

OPTIMIZATION OF MANURE LEVELS AND APPLICATION DEPTH FOR ENHANCING SOIL PHYSICOCHEMICAL PROPERTIES UNDER SALINE CONDITIONS

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Received: August 16, 2025; Revised: April 08, 2026; Accepted: April 22, 2026

Abstract

A field experiment was conducted in 2015 at the Al-Hartha Research Station, Iraq, to evaluate the effects of animal manure application rate, placement depth, and application method on soil salinity and physico-chemical properties in a silty loam soil under drip irrigation. The field was plowed perpendicularly, and the experiment was arranged in a split-split plot design within a Randomized Complete Block Design (RCBD) with three replications. Treatments included three manure application rates (0, 20, and 40 t ha⁻¹), three application depths (10, 20, and 30 cm), and two application methods (mixing and manure placement depth). Corn (*Zea mays* L.) was used as the test crop, and all plots received equal amounts of NPK fertilizers. At the end of the growing season, soil samples from the 0-30 cm depth were collected to determine EC, soil pH, BD, and soil water content. The application of 40 t ha⁻¹ manure combined with manure placement depth from 10-30 cm reduced soil EC 4.63 to 5.87 dS m⁻¹ and pH 7.97 and 8.08, respectively, compared with the control (6.81 dS m⁻¹ and 8.12) and soil bulk density was found to reduce from 1.23 to 1.20 Mg m⁻³ while soil water content was increased from 26.33 to 30.23% when depth of addition was raised from 10 to 30 cm. The manure application 40 t ha⁻¹ combined with manure placement depth from 10-30 cm was more effective than mixing in reducing soil pH, soil salinity, and EC, BD and improved soil water content, particularly at deeper soil layers, resulting in improved soil physical conditions.

Keywords: Organic Fertilizer Machine; Organic Residues; Soil Physicochemical Properties; Soil Salinity

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DOI: <https://doi.org/10.55766/sujst11111>

Suranaree J. Sci. Technol. 33(5):010453(1-16)

Introduction

Soil salinity is one of the most critical constraints affecting agricultural productivity, particularly in semi-arid and arid regions where evapotranspiration exceeds precipitation and salts accumulate in the root zone. Globally, more than 20% of irrigated lands are affected by salinity, leading to substantial reductions in crop yield and soil fertility. High concentrations of soluble salts disturb soil structure, inhibit nutrient availability, reduce water uptake and metabolic functioning and ultimately impair plant growth (Rengasamy, 2010; Qadir *et al.*, 2014).

Organic matter is a vital measure of soil health, significantly influencing the soil's chemical, physical, and biological characteristics. It serves as both a reservoir of soil carbon and a source of essential macro- and micro-nutrients for plant growth (Kibblewhite *et al.*, 2008; Lal, 2013; Murphy, 2015). The decline in organic matter content in arable soils is a global concern and a major driver of soil degradation (Loveland & Webb, 2003). Fermented or composted manure provides a slow release of nutrients, promoting balanced nutrient distribution and enhancing crop yields while benefiting the natural environment (Singh *et al.*, 2014). However, due to the localized nature of animal production, large-scale application of manure is often impractical (Timsina, 2018). As a result, natural fertilizers such as compost are commonly used as alternatives (Singh *et al.*, 2019).

In central and southern Iraq, soils are typically poor in structure, with declining physical properties and fertility, leading to reduced crop growth and yield. This degradation is primarily attributed to low organic matter content, driven by high temperatures, minimal rainfall, and sparse year-round vegetation. Applying organic residues is a widely adopted strategy to enhance soil structure, nutrient availability, and overall ecosystem health. Regular use of organic amendments boosts soil organic matter, improving water retention, porosity, bulk density (BD), drainage, and tilth (Kumar, 2025). Improved soil structure and reduced bulk density are key factors in lowering soil electrical conductivity (EC). Cao *et al.* (2024) and Tejada *et al.* (2006) found that manure-treated soils exhibited lower EC compared to untreated soils, attributed to enhanced porosity and salt leaching. Mahdy (2011) observed a 50% reduction in soil EC with composted manure application, as it decreased BD and improved salinity management through sodium leaching. Additionally, manure application has been shown to reduce soil pH. According to Avnimelech and Kochva (1997) and Ganiger *et al.* (2012), this effect results from the formation of organic acids and CO₂,

which dissolve in soil moisture to form carbonic acid, thereby acidifying the soil. Traditionally, organic materials are either broadcast on the soil surface and tilled in or placed in narrow bands on or below the surface using manual methods or standard fertilizer spreaders. While these techniques are suitable for small-scale applications, they often suffer from uneven distribution, poor rate control, and high labour demands. Additionally, conventional application methods contribute to environmental pollution and expose workers to potential health risks.

To address these challenges, a ditch opener and an organic fertilizer laying machine were designed, manufactured, and field-tested. This machine efficiently opens a trench, deposits manure in a subsurface band (either as a buried layer or mixed with soil), and covers it, ensuring precise placement while minimizing labour, environmental impact, and health hazards.

The objectives of the current studies are given below:

To assess various manure application levels, and their effect on the salinity, pH, BD and soil water content of the soil in salty soil conditions. This study examined the effect of different manure levels, the methods and depth of application of the cattle manure using the manufactured machine on EC and pH of silty loam soil cultivated by corn (*Zea mays* L.).

Materials and Methods

Experimental Site Location

The field experiment was conducted in 2015 at the Al-Hartha Research Station, located in Basra Governorate, southern Iraq. The experimental soil was classified as silty loam. The region experiences a hot desert climate characterized by high temperatures, high evaporation rates and low annual rainfall.

Experimental Design

The use of the Split-split plot design within Randomized Complete Block Design (RCBD) with three replicates adequately controls the high variability inherent in field experiments. Each sub-sub-plot measured 5 m × 4 m (area = 20 m²), with a buffer space of about 0.5-1.0 m maintained between adjacent sub-plots, and 1.0-1.5 m spacing was kept between main plots to avoid treatment interference, particularly lateral movement of salts and nutrients. Treatments were randomly assigned within each level of splitting according to standard split-split plot procedures.

The 0-30 cm soil layer's physico-chemical properties were examined using the techniques defined by Richards (1954), Black (1965), and Page *et al.* (1982). The results are shown in Table 1 (Abdulkareem *et al.*, 2018). In a 2015 field experiment at Al-Hartha research station in Iraq, the agriculture machines and equipment department designed and manufactured the ditch opener and manure-laying equipment that was used to apply manure. The following methods were included in the research:

1. **Manure levels:** Three levels of manure application (0, 20, and 40 t ha⁻¹) were tested. These levels were determined by the machine's forward speed, size the manure-feeding rotational speed, and the manure-feeding openers. For this machine, the rotational speed was set between 25 and 35 rpm, depending on the target application rate (0, 20, or 40 t ha⁻¹) and forward speed, ensuring accurate and consistent placement of manure within the trenches.

2. **Trench dimensions:** Trenches were adjustable, with widths of 15 cm and depths set to 10, 20, or 30 cm according to experimental requirements.

3. **Forward speed:** The machine moved at a uniform speed of 3-4 km h⁻¹ to ensure even distribution of manure and minimal soil disturbance.

4. **Application depths:** The tractor's hydraulic system controlled the application of manure at three different depths (10, 20, and 30 cm).

5. **Application methods:** Two methods of animal manure application were used: mixing and manure placement depth. In the mixing method, the manure was incorporated into the soil using three mixing blades (tines).

Table 1. Basic soil properties prior to the experiment (Abdulkareem *et al.*, 2018)

Property	Unit	Value
EC	dS m ⁻¹	7.61
CaCO ₃	g kg ⁻¹	335.10
pH		8.13
Organic matter	g kg ⁻¹	6.11
Available – K	mg kg ⁻¹	95.34
Available-P	mg kg ⁻¹	16.12
Available-N	mg kg ⁻¹	18.72
CEC	cmol kg ⁻¹	25.25
Mg ²⁺	mmole L ⁻¹	10.90
K ⁺	mmole L ⁻¹	10.60
Ca ²⁺	mmole L ⁻¹	11.13
HCO ₃ ⁻	mmole L ⁻¹	9.34
CO ₃ ²⁻	mmole L ⁻¹	0.00
Cl ⁻	mmole L ⁻¹	30.15
SO ₄ ²⁻	mmole L ⁻¹	19.23
Na ⁺	mmole L ⁻¹	21.32
Sand	g kg ⁻¹	188.87
Silt	g kg ⁻¹	590.46
Clay	g kg ⁻¹	220.67
BD	Mg m ⁻³	1.31

Manure from well-composted livestock waste, mostly from cattle (farmyard manure), pig manure, poultry manure, and green manure, is used as an organic amendment in this study (Magdoff & van Es, 2021). The high nutritional content, microbial activity, and organic matter of this kind of manure are well known for their ability to improve saline soil conditions. Cattle manure was collected from a field near Al-Hartha research station in Iraq. The material was composted in a 2 m × 3 m × 0.5 m (L × W × H) pit for three months, maintaining a moisture content of 60%. During this period, the compost pile was manually turned every 14 days to ensure proper aeration and decomposition. Following the composting period, the manure was air-dried and prepared for experimental use. A representative sample was oven-dried at 50°C and subjected to standard chemical analysis as described by Page *et al.* (1982); the results are presented in Table 2 (Abdulkareem *et al.*, 2018).

Table 2. Some chemical properties of manure used (Abdulkareem *et al.*, 2018)

Property	Unit	Value
EC	dS m ⁻¹	13.25
P	g kg ⁻¹	7.16
N	g kg ⁻¹	17.37
pH	g kg ⁻¹	6.42
K	g kg ⁻¹	10.44
Organic Carbon	g kg ⁻¹	210.69
Organic Matter	g kg ⁻¹	363.22
Bulk density	Mg m ⁻³	0.59
C/N Ratio	—	12.13
C/P Ratio	—	29.43

After plowing the field to a depth of 30 cm in a perpendicular direction, the levels of manure were used to divide the field into three primary blocks. Based on the methods of applying manure, each major block was further divided into two sub-main blocks. Within these sub-main blocks, the depth of manure application was arranged in 10-meter-long rows. Each treatment was duplicated three times and placed in a (RCBD) with a split-split plot arrangement. A drip watering system was used for the experiment. For the management and reclamation of saline soils, irrigation is essential. In addition to promoting crop growth, efficient irrigation helps excess salts to move below the root zone, enhancing soil health and yield. Any soil amelioration machine's efficiency and effectiveness depend heavily on the design and simulation of an effective irrigation system.

A band of the Spanish hybrid maize variety Cadiz (*Zea mays* L.) was sown next to the rows of manure. In order to ensure optimal root development and nutrient uptake without the risk of seed burn or salt stress from the concentrated

organic material, a band of the Spanish hybrid maize variety was sown 15 cm away from the rows of manure. In order to provide effective nutrient diffusion from the manure to the maize root zone during the early growth phases, this spacing was selected based on best practices for nutrient band placement. Fertilizer was applied to each plot at a rate of 200 kg N ha⁻¹ for urea (46% N), 130 kg P ha⁻¹ for triple super phosphate (20.21% P), and 100 kg K ha⁻¹ for potassium sulfate (43% K). Throughout the trial, regular agricultural methods for growing maize those typically used Al-Hartha research station in Iraq, research station commercial production were applied.

Analytical Methods

Soil samples were collected from the experimental plot at a 0-30 cm depth at the end of the growing season (10th October 2015). The samples were air-dried, sieved through a 2 mm sieve, and analyzed. Soil electrical conductivity was measured using a conductivity meter for a 1:1 soil-to-water extract. In contrast, soil pH was determined using a pH meter for a 1:1 soil suspension, following the methods described by Page *et al.* (1982). Soil bulk density measured using the core method (Blake & Hartge, 1986) which involves collecting undisturbed soil cores, drying at 105°C for 24 hours, and calculating bulk density as dry soil weight per unit volume.

Data Collection and Statistical Analysis

Data on soil salinity, pH, bulk density and soil water content were subjected to statistical analysis using analysis of variance (ANOVA) to determine the effects of manure levels, depth, and application methods. All obtained data were subjected to analysis of variance (ANOVA), and the means were compared using the least significant difference (LSD) test at a 5% level of probability (Al-Rawi & Khalaf-Allah, 1980).

Results and Discussion

Soil Salinity Electrical Conductivity (EC)

All investigated depths and soil salinity levels were considerably lowered by biological additions. When supplements were placed using a manure placement depth, salinity levels decreased more effectively, and the most significant reduction in salinity was seen at deeper application depths. This method ensured a more uniform distribution of amendments, leading to enhanced salinity mitigation. The consequences indicate that manure application levels significantly affected soil EC at the end of the corn growing season ($P \leq 0.05$) as

shown in Figure 1. Specifically, increasing manure application resulted in a decrease in soil EC. For application rates of 20 and 40 tons per hectare, the EC values were 5.87 and 4.63 dS m⁻¹, respectively. This corresponds to a reduction in soil EC by 13.80% and 32.01% compared to the control treatment, which had an electrical conductivity of 6.81 dS m⁻¹ without manure application. Soil salinity is significantly affected by the depth at which manure is integrated into the soil ($P \leq 0.05$, Figure 2). As the depth of manure application increased from 10 to 20 and 30 cm, respectively, soil EC decreased from 6.13 to 5.71 and 5.42 dS m⁻¹, with a significant difference between these values.

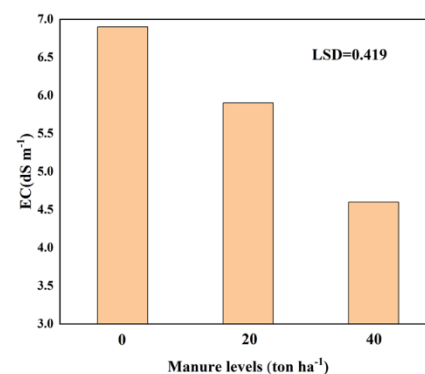


Figure 1. Influence of manure levels on soil salinity (Abdulkareem *et al.*, 2018)

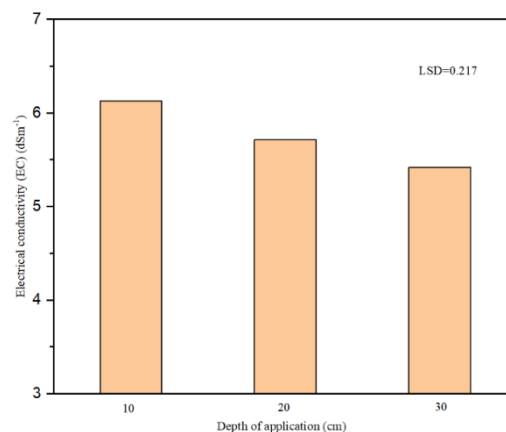


Figure 2. Effect of manure application depth on soil salinity (Abdulkareem *et al.*, 2018).

The manure application techniques had a substantial impact on the salinity of the soil ($P \leq 0.05$, Figure 3). When using the soil-manure mixing approach, soil EC decreased from 6.13 dS m⁻¹ with the subsurface manure banding method to 5.42 dS m⁻¹. By enhancing and decreasing bulk density and soil porosity, the mixing process enhanced soil structure and made it easier for salts to move deeper

into the soil. Soil salinity is related to the soil BD and moisture content by the following equations, respectively: $Y = 19.329X - 17.822$ ($R^2 = 0.9139^{**}$) and $Y = -0.2213X + 11.988$ ($R^2 = 0.9082^{**}$).

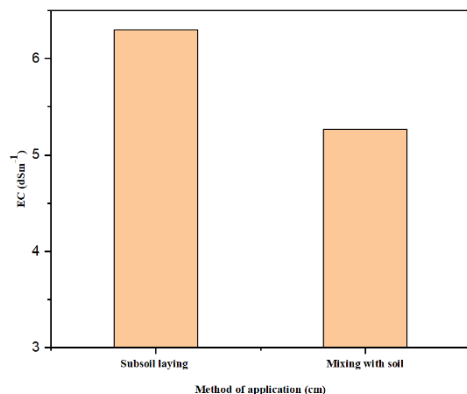


Figure 3. Effect of manure application technique on soil salinity EC (Abdulkareem *et al.*, 2018).

Using the manure-soil mixing method, applying 40 tons ha⁻¹ of manure as a manure placement depth produced an EC value of 5.27 and 5.44 dS m⁻¹, respectively, which was comparable to applying 20 tons ha⁻¹. These findings show that in terms of boosting soil physical properties and lowering soil EC the manure-soil mixing method outperforms the subsurface layer method. The soil EC was significantly ($P \leq 0.05$) impacted by the interaction between the manure levels and application techniques (Figure 4). For both application techniques, the EC of the soil decreased as manure levels increased. In terms of lowering the soil EC at all manure application levels, the manure-soil mixing method significantly surpassed the manure placement depth method. The manure placement depth application of 20 tons ha⁻¹ (6.30 dS m⁻¹) had the second-highest EC value, whereas the 0 tons ha⁻¹ treatment had the highest (6.81 dS m⁻¹). These two values are not significantly varied. However, the 40-ton ha⁻¹ that was applied using the manure-soil mixing method had the lowest EC value (3.99 dS m⁻¹). By 36.67 and 41.41%, respectively, the lowest EC value is lower than the two values above. By reducing BD, increasing porosity, and improving water-holding capacity, the manure-soil mixing method and 40-ton ha⁻¹ level enhanced the soil's ability to leach and wash salts downward. Applying 40 tons of manure per hectare as a layer beneath the soil surface yielded results that were comparable to applying 20 tons of manure per hectare through soil mixing techniques; the corresponding values were 5.27 and 5.44 dS m⁻¹. The findings made it abundantly evident that the subsurface layer method had been surpassed by soil-manure mixing techniques in terms of improving

soil physical characteristics and lowering soil EC (Abdulkareem *et al.*, 2018).

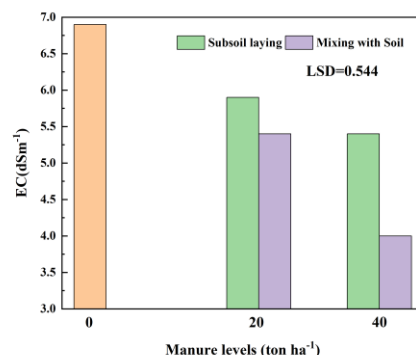


Figure 4. Manure application methods' effects on soil salinity at different levels (Abdulkareem *et al.*, 2018).

The interaction between the manure application level and depth significantly ($P \leq 0.05$) altered the soil EC (Figure 5). 6.81 dS m⁻¹, the highest EC value, was recorded for the control treatment (0 ton ha⁻¹), whereas the manure level of 40 ton ha⁻¹ applied at a depth of 30 cm produced the lowest value (4.14 dS m⁻¹). With the exception of the 40-ton ha⁻¹ treatment at a depth of 20 cm, the lowest value differed significantly from the other values. Pushing the salts farther down in the soil, away from the crop root zone, is the reason for the dominance of treatment 40 tons per hectare and depth of 30 cm (Abdulkareem *et al.*, 2018).

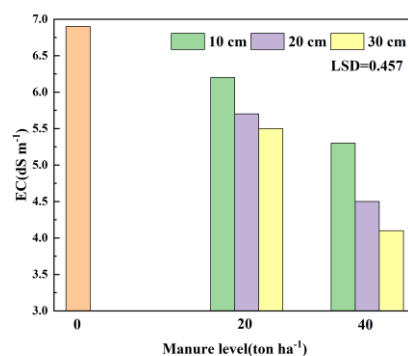


Figure 5. Manure levels affect EC at varying application depths (Abdulkareem *et al.*, 2018).

Soil pH

The application of biological amendments also influenced soil pH. Across different levels and depths, soil pH showed a trend toward neutrality. Deeper application depths, combined with the subsoil laying, resulted in a more pronounced pH

stabilization, indicating that the amendments effectively created a more favorable soil environment for plant growth. Manure application levels significantly affected soil pH at the end of the maize growing season ($P \leq 0.05$), as shown in Figure 6. The soil pH decreased from 8.12 in the control treatment (0 tons per hectare) to 8.08 and 7.97 with manure application rates of 20 and 40 tons per hectare, respectively. The interaction between the depths and levels of manure application has significant effects ($P \leq 0.05$) on the pH of the soil Figure 7.

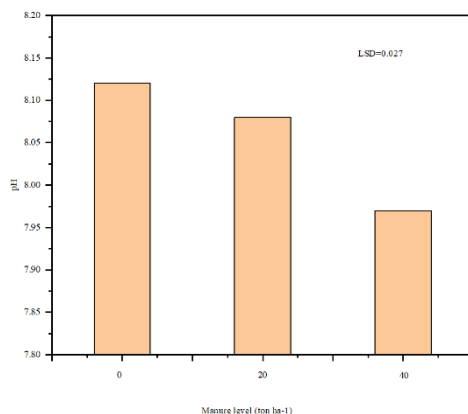


Figure 6. Manure levels' effects on soil pH

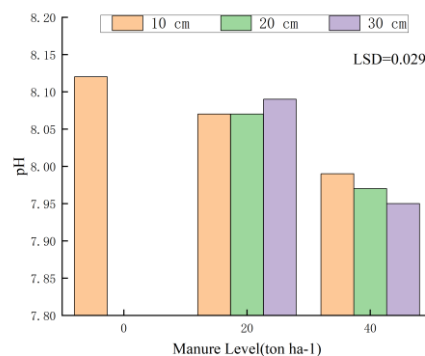


Figure 7. Manure levels' effects on soil pH at various application depths (Abdulkareem *et al.*, 2018).

Bulk Density (BD)

Reduced BD leads to enhanced water infiltration and root growth, as well as enhanced microbial activity. The addition of organic matter and enhanced aggregation decreases the formation of crusts characteristic of saline soils. The green manures decrease the soil bulk density. At the end of the corn plant's growing season, the soil BD was significantly impacted ($P < 0.05$) by the application of manure at different amounts as shown in (Figure 8). The BD decreased from 1.26 to 1.22 and 1.17 Mg

m⁻³, respectively (Shirani *et al.*, 2002; Brye *et al.*, 2004; Mosaddeghi *et al.*, 2009). Manure application techniques had a major impact on the soil BD as shown in (Figure 9). Demonstrated that the BD was significantly impacted by the manure's depth ($P < 0.05$). At 30 cm depth, the lowest soil BD was 1.20 Mg m⁻³, whereas at 10 and 20 cm depths, the BDs were 1.23 and 1.22 Mg m⁻³, respectively. This outcome could be explained by reduced BD in the deeper soil layers due to increased root biomass and soil moisture. It was discovered that varying the depth of manure application affected the BD of the soil (Guo *et al.*, 2016). This consequence could be attributed to the reduced BD observed in the deeper soil layers as a result of improved soil moisture and root biomass. Compared to the subsurface layer approach (1.23 Mg m⁻³), the mixing method produced a lower BD value (1.20 Mg m⁻³). The presence of a manure-free layer beneath the surface in the subsurface method may have reduced the beneficial effect of organic matter on porosity development, leading to higher BD. These findings confirm that mixing manure throughout the entire soil profile improves and stabilizes soil structure. Figure 10 demonstrated that soil BD reduced as manure levels increased, with the mixing method dominating. The control treatment (no manure added) had the highest value, 1.26 Mg m⁻³. Al-Shamy (2013) found that adding organic manure to soil increased soil moisture and root biomass, which decreased BD. However, compared to treated soil, the untreated underlying soil layers had a larger BD. This could be because of the way soil pores are arranged among particles, which results in low soil volume and high BD. The treatment of mixing manure at a rate of 40 tons per hectare yielded the lowest value of 1.14 Mg m⁻³, with a reduction percentage of 9.52% when compared to the control treatment. When manure was applied as a subsurface layer at a level of 40 tons per hectare, the BD was equal to 1.20 Mg m⁻³, which was the same value as when manure was mixed at a level of 20 tons per hectare. Soil BD was also significantly impacted by the interactions between manure levels and application depth (Figure 11). demonstrated that for both the mixing and subsurface layer approaches, soil BD reduced as manure levels increased, with the mixing method dominating. The control treatment (no manure added) had the highest value, 1.26 Mg m⁻³. When mixing manure at a rate of 40 tons per hectare, the lowest value of 1.14 Mg m⁻³ was achieved, with a reduction percentage of 9.52% compared to the control treatment. The amount of BD (1.20 Mg m⁻³) obtained from applying manure at 40 tons ha⁻¹ as a subsurface layer was identical to that obtained from mixing manure at 20 tons ha⁻¹. Soil BD was also significantly

impacted by the interplay between manure levels and application depth (Figure 12). With a trend of $10 > 20 > 30$ cm, the BD declined as the application depth increased at the same application rate. The effects of both application depth and manure level on soil BD can be attributed to enhancements in water content, porosity and soil structure, which collectively resulted in a reduction in BD. The untreated soil had the highest value (1.26 Mg m^{-3}), whereas the soil treated with 40 tons of manure per hectare at a depth of 30 cm had the lowest value (1.14 Mg m^{-3}). Additionally, the results showed that there was no discernible difference between the BD of the plot treated with 20 tons of manure ha^{-1} at a depth of 30 cm and that of the plot treated with 40 tons of manure ha^{-1} at a depth of 10 cm the values were 1.20 and 1.21 Mg m^{-3} . Similarly, this implies that adding less manure (20 tons ha^{-1}) at a deeper depth can produce the same effects as adding more manure (40 tons ha^{-1}) at a shallow depth. This finding might offer a strong chance of a 50% reduction in the quantity of manure added due to applying the manure to the deeper layers.

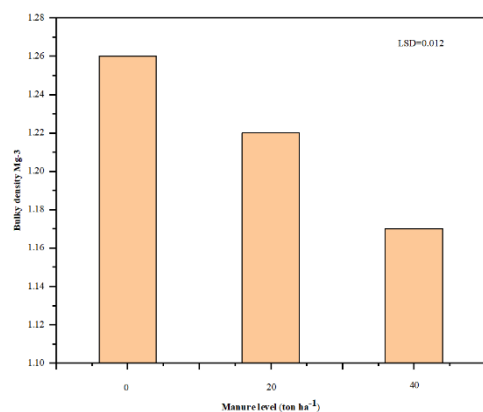


Figure 8. Impact of manure levels on soil BD (Aday *et al.*, 2017).

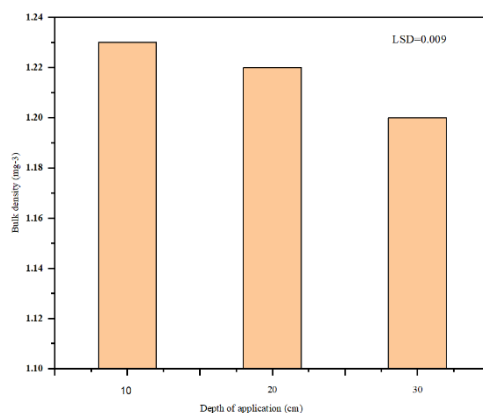


Figure 9. Impact of depth of manure application on soil BD (Aday *et al.*, 2017).

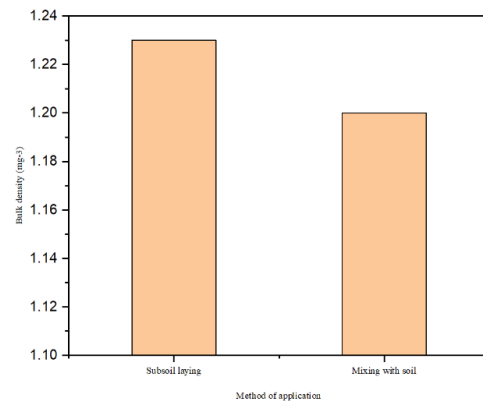


Figure 10. Impact of method of manure application on soil BD (Aday *et al.*, 2017).

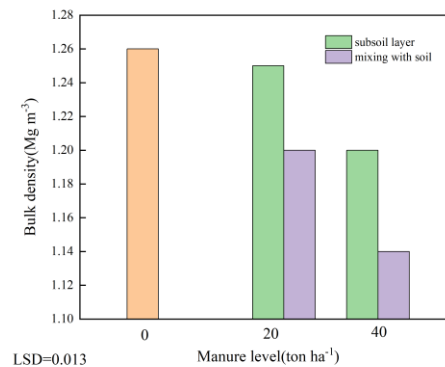


Figure 11. Impact of manure levels on soil BD at different application methods (Aday *et al.*, 2017).

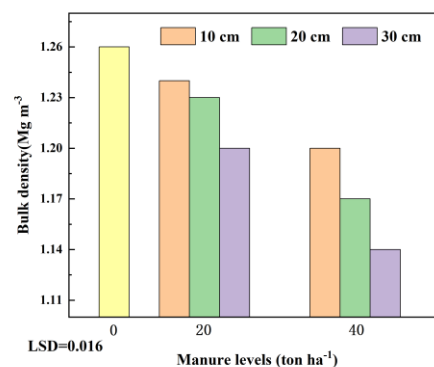


Figure 12. Impact of manure levels on soil BD at different application depths (Aday *et al.*, 2017).

Soil Water Content

Contrary to the BD, the manure application rates increased the soil water content (Figure 13). When the manure levels were increased from 0 to 20 and 40 ton ha^{-1} , the SWC increased from 24.19 to 28.84 and 32.20 %, respectively (Dridi & Toumi,

1999; Al-Hasan, 2008). Application of chemical fertilizers alone (0 ton manure ha⁻¹) lessened the moisture retention capacity (Guo *et al.*, 2016), however, manure application could enhance the total porosity and water holding capacity of soils. The manure can well enhance soil moisture condition. Al-Fadlly (2011) studied that the soil water content (SWC) was increased after the addition of organic residues and that can be attributed to the soil BD lessening and to the high organic matter input. The boosting of water holding capacity of soil treated with manures and reducing rates of evaporation from the soil surface can result in increasing soil moisture content (Jasim *et al.*, 2008). The results presented in Figure 14 showed that soil moisture values were 26.33, 28.67 and 30.23% for application depth of manure of 10, 20 and 30 cm, respectively. The difference was significant ($P \leq 0.05$) among the three depths. The highest soil moisture content was recorded for depth of 30 cm, which may be related to higher accumulation of organic matter in this depth. The mean values were 29.25 and 27.57%, respectively (Figure 15). In addition to the improvement in the soil holding capacity. Green manure enhances water content and aggregate stability, and improves microbial diversity (Sun *et al.*, 2021). Wang *et al.* (2016) reported that organic manure improves water retention, soil water contents, and water infiltration, grain yield. Manure levels had an obvious effect on soil water content in both methods of application as shown in Figure 16. Higher values were obtained for mixing method (30.50 and 33.05 % for 20 and 40 ton ha⁻¹, respectively) while the subsoil laying method values were 27.00 and 31.50 %, respectively. The lowest values of soil water content were recorded in the plot receiving 0 ton ha⁻¹ of manure (24.19%). The results presented in Figure 17 showed that the combination effect of manure levels and depth of application was significant on soil water content ($P \leq 0.05$). Soil water content increased with depths of application (10 to 20 and 30 cm) for the two levels of application. The greatest water content was recorded for soil fertilized with 40 ton ha⁻¹. However, the water content in soil treated with 20 ton ha⁻¹ at 30 cm depth was significantly higher than the water content in the soil treated with 40 ton ha⁻¹ at 10 cm depth. The values of the former treatments were 31.10 and 28.70 %, respectively. This results clearly support the idea that the level of fertilization would not only control soil properties and plant growth, but the placement and the method of fertilizer application would play an important role in fertilizer use efficiency. On the other hand,

increasing manure level from 20 to 40 ton ha⁻¹ increased water content, which reached a higher value of 35.41 % regardless of application depth. Statistical analysis of the experiment showed that the interaction between depth of manure application and method of application had no significant effect on soil water content. The results presented in Figure 18 indicated that combination of experimental factors (depth $\times$ level $\times$ method) caused a significant effect on soil water content ($P \leq 0.05$). Soil water content increased with the application depth and manure levels for the two methods of application. At all depths and manure levels, the highest values were obtained at mixing method as a compared with the subsoil layer method. The highest water content (36.19 %) was recorded in soil mixed with 40 ton ha⁻¹ of manure at 30 cm depth, which surpassed the other values by 5 and 50 %. In this study, using the active depth and the best method of application of the manure by using the machine improved the physical properties of soil.

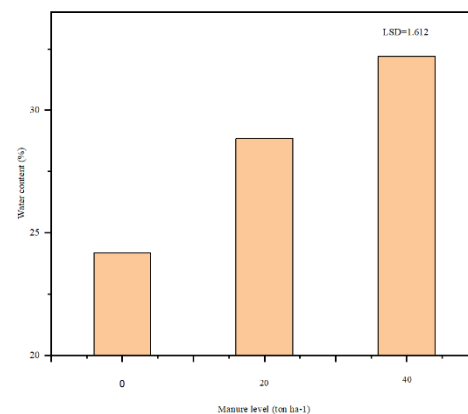


Figure 13. Influence of manure levels on soil water content (Aday *et al.*, 2017).

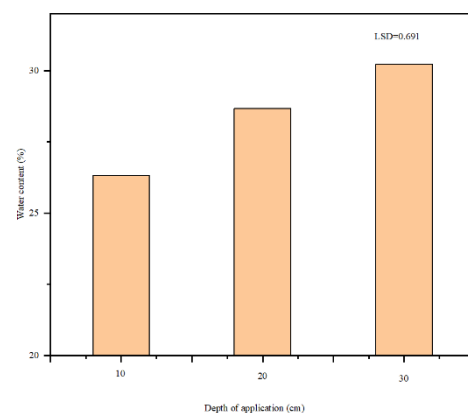


Figure 14. Influence of depth of manure application on soil water content (Aday *et al.*, 2017).

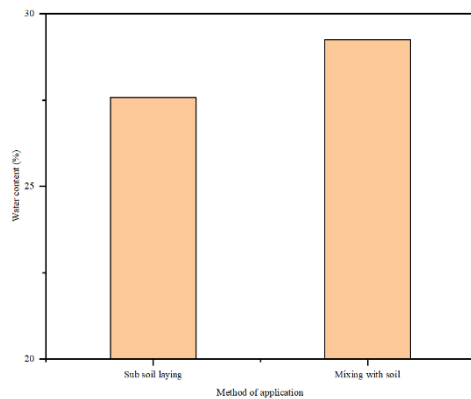


Figure 15. Influence of method of manure application on soil water content (Aday *et al.*, 2017).

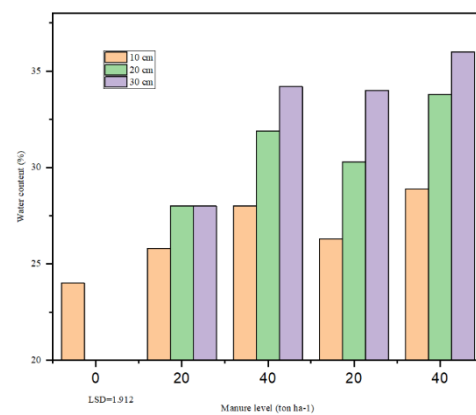


Figure 18. Influence of manure level and method of application on soil water content at different depths of application (Aday *et al.*, 2017).

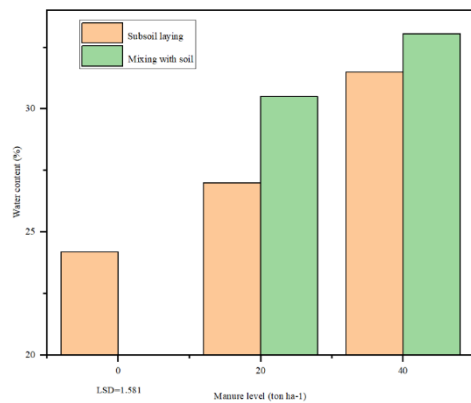


Figure 16. Influence of manure levels on soil water content at different application methods (Aday *et al.*, 2017).

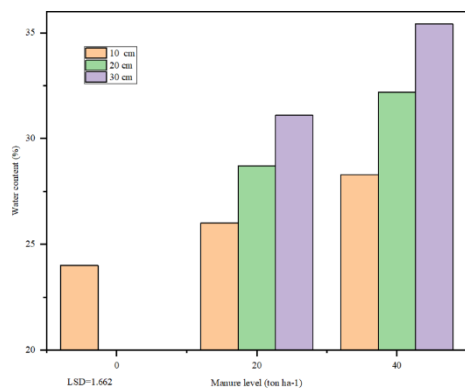


Figure 17. Influence of manure levels on soil water content at different depths of application (Aday *et al.*, 2017).

Discussion

Effects Of Manure Level and Application Depth on Soil Physicochemical Properties

Manure application rate and depth of application had an effect on the physicochemical status of the saline soil. Overall, increase in manure application rate showed improvement in soil quality attributes when compared with untreated control. This is because of the presence of organic matter, which helps in soil aggregation and enhances soil structure by improving porosity of soil, water holding capacity of soil, and solute leaching of salt. The use of organic matter is a well-known technique to improve chemical and physical soil attributes (Leogrande & Vitti, 2019). Andrade Foronda and Colinet, (2022) suggested that the application of cattle or chicken manure could possibly increase the effectiveness of gypsum with leaching on some soils that are saline-alkali. Dugan *et al.* (2024) stated that manure application improved physical properties of the soil and yields under different tillage techniques. Singh *et al.* (2023) examined how the combined application of inorganic and organic amendments can be an effective method to maintain crop productivity while improving the biological and physiochemical characteristics of the soil.

Electrical Conductivity (EC)

The decrease in soil electrical conductivity due to the use of manure demonstrates the contribution of manure in the improvement of the soil's saltiness problem. The fact that the greater decrease is noted in the case of more use of manure shows that there was enough organic material needed for an obvious change in the salt-affected soil. The presence of organic material in the soil increases its aggregation and pore continuity, thus increasing the infiltration process and helping move salts down in the soil during the irrigation process and drainage process. Moreover, the breakdown of organic material can enhance the structure of the soil along with biological activity, thus contributing to salt leaching. The results obtained from this study are consistent with past research conducted which indicated that organic amendments have been found to decrease soil electrical conductivity and facilitate the reclamation of saline and sodic soils. According to a study carried out by Leogrande and Vitti (2019), appropriate amounts of organic amendments have the capability to enhance soil physical, chemical, water infiltration, and retention properties in saline and sodic soils. Likewise, a global meta-analysis study revealed that organic amendments decreased the EC and pH of saline-alkali soils. Depth of application effect is equally crucial. If manure is applied to the proper depth, then the organic matter is going to be distributed in the soil profile instead of being limited to the upper layers only. It might lead to better soil structure and water distribution in the amended layer and, thus, contribute to the salt redistribution and leaching. So, the efficiency of manure in terms of lowering the EC will depend on both its quantity and depth of application.

Aday *et al.* (2017) revealed that the decrease in soil EC is associated with the beneficial effects of manure on the physical properties of the soil, such as moisture and bulk density (BD), which enhanced the soil's capacity to remove salinity from the crop roots zone and, as a result, reduced soil EC. Fu *et al.* (2022) reported that manure application and crop rotation are two popular agricultural activities that can change soil's physical qualities and functions, according to the research collected. The study demonstrates that the crops planted and the texture of the soil impact the improvements in soil physico-chemical qualities that result from applying manure. Are *et al.* (2017) indicated that if one wanted to enhance the physical quality of deteriorated soil, non-composted manure and composted manure would be a better investment than biochar. The soil physical quality (SPQ) of deteriorated soils can be restored and improved in large part by adding organic materials as soil amendments. Agbede *et al.* (2017) and Agbede (2025) showed that the

application of poultry manure enhanced the physical characteristics of the soil and improved the plant growth and crop parameters of carrots more than the N, P, and K⁺ fertilizer. Sharma *et al.* (2021) studied that in subtropical regions with sandy clay loam soil, the use of biochar along with compost improves the hydrophysical properties of the soil, crop productivity, and financial returns. Rasoulzadeh & Yaghoubi (2010) studied that cattle dung is useful for increasing the physical fertility of low organic matter soils, which are commonly farmed in semiarid regions, by adding organic matter. This study showed that adding cattle manure greatly enhanced the physical characteristics of the soil. The application of bovine dung restores the damaged soil structure by raising its infiltration, organic carbon, aggregate size, hydraulic conductivity, accessible water capacity, and lowering bulk and particle density, according to the results. Furthermore, the soil's physical qualities were positively affected by the application of cattle dung. Tejada *et al.* (2006) and Mahdy (2011) stated that adding manure to the soil improved its salinity and sodium leaching because it decreased the bulk density of the soil, increased its porosity, and improved its structure, all of which helped in the leaching of sodium chloride, decreased the percentage of sodium exchange, and decreased the salinity of the soil. Azeez and Van Averbek, (2012) studied poultry manure and green manure, and the possibility of manure-induced soil salinization is extremely significant. It was determined that the liming capability and decreased salinization effect.

Deeper soil disturbance, which increases soil porosity, is probably the cause of this decrease in soil salinity. Manure increases the physical characteristics of the soil, including its moisture content and bulk density, which makes it easier for salts to migrate downhill into the lower soil layers (Aday *et al.*, 2017). Ashraf *et al.* (2005) found that the salinity lessened when manure was used along the depth of 0 - 100 cm. Su *et al.* (2021) discovered that manure enhanced soil organic matter (0-20 cm) by 20.5% and soil water depletion (0-160 cm) by 68.6% when compared to chemical fertilizer. At soil depths of 0-160 cm, soil EC was also reduced by 18.3% and NO₃-N by 62.2% (Liu *et al.*, 2022). When compared to CK, the recommended amendment treatments improved the soil's surface moisture content (0-20 cm). Amendments simultaneously decreased the salinity of the soil to 0-20 cm.

Atee *et al.* (2006) found that the addition of manure to the soil by the mixing method reduced EC of the soil through reducing soil BD, which helped in washing the salts down to the deep soil layers. Miller *et al.* (2005) stated that composted manure

shouldn't increase the salinity and sodicity of the soil more than FM, and controlling some soil salinity factors.

Soil pH

Manure application had effects on the soil pH as well. The decline in soil pH following the application of manure could be attributed to the decomposition of organic materials and formation of organic acids and carbon dioxide through microbial action. This would change the chemistry of the soil reactions, causing a gradual decline in soil alkalinity. Organic materials could also affect the chemistry of soil through the exchange of basic ions and sodium. The decrease in the pH value recorded by this study is similar to findings from past research. There is literature on how organic amendments can help improve the soil's chemical characteristics such as pH in salt-affected soils (Leogrande & Vitti, 2019). Another study found that applying organic amendments resulted in reduced soil pH in saline-alkali soils.

Organic matter from various sources caused a decrease in soil pH. The breakdown of organic matter releases CO₂ and other organic acids, and the activities of soil organisms caused the pH of the soil to decrease. Furthermore, CO₂ is released by crop roots, which reduces the pH of the soil. (Zhao *et al.*, 2009; Wen *et al.*, 2016). Adding manure considerably decreased the pH of the soil as compared to doing nothing. They related the decrease in soil pH to the breakdown of manure, which generated carbonic acid and then 2H⁺, both of which decreased soil pH (Ganiger *et al.*, 2012; Mohammed, 2013).

Bulk Density

Bulk density decrease due to manure application reflects improvement in physical soil quality. The organic manure has less bulk density than the mineral component of soil and increases the organic content of soil. Its decomposition helps in the formation of soil aggregates and improves porosity of soil. Therefore, the bulk density of soil will be less with increasing amount of manure where the results are significantly different. This finding concurs with earlier findings. According to Zhang *et al.* (2014), the use of farmyard manure decreased soil bulk density and improved soil hydraulic properties in the reclamation of salt-affected coastal soils. In this study, the addition of manure increased the soil saturated water content and hydraulic conductivity while lowering soil bulk density, especially in the upper soil layers. Similarly, long-term use of cattle manure in saline-sodic soil resulted in decreased soil bulk density, increased total porosity, and water-holding capacity (Yu *et al.*,

2023). It may be that the impact of the incorporation depth may have something to do with where the manure changes the physical characteristics of the soil. Proper incorporation depth can lead to better pore creation and less compaction. However, the depth of incorporation may not lead to further benefits when the manure is put below the most active root zone.

Guo *et al.* (2023) studied a greater reduction in bulk density as subsoiling depth was increased from 30 to 50 cm. The most effective method for enhancing root development, plant health, and cotton yield was subsoiling to a depth of 40 cm (S40).

When added to the soil, organic materials exhibited low (BD) and higher porosity, resulting in a significant decrease in soil BD. Organic materials also improve microbial activity by supplying carbon and essential nutrients for growth. The binding of soil particles by hyphae and various microbial exudates further improves soil porosity and decreases BD (Al-Mohammed, 2009). Al-Delfi (2013) found that organic manure decreased BD by increasing the mean weight diameter of the soil aggregates. When the manure levels were increased from 0 to 20 and 40 tons ha⁻¹. According to Aday *et al.* (2017) deeper manure mixing increases the water content of the soil while decreasing its BD.

Ewulo *et al.* (2008) inferred from this investigation that poultry manure improved the availability of macronutrients while also decreasing the BD and increasing the moisture content of the soil. This enhanced tomato growth and yield. Applying 25 t ha⁻¹ manure is advised to maximize tomato yield and nutrient content.

Wang *et al.* (2022) studied that manure application (Farmyard manure treatments and FM+PM) significantly lessened BD and enhanced Ks and soil water content (SWC) at 0-20 cm soil depth.

Soil Water Content

The rise in soil moisture level after applying manure indicates that organic matter has contributed to an improvement in soil's water retention capacity. Manure can enhance the stability of aggregates and also improve the percentage of pores in the soil which can hold plant-available water. Better soil structure can minimize quick drainage through the root zone while holding enough pores for water storage. This is confirmed by the study conducted by Zhang *et al.* (2014), which indicated that farmyard manure increased capillary water holding capacity and saturation water content of the reclaimed salt affected soils. Studies carried out regarding the application of manure have revealed that there has been an improvement in soil moisture

and water holding capacity. Avnimelech and Kochva (1997) who found a significant correlation between organic carbon and soil water content in two layers 0-10 and 10-30 cm, suggesting that water holding capacity of the added organic carbon is 341 and 825% in the 0-10 and 10-30 cm layers, respectively, since the organic carbon in 0-10 cm layer is mostly made of the native organic matter, while organic carbon in the lower layer consists of mainly from the organic carbon that was leached down from the compost. Zhang *et al.* (2014) found a negative correlation between bulk density and water content at depths 0-10 and 10-20 cm of soil under farmyard manure application. Soil water content significantly increased in soil mixing manure plot compared with the subsoil laying manure plot. Bladia (2014) obtained high values of soil moisture content in the soil mixed with organic residues, and attributed that to the best distribution of organic colloids in soil, which can hold water greater than the chemical colloids by 10-100 times. Fu *et al.* (2022) studied that manure addition decreased pH by an average of 3–6% for all three sites, and enhanced soil water retention, plant.

Zhang *et al.* (2017) noted that manure is an important source of nitrogen for plants, the ecosystem is threatened by it. The experiment revealed that the method of applying manure had no effect on the amount of nitrogen in the soil, but plowing increased the C/N ratio, which was caused by an increase in the amount of organic carbon in the soil. A properly high organic carbon content in manure may minimize nitrogen leaching. Ren *et al.* (2014) research did not demonstrate a significant increase in the amount of organic matter (OM) in the soil fertilized with manure with a low C/N ratio. It is often believed that simplifying soil cultivation could result in a higher level of humus in the soil (Haddaway *et al.*, 2017). Alcántara *et al.* (2016) and Altikat *et al.* (2018) claim that deep plowing increases the organic matter reserves in agricultural soil. The tillage cultivation approach had a larger soil organic carbon content than the simpler method, as the authors' own research showed. Applying manure above the surface increases CO_2 emissions into the atmosphere, but applying it deeply slows down the rate of mineralization. Diacono & Montemurro (2011) suggested that it will become much more crucial in the future due to climate change and the accelerated rate at which bacteria are mineralizing organic materials. Applying manure improves physical characteristics and makes nutrients more available to plants.

Rutkowska *et al.* (2002) concluded that manure fertilization increases the amount of P in the soil solution. Stepień *et al.* (2002) claimed that manure has no discernible effect on the amount of

phosphorus that is readily available in the soil. Meena and Biswas (2014) reported that organic fertilizer enhances phosphatase activity and microbial biomass, it increases the amount of P in the soil solution. It has been demonstrated that plowing lowers the amount of accessible forms of K and Mg in soil, most likely from cattle manure, when compared to reduced tillage. The topsoil's nutrient concentration is influenced by tillage simplifications. Given that fertilizers can seep into surface waters during periods of intense precipitation, this could have an adverse effect on the environment. Consequently, the soil's macro- and micro-nutrient levels decrease (Włodek *et al.*, 2009). Chaudhary & Narwal (2005) under manure fertilization, the content of micro-nutrients increases, and this increase occurs in the soil's top layer. Kwiatkowski *et al.* (2020) studied micronutrient content in the soil was positively impacted by the plough system in the study. Wang *et al.* (2016) concluded that organic manure has been shown to enhance soil water contents water retention, the water infiltration and grain yield. Ozlu & Kumar (2018) concluded the application of manure enhanced soil properties compared to that of inorganic fertilizer. Yao *et al.* (2007) proved that higher ion concentrations in manure appear to have more of an effect on the ionic composition of soil salinity. Fauzan *et al.* (2025) concluded that organic manure and biochar can enhance soil fertility and promote sustainable farming methods. Purbajanti & Kusmiyati (2024) recommended gypsum and manure as amendments and N resources on the salinity of saline soil and decreased pH , EC, sodium and improved sulfate and potassium content. Zhou *et al.* (2016) and Blanco-Canqui *et al.* (2015) have found that manure amendments can decrease bulk density. Wang *et al.* (2020) studied comparison to those under equal chemical N, P, K input, soil bulk density reduced significantly with organic manure treatment after harvest, coinciding with increases in top-soil total N, organic matter, and accessible P concentrations of 11.9, 18.7, and 97.8%, respectively. Mosavi *et al.* (2010) studied green manure enhancing soil physical properties important to soil water retention in dry land region. Li *et al.* (2024) studied deep vertical rotary tillage improving soil structure, lowering soil salinity and alkali stress, and achieving long-term improvements in soil physicochemical characteristics and sustained improvements in cotton yield, deep vertical rotary tillage can mitigate this problem. A thorough investigation revealed that the local long-term straw-returning management method combined with 60 cm vertical deep rotary tillage is a synergistic way to enhance salinized farmland and boost cotton yield in southern Xinjiang. Cai *et al.*

(2014) found that a deep tillage machine can effectively improve soil structure, decrease soil bulk density, and enhance soil water content. Wang *et al.* (2011) concluded mulching and deep tillage practice to boost soil water content and spring maize yield. Li *et al.* (2025) concluded deep tillage that incorporate straw return have also been observed to increase soil water content, yield, and water use efficiency.

Conclusion

Soil salinization significantly negatively impacts agricultural productivity worldwide, with salt being one of the most harmful environmental factors. Salinity-induced oxidative stress damages cells and disturbs the ionic equilibrium in addition to increasing the uptake of Na^+ ions. This inhibits plant growth and negatively impacts the morphological and biochemical properties of the plants. This strategy could be especially useful in regions where salinity substantially restricts crop yield. The application of 40 t ha^{-1} manure combined with manure placement depth from 10-30 cm reduced soil EC 4.63 to 5.87 dS m^{-1} and pH and 7.97 and 8.08 , respectively, compared with the control (6.81 dS m^{-1} and 8.12) and soil bulk density was found to reduce from 1.23 to 1.20 Mg m^{-3} while soil water content was increased from 26.33 to 30.23% when depth of addition was raised from 10 to 30 cm . The conclusion of the current study the application of 40 t ha^{-1} manure combined with manure placement depth from 10-30 cm was more effective than mixing in reducing soil pH, soil salinity, and electrical conductivity, bulk density and improved soil water content, particularly at deeper soil layers, resulting in improved soil physical conditions.

Future Perspectives & Recommendations

Future research should assess the performance of sub-soil manure application across different soil types, multiple cropping seasons and climatic conditions to validate the effectiveness and adaptability of the method under varied saline conditions. Combining manure application with organic amendments or biochar, gypsum may further improve soil fertility, enhance salinity management, and facilitate crop productivity. Studies exploring synergistic effects are suggested. Research should focus on tailoring manure levels and application depth for different crops, including salt-tolerant species, to increase crop yield and resource use efficiency in saline soils. Investigating

the physico-chemical and biological mechanisms by which sub-soil manure application enhances water retention, soil properties, and nutrient availability will support refine application techniques and enhance predictions of long-term impacts. Future studies should include cost-benefit analysis and environmental impact assessments to ensure the practice is both economically viable and environmentally sustainable for farmers in saline regions.

Long-term effects study

This study was a short-term field experiment (one growing season for corn). It is recommended that future research focuses on the long-term impact of this novel manure application technique on soil quality parameters and sustained crop productivity over multiple growing seasons, confirming its sustainability.

Economic and energy analysis

A study comparing the economic efficiency (cost-benefit analysis) and energy consumption of using the subsoil laying machine versus traditional manure application methods would be highly beneficial to support practical adoption by farmers.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Author Contributions

Waqar Ahmad Khan: Conceptualization, methodology, writing-original draft, writing review & editing

Dongyan Huang: Formal analysis, Supervision;

Gang Wang: Data curation.

Ethics Approval and Consent to Participate

Ethics approval and informed consent were not required for this study.

Declaration of Generative AI

The authors declare that no Generative AI tools were used in the preparation of this manuscript.

Acknowledgements

We are also grateful to our teacher, and all members of the research team for their valuable guidance, technical support, and constructive suggestions throughout the study.

Data availability

Not applicable.

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