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Enhancing beetroot (*Beta vulgaris* L) growth and soil quality through vermicompost–fertilizer integration in coastal saline soil

Mariha Rahman[1], Nishat Farabi[1], Mehedi Hasan[1], Nasrin Akter[2], Mostaque Ahmad[3], Md. Bayzid Sarker[4] and Gazi Md. Mohsin[5]*

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A B S T R A C T

In Bangladesh's coastal areas, soil salinity affects both soil health and agricultural output. An experiment was conducted to assess the combined effects of vermicompost and inorganic fertilizers on improving saline soil properties and the growth performance of beetroot at the Agricultural Research Field, Noakhali Science and Technology University, Noakhali, Bangladesh. The experiment followed a Randomized Complete Block Design with nine treatment comprises of, T_1 (Control); T_2 (100% RDF* + 0 t ha^{-1} VC); T_3 (50% RDF* + 0 t ha^{-1} VC*); T_4 (50% RDF* + 2.5 t ha^{-1} VC*); T_5 (50% RDF* + 5 t ha^{-1} VC*); T_6 (50% RDF* + 10 t ha^{-1} VC*); T_7 (100% RDF* + 2.5 t ha^{-1} VC*); T_8 (100% RDF* + 5 t ha^{-1} VC*); T_9 (100% RDF* + 10 t ha^{-1} VC*). The highest Plant height 49.11 cm, maximum number of leaves per plant 12.27, and maximum leaf area 316.23 (cm^2) per plot were recorded with the T8 treatment, while the maximum green beetroot yield 6.40 t ha^{-1}) and maximum root yield 9.37 t ha^{-1}) were found to be the highest with T_9. Vermicompost application lowered soil electrical conductivity (EC) from 2.94 to 0.98 dS m^{-1}, indicating improved soil conditions and reduced salinity stress. The untreated group (T_1) had the poorest outcome across all variables. These data suggest that integrating vermicompost (5-10 t ha^{-1}) with standard fertilizer doses significantly enhances beetroot growth, yield, and soil quality under coastal saline conditions, offering an effective approach to sustainably producing vegetables in Noakhali and other saline areas. Additional research is encouraged to corroborate these results across a more extensive agroecological context.

Keywords: Beetroot, *Beta vulgaris*, Vermicompost, Saline soil

[1]*Department of Soil, Water and Environmental Sciences, Noakhali Science and Technology University, Noakhali, Bangladesh*
[2]*Department of Chemistry, Noakhali Science and Technology University, Noakhali, Bangladesh*
[3]*Department of Soil, Water and Environment, Dhaka University, Bangladesh*
[4]*Research & Development, Lal Teer Seed Limited, Gazipur, Bangladesh*
[5]*Department of Agriculture, Noakhali Science and Technology University, Noakhali, Bangladesh*

*Corresponding author's email: gazimohsin@nstu.edu.bd (Gazi Md. Mohsin)

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Introduction

Soil salinity is a serious issue for agriculture as it impacts physical growth factors, including root size, biomass, and yield, by causing osmotic stress, ion imbalance, decreased nutrient availability, and agricultural sustainability (AbdElgawad *et al.*, 2016; Machado and Serralheiro, 2017; Khatun *et al.*, 2019; Munns and Tester, 2008). Salinity levels above 4 dS m^{-1} during the dry season can severely limit vegetable cultivation in coastal Bangladesh (SRDI, 2022). Root and tuber crops are typically sensitive to salinity; however, beetroot (*Beta vulgaris* L.) is rich in vitamins, minerals, and antioxidants and is highly adaptable to Bangladesh's varied agro-ecological conditions.

Beetroot is a globally farmed root vegetable and edible plant used for sugar production, fodder, natural dye, and human consumption (Talucder *et al.*, 2025). Beetroot is among the top ten vegetables with the highest concentrations of phenolic compounds and antioxidant activity. Variety, cultivation environment, and morphological characteristics all affect red beetroot's chemical composition and nutritional value. Beetroot is easily maintained in fields. It demonstrates high yield and rapid development and is generally free of complications and pests (Brar *et al.*, 2015; Feizi *et al.*, 2018; dos S. Baião *et al.*, 2020). Beetroot grows well in saline soils when integrated with organic amendments, such as vermicompost, and recommended fertilizer (Kibatu and Mamo, 2014; Chaves *et al.*, 2009). Beetroot can be a good test crop for examining how vermicompost impacts growth and yield performance in saline soil conditions due to its natural resistance to drought and salt (Uddin *et al.*, 2016) and the noticeable effects of vermicompost in lowering soil salinity and enhancing beetroot's leaf production, chlorophyll content, and vegetative growth (Mia and Rashid, 2023; Tahjib-UI-Arif *et al.*, 2019).

Organic amendments, particularly vermicompost, have demonstrated great potential for mitigating the negative effects of salinity on plant development. Vermicompost improves soil physical properties, enhances nutrient availability, and can reduce salt accumulation in the topsoil (Khatun *et al.*, 2019). Previous studies have demonstrated that the application of vermicompost in saline environments can substantially increase soil organic matter, improve soil pH, and enhance the availability of essential nutrients across various cropping systems, including water spinach and wheat (Lazcano and Dominguez, 2011). Co-application of organic amendments with chemical fertilizers has also been shown to improve soil structural stability, stimulate beneficial microbial communities, and ultimately increase plant biomass and yield (Biancardi *et al.*, 2012; Rozema *et al.*, 2015). Salt-affected sedimentary soils have shown that applying vermicompost increases nutrient content and promotes plant growth while decreasing electrical conductivity (EC) and bulk density of the soil (Arancon *et al.*, 2004; Joshi *et al.*, 2020).

Although beetroot can be grown effectively in saline soils with appropriate fertilizer management, its cultivation remains very limited in Bangladesh, especially in the Noakhali region, and a comprehensive study of its potential yield under these conditions is lacking. Similarly, combining vermicompost and inorganic fertilizers has been shown to increase crop yield and soil fertility (Melak *et al.*, 2025), yet studies assessing their combined effects on beetroot growth and physical parameters are lacking in the coastal agroecosystem of Noakhali. The present study is therefore designed with the hypothesis that the integrated use of vermicompost and inorganic fertilizers will enhance the physical growth parameters of beetroot while reducing salinity stress, compared to no fertilization under coastal saline conditions.

Materials and Methods

Study area and sample collection

The experiment was carried out at Noakhali Science and Technology University's Agricultural Investigation Field in Noakhali, Bangladesh (Latitude: 22°47′31″ N; Longitude: 91°06′03″ E) from November 2024 to February 2025 in the agro-ecological region of the Young Meghna Estuarine Floodplain (AEZ-18). In the current investigation, initial soil samples were randomly collected from six sites at depths of 0-20 cm using a hand auger and then thoroughly mixed. The initial soil was silt loam in texture, slightly acidic in reaction, and slightly saline (Table 1 and 2).

Table 1. Physical and chemical properties of the initial soil under study.

Parameters Values	Sub-surface (0-20 cm depth)
Textural class	Silt loam
pH(1:2.5)	6.94
EC (dS/m)	2.92

Table 2. Salinity classes according to the SRDI (2010).

Salinity Class	EC (dS/m)
Non-saline	0-2
Slightly saline	2-4
Moderately saline	4-8
Highly (or strongly) saline	8-16
Very / Extremely saline	>16

Land preparation and experimental design

A mechanical tiller was used to prepare the area thoroughly, followed by a harrow and a shovel. Three replications were used in the Randomized Complete Block Design (RCBD) experiment. The experiment consisted of nine treatments, viz., T_1 (Control); T_2(100% RDF* + 0 t ha^{-1} VC); T_3 (50% RDF* + 0 t ha^{-1} VC*); T_4 (50% RDF* + 2.5 t ha^{-1} VC*); T_5 (50% RDF* + 5 t ha^{-1} VC*); T_6 (50% RDF* + 10 t ha^{-1} VC*); T_7 (100% RDF* + 2.5 t ha^{-1} VC*); T_8 (100% RDF* + 5 t ha^{-1} VC*); T_9 (100% RDF* + 10 t ha^{-1} VC*). The size of each treatment was kept at 1.0 m × 1.0 m. Each treatment was 20 cm high, with 8 cm-deep drainage around each plot to restrict lateral runoff of irrigation or rainfall water. The distance between the two blocks and the two plots was maintained at 0.5 m. Plant spacing was 0.25 m. During the final land preparation, vermicompost was applied at the prescribed treatment rates. According to Islam *et al.* (2017), inorganic fertilizers were applied at the recommended rates.

* RDF = Recommended dose of fertilizer
*VC = Vermicompost

Seed collection and germination test

An approved high-yielding variety of Beetroot (*Beta vulgaris* L) was used in this experiment. A seed that germinates quickly has a higher chance of sprouting in the field. Two distinct petridishes were obtained and sterilized with ethanol in order to determine the germination percentage. Seeds that had been soaked in water were set out on the tissue paper in the petridishes and left at room temperature for a whole day. In the Beets from 50 seeds, 46 seeds germinated, for a germination rate of 92%.

Observation and data collection

Data on several parameters were collected using the sample plants during the experiment, such as the number of leaves per plant, the length, width, and area of the leaves (cm^2), the height of the plant (cm), the initial weight of the roots per plant (g), the root weight per plot (kg), and the root weight (tons per hectare). At 45, 80, and 100 days after sowing (DAS), five randomly chosen plants from each plot had their height, number of leaves per plant, leaf length, and leaf breadth measured in centimeters (cm). Five randomly chosen plants from each plot were oven-dried, and the dry matter content of their roots was measured.

Intercultural practices

Numerous intercultural techniques, including mulching, watering, weed control, and earthing up, were used to enhance plant growth and development. At 30 days after sowing (DAS), a hoe was used to loosen the soil. After the seeds were sown, weeding and thinning were carried out at 8, 25, 45, 65, and 80 days. At 30 and 45 DAS, Indofil M-45 (2 g L^{-1}) was sprayed to prevent fungal assault.

Harvesting

Five samples were uprooted from each plot individually after 100 DAS. After that, the plants were rinsed with water to remove dead and dried plant parts. The plant samples were then taken to the threshing floor to record data.

Collection of post-harvest soil to determine pH and EC

The soil samples were taken between 0 and 20 cm below the surface. Three subsample sets for each sampling site were collected and carefully combined. After being air-dried, ground, and thoroughly mixed, the combined samples were sieved through a 2 mm sieve and then placed in a sterilized plastic container for analysis. The pH of the soil was measured using a glass electrode pH meter. According to Jackson (1962), the soil-to-water ratio in the suspension was maintained at 1:2.5. To measure the sample's electrical conductivity (EC), soil and distilled water were mixed at a 1:5 (w/v) ratio and stirred for 30 minutes. A digital EC meter standardized with a 0.01 N KCl solution at 25 °C was used to measure the EC of the filtrate after the suspension had been filtered through Whatman No. 42 filter paper (Page *et al.*, 1982).

Statistical analysis

According to Gomez and Gomez (1984), the analysis of variance (ANOVA) was used to statistically analyze all obtained data. The Least Significant Difference (LSD) test was used to assess the significance of mean differences at the 5% and 1% significance levels.

Results and Discussion

Effect of various combinations of vermicompost and inorganic fertilizers on post-harvest soil pH and EC

The present study revealed that integrating vermicompost with inorganic fertilizer significantly reduced soil EC, indicating reduced salinity stress on plants and increased nutrient availability (Nell *et al.*, 2014), with minimal effect on pH. The lowest EC level (0.98 dS/m) (Fig. 1) was observed at treatment T_6, which did not differ significantly ($p > 0.05$) from T5, T8, and T_9. However, the highest EC (2.92 dS/m) was observed in the control (T_1). This outcome shows that vermicompost has a beneficial effect in lowering salinity stress. These findings were correlated with the experiment of Petmuenwai *et al.* (2024). In highly salinized soil, they showed that the addition of vermicompost and organic amendments resulted in a lower EC (0.30-5.98 dS/m) than the control treatments. Wang *et al.* (2017) conducted an experiment on tomato and recommended vermicompost as a fertilizer to improve tomato yield and soil quality. They reported that during the final sampling period, EC was lower in the vermicompost treatment. The greatest improvement in saline-alkaline soil was achieved by Ai *et al.* (2023), which improved pH and conductivity.

Soil pH was highest (7.5) where EC was low (Fig. 1). One possible explanation is that higher EC values indicate higher ion content, which pushes hydrogen ions in the soil away and lowers the pH. The findings of the present study are also supported by Debi *et al.* (2019), who reported a negative correlation between pH and EC, a pattern also suggested by many other researchers (Shabbir *et al.*, 2014; Ouhadi and Goodarzi, 2007). The lowest soil pH (6.96) (slightly acidic) was recorded in treatment T_1, which differed significantly ($p < 0.05$) from the treatments receiving vermicompost. This is because vermicompost contains humic compounds and exchangeable cations (Ca^{2+}, Mg^{2+}, and K^+) that buffer soil acidity and enhance soil chemical balance. Lalitha *et al.* (2000), Chaoui *et al.* (2003), and Joshi *et al.* (2015) reported similar patterns, indicating that the application of vermicompost increased soil pH and improved soil fertility in acid-prone soils.

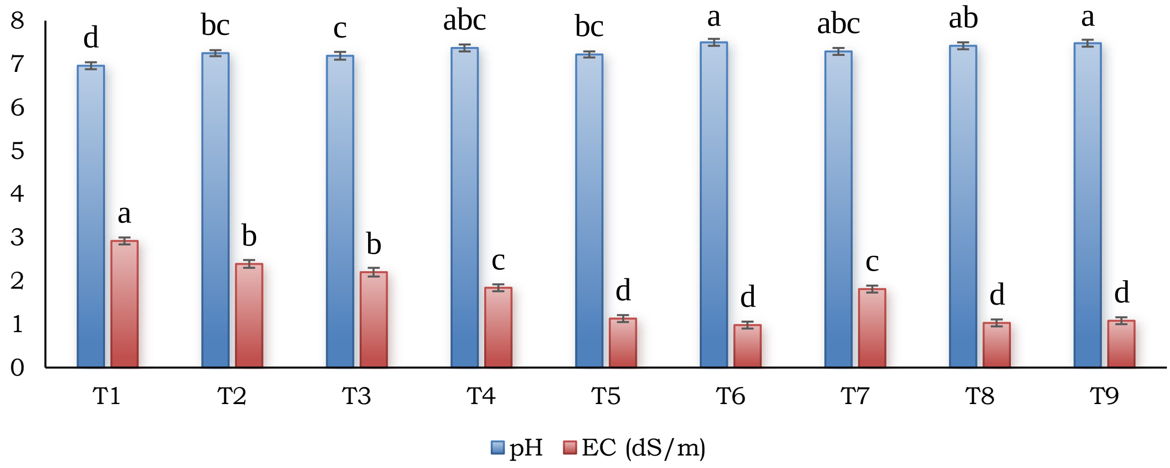

Fig 1. Effect of different fertilizer treatments on post-harvest soil pH and electrical conductivity (EC). A one-way ANOVA was carried out, followed by Tukey's post-hoc test, to see if there were any significant variations in soil pH and EC between the treatments. Significant differences between treatments are shown by different letters above the bars ($p < 0.05$).

Effect of various combinations of vermicompost and inorganic fertilizers on the growth of beetroot

Plant Height

The combined effects of organic and inorganic fertilizers on plant height at various stages of growth are depicted in Figure 2. At 45 days after sowing (DAS), there was a significant difference ($p < 0.05$) between the treatments. The plant height in T_1 (Control) was the lowest (13.96 cm) and differed greatly from those of the other treatments (T_2–T_9). However, at 80 and 100 DAS, no significant differences were observed. This suggests that the difference in plant height decreased at later growth stages, even if fertilizer application affected early plant growth (Mia and Rashid, 2023). These findings are also supported by Du *et al.* (2021). They recorded that during early and mid-growth stages, plant height increased significantly with fertilizer rate. However, by the 60th day, there were insignificant differences in plant height among treatments.

The maximum plant height at 45 DAS (21.42 cm), 80 DAS (49.11 cm), and 100 DAS (47.26 cm) was recorded in treatment T9 (100% RDF + 10 t ha^{-1} VC) over the control. The influence of organic manure on the vegetative growth of maize was examined by Abubakar and Ali (2018). They found that applying more manure resulted in higher plant heights, which was superior to applying inorganic fertilizer. The present study revealed that the survival rate was significantly higher in vermicompost-treated soil. It has been noted that vermicompost, a stable organic compound produced by microbes and earthworms, increases greenhouse crop yields and plant germination (Khatun *et al.*, 2019). Similar results were reported by Majhi *et al.* (2024). The authors observed a significantly increased plant height (38.30 cm) in beetroot with the incorporation of vermicompost, compared with the control.

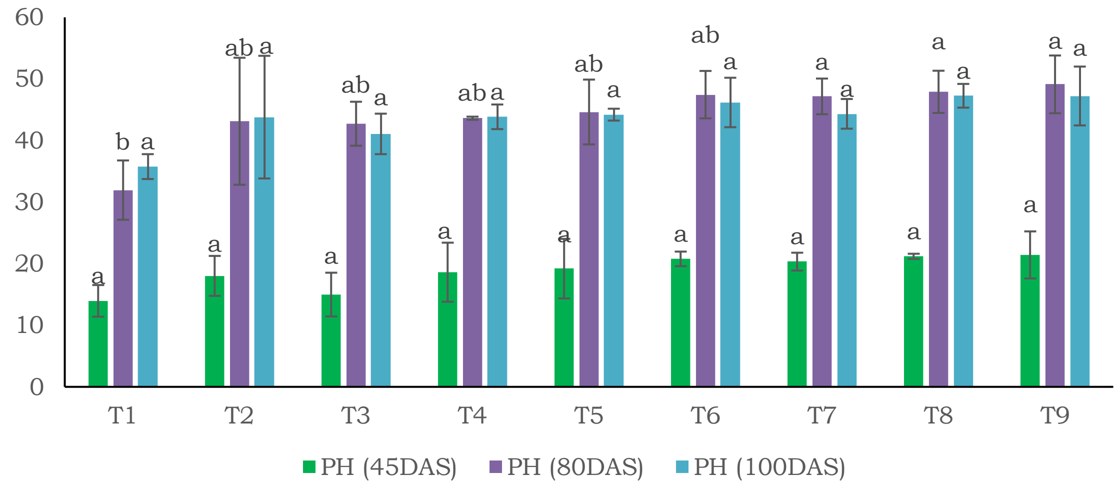

Fig. 2. Response of plant height at various treatments as affected by vermicompost application. A one-way ANOVA was conducted, followed by Tukey's post hoc test, to assess whether there were significant differences in plant height among the treatments. Significant differences between treatments are shown by different letters above the bars ($p < 0.05$).

Number of Leaves

The result indicated that Leaf number per plant increased significantly from 45 DAS through 80 DAS to 100 DAS ($P < 0.05$). At 45 DAS, the control (T_1) had a significantly lower leaf number (3.35/plant) compared with several vermicompost treatments (Majhi *et al.*, 2024). However, as shown in Figure 3, except for the control, the differences among the other treatments were not statistically significant at 45 DAS. Since the plants are still in the early stages of establishment, the effects of treatment and environmental changes have not fully developed, which explains the comparatively low variability at 45 DAS. Likewise, by 100 DAS, plants might have reached the mature vegetative stage under the specified conditions, thereby reducing treatment heterogeneity and differential responses. In contrast, the fast-growing period at 80 DAS increases variability among plants and highlights treatment differences. At 80 DAS, the highest number of leaves (11.18 per plant) was recorded in treatment T_9 (100% RDF* + 10 t ha^{-1} VC*) followed by T_8 (10.37) (100% RDF* + 5 t ha^{-1} VC*), which was significantly greater than the control (5.80), indicating that vermicompost is particularly beneficial during the vegetative phase, though its marginal benefit diminishes as plants approach maturity.

These results align with recent research by Laužike *et al.* (2025), which found that organic amendments such as vermicompost considerably increased leaf number (e.g., in lettuce) by 6.8–16.6% over the control during the vegetative stage, but that variability decreased as plants matured. Similarly, Mia and Rashid (2023) reported the highest number of leaves (10.10) in beetroot at 70 DAP (Days After Planting) with the highest doses of organic amendment application.

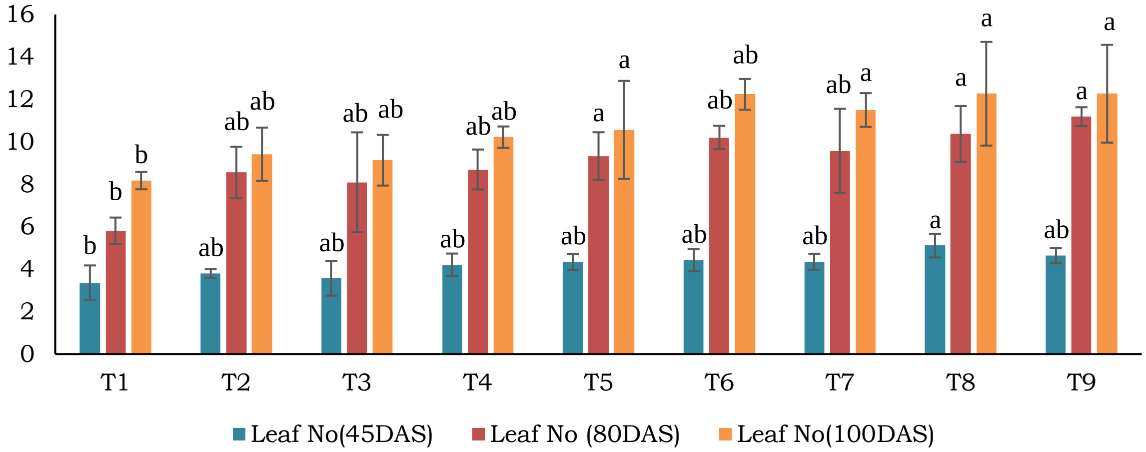

Fig. 3. Response of No. of leaves at various treatments as affected by vermicompost application. A one-way ANOVA was conducted, followed by Tukey's post hoc test, to assess whether there were significant differences in the number of leaves among the treatments. Significant differences between treatments are shown by different letters above the bars ($p < 0.05$).

Leaf Area

Figure 4 reveals that the differences among treatments at 45 DAS are statistically nonsignificant. This suggests that the application of vermicompost didn't significantly affect the rate of leaf expansion during the early vegetative stage. Early growth is often governed by seed reserves and initial soil nutrient status, and the slow mineralization rate of vermicompost delays nutrient availability at this stage (Edwards *et al.*, 2011). Similarly, Atiyeh *et al.* (2002) observed that the effects of vermicompost on vegetative growth parameters (such as leaf area and biomass) in tomato and marigold were minimal during the early stages but became significant later as nutrient release intensified.

However, significant differences ($p<0.05$) among treatments are evident at 80 DAS and 100 DAS. Treatments that received vermicompost, specifically T_8 (100% NPKS ha^{-1} + 5 t ha^{-1} VC) and T_9 (100% RDF* + 10 t ha^{-1} VC*), showed increased leaf area, indicating that vermicompost application enhanced leaf expansion due to improved nutrient supply, better soil aeration, and microbial stimulation (Yadav *et al.*, 2017). At 80 and 100 DAS, T_9 (100% NPKS ha^{-1} + 5 t ha^{-1} VC) and T_8 (316.23 cm^2) had the highest leaf area per plant, respectively, which was significantly greater than the control. The second highest (Fig. 3) was obtained by T_9 (270.50 cm^2) at 100 DAS, whereas the minimum was observed in treatment T_1 (Control).

The above results are comparable to those of Kondal *et al.* (2024), who discovered that beets with 100% organic manure had the largest leaf area. The outcomes of this study are corroborated by Jagadeesh *et al.* (2018), who applied poultry manure to beetroot plants to improve their physical growth. According to Joshi *et al.* (2020), beetroot plants treated with 50% RDF + vermicompost (5 t ha^{-1}) had significantly higher leaf area index compared to the control due to increased N and K uptake, which correlates with our findings.

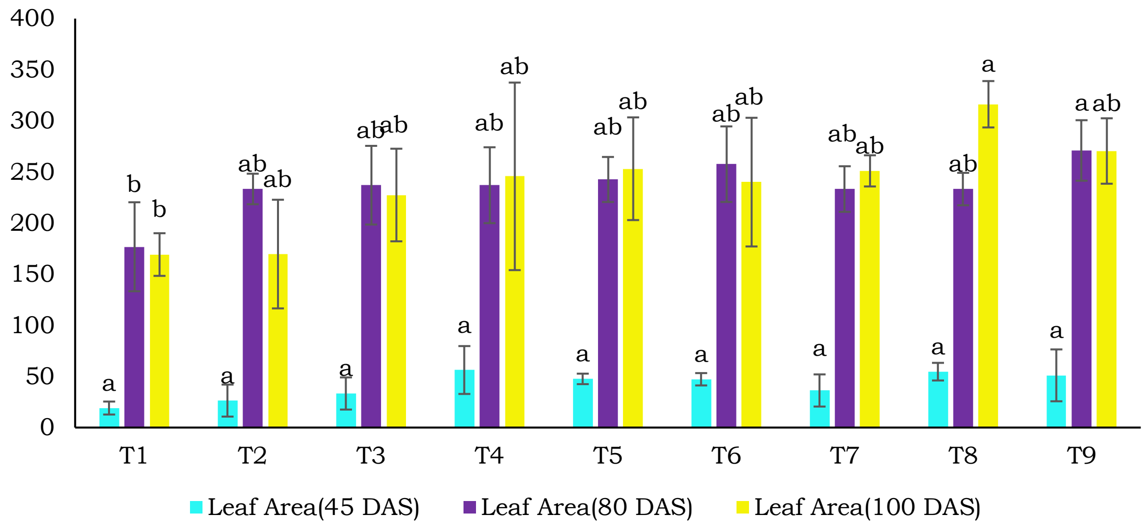

Fig. 4 Response of leaf Area at various treatments as affected by vermicompost application. A one-way ANOVA was conducted, followed by Tukey's post hoc test, to assess whether leaf area differed significantly among the treatments. Significant differences between treatments are shown by different letters above the bars ($p < 0.05$).

Effect of various combinations of organic and inorganic fertilizers on the yield of beetroot

Vermicompost greatly improves beetroot growth and production under saline conditions. This could result from the application of organic amendments, which raise the concentration of Ca2+ in the soil solution, replace Na+, and lower salinity (Khatun *et al.*, 2019). The maximum green beetroot yield (6.4 t ha^{-1}) was recorded in T_9 (100% NPKS ha^{-1} + 10 t ha^{-1} VC) followed by T_8 (100% NPKS ha^{-1} + 5 t ha^{-1} VC) (5.10 t ha^{-1}), which was statistically significant ($p < 0.05$) compared with the untreated control (0.77 t ha^{-1}) (Fig. 5). This correlates with the findings of Maloisane and Kayombo (2022). They reported that high vermicompost rates (e.g., 30 t ha^{-1}) substantially increased vegetative growth, fresh root and leaf yield of beetroot. This is also supported by Patidar *et al.* (2025) and Kibatu and Mamo (2014).

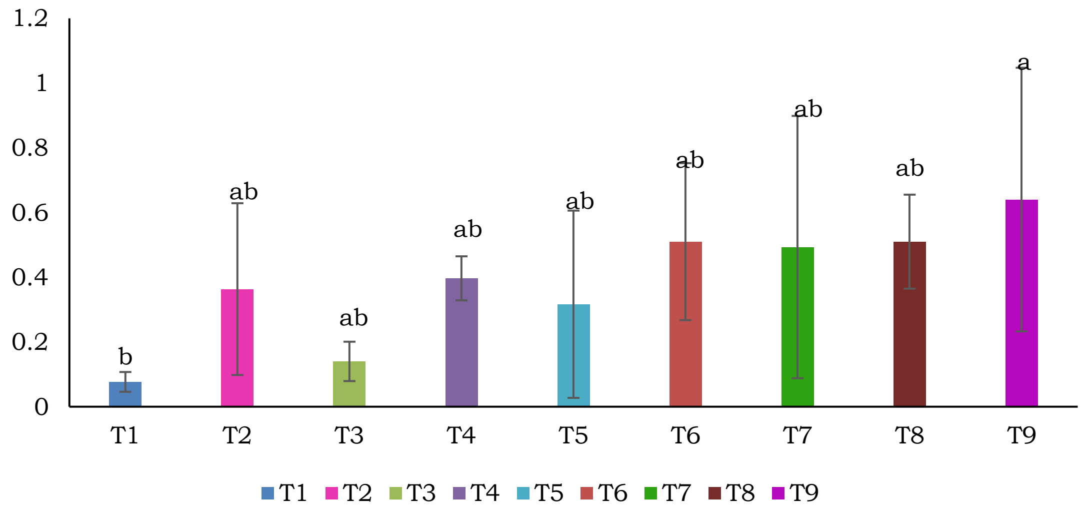

Fig 5. Response of Green Yield at various treatments as affected by vermicompost application. A one-way ANOVA was conducted, followed by Tukey's post hoc test, to assess whether green yield differed significantly among the treatments. Significant differences between treatments are shown by different letters above the bars ($p < 0.05$).

The effect of different treatments on beetroot root yield was found to be statistically significant ($p < 0.05$), as the highest beetroot yield (9.4 t ha^{-1}) was recorded with treatment T9 (100% NPKS ha^{-1} + 10 t ha^{-1} VC), where maximum doses of vermicompost were used. This treatment showed a significantly higher yield compared with the control (T_1), while being statistically similar to T_8 (7.87 t ha^{-1}) and T_6 (6.17 t ha^{-1}). The control (T_1), which did not receive any organic or inorganic amendments, had the lowest root yield (0.90 t ha^{-1}). This is in agreement with other research showing that the integration of organic and inorganic nutrients enhances soil health, nutrient availability, and the sustainability of the yield (Kumar *et al.*, 2014; Joshi *et al.*, 2015). This may be due to the decrease in EC of saline soil, which can be responsible for increasing nutrient availability. These results correspond to those of Khatun *et al.* (2019), who experimented on maize using a combination of vermicompost and cowdung. Their findings show that vermicompost was successful in significantly lowering the soil EC (from 3.94 dS/m to 1.45 dS/m) and that cow dung significantly lowers the soil EC in contrast to other treatments. Liang *et al.* (2005) discovered the same outcome when they used organic fertilizers to recover saline soil. According to Prapagar *et al.* (2012), organic additions were successful in lowering the pH of saline soil. This conclusion is further supported by Kondal *et al.* (2024), who show that organic manure breaks down quickly and releases all the nutrients that enhance soil chemical properties like pH, total N, available P, and organic matter, which promotes early germination. They also propose that a sustainable agricultural system might incorporate a combination of organic and chemical fertilizers to produce vegetables.

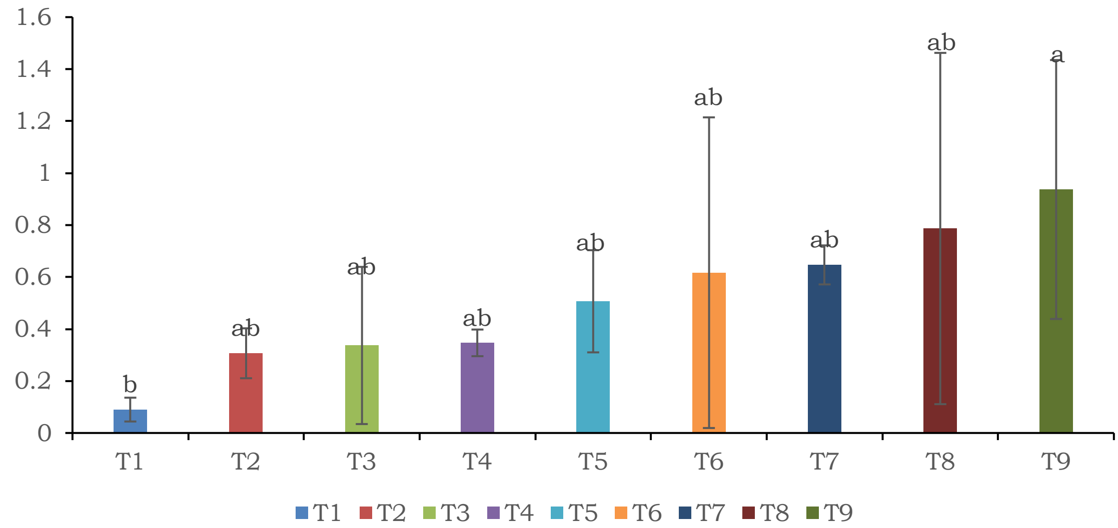

Fig 6. Response of root yield to various treatments affected by vermicompost application. A one-way ANOVA was conducted, followed by Tukey's post hoc test, to assess whether root yield differed significantly among the treatments. Significant differences between treatments are shown by different letters above the bars ($p < 0.05$).

Conclusion

Vermicompost has a major impact on the physico-chemical characteristics of saline soil and on beetroot yield. The above experimental findings demonstrated that combining 5–10 t ha^{-1} vermicompost with 100% RDF was optimal for beetroot growth and yield. Vermicompost has been proven effective in significantly reducing soil EC (from 2.94 dS/m2 to 0.98 dS/m2) and buffering soil acidity, creating a more suitable environment for nutrient absorption and bringing hope to local farmers. Research has shown that the combined use of inorganic fertilizer and vermicompost significantly improves soil quality and crop productivity under saline conditions. However, further long-term research is needed to evaluate their cumulative effects on soil organic matter dynamics, nutrient cycling, and economic feasibility under varying coastal agro-ecological conditions.

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