



Endophytic Microbiome and Soil Conditioners are among the Pillars Supporting Rice Productivity in Salt-affected Environments

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ABSTRACT

A comprehensive field investigation was undertaken in clay-rich soil at the Sahl El-Hossynia Agricultural Research Station situated in the EL-Sharkia Governorate of Egypt. In the summer season of the year 2022, the rice cultivar *Oryza sativa* L. Giza 178 was systematically cultivated was grown using three replications of every treatment in a randomized split plot design, to assess the efficacy of endophytic growth-promoting bacteria (PGPR) as main plots in conjunction with

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various soil conditioners as sub main plots aimed at enhancing soil chemical properties and biological activity, which would ultimately affect rice productivity and mineral nutrient content. The findings showed that, in contrast to the control treatment, organic matter (OM) significantly increased while pH and EC values significantly decreased when PGPR inoculation was coupled with specific soil conditioners. The pH and EC values dramatically dropped of 22.4 and 3.29%, respectively, as compared to the control, while the amount of organic matter increased of 3.48% when compost and potassium silicate were added in addition to inoculation. There were notable positive effects on the available N, K, and Na, along with the total level of microbial activity from bacteria in the soil. In comparison to the control and other treatments, PGPR inoculation in conjunction with compost + potassium silicate yielded a significant enhancement in the productivity of 32.1% and 31.9% for straw and grains rice, respectively. While nutrient contents N, K, and Na were increased over control of 48.2, 107.1 and 62.8 for straw, corresponding for grains of 42.4, 108.7 and 110%, respectively. In conclusion, PGPR inoculation in the presence of soil conditioner especially compost and biochar combination with potassium silicate, improved the saline soil properties, and nutrients uptake that reflected on the yield components.

Keywords: Endophytes; rice; soil conditioners; salt affected.

1. INTRODUCTION

Soil salinization is one of the key agricultural challenges globally, particularly in arid and semi-arid geographical areas, negatively impacting characteristics of soil as well as plant physiological processes (Rajput et al., 2015). It is obvious that future salt-affected areas will grow as a result of seepage, silting, flooding, excessive irrigation, rising water tables, and salinization (Suhani et al., 2020). Negative alterations in the osmotic and ionic characteristics of salt-affected soils can reduce microbial activity and water absorption, which in turn restricts the total content of nutrients in the plant (K, Ca, Mg, and P) as well as lowers yields (Aliya and Asghari, 2016). Saline soil contains elevated levels of soluble salts (Xiaoqin et al., 2021). Among the dissolved salt components, NaCl is a significant one as it leads to the formation of NaCl, Na_2CO_3 , and Na_2SO_4 in the soil. The high concentration of Na ions in saline soil, primarily from NaCl, changes the soil's physical, chemical, and biological characteristics as well as hinders plants' ability to absorb nutrients (Hamid et al., 2021). According to Numan et al. (2018), soil with an exchangeable sodium below 15% and EC value above 4 dS/m is detrimental to microbial activity, plant health, and nutrient absorption. Additionally, important macronutrients like nitrogen (N) become less available in the soil due to the elevated salt concentrations (Gondek et al., 2020).

Some methods to lessen the negative effects of soil salinity on crops include creating salt-tolerant cultivars, applying plant growth regulators, treating seeds with halotolerant strains of plant

growth-promoting rhizobacteria, and adding soil conditioners (Akhtar et al., 2015). FAOSTAT (2019) Over three billion people worldwide rely on rice (*Oryza sativa* L.) as a staple crop and important cereal, which provides 50–80% of their daily calories. Additionally, compared to other crops, rice needs more water during its life cycle. Due to the detrimental effects of numerous environmental stressors, including soil salinity and water scarcity, its output is drastically decreasing (Chandra et al., 2018). In addition to rice productivity, salinity-affected soil and water scarcity alter rice's morphological, physiological, and biochemical characteristics (Reichenauer et al., 2009). Therefore, it is essential to create cost-effective to use environmentally friendly strategies that can reduce the adverse effects of water pressure and salt on rice plants in order to solve the looming problem of food security.

According to Ouyang et al. (2013), biochar is commonly made from waste biomass due to its affordability and benefits for food security. Biochar, an activated-carbon (C) soil conditioner that is typically high in ash, pH, and surface area, is produced by burning biomass in anaerobic conditions at temperatures below 1000 °C by processes of pyrolysis or dry carbonization, according to Naba et al. (2019).

Biochar has garnered significant interest for improving soil health, soil cation exchange capacity (CEC), soil moisture content, and rice crop productivity (Naeem et al., 2017). Biochar has two main effects on soil: it increases the availability of vital minerals like K^+ and decreases the absorption of Na^+ . By improving the soil's physicochemical, biological, and

enzymatic qualities, the second process improves the water status of plants. In water-deficient situations, biochar significantly raised the soil's stomatal conductance, photosynthetic rate, relative water content, chlorophyll content, and water-holding capacity (Chintala et al., 2014).

According to Yang et al. (2020), supplementing plants with biochar increased their growth and production in both normal and water-deficient circumstances. Biochar may have a beneficial effect on plants by increasing their capacity to maintain water, enhancing their ability to absorb organic compounds, and stimulating the activity of beneficial bacteria.

Huang et al. (2022) showed out that the biochar may minimize salt stress, and increasing soil salinity greatly reduces agricultural productivity. Biochar significantly increased rice biomass in salt-stressed soil while reducing electrical conductivity and soluble Na^+ and Cl contents. Additionally, the soil's organic matter, humic acid, nitrogen, phosphorus, and cation exchange capacity increased when biochar was used. The use of biochar altered the structure of the bacterial community under salt stress and further enhanced the number of soil microorganisms. Shahram and Salar (2017) found that the adding biochar to saline-alkaline soil greatly enhanced plant antioxidant enzyme activity, lowering oxidative stress and enhancing biomass and growth. Additionally, biochar improves the biological properties of salt-stressed soils, such as microbial biomass and enzymatic activity, and alters their physical qualities, such as their ability to hold water and nutrients (Sohi et al., 2010).

As is well known, silicon (Si) is a useful element that is crucial for long-term rice production (Datnoff et al., 2007). Ma and Yama (2006) state that silicon increased plants' tolerance to abiotic stressors, pathogens, and insects. Furthermore, plants with high Si accumulation have better light-interception capabilities, more upright leaves, and eventually higher canopy photosynthesis (Pedda et al., 2015). Si is commonly found in silicates (SiO_3) of Al, Mg, Ca, Na, K, or Fe, which are typically unsuitable for crops, according to Chanchal et al. (2016). The ease of access to plant roots is frequently determined by the chemical and biological processes occurring in the soil. The soluble mono-silicic acid that silicon absorbs by plants fortifies the cell wall.

Potassium represents the third significant macronutrients essential for the regular or stressed development of plants. Potassium is essential for promoting drought tolerance because it maintains photosynthetic capacity and protects chloroplasts from oxidative damage, regulating stomatal functions, improving water status, activating of multiple enzymes, increases cell expansion and phloem loading and inducing osmotic adjustment plus net carbon assimilation (Zorb et al., 2014).

Recently, potassium silicate (K-Si) has been used to offset the detrimental effects of drought on crop growth (Pilon-Smits et al., 2009). Compost and other organic additions can help reduce the salt problem in soil (Delgado-Moreno and Peña, 2009; Orozco et al., 2016). Its inputs can benefit the soil by producing aggregates and providing food for bacteria (Durán and Henríquez, 2010; Bonanomi et al., 2014).

Although Wang et al. (2014) found that applying a compost based on vegetable residue mixtures significantly increased the soil's CEC and available levels of N, P, and K, the positive benefits of OM have been linked to an improvement in soil quality because radicular development and the release of root exudates, such as organic acids, regulate soil pH, lessen the negative effects of salt concentration, and improve soil nutrient availability (DeLuca & DeLuca, 1987).

Applying both organic and biofertilizers simultaneously resulted in a higher rice yield under saline conditions, according to Zayed et al. (2013). The volume, solubility, and mobilization of accessible macronutrients, as well as the organic additions' prolonged breakdown process, may be the main causes of this. The addition of organomineral fertilizer compost to saline soil improved the capillary potential of a common bean field by promoting the formation of medium and micropores (i.e., water-holding capacity and usable pores) between simple packing sand particles (Rady et al., 2016). In soils influenced by salt, it has been discovered that a number of Effective Microorganisms (EM) genera, including *Pseudomonas*, *Bacillus*, *Azospirillum*, and *Bradyrhizobium*, improve crop development and yield (Viscardi et al., 2016).

Lee et al. (2019) reported that it is well known that minerals such as phosphates and silicates dissolve considerably when microorganisms are present. Numerous helpful bacteria have been shown to improve plants' absorption of these

minerals, which benefits them in various stressful conditions. According to Ameen et al. (2019), it is commonly recognized that organic acid created by microbes dissolves insoluble phosphate and silicon, making them more accessible to plants. Numerous studies have shown that bacteria solubilize silicates to increase plant availability (Chandrakala et al., 2019).

As a straightforward and inexpensive biological technique, the combination of Plant Growth Promoting Rhizobacteria (PGPR) and Potassium Silicate (PS) applications has demonstrated beneficial effects in terms of enhancing plant growth, improving soil properties, and raising element contents of wheat under salinity stress (El-Nahrawy, 2022).

Even though adding compost or biochar alone might result in a noticeable improvement in the quality of the soil and roselle, combining the two amendments yields a definite advantage. Therefore, it is advised that roselle plants that are irrigated with saline water blend charcoal and compost (Liu et al., 2021).

This study's objective was to determine whether applying soil conditioners alone or combined with microorganisms that promote plant growth will lessen the effects of soil salinity.

2. MATERIALS AND METHODS

2.1 Site Description

At the Sahl El-Hossinia Agric. Res. Station Farm in the EL-Sharkia Governorate, Egypt, a field experiment was conducted during the 2022 season. The farm's coordinates latitude 31° 8' 12.461" N and longitude 31°52' 15.496" E.

The soil at the experimental site, from 0-30 cm depth, soil samples were collected, air-dried, and stored for analyses of various physicochemical properties, as shown in Table (1) using the approach described by Page et al. (1982). Water from the El-Salam Canal was used to irrigate this experiment; Table (2) displays the chemical composition of the irrigated water.

Table 1. Physio-chemical parameters of the experimental soil (0-30 cm) before cultivation

Particle size distribution (%)			
Texture grade		Silt clay	
Coarse sand		4.71	
Fine Sand		10.02	
Silt		35.12	
Clay		52.15	
Chemical parameters			
pH*		8.12	
EC (dS m ⁻¹)**		11.8	
Soil organic matter (%)		0.82	
SAR		13.4	
ESP		15.9	
Soluble cations (meq L ⁻¹)		Soluble anions (meq L ⁻¹)	
Ca ⁺⁺	30.2	CO3 ⁻⁻	nd
Mg ⁺⁺	40.3	HCO3 ⁻	10.5
Na ⁺	79.1	CL ⁻	88
K ⁺	1.21	SO4 ⁻⁻	51.8
Available nutrients (mg kg ⁻¹)			
N		101	
P		3.5	
K		298	
Na		220	
*1:2.5 (soil: water suspension) ** EC soil past extract			

Table 2. Chemical analysis of irrigation water

Parameters	Value	Soluble cations (meq L ⁻¹)				Soluble anions (meq L ⁻¹)			
pH	7.9	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	CO ₃ ⁻⁻	HCO ₃ ⁻	CL ⁻	SO ₄ ⁻⁻
EC (dS m ⁻¹)	1.8	3.5	5.5	8.1	0.4	nd	4.3	7.5	5.7
EC (ppm)	1152								
SAR	3.8								

2.2 Experimental Design and Treatments

During the summer of 2022, rice (*Oryza sativa* L., Giza 178) was grown using three replications of every treatment in a randomized split plot design. Plant Growth Promoting Rhizobacteria (PGPR) were either un-inoculated or inoculated in the main plots.

The sub main plots were sex soil conditioners, control, biochar, compost, potassium silicate, biochare + potassium silicate and compost + potassium silicate.

2.3 Fertilizers Application

Before cultivation, all treatments received mineral fertilizers in the dosages needed for rice crops. Superphosphate (15 % P_2O_5) was added to the soil at a rate of 200 kg fed⁻¹ practically before seeding. Ammonium sulfate (20% N) was used to provide nitrogen to rice in three equal doses at a rate of 100 kg fed⁻¹ at 15, 30, and 60 days after sowing. Two equal doses of potassium sulfate (48 % K_2O) were added at the seeding time and 30 days later, at a rate of 50 kg fed⁻¹.

2.4 Plant Growth Promoting Rhizobacteria (PGPR)

PGPRs were acquired from Cairo University in Egypt's Environmental Studies and Research Unit (ESRU), Department of Microbiology, Faculty of Agriculture. Inoculum of PGPRs (*Pantoea conspicua* (endo30 7/2), *Bacillus safensis* (endo 30 5/1), *B. licheniformis* (endo30 3/0), *B. safensis* (endo 30 5/5) and *B. rugosus* (*B. halotolerans*) (ecto 30 9/2), Table (3). Batches of the liquid CCM were inoculated with the various strains (10%) and then incubated at 30°C in a rotary shaker (100 rpm) until the population density reached approximately 108 cfu ml⁻¹ in order to produce biomass.

Table 3. Rhizobacterial strains used for inoculation

Bacterial strains	Host plants	Accession number
<i>Pantoea conspicua</i> (endo 30 7/2)	<i>Gnaphalium luteoalbum</i> L.	OQ568854
<i>Bacillus safensis</i> (endo 30 5/1)	<i>Scrophularia syriaca</i> Benth.	OQ568863
<i>Bacillus licheniformis</i> (endo 30 3/0)	<i>Cutandia dichotoma</i> (Forssk.) Trab.	OQ568846
<i>Bacillus safensis</i> (endo 30 5/5)	<i>Scrophularia syriaca</i> Benth.	OQ568862
<i>Bacillus rugosus</i> (<i>Bacillus halotolerans</i>) (ecto 30 9/2))	<i>Cyperus conglomerates</i> Rottb.	OQ568864

PGPR Preparation: The experiment's strains were cultured for 48 hours at 30°C on a shaker (150 rpm) in 500 cc of CCM broth medium in a 1000 ml Erlenmeyer flask. Equal amounts of liquid batch cultures were mixed at the same time to create the bio-preparation. Five hundred ml from liquid cultures were used for each plot treatment.

2.5 Measurements

Following harvest, surface soil samples were gathered and analyzed for soil chemical characteristics using the methodology outlined by Cottenie et al. (1982).

From every plot, rice harvest grains and straw were gathered. At the end of the experiment, calculated of yield characteristics such as grain and straw yield (Kg/fed.). In accordance with Page et al. (1982), the plant was crushed, oven-

dried at 70°C for 48 hours, until consistent dry weight, and digestion. N, K, and Na digests were estimated (Cottenie et al., 1982).

2.6 Microbiological Parameters

After 45 days from planting, taken the sampled for the evaluation of total bacterial load on the ecto-rhizosphere representing the closely adhering soil to the plant roots. Initial dilutions were prepared by transferring 5 g of plant roots with closely adhering soil into bottles containing 45 ml of half-strength of basal salts of CCM medium of Hegazi et al. (1998) minus carbon source. Bottles were shaken for 60 min, and further serial decimal dilutions were prepared. Plates were incubated at 30 °C for 2–7 days. Surface-inoculated agar plate technique determined total rhizospheric microorganisms (RMO) in the different treatments, (Hamza, 1994). Agar plates of the standard N-free

combined C-sources medium, CCM, and colony forming units (cfu) were counted. Dry weights for suspended roots (80 °C) were determined.

2.7 Statistical Analysis

Each growing season's findings were statistically analyzed to compare the means using the LSD test at a significance level of 0.05, as Gomez and Gomez (1984) stated.

3. RESULTS AND DISCUSSION

3.1 Soil Chemical Properties

3.1.1 Soil Electric Conductivity (EC) and Soil Reaction (pH)

Results revealed that the values of EC and pH in soil, showed in Table (4), significantly and

insignificantly decreased, respectively, as affected by the studied treatments compared to control. Application of compost + potassium silicate in presence of inoculation led to significant decreases of pH and EC values. Furthermore, these treatments resulted in EC and pH reductions of 22.4 and 3.29%, respectively, as compared to the control. The electric conductivity decreased significantly, despite the pH values decreasing insignificantly, in presence inoculation. Treatments of soil conditioners may be arranged as follows: compost + PC > compost > Bio + PC > PC > Bio for electric conductivity but being compost + PC > PC > Bio + PC > compost > Bio for pH values. These findings are in line with those of Tongtong et al. (2023), who noted that treating the soil with straw compost greatly enhanced its physicochemical characteristics.

Table 4. Chemical properties of the soil after rice harvest as affected by soil conditioners and inoculation

Soil conditioner	EC (dSm ⁻¹)	pH (1:2.5)	OM (%)
Non- Inoculation			
control	10.9	7.91	1.04
Biochar	9.08	7.87	1.14
Compost	7.51	7.85	1.16
Potassium silicate	7.97	7.79	0.97
Biochar + Potassium silicate	7.77	7.77	1.12
Compost + Potassium silicate	7.55	7.74	1.16
Means	8.46	7.82	1.10
Inoculation			
control	9.42	7.89	1.15
Biochar	8.24	7.84	1.17
Compost	7.41	7.76	1.17
Potassium silicate	7.47	7.65	0.98
Biochar + Potassium silicate	7.63	7.66	1.17
Compost + Potassium silicate	7.31	7.63	1.19
Means	7.91	7.73	1.14
Means of soil conditioners			
Control	10.2	7.90	1.11
Bio	8.66	7.86	1.15
Com	7.46	7.81	1.17
PC	7.72	7.72	0.97
Bio+PC	7.70	7.72	1.15
Com+PC	7.43	7.69	1.18
LSD at 0.05			
Inoculation (A)	0.23	NS	0.05
soil conditioner (B)	1.04	NS	0.11
A*B	1.47	NS	0.16

3.1.2 Organic matter (OM)

When soil conditioners were applied in conjunction with inoculation, the amount of organic matter in the soil generally increased compared to the control. The compost + potassium silicate in presence of inoculation showed a high gradual OM of 1.19 % compared to the control of 1.04 %. However, organic matter values decreased when applied potassium silicate in the presence or absence of inoculation. The values of pH in soil insignificantly increased due to inoculation. Generally, the effect of application of soil conditioners can be arranged as follows: compost + PC > compost > Bio + PC > Bio > PC for tested soil crop.

3.1.3 Nutrients availability in soil after harvesting

Table (5) shows the amount of soil nutrients (N, K, and Na) available following rice harvest. Interaction statistical analyses revealed that the treatments of soil conditioners in presence of inoculation increased soil nitrogen and potassium availability, the opposing trend, which is for sodium availability, in soil compared to the control treatment. However, the highest values of soil available nitrogen and potassium of 271 and 117 mg L⁻¹ were due to compost combined with potassium silicate in presence of inoculation compared to the other treatments. The lowest values of sodium of 156 mg L⁻¹ in were attributed to the application of biochar combined with potassium silicate in presence of inoculation.

Table 5. Nutrient availability (mg Kg⁻¹) of soil after rice harvested as affected by soil conditioners and inoculation

Soil conditioner	N	K	Na
Non- Inoculation			
Control	221	94.2	213
Biochar	223	95.5	180
Compost	249	96.2	180
Potassium silicate	242	97.2	186
Biochar + Potassium silicate	229	94.9	170
Compost + Potassium silicate	250	114	177
Means	236	98.7	184
Inoculation			
Control	219	95.8	206
Biochar	225	96.2	199
Compost	250	94.9	167
Potassium silicate	231	102	164
Biochar + Potassium silicate	242	100	156
Compost + Potassium silicate	271	117	174
Means	239	101	178
Means of soil conditioners			
Control	220	94.9	209
Bio	224	95.8	189
Com	249	95.5	173
PC	236	99.9	175
Bio+PC	235	97.5	163
Com+PC	261	116	176
L.S.D at 0.05			
Inoculation (A)	5.15	2.01	16.3
soil conditioner (B)	13.3	6.53	15.4
A*B	18.8	9.23	21.8

It is worth to mention that there is an insignificant effect on the availability of elements (N, K and Na) with the application of inoculation. The lowest values of sodium and highest values of nitrogen and potassium were recorded with inoculation.

Results indicated that the highest significant effects for nitrogen and non-significant for potassium in soil were reported in case of applying soil conditioner of compost combined with potassium silicate compared to other soil conditioners. These findings concur with those that were published by According to Munns et al. (2020), applying compost enhances the soil's nutrient availability, which benefits plant mineral nutrition. Additionally, the plant may better manage the energy expenditure by continuously synthesizing the organic solutes required to maintain the aforementioned osmotic setting to counteract salt.

It is important to remember that while composting can improve plant nutrition, it actual doesn't address the root source of the salt issue. However, its application in these saline soils can

enhance plant growth, microbial biomass, and the soil's chemical characteristics. In the short run, plants may benefit from the usage of compost (Reina et al., 2022).

Treatment with biochar combined with potassium silicate reduced sodium availability in soil. These findings concur with those published by Chakraborty et al (2013) They discovered that biochar and PGPR inoculation increased the contents of Ca^{++} and K^+ in the soil solution by putting Na^+ on exchange sites and releasing additional nutrients into the soil solution.

3.1.4 Soil biological activity in soil after harvesting

After rice harvesting, the impact of PGPR inoculation in conjunction with various soil conditioners on total count bacteria expressive soil activity biological was demonstrated by the results in Table (6). Compared to the control treatment, the total count of bacteria at two-time intervals (after 15 and 45 days) rose in all treatments that received PGPR inoculation.

Table 6. Soil biological activity under saline conditions affected with PGPR inoculation in combination with different soil conditioners

Treatments		Total count of bacteria Log No.	
		15 days	45 days
NPK (control)		4.013	4.013
Inoculation		6.627	8.060
PGPR inoculation	Biochar	6.55	7.183
	Compost	6.860	8.283
	Potassium silicate	7.450	6.380
	Biochar + Potassium silicate	7.530	6.123
	Compost + Potassium silicate	6.617	7.313
LSD		0.596	

However, utilizing compost both by itself and in conjunction with potassium silicate in presence PGPR inoculation had higher values of total count bacteria especially after 45 days. Also, it was noticed that total count bacteria at 15 days were lower than those recorded at 45 days. Generally, either potassium silicate or biochar combination with potassium silicate in presence of PGPR inoculation increased total counts of bacteria after 15 days from sowing. On the other hand, the highest counts were recorded for treatments received compost alone and/or combined with potassium silicate after 45 days of rice harvesting.

In agricultural land, the detrimental effects of soil salinity on soil microbial activity can be mitigated with the use of compost. Microbial activity metrics including respiration and enzymatic activity show the most pronounced impacts of salinity on soil biology (Rath and Rousk, 2015). Sardinha et al. (2003) shown that adding organic matter to salinity soils might be enhance their biological processes and that microbial mass declines in salinity conditions. Salt significantly affects enzyme function and turns toxic to bacteria as concentration increases. According to Lakhdar et al. (2009), this effect can be reversed and microbial activity and populations increased by introducing organic amendments to high salinity or sodic soil conditions. This suggests that adding compost can be a useful strategy for reducing the toxicity conditions brought on by salinization.

Salt conditions affect the times of aerobic conditions and water saturation that define rice fields. But after a paddy field is flooded, the water may become saturated, which could dilute the deposited salts. The salt buildup is visible when the fields are drained, particularly at the soil's surface and top layers. In this sense, soil microorganisms are impacted by both decreased oxygen availability during flooding and elevated soil salinity during drought. Conversely, instead of increasing microbial population stress, Wichern et al. (2020) discovered that waterlogging rice improved carbon mobility in saturated soil, increasing carbon availability for microorganisms. Because more microorganisms are in the soil when

organic amendments are added, soil respiration rises. In line with the findings of Leogrande and Vitti (2018) found that salinity decreased soil respiration, but that this effect was significantly mitigated by the addition of organic matter, a found by Wichern et al. (2006) and Sall et al. (2015).

3.2 Yield and Its Components at Harvest Stage

The straw and grains of rice yields, in Table (7), significantly affected by the various applied treatments either of non-inoculation or inoculation compared to the control treatment.

Table 7. Rice yields (Kg fed-1) of the different treatments of soil conditioners and inoculation

Soil conditioner	Straw	Grains
Non- Inoculation		
Control	4200	3931
Biochar	4939	4217
Compost	5488	4760
Potassium silicate	6065	5113
Biochar + Potassium silicate	5376	4519
Compost + Potassium silicate	6092	5589
Means	5360	4688
Inoculation		
Control	5140	4407
Biochar	5280	4424
Compost	5734	4906
Potassium silicate	6664	5617
Biochar + Potassium silicate	5432	4541
Compost + Potassium silicate	6792	5773
Means	5841	4944
Means of soil conditioners		
Control	4670	4169
Bio	5110	4321
Com	5611	4833
PC	6365	5365
Bio+PC	5404	4530
Com+PC	6443	5681
L.S.D at 0.05		
Inoculation (A)	297	99.9
soil conditioner (B)	409.8	263.1
A*B	579.5	372.1

The treatment that received compost and potassium silicate in the presence of inoculation had the greatest yield component values. However, the groups that received biochar without inoculation had the lowest values for both yield components. Compared to control, yield components of rice plants recorded increases of 32.1% and 31.9% for straw and grains, respectively. Yu et al (2015), It was discovered that applying deteriorated straw compost fermented at room temperature improved the quality and yield of cucumbers. The decomposition of straw can improve field conditions and avoid agricultural desertification by increasing the soil's fertility and organic matter content because of its high nutritional content (Li et al., 2023).

However, around 30% of straw cannot fully decompose in the natural environment due to the difficulty of breaking down polysaccharide components like cellulose, hemicellulose, and lignin. The leftover straw is either burned or thrown away, wasting straw resources and polluting the environment (Li et al., 2018). Recent developments in microbial research have resulted in the growth of certain bacteria for the compost made from decomposed straw, which can improve the yield and quality of cucumbers (Yu et al., 2015). Tongtong et al. (2023) demonstrated that the straw compost-treated rice plants were notably taller than the control plants. Additionally, the height of the rice plants significantly increased as the amount of straw compost in the soil grew. The straw compost considerably boosted both the 100-grain weight

and the length of the rice roots. These findings demonstrate how straw fermentation technology and straw composting can be applied to improve agricultural output.

3.3 Total Contents of Nutrients

Data in Tables (8 and 9) present the effects of applied soil conditioners alone or combined with inoculation by PGPRs on nutrients uptake (N, K and Na) in either straw or grains of rice plants. All applied treatments resulted in a considerable rise in N, K, and Na values when compared to the control. Compost and potassium silicate in the presence of inoculation produced the highest value. Additionally, the overall nutrient composition trended in the same direction as the yield component trends.

Table 8. Nutrients total contents (Kg fed⁻¹) of rice straw as affected by soil conditioners and inoculation

Soil conditioner	Nutrient uptake in straw (Kg/fed.)		
	N	K	Na
Non- Inoculation			
control	45.8	37.3	16.6
Biochar	63.1	39.7	19.8
Compost	63.3	40.3	19.8
Potassium silicate	92.1	83.7	37.6
Biochar + Potassium silicate	63.8	40.7	22.1
Compost + Potassium silicate	83.6	56.3	23.1
Means	68.6	49.7	23.2
Inoculation			
control	64.8	42.0	25.0
Biochar	65.7	64.2	31.1
Compost	73.8	70.7	32.3
Potassium silicate	93.0	72.3	36.0
Biochar + Potassium silicate	79.3	71.4	33.2
Compost + Potassium silicate	96.0	87.0	40.7
Means	78.9	67.9	33.1
Means of soil conditioners			
Control	55.3	39.7	20.8
Bio	64.4	51.9	25.5
Com	68.5	55.5	26.0
PC	92.9	78.0	36.8
Bio+PC	71.6	56.1	27.6
Com+PC	89.8	71.7	31.9
LSD at 0.05			
Inoculation (A)	0.88	3.22	2.85
soil conditioner (B)	5.00	7.69	3.65
A*B	7.07	10.9	5.16

Table 9. Nutrients total contents (Kg fed⁻¹) of rice grains as affected by soil conditioners and inoculation

Soil conditioner	Nutrient uptake in grains (Kg/fed.)		
	N	K	Na
Non- Inoculation			
Control	65.2	30.6	2.85
Biochar	69.9	52.3	3.65
Compost	68.1	46.9	3.30
Potassium silicate	86.6	55.0	3.82
Biochar + Potassium silicate	78.3	53.0	3.72
Compost + Potassium silicate	89.6	64.7	4.60
Means	76.3	50.4	3.66
Inoculation			
control	69.6	40.2	2.89
Biochar	76.8	59.1	4.31
Compost	82.6	50.8	4.05
Potassium silicate	93.1	73.6	4.67
Biochar + Potassium silicate	85.2	60.2	4.45
Compost + Potassium silicate	99.1	83.9	6.09
Means	84.4	61.3	4.41
Means of soil conditioners			
Control	67.4	35.4	2.87
Bio	73.4	55.7	3.98
Com	75.4	48.8	3.68
PC	89.9	64.3	4.25
Bio+PC	81.7	56.6	4.09
Com+PC	94.4	74.3	5.35
LSD at 0.05 %			
Inoculation (A)	5.57	3.86	0.57
soil conditioner (B)	12.4	8.92	1.01
A*B	17.6	12.6	1.43

Also, N, K and Na contents in straw or rice grains generally increased by inoculation with PGPRs compared to without inoculation. The production of phytohormones like IAA may be responsible for the increased physiology, nutrient absorption, and rice growth following PGPR inoculation in saline soil. Banerjee et al. (2017) and Sandhya et al. (2009) showed that, IAA may be connected to the plant's overall biomass and increased nutrient availability. Additionally, it might affect the synthesis of osmolytes, EPS, and ACC deaminase (Hafez et al., 2019). The decreasing concentration of Na⁺ ions in the leaves of maize plants inoculated with PGPR (*Azospirillum lipoferum* + *Bacillus circulance*) under saline soil may be due to the exopolysaccharide that PGPR produces. This occurs as a result of PGPR binding to the soil's Na⁺ ions, which decreases their absorption (Hafez et al., 2021).

Additionally, the findings demonstrated that, in, the level of sodium total content in rice straw gradually rose, comparison to grains. This could suggest that elevated soil salts led to the buildup of salts in plants, which in turn affected how well

plants absorbed nutrients, particularly sodium. Also, adding potassium silicate to compost while inoculating it led to an increase in K uptake and a decrease in Na uptake in both grains and straw. This could be the cause of the better yield under salinity conditions.

4. CONCLUSIONS

In general, the utilization of soil conditioner forms alone or in combination with inoculation improved the chemical characteristics of salinity soil by raising the amount of accessible NKNa and OM% while slightly lowering the EC and pH values. It also increased the biological yield of rice plants and their overall nutrient uptake.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

The authors of this work hereby certify that no generative AI tools, including text-to-text generators and big language models (Chat GPT, COPILOT, etc.), were utilized in its composition or editing.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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