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Evaluation of the effects of deep tillage and organic amendments on soil characteristics and sunflower and okra yield across successive seasons

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Abstract

Clay soils in arid and semi-arid environments are highly prone to compaction and hardpan formation, posing significant risks such as desertification and soil degradation, which significantly impede root growth and limit crop productivity. A trial experiment was executed over two consecutive seasons at the College of Agriculture, University of Basrah, to assess the impact of deep tillage and soil organic amendments (cow manure) on the physical properties of the field soil and crop production. In the first season (S_1), the field was divided into two parts, with the local variety of sunflower (Ishaqi1) planted in one part and the other part remaining unplanted. In the second season (S_2), the entire field was planted with the local variety of okra (Petra). Six treatment combinations were involved in this study, obtained from both seasons. The treatment ($FUPS_{1,2}$) significantly decreased the bulk density and soil penetration resistance while increasing the total porosity. FS_1 produced the highest saturated hydraulic conductivity of (0.594 m day^{-1}). The highest sunflower grain yield, 703.33 g m^{-2}, was obtained under the FS_1 treatment, showing a significant increase compared to the UFS_1 treatment, 508.67 g m^{-2}, during the first season. The $FUPS_{1,2}$ and $FPS_{1,2}$ improved okra yield, recording 1044.09 and 979.94 g plant^{-1}, respectively. These results suggest that the combination of deep tillage, manure, and optimal crop rotation improves the soil's physical properties and enhances the productivity of successive crops. This study demonstrates the feasible benefits of combine tillage machine into agricultural cropping systems for growing multiple crops.

Keywords: Bulk density, deep tillage, hydraulic conductivity, manure, penetration resistance, yield

Introduction

Climate change, rising temperatures, land degradation, and soil erosion aggravate desertification and soil quality deterioration, posing crucial environmental risks to agronomic productivity and ecosystem resilience in arid and semi-arid regions. These adverse factors are most evident in clay soils, which tend to form compacted layers or hardpans that severely hinder growth rate and root proliferation. (Jakobs *et al.,* 2019; El Mekkaoui *et al.,* 2023; Zhang *et al.,* 2024). From this perspective, the appraisal of deep tillage and organic amendments on soil profile and yield of the cropping system represented by sunflower and okra across successive seasons proposes a timely and objective avenue to alleviate these threats, through ameliorating soil characteristics and boosting plant yield under progressively stressed agricultural ecosystems.

Tillage process is one of the main agronomic practices for soil preparation and creates appropriate seedbed conditions by conducting some operations such as breaking up and smoothing the soil clumps. These procedures can improve both the bulk density and resistance to penetration of the soil and increase the ability of the soil to retain moisture, as tillage increases the volume of loose soil, thereby improving the physicochemical properties of the soil (Salar *et al.,* 2013; Xue *et al.,* 2018; Zhang *et al.,* 2023).

Hardpan layers are formed due to compaction of heavy agricultural equipment, particularly under high soil moisture; hence, these hard layers increase, especially when tillage treatments are repeated at constant depths. Moreover, the presence of hard layers negatively affects many soil properties and plant growth, such as high bulk density, prevalence of anaerobic conditions, lack of oxygen necessary for root cell division, increased soil resistance to root penetration, and lack of microbial activity in the soil, resulting in poor plant development and stunted root

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systems (Obour and Ugarte, 2021; Liu *et al.,* 2022; Bhatt *et al.,* 2024; Yu *et al*., 2024).

Deep tillage combined with organic amendments plays a crucial role in improving soil physical properties, draining excess water, increasing porosity, enhancing water retention, and increasing salt leaching (Muhsin *et al.,* 2021; Zhong *et al*., 2023). Also, deep tillage and the application of organic fertilizer decrease the bulk density of the soil and increase its overall porosity (Medeiros *et al.,* 2013; Alfaris *et al.,* 2024). Hence, the porosity rate is dependent on the bulk density rate, as porosity increases with decreasing bulk density (Wang *et al.,* 2020; Robinson *et al.,* 2022).

The hydraulic conductivity of the soil increases when deep tillage uses a combined machine for tillage and the addition of organic fertilizer compared with the non-addition of organic fertilizer (Aday *et al.,* 2019). Parvin *et al.* (2021) reported that the addition of organic matter to clay soil forms large clusters that enhance the soil's hydraulic conductivity and physical characteristics. Additionally, the use of agricultural machinery several times in the field reduces the soil porosity and hydraulic conductivity while increasing its density, whereas the infiltration of water inside the soil decreases, which contributes to surface runoff (Ramadhan and Alfaris, 2023). Determining the hydraulic conductivity is important for characterizing its porosity and aggregate stability (Moosavi *et al.,* 2024).

Sunflower (*Helianthus annuus L.*) is a significant global crop cultivated for its oil, which is one of the oils suitable for human nutrition (Adeleke and Babalola, 2020) and is also used in the manufacture of soap and dyes. The environmental conditions for the cultivation of this crop in Iraq are suitable and promise great potential for the expansion of its cultivation, especially if appropriate agricultural processes are followed that can improve soil properties, create suitable conditions for plant growth, and increase yield. The use of organic fertilizer in the soil and following the crop rotation method improved the productivity of sunflower crops, due to its positive role in improving soil properties and providing nutrients (Zhou *et al*., 2022; Zhao *et al*., 2024), and increasing the plowing depth and adding organic fertilizer led to an increase in the disc diameter and thus an increase in the grain yield of sunflowers (Abbas Jebur *et al*., 2024; Mokgolo *et al*., 2024). Okra (*Abelmoschus esculentus L.*) is a significant edible crop cultivated in the tropical and subtropical regions globally. The leaves, buds, blossoms, pods, stalks, and seeds make it a versatile crop (Gemede *et al*., 2015). Several studies have shown increased okra yields with the use of tillage systems and organic fertilization (Ambo Mamai *et al*., 2021; Odey, 2022). Amjad et al. (2024) reported that the tillage system and planting method had a positive effect on increasing okra yields. Shittu (2025) concluded that tillage and the addition of organic matter resulted in the highest yield of okra.

Due to the lack of research papers examining the effects of deep tillage depth and adding organic fertilizer on soil, as well as the production of sunflower and okra crops. This study planned to assess the impact of deep tillage using a combined machine integrated with the soil application of organic fertilizer on the soil properties and production of sunflower and okra crops across two consecutive seasons.

Materials and Methods

Experimental field

This experiment was carried out in a field at the College of Agriculture, University of Basrah, in silty clay soil. This study aimed to investigate the effects of deep tillage and organic fertilizer application on improving soil physical properties. A plow machine and organic amendment (cow manure) were implemented in this study, with planting local varieties of sunflower and okra crops for two consecutive growing seasons. In the first season (S_1), the field was divided into two parts, with the sunflowers planted in one part and the other part remaining unplanted. Also, the experiment included tillage treatment only and tillage along with the addition of organic fertilizer. In the second season (S_2), the entire field was planted with okra. Additional details of the treatment structures are described in the following sections.

A composite sample of the experimental soil was collected before planting at 0-30 cm depth. The soil samples were then air-dried, sieved through a 2 mm sieve, and analyzed to determine the chemical and physical properties of the soil according to the standard methods adopted by Franzmeier (1965), as the distribution of soil particle sizes was estimated to determine the soil texture. The electrical conductivity of the soil extract (1:1) was measured using a WTW EC-Meter, according to Keeney *et al.* (1982). All soil tests were conducted in the laboratories of the Department of Agricultural Machines and the Department of Soil Science and Water Resources/University of Basrah (Table 1). The pH of the soil suspension 1:1 was measured using a pH meter (WTW Model 3110). Soil organic matter was determined as a percentage by estimating the organic carbon using the Walkley and Black method described by Jackson (1958).

Table 1: Pre-planting physico-chemical properties and elemental analysis of soil

Property	Value	Unit
Sand	11	%
Silt	46	%
Clay	43	%
Soil texture	Silty clay	
Organic matter (O.M.)	10.12	g kg^{-1}
Available nitrogen	35.24	mg kg^{-1}
Available phosphorus	10.06	mg kg^{-1}
Available potassium	102	mg kg^{-1}
Total calcium carbonate	2.74	ml kg^{-1}
pH	7.2	
Electrical conductivity (EC)	7.38	dS m^{-1}
Saturated hydraulic conductivity	0.7	m day^{-1}
EC of irrigation water	2.06	dS m^{-1}

Table 2: Chemical properties and elemental analysis of the organic fertilizer

Property	Value	Unit
EC	13.25	dS m^{-1}
pH	6.42	
Organic Carbon	210.69	g kg^{-1}
Total Nitrogen	17.37	g kg^{-1}
C:N Ratio	12.13	
Organic Matter	363.22	g kg^{-1}
Potassium	10.44	g kg^{-1}
Phosphorus	7.16	g kg^{-1}
Density	0.59	Mg m^{-3}

Soil bulk density, porosity, and Penetration resistance

The soil bulk density was estimated using the metal cylinder method (Core Sample) as reported by Blake and Hartge (1986). The actual density was determined using the pycnometer method, and the total porosity of the soil was calculated from the values of bulk density and actual density proposed by Blake (1965). The soil penetration resistance was measured using a digital penetration device (Eijkelkamp, USA).

Saturated hydraulic conductivity (KS)

The values were estimated following the method of a constant column of water, as described by Smith and Mullins (1991), by applying the following equation:

$$K_S = \frac{Q}{At} \cdot \frac{L}{h}$$

K_S = Saturated hydraulic conductivity of the soil (m day^{-1}).

Q = Volume of water passing through soil column (m^3).

L = Length of the soil column (m).

A = Surface area of the soil section (m^2).

t = Time (days).

h = Length of the soil column + height of the water column above the soil column (m).

Organic fertilizer and Tillage procedure

A sample of organic fertilizer (cow manure) was collected from a local smallholder farm, and an analysis was performed to determine the proportions of its components (Table 2). The plow machine comprised a frame fixed on the moldboard plow of two bodies. The moldboard plow depth can be controlled through holes in the plow leg. Furthermore, a subsoiler installed behind each moldboard plow, deeper than the depth of the moldboard plow, was employed to break up the hard soil that lies below the soil plowed. At the end of the frame, a three-excavator plow was fixed to increase fragmentation and mix the manure fertilizer spreading through the mechanism. A hopper was installed on the frame to store and distribute the manure. The hopper was provided with fins installed on a rotating axis that was driven by an independent engine. The manure was scattered in the trench using a subsoiler plow in the furrow created by the moldboard plow. The depths of the subsoiler and moldboard plows were 60 and 30 cm, respectively. The machine was calibrated to spread 45.5 Mg ha^{-1} of cow manure, which is equivalent to 4.55 kg m^{-2}. The rotational speed of the independent engine was 460 rpm, and the speed of the tractor was 0.37 m s^{-1}. Tillage was performed in strips, with a 15×1.20 m. Each part was divided into 1×10 m plots.

Sunflower seeds were planted on 15 August 2022, alternating between the plots (planting one plot and leaving the other for the second season without planting). The crop was irrigated using a drip irrigation system with three drip pipes located in the middle of each plot, separated by a 40 cm space. The distance between the drippers was 25 cm, and the discharge of one dripper was 8 L h^{-1} (Figure 1). The traits were measured at the end of the first season for the fertilized (FS_1) and unfertilized (UFS_1) treatments.

In the second season, the field was plowed with a disc harrow to break up the soil surface and prepare for planting the okra seeds. As in the first season, the field was divided into plots and marked according to the type of plot (planted in the previous season and unplanted), in both cases, with organic fertilizer and without fertilization. Okra seeds were planted on 5 March 2023, six months after the first season planting.

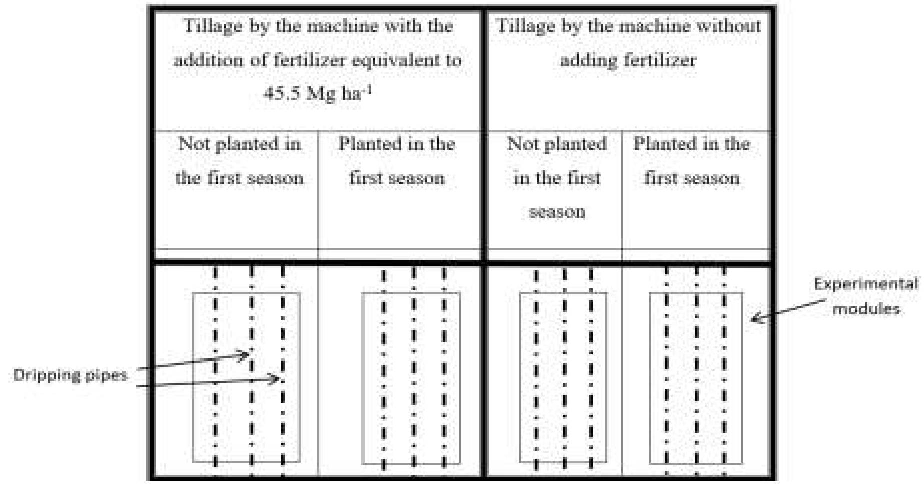

Figure 1: The distribution of treatments in the experimental field

The second season included the following treatments: fertilized and planted in the previous season ($FPS_{1,2}$), fertilized and unplanted in the previous season ($FUPS_{1,2}$), unfertilized and planted in the previous season ($UFPS_{1,2}$), and unfertilized and unplanted in the previous season ($UFUPS_{1,2}$).

The treatments studied were as follows:

First season (S_1):

1- Fertilized (FS_1)

2- Unfertilized (UFS_1)

Second season (S_2):

3- Fertilized unplanted first season ($FUPS_{1,2}$)

4- Fertilized planted first season ($FPS_{1,2}$)

5- Unfertilized unplanted first season ($UFUPS_{1,2}$)

6- Unfertilized planted first season ($UFPS_{1,2}$)

At the end of each growing season, the soil bulk density, total porosity, resistance to penetration, and saturated hydraulic conductivity were measured at depths of d_1=10, d_2=20, d_3=30, d_4=40, and d_5=50 cm.

Sunflower and Okra yield

As the sunflowers reached maturity, random samples were collected from the experimental units of an area of 1 m^2. The seeds were threshed and cleaned of impurities, followed by drying for 24 h in an oven at 65 °C to remove excess moisture, and weighed to calculate the final yield in g m^{-2}. At the end of the season, the yield was collected cumulatively through multiple harvests from randomly selected plants in each experimental unit. The total yield was then measured in g $plant^{-1}$.

Statistical analysis

The field trial was conducted in a factorial arrangement according to a randomized complete block design (RCBD). Differences between the averages of treatments were tested by the LSD test at a significant level of 0.05. GenStat v. 12 software was used for all statistical analyses. All graphs were prepared using Microsoft® Office Excel 365 ProPlus.

Results and Discussion

Bulk density of the soil

The treatments of the study differed significantly ($p \leq 0.05$), as the treatment of UFS1 and UFPS1 recorded the highest bulk density value, reaching 1.23 Mg m^{-3}, followed closely by the treatment of $UFUPS_{1,2}$. Conversely, the $FUPS_{1,2}$ revealed the lowest value of this attribute, measuring 1.104 Mg m^{-3} (Figure 2). These discrepancies can be ascribed to the availability of favorable conditions for the decomposition of organic material, microbial dynamics, and proliferation of plant root systems (Guo *et al.,* 2016; Sun *et al.,* 2023). Figure 3 shows that the bulk density of fertilized soil for the two seasons steadily increased with increasing soil depth, presenting a linear pattern and a strong positive correlation between them. This supports the results of a study on organic additions, which showed that soils treated with organic matter had much lower bulk density in the 0–15 cm layer than controls, especially in the second season. The study ascribed this to the organic residues' slow integration and breakdown, which over time improved the soil's structure (Ray *et al.,* 2025).

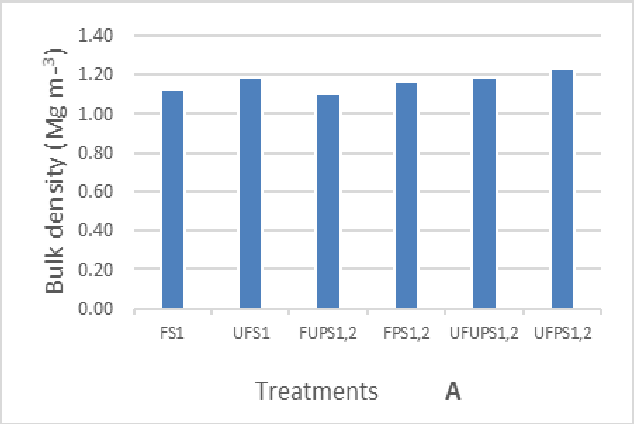

Figure2: Effect of the treatments on soil bulk density for the two seasons (Mg m^{-3})

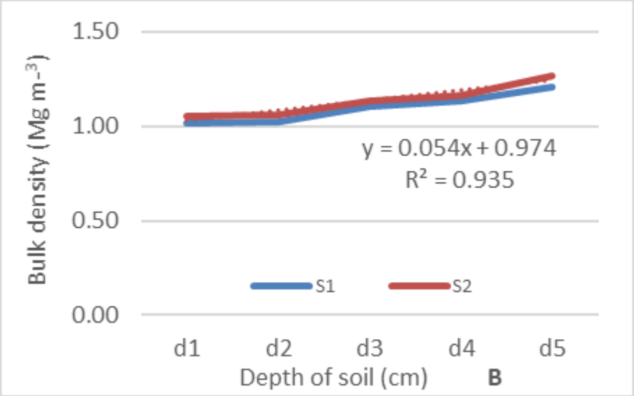

Figure 3: Relationship between the depth of soil and bulk density of fertilized soil for two seasons

Total porosity

The treatments showed significant differences in the overall porosity ($p \leq 0.05$), which amounted to 57.87% and 57.10% for FUPS$_{1,2}$ and FPS$_{1,2}$, respectively (Figure 4). The treatment of UFPS$_{1,2}$ recorded the lowest porosity of 53.01%. Tillage incorporated with organic fertilizer binds soil grains and builds small aggregates, resulting in expanded soil porosity due to a decline in bulk density (Evanylo *et al.,* 2008). The FUPS$_{1,2}$ treatment exhibited greater total porosity than FPS$_{1,2}$ at the end of the second growing season.

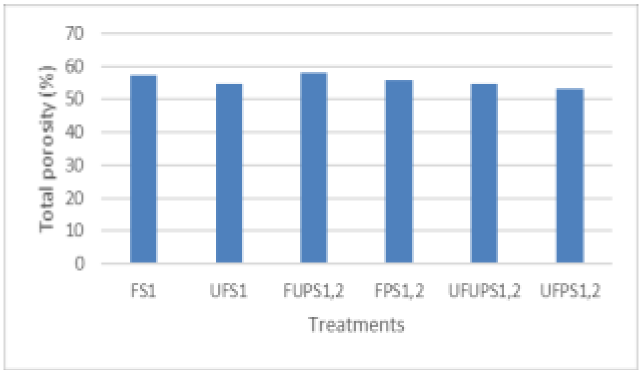

Figure 4: Effect of different treatments on the total soil porosity for the two seasons

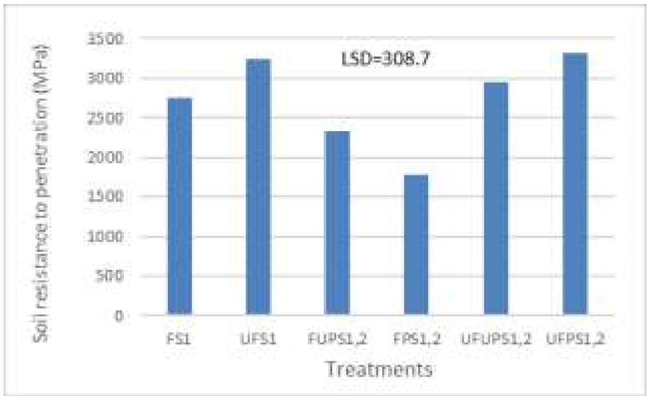

Figure 5: Effect of different treatments on soil resistance to penetration (MPa)

Soil penetration resistance

The UFUPS$_{1,2}$ planted in the second season recorded the highest soil penetration resistance, followed by FPS$_{1,2}$, without a significant difference between them at 3315.79 and 3247.37 MPa, respectively (Figure 5). In contrast, FUPS$_{1,2}$ planted in the second season displayed a minimum penetration resistance of 1778.95 MPa. However, amendments of organic fertilizer and its subsequent decomposition preserve soil texture from compaction and hardening. This process results in the accumulation of soil particles into small groups or clusters, thereby reducing the cone obstruction force index from the soil penetration (Xin *et al.,* 2016).

The relationship between soil bulk density and Soil penetration

The experiment results showed varying relationships between soil bulk density and penetration resistance of soil over the two seasons. In particular, the treatment (FS$_1$) in the first season showed an irregular pattern with no clear correlation between bulk density and soil resistance to penetration (Figure 6, S$_1$). Nonetheless, the treatment (FS$_2$) in the second season showed a strong quadratic relationship (second degree) between both density and soil resistance to penetration (Figure 6, S$_2$). The high correlation observed may be due to the regularity of the soil structure as a result of deep tillage and subsequent decomposition of organic fertilizer, which likely reduced the compression of the soil below 30 cm, as well as enhanced the soil's water-holding capacity. These soil modifications are positive indicators of improved soil physical properties and of maintaining fragile soil around the root zone.

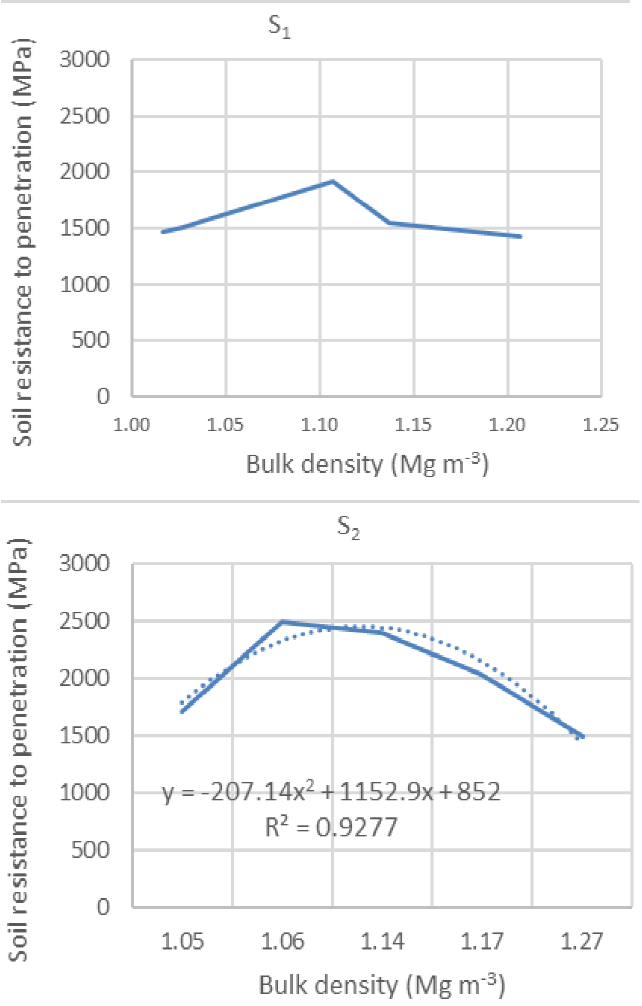

Figure 6: The correlation between bulk density and soil resistance to penetration of fertilized soil, first and second season denoted by S$_1$ and S$_2$, respectively

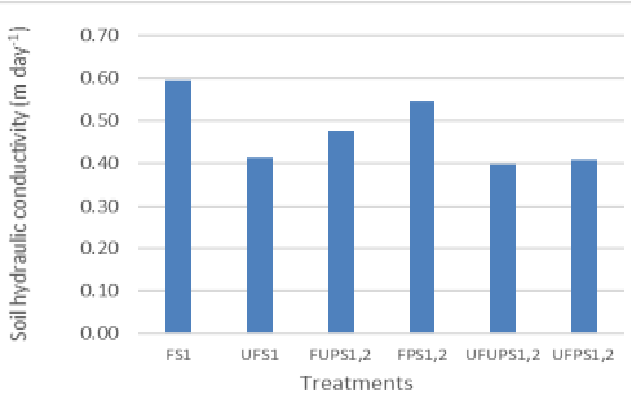

Figure 7: Effect of the treatment on soil hydraulic conductivity (m day^{-1})

Soil hydraulic conductivity

There were significant differences between the treatments in the experiment ($p \leq 0.05$) in terms of soil hydraulic conductivity (Ks) (Figure 7). The FS$_1$ recorded the highest Ks of (0.594 m day^{-1}), followed by FPS$_{1,2}$ with a value of 0.542 m day^{-1}, while the values of Ks were 0.397, 0.406, and 0.411 m day^{-1} for UFUPS$_{1,2}$, UFPS$_{1,2}$, and UFS$_1$, respectively. As the soil structure improved, its density decreased, resulting in increased soil porosity. This, in turn, enhanced the interstitial spaces as well as the regularity of capillary channels that facilitate the downward movement of water. Accordingly, the Ks of the soil improved, leading to a higher rate of water passing through the soil cross-section per unit of time (Shi *et al.,* 2016).

At the end of the first season, bulk density increased due to an increase in soil depth; the treatments Ks at depths of less than 30 cm had approximately similar values. Nevertheless, the K$_S$ values increased significantly at depths greater than 40 cm (Figure 8, S$_1$). This increase can be associated with the impact of deep tillage and the presence of organic matter at depths near the surface, which hinders the movement of water and avoids compaction in the underlying soil layers. Despite the increase in bulk density, the hydraulic conductivity increased (Aday *et al.,* 2019).

In the second season, there was a strong correlation of a second-order relationship between the bulk density and Ks (Figure 8, S$_2$), which decreased after a depth of 30 cm. In contrast, shallow depths indicated that Ks took the same path in the first season, with an increase in the values of Ks despite the rise in bulk density. The reason behind this may be attributed to the significant decomposition of organic matter while comparing the second season to the first, which resulted in a reduction in Ks at the surface depths.

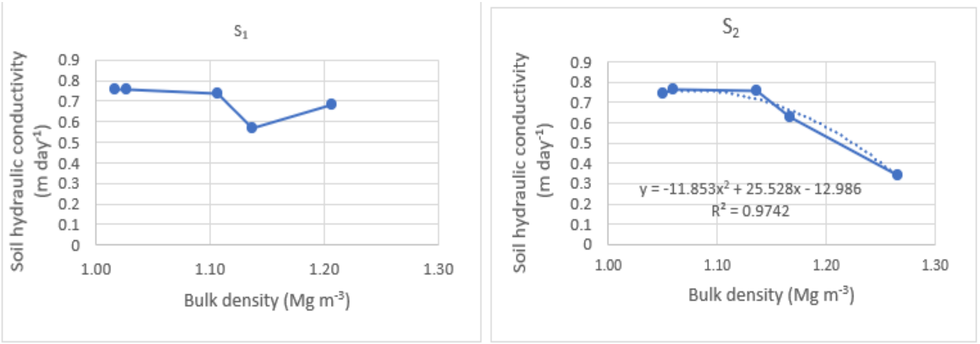

Figure 8: The correlation between bulk density and soil hydraulic conductivity of the fertilized soil, first and second season denoted by S_1 and S_2, respectively.

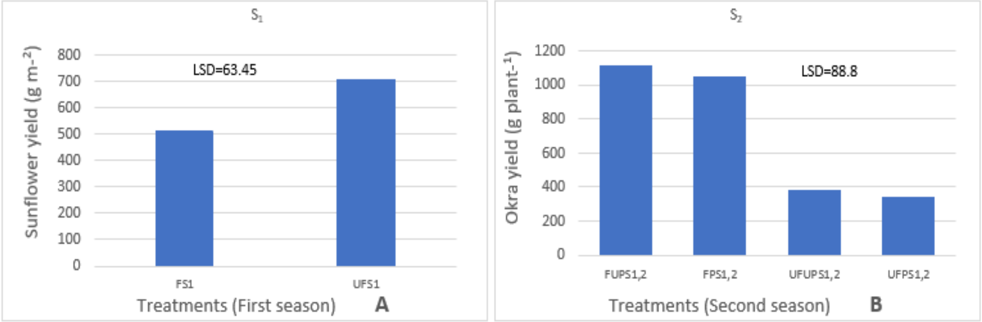

Figure 9: Effect of fertilized and unfertilized treatments on sunflower yield (g m^{-2}) A, and okra yield (g $plant^{-1}$) B.

Yield of the first season

The fertilized (FS_1) soil significantly outperformed the unfertilized (UFS_1) treatment ($p \leq 0.05$) for the first season in terms of sunflower yield (Figure 9, A). The total yield of the two treatments was 703.33 and 508.67 g m^{-2}, respectively. The improvement in sunflower yield can be ascribed to several factors that provide favorable growth conditions. Some of these include the availability of appropriate environmental conditions, decomposition of organic matter, breakdown of compacted soil layers, and improvements in the physical properties of the soil. Such factors helped in the growth and spread of the root group system, which stimulated the vegetative growth of the plant and increased nutrient uptake, contributing to a higher grain yield (Bu *et al.,* 2023).

Yield of the second season

In the second season, the $FUPS_{1,2}$ and $FPS_{1,2}$ treatments apparently but not statistically achieved the highest yield of okra (1044.09 and 979.94 g $plant^{-1}$), respectively (Figure 9, B), while the lowest rate of okra yield was 270.63 and 310.62 g $plant^{-1}$ in the $UFPS_{1,2}$ and $UFUPS_{1,2}$ treatments, respectively.

Conclusion

The use of a soil tillage machine, incorporated with the application of soil organic fertilizer, resulted in a significant enhancement of the soil properties, which were then maintained over two consecutive growing seasons. This improvement led to increased yields of sunflower and okra crops. For the second season, planting with the no-till method, where only the soil surface is disturbed to prepare seed beds, reduced the damaging effects of repeated tillage and minimized soil compaction caused by agricultural tractors. Furthermore, utilizing the tillage machine for the second season not only reduced the effort and time but also decreased costs, as it required only disc harrows to disturb the surface layers. These results suggest that the combination of deep tillage, targeted fertilization, and optimal crop succession can significantly boost the soil's physical properties and enhance the productivity of successive crops. This study demonstrates the feasible benefits of integrating tillage machines into agricultural cropping systems for growing multiple crops.

Data availability

The dataset can be requested by email if needed.

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