



Article

Compost-Mediated Enhancement of Maize Seedling Growth Under Salinity Stress

Muhammad Muneeb Khan¹, Awais Ahmad^{1*}, Shah Fahad^{1*}

¹ Department of Agronomy, Abdul Wali Khan University Mardan, 23200, Khyber Pakhtunkhwa, Pakistan; muneebpro09@gmail.com; awaisawkummdn@gmail.com; shah_fahad80@yahoo.com

* Correspondence: awaisawkummdn@gmail.com; shah_fahad80@yahoo.com

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Abstract

Salt stress is a major abiotic constrain for maize growth and productivity, especially in arid and semi-arid regions. This study assesses compost amendment applications mitigating salt stress on maize by measuring several critical growth parameters under varying salt concentrations (0, 75 and 150 mM NaCl) with and without compost applications (0 and 20 g kg⁻¹ soil). The study used completely randomized design (CRD) with factorial arrangement having three replications of each treatment. The results indicated that salinity significantly affected all growth parameters, whereas compost application significantly enhanced performance under both normal and stressed conditions. Under high salinity (150 mM), compost significantly increased leaf area, root length and shoot length by 24.83%, 16.37% and 23.40%, respectively. Biomass traits i.e., fresh root weight and dry shoot weight were also greatly improved with compost application. Correlation analysis revealed strong positive correlations among traits, with leaf area showing high correlation with shoot length ($r = 0.99$) and biomass parameters (>0.90), suggesting a coordinated physiological response. The treatment–trait correlation also revealed positive relationships between compost amended treatments for all growth and biomass parameters and high salinity without compost had strong negative relationships ($r = -1.00$). Conclusively, compost application significantly alleviated salinity stress and enhanced maize growth performance. The results emphasize the potential of compost as sustainable soil amendment to enhance the productivity of crops in saline soils.

Keywords: Maize; Salt stress; Compost; Growth traits.

1. Introduction

Agricultural system is severely threatened by different biotic and abiotic factors (Lamichhane *et al.*, 2018). Among abiotic factors, salt stress is one of the notable abiotic factors. Soil salinity is defined as the presence of soluble salts in the soil profile, such as sodium, magnesium and calcium ions, that exceed tolerable thresholds for crops (Pessarakli & Szabolcs, 2019). It poses a major global challenge to agricultural productivity and sustainability. Today, approximately 1.4 billion hectares are currently salt-affected, making over 10% of the total land surface and nearly 20% of total irrigated lands unproductive (Basak *et al.*, 2022). This problem mainly happens in the arid and semi-arid regions that have high rates of evapotranspiration accompanied by little rainfall, making it difficult for the

natural leaching of salts to occur, which eventually leads to progressive accumulation of salts in the root zone (Singh, 2022). The effects of soil salinity on agriculture are very deep and multifaceted (Faisal *et al.*, 2024).

Salt stress extremely effects both soil properties and plant physiology, leading adverse effects growth and productivity (Marchuk, 2013). Saline soils have an excess of soluble salts particularly sodium and chloride ions, leading to an increase in the electrical conductivity of the soil and poor soil structure due to the dispersion of soil particles (Yadav *et al.*, 2019). This causes decreased aeration of soils with poor water infiltration and retention, hence limiting root access to moisture and nutrients (Osman, 2018). Osmotic stress combined with low potential of soil water restricts root water uptake, causing drought conditions although soil moisture is

available (Haghnazari *et al.*, 2015). High concentration of the toxic ions such as sodium and chloride, disturbs the cells homeostatic condition, resulting in ion toxicity, which impairs metabolic functions (Álvarez *et al.*, 2012). Furthermore, salt stress creates nutrient imbalances due to a malfunction in the uptake and transport of major nutrients such as potassium, calcium and nitrogen; this also inhibits growth in plants (Morland *et al.*, 2016). These combine effects reduce overall plant health and development by affecting several essential processes (Shahid *et al.*, 2020).

Maize (*Zea mays* L.), also known as corn is a major cereal crop worldwide (Ranum *et al.*, 2014). Maize plays an important role in many countries as a staple food crop, livestock feed and raw material regarding industrial applications (Nuss & Tanumihardjo, 2010). It uses include direct human consumption in forms of corns, flour and processed products; animal feed for the livestock sector; and for industrial uses like biofuel production, especially ethanol, starch manufacturing and bioplastics. USA, China, Brazil, Argentina and European Union are the key producer countries of maize (Ranum *et al.*, 2014). Maize crop is sensitive to salt stress (Ali *et al.*, 2021). Salinity affects important growth stages such as seedling growth, reduced photosynthetic efficiency, damage cells, impair water and nutrient uptake which results in leaf necrosis, poor vegetative development and lower crop yield (Sharma, 2021). Therefore, salinity management for an efficient maize production is necessary (Farooq *et al.*, 2015). Conventional methods include leaching with good-quality water, gypsum application and breeding for salt-tolerant crop varieties, but these methods have several limitations. In this context, compost, a substance derived from the aerobic decomposition of organic matter, provides a promising approach improving soil and plant health under severe saline condition (Gondek *et al.*, 2020).

The application of compost improves soil organic matter, soil fertility, soil structure and facilitating microbial activity to ensure crop growth (Lakhdar *et al.*, 2009). In salt-affected soils, compost acts as an ion buffer by adsorbing excess sodium ions, reducing electrical conductivity and sodium adsorption ratio (Leogrande & Vitti, 2019). This buffering effect stabilizes nutrient availability and prevents nutrient imbalances (Kelbesa, 2021). Compost also improves water-holding capacity, porosity and aggregate stability in soils; thus, providing root access to moisture and nutrients. It also enhances soil microorganism activities that contribute to nutrient cycling process and helps plants tolerate stress (Kamal *et al.*, 2024). Physiologically, compost amendment improves chlorophyll content, biomass, antioxidant enzyme activity and overall resilience to salinity-induced oxidative stress in plants under saline soils (Irin &

Hasanuzzaman, 2024). Thus, compost serves as a promising approach for restoring plant and soil health under salt stress conditions (Lashari *et al.*, 2015).

Keeping the current problem under view, the current study was designed with the major aim to explore the potential of compost on alleviating salt stress in maize crop. Some of the minor objectives are: a) To assess the impact of salt stress on maize growth traits, b) to evaluate the impact of compost on maize growth traits and c) to evaluate the impact of compost on maize growth under salt stress condition.

2. Materials and Methods

2.1. Experimental site and Treatments

The controlled greenhouse experiment was conducted at Agriculture Research Farm (ARF), Department of Agriculture, Abdul Wali Khan University Mardan (AWKUM), Khyber Pakhtunkhwa, Pakistan, under the kharif season of 2025. The study uses a completely randomized design (CRD) with factorial arrangement, having three replications of each treatment. The compost was collected from local farm, located at Mardan, Khyber Pakhtunkhwa, while the soil was obtained from the ARF. The collected soil was allowed to sieve through the perforated mesh to remove debris and large particles. The compost was applied at two levels including control (0 and 20 g kg⁻¹ of soil) by thoroughly mixing it with the soil. The maize seed (variety: Jalal) was used in the experiment. In each pot 6 seeds were sown at a depth of 5 cm. After successful germination, 3 uniform plants were retained; the remaining were uprooted. Salt stress was imparted after seed germination at varying levels of 0, 75 mM and 150 mM NaCl.

2.2. Data Attributes

Essential growth parameters, including leaf area, root length, shoot length, root fresh and dry weight and shoot fresh and dry weight, were measured to assess maize response to compost application under salt stress. During the vegetative growth stage, 3 plants were selected within each treatment from each replicate. Shoot and root lengths were measured from the base to the tip of the plant using a measuring scale. Biomass measurements were recorded by carefully uprooting plants from the pots and washing roots to remove soil particles. Shoots and roots' fresh weights were recorded immediately using a digital balance. After recording fresh weights, the samples were sun-dried until a constant weight was achieved and dry weights were measured accordingly.

2.3. Statistical Analysis

The obtained data were subjected to statistical analysis using Statistix 8.1 software. Analysis of variance (ANOVA) was employed using complete randomized design (CRD) with factorial arrangement. The mean comparison of different treatments was performed using the Least Significant Difference (LSD) at a 5% probability level ($P \leq 0.05$). Correlation analysis (r) was performed to study the association between traits to traits and treatments to traits using Python (3.14.11). Principal Component Analysis was performed to visualize the relationship between variables and pattern of variations within the dataset. All graphical visualization were generated using Python (Libraries: Matplotlib and Seaborn).

3. Results

3.1. Growth traits

The growth attributes were negatively affected by increasing salt concentration, however, compost application improved plant growth under both normal and saline conditions, showing its protective role against salinity stress, as shown in Figure 1. The leaf area decreased with different salt levels (Figure 1a), by 23.79% at 75 mM and 33.43% at 150 mM in the absence of compost, whereas compost application increased leaf area by 5.19%, 21.20% and 24.83% at 0, 75 and 150 mM salinity stress, respectively. Root length also reduced with salinity stress with 20.93% at 75 mM and 32.72% at 150 mM salinity (Figure 1b), while it improved by 3.47%, 20.17% and 16.37% at 0, 75 and 150 mM salinity respectively when applied with compost. Similarly, shoot length decreased by 19.97% and 31.62% at 75 and 150 mM without compost applications, whereas it increased by 11.49%, 16.94% and 23.40% at 0, 75 and 150 mM, respectively, with compost application, presenting the better growth performance with compost.

3.2. Plant Biomass accumulation traits

Data regarding plant biomass accumulation traits (Figure 2) showed that increasing salt concentration significantly reduce biomass attributes, while compost application resulted in the increase of biomass attributes both under normal and saline conditions. Furthermore, fresh root weight decreased by 3.30% at 75 mM and 7.50% at 150 mM without compost, while compost application increased fresh root weight by 17.84%, 10.93% and 7.62% at 0, 75 and 150 mM, respectively (Figure 1c). The dry root weight (Figure 2a) was decreased by 12.11% and 17.94%

at 75 and 150 mM, respectively, nonetheless increased by 15.25%, 12.24% and 9.84% at salinity levels of 0, 75 and 150 mM, respectively, with the addition of compost. In the similar manner, the fresh shoot weight had declined by 7.19% and 9.44% at 75 and 150 mM without compost applications (Figure 2b). Similarly, dry shoot weight decreased 12.25% and 19.21% under 75 mM and 150 mM salinity without the use of compost (Figure 2c). In contrast, application of compost, resulted increase in dry shoot weight by 7.92% and 7.79% under salinity of 75 and 150 mM, respectively, presenting better dry shoot weight under compost amended conditions.

3.3. Correlation Analysis

The heatmap analysis (Figure 3) revealed clear differences in growth and biomass characteristics among treatments under salinity stress. The treatments-traits correlation (Figure 3a) showed that Treatment of 0 mM salinity with 20 g kg⁻¹ soil compost had the highest positive correlation with all traits (1.00). However, salinity (150 mM) without compost had the highest negative relationship with each trait, -1.00. Salinity (150 mM) without compost, presented the highest negative relationship with each trait (-1.00), indicating maximum suppression of growth under severe salinity. All traits were significantly decreased without compost (75 mM) with the fresh shoot weight being the most affected (-0.74), followed by dry shoot weight (-0.73), fresh root weight (-0.67) and dry root weight (-0.65). But application of compost at 75 mM had higher response on major growth traits as root length (0.53) and leaf area (0.34) with weak or slightly negative biomass traits. At 150 mM, the salinity damage was also recorded with compost, but it was less intense than without compost, indicating mitigating effect by compost. The trait-traits correlation (Figure 3b) revealed that all growth and biomass traits were positively correlated. The highest correlation was observed between leaf area and shoot length with a value of 0.99, shoot length and dry root (0.97), leaf area and dry root weight (0.94) and leaf area and root length (0.90). Root length also was highly correlated with shoot length (0.90) and plant biomass parameters, while fresh root weight was moderately correlated with leaf area (0.63), shoot length (0.68) and dry root weight (0.65). Generally, the figures showed that salinity stress negatively affect maize growth traits, whereas, the application of compost reduce significantly reduce the negative impact of salt stress in maize plants.

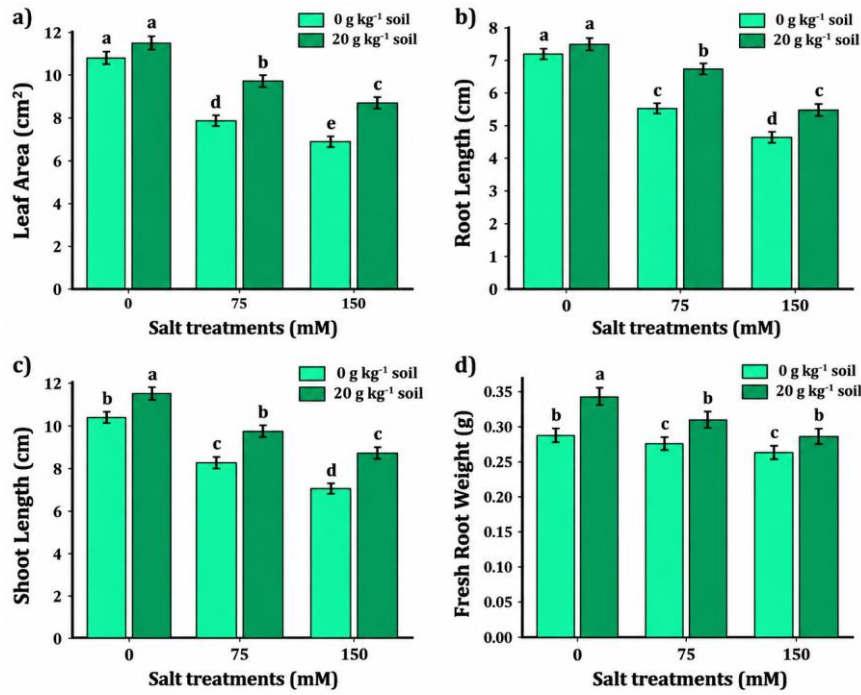


Figure 1. The figure presents the impact of compost application on growth and biomass parameters (a: leaf area, b: root length, c) shoot length and d: fresh root weight. Error bars on each bar represent the standard error mean. Various letters above the bars indicate significant differences among treatments, as determined by the Least Significant Difference (LSD) at $p \leq 0.05$.

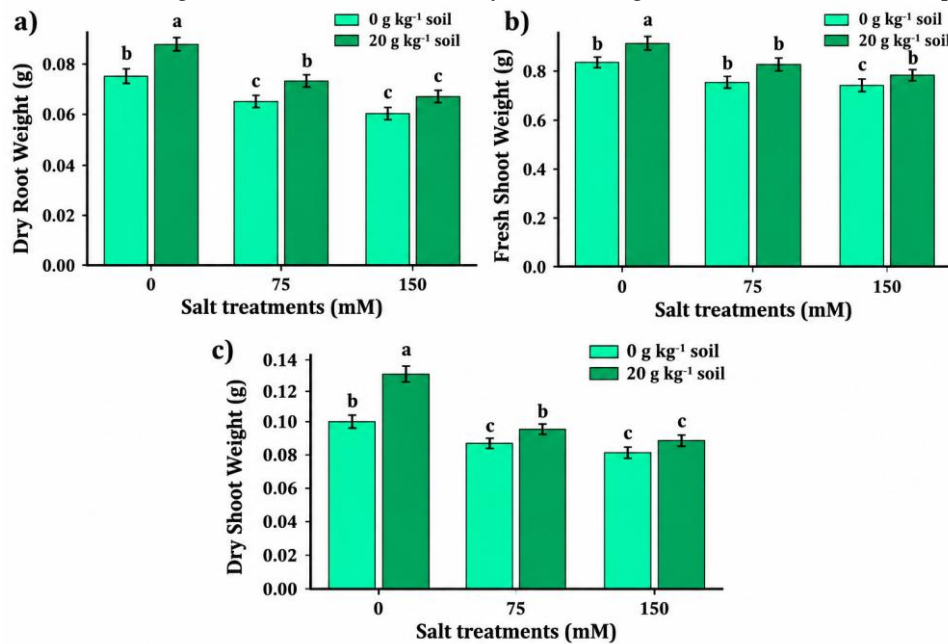


Figure 2. The figure presents the impact of compost application on growth and biomass parameters (a: dry root weight, b: fresh shoot weight and c: dry shoot weight). Error bars on each bar represent the standard error mean. Various letters above the bars indicate significant differences among treatments, as determined by the Least Significant Difference (LSD) at $p \leq 0.05$.

4. Discussion

Salinity stress is a major abiotic stress that limit plant growth and productivity because of the osmotic stress, toxicity, oxidative stress and nutrient imbalance (Khan et al. 2022). The present study revealed significant reduction in maize growth traits with increasing salinity levels, which is a result of the sensitivity of maize to salinity. The decreased plant performance under salt stress could be related to reduced water uptake,

photosynthesis, metabolic disturbances and disruption of cellular homeostasis (Shabana et al. 2025). Under saline conditions excessive accumulation of Na⁺ and Cl⁻ will disrupt ion balance by decreasing K⁺ uptake and will therefore negatively impact on enzyme activity, nutrient transport and plant growth (Munns and Tester, 2008). Compost application, however, had a significant positive effect on the growth of maize under both non-saline and saline conditions, thereby showing the protection and

ameliorative effect of the compost. The improvement could be attributed to the improvement of the soil structure, water holding capacity, nutrient availability, and beneficial microbial activity (Zhao et al., 2022). Under saline conditions, compost also helps to maintain the soil on an optimum ionic balance and reduces the sodium toxicity of soil (Hasanuzzaman et al. 2018).

Salinity stress reduced the leaf area, root length, and shoot length, which reflected the inhibition of cell division, elongation and photosynthetic efficiency. Applying compost reduced these negative effects and increased vegetative growth, however. Khan et al. (2022) also found that organic amendments increased leaf area of salt-stressed sorghum by improving the uptake of nutrients and mitigating sodium toxicity. In addition, Zhao et al. (2022) reported a remarkable increase in nutrient cycling and enhanced microbial activity following compost application under salt stress conditions. The increase in root and shoot growth after composting could be due to increased water absorption, improved soil aggregation, reduced compaction and improved root development, which are likely to improve water and nutrient uptake under stress. Kamal et al. (2024) and Ndubo (2023) also found that compost amendment resulted in enhanced root development and biomass production in saline maize.

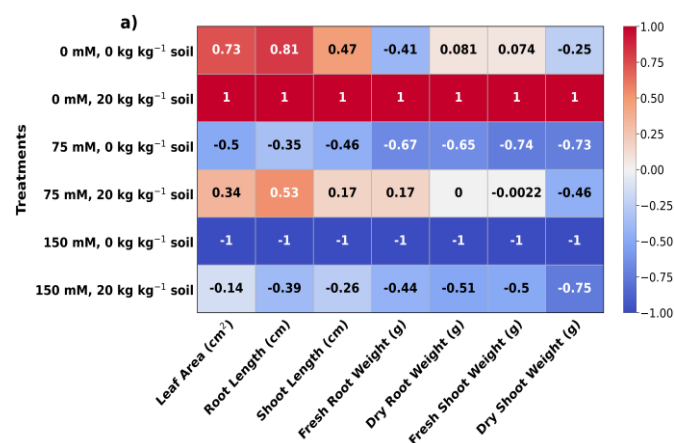
The salinity effect on biomass accumulation was similar, with salt stress decreasing fresh and dry biomass of both root and shoot. This loss could be attributed to decreased photosynthetic activity, diminished assimilation production, and problems with nutrient transport, as well as stress response metabolic expenses. Biomass production was significantly increased by compost application at all salinity levels, which shows that it has improved the physiological performance and tolerance to salinity stress. The beneficial impact of compost could be linked to higher soil fertility, greater root activity and increased nutrient availability. Under saline conditions, compost increases nutrient mineralization and nutrient cycling by microbes, which increases the availability of essential nutrients including N, P, and K (Etesami and Noori, 2019). Lakhdar et al. (2009) reported that compost resulted in higher root biomass under salinity stress as it enhanced water holding capacity and lowered the salinity stress effects in soil, while Leogrande and Vitti (2019) reported increased shoot biomass due to the improvement of OM and nutrient content.

Similarly, the positive salinity stress-induced effects of compost are correlated to enhanced osmotic adjustment and antioxidant defense. Application of compost causes better water relations in plants, which helps to maintain cellular hydration and accumulation of osmoprotectants like proline and soluble sugars by plant

cells (Gupta and Huang 2014). In addition, reactive oxygen species (ROS) can lead to oxidative stress and damage membranes and cellular components because of salinity. The antioxidant defense system may be improved by the increase in antioxidant enzymes with compost application, including the increase in the activity of superoxide dismutase (SOD), catalase (CAT), peroxidase (POD), and ascorbate peroxidase (APX), which helps reduce oxidative damage (Hasanuzzaman et al. 2021).

The correlation analysis showed highly significant positive relationships between leaf area, shoot length, root length, biomass traits, which in turn showed close association among them to determine maize productivity under stress conditions. The negative relationship between growth traits and salinity levels demonstrated the growth inhibitory effects of salinity stress. The positive relationships among growth parameters were, however, more strongly positive in the compost-treated plants, indicating better coordination of physiological responses. In general, the use of compost increased the tolerance of maize to salinity by improving soil properties, maintaining ion balance, increasing nutrient availability, stimulating microbial activity, improving osmotic regulation, and strengthening antioxidant defense mechanisms.

The present controlled greenhouse pot study showed the positive role of compost on the growth of maize under saline conditions; however, this may not reflect the complexity of field condition. While pot experiments give important information under controlled conditions, there are a number of limitations to consider, including limited root growth, different soil microbial reactions and different distribution of salts in pots than in field soils. Hence, validation at the field level under various soil types, climatic conditions and salinity levels is required before the use of compost at field level as a viable solution to enhance maize production in saline agriculture.



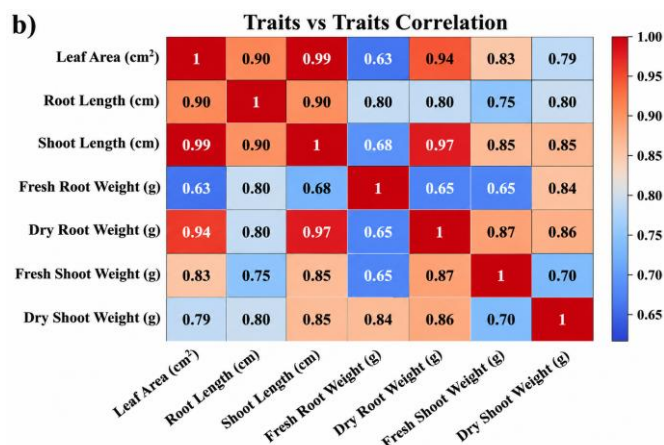


Figure 3. The figures present correlation analysis between: a) treatment-traits and b) traits-traits.

5. Conclusions

The present study shows that salinity applications significantly affected maize growth and biomass performance, however, compost application had a significant ameliorative effect. Among all treatments, the combination of 0 mM salinity with compost recorded the highest performance, showing maximum improvement in all traits. Under compost amended conditions, the leaf area, root length and shoot length increased. Similarly, significant improvements were observed for biomass traits, with fresh root weight improving and dry shoot weight under compost application. Compost was found very protective even under extreme salinity (150 mM), where it enhanced growth compared to non-amended plants. Correlation analysis also showed strong positive correlations between all the attributes, which suggested coordinated growth responses. Generally, compost was the most effective treatment that improved the tolerance of maize by improving growth and biomass accumulation under salinity stress conditions. Future studies are needed to assess compost application on field-scale to enhance maize growth and productivity under different saline conditions.

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