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EFFECTS OF TILLAGE AND COMPOST APPLICATION ON SOIL ORGANIC CARBON CONTENT AND TEFF GROWTH AND YIELD IN SOUTH AFRICA

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Abstract: Intensive farming negatively affects soil quality, by reducing the soil organic matter and increasing acidification, nitrification, desertification, contamination by agrochemicals, compaction, and erosion. The use of appropriate tillage systems (TS) and fertilizer rates is of importance to reduce these negative impacts on the environment. The integrated effect of TS and compost application on crop performance and soil quality is not often studied and requires more exploration. A factorial experiment was set-up to investigate the interaction effect of compost rate (CR) and TS on soil organic carbon (SOC), teff growth and yield during the 2021-2022 summer cropping season. Treatments consisted of two TS (minimum [MT] and conventional [CT] TS) and three rates of chicken manure co-composted with cattle manure (0, 20 and 40 t ha^{-1}). MT involved chisel-ploughing, whereas CT involved the use of chisel-plough, mould-board plough, and disc-harrow. Grain yield (GY) and SOC from the MT were significantly higher (35% and 69%, respectively) than those recorded from the CT. The 20 t ha^{-1} rate under MT gave the highest SY (2511 kg ha^{-1}), while the control under CT gave the lowest SY (1223 kg ha^{-1}). Generally, compost application increased SOC, plant height, panicle length, GY and SY by up to 30%, 8%, 15%, 24% and 44% (20 t ha^{-1}), respectively, compared to control. In conclusion, this study revealed that reducing tillage activities leads to more SOC and that it is important to consider the CR and TS interaction when selecting the agronomic practices for optimizing straw production.

Keywords: compost, minimum tillage, soil organic carbon, sustainable agriculture, teff yield

Introduction

Teff (*Eragrostis tef* [Zucc.] *Trotter*) is an annual cereal crop which originated from Ethiopia and Eritrea in Africa. It is known as the grain crop that has numerous health benefits, including the ability to prevent and treat conditions such as celiac disease, diabetes, and anaemia (Nascimento et al. 2018). Teff grain is gluten-free in nature (Jha et al. 2018) and its flour-based products have a longer shelf life, low glycemic index, and high contents of very important amino acids, minerals and crude fibre as compared to those made from wheat, sorghum, rice, barley and maize (Gebru et al. 2020). In South Africa, teff is usually used as a fodder crop because of its good nutritional qualities (FAO 2021). Teff fodder production is dependent on climatic conditions and crop management practices, but teff can produce between 2 and 8 tons of dry mater per hectare in South Africa (Grain SA 2021). The use of teff as a cover crop also improves the soil's organic matter, aggregates stability and water infiltration rate (Yayeh & Merkuz 2014) and reduces soil erosion (Sana & Christy 2021). Although teff has a low soil nutrient requirements, good growth and high grain production of teff (Gebrehiwot et al. 2020) demand sufficient amounts of plant nutrients such as nitrogen (N), phosphorus (P) (Girma et al. 2012; Abay et al. 2016) and potassium (K) (Gebrehawariyat et al. 2018).

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Conventional tillage (CT) is used by farmers to prepare a fine, firm and weed-free seedbed for a better teff crop establishment (Gebrehiwot et al. 2020; Mihretie et al. 2021). It involves the use of machinery to manipulate the soil and influences nutrient release through mineralisation and oxidation after exposure of soil organic matter to air (Rusu 2018; Van der Merwe 2022). Conventional tillage also modifies soil structure and crop residue distribution and in turn affects the ability of soil micro-organisms to degrade soil organic matter and release nutrients (Six et al. 2000; Rusu 2018). Continuous ploughing promotes soil erosion (Sana & Christy, 2021), soil compaction and loss of soil moisture, and speeds up the breakdown of organic matter and exposes farmers to high labour and traction expenses (Godfray et al. 2010; Chen et al. 2019; Mihretie et al. 2021). Farmers using chemical fertilizers to add plant nutrients and conventionally tilling the soil will not curb the soil degradation caused by CT. Minimum tillage (MT) technologies and use of organic-based fertilizer are amongst many regenerative management practices that may be used to curb or reverse the soil degradation and ultimately enhance the growth and yield of crops while reducing weed infestation (Popescu et al. 2022). MT as a conservation tillage system is aimed at reducing tillage to the minimum necessary, but still ensure a good seedbed, rapid germination, a good plant stand and favourable conditions for plant growth. Compost, manure or crop residues incorporated in the soil release plant nutrients as they break down (Cakmak 2005; Rasool et al. 2017). Organic fertilizers are not only used to supply plant nutrients, but also to enhance the physical and biological properties as well as other soil chemical characteristics (Brady & Weil 2016).

Intensive farming negatively affects soil quality, by reducing the soil organic matter and increasing acidification, nitrification, desertification, contamination by agrochemicals, compaction, and erosion (Cataldo et al. 2021). The use of appropriate tillage systems (TS) and fertilizer rates is of importance to reduce these negative impacts on the environment. Although the effects of different tillage systems and compost application on crop yield and soil properties have been previously reported, the integrated effect of compost application and TS on crop performance and soil quality is rarely explored. Hence, the objective of this study was to determine the effects of tillage system, compost application rate and their interaction on soil organic carbon, teff growth and yield parameters. The hypothesis of this study was that tillage system, compost application rate and their interaction will affect the soil organic carbon content, teff growth and yield parameters.

Materials and methods

Description of the study site

The study was conducted at the experimental farm of the University of Limpopo (23°50′42.86″S; 29°42′44.35″E) located within the Capricorn District of the Limpopo Province, South Africa. Limpopo province has hot summers with mean maximum temperatures reaching approximately 28°C (Maluleke et al. 2024) and annual rainfall of approximately 600 mm (Maponya & Mpandeli 2016). Rainfall, temperature, relative humidity, and solar radiation recorded during the 2021-2022 summer cropping season is shown in Table 1. The soils found in this farm are formed from sandstone, basalt, and biotic gneiss, and naturally have poor fertility status (FAO 2009). The soil has been classified as Hutton using the Soil Classification Working Group (2018) and as Rhodian Ferralsol by the IUSS Working Group (2015). Selected physico-chemical properties (Table 2) of soil used in this study were analysed prior to planting using standard laboratory procedures described by the Non-Affiliated Soil Analyses Work Committee (1990).

Table 1. Total rainfall, temperature, relative humidity, and solar radiation recorded during the 2021-2022 summer cropping season (Moeletsi et al. 2022)

Climate variable	November	December	January	February	March
Average daily minimum temperature (°C)	15.6	16.5	15.8	15.1	13.9
Average daily maximum temperature (°C)	28.6	27.3	27.9	30.2	27.2
Average daily minimum relative humidity (%)	38.5	48.6	44.9	34.6	42.2
Average daily maximum relative humidity (%)	92.2	95.9	94.9	96.3	95.9
Average daily solar radiation (MJ m-2)*	21.8	20.3	20.9	22.8	19.1
Total rainfall (mm)	177.3	115.8	55.6	49.0	8.9

**Total radiation calculated from hourly data*

Table 2. Physio-chemical properties of experimental soil before planting

Soil property	Value
Clay (%)	10.93
Silt (%)	5.07
Sand (%)	84
Soil texture	Loamy sand
pH(water)	6.29
Electrical conductivity (µS/cm)	135
Soil organic carbon (%)	0.75
Bray-1 P (mg/kg)	63.0
Total mineral N (NO3 + NH4) (mg/kg)	5.33

Treatments, experimental design and procedures

The study comprised of two TS (minimum [MT] and conventional [CT] TS) and three compost application rates (0, 20 and 40 t ha^{-1}) as treatment factors. The compost rates selected are within the range of those used in practice, which range from 10 to 40 t ha^{-1} (Elherradi et al. 2005). The treatments were laid out in split-plot arrangement fitted into randomized complete block design. The tillage treatments represent the main plots, while compost rate treatments represent the sub-plot. Each sub-plot measured 6 m^2 (3 m × 2 m); and replicated three times. The space between the blocks was 2 m. Main plots were 4 m apart, while sub-plots were 1 m apart. The MT (ploughing to 12 cm) involved chisel-ploughing of the field to provide minimal soil disturbance for seed sowing and compost application. The CT (ploughing to 30 cm) on the other hand involved the use of chisel-plough followed by mouldboard-plough and a disc-harrower to obtain level and well-pulverized soil. Compost application was done 10 days before planting to allow nutrient mineralization prior to planting. A commercial compost made from a mixture of chicken manure (70%), cattle manure (15%) and sawdust (15%) (dry-weight basis) was used. Six furrows (5 cm deep) per plot were opened using a hand-hoe and the seeds sown in the furrows at a seeding rate of 10 kg ha^{-1} (6 g $plot^{-1}$) (Donaldson 2001). The study was conducted under rain-fed conditions. Weeding was done manually using a hand-hoe. Table 3 shows the chemical properties of the compost used in this study.

Table 3. Chemical properties of the compost used in this study

Chemical property	Value
pH(KCl)	8.0
Electrical conductivity	1020 (μS/cm)
C: N	18:1
Total N	1.10%
Total P	0.59%
Total K	0.89%

Plant growth parameters, straw yield and grain yield

Plant height (cm) was measured from the base of the stem of the main tiller to the tip of the panicle at harvest maturity. Panicle length (cm) was measured from the node where the first panicle branch starts up to the tip of the main panicle at harvest maturity (Birhanu et al. 2020). Straw yield (SY) was determined at harvest maturity (Birhanu et al. 2020) by cutting the grass from the central rows of each plot. Following the collection of samples, the samples were washed with tap water and oven-dried at 65°C until a constant mass was reached. For the grain yield (GY) determination, the grains were manually threshed from the panicles, separated from straw, and weighed using a weighing balance. The GY was adjusted to 12% moisture content.

Soil sample collection and analysis of soil organic carbon

Soil samples (0-15 cm depth) were collected from 4 randomly selected points in each plot using a soil auger. Following this, the collected samples were thoroughly mixed, air-dried, passed through a 2-mm sieve, and bulked into one composite sample of approximately 300 g plot^{-1}. Soil organic carbon (SOC) was determined following the Walkley-Black method (Walkley & Black 1934).

Data analysis

The data collected was subjected to analysis of variance using the Statistical Analysis Software (Version 9.4). The Fisher's least significant difference (LSD) test was used to separate the treatment means at the 5% level of significance.

Results and Discussion

The response of plant height, panicle length, GY and SY to the compost rate is shown in the Figure 1. Although there are no significant differences in plant height, panicle length, GY and SY amongst the compost rates, compost application increased the plant height, panicle length, GY and SY by up to 8%, 15%, 24% and 44% (20 t ha^{-1}), respectively, compared to control. These findings highlight a potentially positive impact of compost application on teff growth and yield. Several studies have reported the potential reasons for the lack of responsiveness of crops to compost application, such as the slow release of nutrients during early crop growth stages (Bending et al. 2002; Bulluck et al. 2002; Nair & Ngouajio 2012).

Although the compost rate had no significant effect on SOC, an increase of up to 30% in SOC (Figure 2A) with increasing compost rate shows a possibility of significant increase in the SOC in the long-term. A study by Atoloye et al. (2022) showed SOC increasing after two to three years after compost application. The soil from the plot under MT had a SOC that was significantly higher (69%) than that recorded from to the MT plot (Figure 2B). Jacobs et al. (2009) reported SOC increase under MT resulting from improved macroaggregate stability. Stable aggregates provide a physical protection for organic matter, resulting in slow microbial decomposition of organic materials (Liu et al. 2019). This observed significant increase in SOC caused by MT emphasises the benefits of MT for soil carbon sequestration. Minimal soil disturbance in MT can help preserve organic matter and prevent the loss of SOC, thus contributing to improved soil structure, moisture retention and long-term soil health (Kumar et al. 2022).

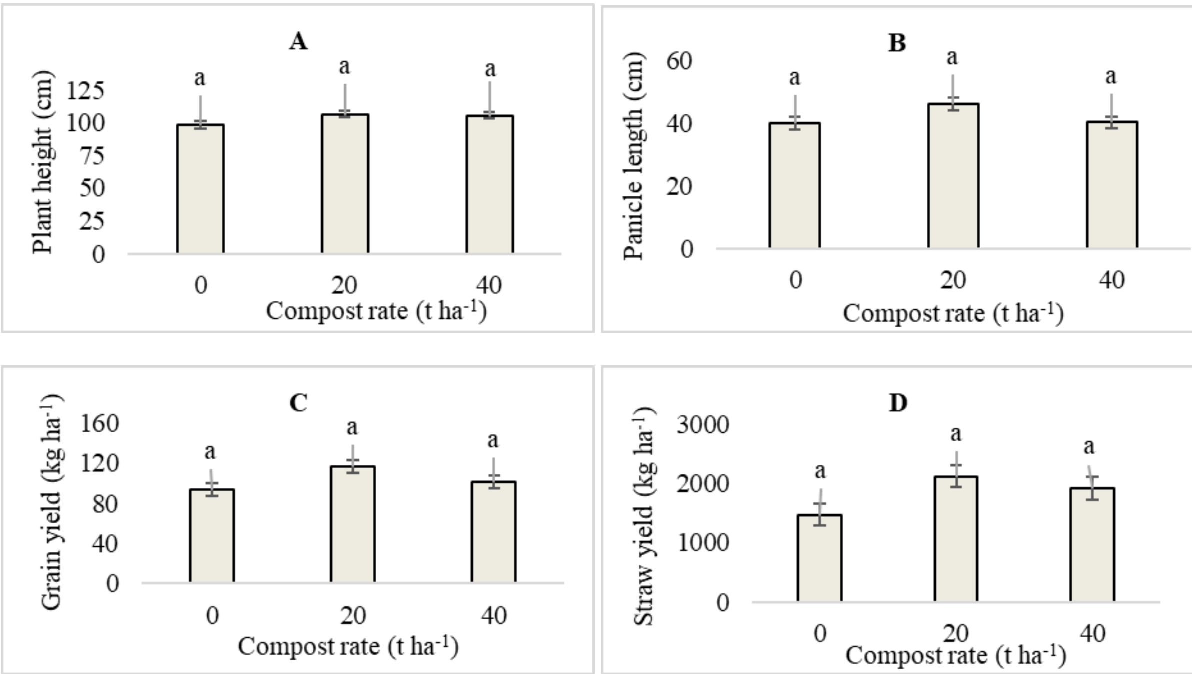

Figure 1. Effect of compost rate on (A) plant height, (B) panicle length, (C) grain yield and (D) straw yield. Means with the same letter are not significantly different at a 5% level of significance. Bars indicate the standard error of the treatment mean.

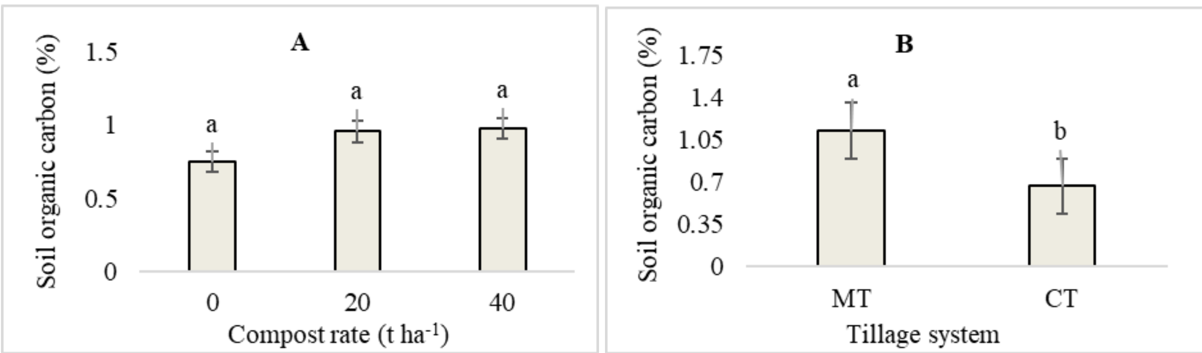

Figure 2. Effect of (A) compost rate and (B) tillage system on soil organic carbon. Means with the same letter(s) are not significantly different at a 5% level of significance. MT and CT denote minimum and conventional tillage systems. Bars indicate the standard error of the treatment mean.

Tillage system had no significant effect on plant height, panicle length and SY (Figure 3). The results from this study indicate that the MT appears promising for improving SY compared to CT. The MT has significantly boosted GY by 35% compared to MT (Figure 3C). This substantial increase in GY indicates that MT system provides conducive soil conditions for a better teff productivity. Minimal soil disturbance under MT can lead to better moisture retention, improved soil structure, and reduced erosion (Bhatt & Khera 2006).

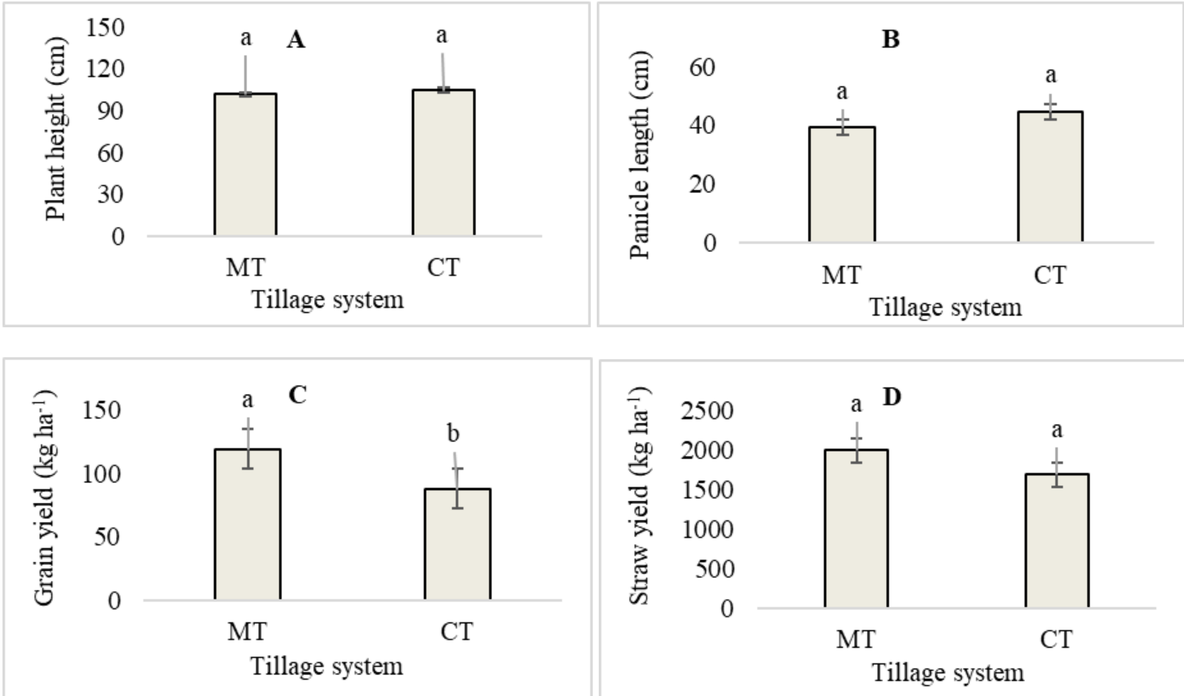

Figure 3. Effect of tillage system on (A) plant height, (B) panicle length, (C) grain yield and (D) straw yield. Means with the same letter are not significantly different at 5% probability level. Bars indicate the standard error of the treatment mean. MT and CT denote minimum and conventional tillage systems.

The interaction effect of tillage system and compost rate on SOC, plant height, panicle length, GY, and SY is illustrated in Table 4. In many instances, compost application at 20 and 40 t ha^{-1} appears promising for improving SOC, plant height, panicle length, GY and SY in comparison with the control within each tillage system. The 20 t ha^{-1} rate under the MT gave a significantly higher SY as compared to 0 and 40 t ha^{-1} rates under MT and 0 and 20 t ha^{-1} rates under CT. The 40 t ha^{-1} rate gave a significantly higher SY in comparison with the control under CT.

Table 4. The interaction effect of tillage system and compost rate on soil organic carbon, plant height, panicle length, grain yield, and straw yield

Tillage system	Compost rate (t ha^{-1})	SOC (%)	PH (cm)	PL (cm)	GY (kg ha^{-1})	SY (kg ha^{-1})
Minimum tillage						
	0	1.03a	95a	36a	118a	1726bc
	20	1.10a	107a	45a	134a	2511a
	40	1.24a	103a	37a	106a	1739bc
Conventional tillage						
	0	0.47a	101a	44a	69a	1223c
	20	0.81a	106a	47a	99a	1735bc
	40	0.71a	108a	43a	97a	2103ab

Means sharing the same letter in the same column are not significant at P≤0.05; SOC = soil organic carbon; PH = plant height; PL = Panicle length; GY = grain yield; SY = straw yield; LSD = least significant difference

Conclusion

The results of this study showed that tillage system affects SOC and teff GY, while its interaction with compost rate influences the teff SY. The MT system appeared to be a beneficial system for achieving higher teff GY compared to CT system. Generally, compost application at the 20 t ha^{-1} rate increased the plant height, panicle length, GY and SY compared to control; showing a potentially positive effect of compost application on teff growth and yield. The MT system in combination with 20 t ha^{-1} compost rate appears to offer advantages for the improvement of teff SY. Lastly, this study revealed that reducing tillage activities leads to more SOC and that it is important to consider the CR and TS interaction when selecting the agronomic practices for optimizing teff straw production. To make conclusive recommendations, this trial should be repeated to validate these findings. The study should also be conducted at different locations with different soil types and climate conditions. Lastly, further research studies should consider more than three application rates and different types of organic compost with different physico-chemical and biological properties.

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Declaration of Interest Statement

The authors declare no conflict of interest.

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