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Residual Effects of Application of Compost and /or Sand on Some Properties of a Heavy Textured Soil as Well as Production of Maize (*Zea mays L.*) Cultivated Therein.

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Abstract

Maize (*Zea mays L.*) ranks as one of the most vital strategic crops on a global scale, functioning as an essential source for food, livestock feed, and biofuel security. The objective of this study is to assess the residual impacts of sand and compost, as well as surface and deep tillage treatments, applied to a heavy-textured soil during the initial (winter) season. This evaluation will encompass the physical and chemical properties of the soil, along with the growth parameters and productivity of maize cultivated therein. The experimental design employed was split-split plot design featuring three replications, which included four different rates of sand and four different rates of compost. Maize was subsequently grown in the same plots utilized in the previous (winter) season without the reapplication of treatments in the second season. This experiment was conducted during the summer of 2024, adhering to the recommended NPK fertilization rates in accordance with standard agricultural practices pertinent to the soil region. The findings demonstrated significant enhancements in maize yield attributable to the treatments administered previously. The improvement in yield was notably more significant under deep tillage in comparison to surface tillage. Furthermore, there were substantial increases in hydraulic conductivity and soil organic matter content, which, in turn, led to enhancements in cation exchange capacity relative to their corresponding values recorded during the first season. These improvements in soil properties had a favorable impact on the productivity of maize grown in this soil.

Key words: Management practices; Organic additives; Chemical characteristics; Nutritional status

Introduction

In the context of resource scarcity and climate instability, the urgent need to adopt sustainable practices in food production underscores the importance of converting agricultural by-products into sources of organic matter. This transformation represents a critical approach towards establishing a circular and resilient agricultural system. Such practices not only enhance soil health and boost crop productivity but also mitigate the disposal of carbon-rich residues as waste **(Cameron et al., 2013; Nattassha et al., 2020; Velasco-Muñoz et al., 2022; Brichi et al.,2023; L haj et al., 2024; Hoque et al., 2025).** When integrated with crop diversification, conservation tillage, and organic soil amendments, this strategy emerges as a potent mechanism for rehabilitating degraded lands, improving soil quality, and restoring ecosystems adversely affected by degradation and pollution **(Garcia et al. 2017; Altobelli et al. 2020; Babu et al., 2023; Al-Shammary et al., 2024).** Soils exhibiting optimal physical characteristics possess the capacity to effectively store and transmit water, air, nutrients, and agrochemicals, thereby fostering maximal crop productivity while minimizing environmental degradation **(Reynolds et al., 2007; Woldeyohannis et al., 2024).** Deep tillage has been acknowledged **Peralta et al. (2021)** as an intermediate drainage strategy that lies between surface and subsurface drainage systems. This approach yields advantageous effects on heavy clay soils impacted by salinity, as it facilitates the disruption of dense soil layers, augments water infiltration and movement within the soil, and fosters root development. Incorporating sand into heavy clay soils is an effective method for improving their properties and reducing inherent limitations **(Muzan, 2021).** Variations in sand content significantly affect the hydrological and geotechnical characteristics of clay soils by decreasing plasticity through changes in soil structure and particle arrangement **(Goufi et al., 2022).**

Compost is a substance resembling humus that functions as an organic amendment due to its abundant organic matter content. Throughout the composting process, readily degradable organic materials undergo decomposition, resulting in the formation of less readily degradable compounds. This process facilitates the accumulation of humified material within the biomass, thereby improving its overall quality and nutrient composition **(Fabrizio et al., 2009; Li et al., 2021).** The utilization of organic fertilizers is widely acknowledged for its effectiveness in significantly enhancing crop productivity while favorably influencing the physical, chemical, and biological properties of the soil **(Gautam et al. 2022; Ozlu et al. 2022; Zhang et al., 2023; Khan et al., 2024).** The application of organic amendments is essential for the enhancement of soil properties and fertility **(Khan et al., 2024; Acar et al., 2025),** additionally providing a cost-effective alternative to the reliance on costly chemical fertilizers. Nutrients present in organic fertilizers are released gradually and are retained in the soil for extended periods, thus offering a prolonged residual effect **(Tadesse et al., 2013; Leogrande et al., 2024).** The application of organic amendments has been shown to improve the physical and chemical characteristics of the soil by enhancing water retention capacity, aggregate stability, soil aeration, and increasing saturated hydraulic conductivity **(Ndiaye et al., 2007; Acar et al., 2025),** as well as cation exchange capacity, seed germination, and plant growth **(Loper et al., 2010; Salahin et al., 2011; Aiad et al., 2012; Chekole, 2015; Adugna, 2016; Schoebitz and Vidal, 2016; Kamran et al., 2021; Šimanský et al., 2022)**.

Different management practices are adopted to increase and optimize the maize yields. For example, use of organic manures alongside inorganic fertilizers often lead to increase SOM **(Acar et al., 2025)**, soil structure, water holding capacity and improved nutrient cycling and helps to maintain soil nutrient status, cation exchange capacity and soils biological activity **(Saha et al., 2008; Hepperly et al., 2009; Bhanwaria et al., 2022).** Elevating the rate of compost application improved the overall quality of maize crops **(Abdel-Rahman, 2009; Acar et al., 2025)** and had a substantial effect on the protein content of seeds **(Tayebeh et al., 2010).**

This research aimed to assess the residual influence of plowing at either of two different depths (surface and deep) with compost and/or sand amendments added to a heavy textured soil previously grown with wheat on the physico-chemical properties of this soil and their subsequent effects on maize performance and yield. The amendments were implemented in the initial (winter) season, while the second season comprised maize cultivation without further amendment applications, except for the standard recommended fertilization.

Materials and Methods

1. Experimental site and treatments

Maize was grown in the summer season of 2024 at the farm of Faculty of Agriculture at Moshtohor, Benha University(located at 31° 22' 26" E and 30° 36' 02" N), in the same site and plots used for growing wheat in the previous winter season with no further application of sand or compost treatments. The objective was to find out, to what extent, could the treatments applied in the first season affect some of the soil characteristics which are thought to enhance plant productivity. These treatments were two plowing depths (main plots); surface (0-20cm) and deep (0-40cm), four different rates of sand addition per plot (sub-main plots); S_0 (0%, equating to 0 Mg ha^{-1} sand), the control treatment – S_5 (5% , corresponding to 133.3Mg ha^{-1} sand) – S_{10} (10%, amounting to 266.6 Mg ha^{-1}sand) and S_{15} (15% , equivalent to 400 Mg ha^{-1}sand) , four varying percentage rates of compost application per plot (sub-sub plots); C_0 (0%, amounting to 0 Mg ha^{-1} compost), C_1 (0.5%, translating to 13.3 Mg ha^{-1}compost), C_2 (1%, corresponding to 26.7 Mg ha^{-1} compost) C_3 (2%, equating to 53.3 Mg ha^{-1} compost). After harvesting winter crop in May, the plots were tilled and prepared for maize planting (vr. Hytech 1101). The recommended rates of nitrogen and phosphorus fertilizers i.e.285.6 kg ha^{-1}and 357 kg ha^{-1}, respectively were implemented. Fall armyworm (***Spodoptera frugiperda***) was controlled by six applications of poison bait to prevent infestation, which could otherwise lead to significant yield reduction. Subsequently, the maize crop was harvested after 105 days, while the cobs were fully developed and the grains had reached maturity Plant samples were gathered from each experimental plot. The maize was then harvested after the cobs had dried completely. The physical and chemical properties of the soil prior to the commencement of the experiment are detailed in Table 1.

Table 1. Physical and chemical characteristics of the investigated soil.

Physical Characteristics	**Total sand (%)**	**silt (%)**	**clay (%)**	**Textural class**	**Bulk density bd (Mgm^{-3})**	**Penetration resistance (MPa)**		**Hydraulic conductivity (cm/day)**
	5.44	33.86	60.7	H Cl*	1.3	0.153		0.625
Chemical Characteristics	**pH****	**EC*** (dSm^{-1})**	**SOM (g kg^{-1})**	**$CaCO_3$ (g kg^{-1})**	**CEC (cmol$_c$ kg^{-1})**	**N (mg kg^{-1})**	**P (mg kg^{-1})**	**K (mg kg^{-1})**
	7.7	0.804	9.83	48.8	69.74	65.29	18.06	197.40

* H Cl = Heavy clay**pH was determined in a soil: water suspension prepared at a ratio of 1:2.5 ***EC was determined in a soil paste extract.

2. Soil physical analysis

The resistance of soil penetration was assessed in situ employing a penetrometer, as documented by **Lowery and Morrison (2002),** and the results were categorized in **Table (2)** according to the **Soil Science Division Staff (2017)**. The saturated hydraulic conductivity of the soil (Ks) was determined utilizing undisturbed soil samples in a laboratory setting with a constant water head, following the methodology described by **Klute (1986).** The findings from this measurement were also classified according to the system outlined by **the Soil Science Division Staff (2017),** as presented in **Table (2).**

3. Soil chemical analysis

Soil organic matter was analyzed utilizing the modified Walkley and Black method, whereas the cation exchange capacity was determined through the application of a sodium acetate solution at pH 8.2, in conjunction with the ethanol and ammonium acetate method at pH 7. Available nitrogen was extracted using potassium chloride (KCl), available phosphorus was extracted with sodium bicarbonate ($NaHCO_3$), and available potassium was obtained through ammonium acetate (NH4OAC). All these chemical analytical techniques are documented in the research conducted by **Estefan et al. (2013).**

4. Statistical analysis

The statistical analysis was carried out using two-way ANOVA using SPSS ver. 27. Data were treated as a complete randomization design according to **Steel et al. (1997)**. Multiple comparisons were carried out applying Duncun test and the significant level was set at <0.05.

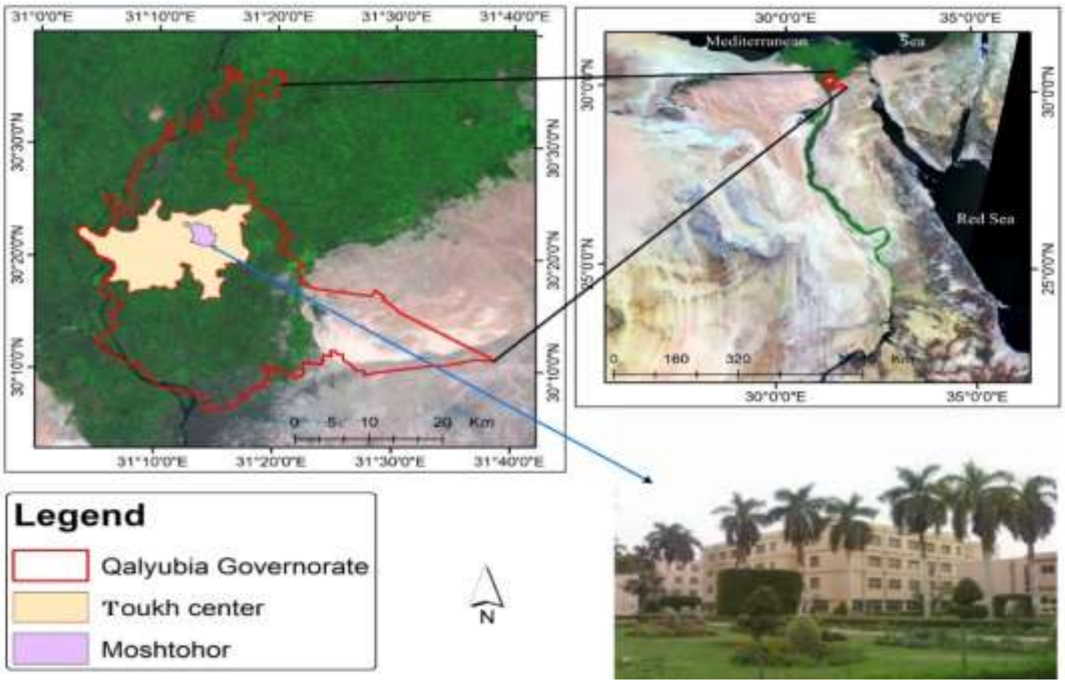


Fig.1. Location map of the studied area

Table 2. Classification of the penetration resistance and hydraulic conductivity**.**

Class	Rating
Penetration resistance (MPa)	
Small	**< 0.1**
Extremely low	< 0.01
Very low	0.01 to < 0.1
Intermediate	**0.1 to < 2**
Low	0.1 to < 1
Moderate	1 to < 2
Large	**> 2**
High	2 to < 4
Very high	4 to < 8
Extremely high	> 8
Hydraulic conductivity (cm/day)	
Very low	<0.0864
Low	0.0864 to < 0.864
Moderately low	0.864 to < 8.64
Moderately high	8.64 to < 86.4
High	86.4 – < 864
Very high	≥864

Results and discussion

1. Residual effect of the previously applied sand and/or compost treatments on soil penetration resistance (PR).

The results presented in **Table 3** indicate that, generally, values of soil penetration resistance (MPa) Significantly decreased as a result of increasing rates of the residual effect of the applied compost as compared to that of the control **(refer to Fig. 2),** however, there was insignificant effect between the two rates 26.7 and 53.3 Mg ha^{-1}of the applied compost. In general, applying sand decreased PR values significantly, however, there were insignificant difference in PR values attained due to the application of sand neither between the rates of 133.3 and 266.6 nor the rates between 266.6 and 400 Mg ha^{-1}. This trend was consistent across both tillage depths. Moreover, Generally, the interaction of these factors appeared at both plowing depths significantly compared with control. The reduction of penetration resistance values can be attributed to the residual effect of sand and compost amendments amelioration of soil structural properties. Sand incorporation reduces inter-particle cohesion among clay particles, enhances macro-porosity, and mitigates surface cracking under desiccation conditions **(Al Badran and Al- Ameri, 2020).** Likewise, compost applications promoted soil aggregation, increased total porosity, and improved structural stability **(Abdulridha and Essa, 2023)**. These results agree with those reported by **Bazzof et al. (1998)** who found that compost addition caused a significant decrease in penetration resistance in the second and third year from addition. The combined effect of sand and compost (400 Mg sand ha^{-1} and 53.3 Mg compost ha^{-1}) significantly decreased soil compaction, thereby facilitating enhanced root penetration, improved nutrient absorption and ultimately increasing crop productivity.

2. Residual effect of the previously applied sand and /or compost on soil hydraulic conductivity (H.C)

The data presented in **Table 3** suggest that the prior application of compost led to a significant increase in H.C values relative to the control group. However, the increases in H.C values resulting from incremental compost application rates from 26.7 to 53.3 Mg ha^{-1} were not statistically significant. Additionally, augmenting the sand application to 400 Mg ha^{-1} resulted in higher H.C values than those achieved with sand applied at rates of 133.3 and 266.6 Mg ha^{-1}, particularly under conditions of surface plowing **(refer to Fig. 2).** Notably, under conditions of deep plowing, the differences in H.C values obtained from sand applications at rates of 266.6 and 400 Mg ha^{-1} were negligible. The overall interaction between compost and sand produced a significant increase in H.C values compared to the control, with the highest values recorded from the combination of compost applied at a rate of 53.3 Mg ha^{-1} with sand applied at a rate of 400 Mg ha^{-1} under surface plowing, and with 133.3 Mg sand per hectare under deep plowing. The increase in H.C values attributed to compost application corresponds with findings from **Acar et al. (2025),** who reported elevated H.C at a compost application rate of 25 Mg ha^{-1} compared to the control. The addition of sand is believed to enhance the proportion of macro-pores, thereby facilitating improved water percolation through the soil. A modest rise in H.C was also noted with increased compost application rates, which may be linked to the initial decomposition of compost that promotes aggregate distribution and enhances water movement; these findings are in accordance with the research conducted by **Ouyang et al. (2013) and Turky et al. (2020).**

Table 3. Residual effect of applied sand and/ or compost on soil penetration resistance (MPa) and hydraulic conductivity (cm/day).

Plowing Depth	Rate of the applied sand (%)	Rate of the applied compost (%)									
		0	PR class	**0.5**	PR class	**1**	PR class	**2**	PR class	**Mean**	**PR class**
		Soil penetration resistance (MPa)									
Surface	**0**	0.060^{a}	VL	0.060^{a}	VL	0.043^{abc}	VL	0.037^{bc}	VL	0.050^{a}	**VL**
	5	0.053^{ab}	VL	0.043^{abc}	VL	0.043^{abc}	VL	0.030^{c}	VL	0.043^{ab}	**VL**
	10	0.043^{abc}	VL	0.037^{bc}	VL	0.037^{b}	VL	0.030^{c}	VL	0.037^{bc}	**VL**
	15	0.037^{bc}	VL	0.037^{bc}	VL	0.030^{c}	VL	0.030^{c}	VL	0.033^{c}	**VL**
	Mean	0.048^{a}	VL	0.044^{a}	VL	0.038^{ab}	VL	0.032^{b}	VL		
Deep	**0**	0.050^{ab}	VL	0.060^{a}	VL	0.043^{abc}	VL	0.053^{ab}	VL	0.052^{a}	**VL**
	5	0.037^{bc}	VL	0.043^{abc}	VL	0.037^{bc}	VL	0.030^{c}	VL	0.037^{b}	**VL**
	10	0.037^{bc}	VL	0.037^{bc}	VL	0.030^{c}	VL	0.030^{c}	VL	0.033^{b}	**VL**
	15	0.043^{abc}	VL	0.043^{abc}	VL	0.030^{c}	VL	0.030^{c}	VL	0.037^{b}	**VL**
	Mean	0.042^{ab}	VL	0.046^{a}	VL	0.035^{b}	VL	0.036^{b}	VL		
		Hydraulic conductivity (cm/day)									
		0	H.C class	**0.5**	H.C class	**1**	H.C class	**2**	H.C class	**Mean**	**H.C class**
Surface	**0**	0.36^{g}	L	0.61^{g}	L	0.43^{g}	L	0.45^{g}	L	0.46^{d}	**L**
	5	1.06^{g}	ML	1.24^{g}	ML	8.52$^{d\text{-}g}$	ML	22.63$^{b\text{-}f}$	MH	8.36^{c}	**ML**
	10	2.08^{g}	ML	6.82^{efg}	ML	26.62^{abc}	MH	29.56^{abc}	MH	16.27^{b}	**MH**
	15	31.11^{ab}	MH	29.88^{ab}	MH	24.62$^{a\text{-}e}$	MH	31.55^{ab}	MH	29.29^{a}	**MH**
	Mean	8.65^{c}	MH	9.64^{bc}	MH	15.05^{ab}	MH	21.05^{a}	MH		
Deep	**0**	0.59^{g}	L	1.16^{g}	ML	2.20^{g}	ML	2.69^{g}	ML	1.66^{c}	**ML**
	5	17.03$^{b\text{-}g}$	MH	13.69$^{b\text{-}g}$	MH	29.83^{ab}	MH	42.48^{a}	MH	25.76^{a}	**MH**
	10	6.36^{f}	ML	11.75$^{c\text{-}g}$	MH	14.58$^{b\text{-}g}$	MH	16.82$^{b\text{-}g}$	MH	12.38^{b}	**MH**
	15	5.68^{f}	ML	14.40$^{b\text{-}g}$	MH	25.18$^{a\text{-}d}$	MH	30.55^{ab}	MH	18.95^{b}	**MH**
	Mean	**7.41^{b}**	**ML**	**10.25^{b}**	**MH**	**17.95^{a}**	**MH**	**23.14^{a}**	**MH**		

Penetration resistance **VL=** Very low **Hydraulic conductivity** **L=** Low **ML=** Moderately low **MH=** Moderately high

Means with the same letters within column are not significantly different.

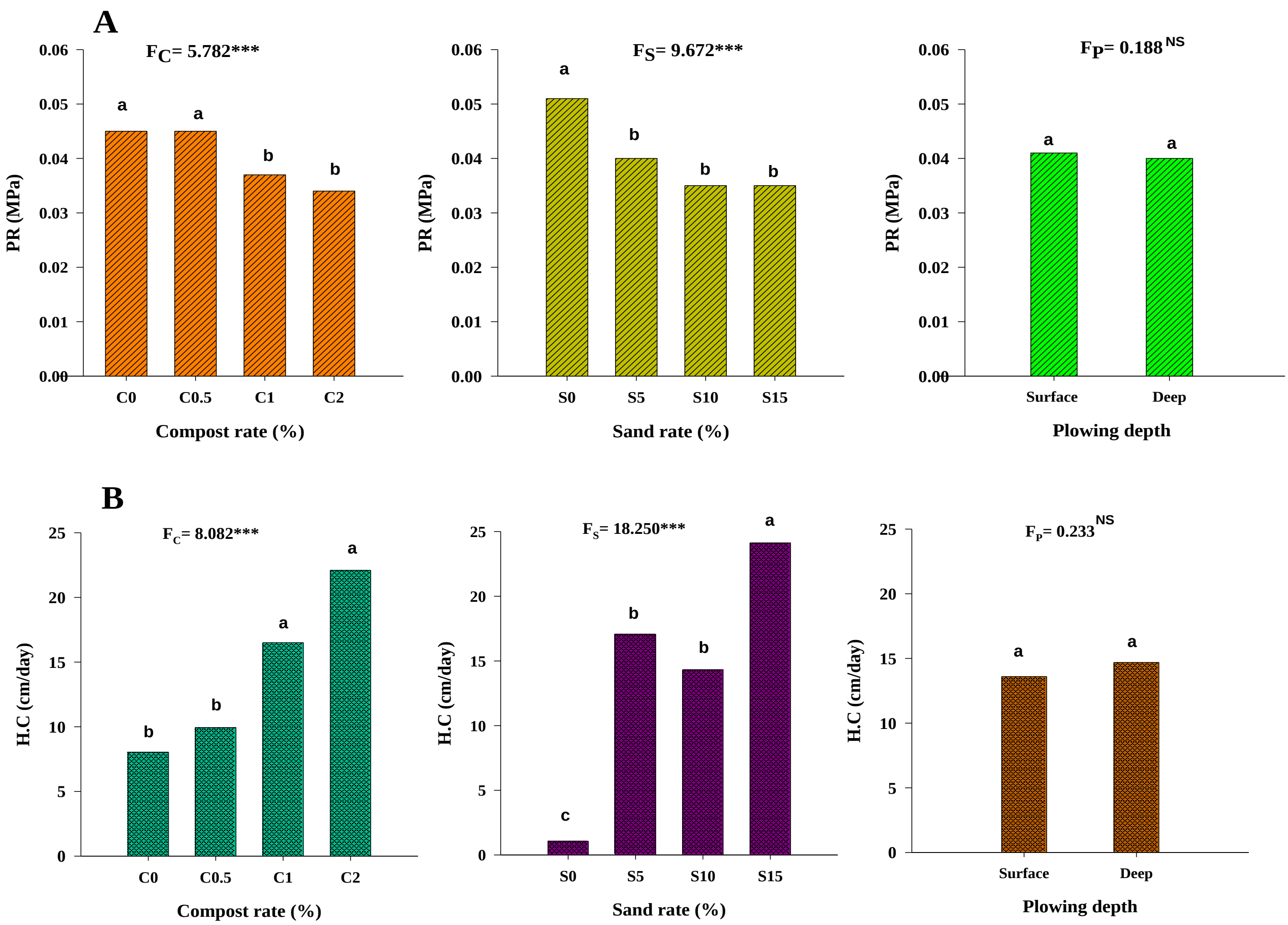


Fig.2. Grand mean of penetration resistance (A) and hydraulic conductivity (B) in soil as affected by treatments. Means with the same letters within column are not significantly different.

3. Residual effect of the previously applied sand and /or compost on soil organic matter (OM)content.

Table 4 illustrates the organic matter contents (g kg⁻¹) recorded during the second season. An increase in the rate of compost application, amounting to 53.3 Mg ha⁻¹, resulted in elevated organic matter values in comparison to those observed in the control group **(see Fig. 3).** The application of compost at rates of 13.3 and 26.7 Mg ha⁻¹ yielded insignificant differences in organic matter under both plowing depths. Notably, organic matter levels due to the incorporation of organic amendments into the soil, which may encourage plants to develop more extensive root systems and release greater quantities of root exudates. These exudates are significant contributors to belowground biomass, consequently enhancing the soil organic matter (SOM) content. The magnitude of this effect is contingent upon several factors, including the chemical composition of the compost and its carbon-to-nitrogen (C/N) ratio **(Mahmoud, 2006; Oshins et al., 2022; Leogrande et al., 2024).** The application of compost has been shown to significantly augment organic matter content, whereas an increase in sand content resulted in a notable decrease, attributable to the expansion of soil bulk volume and the lack of organic matter in sand. Additionally, the combined application of sand and compost was found to enhance organic matter levels **(Yassin et al., 2023; Acar et al., 2025)** when contrasted with the control, across both surface and deep plowing, highlighting the residual effects of the treatments. Moreover, an increase in clay particles and organic matter content within the soil creates favorable conditions for the enhancement of microbiological activities. This improvement facilitates an increased decomposition rate of organic matter as well as the stabilization of soil aggregates.

The presence of organic matter also contributes to the enhancement of soil structure by transforming primary soil particles into more stable micro-aggregates. Furthermore, these micro-aggregates are interconnected by fungal and bacterial residues **(Abdulridha and Essa, 2023).**

4. Residual effect of the previously applied sand and /or compost treatments on soil cation exchange capacity (CEC).

Data illustrated by **Table 4** reveal that values of cation exchange capacity ($cmol_c kg^{-1}$) increased with higher compost application rates, where this increase had a significant effect on soil CEC. The obtained CEC results coincide with those of the OM that were previously mentioned. The CEC values increased significantly due to applying the compost at a rate of 53.3 Mg ha^{-1} **(see Fig. 3),** where as insignificant effect occurred on CEC values owing to applying 26.7 Mg compost ha^{-1}. On the other hand, sand application resulted in significant decreases on CEC values as compared to the control treatment under both plowing depths. However, CEC values increased relying on interaction of compost and sand levels compared to control. This can be attributed mainly to the enhanced decomposition of compost and wheat roots as a result of higher temperatures during the summer season, on one hand, and the more aeration and consequently more available oxygen required for the decomposition of the applied compost on the other hand. The decomposition of the compost led to the formation of several functional groups representing a considered addition to the negative charge of the clay particles **(Abou Hussien et al., 2020).** These results agree with those of **Demelash et al. (2014) and Bhanwaria et al. (2022)** who demonstrated that CEC of the soil increased due to the residual effect of application of 8 Mg compost ha^{-1}. On the other hand, increasing the rates of sand addition caused significant reduction in CEC values, due to the poor organic matter content of sand and its lack of exchange sites compared with the clay or compost. Nevertheless, the interaction between sand and compost resulted in significant increases in CEC compared with the control, under both the surface and deep tillage levels.

5. Residual effect of the previously applied sand and /or compost treatments on soil available N, P and K (/mgkg^{-1}).

5.1. Available Nitrogen (N):

The findings in **Table 5** show that compost application significantly boosted soil nitrogen compared to the control, with peak N values at 26.7 and 53.3 Mg compost ha^{-1} for both plowing depths. This increase is statistically significant, indicating enhanced nitrogen mineralization and microbial activity from organic matter inputs **(Phares and Akaba 2022).** Similar results were found by **Mahmoud (2006),** noting that treated soil had more available N after the second maize harvest than the control. This is likely due to organic N mineralization from compost, boosting microbial activity and releasing plant-available forms like ammonium (NH_4^+) and nitrate (NO_3^-). Conversely, sand addition at 400 Mg ha^{-1} reduced nitrogen availability **(refer to Fig. 4)** compared to lower rates due to sandy particles' low cation exchange capacity, which fails to retain N against leaching. Nonetheless, combining sand and compost enhanced N availability. Additionally, surface plowing resulted in higher N values than deep plowing, likely due to organic residue accumulation and increased microbial activity in the topsoil **(Kramer et al. 2002).**

5.2. Available Phosphorus (P):

The results **(refer to Table 5)** also showed that compost application significantly increased soil P content, especially at the highest rate of 53.3 Mg ha^{-1}. This increase is linked to the decomposition of compost, which releases organic P that becomes more accessible in inorganic forms. However, there was no significant difference in P content between the lower rates of 13.3 and 26.7 Mg compost ha^{-1}**(see Fig. 4).** This phenomenon can be explained by organic acids in compost that solubilize soil phosphate, enhancing bioavailability. **Mahmoud (2006)** reported similar findings where compost increased available P after maize harvesting compared to control. The increase is likely due to the P content in compost and the improved solubility of native soil P. Decomposition of organic residues likely released organic acids aiding P solubilization **(Phares and Akaba 2022).** Phosphate-solubilizing microorganisms in compost may have also helped release plant-available P. Supporting these findings, **Demelash et al. (2014)** noted a 138–173% increase in available P with compost application in residual effects trials. Sand alone showed minimal impact, but higher rates combined with compost improved P availability, possibly from better aeration and reduced clay fixation. Generally, available P differences between surface and deep plowing were minor, with a trend toward higher responses in the surface layer.

Table 4. Residual effect of the applied sand and/or compost treatments on soil organic matter, cation exchange capacity and maize grain yield.

Plowing depth	Rate of the applied sand (%)	Rate of the applied compost (%)				
		0	0.5	1	2	Mean
		Organic matter (gkg^{-1})				
Surface	0	29.90^{b-e}	30.90^{bcd}	33.60^{b}	46.70^{a}	**35.28^{a}**
	5	19.80^{f-i}	19.93^{f-i}	19.17^{ghi}	24.87^{d-h}	**20.94^{c}**
	10	23.83^{d-h}	24.87^{d-h}	27.47^{b-e}	26.53^{b-f}	**25.68^{b}**
	15	13.47^{i}	26.57^{b-f}	26.17^{c-g}	29.37^{b-e}	**23.89^{b}**
	Mean	21.75^{c}	25.57^{b}	26.60^{b}	31.87^{a}	
Deep	0	27.10^{b-f}	29.90^{b-e}	27.33^{b-e}	32.70^{bc}	**29.26^{a}**
	5	18.37^{hi}	28.37^{b-e}	27.57^{b-e}	27.33^{b-e}	**25.41^{b}**
	10	22.63^{e-h}	28.00^{b-e}	29.90^{b-e}	29.67^{bcd}	**27.55^{ab}**
	15	24.23^{d-h}	24.83^{d-h}	24.87^{d-h}	30.43^{bcd}	**26.09^{b}**
	Mean	23.08^{c}	27.78^{b}	27.42^{b}	30.03^{a}	
		Cation exchange capacity (cmol$_c$kg^{-1})				
Surface	0	62.13^{c-g}	63.82^{a-g}	86.74^{ab}	85.14^{abc}	**74.46^{a}**
	5	54.34^{efg}	60.25^{d-g}	70.00^{a-f}	70.87^{a-f}	**63.86^{b}**
	10	58.36^{d-g}	60.77^{d-g}	67.99^{a-g}	64.96^{a-g}	**63.02^{b}**
	15	56.75^{d-g}	66.09^{a-g}	53.54^{efg}	66.42^{a-g}	**60.70^{b}**
	Mean	57.90^{c}	62.73^{bc}	69.57^{ab}	71.85^{a}	
Deep	0	55.53^{efg}	71.07^{a-f}	79.78^{a-d}	86.84^{a}	**73.31^{a}**
	5	59.11^{d-g}	65.59^{a-g}	65.50^{a-g}	67.19^{a-g}	**64.35^{b}**
	10	45.89^{g}	51.93^{efg}	72.01^{a-e}	64.52^{a-g}	**58.59^{bc}**
	15	49.01^{efg}	48.39^{fg}	49.65^{efg}	63.73^{b-g}	**52.69^{c}**
	Mean	52.38^{c}	59.25^{bc}	66.74^{ab}	70.57^{a}	
		Maize grain yield (Mgha^{-1})				
Surface	0	6.47^{h}	8.55^{e-h}	8.39^{e-h}	8.74^{d-h}	**8.04^{a}**
	5	8.72^{d-h}	8.55^{e-h}	8.09^{e-h}	8.18^{e-h}	**8.38^{a}**
	10	6.67^{gh}	6.75^{fgh}	8.97^{d-h}	9.96^{ce}	**8.09^{a}**
	15	7.40^{e-h}	7.52^{e-h}	8.64^{d-h}	8.38^{e-h}	**7.98^{a}**
	Mean	7.31^{b}	7.84^{ab}	8.52^{a}	8.82^{a}	
Deep	0	6.65^{fgh}	9.64^{c-g}	11.65^{bcd}	15.81^{a}	**10.94^{a}**
	5	8.25^{e-h}	9.06^{d-h}	9.28^{d-h}	12.59^{bc}	**9.80^{bc}**
	10	7.93^{e-h}	9.47^{d-h}	9.69^{c-g}	13.58^{ab}	**10.17^{ab}**
	15	7.43^{e-h}	9.18^{d-h}	9.82^{c-h}	9.25^{d-h}	**8.92^{c}**
	Mean	**7.57^{c}**	**9.34^{b}**	**10.11^{b}**	**12.81^{a}**	

Means with the same letters within column are not significantly different.

5.3. Available Potassium (K):

Table (5) and Fig. (4) indicate that the application of compost at a rate of 53.3 Mg ha^{-1} significantly enhanced the potassium content in the soil compared to the control group. This effect can be attributed to the relatively high potassium content present in the compost and the efficient release of potassium during the decomposition of organic matter. These findings are consistent with those reported by **Mahmoud (2006),** who noted an increase in available potassium in the soil treated with compost relative to the control. The observed increase may be due to the potassium released from the applied compost as well as from the native soil reserves **(Phares and Akaba 2022).** Furthermore, the presence of organic colloids within the compost may have contributed to improved potassium retention in the soil by mitigating leaching losses. In general, the addition of sand alone was associated with a decrease in potassium levels compared to the control, primarily due to its limited capability to retain nutrients. There was no significant difference among various sand rates under surface plowing; however, the 400 rate demonstrated a notable advantage over the 133.3 and 266.6 rates under conditions of deep tillage. Nonetheless, when used in conjunction with compost, the sand treatments exhibited enhancements in potassium content in comparison to the control. Most treatments did not reveal significant differences between surface and deep plowing, indicating that potassium tends to migrate within the soil profile to a certain degree.

Table 5. Residual effect of the applied sand and/ or compost treatments on soil available NPK(mgkg^{-1}).

Plowing depth	Rate of the applied sand (%)	Rate of the applied compost (%)				
		0	**0.5**	**1**	**2**	Mean
			Nitrogen (N)			
Surface	**0**	60.67^{e}	112.00^{bc}	84.00^{cde}	86.33^{cde}	**85.75^{b}**
	5	91.00^{cde}	77.00^{cde}	93.33^{cde}	177.33^{a}	**109.67^{a}**
	10	77.00^{cde}	107.33^{bcd}	137.67^{b}	84.00^{cde}	**101.50^{a}**
	15	72.33^{de}	70.00^{de}	93.33^{cde}	81.67^{cde}	**79.33^{b}**
	Mean	75.25^{c}	91.58^{b}	102.08^{ab}	107.33^{a}	
Deep	**0**	81.67^{cde}	98.00^{cde}	70.00^{de}	74.67^{cde}	**81.08^{a}**
	5	65.33^{e}	67.67^{e}	72.33^{de}	88.67^{cde}	**73.50^{ab}**
	10	65.33^{e}	63.00^{e}	63.00^{e}	70.00^{de}	**65.33^{b}**
	15	67.67^{e}	65.33^{e}	81.67^{cde}	70.00^{de}	**71.17^{ab}**
	Mean	70.00^{a}	73.50^{a}	71.75^{a}	75.83^{a}	
			Phosphorus (P)			
Surface	**0**	1.10^{f}	1.64^{def}	1.36^{ef}	2.74^{abc}	**1.71^{b}**
	5	1.34^{ef}	1.38^{ef}	1.69^{def}	1.79^{c}	**1.55^{b}**
	10	1.37^{ef}	1.63^{ef}	1.85^{c-f}	2.22^{b-e}	**1.77^{ab}**
	15	1.54^{ef}	1.79^{c-f}	1.93^{c-f}	3.05^{ab}	**2.08^{a}**
	Mean	1.34^{b}	1.61^{b}	1.70^{b}	2.45^{a}	
Deep	**0**	1.06^{f}	1.30^{ef}	1.41^{ef}	2.65^{a-d}	**1.61^{ab}**
	5	1.14^{f}	1.18^{f}	1.32^{ef}	1.39^{e}	**1.26^{b}**
	10	1.47^{ef}	1.79^{c-f}	1.19^{f}	1.59^{e}	**1.51^{b}**
	15	1.34^{ef}	1.42^{ef}	1.63^{ef}	3.39^{a}	**1.95^{a}**
	Mean	1.26^{b}	1.42^{b}	1.39^{b}	2.26^{a}	
			Potassium (K)			
Surface	**0**	168.13^{cde}	188.23^{b-e}	187.15^{b-e}	238.41^{abc}	**195.48^{a}**
	5	140.46^{de}	153.56^{de}	189.66^{bcd}	190.78^{bcd}	**168.61^{ab}**
	10	149.67^{de}	153.47^{de}	156.93^{de}	161.39^{cde}	**155.37^{b}**
	15	162.42^{cde}	166.08^{cde}	173.18^{b-e}	174.78^{b-e}	**169.11^{ab}**
	Mean	155.17^{b}	165.33^{ab}	176.73^{ab}	191.34^{a}	
Deep	**0**	147.78^{de}	189.09^{bcd}	201.02^{bcd}	248.62^{ab}	**196.63^{a}**
	5	127.65^{de}	158.89^{de}	169.74^{cde}	171.95^{b-e}	**157.06^{bc}**
	10	133.81^{de}	141.38^{de}	145.95^{de}	170.65^{b-e}	**147.95^{c}**
	15	110.27^{e}	136.80^{de}	177.97^{b-e}	290.58^{a}	**178.91^{a}**
	Mean	**129.88^{c}**	**156.54^{bc}**	**173.67^{b}**	**220.45^{a}**	

Means with the same letters within column are not significantly different.

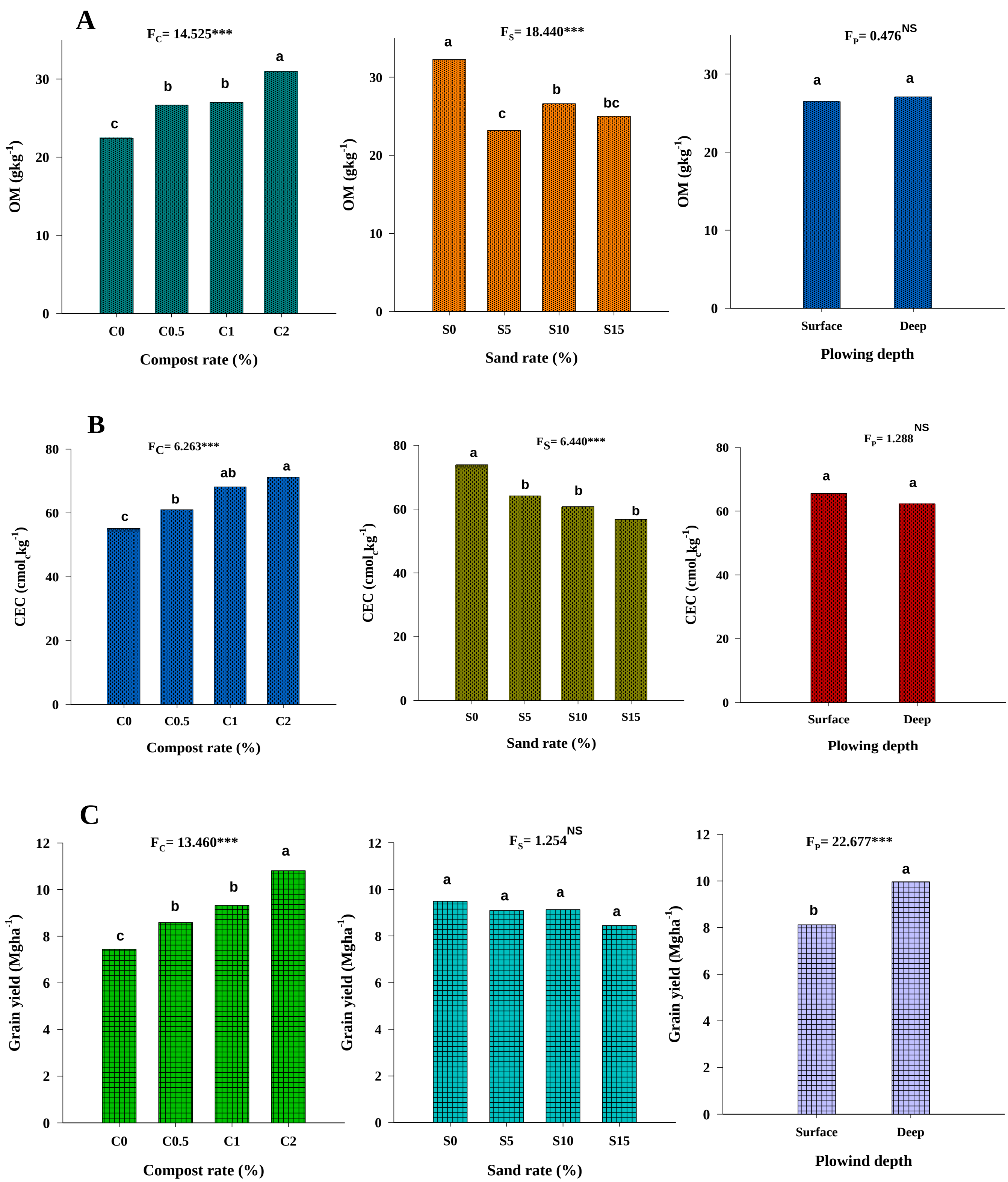
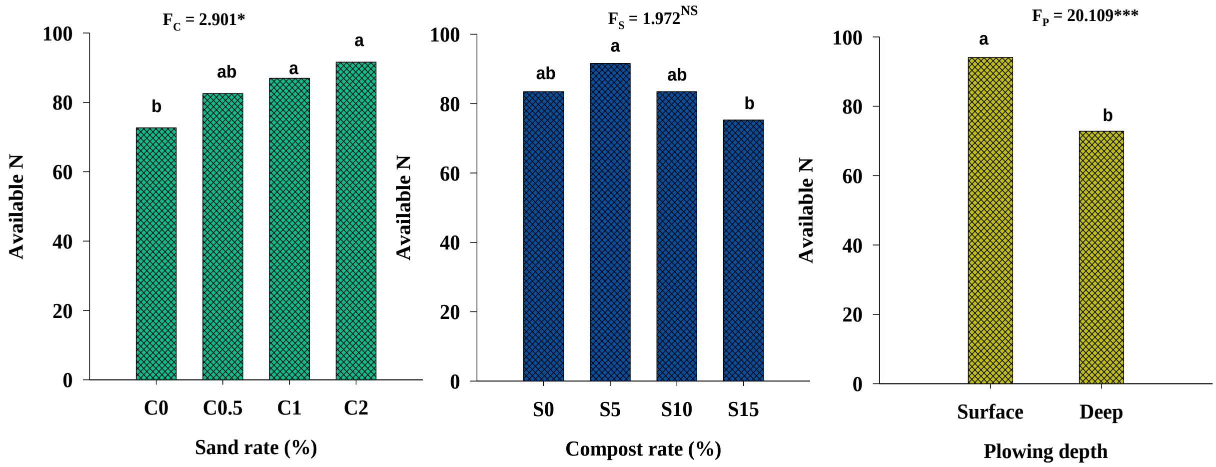


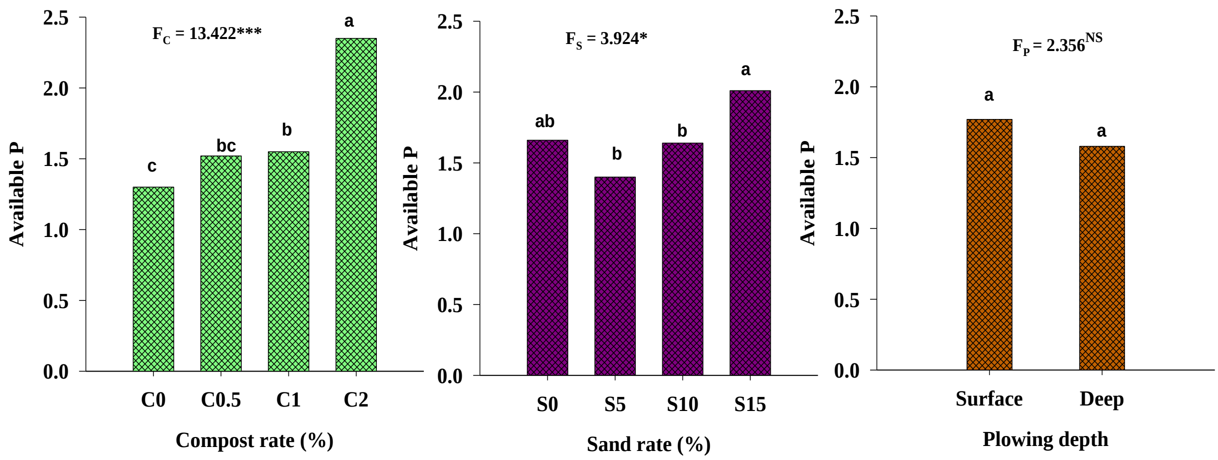
Fig.3.Grand mean of organic matter (A), cation exchange capacity (B) content in soil and maize grain yield (C) as affected by treatments. Means with the same letters within column are not significantly different.

6. Residual effect of the previously applied sand and /or compost treatments on maize grain yield.

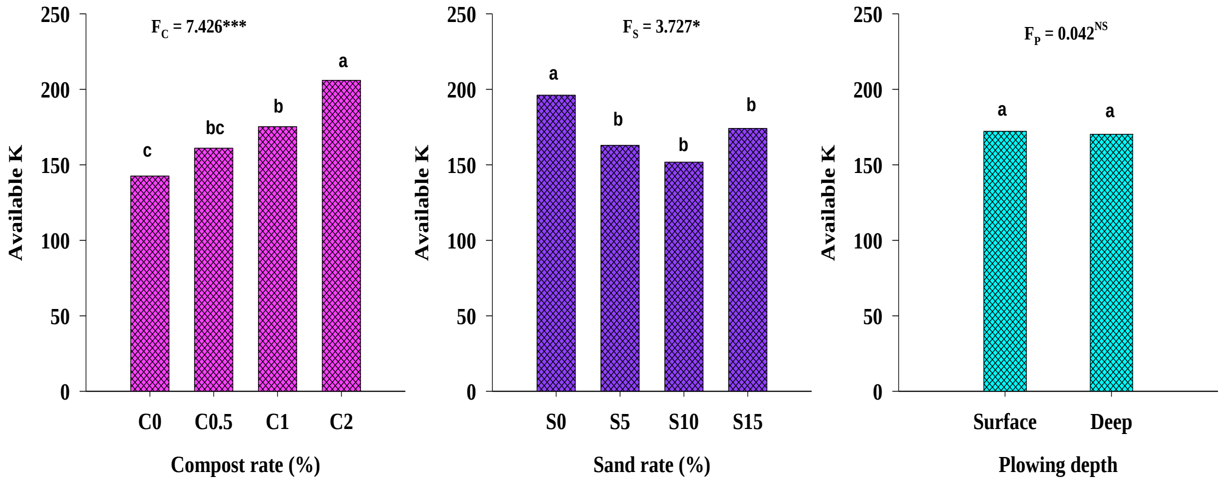
The findings outlined in **Table 4** indicate that the application of compost during the initial season had a notable residual effect in subsequent seasons, as evidenced by a significant increase in maize yield corresponding to higher rates of compost application. A marked enhancement in grain productivity was observed upon the application of compost at a rate of 53.3 Mg ha^{-1}, as shown in **Figure 3**; however, no substantial differences in grain yield were noted with the lower rates of compost application at 13.3 and 26.7 Mg ha^{-1}. This phenomenon can be attributed to the ongoing decomposition of the compost, which released vital nutrients in forms readily available to plants, alongside improvements in soil structure, moisture retention, and nutrient retention capacity. The highest yield values were associated with increased rates of compost application, particularly in conjunction with deep plowing techniques. This suggests that compost serves not only as a nutrient source for crops but also enhances the physical and chemical properties of the soil **(Kravchenko and Thelen, 2007; Saha et al., 2008; Ali, 2011).** Numerous studies have emphasized that the incorporation of organic inputs enhances soil physical properties, thereby promoting root development and improving the uptake of nutrients and **water (Bayu et al., 2006; Abedi et al., 2010; Tilahun-Tadesse et al., 2013; El-Sonbaty et al., 2025).** In general, the addition of sand alone did not consistently yield a positive effect on maize yield; in some instances, it led to slight reductions owing to its limited fertility and deficient cation exchange capacity. Nevertheless, when combined with compost, the addition of sand positively influenced soil aeration in heavy clay soils, subsequently enhancing compost decomposition and nutrient availability for the crops, thus resulting in increased productivity.



(A)



(B)



(C)

Fig.4. Grand mean of available nitrogen (A), phosphorus (B) and potassium (C) as affected by treatments. Means with the same letters within column are not significantly different.

Conclusions

The residual effect of the previously applied compost played a key role in enhancing maize productivity, while sand contributed to improving soil physical properties and reinforcing the effect of compost. The combined application of sand and compost has been proven to be more effective than application of either solely. Moreover, the benefits of these amendments are expected to extend beyond two growing seasons and the continuous application of organic fertilizers enhances soil properties, increases plant resistance to diseases, and improves crop productivity and its quality. Nonetheless, more soil organic matter is required in the sub-soil than at the surface due to most soil physical properties tend to decline with depth, highlighting their potential for sustainable soil improvement and crop production.

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