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Impact of Tillage Practices and Soil Amendments on Soil Strength and Yield of Okra (*Abelmoschus esculentus* (L.) Moench) in Nigeria

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Abstract

The combined effects of tillage, soil strength and organic soil amendment influence crop yield. The study evaluated the effects of tillage and different soil amendment sources on soil strength, moisture content and okra yield in the Osun State University Teaching and Research Farm. There were 12 treatment combinations: i. TRP (Plough + Poultry dung) ii. SPP (Spray + Poultry dung) iii. TCD (Plough + Cow dung) iv. TRF (Plough + NPK 15 15 15) v. SPC (Spray + Cow dung) vi. SLC. (Slash + Cow dung) vii. SPF (Spray + NPK 15 15 15) viii. TRO (Plough Only) ix. SLP (Slash + Poultry dung) x. SLF (Slash + NPK 15 15 15) xi. SPO (Spray Only) xii SLO (Slash Only). Results revealed that soil strength averaged across TRF (1.91 MPa), SLC (1.7 MPa), SPP (1.53 MPa) and TCD (1.59 MPa) in the year 2021 has been reduced to TRF (1.1 MPa), SLC (1.19 MPa), SPP (1.25 MPa) and TCD (1.25 MPa) in the year 2022, approximately 42.41 %, 30 %, 22.88 % and 21.36 % respectively. Experimental plots with TRP (2.86 t ha^{-1}) and SPP (1.88 t ha^{-1}) had the highest okra yield and were significantly different from TRO (0.60 t ha^{-1}), SPO (0.31 tons ha^{-1}), and SLO (0.25 t ha^{-1}) in the year 2022. Organic soil amendment practices can lower soil strength, enhance moisture storage and promote good root growth characteristics.

Keywords: Environment; Physical degradation; Experimental plot; Soil moisture; *Abelmoschus esculentus*

Introduction

Climate change, decline in soil fertility, and food insecurity are just a few of the challenges facing sub-Saharan Africa (SSA), where 23 % of the population is undernourished and over 35 million people are expected to be food insecure by 2050 (Altierii et al. 2015). According to Altierii et al. (2015), implementing farming methods that are resistant to climate change and extreme weather conditions is a crucial tactic for dealing with these issues. Good land management methods and organic matter (OM) content contribute positively to climate resilient agricultural systems (Lal 2011, Cardoso et al. 2013). The physical characteristics of soils, such as their strength and moisture content, under various land preparation systems can therefore be understood to get insight into how resilient these systems are to shifting environmental conditions.

As a dependable source of vitamins, minerals, and revenue, okra is a vegetable crop that is crucial to human nutrition and health management (Keatinge et al. 2010). Fresh okra fruit is a wonderful source of vitamins, minerals, and plant protein. It has 20% protein and edible oil, and its mucilage is used medicinally. It is thought to be a low-calorie, fat-free powerhouse of important nutrients (Sharma and Prasad 2010) and also has strong antioxidant qualities, primarily because of its high carotenoids and flavonoids content (Gemede et al. 2014). Okra also has anti-diabetic, anti-hyperlipidemic, anti-microbial, anti-ulcer, and anti-neurodegenerative capabilities (Kamalesh et al. 2014). Okra has about the same amount of essential and non-essential amino acids as soybeans.

Continuous land use and high economic growth threaten resources sustainability and agricultural land in developing countries (Shittu et al. 2023). Conservation agriculture (CA) and other sustainable land management techniques that can enhance the physical characteristics of soil are promoted as ways to protect agricultural production from climatic stress. Under climate stress, CA is thought to produce more okra than conventional agricultural practices (CAP) primarily because of improvements in soil penetration resistance that leads to increased soil water retention and nutrient availability for plant (Steward et al. 2019).

As reported by Nkakini et al. (2008), the preparation of land for crop development and growth is crucial for soil productivity because it produces the ideal soil conditions for crop growth. Infiltration, nutrient availability, soil erosion, root system growth, and soil aeration are all significantly affected by tillage techniques. According to Rashidi and Keshavazpour (2007), one of the key elements influencing crop output and soil physical characteristics is land preparation. Bulk density and soil penetration resistance are the most often utilized variables to evaluate soil strength in land preparation studies (Lampurlanes and Cantero-Martizez 2003). A measure of the amount of porous space remaining in the soil for the passage of water and air, total soil porosity, is negatively correlated with soil penetration resistance. Low porosity hinders root growth by decreasing aeration and increasing penetration resistance, whereas high porosity is typically linked to poor soil-root contact. Primary objectives of tillage are to increase the productivity of the soil, improve physical characteristics of the soil, increase in nutrient uptake and increases crop output. Sustainable farming in the agro-ecosystems of developing nations depends on the selection of an appropriate tillage system and improved soil amendments. A good tillage practices with appropriate nutrient management packages is an efficient choice to be considered for environmental improvement in the tropics due to high levels of organic matter decomposition, leaching of the nutrients, and low activity clay minerals (Lampurlanes and Cantero-Martizez 2003). The impact of soil amendments and tillage techniques on specific soil physical characteristics has received little to no attention in the recent literature. This study is justified because, despite the relatively well-established link between CA and increased infiltration (TerAvest et al. 2015), few studies have examined the effects of CA on other important soil physical characteristics like moisture content and penetration resistance. Given this, this study aimed to assess how various tillage techniques and soil amendments affected the soil strength, gravimetric water content (θw) and yield of okra fruits

Materials and Methods

Field experiments were carried out during the early cropping seasons of 2021 and 2022 at the Teaching and Research Farm of the Osun State University, Ejigbo Campus, to assess the impact of tillage practices and soil amendments on soil strength and okra (*Abelmoschus esculentus* (l.) Moench) yield in Ejigbo, Osun State, Nigeria. The coordinates of the location range from latitude 7.874021 N to 7.871700 N and longitude 4.306290 E to 4.182864 E in the derived savanna zone of Southwest Nigeria. The average humidity is 70.30 %, the maximum temperature is 32.80 °C, and the lowest temperature is 20.83 °C. The climate is hot and humid, with both dry and rainy seasons. The annual rainfall is approximately 950 mm. The soils of the agro-ecological zone is developed from crystalline Basement Complex rocks (Bennet 1980), which are the dominant parent material in Nigeria. Broom weed (*Sida acuta* Burm) and Siam weed (*Chromolaena odorata* L) were the most common weeds at the experimental site. In 2021, a week prior to the growing season, soil samples were taken using an Edelman auger at 0–15 cm and 15–30 cm. Using conventional techniques, composite soil samples at each depth were bulked, fully mixed, and subsampled in order to determine specific physical and chemical soil parameters. The Physicochemical properties of the soil used for the study (2021-2022) was presented in Table 1. The same location was used for the 2022 okra production.

Field Layout

Tillage treatments were performed in May 2021 and 2022. Three options for land preparation were included in the treatments: i. Slashing (SL), which involved manually clearing the plots of vegetation with cutlasses and then hand-picking the remaining weeds; ii. Spraying (SP), which involved manually spraying glyphosate herbicide on the plots using 15-liter Knapsack sprayer herbicides; and iii. Plough-plough tillage (TR), which involved plowing the soil with a disc plough mounted on a tractor. Seven days after the initial plough on the designated experimental plots, a second plough was conducted; the maximum depth of tillage was kept at 15 cm, and three different types of nutrient management packages were applied, including cow dung (D) and poultry manure (P) at the same rates (25 t ha^{-1} yr^{-1}, dry weight) Ismail et al. (2010) and 120 kg ha^{-1} N.P.K. (15:15:15) (F) from chemical fertilizer and three control plots (Tillage without nutrient packages i.e. Slash only (SLO), Spray only (SPO) and Plough only (TRO)

Cattle manure (from a local smallholder farmer) and poultry manure (from the broiler house at Osun State University in Ejigbo) were the sources of the organic manure. The manure (cattle and poultry dung) was carefully mixed, and the larger particles were reduced by hand before being applied to the soil. For the studies conducted in 2021–2022, the Institute of Agricultural Research & Training (IAR&T) in Ibadan, Nigeria, ran the chemical composition analysis of the cow dung and poultry manure, Table 2.

The manure was distributed evenly and then completely mixed into the corresponding experimental plots with a hand hoe down to 10 cm soil depth. 21 days prior to planting, manure was applied to give the soil enough time to react (Okorogbona et al. 2011, Mehdizadeh, et al. 20013). There were 12-treatment combinations: i. TRP (Plough + Poultry dung) ii. SPP (Spray + Poultry dung) iii. TCD (Plough + Poultry dung) iv. TRF (Plough + NPK 15 15 15) v. SPC (Spray + Cow dung) vi. SLC. (Slash + Cow dung) vii. SPF (Spray + NPK 15 15 15) viii. TRO (Plough Only) ix. SLP (Slash + Poultry dung) x. SLF (Slash + NPK 15 15 15) xi. SPO (Plough Only) xii SLO (Slash Only). The plot size was 3m × 3m. The experiment was set up in a 2 factor Randomized Completely Block Design with 3 replications. The conventional tillage (CT) and no-till were performed on 24–30 May 2021 and 14–20 May 2022. As per treatment, the entire amount of Poultry Manure and Cow Dung were applied 3 weeks before okra seeds were sown to the designated plots and the NPK 15:15:15 fertilizer was applied two weeks after okra seeds were sown to the appropriate plots.

Crop Establishment

The early maturing Okra cultivar (IT89KD-288), which takes 56–63 days, was obtained from the National Horticultural Research Institute of Ibadan (NIHORT). The dates of its sowing were May 30th, 2021, and

May 21st, 2022. After two weeks, three seeds were sown in each hole, with 0.6 and 0.6 m between rows, the okra was thinned to one plant per stand, resulting in a plant population of roughly 27,778 plants ha^{-1}. Ripcord at 2 ml L^{-1} water was sprayed twice to reduce insect pests. In all treatments, weeds were managed by handpicking and using a hand hoe.

Monitoring of soil moisture and the penetration resistance were done at the 0 – 30 cm depth (0-15 and 15-30 cm soil depth) for moisture content and soil penetration readings were recorded in 7.5-cm increments to a depth of 30 cm) due to the concentration of active roots for arable crops. The moisture content in soil was determined gravimetrically.

Soil Moisture Content Determination

$$\text{Moisture content } (\%) = \frac{(\text{Wet soil weight}) - (\text{Oven dried soil weight})}{\text{Oven dried soil weight}} \, x \, 100$$

Soil Strength Measurements

A soil compaction meter with a stainless-steel cone tip 12.8 mm diameter, 30° cone) was pushed steadily into the soil to measure the soil strength (SS). At the time of SS measurements, moisture contents were determined for each plot. Soil SS and gravimetric moisture content (θm) were measured thrice over the growing season, the same operator conducted all soil strength measurements for the two seasons to maintain an insertion rate, as uniform as possible. Soil penetration readings were recorded in 7.5-cm increments to a depth of 30 cm. 7.5, 15, 22.5 and 15 cm using a cone penetrometer (Eijkelkamp equipment type 1B) and at every three weeks intervals for 8 weeks during the growing seasons: i. two days after planting (1st week), ii. at fully grown vegetation (4th week) and iii. at the flowering stage (7th week) in no-till and conventional tillage plots under the okra. Five soil crust strength measurements were taken at randomly selected positions in each plot

Data on Okra Fruits

Yields of the okra fruit were harvested at physiological maturity for all the experimental plots and weighed.

Data Analysis

Data collected on penetration resistance, moisture content and okra yield were subjected to analysis of variance (ANOVA) to assess treatments effects, using SAS software (SAS 1999). Data were checked for normality and homogeneity of variances using Shapiro and Bartlett tests respectively. The Duncan Multiple Range Test (DMRT) (P = 0.05) was used to differentiate mean differences.

Results and Discussion

Physical and chemical properties of the soil used for the okra production

Table 1 revealed the physical and chemical properties of the soil used for the okra production in the years 2021 and 2022. As reported by Akinrinde and Obigbesan (2000), the organic Carbon and available P are low however, total Nitrogen is high at the two soil depths considered. This suggests a possible soil amendment to improve the okra productivity. The soil is strongly acidic; if managed with proper care, it can sustain the good growth of the crop (Adepetu et al. 2014). The texture of the soil used for the trial was sandy loam at the topsoil (0-15 cm) and clay at the subsoil (15-30 cm). Chemical compositions of compost and manure used in the experiments during the 2021-2022 cropping season is shown in Table 2

Table 1: Physical and chemical properties of the soil used for the analysis (2021-2022).

Soil Parameter	Soil depth	
	0-15 cm	15-30 cm
Clay (g kg^{-1})	160	720
Silt (g kg^{-1})	100	100
Sand (g kg^{-1})	740	180
Texture*	Sandy loam	Clay
OC (g kg^{-1})	0.059	0.074
Total N (%)	0.32	0.28
pH (H_2O)	5.4	5.29
Available P (mg kg^{-1})	4.68	3.24
C/N ratio	1.84	2.64

* The texture class according to USDA; OC – Organic carbon

Table 2: Chemical compositions of compost and manure used in the experiments (2021-2022)

Soil Parameter	Cow dung	Poultry Manure
Organic matter (g kg^{-1})	295	423
Total N (g kg^{-1})	9.7	17.0
Total P (g kg^{-1})	2.6	4.0
Total K (g kg^{-1})	4.5	10.4
pH (H2O, 1:5)	7.20	7.51
Electrical conductivity (H_2O, 1:5) (dS m^{-1})	4.1	3.7
C/N ratio	17.7	14.0

Effects of Cone Index Measurement on Different Land Preparation and Soil Amendments

Soil Penetration Resistance

Plant growth and crop output are measured by the cone index, which gauges the firmness of the soil and the ease with which roots may penetrate through it. Tillage treatments significantly ($P < 0.05$) affected soil strength at the experimental site (Table 3). Soil strength in 2021 and 2022 plots averaged 1.61 and 1.26 MPa respectively across the 0 - 30 cm depth range, this is 21.73 % reduction in soil strength in the year 2022 compared to the year 2021. The lower soil strength in 2022 was likely the result of tillage amended with poultry and cow dung that led to soil loosening caused by decomposition of soil amendment use by soil micro-organisms. Soil penetration resistance was greater in conventional plots than in conservation plots during the first year (2021) of field trial. Average soil strength was significantly higher by 11.2%, 11.8% and 12.4 % in TRO (1.89 MPa), TRP (1.90 MPa) and TRF (1.91 MPa) (Conventional tillage), respectively, compared to SLC (1.70 MPa) which had the highest soil strength in conservation tillage.

This indicates that the conventional activities increased soil strength resistance due to frequent traffic passes induced by this tillage system; a similar observation was reported by Shittu et al. 2017. The adverse effect of soil compaction as a result of increase in penetration of the soil may lead to decrease in soil water infiltration and water-holding capacity (Dexter 2004).

Elimination of secondary tillage and more limited vehicular traffic in conservation tillage plots (SPO, SLO) probably contributed to decreased penetration resistance compared to conventional tillage plots as the conservation system includes only slashed and sprayed plots with little or no soil disturbance event that decreases soil strength (Licht and Al-Kaisi 2005).

During the second cropping season (2022), there were decrease in penetration resistance among the conventional tillage compared to 2021 cropping season. Treatments with TRP (1.90 MPa), SPP (1.53 MPa), TRF (1.91

MPa) and TCD (1.59 MPa) that had higher penetration resistance during the first cropping season (2021) were reduced by 27.5 %, 22.88 %, 73.6 % and 27.2 %, respectively, in the second cropping season (Table 3). However, Soil strength in experimental plots without soil amendment, SLO and SPO treatments that had lower penetration resistance among the treatments involved in the first cropping season, had their soil strength increased by 12.58% and 23.58 %, respectively.

Soil strength averaged across TRF (1.91 MPa), SLC (1.7 MPa), SPP (1.53 MPa) and TCD (1.59 MPa) in the year 2021 has been reduced to TRF (1.1 MPa), SLC (1.19 MPa), SPP (1.25) MPa) and TCD (1.25 MPa) in the year 2022, approximately 42.41 %, 30 %, 22.88 % and 21.36 % respectively. Our results showed that, in comparison to 2021, soil strength levels were lower in 2022. The lower soil strength values in the 2022 trial may have been caused by soil loosening from ploughing and manure incorporation in the top layer, which showed up in the morphology of the roots (Figure: 1. j, g, f, h, l) and the improved physical environment that year. Our findings concurred with those of Idowu et al. (2019). Blanco-Canqui and Ruis (2018), found that NT management techniques increased soil strength in comparison to traditional tillage techniques. The reason for the reduction in penetration resistance in the conventional tillage (CT) might be as a result of soil amendment, which mostly comprises materials that can easily decompose by soil micro-organisms and are later incorporated into the soil and eventually reduce its penetration resistance.

Table 3: Effects of land preparation and soil amendments on soil strength measurement in okra plots for the 2021-2022 growing seasons

Treatment	Pen. MPa (2021)	Pen. MPa (2022)
TRP	$1.90^{a} \pm 0.14$	$1.49^{b} \pm 0.13$
SPP	$1.53^{bc} \pm 0.09$	$1.18^{cd} \pm 0.08$
TCD	$1.59^{bc} \pm 0.14$	$1.25^{cd} \pm 0.13$
TRF	$1.91^{a} \pm 0.13$	$1.10^{d} \pm 0.12$
SPC	$1.49^{bc} \pm 0.13$	$1.33^{bc} \pm 0.12$
SLC	$1.70^{ab} \pm 0.13$	$1.19^{cd} \pm 0.11$
SPF	$1.45^{bcd} \pm 0.11$	$1.35^{bc} \pm 0.11$
TRO	$1.89^{a} \pm 0.152$	$1.06^{d} \pm 0.12$
SLP	$1.38^{cd} \pm 0.10$	$1.22^{cd} \pm 0.11$
SLF	$1.52^{bc} \pm 0.11$	$1.26^{dc} \pm 0.10$
SPO	$1.23^{d} \pm 0.09$	$1.52^{ab} \pm 0.12$
SLO	$1.51^{bc} \pm 0.10$	$1.70^{a} \pm 0.14$
Mean	1.61	1.26

Means followed by the same letter in a column are not significantly different at the 5% level by DMRT

Pen. – Penetration resistance

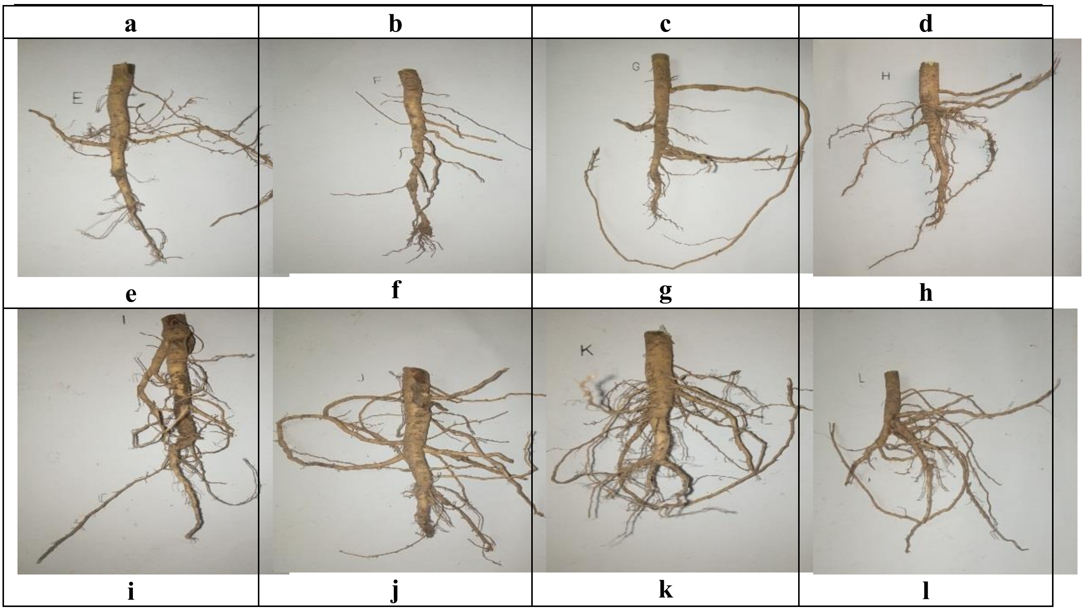

Figure 1: Effects of different land preparation on the growth of Okra roots in field soils
a = SLO, b = SPO, c =TRO, d = SLP, e = SLF, f = SLC, g = TRF, h = SPP, i = SPC, j = TRP, k= SPF, l = TCD

Soil Strength for the Two Periods of Okra Growth at Different Tillage Practices Without Soil Amendment

Measurements of soil strength for 2021 and 2022 at a depth of 30 cm for conventional tillage and minimal/no-till systems without soil amendments under okra were significantly influenced by the treatments Figure: 2. Average SS in the year 2021 was 1.54 MPa and significantly higher than 1.42 MPa by 8.45 % observed in the year 2022.The experimental treatments with SLO had the highest SS in the two year of the experiment when compared with TRO and SPO, minimal disturbance of the area coupled with little plant debris that can be decomposed by micro-organisms could have been responsible for this.

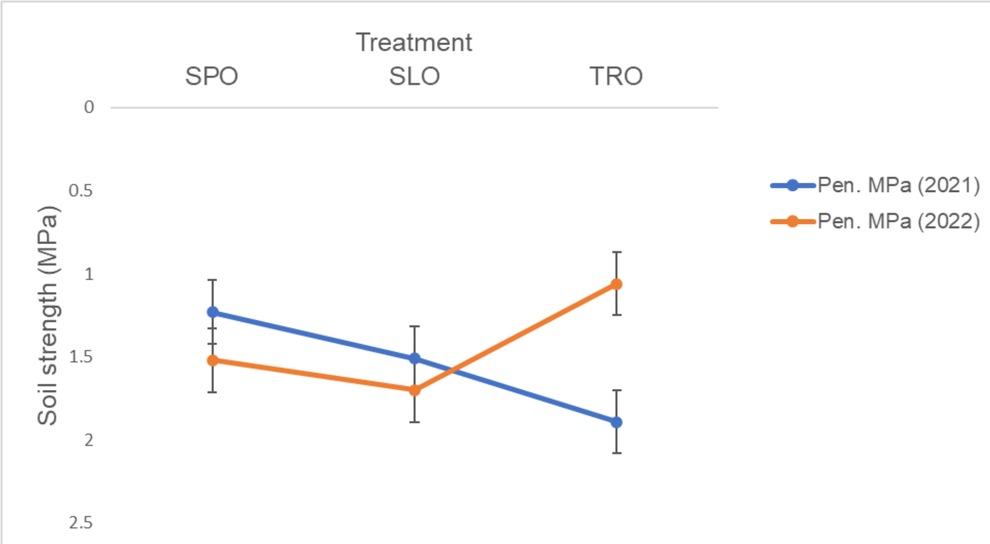

Figure 2: Mean soil strength (SS) over 2021-2022 as a function of depth (0 - 30 cm) in tillage without amendments. Bars represent two standard errors; Pen. – Penetration resistance.

Effects of Different Methods of Tillage and Soil Amendment on Moisture Content

The results of the analysis of variance for the top 0–15 and 15 -30 cm depth showed that moisture content (θ m) was significantly affected by the different treatments involved in Figure 3. Average moisture content (week 1, week 2 and week 3) in the soil was higher by 43.07 % in 2022 (13.32) %) compared to 2021 (9.31 %) for 0-15 cm soil depth. This could be associated with a higher amount of rainfall during the growing period in 2022. Also, there was 17.82 % increase in moisture content in 2022 (12.23 %) at 15-30 cm soil depth when compared with the amount of moisture in the soil in 2021 (10.38 %) for the same soil depth Figure 4. This could be cumulative effects of soil amendment applied over the two growing years due to their efficacy to reduce evaporation by moderating soil temperature and conserving soil moisture and augment water retention capacity through improvement of soil physical conditions, A similar observation has been previously reported (Hati et al. 2015, Sharma and Acharya 2000).

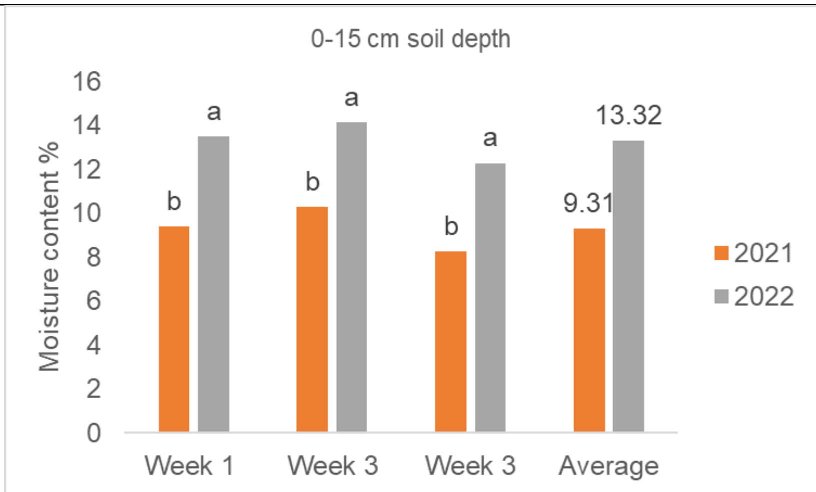

Figure 3: Mean of moisture content between 0-15 cm soil depth for the two growing year season

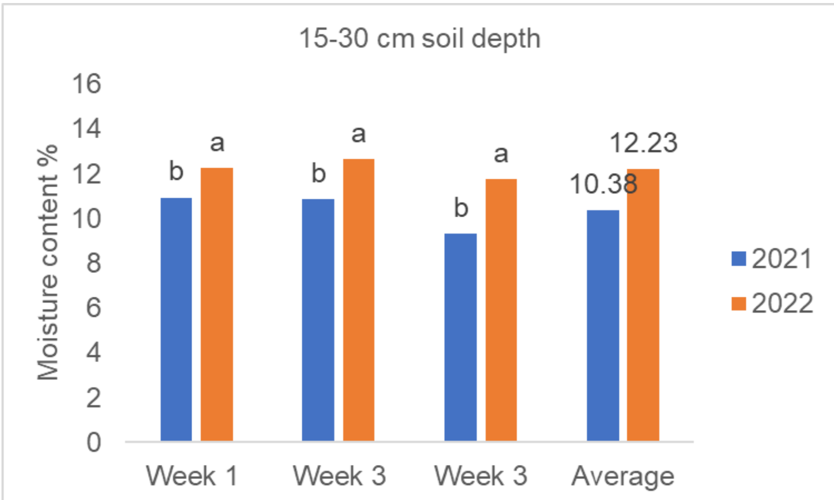

Figure 4: Mean of moisture content between 15-30 cm soil depth for the two growing years

Experimental plot with treatment SLO (3.10 %) had the lowest moisture content in 2021 at 0-15 cm soil depth was significantly lower than treatment with TCD (6.79 %) by 54.34 % (Table 4). Also, treatment with TRO (10.98 %) had the least moisture content in 2022 at 0-15 cm soil depth was significantly lower than SLP (15.81 %) by 30.55 %, that had the highest value. Similarly, TCD with moisture content of 9.78 % had the highest moisture content at 15-30 cm soil depth and was significantly higher than TRO (4.15 %), SPO (4.39 %) and SLO (3.85 %) by 135.66, %, 122.78 %, 154.03 % respectively, Table 5.

This simply implies that soil amendment incorporated to the topsoil of TCD experimental plots assisted in holding more moisture content for the okra for optimal fruits and better root formation. In a previous study Fabrizzi et al. 2005 reported similar observation when he experienced an increase in soil moisture storage under tillage due to increase in soil infiltration and the enhanced soil protection from rainfall impact due to soil amendment. This is also reflected in the morphology of the roots (Figure 1). Because of the manure and surface residue cover, which probably lowers the quantity of evaporation from the soil surface, tillage with soil amendment preserves greater soil water content in the soil profile than tillage without amendment, our findings aligned with the observations of Jabro et al. (2016) and Salem et al. (2015). Crops can satisfy their water needs for longer periods without experiencing stress because manure-amended soils retain more soil moisture than conventional till systems (Acharya et al. 2018, Mondal et al. (2018). Improved aggregation, carbon sequestration, macropore continuity, increased water infiltration time, and decreased runoff have all been linked to improved soil water storage possessed by tillage with soil amendment (Yadav et al. 2018).

Table 4: Tillage and soil amendment effects on moisture content at 0-15 cm soil in 2021 and 2022 cropping seasons

Treatment	Moisture content (%) 2021	Moisture content (%) 2022
TRP	5.81^{ab} ± 0.60	13.33^{abc} ± 0.56
SPP	5.73^{ab} ± 0.58	12.81^{abc} ± 0.78
TCD	6.79^{a} ± 1.12	12.09^{bc} ± 0.83
TRF	3.97^{bc} ± 0.44	12.39^{bc} ± 1.16
SPC	4.51^{abc} ± 0.40	12.89^{abc} ± 0.96
SLC	2.98^{c} ± 0.36	13.86^{abc} ± 1.03
SPF	4.94^{abc} ± 0.96	13.33^{abc} ± 1.02
TRO	4.13^{bc} ± 1.10	10.98^{c} ± 0.63
SLP	6.58^{a} ± 0.30	15.81^{a} ± 1.63
SLF	4.81^{abc} ± 0.59	15.33^{ab} ± 1.38
SPO	4.76^{abc} ± 0.93	13.15^{abc} ± 0.74
SLO	3.10^{c} ± 0.89	13.56^{abc} ± 1.60
Mean	9.69	13.36

Means followed by the same letter in a column are not significantly different at the 5% level by DMRT

Table 5: Tillage and soil amendment effects on moisture content at 15- 30 cm soil

Treatment	Moisture content (%) 2021	Moisture content (%) 2022
TRP	9.16^{ab} ± 0.88	12.11^{abc} ± 0.64
SPP	7.44^{bc} ± 0.26	11.87^{abc} ± 0.48
TCD	9.78^{a} ± 1.05	10.90^{bc} ± 0.49
TRF	7.04^{bc} ± 0.42	12.09^{abc} ± 0.41
SPC	7.43^{bc} ± 0.35	11.89^{abc} ± 0.39
SLC	6.63^{c} ± 0.51	13.64^{a} ± 0.97
SPF	9.32^{ab} ± 0.47	13.33^{ab} ± 0.57
TRO	4.51^{d} ± 0.98	9.91^{c} ± 0.41
SLP	8.38^{abc} ± 0.96	12.19^{abc} ± 0.70
SLF	8.76^{abc} ± 0.66	13.44^{ab} ± 0.79
SPO	4.39^{d} ± 0.85	11.94^{abc} ± 0.44
SLO	3.85^{d} ± 1.04	12.94^{ab} ± 1.79
Mean	14.53	12.19

Means followed by the same letter in a column are not significantly different at the 5% level by DMRT

Effects of tillage practices and soil amendment on Okra yield

Tillage with soil amendment significantly affected the yield of okra in both 2021 and 2022 years of production, Table 6. The average yield of okra in 2021 was 0.089 t ha^{-1}, which was lower than average okra yield in 2022 (0.962 t ha^{-1}). The reason might be as a result of delay in nutrients release for crop uptake, growth and yield compared to the year 2022 that the soils would have released most of the nutrients for crop uptake.

The average okra yield in the amended plots in the first year of production was 0.118 t ha^{-1} which was far above average yield (0.089 t ha^{-1}) got in that year. However, the average okra yield in the non-amended plots (control) in the first year of production were 0.001, 0.002 and 0.004 t ha^{-1} for TRO, SLO and SPO, respectively; these values were far below the average crop yield in that year. Similarly, the average yield of okra in the 2022 crop production year for amended plots was 1.153 t $ha^{-1,}$ which was also far above the average yield (0.961 t ha^{-1}) obtained in that year. Treatments TRO, SLO and SPO (control plots) had 0.60,0.25, 0.31 t $ha^{-1,}$ respectively; these were below the average yield in that year. Experimental plots, TRP, with value 0.034 t ha^{-1} that had the least okra yield among the treatment that was amended in 2021 had over 750 % increase in okra yield compared to SPO (0.004 t ha^{-1}) treatment plots that had the highest value among the control plot, Table 6. Also, experimental plots with TRP (2.86 t ha^{-1}) and SPP (1.88 t ha^{-1}) had the highest okra yield and was significantly different from TRO (0.60 t ha^{-1}), SPO (0.31 tons ha^{-1}), SLO (0.25 t ha^{-1}) in the year 2022. The huge difference in crop yield between tillage with soil amendment and tillage without amendments might partly be due to additional soil nutrients introduced, decrease in soil strength over time for TRP and SPP treatments (Table 3) and high moisture contents, Tables 4 and 5, in these experimental plots during the two-active year of okra production. However, lower okra yield in 2022 for SPO, SLO and TRO might be due to high soil strength and poor roots development, Figure 1 (a,b,c). The strength of the soil was a limiting factor in the crop yield in 2021 and 2022. Other publications have also reported on the significant effect of this physical parameter of the soil on crop yield (Baumgart and Jones 2002, Munkholma et al. 2003).

Table 6: Effects of tillage and soil amendments on the yield of okra in the 2021 and 2022 cropping seasons

Treatment	**2021 Yield (t ha^{-1})**	**2022 Yield (t ha^{-1})**
TRP	0.0338 ^{ab} ± 0.004	2.86 ^{a} ±0.64
SPP	0.154 ^{ab} ± 0.059	1.88 ^{b} ± 0.46
TCD	0.097 ^{ab} ±0.043	1.40 ^{bc} ± 0.17
TRF	0.151 ^{ab} ±0.070	1.28 ^{bcd} ± 0.23
SPC	0.074 ^{ab} ± 0.042	0.87 ^{cde} ± 0.12
SLC	0.141 ^{ab} ± 0.009	0.90 ^{cde} ± 0.18
SPF	0.166 ^{a} ±0.009	0.44 ^{de} ± 0.07
TRO	0.001^{b} ± 0.000	0.60 ^{cde} ± 0.27
SLP	0.130 ^{ab} ± 0.086	0.41 ^{de} ± 0.1
SLF	0.121 ^{ab} ± 0.005	0.34 ^{e} ± 0.12
SPO	0.004 ^{b} ± 0.000	0.31 ^{e} ± 0.1
SLO	0.002 ^{b} ± 0.000	0.25 ^{e} ± 0.06
Average	0.089	0.961

Means followed by the same letter in a column are not significantly different at the 5% level by DMRT.

Conclusions

Soil strength and soil moisture content were the two factors that contributed most to the variability of the crop yield components. There was a reduction in soil strength in the year 2022 compared with 2021. The lower soil strength in 2022 was likely the result of tillage amended with poultry and cow dung, which led to soil loosening caused by decomposition of the soil amendment used by soil microorganisms. Soil strength averaged across the treatments in the year 2021 was reduced in the year 2022. Experimental plots with TRP (2.86 t ha^{-1}) and SPP (1.88 t ha^{-1}) had the highest okra yield in the year 2022. The huge difference in crop yield between tillage with soil amendment and tillage without amendments might partly be due to a decrease in soil strength and an increase in moisture content between 0-30 cm soil depth, and increasing root depth and development in the year 2022, in okra production. Various organic soil amendment practices can lower soil strength and enhance moisture storage, nutrient use efficiencies and also affect good root growth characteristics.

Declarations

Conflict of interest. The authors have no conflicts of interest to declare and no financial interest to report.

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