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Effects of Compost and/or Sand Addition on Improving Properties of a Heavy Textured Soil Under Production of Wheat (*Triticum aestivum* L.)

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WHEAT is regarded as one of the most significant strategic crops in Egypt, serving as a fundamental source of nutrition. Due to the excessive consumption levels relative to domestic production, Egypt has emerged as one of the principal wheat-importing nations in order to bridge the food supply gap. Consequently, it is imperative to prioritize the enhancement of wheat productivity to achieve self-sufficiency and diminish reliance on imports. This study seeks to enhance the physical and chemical characteristics of heavy clay soils through the implementation of specific tillage practices and soil amendments. Both surface and deep tillage methods were employed alongside the addition of sand and compost. The experiment was designed using a randomized complete block design (RCBD), incorporating four rates of sand (0 Mg ha^{-1}, 133.3 Mg ha^{-1}, 266.6 Mg ha^{-1}, and 400 Mg ha^{-1}) and four rates of compost (0 Mg ha^{-1}, 13.3 Mg ha^{-1}, 26.7 Mg ha^{-1}, and 53.3 Mg ha^{-1}). Wheat was sown in the experimental plots to evaluate the impact of these treatments on soil properties and, consequently, on wheat crop productivity. The experiment was conducted during the winter of 2023, and the recommended fertilization rates were implemented. The findings indicated a significant increase in wheat yield corresponding to the elevated rates of sand and compost application across both tillage conditions when compared to the control group. This enhancement can be ascribed to modifications in soil texture, which improved root penetration resistance and elevated water hydraulic conductivity, in addition to reducing the calcium carbonate content. Furthermore, the incorporation of compost effectively augmented the soil's organic matter content, thereby increasing cation exchange capacity (CEC) and facilitating enhanced nutrient uptake, resulting in improved wheat growth and higher productivity. Surface tillage yielded superior results relative to deep tillage, given that wheat is characterized by a shallow root system.

Keywords: Heavy clay soils; Physical and chemical properties; Sandification; Compost; Wheat.

1. Introduction

Wheat ranks among the most vital cereal crops globally, functioning as a fundamental food source and serving as a key component in the manufacture of bread and a variety of other food items (Abd El-Aty et al. 2024; Rashwan et al. 2024). Consequently, it plays an indispensable role in ensuring global food security (Bohra et al., 2024). The efficacy and adaptability of wheat cultivars are significantly shaped by environmental variables and farming methodologies (Muhumed et al., 2024). Critical determinants such as climate conditions, soil fertility, and agricultural management practices markedly influence both the yield and quality of wheat. Given the escalating environmental issues, including climate change and the depletion of water resources (Demissew et al. 2025; Sharma et al., 2025), there is a mounting necessity for sustainable agricultural approaches aimed at improving wheat productivity and optimizing resource utilization.

Heavy clay soils, characterized by their significant clay content, are classified as soils containing 50-80% clay in the top layer. The elevated proportion of clay particles in such soils likely influences various soil properties (Sarkar et al., 2018), leading to soil compaction, which represents a critical issue for heavy clay soils in the Nile Delta of Egypt (Churchman, 2018). This condition may give rise to numerous detrimental effects, including reduced infiltration rates (Alaoui et al., 2018), as well as suboptimal drainage and aeration conditions (Obia et al., 2018). Soil compaction in heavy clay soils exemplifies a physical manifestation of soil degradation that adversely affects porosity, soil structure, water movement, aeration, and microbial activity within the soil (Mueller et al., 2010). Consequently, this degradation may result in diminished crop yields (Nawaz et al., 2013). The process of compaction leads to an increase in bulk density (Layman, 2010), which can further restrict root penetration and development(Frene et al., 2024). In efforts to mitigate soil compaction, tilling and the

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incorporation of compost are frequently employed practices (Kranz et al., 2020). The management of heavy clay soils in the Nile Delta is complicated by the reliance on heavy machinery in agricultural operations (Afifi and El Semary, 2018; Obour and Ugarte 2021; Mondal and Chakraborty, 2023). 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. These enhancements ultimately bolster the potential for increased crop production (Khan et al., 2010; Heckman et al., 2022; Richardville et al., 2022).

The most effective method for enhancing the properties of clay involves the incorporation of sand into heavy clay soils to mitigate their limitations (Muzan, 2021). Variations in the percentage of sand particles within clay soils have been shown to induce modifications in the hydrological properties of these soils (Goufi et al., 2022). The addition of sand can enhance the geotechnical properties of expansive clay soils by reducing their plasticity, which occurs due to alterations in the soil structure and rearrangement of the particles. Compost serves to improve soil quality by enriching it with nutrients, organic matter, enhancing water retention capacity, promoting soil aeration, and increasing cation exchange capacity (Al-Turki, 2010; Yuksel and Kavdir, 2020; Ng et al., 2022; Yassin et al., 2023 Abbas et al., 2024; Farooqi et al., 2024). Compost can be derived from plant materials (Farid et al., 2018) or animal residues (Ravindran et al., 2019). The lignin content present in plant residues is particularly significant, especially in fresh remnants (Almagro et al., 2021), contributing to a substantial reduction in the degradation rate of the material in soil (Kamimura et al., 2019), thus ensuring long-term sustainability and improvements in soil physical characteristics. Conversely, animal residues biodegrade readily (Muchanga et al., 2019) and can enrich soils with essential nutrients (Brust, 2019). It is posited that the growth of plants is a direct consequence of enhancements in both the physical and chemical attributes of the soil. The application of compost leads to a reduction in bulk density and an increase in soil porosity and the rate of infiltration (Amer and Hashem, 2018; Rodriguez et al., 2025). This, in turn, facilitates the leaching of salts from the upper layers of the soil and promotes mole drainage processes (Daur and Tatar, 2013; Amer, 2015; Hamad, 2015; Zia-Ur-Rehman et al., 2016; Amer, 2017; Kima et al., 2017; Saqib et al., 2017; Hafez et al., 2017; Ravinder et al., 2017). Compost is notably rich in essential plant nutrients, including nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S), along with various critical trace elements (Agegnehu et al., 2014; Heckman et al., 2022; Richardville et al., 2022). The application of waste compost results in increased concentrations of available N, P, K, and micronutrients in the soil (Soheil et al., 2012; Gao et al., 2025). Additionally, the incorporation of compost into salt-affected soils promotes the dissolution of calcium carbonate ($CaCO3$) and enhances soluble calcium levels, leading to effective sodium displacement and leaching (Yassin et al., 2023). compost amendments have been shown to elevate cation exchange capacity (CEC) in soils (Agegnehu et al., 2014) owing to the introduction of stabilized organic matter abundant in functional groups (Amer and Hesham, 2018; AbouHussien et al., 2019). Increased rates of compost application are associated with enhancements in soil CEC, a critical indicator of soil quality that signifies a notable improvement in the nutrient exchange capacity of the soils (Abbas et al., 2024; Farooqi et al., 2024). Furthermore, the application of compost has beneficial effects on both the physical and chemical properties of the soil (Lentz and Lehrsch, 2014; Wang et al., 2024; Głab et al., 2025). Collectively, these improved properties contribute to increased productivity of wheat. This research has been undertaken to assess the impact of sand and compost applications on certain physical properties (specifically pore size distribution, soil penetrability, bulk density, and hydraulic conductivity) as well as chemical properties (including organic matter content, calcium carbonate levels, and cation exchange capacity) of heavy clay soils, and to analyze their influence on wheat growth and productivity.

2. Materials and Methods

2.1.The area of study

The experiment was conducted at the Agricultural Experimental Farm of the Faculty of Agriculture at Moshtohor, Benha University, situated at coordinates 31° 22' 26" E and 30° 36' 02" N (refer to Fig. 1). This geographical area is part of the late Pleistocene epoch, characterized by deposits associated with the Neonile, which flowed into Egypt. Additionally, the region encompasses sediments formed during the river's recessional phases. The climate of the area is characterized by hot, arid summers and mild, rainy winters, with an average annual temperature of 20.3 °C. The peak temperature recorded is 36.7 °C in July, whereas the lowest temperature noted is 6.4 °C in January (Abuzaid, 2018). The soil is compacted due to the high clay content, intensive use of heavy agricultural machinery, and insufficient application of organic fertilizers. 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 ($cmol_c\ kg^{-1}$)**		
	7.7	0.804	9.83	48.8	69.74		

* 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

2.2. The experimental layout and treatments

The field experiment was organized utilizing a split-split plot design with three replicates. The primary plots consisted of two distinct tillage systems, while the sub-main plots incorporated four varying percentages of sand application. Furthermore, the sub-sub plots included four different rates of compost application. Each individual plot measured 2 by 3 meters, totaling an area of 6 square meters. The treatments were delineated as follows: the principal treatments involved two plowing depths, namely surface (0-20 cm) and deep (0-40 cm). The sub-main plot treatments included four percentages of sand addition per plot: S0 (0%, equivalent to 0 Mg ha^{-1} of sand), serving as the control treatment; S5 (5%, corresponding to 133.3 Mg ha^{-1} of sand); S10 (10%, equating to 266.6 Mg ha^{-1} of sand); and S15 (15%, amounting to 400 Mg ha^{-1} of sand). The sub-sub plot treatments encompassed four different compost application rates per plot: C0 (0%, or 0 Mg ha^{-1} of compost); C1 (0.5%, translating to 13.3 Mg ha^{-1} of compost); C2 (1%, amounting to 26.7 Mg ha^{-1} of compost); and C3 (2%, corresponding to 53.3 Mg ha^{-1} of compost). The yellow sand was sourced from the sand barn, and the compost was derived from the composting and fermentation of plant and animal wastes over a period of three months. Both sand and compost were incorporated into the soil at a depth of 15 cm. Basic chemical analyses of the sand and compost applied are presented in Table 2. Wheat (*Triticum aestivum*, cultivar Giza 171), classified as a winter crop, was procured from the Central Administration of Seeds Production (CASP) under the Ministry of Agriculture in Egypt, and was sown at a rate of 300 kg ha^{-1} on December 9, 2023, with harvesting occurring 148 days later on May 4, 2024.

Table 2. Some chemical properties of the applied sand and compost.

	pH*	EC** ($dS\ m^{-1}$)	SOM ($g\ kg^{-1}$)	$CaCO_3$ ($g\ kg^{-1}$)	CEC ($cmol_c\ kg^{-1}$)	moisture content (%)	N (%)	P (%)	K (%)
Sand	7.92	0.749	1.02	37.3	21.92	2.8	0.27	0.08	0.05
Compost	7.3	2.51	49.57	31.0	68.52	16.3	1.11	0.75	0.6

*pH of the sand was determined in a sand: water suspension at a ratio of 1:2.5 **EC of the sand was determined in a sand paste extract **EC of the compost and its pH* were determined in a compost: water at a ratio of 1:10

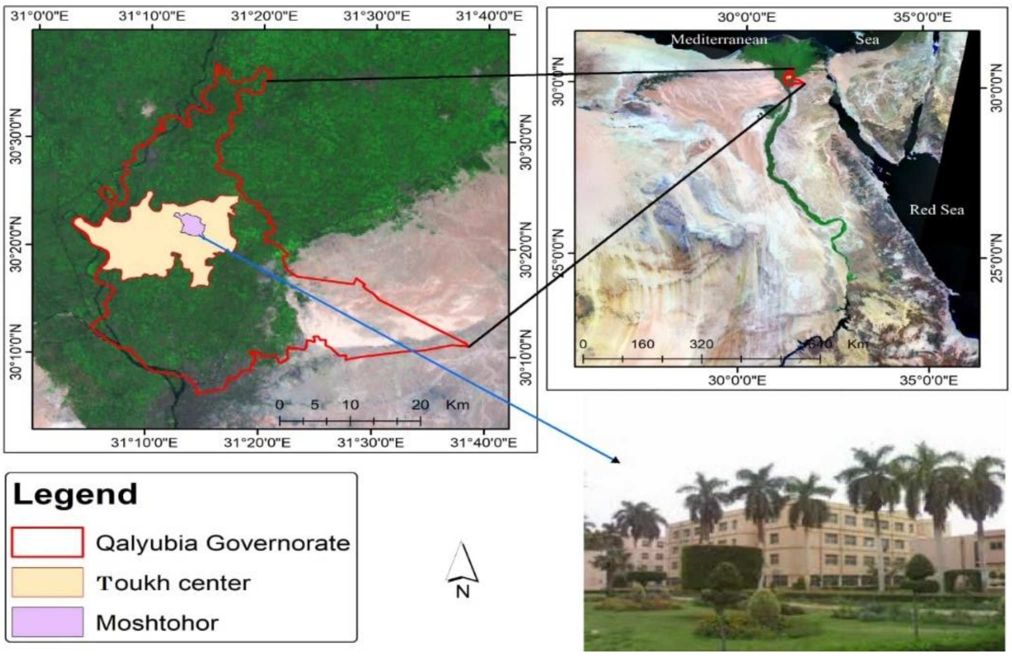

Fig. 1. Location map of the studied area.

2.3. Soil physical and chemical analysis

The particle size distribution of the soil was assessed using the pipette method as outlined by Soil Survey Staff (2014). The bulk density (bd) of the soil was evaluated employing an undisturbed soil sample, in accordance with the procedures established by Soil Survey Staff (2014). The soil's penetration resistance was measured in situ utilizing a penetrometer (Lowery and Morrison, 2002), and the results were categorized based on the criteria established by Soil Science Division Staff (2017), presented in Table 3. Additionally, the saturated hydraulic conductivity (Ks) of the soil was determined in the laboratory through the use of an undisturbed soil sample subjected to a constant water head, following the methodology of Klute (1986). The outcomes were then classified according to the system delineated by Soil Science Division Staff (2017), as shown in Table 3.

Table 3. 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

Soil organic matter was assessed using the modified Walkley and Black method, whereas the quantification of soil calcium carbonate was conducted utilizing a calcimeter. This process involved the destruction of the carbonate by hydrochloric acid, followed by the measurement of the volume of carbon dioxide released under controlled temperature and pressure conditions. The cation exchange capacity was evaluated using a sodium acetate solution at pH 8.2, alongside the ethanol and ammonium acetate method at pH 7. All of these chemical analytical techniques are referenced in the work of Estefan et al. (2013).

2.4. Statistical analyses

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.

2.5. Economic evaluation

In the context of the economic assessment of soil management practices, various parameters and computational methodologies were taken into account. Essential cost elements encompassed farm rent, tillage operations, compost application, sand amendments, seed input, irrigation scheduling, conventional fertilization, pest management, labor requirements across the different treatments, and harvesting processes. The investment ratio was calculated utilizing standardized economic parameters and equations as detailed in the work of Mubashir et al. (2010), while considering total input and output costs.

3. Results

3.1. Effect of sand and / or compost applications on the soil particle size distribution

The sandification technique entails the incorporation of sand into heavy-textured soils to enhance the flow of air and water. Following the wheat harvest, a mechanical analysis of the soil was conducted, and the data presented in Table 4 illustrates the particle size distribution.

Table 4. Effect of sand and /or compost applications on the soil particle size distribution and soil textural class after wheat season.

Plowing depth	Rate of the applied sand (%)	Rate of the applied compost (%)							
		0			Textural Class	0.5			Textural Class
		T. Sand	Silt	Clay		T. Sand	Silt	Clay	
Surface	0	5.92 j	34.87 a	59.21 a	H Cl	8.29 i	33.61 ab	58.10 a	H Cl
	5	14.42 gh	32.71 b-g	52.87 cde	H Cl	15.06 g	32.19 c-g	52.75 de	H Cl
	10	20.83 f	32.19 c-g	46.97 gh	H Cl	21.27 ef	33.07 b-f	45.66 hi	H Cl
	15	26.70 ab	29.32 lm	43.98 jkl	L Cl	27.55 a	29.35 lm	43.10 klm	L Cl
Deep	0	8.96 i	33.07 b-f	57.97 a	H Cl	7.80 i	33.33 b-e	58.87 a	H Cl
	5	12.97 h	32.08 e-h	54.95 b	H Cl	13.78 gh	32.10 d-h	54.12 bcd	H Cl
	10	21.66 def	29.83 j-m	48.50 fg	H Cl	21.35 ef	29.90 j-m	48.76 fg	H Cl
	15	26.45 abc	28.85 m	44.70 ij	L Cl	25.74 bc	29.60 klm	44.66 ijk	L Cl
		1			Textural Class	2			Textural Class
		T. Sand	Silt	Clay		T. Sand	Silt	Clay	
Surface	0	7.94 i	33.59 ab	58.47 a	H Cl	8.44 i	33.49 bc	58.08 a	H Cl
	5	15.25 g	32.36 b-g	52.39 e	H Cl	14.57 g	31.70 gh	53.74 b-e	H Cl
	10	22.92 d	30.85 g-k	46.23 hi	H Cl	22.03 def	31.00 hij	46.97 gh	H Cl
	15	27.79 a	29.62 klm	42.59 lm	L Cl	27.47 a	30.38 i-l	42.15 m	L Cl
Deep	0	8.27 i	33.13 b-f	58.59 a	H Cl	8.86 i	33.51 bcd	57.63 a	H Cl
	5	14.08 gh	31.98 fgh	53.94 b	H Cl	13.61 gh	31.93 fgh	54.46 bc	H Cl
	10	21.48 def	30.30 i-m	48.22 fg	H Cl	21.91 def	30.06 i-m	48.03 fg	H Cl
	15	25.13 c	30.07 i-m	44.80 ij	L Cl	26.37 abc	28.80 m	44.82 ij	L Cl

T. sand= Total sand. H Cl = Heavy clay (>45% clay). L Cl = Light clay (< 45% clay). Means with the same letters within column are not significantely different.

The total values of sand and clay serve as pivotal indicators of both the sandification and composting treatments. The findings indicate that an increase in the percentage of sand added correlates with a modification in soil texture when compared to the control, evidenced by a marked reduction in the percentages of clay and silt. Specifically, the application of 133.3 and 266.6 Mg ha^{-1} of sand, resulted in a decrease in clay content and an increase in sand content by 14.4% and 20.8%, respectively, upon surface plowing, with significant differences noted when juxtaposed with the control. Conversely, the application of 400 Mg ha^{-1} of sand, resulted in a noteworthy enhancement of the sand percentage, thereby altering the soil texture from heavy clay to light clay. Nevertheless, it was observed that compost did not exert a significant effect on soil texture across the four sand treatments.

3.2. Effect of sand and / or compost applications on soil bulk density

The data presented in Figure 2 indicate that the value of soil bulk density experienced a marked decline as a result of compost application, particularly with higher rates of compost utilization. Conversely, the introduction of sand, resulted in a slight increase of approximately 5% in bulk density values following the wheat growing season. This effect stands in contrast to that observed with compost, which led to a 3% reduction in bulk density values, as detailed in Table 5. The positive effect of sand can be attributed to its inherently high bulk density. Consequently, the combined effects of these two agents yield a compensatory influence on both bulk density and porosity (Table 5). Notably, a significant effect is observed with the application of 266.6 Mg ha^{-1} of sand, in conjunction with the absence of compost (0 Mg ha^{-1}) when compared to treatments involving increased amounts of compost. This interaction enhances aeration, soil penetration, hydraulic conductivity, and biological activity.

Table 5. Effect of sand and or compost applications on soil bulk density.

Plowing depth	Rate of the applied sand (%)	Rate of the applied compost (%)			
		0	0.5	1	2
Surface	0	1.24 ef	1.19 fg	1.19 fg	1.16 g
	5	1.28 ce	1.26 ef	1.27 de	1.29 cde
	10	1.45 a	1.39 ab	1.28 cde	1.25 ef
	15	1.28 cde	1.29 cde	1.35 bc	1.23 efg
Deep	0	1.33 b	1.31 cd	1.26 ef	1.23 efg
	5	1.27 de	1.46 a	1.29 cde	1.29 cde
	10	1.28 cde	1.29 cde	1.26 ef	1.25 ef
	15	1.25 ef	1.25 ef	1.24 ef	1.34 bcd

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

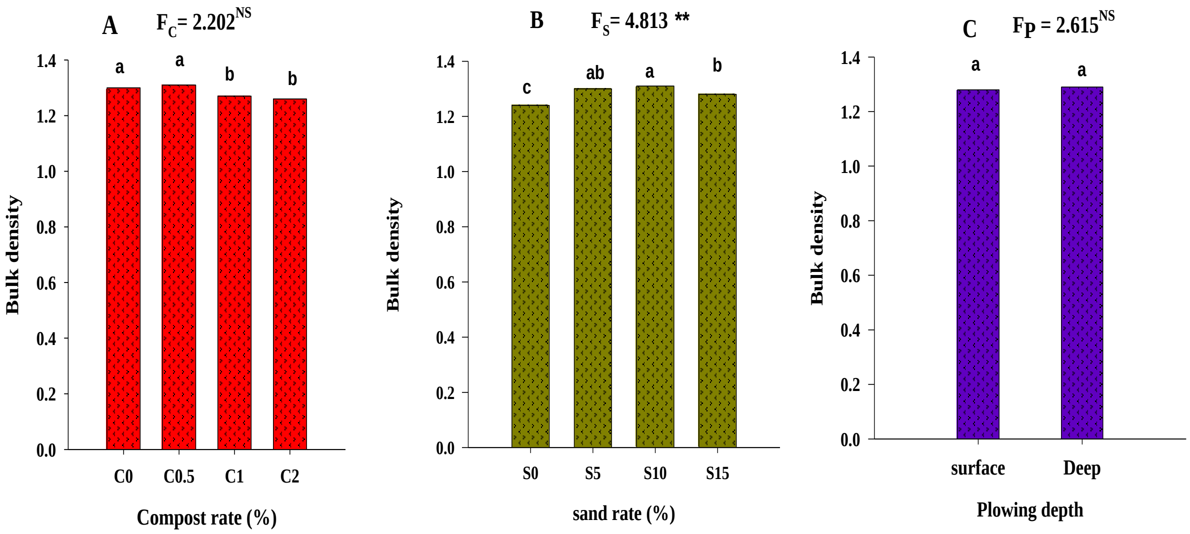

Fig. 2. Grand mean of the bulk density in soil as affected by treatments. Means with the same letters within column are not significantly different.

3.3. Effect of sand and /or compost applications on soil penetration resistance (PR)

Deep plowing consistently resulted in a reduction of the penetration value by 32% when compared to surface plowing. The addition of sand acts as a dispersing agent for clay clusters within the soil, adversely impacting and reducing penetration resistance values in both surface and deep layers (see Fig. 3). Conversely, compost exhibited two contrasting effects; it slightly reduced penetration resistance values by 12% when applied alone, in comparison to the control, and also slightly decreased values when used in conjunction with sand (refer to Table 6). All treatments applied had a favorable impact on soil hardness, indicative of the heavy clayey nature of the experimental soil. This phenomenon contributes to the establishment of a suitable seedbed, facilitating plant penetration into the soil, thereby promoting root elongation and enhancing overall yield.

Table 6. Effect of sand and/ or compost applications 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
soil penetration resistance (MPa)									
Surface	0	0.140 ab	L	0.127 bc	L	0.153 a	L	0.160 a	L
	5	0.137 ab	L	0.110 cd	L	0.103 cd	L	0.103 cd	L
	10	0.087 d-g	VL	0.070 f-i	VL	0.070 f-i	VL	0.077 e-h	VL
	15	0.067 g-j	VL	0.060 hij	VL	0.053 hij	VL	0.047 ij	VL
Deep	0	0.100 de	L	0.097 def	VL	0.097 def	VL	0.093 def	VL
	5	0.077 e-h	VL	0.077 e-h	VL	0.060 hij	VL	0.060 hij	VL
	10	0.060 hij	VL	0.060 hij	VL	0.067 ghj	VL	0.050 ij	VL
	15	0.060 hij	VL	0.043 j	VL	0.050 ij	VL	0.047 ij	VL
Hydraulic conductivity(cm/day)									
		0	H.C class	0.5	H.C class	1	H.C class	2	H.C class
Surface	0	25.27 b-g	MH	27.86 b-g	MH	26.64 b-g	MH	31.77 b-g	MH
	5	40.54 a-e	MH	31.93 b-g	MH	22.24 c-g	MH	32.86 b-g	MH
	10	54.75 ab	MH	49.76 ab	MH	27.07 b-g	MH	42.98 a-d	MH
	15	51.58 abc	MH	37.79 a-f	MH	55.85 ab	MH	42.13 a-e	MH
Deep	0	2.22 g	ML	6.34 fg	ML	5.82 fg	ML	31.58 b-g	MH
	5	44.12 a-d	MH	40.70 a-e	MH	10.67 efg	MH	28.00 b-g	MH
	10	42.09 a-e	MH	36.54 a-f	MH	15.35 d-g	MH	15.57 d-g	MH
	15	56.62 ab	MH	65.63 a	MH	45.02 a-d	MH	33.53 a-g	MH

Soil penetration resistance: L= Low VL =Very low Hydraulic conductivity:MH= Moderately high ML= Moderately low.
Means with the same letters within column are not significantly different.

3.4. Effect of sand and/ or compost applications on saturated hydraulic conductivity (H.C)

Table 6 indicates a rising trend in H.C values due to the doubling of sand addition, which exhibits a more pronounced effect compared to the control (refer to Fig. 3). The variation in H.C values produced by compost differs somewhat from that of sand; specifically, the lower application rates of compost, namely 13.3 and 26.7 Mg ha^{-1}, resulted in reduced H.C values. However, the highest application rate of compost, 53.3 Mg ha^{-1}, led to increased H.C values under both surface and deep plowing conditions, although a rate of 26.7 Mg ha^{-1} of compost, did decrease H.C values when applied under deep plowing. The overall interaction between sand and compost (when comparing S_0C_0 and $S_{15}C_1$) resulted in a doubling of H.C values, underscoring the significance of applying both treatments in tandem. Moreover, similar trends were observed under deep tillage, with a greater disparity noted between S_0C_0 and $S_{15}C_{0.5}$, reaching a tenfold increase.

3.5. Effect of sand and /or compost applications on soil organic matter (OM)content

The data regarding the concentration of organic matter (g kg^{-1}) in soil post-harvest are presented in Table 7, which indicates that both factors investigated had a significant impact on the soil organic matter concentration. Compost application had a pronounced effect on the concentration of soil organic matter, particularly in the context of both surface and deep plowing, as evidenced by a threefold increase resulting from the treatment with 53.3 Mg ha^{-1} of compost. Additionally, the levels of organic matter diminished with the higher rates of sand addition (refer to Fig. 4). The application of sand at a rate of 266.6 Mg ha^{-1} under compost treatments for both surface and deep plowing led to a reduction in organic matter values, while the addition of 133.3 Mg ha^{-1} of sand, resulted in organic matter content under deep plowing that was lower than the corresponding values obtained with surface plowing. Nonetheless, despite the opposing effects of compost and sand additions, there was a notable overall increase in soil organic matter, with the levels of organic matter being greater under deep tillage in comparison to those measured under surface tillage.

3.6. Effect of sand and /or compost applications on soil calcium carbonate ($CaCO_3$)

The findings presented in Table 7 indicate that an increase in sand application rates results in a slight reduction in the concentration of $CaCO_3$ (g kg^{-1}), attributable to the minimal $CaCO_3$ content present in sand. Conversely, the incorporation of compost leads to a significant reduction in $CaCO_3$ levels at a rate of 13.3 Mg ha^{-1} of compost, while no significant changes are observed with other levels of compost application (refer to Fig. 4). When both sand and compost are applied together-each exhibiting contrasting effects—a mutual interaction occurs, resulting in an overall decrease in $CaCO_3$ by 7-8%. This suggests that the compost's impact on reducing $CaCO_3$ surpasses that of sand. These results highlight the importance of judiciously selecting these treatments, leveraging sand as a dispersing agent for clay clods, and compost as an effective agent for the dissolution of $CaCO_3$.

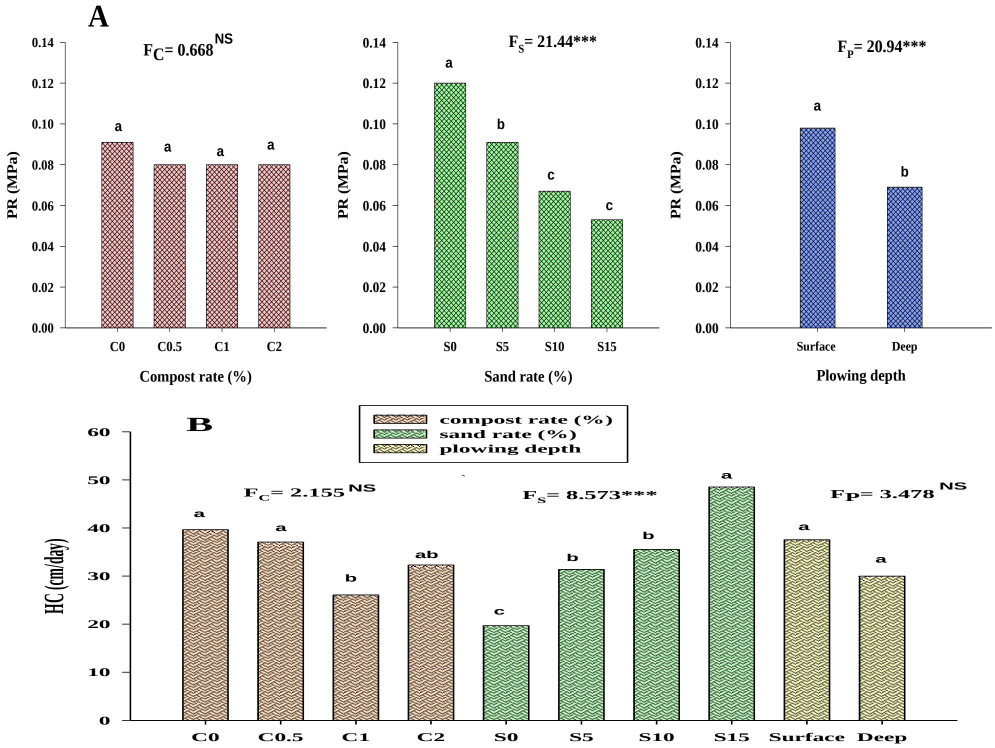

Fig. 3. Grand mean of penetration resistance (A) and hydraulic conductivity (B) in soil as affected by treatments. Means with the same letters within column are not significantly different.

3.7. Effect of sand and/or compost applications on soil cation exchange capacity(CEC)

Table 7 presents the cation exchange capacity (CEC) values, revealing that increments in compost application rates corresponded with a notable rise in CEC figures. Nonetheless, there were no statistically significant differences identified between the compost treatments of 13.3 Mg ha^{-1} and 26.7 Mg ha^{-1}. Conversely, the incorporation of sand resulted in a significant reduction in CEC, with no significant differences observed between the sand application levels of 266.6 Mg ha^{-1} and 400 Mg ha^{-1} (refer to Fig. 4). Furthermore, CEC values exhibited a slight decline under deep plowing conditions when compared to surface plowing, attributable to the larger pore sizes that facilitate enhanced leaching of exchangeable cations..

Table 7. Effect of sand and/or compost applications on soil OM, $CaCO_3$ and CEC content.

Plowing depth	Rate of the applied sand (%)	Rate of the applied compost (%)			
		0	0.5	1	2
OM (gkg^{-1}).					
Surface	0	10.97 c-g	18.80 bd	11.20 c-g	36.73 a
	5	3.00 g	6.27 efg	15.23 b-f	26.93 ab
	10	2.43 g	4.70 fg	6.03 efg	18.37 bcd
	15	4.00 fg	10.97 c-g	13.87 c-g	17.50 b-e
Deep	0	4.27 fg	12.47 c-g	15.47 b-f	19.47 bce
	5	8.93 c-g	4.93 fg	7.63 c-g	5.37 efg
	10	6.70 d-g	3.40 fg	9.17 c-g	5.83 efg
	15	9.63 c-g	9.83 c-g	10.97 c-g	17.70 b-e
$CaCO_3$ (g kg^{-1}).					
Surface	0	49.02 c-f	50.14 b-e	44.57 c-i	51.93 a-d
	5	53.35 abc	47.62 c-g	49.46 b-e	36.55 h-m
	10	41.22 d-l	23.26 n	38.33 f-m	41.17 d-l
	15	61.34 a	35.16 h-m	31.32l mn	34.05 i-n
Deep	0	37.58 g-m	45.44 c-h	60.28 ab	47.77 c-g
	5	36.11 h-m	33.48 j-n	43.97 c-j	33.16 j-n
	10	45.96 c-h	50.26 b-e	37.39 g-m	45.44 c-h
	15	39.71 e-l	27.40 mn	45.88 c-h	32.94 k-n
CEC (cmol$_c$ kg^{-1})					
Surface	0	74.57 abc	78.31 a	70.02 bcd	81.72 a
	5	55.98 e	44.49 f-k	47.09 fgh	66.28 cd
	10	48.53 ef	36.90 jkl	36.68 kl	40.96 f-k
	15	44.22 f-k	40.43 g-l	44.90 f-j	42.09 f-l
Deep	0	65.75 d	80.88 a	67.42 cd	76.86 ab
	5	65.30 d	44.71 f-j	43.84 f-k	47.49 fg
	10	43.41 f-l	45.47 f-i	38.04 i-l	39.75 g-l
	15	37.02 jkl	35.50 l	39.27 h-l	38.92 h-l

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

3.8. Effect of sand and or/ compost applications on wheat grain yield

The findings regarding wheat grain yield, as presented in Table 8, indicate that the application of compost exerts a significant positive influence on wheat yield across the majority of sand levels and both plowing depths. Generally, higher levels of compost led to improved yields, with the most substantial yields recorded at 26.7 and 53.3 Mg ha^{-1}of compost, respectively, contingent upon the specific treatment. Additionally, the results illustrated in Figure 5 reveal that higher sand application rates correspondingly enhanced yield at both depths of plowing. Notably, the combination of an increased sand level of 400 Mg ha^{-1} with compost significantly bolstered yield in most instances, especially at 26.7 Mg ha^{-1} of compost under surface plowing and 53.3 Mg ha^{-1} of compost under deep plowing. The augmentation of wheat yield attributed to the incorporation of compost and sand was notably more significant under surface plowing compared to deep plowing.

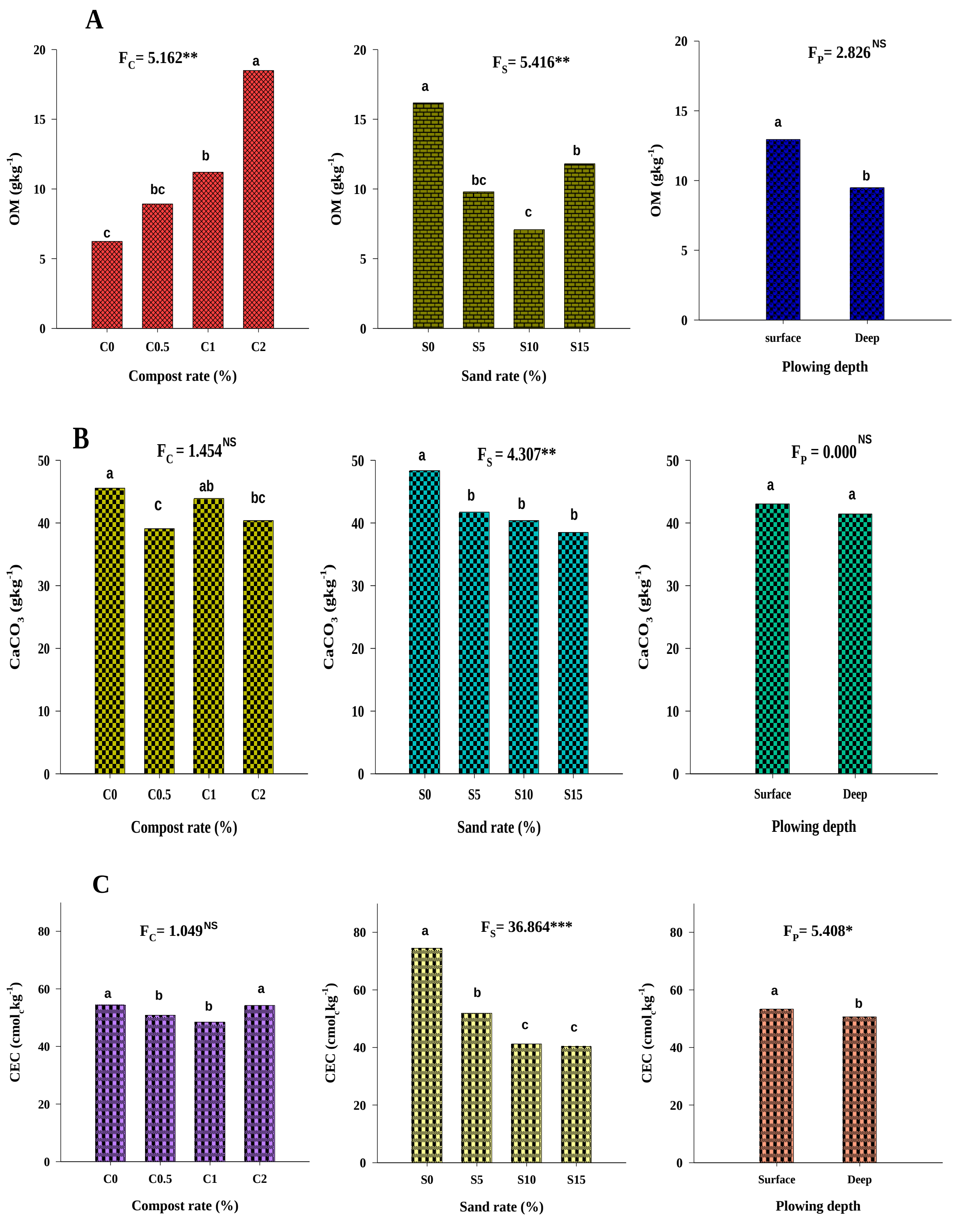

Fig. 4. Grand mean of OM (A), $CaCO_3$ (B) and CEC (C) content in soil as affected by treatments. Means with the same letters within column are not significantly different.

3.9. Effect of sand and/ or compost applications on wheat straw yield

Table 8 demonstrates an increase in straw yield attributed to the application of compost when compared to the control group. The variations between different compost applications are not statistically significant; however, a compost application rate of 26.7 Mg ha^{-1} yields a higher straw output than the other compost treatments. Furthermore, an increase in sand application to 400 Mg ha^{-1} enhances straw yield relative to both the other treatments and the control at the surface plowing stage, though no significant differences are observed in the sand applications during deep plowing (refer to Figure 5). The interaction between these two factors appears to be statistically significant, with the highest yield achieved at a combination of 400 Mg ha^{-1} of sand and 13.3 Mg ha^{-1} of compost under surface plowing conditions. No significant differences were noted with 26.6 Mg ha^{-1} of compost, in conjunction with sand applications of 133.3, 266.6, and 400 Mg ha^{-1}, respectively, as well as with 53.3 Mg ha^{-1} of compost, when paired with 400 Mg ha^{-1} of sand under deep plowing conditions.

Table 8. Effect of sand and /or compost applications on wheat grain and straw yield (Mg ha^{-1}).

Plowing depth	Rate of the applied sand (%)	Rate of the applied compost (%)			
		0	0.5	1	2
wheat grain yield(Mg ha^{-1})					
Surface	**0**	7.95 c-i	7.86 d-i	9.55 a-e	8.11 c-i
	5	6.68 ghi	8.14 c-h	8.54 a-g	8.12 c-i
	10	7.17 g-i	8.39 b-g	8.09 c-i	10.01 abc
	15	7.98 c-i	10.03 a-d	10.69 a	8.07 c-i
Deep	**0**	8.42 b-i	7.41 e-i	5.93 i	7.92 c-i
	5	7.41 e-i	6.12 hi	9.21 a-f	6.59 ghi
	10	7.92 c-i	6.98 ghi	9.72 a-d	6.38 ghi
	15	6.88 ghi	7.26 f-i	9.25 a-f	10.47 ab
wheat straw yield (Mg ha^{-1}).					
Surface	**0**	10.08 a-f	8.89 b-g	10.37 a-e	9.64 b-g
	5	7.56 efg	9.71 b-g	9.50 b-g	8.20 c-g
	10	8.43 b-g	10.06 a-f	9.48 b-g	11.13 a-d
	15	9.40 b-g	12.89 a	11.40 ab	11.04 a-d
Deep	**0**	9.65 b-g	8.92 b-g	6.64 g	10.26 a-f
	5	7.48 ef	7.45 efg	11.11 a-d	7.13 fg
	10	9.80 a-f	8.25 c-g	10.52 a-e	8.04 d-g
	15	7.73 efg	8.60 b-g	10.59 a-e	11.19 abc

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

3.10. Economic evaluation and investment ratio (IR) of soil management practices and their impact on wheat grain and straw productivity

The findings detailed in Table 9 illustrate that both the depth of plowing and the quantities of sand and compost applied significantly affected the total yield, overall outputs, and investment ratio (IR) associated with wheat production. In general, the total input costs demonstrated a consistent increase in correlation with higher levels of sand and compost application, primarily attributable to the escalating costs of these soil amendments. The total inputs varied from 62,370 EGP per hectare in treatment S_0C_0 to 84,170 EGP per hectare in treatment $S_{15}C_2$. Conversely, the total outputs, which encompass both grain and straw yields, exhibited a pronounced positive response to the application of sand and compost, particularly at moderate levels of these amendments. The treatments $S_{15}C_1$ under surface plowing and $S_{15}C_2$ under deep plowing achieved the highest total yields. These results signify that a judicious combination of organic and physical soil amendments contributes to improved soil structure and nutrient availability, thus enhancing the performance of crops. Concerning the investment ratio (IR), values ranged from 2.37 to 3.32 for surface plowing and from 1.93 to 3.21 for deep plowing. The peak IR value of 3.32 was recorded from the treatment designated $S_{15}C_{0.5}$ under surface plowing, with $S_{15}C_1$ following closely at 3.21. This indicates that the combination of a high sand content and a moderate level of compost yields the most advantageous economic return. In the case of deep plowing, the highest IR values were noted in S_0C_0 at 3.21 and $S_{10}C_1$ at 3.04, suggesting that moderate amendment applications can optimize profitability when integrated with deeper tillage practices. However, it is noteworthy that surface plowing consistently demonstrated superior economic efficiency compared to deep plowing. Overall, the results corroborate that the incorporation of sand and compost into heavy-textured soils markedly enhances wheat productivity and resource-use efficiency. Therefore, the combination of surface plowing with a high sand ratio (S_{15}) and a moderate compost level ($C_{0.5}$) is recommended as the most effective and economically viable strategy for improving wheat performance under comparable soil conditions.

Table 9. Economic evaluation and investment ratio (EGP) of soil management practices

Items	Treatments															
	S_0C_0	$S_0C_{0.5}$	S_0C_1	S_0C_2	S_5C_0	$S_5C_{0.5}$	S_5C_1	S_5C_2	$S_{10}C_0$	$S_{10}C_{0.5}$	$S_{10}C_1$	$S_{10}C_2$	$S_{15}C_0$	$S_{15}C_{0.5}$	$S_{15}C_1$	$S_{15}C_2$
Inputs of surface and deep plowing																
Farm rent	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800	14800
Plowing	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470	1470
Sand	-	-	-	-	2600	2600	2600	2600	5200	5200	5200	5200	7800	7800	7800	7800
Compost	-	3500	7000	14000	-	3500	7000	14000	-	3500	7000	14000	-	3500	7000	14000
Seeds	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000
Irrigation	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200	4200
Traditional fertilization	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700	17700
Pesticides	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850	2850
Labors	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750	4750
Harvesting	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600	6600
Total input	62370	65870	69370	76370	64970	68470	71970	78970	67570	71070	74570	81570	70170	73670	77170	84170
Outputs of surface plowing																
Yield	139400	137925	159100	142379	118362	142623	149206	142257	126409	146768	141648	174688	140063	173956	185050	141405
Straw yield	55172	48672	56732	52780	41392	53144	52000	44876	46124	55068	51896	60944	51480	70564	62400	60624
Total outputs	194572	186597	215832	195159	159754	195767	201206	187133	172533	201836	193544	235632	191543	244520	247450	202029
IR	3.12	2.83	3.11	2.56	2.46	2.86	2.80	2.37	2.55	2.84	2.60	2.89	2.73	3.32	3.21	2.40
Outputs of deep plowing																
Yield	147135	130188	105683	139088	130188	108974	160302	116777	138965	123118	168957	113363	121655	127993	161033	181515
Straw yield	52832	48828	36348	56160	40924	40768	60840	39000	53664	45188	57564	43992	42276	47112	57928	61256
Total outputs	199967	179016	142031	195248	171112	149742	221142	155777	192629	168306	226521	157355	163931	175105	218961	242771
IR	3.21	2.72	2.05	2.56	2.63	2.19	3.07	1.97	2.85	2.37	3.04	1.93	2.34	2.38	2.84	2.88

Input = total cost during the season. Output = total gain of grain and straw yield. Investment ratio = Output / Input as described by Awadalla et al., (2002).

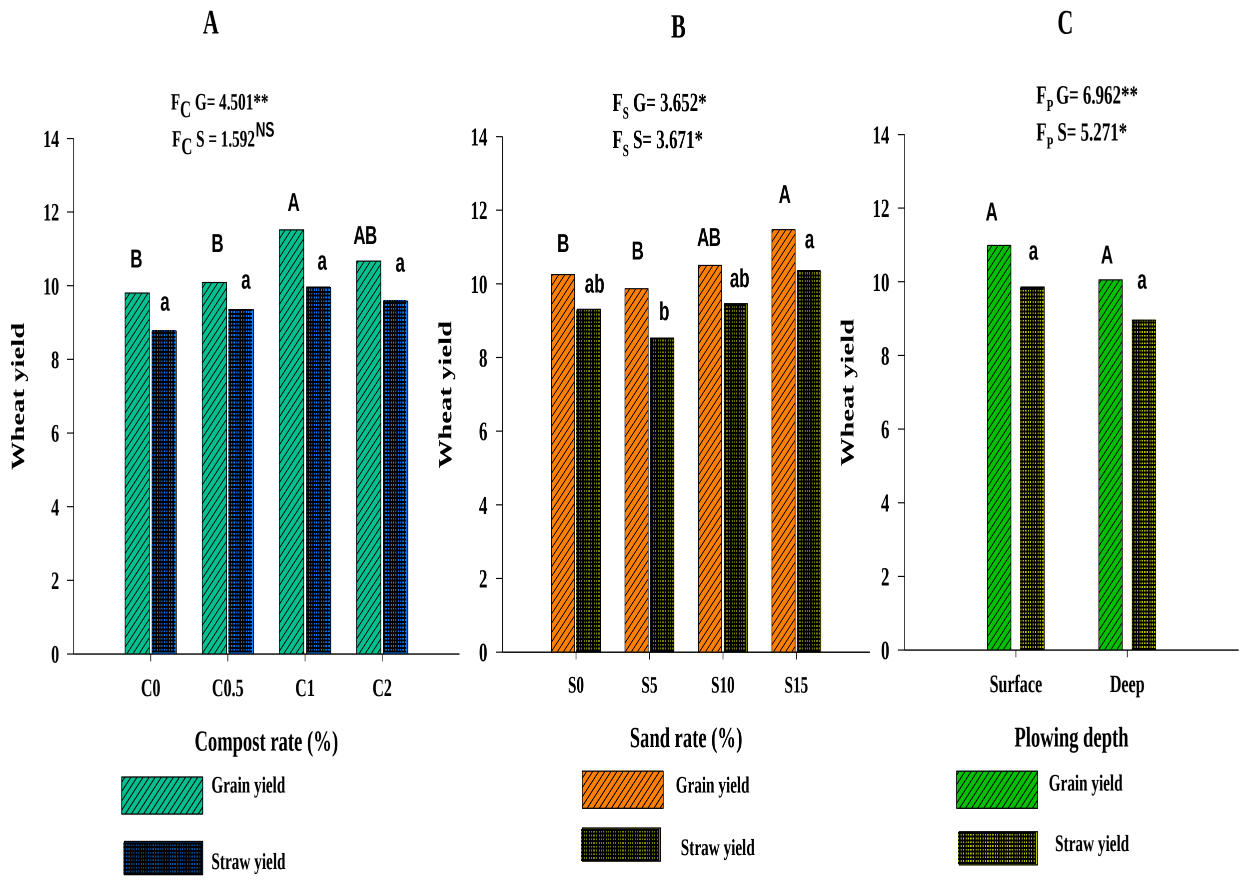

Fig. 5. Grand mean of wheat yield as affected by treatments. Means with the same letters within column are not significantly different.

4. Discussion

4.1. Effect of applied sand and /or compost on soil physical characteristics

The modification in soil texture markedly enhances the physical attributes of the soil. Research findings consistently highlight the substantial influence of sand on particle size distribution and the resultant modifications in the hydrological characteristics of the soil (Muzan, 2021; Goufi et al., 2022; Yassin et al., 2023). The incorporation of compost serves to enhance both the structure and quality of the soil by enriching it with nutrients, increasing organic matter content, improving water retention capacity, enhancing soil aeration, and augmenting cation exchange capacity (Al-Turki, 2010; Yassin et al., 2023). The observed reduction in bulk density attributable to compost application aligns with the findings of Shirani et al. (2002), who indicated that the application of manure significantly reduces bulk density(Neupauer et al., 2023). This suggests that compost and sand exhibit opposing effects, as compost's introduction appears to negatively influence the cohesion among soil components. Conversely, an increase in bulk density may be attributed to the higher quantities of sand introduced into the soil (El-Mosselly, 2013), while decreases in soil bulk density can be ascribed to organic matter possessing a lower density than the mineral content of the soil (Layman, 2010; Kranz et al., 2020). The results indicating a decrease in penetration resistance corroborate the findings of Lampurlanes and Cantero-Martinez (2003) and Abdulridha and Essa (2023), who established that penetration resistance rises with an increase in clay and silt content, while it diminishes with an augmented sand fraction. The addition of sand to soils with heavier textures mitigates penetration resistance by disrupting the cohesive forces among clay particles, promoting the formation of macropores, reducing compaction, and facilitating root development. The enhancement of hydraulic conductivity values through the application of sand is attributed to the increase in macropores, which facilitates improved water percolation within the soil. These observations are consistent with studies by Watabe et al. (2011), Cannavo et al. (2014), and Alnmr and Ray (2024), which noted that hydraulic conductivity initially rises with an increase in sand content, up to approximately 20%. Furthermore, the addition of compost also contributes to a modest increase in hydraulic conductivity due to improved aggregate distribution, where such aggregates create macropores that allow for greater water movement (Aggelides and Londra, 2000; Curtis and Claassen, 2009; Olson et al., 2013). Organisms involved in compost decomposition generate tunnels that enhance soil permeability and water infiltration, which aligns with the findings of Turky et al. (2020), who reported that the increase in hydraulic conductivity of soil can be attributed to soil amendments that reduce bulk density, thereby enhancing soil porosity and improving water infiltration and hydraulic conductivity.

4.2. Effect of applied sand and /or compost on soil chemical characteristics

The incorporation of compost has been found to enhance the organic matter content of soil, attributable to its elevated levels of stable carbon (Bouajila and Sanaa, 2011; Soheil et al., 2012). The presence of organic matter is widely recognized for its role in promoting soil health and enhancing the availability of essential plant nutrients. Numerous contemporary studies emphasize the significance of organic matter in relation to climate change. Additionally, organic waste comprises an array of nutrients that can mitigate the necessity for mineral fertilizers, a consideration of increasing importance given the diminishing availability of mineral fertilizer resources (Adewopo et al., 2014; Lin, 2014; Amundson et al., 2015; Baveye, 2015). Research indicates that the application of compost significantly reduced calcium carbonate ($CaCO_3$) levels at a rate of 13.3 Mg of compost per hectare, with no significant changes observed among other compost applications. This effect can be attributed to the compost's chemical composition, which releases various organic acids capable of dissolving $CaCO_3$ by converting it to soluble calcium bicarbonate ($Ca(HCO_3)_2$). The addition of sand resulted in a slight decrease in $CaCO_3$ concentration due to its inherent $CaCO_3$ content; however, this reduction is associated with the enhancement of soil structure and an increase in water infiltration, which facilitates the transport of calcium bicarbonate away from the root zone.

Furthermore, elevated compost application rates have been shown to enhance cation exchange capacity (CEC). This phenomenon is due to the negatively charged surfaces of clay minerals and various components of soil organic matter, which are capable of adsorbing and retaining positively charged ions (cations) through electrostatic forces. The presence of such negative charges is crucial for nutrient availability to plants, as many essential nutrients exist in the soil in cationic forms, including magnesium (Mg^{2+}), potassium (K^+), calcium (Ca^{2+}), and other elements. Generally, soils exhibiting a higher degree of negative charge are characterized by greater fertility, as they are able to bind and retain larger quantities of cations (Ćirić et al., 2023). Furthermore, long-term studies have demonstrated that compost enhances CEC values, thereby improving soil fertility (Farrell and Jones, 2009; Abdel-Motaleb et al., 2025). In contrast, the application of sand decreased CEC values, attributable to its limited exchange sites, which render it incapable of contributing nutrients to the soil. This increase in soil volume promotes leaching of exchangeable cations, ultimately resulting in lower CEC values.

4.3. Effect of sand and/ or compost applications on wheat grain and straw yield.

The productivity of grain yield is observed to be superior in surface plowing compared to deep plowing. This phenomenon can be explained by the shallow root system of wheat, which primarily occupies the upper layers of soil. The practice of surface plowing, when combined with the application of compost and sand, has resulted in notable enhancements in the physical characteristics of the topsoil, including porosity, aeration, and water retention. Such improvements have facilitated optimal root distribution and have augmented the absorption of nutrients released during the decomposition of compost (Tadesse et al., 2013). These findings are corroborated by Farouk et al. (2024), who demonstrated that the integration of compost was beneficial, leading to a significant increase of 4.1% in grain yield. Consequently, the availability of nutrients and the accessibility of water within the root zone were optimized, thereby resulting in increased productivity under conditions of surface plowing.

An increase in the seeding rate in conjunction with the application of sand and compost has been shown to enhance wheat yield, attributed to the improvements in both physical and chemical properties. This enhancement is a result of increased water infiltration rates, which in turn has elevated the availability of nutrients, leading to a rise in grain yield. These results align with the studies conducted by Shah et al. (2016) and Laghari et al. (2011), who reported an increase in grain yield proportional to the seeding rate, with the peak yield achieved at a seeding rate of 120 kg ha^{-1}. Furthermore, an analysis revealed that the interaction between irrigation levels and seed rate had a significant effect on grain yield, consistent with the findings of Jaime et al. (2004). Similar results were reported by El-Hayes (2023), who noted that increasing the sand application rate to 226.7 Mg ha^{-1}, in conjunction with 45.4 Mg ha^{-1} of compost, led to a grain yield increase to 11.69 Mg ha^{-1}.

The enhancement of straw yield through compost application is corroborated by the research of El-Gamal et al. (2019) and Turky et al. (2020), who found significant increases in straw yields following the application of compost to clay soil. These findings are consistent with those of El-Hayes (2023), who established that applying sand at a rate of 113.4 Mg ha^{-1}, alongside 45.38 $Mgha^{-1}$ of compost, resulted in a straw yield increase to 16.64 Mg ha^{-1}`. Such increases were attributed to improved nutrient availability in clay soil, consequently promoting plant growth and yield. The advantageous effects of compost on wheat yields can be ascribed to its positive influence on root absorption efficiency. Organic amendments play a vital role in plant metabolic processes as they are essential components of nucleic acids, phospholipids, amino acids, and proteins (Magda et al., 2010).

5. Conclusions

The physical and chemical characteristics of heavy-textured soils were significantly improved through the strategic addition of sand and compost treatments. Furthermore, by incorporating 400 Mg ha^{-1} of sand, the soil texture transformed from heavy clay to a much lighter clay composition. As a result, the values for soil penetration resistance decreased considerably, indicating a reduction in compaction. At the same time, the water infiltration rate increased markedly, allowing for better water absorption by the soil. Aeration improved notably, leading to enhanced conditions for root growth. Additionally, there was a substantial decrease in the amount of calcium carbonate present in the soil, while the organic matter content experienced a significant increase. These improvements positively reflected on wheat growth and productivity, culminating in yields that were noticeably higher when compared to the control group. Overall, the incorporation of these treatments proved to be beneficial for enhancing soil health and agricultural output.

Declarations

Ethics approval and consent to participate

Consent for publication: The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

Availability of data and material: Not applicable.

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