pulses in normal as well as salt affected soils and effective in soil health management to promote organic farming.

Halophilic bio-formulation refers to the use of microorganisms that thrive in high-salinity environments to enhance agricultural productivity, particularly in saline or saline-alkaline soils. These bio-formulations harness the unique properties of halophilic microorganisms, which can withstand and even flourish in salty conditions. Several researchers reported that introduction of these microbes are found very effective in salt affected soils to improve the crop productivity, quality of produce and soil properties (Kumar *et al.*, 2014; Sahay and Patra, 2013). Halophilic bio-formulation can play a greater role in such soil conditions to improve crop productivity and soil fertility as well. Halophilic bio-formulations present a promising approach to managing saline soils and improving agricultural productivity in challenging environments. Their unique properties and capabilities make them valuable tools in sustainable agriculture, especially as global salinity levels rise due to various environmental factors. Utilizing these bio-formulations can lead to more resilient croping systems and improved food security (Mohasin *et al.*, 2022).

Sitapur district, located in the northern Indian state of Uttar Pradesh, has a diverse agricultural landscape, with rice being one of the key crops cultivated in the region. The district benefits from a favorable climate and fertile alluvial soil, which are conducive to rice cultivation, particularly during the *Kharif* season. Farmers in Sitapur primarily grow traditional varieties of rice, often supplemented with improved varieties to enhance yield and resilience against pests and diseases. The region faces challenges such as water scarcity and varying rainfall patterns, which can impact rice production. Efforts to improve irrigation facilities, promote sustainable agricultural practices and provide support for farmers are crucial to enhancing rice productivity in Sitapur. Additionally, initiatives aimed at improving access to markets and providing training on modern farming techniques can further support the livelihoods of rice farmers in the district.

MATERIALS AND METHODS

The experiment was planned at the research fields of Parsendi block of Sitapur district Uttar Pradesh under the prejudicing of KVK, Sitapur. The site is situated from 27°71″ North latitude to 80°90″ East longitude and 138 meter high from the mean sea level. It is located in the middle section of Uttar Pradesh, India. The land of district Sitapur is salt affected and major portion of this land occupied in Parsendi block. Average annual rainfall in the district is 989 mm. Transplanting of paddy is shown in Fig 1.



Fig 1: Transplanting of paddy.

The investigation aims to find out the impact of halophilic bioformulations, halophilic azotobacter (Halo-Azo), halophilic phosphate solubilizing bacteria (Halo-PSB), halophilic zinc (Halo-Zn) and halophilic mixture with effective salt tolerant variety of rice (CSR 43) on crop productivity and soil fertility in sodic as well as natural soil. The treatment schedule is given as:

T1: OA (Un-inoculated).
T2: Halo-Azo inoculation + OA+100% P and K + 75% N.
T3: Halo-PSB inoculation + OA+100% N and K + 75% P.
T4: Halo-Zinc inoculation+ OA+100% RDF.
T5: Halo-Mix inoculation + OA+75% RDF.

The experiment was conducted with four replications and five given treatments in randomized block design (RBD). The efficiency of halophilic bio-formulation was evaluated in terms of various characteristics of crop and soil fertility. The certified seeds of paddy (CSR 43) and halophilic bio-formulations were procured from Central Soil Salinity Research Institute. Rice seeds were soaked in bio-formulation solutions before nursery sowing according to different treatments. The nursery for the trials was grown in first week of June. One month old rice seedling roots were again treated with same bio-formulations before transplantation. The grain and straw yield data were recorded at harvest. The data was subjected to analysis of variance (ANOVA) and least significant differences (LSD) were calculated using the F-test (Sokal and Rohlf, 1981).

Soil sampling and analysis

The initial soil samples (0-15 cm depth) were drawn from different places throughout the study field and combined together to generate a representative composite sample. Soil sampling was done after the harvest of crop. The soil pH of the samples was determined in 1:2.5 substrate water suspensions by using digital pH meter (Jackson, 1973). The electrical conductivity was determined by conductivity meter (Jackson, 1973). Soil organic-carbon was estimated following the method described by (Walkley and Black, 1934). The available N, P and K in soil were determined by alkaline permanganate method (Subbiah and Asija, 1956), ascorbic acid method (Olsen *et al.*, 1954) and neutral normal ammonium acetate method by using flame photometer (Hanway and Heidel, 1952) respectively.

RESULTS AND DISCUSSION

Different growth parameters of paddy *viz.* plant height, no. of tillers/hill, no. of grains/panicle, length of panicle, test weight and grain yield were evaluated in sodic and normal soil and all are found significantly promoted by the inoculation of bio-formulations. Sodicity is one of the environmental factors that have a critical influence on the germination of seeds and plant establishment (Williams *et al.*, 1998). Inoculation of bio-formulations improves the growth parameters (in percent) as compared to control. Halophilic bio-formulations enhance plant resilience under salinity. Halotolerant PGPR isolated from Sesuvium were also shown to improve yield and salt tolerance in leguminous crops (Jha and Singh, 2022).

Effect of bio-formulation on different growth parameters of paddy crop under sodic soil

The effect of bio-formulation on different growth parameters of paddy crop under sodic soil is shown in Table 1. The increase in plant height was observed 2.5, 3.05, 4.35 and 7.50% maximum over control, by the inoculation with bio-formulations, *viz*. Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in salty soil. The treatment T5 recorded with highest plant height (116.3 cm.) for the sodic soil which was statistically at par with T4. However, T4 and T5 were found to be better than T1 treatment.

The increase in highest length of panicle per plant was observed 3.66, 18.34, 25.22 and 33.48% maximum over control, by the inoculation with bio-formulations, *viz*. Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in sodic soil. The treatment T5 recorded with highest length of panicle per plant (29.1) for the salty soil which was statistically different with all the other treatments. However, all treatments were found to be better than T1 treatment. The increase in number of tiller / hill was observed 8.57, 9.52, 10.47 and 12.38% maximum over control, by the inoculation with bio-formulations, *viz*. Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in sodic soil. The

Table 1: Effect of bio-formulation on different growth parameters of paddy crop under sodic soil.

Treatment	Plant height (cm)	Length of panical/plant (cm)	No. of tiller/ hill	Test weight (1000 gm)	Grain yield (q/ha)	No. of grains/ panicle
T1: OA	107.9	21.8	10.5	24.1	42.64	129.0
T2: Halo-Azo inoculation + OA+100% P and K+75% N	110.6	22.6	11.4	25.6	43.04	134.0
T3: Halo-PSB inoculation + OA+100% N and K+75% P	111.2	25.8	11.5	26.4	44.21	136.0
T4: Halo-Zinc inoculation+ OA+100% RDF	112.6	27.3	11.6	27.2	44.56	139.0
T5: Halo-Mix inoculation + OA+75% RDF	116.3	29.1	11.8	28.1	45.87	142.0
CD	4.28	1.03	0.409	0.96	1.67	4.99
CV	2.11	2.24	1.993	2.01	2.10	2.02
Sem	1.18	0.40	0.11	0.37	0.65	1.38

treatment T5 recorded the highest No. of tiller per hill (11.8) for the sodic soil which was statistically at par with T2, T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment.

The increase in test weight was observed 6.22, 9.54, 12.86 and 16.59% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in sodic soil. The treatment T5 recorded the highest test weight (28.1 gm) for the sodic soil which was statistically at par with T2, T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment. The increase in grain yield was observed 0.93, 3.68, 4.50 and 7.57% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in sodic soil. The treatment T5 recorded the highest grain yield (45.87 q/ha) for the sodic soil which was statistically at par with T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment. The increase in no. of grains per panicle was observed 3.87, 5.42, 7.75 and 10.07% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in sodic soil. The treatment T5 recorded the highest no. of grains/ panicle (142) for the sodic soil which was statistically different with T1, T2, T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment.

Effect of bio-formulation on different growth parameters of paddy crop under normal soil

Bio-formulations significantly improved test weight and grain yield, especially under sodic conditions. The positive correlation between nutrient availability and crop productivity is well established. Similar effects of biochar and microbial inoculation on enhancing nutrient use efficiency and plant growth under stress conditions have been reported by Singh *et al.* (2010).

The effect of bio-formulation on different growth parameters of paddy crop under normal soil is shown in Table 2. The increase in plant height was observed 2.4, 3.03, 3.81 and 4.89% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in normal soil. The treatment T5 recorded with highest plant height (107.2 cm) for the normal soil which was statistically at par with T2, T3 and T4. However, all treatments were found to be better than T1 treatment. The increase in length of panicle per plant was observed 1.45, 8.73, 20.87 and 28.64% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in normal soil. The treatment T5 recorded with highest length of panicle per plant (26.5 cm) for the normal soil which was statistically different with all the other treatments. However, all treatments were found to be better than T1 treatment.

The increase in No. of tiller/hill was observed 1.96, 9.80, 10.78 and 12.74% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-mix respectively in normal soil. The treatment T5 recorded the highest number of tiller per hill (11.5) for the normal soil which was statistically at par with T2, T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment.

The increase in test weight was observed 5.35, 8.03, 16.51 and 17.85% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-mix respectively in sodic soil. The treatment T5 recorded the highest test weight (26.4 gm) for the normal soil which was statistically at par with T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment. The increase in grain yield was observed 2.84, 3.66, 6.23 and 7.12% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-Mix respectively in sodic soil. The treatment T5 recorded the highest grain yield (42.98 q/ha) for the normal soil which was statistically at par with T2, T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment. The increase in number of grains per panicle was observed 3.2, 5.6, 7.2 and 10.4% maximum over control, by the inoculation with bio-formulations, *viz.* Halo-Azo, Halo-PSB, Halo-Zn and Halo-mix respectively in sodic

Table 2: Effect of bio-formulation on different growth parameters of paddy crop under normal soil.

Treatment	Plant height (cm)	Length of panical/ plant(cm)	No. of tiller/ hill	Test weight (1000 gm)	Grain yield (q/ha)	No. of grains/ panicle
T1: OA	102.20	20.60	10.20	22.40	40.12	125.00
T2: Halo-Azo inoculation + OA+100% P and K+75% N	104.60	20.90	10.40	23.60	41.26	129.00
T3: Halo-PSB inoculation + OA+100% N and K+75% P	105.30	22.40	11.20	24.20	41.59	132.00
T4: Halo-Zinc inoculation + OA+100% RDF	106.10	24.90	11.30	26.10	42.62	134.00
T5: Halo-mix inoculation + OA+75% RDF	107.20	26.50	11.50	26.40	42.98	138.00
CD	3.93	0.92	0.50	1.07	1.92	6.25
CV	2.06	2.21	2.55	2.42	2.54	2.62
Sem	1.08	0.25	0.13	0.29	0.53	1.72

soil. The treatment T5 recorded the highest number of grains/panicle (138) for the sodic soil which was statistically different with T3 and T4. However, all T2, T3, T4 and T5 were found to be better than T1 treatment.

Effect of bio-formulation on chemical properties of sodic soil

Soil sampling of sodic soil was done before planting and after crop harvest. There was difference in nutrient and chemical status of soil before planting and after harvesting of crop. Soil analysis before planting had shown chemical properties *viz.*, alkaline pH of 9.2, EC of 0.428 dS/m and 0.158% OC. Macronutrient *viz.*, Nitrogen (134.80 kg/ha), Phosphorous (10.21 kg/ha) and Potassium (248.57 kg/ha) were also less initially. After crop harvest, these above mentioned soil parameters showed some improved fertility status of soil that ultimately increased yield and quality of paddy crop (Table 3).

Among different treatments pH was not found near to neutral in all the treatments. It was near to sodic condition in T5 (8.94) followed by T3 (8.99), T4 (9.0), T2 (9.04) and T1 (9.06). There was no significant difference was found among the treatments regarding pH value. Treatments T1 had lowest EC (0.41 dS/m) followed by T3 (0.463 dS/m), T2 (0.472 dS/m) and T4 (0.475 dS/m). Comparatively higher EC was recorded in T5 (0.486 dS/m). The treatment T5 was found statistically significant with all other treatments in case of EC.

Among different treatments OC was highest in T5 (0.23 %). Comparatively lowest OC was recorded in T1 (0.16%). Treatment T5 was found statistically significant with all other treatments in case of OC. While nutrient status of soil *viz.*, nitrogen (169.34 kg/ha), phosphorous (19.92 kg/ha) and potassium (249.28 kg/ha) was found to be higher in T5 (Halo-mix). Among the treatments nitrogen was highest in T5 (169.34 kg/ha). Comparatively lowest nitrogen was recorded in T3 (156.7 kg/ha). Treatment T5 was statistically at par with T4 and significant different with all other treatments.

Treatments showed variation for phosphorous content in soil and it was highest in T5 (1992 kg/ha). Comparatively lowest phosphorous was recorded in T3 (16.23 kg/ha). Treatment T5 was statistically at par with T1 and significant different with all other treatments.

Among the treatments potassium was highest in T5 (249.28 kg/ha) followed by T2 (244.16 kg/ha), T1 (243.04 kg/ha) and T4 (239.68 kg/ha). Comparatively lowest potassium was recorded in T3 (234.08 kg/ha). There was no significant difference was found among the treatments regarding potassium.

Effect of bio-formulation on chemical properties of normal soil

Soil sampling was done before planting and after crop harvest. Initially soil parameters like pH was slightly acidic (6.74), EC was 0.124 dS/m, organic carbon was less (0.358%), nitrogen was 238.57 kg/ha, potassium was 158.2 kg/ha and phosphorus was 9.80 kg/ha for the normal soil. After crop harvest, these above mentioned soil parameters showed some improved fertility status of soil that ultimately increased yield and quality of paddy crop (Table 4).

Among different treatments pH was found near to neutral in T3 (6.22) followed by T4 (6.25), T2 (6.43), T5 (6.58) and T1 (6.80). There was no significant difference

Table 3: Effect of bio-formulation on chemical properties of sodic soil.

Treatment	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
T1: OA	9.06	0.410	0.1658	137.984	18.50	243.04
T2: Halo-Azo inoculation + OA+100% P and K + 75% N	9.04	0.472	0.1994	156.800	16.23	244.16
T3: Halo-PSB inoculation + OA+100% N and K + 75% P	8.99	0.463	0.1762	156.800	16.56	234.08
T4: Halo-Zinc inoculation+ OA+100% RDF	9.00	0.475	0.2239	163.072	18.37	239.68
T5: Halo-mix inoculation + OA+75% RDF	8.94	0.486	0.2326	169.344	19.92	245.28
CD	NS	0.03	0.015	12.25	1.422	NS
CV	4.23	4.16	4.15	4.15	4.22	4.24
Sem	0.31	0.015	0.006	5.31	0.61	8.35

Table 4: Effect of bio-formulation on chemical properties of normal soil.

Treatment	pH	EC (dS/m)	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
T1: OA	6.80	0.174	0.5761	206.98	14.22	187.5
T2: Halo-Azo inoculation + OA+100% P and K + 75% N	6.43	0.150	0.4352	238.34	12.35	165.8
T3: Halo-PSB inoculation + OA+100% N and K + 75% P	6.22	0.157	0.4535	244.61	12.10	158.8
T4: Halo-Zinc inoculation+ OA+100% RDF	6.25	0.149	0.5549	246.16	12.82	187.3
T5: Halo-Mix inoculation + OA+75% RDF	6.58	0.158	0.5393	288.51	13.99	178.6
CD	NS	0.012	0.0400	19.04	1.05	14.10
CV	4.27	4.29	4.29	4.12	4.29	4.26
Sem	0.22	0.005	0.017	8.25	0.45	6.11

among the treatments regarding pH value. Treatments T4 had lowest EC (0.149 dS/m) followed by T2 (0.150 dS/m), T3 (0.157 dS/m) and T5 (0.158 dS/m). Comparatively higher EC was recorded in T1 (0.174). Treatment T1 was found significant different with all other treatments.

Among different treatments OC was highest in T1 (0.57%). Comparatively lowest OC was recorded in T2 (0.43%). Treatment T1 was statistically at par with T4 and T5 and significant different with all other treatments. Nitrogen was found highest with the application of T5 (288.51 kg/ha). Comparatively lowest nitrogen was recorded in T1 (206.98 kg/ha). Treatment T5 was found significant different with all other treatments.

Treatments showed variation for phosphorous content in soil and it was highest in T1 (14.22 kg/ha). Comparatively lowest phosphorous was recorded in T3 (12.1 kg/ha). Treatment T1 was statistically at par with T5 and significant different with all other treatments. Among the treatments potassium was highest in T1 (187.5 kg/ha) followed by T4 (187.3 kg/ha), T5 (178.6 kg/ha) and T2 (165.8 kg/ha). Comparatively lowest potassium was recorded in T3 (158.8 kg/ha). Treatment T1 was statistically at par with T4 and T5 and significant different with all other treatments.

Nitrogen was found highest with the application of T5 (288.51 kg/ha). Comparatively lowest nitrogen was recorded in T1 (206.98 kg/ha). Such improvements in soil nitrogen and phosphorus have also been observed in orchard crops with the use of Azotobacter and PSB biofertilizer combinations (Vijay *et al.*, 2023).

Overall, the findings demonstrate the potential of halophilic bioformulations in managing sodic soils for sustainable agriculture. These results are consistent with studies highlighting the efficacy of microbial formulations for sustainable crop production under salt-affected conditions (Meena *et al.*, 2021).

CONCLUSION

The present study revealed that inoculation with halophilic bio-formulations for a salt-tolerant variety of paddy significantly enhanced crop production and soil fertility. Sodic soils are generally poor in essential nutrients such as nitrogen, phosphorus and micronutrients, leading to limited crop productivity. The experimental results demonstrated that treated plots had improved growth metrics and yield parameters as compared to control.

Soil analysis confirmed better pH stabilization, increased organic carbon and improved macro-nutrient content in both sodic and normal soils. Halo-mix treatment emerged as the most effective, suggesting its potential application in reclamation and enhancement of productivity in salt-affected areas of Sitapur and similar agro-ecological regions.

This suggests that halophilic bio-formulations can play a pivotal role in sustainable paddy cultivation under saline/ sodic soil conditions.

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Conflict of interest

The authors declare that they have no conflict of interest for Publication of this article

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