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Short-term effects of tillage and leaf mulch on soil properties and sunflower yield under semi-arid conditions

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Abstract: A study was conducted at the University of Venda Experimental Farm, Limpopo province, South Africa to determine the effects of tillage and mulching on selected soil properties, and yield of sunflower (*Helianthus annuus* L.). The experiment was laid out in a split plot design with three replications during the 2018/19 and 2019/20 cropping seasons. Treatments consisted of conventional tillage (CT) and minimum tillage (MT) and three levels of avocado leaf mulch (0, 6 and 12 t/ha). Bulk density (BD), aggregate stability (AS), infiltration rate (IR), soil water content (SWC) and grain yield were determined. Tillage had no significant effect on BD in either season but influenced SWC and sunflower grain yield. CT recorded a significantly higher AS than MT during 2018/19 cropping season. Tillage × mulch interaction was significant during 2018/19 season with CT at 12 t/ha mulch recording higher AS than the MT. IR was significantly influenced by tillage × mulch interaction in both seasons with MT recording higher IR than the CT during 2018/19. Avocado mulch had no significant effect on sunflower grain yield in either season but influenced SWC in 2019/20 season. It was concluded that avocado mulch could be a relevant component of conservation agriculture but long-term studies are needed to validate the benefits observed in this study.

Keywords: oil seed crop; drought tollerant; dryland; smallholder farmers

Dryland crop production in Sub-Saharan Africa (SSA) is the dominant means of food production for most smallholder farmers (Thierfelder et al. 2013). However, the frequent occurrence of droughts and dry spells is threatening smallholder farmers' food security (Mafongoya et al. 2016). Hence farmers need to adapt to the changing weather patterns to address food demands of the ever-growing population. Conservation agriculture (CA) is one of such promising innovation to address food shortages in the region. CA butresses on three basic practices which are minimum soil disturbance, at least 30% soil cover and crop rotation. Smallholder farmers in southern Africa opted for the manual form of technology (Thierfelder et al. 2013, Nyamangara et al. 2014). Although most smallholder farmers successfully embraced minimum tillage, achieving minimum 30% organic mulching is not tenable because of low yield of crop residues not enough for mulching as well as meeting other competing uses of crop residues such as feed for livestock, firewood and building material (Nyamangara et al. 2014). Despite the limitations, major successes of CA technology have been reported world-wide and in southern Africa under farmer's fields (Mazvimavi and Twomlow 2009). However, in South Africa results are inconclusive (Bennie and Hensley 2001). Reported benefits of CA practices include improved water infiltration rate (Glab and Kulig 2008); reduced soil evaporation and improved soil water content (Bennie and Hensley 2001); moderation of soil temperature (Sarkar and Singh 2007) and reduction of runoff and soil erosion (Erenstein 2002).

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However, bulk density values widely showed no trends across agroecological zones and management practices (Mazvimavi and Twomlow 2009). Although literature is awash with CA research, there are still disparities between regions and results vary from site to site, and are crop specific. Given the wide range of CA results in other parts of the world, it is important to investigate the feasibility and potential of CA to minimise food shortages in southern Africa under various environmental conditions (Nyamangara et al. 2014). Specifically, alternative forms of mulching such as avocado tree leaves could improve crop yields among smallholder farmers practising CA. Unlike crop residues, the avocado tree leaves are in abundance and could be a viable alternative. It is anticipated that the adoption of minimum tillage with avocado tree mulch form of CA technology could enhance soil structural properties and thereby improve crop yields. Bennnie and Hensley (2001) reported that a combination of soil tillage and mulch application increases crop yields, soil organic carbon, moisture content, aggregate stability and infiltration rate, reduces soil evaporation, and soil bulk density and moderates soil temperature. However, avocado leaf mulch use on field crops is not documented in literature. Sunflower is the third most important field crop after maize and wheat in South Africa. Previous studies indicated that good soil and water management could improve sunflower yield under semi-arid conditions of the country (Mzezewa et al. 2011). The aim of the study was to investigate the short-term effects of minimum tillage and avocado leaf mulch on soil bulk density, aggregate stability, infiltration rate, soil water content and grain yield of sunflower under dryland conditions. Conventional tillage was used as the control.

MATERIAL AND METHODS

Site description. A field experiment was conducted during the 2018/19 and 2019/20 cropping seasons under dryland conditions at the University of Venda Experimental Farm (22°58'S, 30°26'E) in Thohoyandou, Limpopo province, South Africa. The site is 596 m a.s.l. and receives 500 to 600 mm annual rainfall. The rainfall is highly seasonal with 85% occurring between October and March. The soil is 10% sand, 30% silt and 60% clay and acidic with an average pH_{H_2O} of 6.1 and pH_{KCl} of 5.2 (Mzezewa et al. 2011). The soils are classified as Rhodic Ferralsol (WRB 2006).

Experimental design and treatments. The experiment was laid out as a split plot design with three replications. Treatments consisted of conventional tillage (CT) and minimum tillage (MT) as main plots (14 m × 17 m) and sub-plots measuring 4 m × 5 m. Three levels of fresh dry avocado leaf mulch (0, 6 and 12 t/ha, which were repeated the following season, were applied in sub-plots). CT was achieved by using mouldboard plough, disk harrow and roller at the beginning of the experiment and in subsequent season hand hoes were used to prepare the plots to a depth of 30 cm in both seasons. Hand hoes were used to remove weeds. MT consisted of opening planting holes using hand hoes on unploughed land. Two sunflower seeds (cv. NK Andiago) were planted per hole at intra row spacing of 0.3 m and 1 m inter row spacing at an approximate depth of 2.5 to 3 cm in each plot. The seedlings were thinned to one stand per hole two weeks after emergence, herbicide (glyphosate) was applied between rows while manual weeding was done within plant rows. No fertiliser was applied in either tillage system. The planting date for 2018/19 season was on 26 November when the minimum and maximum temperature were 20.1 °C and 37.4 °C, respectively. In 2019/20 season the crop was planted on 1 December when minimum and maximum temperature were 17.4 °C and 36.2 °C, respectively. No rainfall was recorded over the planting periods. Consequently 20 mm pre-emergence irrigation water was applied. No irrigation water was applied thereafter over the experimental period.

Soil sampling and analysis. Soil samples were collected in triplicates, giving a total of 9 samples for each factor that was evaluated. SWC was determined by sampling 0–30 cm soil layer between plant rows fortnightly using gravimetric method using a 10-cm bucket auger in both tillage systems. In the laboratory, the soil samples were weighed and oven dried at 105 °C for 24 h. Bulk density (BD) was determined using the core method (Blake and Hartge 1986). Soil samples were collected from 0–5 cm depth between plant rows using a core ring measuring 5 cm diameter and 5 cm height (98.17 cm^3). The core was driven into the soil using a core sampler until flush with the soil surface and then carefully excavated and trimmed using a soil knife. The soil cores were taken to the laboratory and dried in the oven as described before. Soil infiltration rate was determined using a double ring infiltrometer (Bouwer 1986) after clearing the site of debris. The infiltrometer consisted of an inner ring measuring 28 cm (diameter) × 0.5 cm (thickness) ×

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25 cm (height) while the outer ring measured 53 cm (diameter) × 0.5 cm (thickness) × 25 cm (height). The infiltrometer was driven to a depth of 5 cm below the soil surface. Three infiltration tests were carried out per plot, giving a total of 9 tests per treatment. Soil samples for AS determination were sampled from 0-30-cm layer using an auger as described above, at the end of each season and analysed using wet sieving apparatus (Kemper and Rosenau 1986) on 4.0 g of 2 mm-diameter air dried soil aggregates placed on 8 sieves (with 60 Mesh screen).

Yield components and grain yield. At physiological maturity, two middle rows in each plot were harvested for yield component determination. Sunflower head diameter for each sampled plant was measured. Head dry matter and total seed weight were measured. Seeds were oven dried at 65 °C for 24 h and grain yield was adjusted to 13% seed moisture content.

The data were subjected to 2-way analysis of variance using IBM SPSS Statistics for Windows, version 20 (IBM Corp., Armonk, USA). Treatment means were separated by the least significant difference (*LSD*) when the analysis of variance *F*-test was significant at the $P < 0.05$ probability level.

RESULTS AND DISCUSSION

Weather conditions during the experimental period. Temperatures were generally similar during both cropping seasons. During 2018/19 average minimum and maximum temperatures were 17.6 °C and 29.2 °C, respectively; whilst in the 2019/20 season minimum and maximum temperatures were 16.3 °C and 28.0 °C, respectively. Total rainfall received during 2018/19 season (397 mm) was slightly lower compared to 2019/20 season (479 mm). The January recorded the highest rainfall amount in both seasons (2018/19 = 202.1 mm; 2019/20 = 211.6 mm). Of the total 32 rainy days (rainy day = ≥ 2.5 mm of rainfall) during 2018/19 season, the highest and least number of rainy days were recorded in December 14 and March 3, respectively. A total of 33 rainy days during 2019/20 were evenly distributed.

Bulk density. Tillage × mulch interaction was not significant on bulk density in either season. In addition, BD was not significantly different between tillage methods during 2018/19 (CT =1.3 g/cm^3; MT = 1.23 g/cm^3) and 2019/20 (CT = 1.21 g/cm^3; 1.34 g/cm^3) seasons, contrary to the results of Salem et al. (2015), who reported a greater BD in MT than CT in the upper soil layers of a loamy soil. However, our results agree with Haruna et al. (2017) who reported asimilar BD between tilled and untilled plots on a silt loam soil texture. Avocado leaf mulch application resulted in no significant difference in BD among all mulch treatments during 2018/19 (control = 1.23 g/cm^3; 6 t/ha = 1.27 g/cm^3; 12 t/ha = 1.29 g/cm^3) and 2019/20 (control = 1.28 g/cm^3; 6 t/ha = 1.28 g/cm^3; 12 t/ha = 1.32 g/cm^3). Similar results were obtained by Duiker and Lal (1999) between wheat straw mulched and unmulched plots. In contrast, Kahlon et al. (2013), reported a higher BD under no-mulch treatment compared to 8 t/ha and 16 t/ha straw mulch treatments, suggesting that the form of tillage, mulch type and amount play a significant role on BD response. The non-significant difference between 0, 6 and 12 t/ha was attributed to the low mulch rates used in our study. This is corroborated by Pervaiz et al. (2009) who reported a significant BD difference between mulch rates of 0 t/ha (1.41 g/cm^3), followed by 7 t/ha (1.39 g/cm^3) and lowest in 14 t/ha (1.35 g/cm^3) of wheat straw mulch in a sandy clay loam.

Aggregate stability. Interaction between tillage and mulch on aggregate stability (AS) was non-significant during 2018/19 season. The AS in the MT (0.83 g/g) treatment was significantly lower by 7% compared to CT (0.89 g/g) treatment during the 2018/19 season. The differences in AS was probably due to more microaggregates formed in CT compared to MT as previously reported (Verberne et al. 1990). In contrast, Kahlon et al. (2013) found greater water stable aggregates under no-tillage method compared to plough tillage on a silt loam soil texture. There was no significant effect of avocado mulch on AS during 2018/19 (control = 0.85 g/g; 6 t/ha = 0.86 g/g; 12 t/ha = 0.87 g/g). However, during 2019/20 season tillage × mulch interaction had a significant effect on AS. The results showed that 12 t/ha mulch treatment on CT had significantly higher AS than MT with the same mulch treatment (Figure 1A), suggesting that higher mulch application rates could be needed to significantly influence AS. Similar results were obtained in straw mulch plots and no-mulch plots under cultivated soils from a three-year experiment under semi-arid conditions (Jordán et al. 2010, Kahlon et al. 2013). In contrast, Song et al. (2016) reported greater water stable aggregates in zero tillage with straw mulch incorporation than in CT with straw mulch incorporation in a three-year rice-wheat rotation experiment.

Final infiltration rate. Significant tillage × mulch rate interaction effect was observed on final infil-

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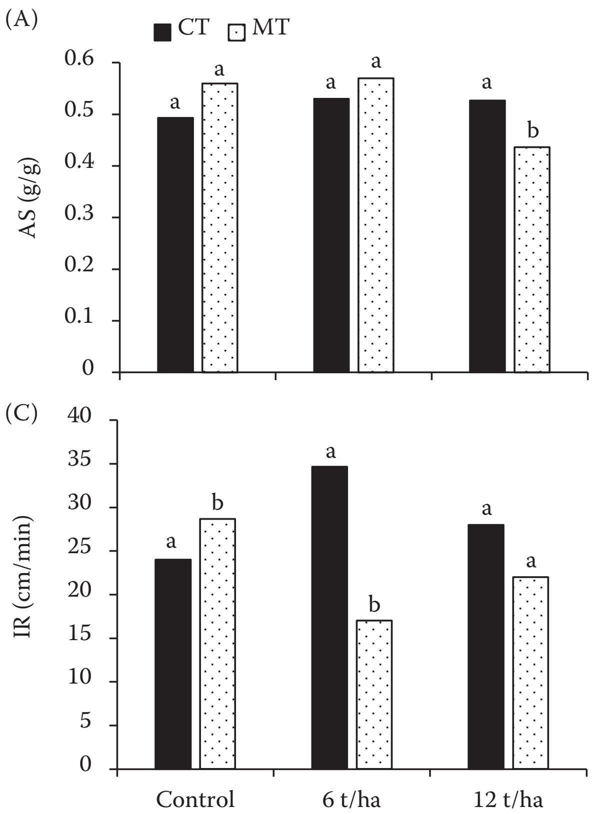

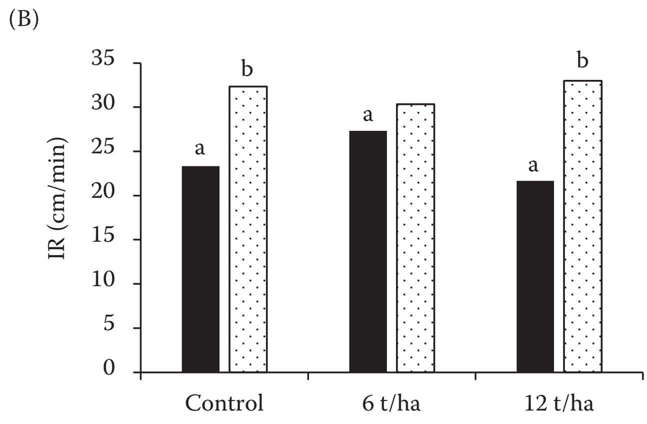

Figure 1. Interactive effect of tillage and avocado leaf mulch application rate on (A) aggregate stability (AS) during 2019/20; (B) final infiltration rate (IR) during 2018/19 and (C) final IR during 2019/20 cropping season (0–30 cm) (n = 9). CT – conventional tillage; MT – minimum tillage. Different letters indicate significant differences between tillage methods at each application rate (P < 0.05). n – number of soil samples

tration rate (IR) during the two cropping seasons (Figure 1B, C). MT at all mulch treatments recorded consistently higher final IR compared to CT treatment during the 2018/19 cropping season, as reported Ogban et al. (2008). In contrast, IR was inconsistent during the 2019/20 cropping season where CT with 6 t/ha recorded the highest IR compared to MT treatment (Figure 3). This was considered an outlier caused by an experimental error. Mupangwa et al. (2013) reported similar IR irrespective of tillage method, amount of mulch cover and number of cropping seasons under CA in semi-arid environment, contrary to our results.

Soil water content. Tillage × mulch interaction was not significant on soil water content (SWC) at all measuring periods in both seasons (Tables 1 and 2). However, tillage practice had a significant effect on SWC at 56 days after planting (DAP) and 70 DAP

Table 1. Mean soil water content (%) (0–30 cm) as affected by tillage and mulching during 2018/19 cropping seasons (n = 9)

Treatment		Days after planting				
		42	56	70	84	98
Tillage	CT	22.26	28.02[a]	20.53	16.42	20.11
	MT	23.20	25.41[b]	19.39	19.40	19.71
Mulch rate (t/ha)	0	22.72	26.26	19.24	17.33	20.31
	6	22.93	26.31	20.07	18.98	19.10
	12	22.54	27.67	20.57	17.44	20.32
P-value	tillage	ns	*	ns	ns	ns
	mulch rate	ns	ns	ns	ns	ns
	tillage × mulch rate	ns	ns	ns	ns	ns

CT – conventional tillage; MT – minimum tillage; ns – not significant; *P < 0.05. Different letters in the same column means significant difference. n – number of soil samples

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Table 2. Mean soil water content (%) (0–30 cm) as affected by tillage and mulching during 2019/20 cropping season (n = 9)

Treatment		Days after planting				
		42	56	70	84	98
Tillage	CT	31.82	22.98	36.06[a]	24.07	28.69
	MT	32.78	25.08	27.47[b]	23.52	28.18
Mulch rate (t/ha)	0	30.02[a]	22.15	36.53	21.10[a]	26.82[a]
	6	33.48[b]	25.83	30.83	24.55[b]	28.72[b]
	12	33.40[b]	24.10	27.92	25.73[b]	29.77[b]
P-value	tillage	ns	ns	*	ns	ns
	mulch rate	*	ns	ns	*	*
	tillage × mulch rate	ns	ns	ns	ns	ns

CT – conventional tillage; MT – minimum tillage; ns – not significant; *P < 0.05. Different letters in the same column means significant difference. n – number of soil samples

during the 2018/19 and 2019/20 cropping seasons, respectively. CT exhibited significantly higher SWC compared to MT in those instances where tillage was significant, in both seasons. The similarity in SWC response between the CT and MT in the current study was attributed to short-term implementation of the MT method. Like in this study, Li et al. (2018) reported no significant differences in SWC between CT and no-tillage treatments in a seven-year experiment on a sandy loam soil texture. Avocado leaf mulch application had a significant effect on SWC during 2019/20 cropping season at 42, 84 and 98 DAP (Table 2). The significant effect in SWC due to avocado leaf mulch application could be attributed to reduced evaporation of soil moisture as previously reported under straw mulching (Jordán et al. 2010). However, there was no difference between 6 t/ha and 12 t/ha throughout the measuring period. Lack of significant difference at other measuring periods was reported in previous studies on sandy loam soil (Li et al. 2018).

Sunflower yield components and grain yield. There was no significant difference in sunflower yield components and grain yield between CT and MT during the 2018/19 cropping season (Table 3), as previously reported (Sessiz et al. 2008). The similarity between tillage methods during the first season was attributed to short duration of the experiment that

Table 3. Mean sunflower head diameter, head dry weight and grain yield during the 2018/19 and 2019/20 cropping seasons

Treatment	Head diameter (cm)		Head dry weight (g/head)		Grain yield (kg/ha)	
	2018/19	2019/20	2018/19	2019/20	2018/19	2019/20
Tillage						
CT	22.18	16.02[a]	90.53	27.70[a]	1 804.44	488.89[a]
MT	20.91	18.01[b]	103.31	39.01[b]	1 880.00	711.11[b]
Mulch rate (t/ha)						
0	20.70	16.15	93.74	31.01	1 776.67	550.00
6	21.80	17.57	101.61	36.07	1 903.33	600.00
12	22.14	17.33	95.40	32.80	1 846.67	650.00
***P*-value**						
Tillage	ns	*	ns	*	ns	*
Mulch rate	ns	ns	ns	ns	ns	ns
Tillage × mulch rate	ns	ns	ns	ns	ns	ns

CT – conventional tillage; MT – minimum tillage; ns – not significant; *P < 0.05. Different letters in the same column means significant difference

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gave little time for significant change in soil structural properties, as previously reported on a similar soil type (Mzezewa et al. 2011). In contrast, MT had a significantly greater head diameter and head dry weight compared to CT during 2019/20 cropping season (Table 3). Additionally, sunflower grain yield was 45% higher in MT than CT treatment during the 2019/20 season as reported previously (Zamir et al. 2013). In contrast, Kumar and Angadi (2016) reported the opposite in chickpea grain yield. The grain yields recorded during the 2018/19 cropping season were higher than 2019/20 cropping season, irrespective of the tillage systems. This could be attributed to nutrient mining and possibly better performance of sunflower under low rainfall (397 mm) during the first season compared to the second season's rainfall of 479 mm. Avocado leaf mulch application had no effect on yield components and sunflower grain yield in either cropping season (Table 3). This was attributed to short duration of the experiment that could have minimised cumulative effect of avocado leaf mulch.

Results of this study suggest that the practice of MT could improve sunflower grain yield compared to the CT although the tillage effect tended to be seasonal. In addition, this study demonstrated that the application of avocado leaf mulches over a short-term had non-significant effect on sunflower performance, further suggesting that the effect of mulches is additive and that long-term studies are needed to validate the results.

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