International Journal of Plant & Soil Science

Volume 38, Issue 9, Page 635-644, 2026; Article no.IJPSS.165802
ISSN: 2320-7035

Effect of *Trichoderma* Enriched Biofertilizer on Rice Yield and Nitrogen Use Efficiency under Salinity Stress

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Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i96325

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/165802

Original Research Article

Received: 11/07/2026
Accepted: 08/09/2026
Published: 14/09/2026

Abstract

Salinity restricts rice growth and nutrient acquisition and can reduce nitrogen use efficiency (NUE). This pot experiment evaluated *Trichoderma enriched* biofertilizer, urea, and their combined application for rice (*Oryza sativa*) under saline conditions. BR 29 rice was grown in 21 pots using a completely randomized design (CRD) with seven treatments and three replications. The treatments included control and *Trichoderma enriched* biofertilizer, urea, or their combination under 85 and 140 mM salinity. Plant growth, yield attributes, macronutrient uptake, apparent NUE, and agronomic NUE were assessed. Treatment responses differed across the two salinity levels. The combined *Trichoderma enriched* biofertilizer and urea treatment under 85 mM salinity (T_3S_1) produced the highest recorded growth and yield responses, including a plant height of 101 cm, and showed the greatest shoot uptake of nitrogen, phosphorus, and potassium. This treatment also recorded the highest apparent and agronomic NUE values, 6.00 and 12.47, respectively. At 140 mM salinity, growth, yield, and NUE were generally lower, and the urea-only treatment (T_5S_2) produced no grain. Overall, combining *Trichoderma enriched* biofertilizer with urea gave the most favorable rice performance under the moderate salinity treatment used in this experiment. Because the study was conducted in pots, field-scale validation is required before broader agronomic conclusions are drawn.

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Cite as: *Jannat, J., Sohag, M. A. I., & Hossain, S. (2026). Effect of Trichoderma Enriched Biofertilizer on Rice Yield and Nitrogen Use Efficiency under Salinity Stress. International Journal of Plant & Soil Science, 38(9), 635–644. https://doi.org/10.9734/ijpss/2026/v38i96325*

Keywords: *Oryza sativa; salinity stress; Trichoderma enriched biofertilizer; urea; nitrogen use efficiency; macronutrient uptake; grain yield.*

1. Introduction

The Soil Resource Development Institute (SRDI) estimated that salinity affects 1.06 million hectares of land in Bangladesh out of 2.86 million hectares of coastal and offshore lands. Saline soil is defined as soil that shows a nearly neutral reaction when exposed to the electrolyte of sodium salts. In saline soil, pH typically remains below 8.5 (7.0 to 8.5), and electrical conductivity is higher than 4 dS/m. Agriculture is a major sector of Bangladesh's economy, and the coastal area of Bangladesh is suitable for growing various crops; however, crop growth is affected by different levels of salinity (Akter *et al*., 2023). According to Karim *et al.* (1990) and Sultan *et al.* (2023), almost 30% of Bangladesh's cultivable land is located along the coast, and increasing salinity is a concern (Chen & Mueller, 2018). Farmers mostly cultivate low-yielding, traditional rice varieties during the wet season. Due to poor drainage conditions, poor irrigation water quality, and soil salinity, the majority of the land is left fallow throughout the dry season, which occurs from January to May (Karim *et al*., 1990; Soil Resource Development Institute, 2010; Mondal *et al*., 2006). Agricultural production is hampered by several factors, including decreased water use efficiency, the presence of organic soil and extremely acidic sulphate soil, a lack of fresh surface water and groundwater, and impaired seed germination.

Chemical fertilizers have been widely used in recent decades, whereas biofertilizers have been overlooked. However, because of the inconsistent and frequent use of chemical fertilizers and their adverse effects on human and soil health, biofertilizers have gained attention for meeting plant nutritional requirements (Chaudhary *et al*., 2021; Shahwar *et al*., 2023). Additionally, repeated application of inorganic fertilizer is one of the factors associated with increasing soil salinity (Sarkar *et al*., 2025). Inorganic fertilizers can contribute to pollution in streams, ponds, and other open water bodies if heavy rain occurs soon after application (Wang *et al*., 2025). *Trichoderma*, a fungal genus, is one of the microorganisms used as active ingredients in biofungicides, biofertilizers, growth enhancers, and stimulants of natural resistance (Woo *et al*., 2014; Tyśkiewicz *et al*., 2022). *Trichoderma* species are the most prevalent fungal group in soils and are present worldwide across almost all soil types (Kubiak *et al*., 2023; Kredics *et al*., 2024). They are microscopic and are generally considered virulent plant symbionts. *Trichoderma* sp. has been known for decades to increase plant growth and crop yield (Contreras-Cornejo *et al*., 2016; Halifu *et al*., 2019), improve nutrient uptake by plants (Mehetre & Mukherjee, 2015), accelerate plant growth and enhance plant greenness (Harman, 2006), and control numerous plant pathogens (Shoresh & Harman, 2008; Kredics *et al*., 2024). The introduction of *Trichoderma* strains with or without pathogens did not affect existing beneficial soil populations (Shanmugaiah, 2009; Wang *et al*., 2025). For these reasons, *Trichoderma* species are known as plant growth-promoting fungi or biofertilizers.

Nitrogen (N) is one of the essential macronutrients required for proper plant growth and soil health. However, improper management of N fertilizer application can result in significant environmental consequences. Because of substantial N losses through ammonia volatilization, denitrification, surface runoff, and leaching in the soil-flood water system, excessive N fertilizer input results in low nitrogen use efficiency (NUE) (Govindasamy *et al*., 2023). As a consequence, significant environmental problems, including soil acidification, air pollution, and water eutrophication, can occur.

Integrated nutrient management combining mineral fertilizers with beneficial microorganisms may provide an effective approach for improving crop productivity. Previous rice studies have reported that combined mineral and biofertilizer inputs can affect nutrient uptake and nitrogen-use efficiency (Malo & Sarkar, 2019). Recent rice studies support integrated organic-mineral nutrient management for improving yield and nitrogen-use efficiency, including under saline conditions (Hlaing *et al*., 2025; Islam *et al*., 2024; Li *et al*., 2025). However, direct comparison of *Trichoderma enriched* biofertilizer, urea, and their combination across salinity levels remains necessary to assess rice growth, yield, and nitrogen-use efficiency within one experimental framework.

Considering the constraints imposed by salinity in coastal lands and the economic condition of most farmers in Bangladesh in managing saline soils and maintaining yield, the objectives of this paper were: (a) to compare the effects of *Trichoderma enriched* biofertilizer and inorganic fertilizer (urea) on rice growth and yield parameters under saline conditions; and (b) to assess the effects of biofertilizer and inorganic fertilizer on the nitrogen use efficiency of rice under saline conditions.

2. Materials and Methods

2.1 Soil Sample Collection and Properties of The Soil

The agricultural soil was collected from Dhamrai Upazila (Dhaka district). Soil samples from a depth of 0-15 cm below the soil surface were collected using the composite sampling method from 2-3 points to determine the initial nutrient status of the soil. Analysis showed that the soil had a pH of 7.19 (1:2.5 w/v H_2O) (Jackson, 1965), an electrical conductivity of 0.68 mS/m (1:5 w/v H_2O) (Jackson, 1965), organic carbon of 0.34% (Jackson, 1973), organic matter of 0.59%, available nitrogen of 0.14% (Kjeldahl extraction) (Jackson, 1965), available phosphorus of 550.6 mg/kg (blue colour method using ascorbic acid following the Olsen method; Jackson, 1973), available potassium of 3044.33 mg/kg measured by flame photometer, available sulphur of 172.905 mg/kg (turbidimetric method measured by spectrophotometer) (Page *et al*., 1982), sand of 25.13%, silt of 53.3%, and clay of 21.57%, a silty clay loam textural class, and a moisture content of 1.53%.

2.2 Collection, Composition, and Properties of *Trichoderma enriched* Biofertilizer

Trichoderma enriched biofertilizer was collected from the Bangladesh Agricultural Research Institute (BARI), Government of the People's Republic of Bangladesh. The composition of 1 kg *of Trichoderma enriched* biofertilizer is presented in Table 1. Various physical, physicochemical, and chemical properties of the *Trichoderma enriched* biofertilizer were determined using standard methods. These properties are presented in Table 2.

2.3 Pot Experiment

The pot experiment was carried out in the net house of the Department of Soil, Water, and Environment from 28 January 2019 to 7 May 2019. For the pot experiment, winter rice (*Oryza sativa*) variety BR 29 (Boro) was selected. The seedlings were planted at 30 days of age. The experiment was laid out in a completely randomized design with three replications of each treatment in a total of 21 pots. *Trichoderma enriched* biofertilizer and urea were applied at 15000 kg ha^{-1} and 267 kg ha^{-1}, respectively, either separately or in combination under two salinity treatments (85 mM and 140 mM). These treatments were designated as T_0S_0 (control), T_1S_1 (*Trichoderma* biofertilizer+85 mM), T_2S_1 (Urea+85mM), T_3S_1 (*Trichoderma* biofertilizer & Urea+85mM), T_4S_2 (*Trichoderma* biofertilizer +140 mM), T_5S_2 (Urea+140 mM), and T_6S_2 (*Trichoderma* biofertilizer & Urea+140mM). First, pots were filled with 4 kg of air-dried soil samples. The soils were mixed with the required amounts of biofertilizer and urea according to the pot labels for 9 days. The recommended fertilizer doses for rice growth were added to each pot, with NPK supplied as urea, TSP (Triple Super Phosphate), and MP (Murate of Potash). Three seedlings were then transplanted into each pot in a triangular arrangement. Each pot was maintained with a 2-inch depth of standing water throughout the growth period.

Table 1. Composition of *Trichoderma enriched* biofertilizer

Element	Percentage
Cow dung	28%
Chicken shit	36%
Vegetable leftovers	11%
Water hyacinth	20%
Wood pulse	3%
Corn pulse	1%
Ash	1%
Trichoderma spp.	3×10^7 CFU (Colony Forming Unit)/g

Table 2. Properties of *Trichoderma enriched* biofertilizer

Properties	***Trichoderma* enriched biofertilizer**
Physical properties	
Color	Light brown to brown
Physical condition	Non-granular form
Odor	Presence of foul odor
Physicochemical and chemical properties	
pH	8
OC (%)	20
OM (%)	34.4
Total N (%)	1.2
Total P (%)	3.47
Total K (%)	0.93
Total S (%)	0.24
Total Ca (%)	1.71
Total Mg (%)	0.40
Total Fe (%)	0.12
Total Cu (%)	0.01
Total Zn (%)	0.0512

2.4 Preparation of Salinity Treatment

Seawater was artificially simulated using NaCl and $MgCl_2$. Artificial saline water with salt concentrations of 0 (control), 85, and 140 mM was prepared in the laboratory. The 85 mM salt solution was prepared by dissolving 4.216 g NaCl and 0.773 g $MgCl_2$ together in 1000 mL of water. Similarly, the 140 mM salt solution was prepared by dissolving 7 g NaCl and 1.218 g $MgCl_2$ in 1000 mL of water.

2.5 Harvesting and Preparation

After 100 days of transplantation, when grains had appeared in most treatments, seedling, stem, leaf, and grain samples were collected separately from each pot. These were placed in paper bags with appropriate labelling and brought to the laboratory. The collected plant samples were washed first with tap water and then with distilled water. The heights of the collected plants were recorded. The fresh weights of plants and grains were measured separately using an electric balance. The samples were air-dried for one day and then oven-dried at 70±5°C for 48 hours. The oven-dry weights of the samples were also recorded. The shoot and root were then separated from each plant and ground with a mortar and pestle. The ground samples were kept in envelopes with appropriate labelling and stored in a dry place. For each ground shoot, root, and grain sample, 0.5 g was weighed separately and placed in a 100 mL Pyrex beaker. Each weighed sample was mixed with 15 mL of concentrated nitric acid (HNO_3) and left overnight for pre-digestion. The pre-digested samples were heated in a sand bath for about 15 minutes. The samples were then cooled, and 5 mL of perchloric acid ($HClO_4$) was added. The samples were further digested until the contents became colorless. The digests were cooled, filtered, diluted to 50 mL, and transferred into dry plastic bottles (Jackson, 1973). This extract was used for further analysis.

2.6 Nitrogen Use Efficiency

The nitrogen use efficiency of the plant was calculated in two ways:

1. Apparent N use efficiency = (N uptake by plant with N application- N uptake by plant without N application)/ the amount of N applied.
2. Agronomic NUE (kg kg^{-1}) = Grain yield treated - Grain yield in control plot/Quantity of nitrogen applied.

2.7 Data Analysis

The data collected in the experiment were calculated, and the results were evaluated graphically using Microsoft Excel (version 2010). The calculated results were statistically analyzed using one-way analysis of variance (ANOVA) in SPSS (version 20) software.

3. Results

3.1 Growth Parameters

Plant growth is generally assessed using morphological properties and yield parameters. Differences in the morphological properties (plant height, tiller number, and grain weight) of *Oryza sativa* among the various treatments are presented in Table 3.

Growth parameters increased with time and varied significantly ($p \leq 0.05$) among treatments. Plant height was measured from the base of the plant to the tip of the top leaf at different growth stages. Plant height across the treatments ranged from 81 to 101 cm. The tallest plant (101 cm) was recorded under treatment T_3S_1 (Tri & U+85mM), which was 24.7% higher than under treatment T_0S_0 (control). The highest tiller production, 45 tillers per plant, was recorded under treatment T_3S_1. A visible difference in plant height and tiller production was observed between the 85 mM and 140 mM salinity treatments. Significant differences were observed among treatments based on the LSD at the 5% significance level.

The different treatments had different effects on panicle length and the number of panicles of *Oryza sativa.* The maximum panicle length (17 cm) and number of panicles (11.3) were observed under treatment T_3S_1, representing increases of 41.67% and 69%, respectively, over the control. The lowest panicle length (13 cm) and number of panicles (5), excluding the control, were recorded under treatment T_4S_2.

Table 3. Growth parameters of Oryza sativa under different fertilizer and salinity treatments

Treatment	Plant Height (cm)	Root length (cm)	Tiller no. per plant	No. of panicles per plant	Panicles Length (cm)	Shoot-root ratio
T_0S_0	81	13.5	24	7	12	6
T_1S_1	94	16.5	34	10	16	5.7
T_2S_1	90	21	26	8	15	4.3
T_3S_1	101	14	45	11.3	17	7.2
T_4S_2	84.5	11	23	5	13	7.6
T_5S_2	82	12	16	-	-	6.8
T_6S_2	89	10	29	9	14.7	8.9
P-value	**0.001**	**0.001**	**0.002**	**0.0002**	**0.045**	**-**
LSD	**8.365**	**3.989**	**10.689**	**1.96**	**3.19**	**-**

**T_0S_0= control; T_1S_1= Trichoderma + 85 mM; T_2S_1= Urea + 85 mM; T_3S_1= Trichoderma & Urea + 85 mM; T_4S_2= Trichoderma+ 140 mM; T_5S_2= Urea + 140 mM; and T_6S_2= Trichoderma & Urea + 140 mM.*

3.2 Yield Properties

Different yield parameters (fresh weight, dry biomass, straw yield, grain yield, and harvest index) of *Oryza sativa* were observed under two salinity treatments and fertilizer application (Table 4).

The highest fresh weight, dry biomass, straw yield, and grain yield were observed under the combined application of inorganic and biofertilizer (T_3S_1). Differences in the fresh weight of BR-29 among treatments are shown in Table 4 and were significant ($p \leq 0.05$). The maximum fresh weight (780 kg ha^{-1}) was obtained under treatment T_3S_1, which was 188.87% higher than the control. The second-highest fresh weight (640 kg ha^{-1}) was obtained under treatment T_6S_2, which was 137.04% higher than the control. In contrast, the minimum fresh weight (130 kg ha^{-1}) was obtained under treatment T_4S_2, which was 37.03% lower than the control. Dry biomass is an indicator of the organic matter in a plant. Treatment T_3S_1 produced the highest dry biomass (70.71%), which was

11.48% higher than treatment T_0S_0 (Table 4; Fig. 1). The highest decrease (18.3%) in biomass over the control was observed in treatment T_5S_2. These results indicate the negative impact of salinity stress on biomass accumulation, particularly at higher salinity levels. However, the application of biofertilizers mitigated the negative impacts of salinity and improved biomass production under saline conditions. Differences among treatments in grain yield, straw yield, dry weight, and fresh weight were statistically significant ($p < 0.05$) (Table 4). Detailed rice yield results for the different treatments are shown in Table 4. Based on the findings, plants produced a higher yield under salinity treatment 1 than under salinity treatment 2. The highest grain (50 kg ha^{-1}) and straw yields (490 kg ha^{-1}) were recorded under treatment T_3S_1. The maximum straw (290 kg ha^{-1}) and grain yield (30 kg ha^{-1}) under 140 mM were recorded under treatment T_6S_2. No grain was produced under treatment T_5S_2 due to the higher salinity level. Percentage changes relative to the control for grain and straw yield are shown for each treatment in Table 4 and Fig. 2. These values show the increase or decrease in straw and grain yield under the different treatments compared with the control. The grain and straw yields of T_3S_1, which showed the highest yield, were 150% and 114.04% higher, respectively, than the control. Under treatment T_4S_2, grain and straw yields decreased by 50% and 56.52%, respectively, relative to the control.

Table 4. Fresh weight, grain yield, straw yield, and harvest index of *Oryza sativa* under fertilizer and salinity treatments

Treatment	Fresh Weight (kg ha^{-1})		Dry Biomass (%)		Grain Yield (t/ha)		Straw Yield (kg ha^{-1})		Harvest Index
	Weight	IOC (%)	Weight	IOC (%)	Yield	IOC (%)	Yield	IOC (%)	
T_0S_0	270	-	174.8	-	20	-	230	-	0.099
T_1S_1	380	28.95	244.7	28.6	40	100	310	34.78	0.11
T_2S_1	520	92.59	356.2	50.9	26	30	240	4.35	0.15
T_3S_1	780	188.9	548.6	68.1	50	150	490	114	0.10
T_4S_2	130	-51.85	68.5	-155.2	10	-50	100	-56.52	0.09
T_5S_2	230	-14.81	116.9	-49.5	-	-	120	-47.83	-
T_6S_2	640	137	354.1	50.6	30	50	290	26.09	0.11
P-value	**<0.001**		**0.01**		**0.001**		**0.002**		**NS**
LSD	**0.072**	**-**	**15.47**	**-**	**0.015**	**-**	**0.148**	**-**	**0.096**

T_0S_0= control; T_1S_1= Trichoderma + 85 mM; T_2S_1= Urea + 85 mM; T_3S_1= Trichoderma & Urea + 85 mM; T_4S_2= Trichoderma+ 140 mM; T_5S_2= Urea + 140 mM; and T_6S_2= Trichoderma & Urea + 140 mM

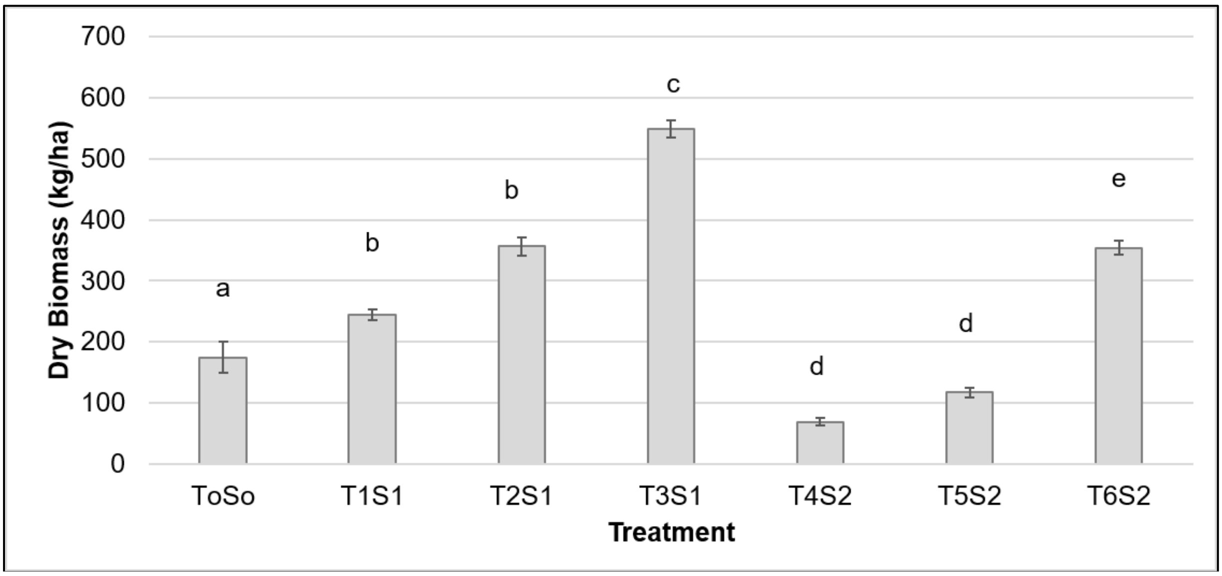

Fig. 1. Plant dry biomass in response to fertilizer and salinity treatments

To examine the relationships among plant growth parameters, Pearson correlations were determined among plant height, tiller number per plant, number of panicles per plant, dry weight, grain yield, straw yield, nitrogen, phosphorus, potassium, and sulphur. Plant height showed high positive correlations, with reported R values of 0.94, 0.79, 0.69, 0.88, 0.89, and 0.88, and all were significant at the 1% level.

Based on grain and straw yields, the *Trichoderma enriched* biofertilizer performed better than the inorganic fertilizer under salinity treatment. However, the combined application of biofertilizer and inorganic fertilizer was more effective.

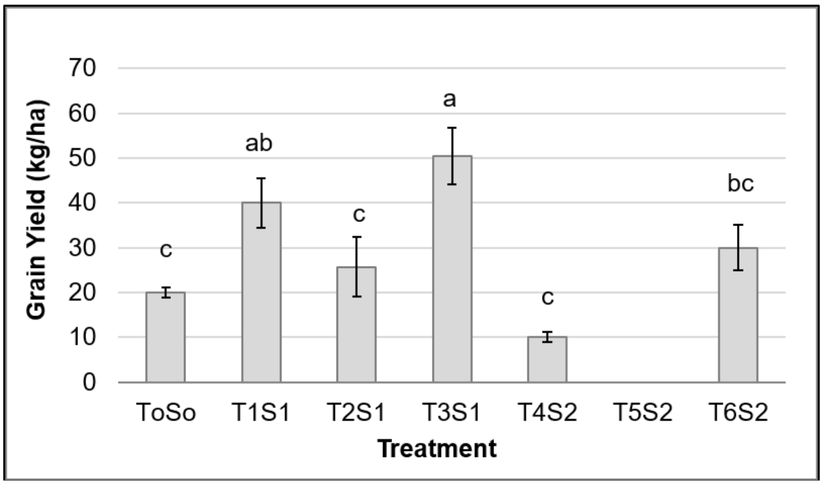

Fig. 2. Grain yield of *Oryza sativa* and its percentage difference under different fertilizer and salinity treatments

Table 5. Macronutrient uptake by *Oryza sativa* under fertilizer and salinity treatments

Treatment	Macronutrient uptake (kg ha^{-1})							
	Total Nitrogen		Total Phosphorus		Total Potassium		Total Sulfur	
	Shoot	Grain	Shoot	Grain	Shoot	Grain	Shoot	Grain
T_0S_0	4.16	0.39	0.17	0.01	1.99	0.03	0.57	0.02
T_1S_1	7.19	1.03	0.83	0.10	2.08	0.08	1.07	0.14
T_2S_1	5.13	0.67	0.45	0.05	1.69	0.08	0.89	0.09
T_3S_1	14.55	1.48	1.06	0.11	4.28	0.13	1.88	0.08
T_4S_2	2.25	0.23	0.21	0.02	0.85	0.02	0.62	0.07
T_5S_2	3.29	-	0.15	-	1.18	-	0.46	-
T_6S_2	6.65	0.71	0.49	0.05	2.26	0.07	0.75	0.09
LSD	**3.44**	**0.89**	**0.86**	**0.06**	**1.42**	**0.07**	**1.13**	**0.08**

**T_0S_0= control; T_1S_1= Trichoderma + 85 mM; T_2S_1= Urea + 85 mM; T_3S_1= Trichoderma & Urea + 85 mM; T_4S_2= Trichoderma+ 140 mM; T_5S_2= Urea + 140 mM; and T_6S_2= Trichoderma & Urea + 140 mM*

3.3 Macronutrient Uptake

The uptake of macronutrients such as nitrogen (N), phosphorus (P), potassium (K), and sulphur (S) by *Oryza sativa* under different treatments is shown in Table 5. Nutrient uptake showed visible differences between the two salt treatments with organic and inorganic fertilizers. The highest nitrogen (14.55 kg ha^{-1}), phosphorus (1.056 kg/ha), and potassium (4.282 kg ha^{-1}) uptakes were observed in the plant shoot under treatment T_3S_1 (*Trichoderma enriched bio-fertilizer* in combination with urea under 85 mM salt treatment). In grain, the maximum nitrogen (1.48 kg ha^{-1}), phosphorus (0.112 kg ha^{-1}), and potassium (0.134 kg ha^{-1}) uptakes were also observed under the same treatment as in the shoot. Lower nitrogen uptake than the control was observed under T_4S_2 and T_5S_2 in the shoot and only under T_4S_2 in the grain. Lower phosphorus uptake in the shoot than in the control was observed under treatment T_5S_2. In treatments T_2S_1, T_4S_2, and T_5S_2, potassium uptake by the plant shoot was lower than in the control.

Macronutrient uptake (N, P, S, and K) showed high or moderate positive correlations with plant growth and yield parameters, except for the number of panicles. Correlations with the number of panicles were not significant for nitrogen, potassium, and sulphur uptake. Nitrogen uptake showed high positive correlations with plant height, tiller number per plant, dry weight, grain yield, straw yield, phosphorus, potassium, and sulphur (R=0.982, R=0.954, R=0.968, R=0.886, R=0.968, R=0.917, R=0.977, and R=0.961, respectively) at the 1% level. Its correlation with the number of panicles was not significant. The correlation analysis indicates that higher nitrogen uptake was associated with crop yield, plant growth and yield parameters, and the uptake of other macronutrients (P, S, and K).

For macronutrient uptake, the best result was observed under treatment T_3S_1, where *Trichoderma* biofertilizer was applied in combination with urea under the 85 mM salt treatment. Compared with inorganic fertilizer, organic fertilizer showed better macronutrient uptake under both salt treatments.

3.4 Nitrogen Use Efficiency

Nitrogen use efficiency was determined using two methods: apparent nitrogen use efficiency and agronomic nitrogen use efficiency. Table 6 shows that nitrogen use efficiency decreased with increasing salinity according to both methods. Plaut (1974) reported that NaCl stress inhibits N metabolism in wheat seedlings by affecting nitrate reductase activity. Chloride was found to strongly inhibit net NO_3-uptake (Ward *et al*., 1986). The apparent nitrogen use efficiency of rice ranged from 1.3% to 6% across treatments. The maximum nitrogen use efficiency (6%) was recorded under treatment T_3S_1, where *Trichoderma enriched* biofertilizer and urea were applied together under the 85 mM salinity treatment. The minimum nitrogen use efficiency (1.3%) was observed under treatment T_4S_2, where *Trichoderma enriched* biofertilizer was applied under the 140 mM salt treatment.

In terms of agronomic nitrogen use efficiency, the highest nitrogen use efficiency (12.47%) was recorded in the grain under treatment T_3S_1, and the lowest result was found under treatment T_4S_2. Under both salinity treatments, *Trichoderma enriched* biofertilizer in combination with urea showed higher nitrogen use efficiency than the other two treatments. Agronomic nitrogen use efficiency under treatment T_3S_1 was 106.79% and 124.46% higher than under treatments T_1S_1 and T_2S_1, respectively, under 85 mM salinity treatment. Under the 140 mM saline treatment, T_6S_2 was 21.85% higher than under treatment T_4S_2. The nitrogen use efficiency values may have been influenced by the pot-experiment conditions; field experiments may yield different NUE values.

4. Discussion

The main aim of this research was to compare the capacity of a *Trichoderma enriched* bio-organic fertilizer and urea to stimulate rice growth, soil nutrient availability, and, most importantly, the nitrogen use efficiency of rice under saline conditions, to reduce nitrogen loss and minimise environmental pollution. For this purpose, a pot experiment on *Oryza sativa* was conducted in the Department of Soil, Water, and Environment, University of Dhaka. In this experiment, plant morphological properties (plant height, root length, tiller number, panicle length, panicle number, and grain weight), yield parameters (fresh weight, dry biomass, straw yield, grain yield, and harvest index), plant nutrient uptake (macronutrients and micronutrients), and post-harvest soil properties were assessed using appropriate laboratory methods.

Table 6. Nitrogen use efficiency (NUE) of *Oryza sativa* under fertilizer and salinity treatments using two methods

Treatment	Apparent NUE	Agronomic NUE
T_1S_1	2.11	6.03
T_2S_1	2.51	5.6
T_3S_1	6	12.47
T_4S_2	1.3	4.76
T_5S_2	-	-
T_6S_2	2.27	5.8
LSD	**2.47**	**2.42**

T_1S_1= Trichoderma + 85 mM; T_2S_1= Urea + 85 mM; T_3S_1= Trichoderma & Urea + 85 mM; T_4S_2= Trichoderma+ 140 mM; T_5S_2= Urea + 140 mM; and T_6S_2= Trichoderma & Urea + 140 mM.

There were visible differences in plant growth parameters and nutrient uptake between the two salinity treatments. Under both salinity treatments (85 mM and 140 mM), the highest values for plant morphological properties and yield parameters were recorded under the *Trichoderma enriched* biofertilizer combined with urea treatment compared with the other two treatments. The highest plant height (101 cm), dry biomass (548.6 kg ha^{-1}), straw yield (490 kg ha^{-1}), and grain yield (50 kg ha^{-1}) were recorded under treatment T_3S_1 (*Trichoderma enriched* biofertilizer in combination with urea under the 85 mM saline treatment). This treatment produced the highest recorded values among the treatments. Although the plant grew under treatment T_5S_2 at the higher salinity level, it produced no grain. The effect of *Trichoderma* on plant height was consistent with the findings of another study, in which *Trichoderma*-inoculated rice plants showed increased shoot length compared with the control (Doni *et al*., 2014). In another study, rice plant height ranged from 81.7 to 86.1 cm with the application of different *Trichoderma* isolates, whereas plant height was 81.5 cm under the control treatment (Anhar *et al*., 2020). Another study found that *Trichoderma* enhanced rice growth components such as plant height, leaf number, tiller number, root length, and shoot fresh weight (Doni *et al.*, 2014). In a study conducted by Song *et al*. (2025) in China, *Trichoderma* inoculant increased plant height, root length, dry weight, and fresh weight of rice under saline conditions. *Azospirillum*, *Trichoderma*, blue-green algae, and *Azolla* have been shown to reproduce very quickly, reducing the application of inorganic N fertilizers by up to 25% through atmospheric N (Patel, 1998), and play a dynamic role in supporting rice yield increases (Gnanamanickam *et al*., 2002). Similarly, the application of *Trichoderma* biofertilizer, either individually or in combination with different rates of nitrogen fertilizer, significantly increased root length, shoot length, and fresh and dry weight of rice (Singh *et al*., 2019). In another study conducted by Elita *et al.* (2022), the combined application of *Trichoderma asperellum* and biochar enhanced the observed growth and yields, resulting in a 55.31% increase compared with the application of the full dose of inorganic fertilizer.

Saline conditions make it difficult for plants to take up nutrients. In this experiment, *the Trichoderma enriched* biofertilizer played an important role. The macronutrient and micronutrient contents in the plant were within the optimum range for plant growth. The effects of saline conditions on plant nutrient content were evident from the analyzed data. In the shoot, the highest total nitrogen (2.902%), total phosphorus (0.283%), and total potassium (1.013%) contents were recorded in *Oryza sativa* under treatment T_3S_1. However, the maximum sulphur content (0.49%) and total magnesium content (0.409%) were recorded under treatments T_1S_1 (*Trichoderma enriched* biofertilizer under the 85 mM saline treatment) and T_4S_2 (*Trichoderma enriched* biofertilizer under the 140 mM saline treatment), respectively. A similar pattern was observed for the macronutrient content of grain. Most of the highest macronutrient contents in grain were recorded under treatment T_3S_1, with exceptions under treatments T_1S_1 and T_4S_2. Some genes of *Trichoderma* species can confer resistance to biotic and abiotic stresses such as salt, heat, and drought (Kuc, 2001). Some *Trichoderma* rhizosphere-competent strains that can colonise root surfaces have been shown to have direct effects on plants, increasing their growth potential and nutrient uptake, fertilizer efficiency, consumption, proportion, and rate of seed germination, and inducing systemic resistance (ISR) to diseases (Shoresh *et al*., 2010).

Nitrogen use efficiency of *Oryza sativa* was measured using two methods: apparent NUE and agronomic NUE. Under saline conditions, nitrogen use efficiency was lower under the 140 mM salinity treatment than under the 85 mM salinity treatment. Under these stress conditions, nitrogen use efficiency of rice was higher when *Trichoderma enriched* biofertilizer was applied in combination with urea. Urea is a commonly used fertilizer worldwide as a nitrogen source for plant growth. However, under saline conditions, biofertilizer performed better than inorganic fertilizer in terms of nitrogen use efficiency. The highest apparent NUE (6%) and agronomic NUE (12.47%) were recorded under treatment T_3S_1. Nitrogen is a limiting factor for crop growth under saline conditions because the availability of nitrogenous fertilizer in salt-affected soils depends on the nature of the fertilizer, degree of salinity, and presence or absence of organic matter in the soil. Under these conditions, N may minimize the adverse effects of salinity on plant growth and yield (Singh & Kashyap, 2007; Esmaili *et al*., 2008; Abdelgadir *et al*., 2005, 2010) and help increase plant salt tolerance (Sairam & Tyagi, 2004). *T. virens* GV41 increased fertilizer N use efficiency of lettuce, favored the uptake of native soil N by both lettuce and rocket, and also improved N uptake by roots under low N availability conditions (Fiorentino *et al*., 2018).

5. Conclusion

Salinity is a major problem for agriculture in Bangladesh and worldwide. It adversely affects plant growth and soil health. In addition, inadequate fertilizer management during crop growth can contribute to nutrient losses and environmental pollution.

Biofertilizer may provide a natural approach to addressing these two problems. After analyzing the evaluated properties of *Oryza sativa* and the post-harvest soil, the combined application of *Trichoderma enriched* biofertilizer and urea was associated with reduced effects of salinity on plant growth. However, because this was a pot experiment, further research under larger-scale conditions is required before broader conclusions are drawn. Greater use of biofertilizer may reduce reliance on chemical fertilizers. The combined use of biofertilizer and inorganic fertilizer may support crop growth while reducing inorganic fertilizer use. This approach may also help minimise environmental pollution associated with excessive chemical fertilizer use.

6. Limitations

This study was conducted as a pot experiment using one rice variety (BR 29), two salinity levels (85 and 140 mM), seven treatments, and three replications. The controlled conditions and limited experimental scale may not represent field variability in soil, climate, water management, and crop response. In addition, the experiment was conducted over a single crop cycle. Consequently, the observed effects on growth, yield, nutrient uptake, and nitrogen use efficiency should be validated through larger, replicated field experiments before broad agronomic recommendations are made.

Declaration of AI Use

This manuscript was prepared through the intellectual contributions of the author(s) to the study design, data analysis, interpretation of results, and scholarly content. Grammarly and ChatGPT were used solely to assist with grammatical refinement and reference formatting during manuscript revision. The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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