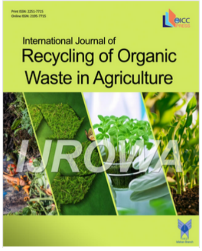

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Role of organic amendments in improving physiological and yield parameters of okra grown under saline conditions

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Original Research

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Abstract:

Purpose: Salinity is a devastating abiotic stress that poses serious risks to agricultural sustainability and global food security. The yield of okra [*Abelmoschus esculentus* (L.) Moench] is adversely affected by salinity stress. The research was conducted to evaluate the effects of organic amendments on the physiological and yield parameters of okra plants under saline conditions.
Method: In a pot experiment, okra plants were grown in non-saline and saline (50 mM sodium chloride) soil supplemented with municipal solid waste compost, farmyard manure (FYM), and press mud, each applied individually or in various combinations (Compost + FYM, FYM + Press mud and Compost + Press mud).
Results: Salinity stress significantly reduced relative water content, membrane stability index, chlorophyll and carotenoid contents, photosynthetic rate, fruit length, fruit diameter, no. of fruits per plant, fruit fresh weight, fruit dry weight, fruit yield per plant, no. of seeds per pod and 100 seeds weight of okra plants, compared to control. Under saline conditions, 5% (FYM + Press mud) was the most effective treatment in significantly improving stomatal conductance, intercellular carbon dioxide concentration, no. of fruits per plant, fruit dry weight, and fruit yield per plant of okra, compared to saline soil.
Conclusion: Application of 5% (FYM + Press mud) could improve the physiological and yield parameters of okra grown in saline soil (50 mM Sodium chloride) by mitigating adverse effects of salinity and could be used as a cost-effective and bio-rationale approach for alleviation of salinity stress in crops to attain agricultural sustainability.

Keywords: Salinity; *Abelmoschus esculentus*; Compost; Farmyard manure; Press mud

1. Introduction

Salinity stress is one of the critical major limitations to crop yield and growth (Seleiman et al., 2022). It was estimated that 20% of the irrigated lands which contribute to providing 1/3rd of global food production have been affected by salinity (Shahid et al., 2018),endangering food security and agricultural sustainability (Ivushkin et al., 2019b). Salinity stress disturbs nutrient homeostasis and photosynthetic processes causing a substantial reduction in plant growth and productivity (Singhal et al., 2021; Dustgeer et al., 2021). Salinity stress disrupts the metabolic activities of plants by inducing osmotic stress due to elevated solute concentration and specific ion effect or ion toxicity, instigating oxidative stress in plants (Kamran et al., 2020).

Due to the deleterious effects of salinity on plants, soil, and the environment, a comprehensive evaluation of techniques is imperative to comprehend their role in providing sustainable crop production under stress conditions (Hopmans et al., 2021). Compared to high-priced inorganic fertilizers, one of the cost-effective methods for reclamation of saline-sodic soils is the addition of organic materials (Chávez-García and Siebe, 2019).
Following the Sustainable Development Goals (SDGs), many developed countries have implemented waste management measures in order to lessen the adverse impacts of waste on humans and the environment (Bernal et al., 2017). The use of recycled organic waste products to improve soil fertility and crop yield has been employed as a conventional

approach in agriculture for years (Wu et al., 2021). Various organic amendments such as farmyard manure, press mud (Hassan et al., 2021; Khan et al., 2022),and plant wastes have been effectively applied for the remediation of saline soils and improved plant growth (Chen et al., 2021). In spite of the efficacy of organic amendments in the reclamation of agricultural soils and in improving plant yields, there is a dire need to monitor and scrutinize the plant toxicity factor associated with them in order to secure their safe application for the cultivation of crops in saline conditions (Meena et al., 2019).

Municipal solid waste compost is an efficient source of slow-release nitrogen, phosphorus, and other nutrients that contributes to mitigating the adverse impacts of salinity (Leogrande and Vitti, 2019) by improving fertility and productivity of saline soils (Oueriemmi et al., 2021). In Pakistan, the production of municipal solid waste compost from Lahore Waste Management Company was estimated to be 500 tons/day (Azam et al., 2020). Farmyard manure (FYM) is a rich source of macronutrients, trace elements, and microorganisms from the digestive system of animals (Feng et al., 2020). The annual livestock manure production in Pakistan was estimated to be 417.3 million tons in 2018 (Khan et al., 2021).

Press mud is a by-product of the sugar industry and is used as an effective soil conditioner to enhance the nutrient status of soil (Sher et al., 2022). Press mud is enriched with organic matter, carbonate, sulphate, and lime (Negim, 2016). In addition, it contains sugar, protein, fiber, wax, ash, and oxides of phosphorus, silicon, calcium, magnesium, and other macronutrients (Bhatnagar et al., 2016).

Press mud can reduce soil pH, electrical conductivity, and exchangeable sodium percentage when applied alone or in combination with other fertilizers (Negim, 2016) and thus could be used for restoration of saline soils (Kumar et al., 2017). The application of press mud as compost resulted in improved productivity of crops (Diaz, 2016). Moreover, the combined application of press mud and cow dung has been found to improve soil nutrient status and provide a favorable environment which contributed to enhanced activity and reproduction of earthworms and also increased the nutrient availability of press mud (Bhat et al., 2016, 2017). The global press mud production was estimated to be 36.8 million tons in 2017 (James, 2020). In Pakistan, the annual production of fresh press mud has reached about 2.7 million t in 2022/2023 (Salman et al., 2023).

Okra [*Abelmoschus esculentus* (L.) Moench] is an annual vegetable crop of the Malvaceae family which is commonly grown in tropical and subtropical regions of Asia, Africa, America, and Europe (Dantas et al., 2021). Being a rich source of carbohydrates, proteins, minerals, fats, and vitamins, it is important for the human diet (Farias et al., 2019). In Pakistan, the annual yield of okra has been estimated to be 114 , 657 tons/hectares (Nawaz et al., 2020). In spite of the increased cultivation of okra in Pakistan, it has low yield in many areas due to increased soil and water salinity (Qureshi, 2020). Salinity has a detrimental influence on the yield and physiological parameters of okra plants (Costa et al., 2022; Ali et al., 2022). To fulfill future demand for vegetables and ensure global food security, there is a need to develop a sustainable and cost-effective approach for mitigating the harmful impacts of salinity on okra.

Although various organic amendments have been employed for increasing crop productivity under saline conditions, yet there is a need to explore whether the application of organic amendments, alone or in a combined form, could improve the yield of okra grown in saline soil. In this perspective, present research was conducted to evaluate the effects of municipal solid waste compost, FYM, and press mud on yield and physiological parameters of okra plants under saline conditions.

2. Materials and methods

The pot experiment was performed in the Botanical Garden Department of Botany, Lahore College for Women University, Jail Road Lahore, Pakistan, in (April – August) 2021. The plant material used in the experiment was okra [*Abelmoschus esculentus* (L.) Moench] cv. Swat Green. Okra seeds were acquired from the National Agricultural Research Council, Islamabad (Pakistan), and kept in air tight-bags.

Before sowing, seeds were sorted out and surface sterilized by immersing in sodium hypochlorite solution (0.2% v/v) for 20 min followed by washing with tap water and then with distilled water. Afterward, the seeds were dried on aseptic filter paper sheets. In total, 14 groups of treatments were arranged in a completely randomized design. Each treatment was replicated 3 times. The soil used in the experiment was obtained from a local nursery. The soil was air-dried, sieved (5 mm), and 7 kg of soil was filled in each of the 84 pots. In each pot, 10 okra seeds were sown. In half of the pots, salinity was imposed by adding sodium chloride (analytical grade, Merck, Germany) at 50 mM per pot. The organic amendments of municipal solid waste compost, farmyard manure (FYM), and press mud were applied each @ 5 or 10% per pot and in various combinations (Compost + FYM, FYM + Press mud, and Compost + Press mud, each amendment applied @ 2.5 or 5% per pot). Municipal solid waste compost was obtained from the Lahore Compost Plant, Lahore (Pakistan). FYM was acquired from a local nursery (Lahore, Pakistan). Press mud was obtained from Choudhury sugar mill, Gojra, Faisalabad (Pakistan). The application of organic amendments was carried out 1 month before seed sowing. The NPK (inorganic fertilizer) was applied as super phosphate (5 g/pot), potassium sulfate (25 g/pot), and urea (6 g/pot) in 2 splits before seed sowing. The control plants were left without any treatment. On alternate days, plants were irrigated with tap water. The treatments applied to non-saline and saline soils were controlled, NPK, Municipal solid waste compost (5 or 10%), FYM (5 or 10%), Press mud (5 or 10%), Municipal solid waste compost + FYM (2.5 or 5%), FYM + Press mud (2.5 or 5%) and Municipal solid waste compost + Press mud (2.5 or 5%). Plants were thinned after 2 weeks of seed emergence and 5 plants were left in each pot. For plant sampling, 3 plants were randomly selected from each treatment, cleaned, and preserved in labeled paper bags. Okra leaves from each treatment were used to determine the following parameters.

Determination of relative water content

To estimate the relative water content (RWC), the method of Weatherley (1950) was followed. Fresh leaf samples (3rd true leaf) from each pot were weighed on a digital weighing balance (Shimadzu EL-600SA, Japan). Leaves were placed in distilled water taken in the petri plates for about 1 hour and their turgid weight was determined. The oven dry weight of leaves was determined after placing them in a drying oven (Hinotech, GX30B WHL-25A, China) at 70 °C for 72 h. The relative water content of leaves was determined using the following equation.

$$\text{RWC} = [(\text{fresh weight} - \text{dry weight}) / (\text{saturated weight} - \text{dry weight})] \times 100$$

Determination of membrane stability index

To determine the membrane stability index (MSI), the method of Premchandra et al. (1990), as modified by Sairam (1994), was followed. Approximately 0.1 g of leaf discs were weighed, rinsed with tap water, and then with double distilled water. Leaf discs were dipped in 10 mL of double distilled water in test tubes and heated in a water bath (TBT HH-S4, China) at 40 °C for half an hour. After cooling, the electrical conductivity (EC) of water (C_1) was recorded with an EC meter (wtw inoLab, Germany). The test tubes were again heated in a water bath at 100 °C for 10 min. After cooling, the EC of water (C_2) was determined again. The membrane stability index of leaves was determined by using the following equation;

$$\text{Membrane stability index (MSI)} = [1 - (C_1/C_2)] \times 100$$

Determination of chlorophyll and carotenoid content

The chlorophyll and carotenoid contents of okra leaves were determined following the method of Arnon (1949). About 0.1 g fresh leaves were ground in a pestle and mortar and homogenized with 5 mL of 80% acetone which was prepared by mixing 80 mL acetone with 20 mL distilled water. The mixture was centrifuged for 5 min. and the filtrate was transferred to a quartz cuvette. The absorbance of each sample was determined at 663 nm, 645 nm, and 470 nm using a double-beam UV-vis spectrophotometer (Shimadzu UV-2600 BMS, Japan). The chlorophyll and carotenoid contents of leaves were estimated using the Lichtenthaler and Wellburn (1983) formulae given below.

$$\text{Chlorophyll a} = 12.21(\text{A663}) - 2.81(\text{A645})$$

$$\text{Chlorophyll b} = 20.13(\text{A645}) - 5.03(\text{A663})$$

$$\text{Total chlorophyll} = 20.2(\text{A645}) + 8.02(\text{A663})$$

$$\text{Carotenoid content} = [1000\ \text{A470} - 3.27(\text{Chlorophyll a}) - 104(\text{Chlorophyll b})]/227$$

Chlorophyll content/g plant tissue was calculated by using the following formula.

$$\text{C} \times \text{V}/1 \times \text{g}$$

C = pigment concentration (mg L^{-1})
V = volume of acetone
g = weight of leaves
The chlorophyll a/b ratio was calculated.

Determination of gas exchange parameters

For estimation of leaf photosynthesis rate, transpiration rate, stomatal conductance, and intercellular CO_2 concentration of okra leaves, a portable Infra-red gas analyzer, (LI-6400 XT LI-COR Inc, Lincoln, NE, USA) was used. The intact leaves from each treatment were placed in the leaf chamber of the instrument. Gas exchange measurements were performed from 9.00 to 11.00 AM under these conditions: photosynthetically active radiation (PAR) =950 $\mu\text{mol} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$, leaf chamber temperature = 32-38 °C, atmospheric CO_2 concentration = 450 $\mu\text{mol} \cdot \text{mol}^{-1}$, and atmospheric pressure = 980 mbars.

Yield analysis

After harvest, okra pods were collected and fruit yield per plant and yield-related attributes including fruit length, fruit diameter, number of pods per plant, fresh and dry fruit weights, no. of seeds per pod, and 100 seeds weight were determined. The total no. of fruits/plant was counted and their average was worked out. Okra pod length and diameter were estimated and their average values were calculated. Fresh and dry weights of fruits were determined using a digital weighing balance. Fresh weight of fruit and no. fruits/plant were multiplied together to estimate the fruit yield/plant. Okra plants were sun-dried for a week and pods were collected. The number of seeds in each dry pod sample was counted manually and the weight of 100 seeds from each treatment was determined on a digital weighing balance.

Statistical analysis

All the data was statistically analyzed through Statistics (ver. 8.1 User's Manual, Analytical Software, Tallahassee, FL), using ANOVA (analysis of variance). Means were compared using the Least Significant Difference at $p < 0.05$.

3. Results and discussion

Salinity stress significantly ($p < 0.05$) reduced relative water content (59.03%), membrane stability index (44.83%), chlorophyll a (67.21%), chlorophyll b (72.90%), total chlorophyll (72.47%), carotenoid content (73.58%), chlorophyll a/b (65.92%), and photosynthetic rate (7.90%) of okra plants, compared to control. Under saline conditions, application of treatments significantly ($p < 0.05$) improved relative water content (Fig. 1), membrane stability index (Fig. 2), chlorophyll a (Fig.3), chlorophyll b (Fig. 4), total chlorophyll (Fig. 5), carotenoid content (Fig. 6), chlorophyll a/b (Fig. 7), photosynthetic rate (Fig. 8), transpiration rate (Fig. 9), stomatal conductance (Fig. 10), and intercellular carbon dioxide concentration (Fig. 11) of okra plants, compared to saline soil.
Under saline conditions, treatments of 2.5% (Compost + Press mud) and 5% FYM resulted in maximum significant ($p < 0.05$) improvement in leaf relative water content (256.83%) and membrane stability index (125.36%) of okra

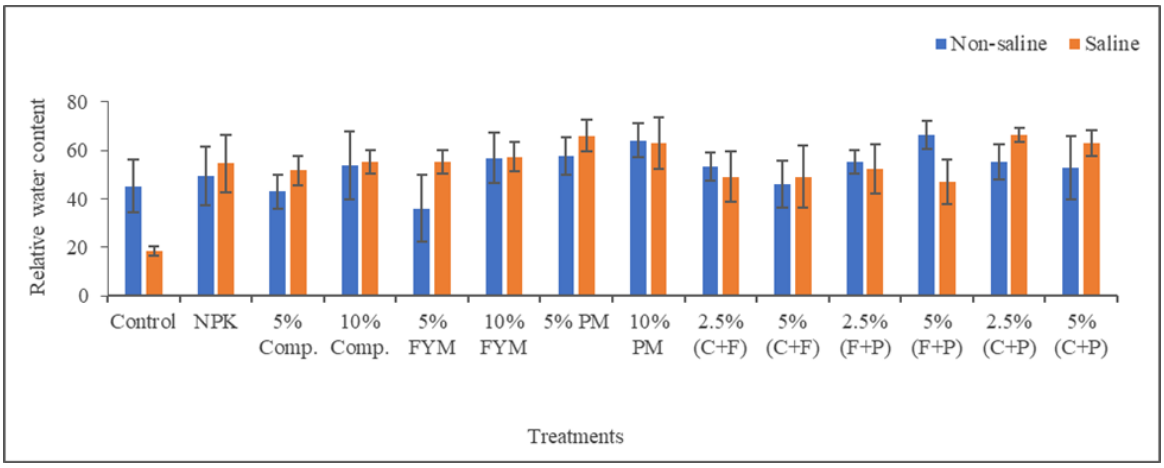

Figure 1. Effect of treatments on relative water content of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

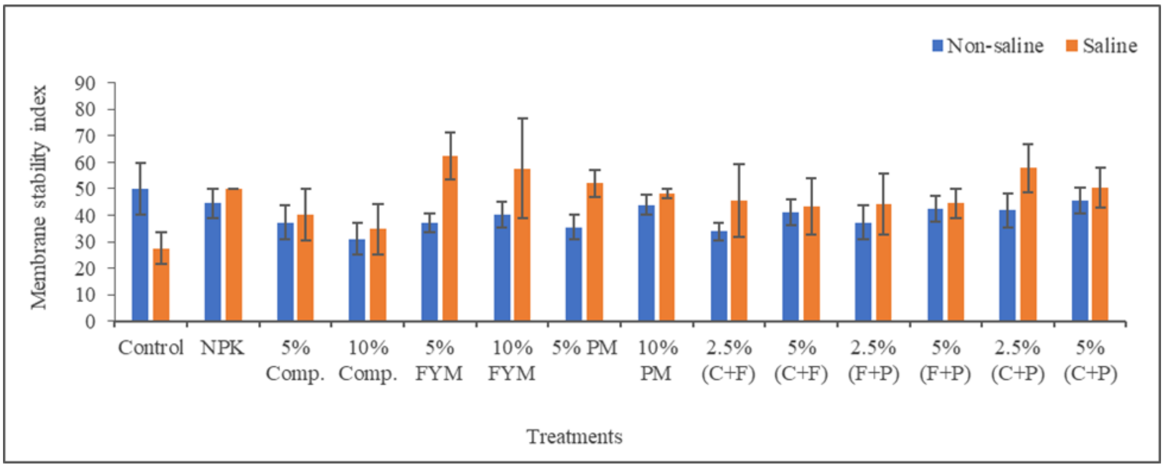

Figure 2. Effect of treatments on membrane stability index of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

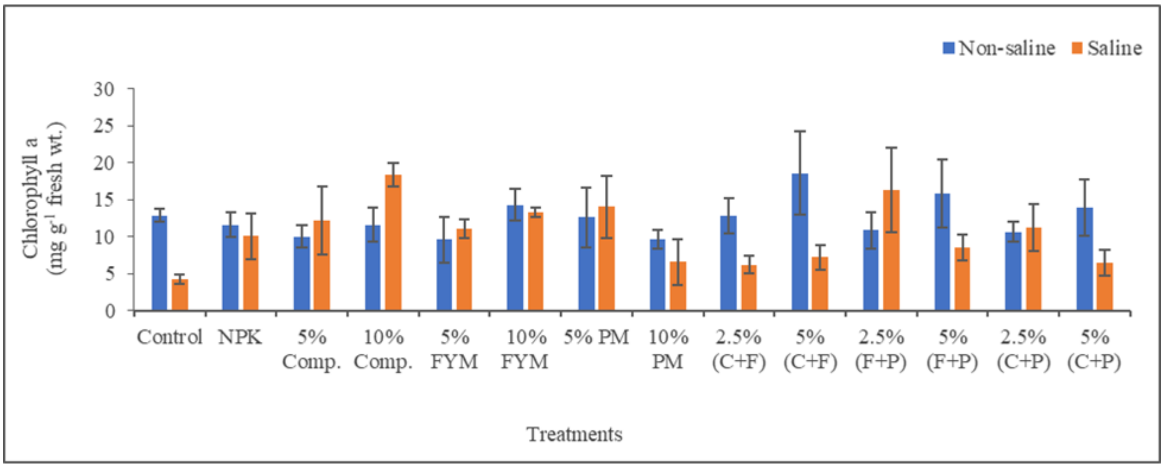

Figure 3. Effect of treatments on chlorophyll a of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

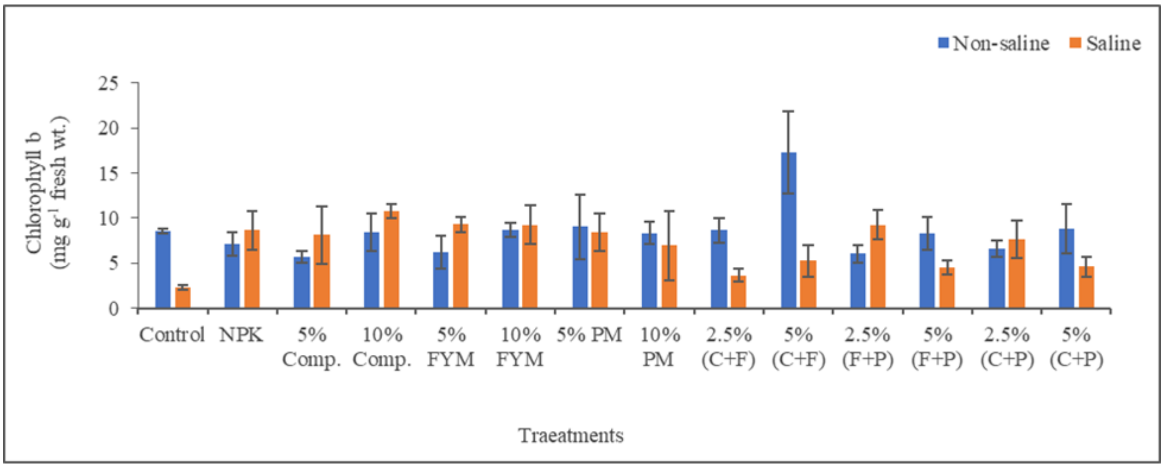

Figure 4. Effect of treatments on chlorophyll b of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

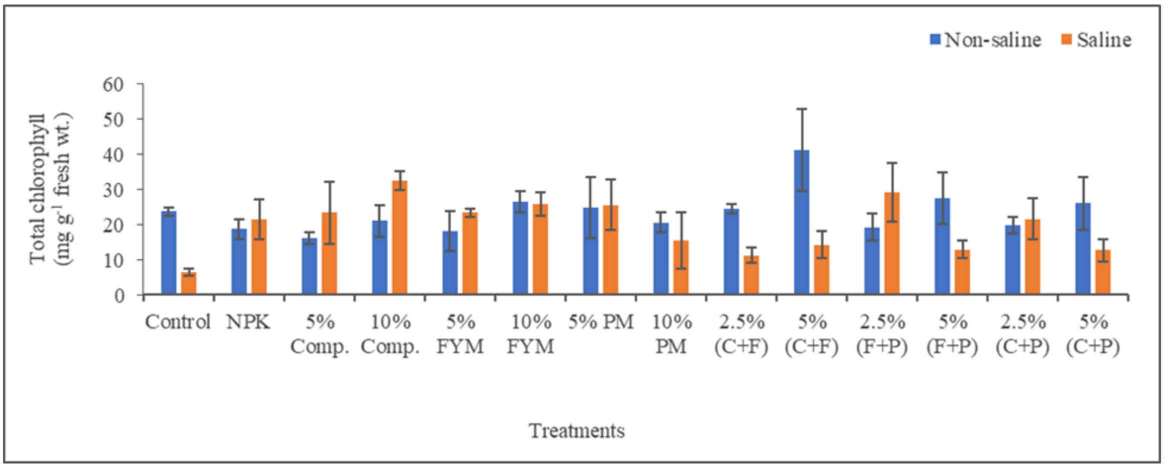

Figure 5. Effect of treatments on total chlorophyll of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

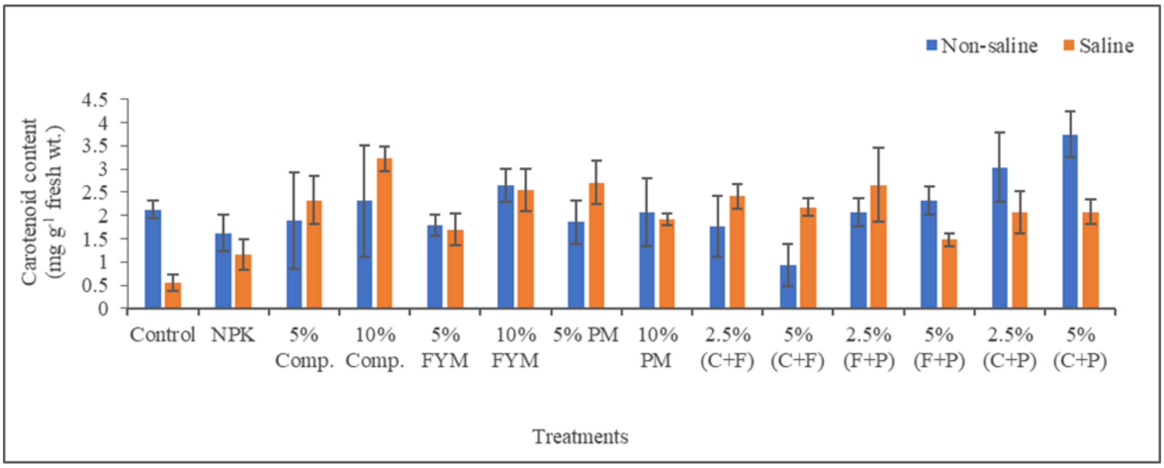

Figure 6. Effect of treatments on carotenoid content of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with same the letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

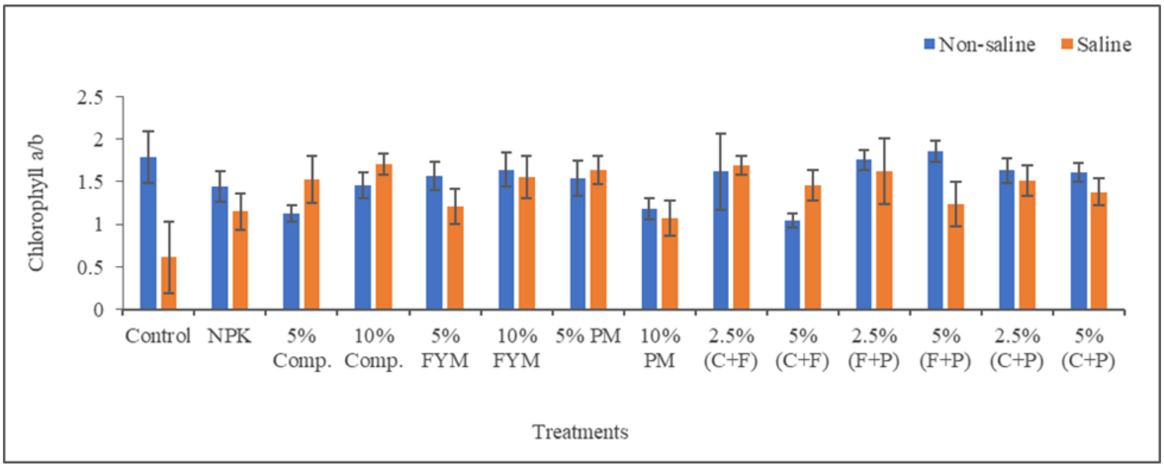

Figure 7. Effect of treatments on chlorophyll a/b ratio of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

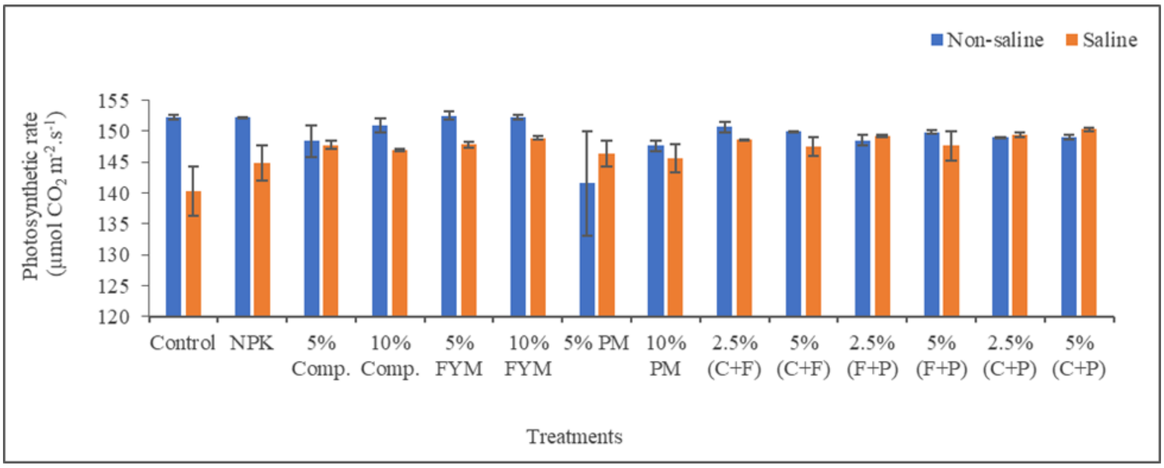

Figure 8. Effect of treatments on photosynthetic rate of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

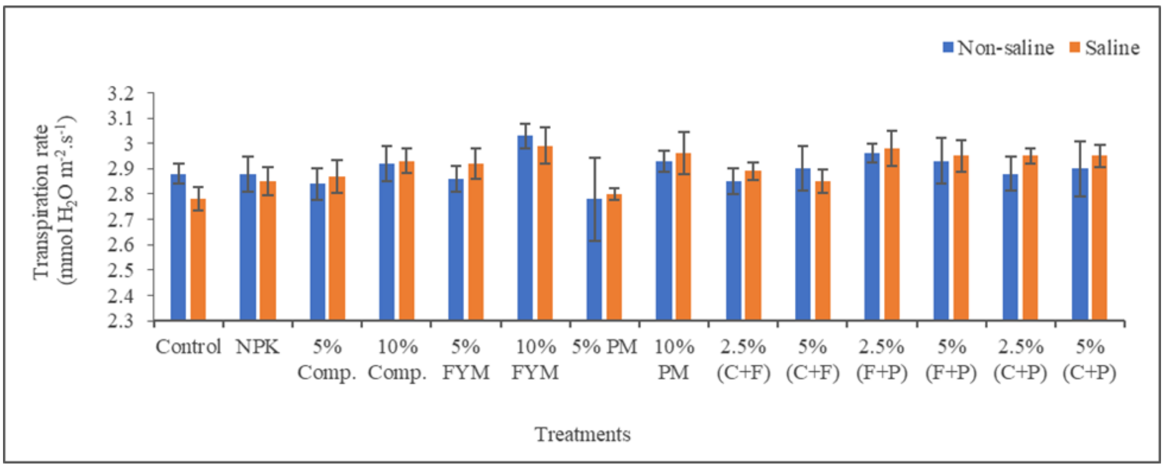

Figure 9. Effect of treatments on the transpiration rate of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

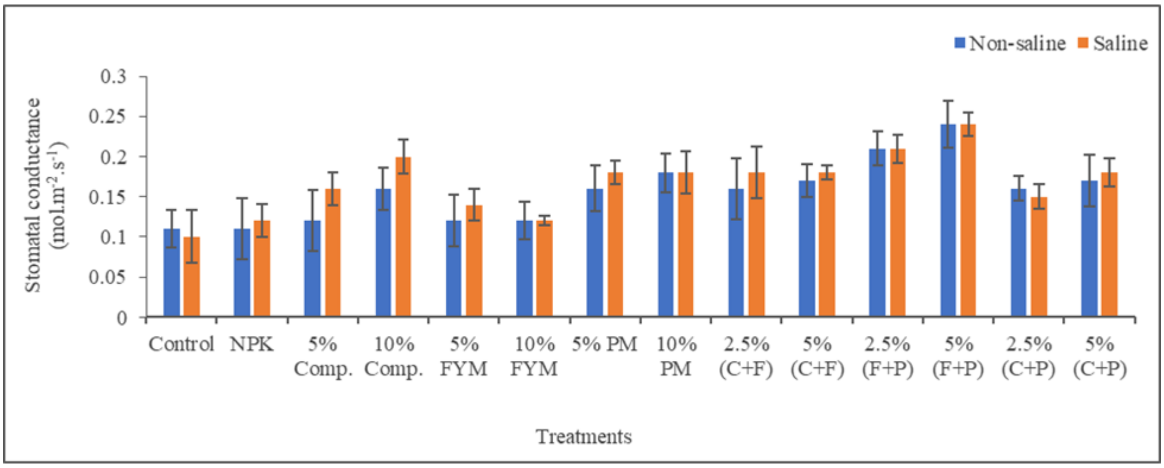

Figure 10. Effect of treatments on stomatal conductance of okra plants grown in saline and non-saline soil.
Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

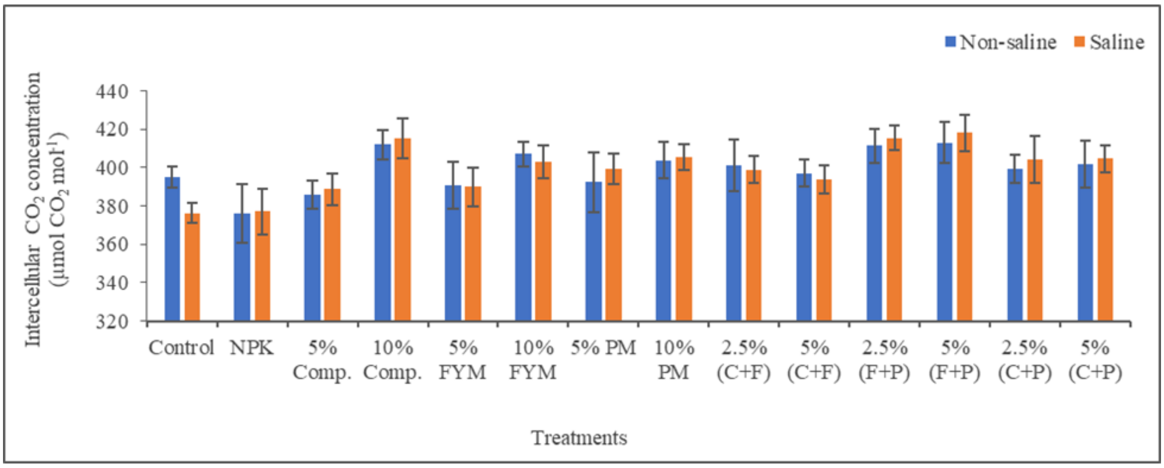

Figure 11. Effect of treatments on intercellular carbon dioxide concentration of okra plants grown in saline and non-saline soil.
Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

leaves, respectively, compared to saline soil.

The adverse effects of salinity on plants disturbed the mineral nutrient homeostasis and resulted in declined plant productivity, growth, and photosynthesis (Eissa, 2019). Relative water content (RWC) and membrane stability index (MSI) are the major stress markers for appraisal of salinity impacts on plants (Ashraf et al., 2017). Relative water content is a significant indicator of the water status of plants subjected to salinity and water stress conditions and indicates the highest amount of water that turgid leaves can acquire (Khatami et al., 2022). In plants subjected to salinity stress, low RWC is caused by decreased water absorption in response to osmotic constraint and stomatal closure due to abscisic acid (Evelin et al., 2019). Similar to the results of the present study, salinity-induced reduction in relative water content has been reported in okra (Ali et al., 2022; Mendonça et al., 2022). However, it was found that the application of organic amendments could increase the RWC of plants under salinity stress by improving soil status and absorption of water (Soni et al., 2016) which is in line with the findings of this study.

The stability of membranes is considered a preventive measure to combat the accumulated free radicals (Isayenkov and Maathuis, 2019). Membrane injury is the foremost impact of salinity stress (Fatima et al., 2021). A higher concentration of sodium ions functions as a signaling molecule in transduction channels and contributes to enhancing the reactive oxygen species (ROS) accumulation (Fatima et al., 2021) and lipid peroxidation (Zhang et al., 2018) which accelerates membrane permeability and results in the ion leakage from cells (Sultan et al., 2021). Similar to the results of the present study, Ansari et al. (2019) observed that the accumulation of salts in various parts of plants caused the deterioration of cell membranes with subsequent reduction in membrane stability index. It was reported that the addition of calcium-fortified compost could improve the plant water status in maize plants subjected to various levels of salinity stress by enhancing RWC and reducing electrolyte leakage (Niamat et al., 2019).

Application of 10% Compost was the most effective treatment which resulted in the maximum significant ($p <$ 0.05) increase in chlorophyll a (334.83%), chlorophyll b (363.79%), total chlorophyll (398.47%) and carotenoid (475%) contents, and chlorophyll a/b ratio (180.24%) of okra leaves, compared to saline soil.

Salinity stress affects several physiological functions of plants including photosynthesis which is regarded as a substantial and complicated attribute (Allel et al., 2018). The declined photosynthesis under salinity stress is ascribed to the closing of stomata and reduction in chlorophyll content, water potential, internal carbon dioxide concentration, and enzyme activities as well as enhanced accumulation of ROS (Amiri et al., 2016; Kumar et al., 2020). In salinity-stressed plants, excess of Na^+ ions reduces the chlorophyll content through increased activity of chlorophyll denaturing enzyme (chlorophyllase), deterred protein synthesis and distortion of chlorophyll synthesizing enzyme, and pigment-protein complex (Alzahib et al., 2021). As revealed by the results of this study, Ashraf et al. (2019) reported reduced chlorophyll content in okra under saline conditions.

The improved chlorophyll content by the addition of organic amendments might be a consequence of better soil conditions and enhanced absorption of macronutrients (NPK) and magnesium, as magnesium is an integral part of the chlorophyll molecule (Dineshkumar et al., 2020). Similar to the results of this study, the addition of organic amendments increased the chlorophyll content in maize under saline conditions (Afzai et al., 2022). In quinoa plants, increased carotenoid content after the addition of compost has increased their potential to lessen ROS-induced destruction with subsequent improvement in chlorophyll content (El-Sebai et al., 2016). These results are in line with those of the present study. The supplementation of soil with compost maintains a constant supply of plant vital nutrients during the mineralization process (Mohamed et al., 2020). In addition, the salinity tolerance of plants could be increased by the application of press mud through improved plant water relations, membrane stability, and photosynthetic efficiency (Sheoran et al., 2021).

Regarding gaseous exchange parameters, under saline conditions, the maximum significant ($p < 0.05$) increase in photosynthetic rate (7.18%) and transpiration rate (7.55%) was with application of 5% (Compost + Press mud) and 10% FYM, respectively, compared to saline soil. Under saline conditions, 5% (FYM + Press mud) was the most effective treatment which significantly ($p < 0.05$) improved the stomatal conductance (140%) and intercellular carbon dioxide concentration (11.07%) in okra leaves, compared to saline soil.

Parihar et al. (2015) found that reduced water potential could contribute to a decrease in the photosynthetic rates of plants grown in saline medium. The regulation of gaseous exchange in plants occurs through stomata (Fernandes et al., 2022). In order to control the excessive water loss, plants manage to close their stomata. The closing of stomata declines the transpiration rates and carbon dioxide fixation as a result of which plants can sustain optimum photosynthetic rates for a limited time (Javed et al., 2017). Higher values of transpiration rates reflect the critical situation of salinity-stressed plants under high water deficit which renders them unable to sustain their growth (Allel et al., 2018). Similar to the results of this study, a reduction in gas exchange parameters has been reported in okra (Sales et al., 2021; Naqve et al., 2021).

Salinity significantly ($p < 0.05$) reduced fruit length (57.31%), fruit diameter (44.40%), no. of fruits per plant (71.24%), fruit fresh weight (59.64%), fruit dry weight (68.42%), fruit yield per plant (77.84%), no. of seeds per pod (51.34%), and 100 seeds weight (33.51%) of okra plants, compared to control. Under saline conditions, application of organic amendments significantly ($p < 0.05$) improved fruit length (Fig. 12), fruit diameter (Fig. 13), no. of fruits per plant (Fig. 14), fruit fresh weight (Fig. 15), fruit dry weight (Fig. 16), fruit yield per plant (Fig. 17), no. of seeds per pod (Fig. 18), and 100 seeds weight (Fig. 19) of okra, compared to saline soil.

Under saline conditions, 5% (FYM + Press mud) was the most effective which resulted in the maximum significant ($p < 0.05$) increase in no. of fruits per plant (646.27%), fruit dry weight (445.83%), and fruit yield per plant (634.31%)

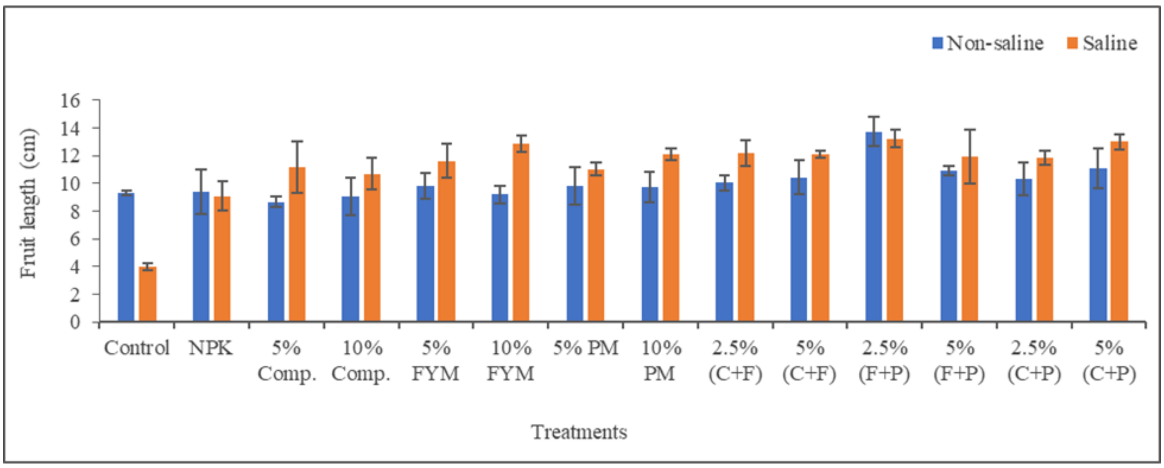

Figure 12. Effect of treatments on fruit length of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

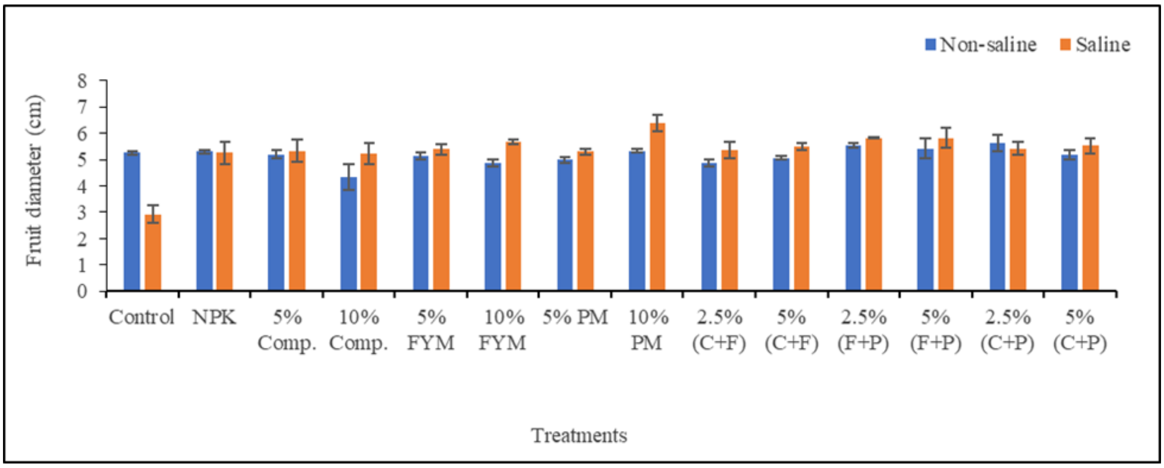

Figure 13. Effect of treatments on fruit diameter of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

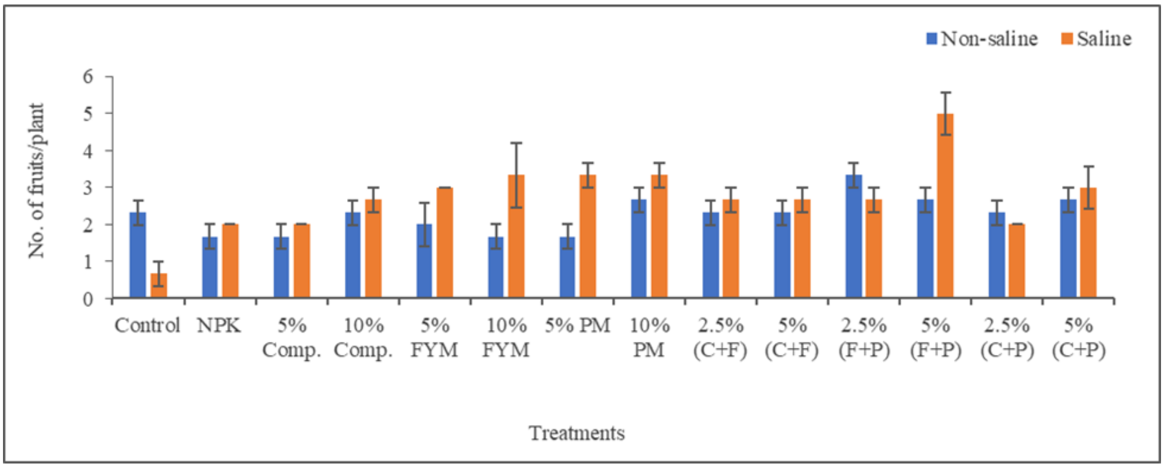

Figure 14. Effect of treatments on the number of fruits per plant of okra grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

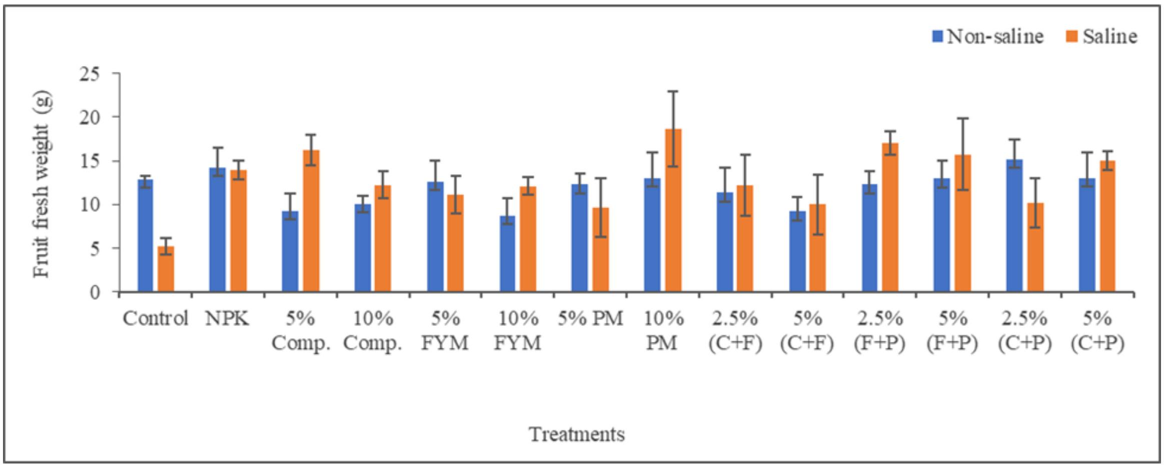

Figure 15. Effect of treatments on fruit fresh weight of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

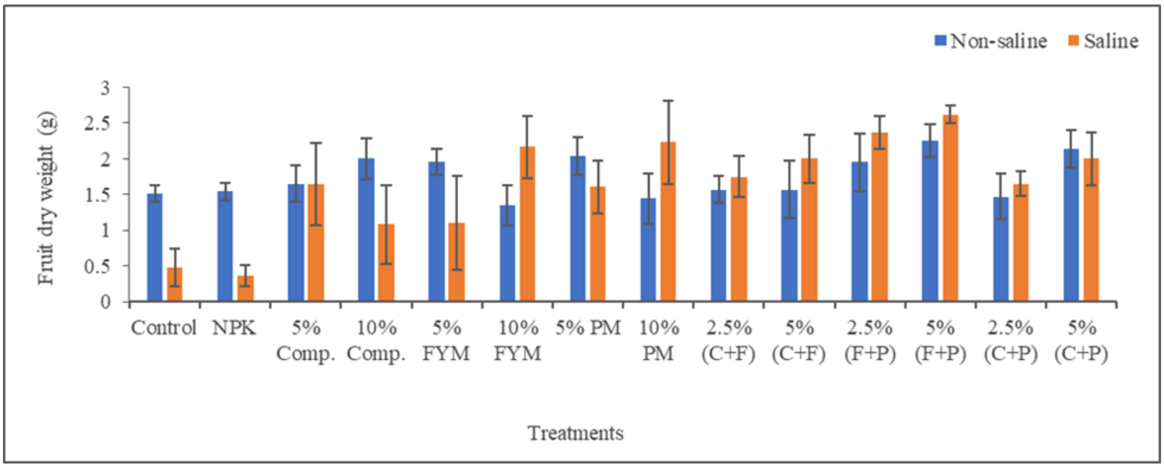

Figure 16. Effect of treatments on fruit dry weight of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

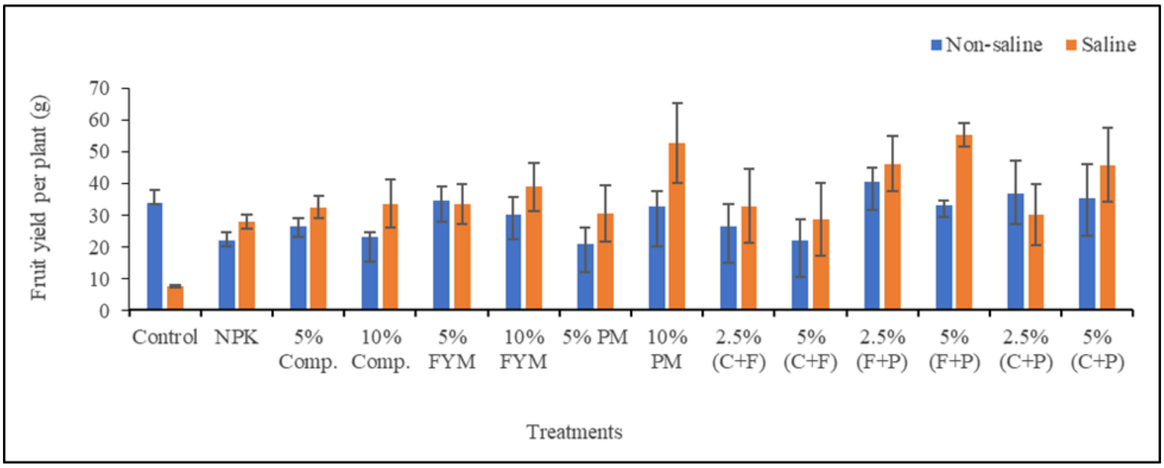

Figure 17. Effect of treatments on fruit yield per plant of okra grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

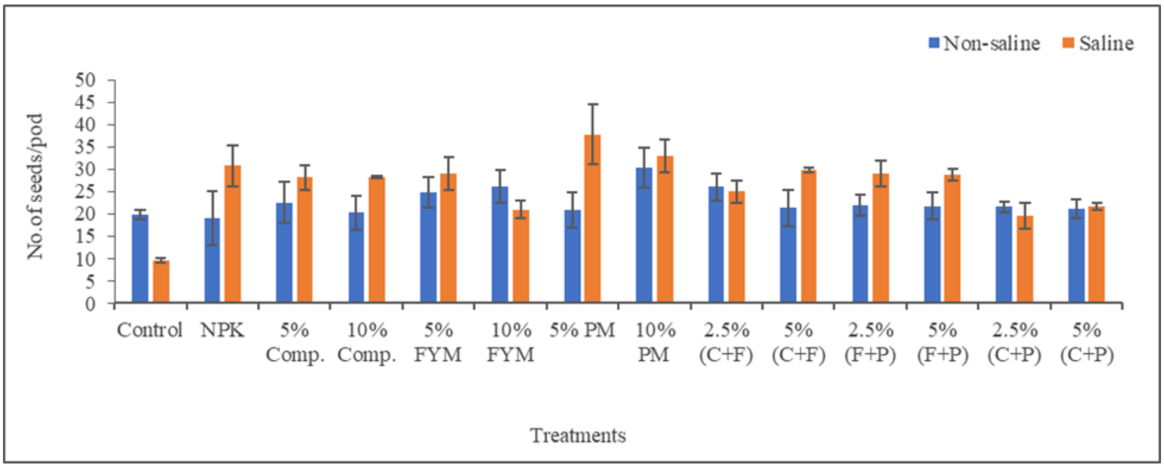

Figure 18. Effect of treatments on number of seeds per pod of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

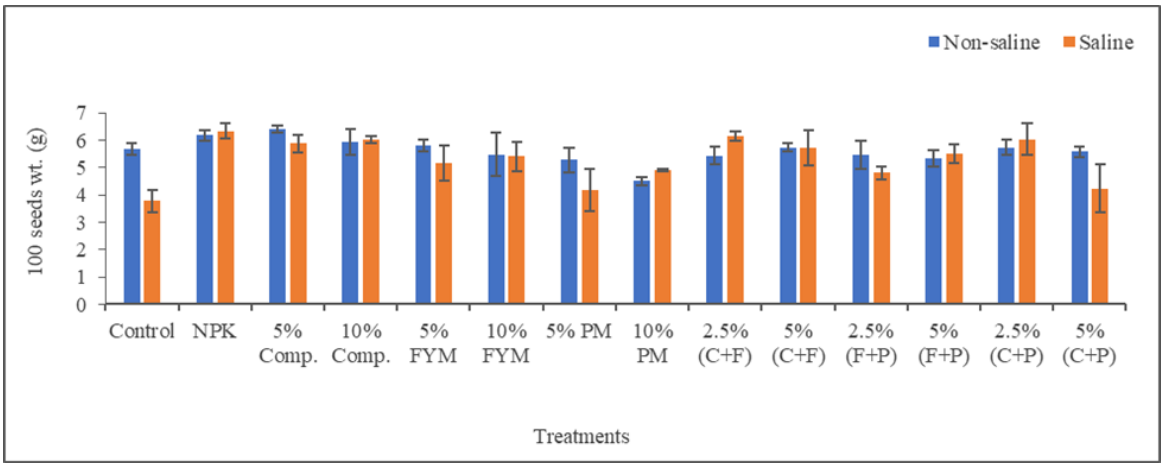

Figure 19. Effect of treatments on 100 seeds weight of okra plants grown in saline and non-saline soil. Bars represent the standard error of mean and means with the same letters are not significantly different at $p < 0.05$. (Comp., C = Compost; FYM, F = Farmyard manure; PM, P = Press mud)

of okra, compared to saline soil. Under saline conditions, the application of 10% Press mud resulted in the highest significant ($p < 0.05$) increase in fruit diameter (118.43%) and fruit fresh weight (259.34%) of okra plants, compared to saline soil. While the maximum significant ($p < 0.05$) increase in no. of seeds per pod (292.31%), fruit length (233.25%), and 100 seeds weight (67.90%) of okra plants were obtained after applying 5% Press mud, 2.5% (FYM + Press mud) and NPK, respectively, compared to saline soil. Low productivity of many valuable crops is a consequence of salinity (Ivushkin et al., 2019a). The osmotic and ionic stresses caused by salinity disturb nutrient absorption and antioxidant defense mechanisms in the cytoplasm, causing oxidative injury which restricts growth and declines productivity of crops (Hussain et al., 2018). According to Ren et al. (2019),the collapse of natural reserves by salinity resulted in low crop production. Salinity-induced reduction in okra yield has been reported (Motamedi et al., 2021; Costa et al., 2022).Azhar et al. (2019)evaluated that press mud could decrease the absorption of toxic ions and enhance crop productivity due to improved availability of nutrients and organic matter which is in accordance with the results of this study. A similar increase in crop yield was observed by Mbarki et al. (2020) in alfalfa, after applying compost and farmyard manure. In addition to improved soil fertility and crop yield, the application of farmyard manure and cow manure to saline soils was found a harmless measure for improved salinity tolerance of crops (Baddour et al., 2017). In this respect, further research is required to explore the underlying mechanisms of the positive impacts of organic amendments on salinity-stressed plants.

4. Conclusion

In this study, salinity stress significantly reduced relative water content, membrane stability index, chlorophyll and carotenoid contents, photosynthetic rate, fruit length, fruit diameter, no. of fruits per plant, fruit fresh weight, fruit dry weight, fruit yield per plant, no. of seeds per pod, and 100 seeds weight of okra plants, compared to control. Under saline conditions, 5% (FYM + Press mud) was the most effective organic amendment in significantly improving stomatal conductance, intercellular carbon dioxide concentration, no. of fruits per plant, fruit dry weight, and fruit yield per plant of okra, compared to saline soil. The application of 5% (FYM + Press mud) to saline soil (50 mM NaCl) could be recommended as a low-cost and eco-friendly measure to improve okra yield by ameliorating the adverse effects of salinity. The research ensures the recycling of organic wastes and promotes organic agriculture for the support of small-scale farmers due to the utilization of locally available waste products as organic amendments to alleviate salinity stress in crops.

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Author contribution
A.N. performed the experimental work and wrote the manuscript. S.I. designed and supervised the practical work and paper write-up. K.J. assisted in experimental procedures and data analysis.

Conflict of interest statement
The authors declare that they are no conflict of interest associated with this study.

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