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Full Length Article

Tillage and Crop Rotation Effects on Selected Soil Chemical Properties and Wheat Yield in a Sandy Loam Oakleaf Soil in the Eastern Cape, South Africa

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Abstract

The effects of tillage and crop rotation on soil selected chemical properties and wheat yield were evaluated during the 6th season of an on-going field trial at the University of Fort Hare Farm (UFH), South Africa. Two tillage systems; conventional tillage (CT) and no-till and crop rotations; maize (*Zea mays* L.)-fallow-maize (MFM), maize-fallow-soybean (*Glycine max* L.)- (MFS); maize-wheat (*Triticum aestivum* L.)-maize (MWM) and maize-wheat-soybean (MWS), were evaluated. Residues were retained in all treatments after each cropping season. No-till resulted in significantly higher soil organic carbon (SOC), ammonium-N (NH_4-N), nitrate-N (NO_3-N), P, K, Ca and Zn relative to CT. The MWS rotation recorded significantly higher SOC while the MFM rotation had the least SOC under both tillage treatments. Tillage and crop rotation effects were not significant (p >0.05) with regards to grain yield in all the seasons. Generally, higher wheat grain yield was found in the MWS rotation under no-till. Soil organic carbon, P and total mineral N were positively correlated with grain yield. It is concluded that, in the long term, regular inclusion of soybean in rotation coupled with surface residue retention under no-till is expected to have a positive significant impact on soil health and wheat grain yield.

Keywords: Conservation agriculture; Crop residue; Crop rotation; Tillage; Soil chemical properties

Introduction

In the Eastern Cape Province of South Africa, soil degradation has reached alarming levels leading to general poor soil fertility and crop yield reduction (Loveland and Webb, 2003). The common soil degradation processes; water and wind erosion are associated with loss of soil organic matter and soil nutrients (Duiker and Beagle, 2006). More often, the farmers' practice of conventional tillage (CT) without residue retention promotes the reduction of soil organic matter (SOM) through erosion and accelerated oxidation (Malhi *et al*., 1996). As a result, most soils in the Eastern Cape are reported to have less than 1% soil organic carbon (SOC), far below the critical level of 2% by which soil quality declines. Research has shown that SOC can be increased over time through changes in the management practices of arable soils (Reeves, 1997). Conservation agriculture (CA) is one such technology, which plays an important role in sustainable soil productivity (Karlen *et al*., 1991). CA consists of a set of practices including (1) minimum soil tillage or no-till, (2) organic soil cover and (3) crop rotation. If the principles are applied together, they can reverse the process of soil degradation and improve soil fertility and the overall soil health (Maali, 2003).

CA, advocates for residue retention on the soil surfaces, which is known to enhance carbon sequestration over time. Soils covered with residues therefore act as carbon sinks in cropping fields and this has an environmental advantage of reducing global warming through reduction of greenhouse gas (GHG) emissions as noted by Smith (2007). Crop rotations, as opposed to monoculture cropping, may result in higher crop yields as well as reduced production costs. Several long-term studies have demonstrated benefits of crop rotation in maintaining agronomic productivity by increasing carbon inputs into the soil (Reeves, 1997; Sebetha, 2015). No-till practised under CA is more efficient compared to other tillage systems especially in areas of low rainfall (Maali, 2003). Increased crop yields under no-till is associated with better soil water conservation and greater water use efficiency compared to CT (Maali, 2003). Aslam *et al*. (1999), for example, found that no-till produced 10% more wheat grain compared to farmers' practices of CT.

Little information is available on the effects of CA on soil chemical properties, particularly in rotations that involve wheat in the Eastern Cape Province. Wheat is adapted to the Eastern Cape agro-ecological conditions with great economic potential if grown by the stallholder farmers of Eastern Cape. Planting a winter crop such as wheat is believed to result in timely utilization of available water, reduce soil erosion, and build organic matter in the soil. In

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addition, a longer rotation including wheat often aids in weed management by suppressing the common winter weeds. CA practices need to be determined for improved wheat yield and sustainable soil fertility in semi-arid environments such as those experienced in the Eastern Cape. Therefore, the main objective of this study was to investigate the effect of tillage and crop rotation on selected nutrients and winter wheat grain yield in the Eastern Cape, South Africa.

Materials and Methods

Experimental Site

The field trial was established in 2012/13 at the University of Fort Hare research farm (UFH) in the Eastern Cape, South Africa. The UFH site (32°47′ S and 27°50′ E) is at an altitude of 508 metres above sea level. The site is in a semi-arid area and receives an average of 575 mm annual rainfall. About 30% of the annual rainfall is received in winter and the rest in summer (Palmer and Ainslie, 2006). The site has surface layer soils of the Oakleaf form (Soil Classification Working Group, 1991). Prior to the establishment of the trial, the land was under lucerne (*Medicago sativa*) production.

Experimental Design

The field trial was a split-split plot design with 16 treatments and 3 replicates. Main plots were allocated to no-till and conventional tillage (CT). The main plots were split into four crop rotations; maize-fallow-maize (MFM), maize-fallow-soybean (MFS), maize-winter wheat-maize (MWM) and maize-winter wheat-soybean (MWS). The sub sub-plots were allocated to residue management at two levels; residue removal (R-) and residue retention (R+). The main plot sizes were 32.5 × 10 m, sub plots were 7 × 10 m and sub-sub plots were 5 × 7 m. The net plot size was 3 m × 4 m. However, for the purpose of this study, only tillage and crop rotations under residue retention were considered to give a 2 × 4 factorial experiment laid out in randomized complete block design.

The experimental site was ploughed, disked and harrowed to create uniform conditions before the initial crop establishment. A short season and prolific maize cultivar (BG 5785BR) was planted in summer (October–February) targeting a population of 25,000 plants/ha, recommended for dryland conditions in the central Eastern Cape Province of South Africa (Department of Agriculture, 2003). The maize was spaced at 1 m between rows and 0.4 m within rows to give a plant population of 25 000 plants/ha. Planting stations were opened using hoes and three seeds were dropped per hole, and later thinned to one plant per station at 2 weeks after emergence (WACE). An early maturing, dryland spring wheat cultivar (SST015) was planted in winter (May–August) at a seeding rate of 100 kg/ha. Soybean cultivar (PAN 5409RG) was sown in summer targeting a population of 250,000 plants/ha (~100 kg/ha). Both, soybean and wheat were planted in rows spaced at 0.5 m apart and at a depth of 3–5 cm. Fertilizer was only applied to the summer maize crop at a rate of 90 kg N, 45 kg P and 60 kg K per ha in all plots for a target yield of 5 tons/ha. All the P, K and a third of the N fertilizer was applied at planting as a compound (6.7% N; 10% P; 13.3% K + 0.5% Zn) and the rest (60 kg) as limestone ammonium nitrate (LAN) at 6 weeks after planting by banding. Soybean was inoculated with *Rhizobium leguminosarium* before sowing. No irrigation was applied. Residue retention was implemented soon after harvesting each crop, whereas tillage treatments were implemented just before planting of each cropping cycle (Table 1).

Field and Laboratory Measurements

Soil samples for the study were taken after harvesting the 2015 winter wheat. Five soil cores were collected randomly to make a composite sample from each plot at three depths of 0–5; 5–10 and 10–20 cm using a spade for the top layer and a graduated 7 cm diameter auger for the 5–10 and 10–20 cm layers. The surface litter layer was cleared away before sample collection. The samples were stored in a cold room (4ºC) until use. Before laboratory work, soil samples were air dried, sieved with a 2 mm sieve. SOC was determined by dry combustion (LECO Tru-Spec C/N, St. Joseph, MI USA). Ammonium-N (NH_4-N) and nitrate-N (NO_3-N) was determined colorimetrically after extraction with 0.5 *M* potassium sulphate (K_2SO_4) following the methods in Okalebo *et al*. (2002). Total mineral-N was the sum of NH_4-N and NO_3-N. Olsen P was determined using a continuous flow analyzer (San 2^{++} Skalar CFA, Skalar Analytical B.V., The Netherlands) employing the ammonium molybdate – antimony potassium tartrate – ascorbic acid method after extraction with 0.5 *M* sodium bicarbonate ($NaHCO_3$) (AGRILASA, 2004). Extractable K, Mg, Ca and Zn were determined after extraction with 1M ammonium nitrate (NH_4NO_3) solution as described in AGRILASA (2004). The cations were then analyzed using Inductively Coupled Plasma – Optical Emission Spectrometer (ICP-OES, Varian Inc., The Netherlands).

Soil pH was determined using a WTW pH 526 meter (Eutech instruments, Singapore) in a 1:2.5 (v/v) soil water ratio whereas electrical conductivity (EC) readings were taken using a conductivity meter (Eutech instruments, Singapore) on the same suspension used for pH reading after 1 h settling period (Okalebo *et al*., 2002). Wheat grain yield (tons/ha) was determined for 2013, 2014 and 2015 winter seasons. The grain yield was collected after threshing the wheat and separating grain from the straw. The grain yields were adjusted to 12.5% moisture content after grain moisture determination with a digital grain moisture meter tester model number MC-7825G (Omni Instruments Ltd., Arroyo Grande, California, USA). Climatic data (temperature and rainfall) for the duration of the experiment was obtained from an automatic weather station (2013 to 2015) at the University of Fort Hare Research Farm. The data was compared to the long-term climatic data (1979 to 2014) measured at the same station.

Statistical Analysis

Statistical analysis was carried out using analysis of variance (ANOVA) techniques as outlined by Gomez and Gomez (1984). A JMP statistical package version 13.1 (SAS Institute Inc.) was used for the analysis of variance. Treatment means were separated using Fisher's unprotected least significant difference test at 5% probability level. Correlation analyses were done to determine the relationships between wheat yield and soil parameters. Significant differences were identified at $p \leq 0.05$.

Results

Rainfall and Temperature

Long-term annual rainfall was higher compared to the 2013, 2014 and 2015 (Fig. 1). Of the experimental years, 2014 had the least annual rainfall compared to 2013 and 2015 season. The 2015 wheat growing season (March–August) had the greatest rainfall compared to the rest of the years. Mean temperature during the growing period of wheat (March – August) was least in 2015 compared to the 2013 and 2014 seasons as well as the long-term temperature data (Fig. 2).

Soil Chemical Properties

Soil organic carbon: Tillage and crop rotation had significant effect ($p < 0.05$) on SOC at 0–5 cm and 5–10 cm soil depth (Table 2). No-till plots had higher SOC compared to CT plots in the 0–5 and 5–10 cm soil depths (Table 3). MFM had lower SOC compared with the rest of the crop rotations at all the sampling depths. The interaction of tillage and crop rotation was not significant ($p > 0.05$) on SOC at all the sampling depths (Table 2).

Mineral nitrogen: Tillage had an influence on soil NH_4-N levels at all soil sampling depths and NO_3-N levels only at 0–5 cm soil depth (Table 2). The levels of NH_4-N were found to be greater in no-till than CT plots and decreased with depth (Table 3). Ammonium-N was lower under continuous maize rotation, whereas MFS recorded greater levels of NH_4-N at 0–5 cm and 5–10 cm soil depths (Table 3). MWS had significantly higher NH_4-N concentration than other crop rotation treatments at the 10–20 cm soil depth. Continuous maize rotation (MFM) had significantly lower NO_3-N than other crop rotation treatments at 0–5 cm soil depth (Table 3). MFS recorded higher NO_3-N concentration at the 0–5 cm and 5–10 cm soil depths. The tillage × crop rotation interaction effect was not significant ($p > 0.05$) on NH_4-N and NO_3-N at all soil depths (Table 2). Total mineral-N (sum of NH_4-N and NO_3-N) showed significant tillage effect ($p < 0.05$) at all the sampling depths (Table 2). Total mineral-N was greater in no-till than CT and decreased with depth (Table 3). Crop rotation also had a significant effect ($p < 0.05$) on the total mineral-N measured at 5–10 cm. The total mineral-N followed the order MFS>MWM≥MWS≥MFM (Table 3).

Phosphorus and potassium: Phosphorus levels were significantly affected by tillage at 5–10 cm and 10–20 cm soil depths (Table 2) and in all the depths, no-till resulted in higher extractable P levels than CT (Table 3). Crop rotation significantly affected the P levels at all depths. MWS increased soil P availability in all soil depths compared with other crop rotation treatments (Table 3). However, K was significantly affected by tillage ($p < 0.05$) only at 0–5 cm soil depth (Table 2). No-till increased soil K concentration relative to CT at all sampling depths (Table 3). Regardless of the tillage type, K was significantly affected by crop rotation ($p < 0.05$) at 0–5 cm and 5–10 cm soil depth. MFS had higher K concentration at 0–5 cm soil depth compared to MWS (Table 3).

Calcium, magnesium and zinc: Tillage had significant effect on Ca at 5–10 cm soil depth and Zn at 0–5 cm. In both cases, no-till significantly increased Ca and Zn compared to CT (Table 3). Crop rotation had a significant effect ($p < 0.05$) on Ca at 0–5 cm and 5–10 cm soil depth. Soil Ca tended to accumulate at upper soil level and decreased with soil depth (Table 3). Crop rotation interacted with tillage on Ca at the 5–10 cm soil depth. Crop rotation had a significant effect ($p < 0.05$) on Mg concentration at 0–5 cm and was greater in MWS and lower in MFM at 0–5 cm soil depth.

Soil pH and electrical conductivity (EC): Tillage and crop rotation had no effect on pH but on EC. Soil EC was significantly affected by tillage ($p < 0.05$) at the 0–5 cm soil depth (Table 2). No-till resulted in significantly lower EC relative to CT in 0–5 cm depth (Table 3). Tillage systems had no significant difference on soil EC at 5–10 and 10–20 cm sampling depths (Table 2). Soil EC decreased with an increase in soil depth across the tillage treatments (Table 3). The MWS rotation had significantly higher EC at the 0–5 cm soil depth (Table 3).

Wheat Grain Yield

The analysis of variance of the wheat grain yields from winter seasons 2, 4 and 6 showed no significant ($p > 0.05$) main effects nor their interaction (Table 4). Overall, the highest yields were obtained in season 6. The grain yields ranged from 2.8 to 3.5 tons/ha.

Correlation between Wheat Grain Yield and Soil Chemical Properties

Relationships between wheat grain yield and selected soil properties are shown in Fig. 3, 4 and 5. Wheat grain yield was positively correlated to SOC under both MWM and MWS rotations (Fig. 3).

Table 1: Summary of the crop rotation treatments at UFH experimental site

Crop rotation	Summer 2012/13 Season 1	Winter 2013 Season 2	Summer 2013/14 Season 3	Winter 2014 Season 4	Summer 2014/15 Season 5	Winter 2015 Season 6
MFM	Maize	Fallow	Maize	Fallow	Maize	Fallow
MFS	Maize	Fallow	Soybean	Fallow	Maize	Fallow
MWM	Maize	Wheat	Maize	Wheat	Maize	Wheat
MWS	Maize	Wheat	Soybean	Wheat	Maize	Wheat

MFM, maize-fallow-maize; MFS, maize-fallow-soybean, MWM, maize-wheat-maize and MWS, maize-wheat-soybean
Summer season month are October, November, December, January and February
Winter season months are May, June, July and August

Table 2: ANOVA results for soil chemical properties at UFH experimental site

Treatments	SOC	NH_4-N	NO_3-N	Total Mineral-N	P	K	Ca	Mg	Zn	pH	EC
0–5 cm depth											
Tillage	*	*	*	**	ns	**	ns	ns	ns	ns	**
Crop rotation	*	ns	ns	ns	*	*	**	**	ns	ns	ns
Tillage × crop rotation	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
5–10 cm depth											
Tillage	**	*	ns	*	*	ns	**	ns	*	ns	ns
Crop rotation	*	ns	ns	ns	*	**	**	ns	ns	ns	ns
Tillage × crop rotation	ns	ns	ns	ns	ns	ns	**	ns	ns	ns	ns
10–20 cm depth											
Tillage	ns	*	ns	*	*	ns	ns	ns	ns	ns	ns
Crop rotation	*	ns	ns	**	*	ns	ns	ns	ns	ns	**
Tillage × crop rotation	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns - treatment not significant at $p \leq 0.05$ probability level
*, **- treatment significant at p=0.05 and 0.01 probability level, respectively

Table 3: Tillage and crop rotation effects on SOC, NH_4, NO_3, total mineral-N, P, K, Ca, Mg, Zn, pH and EC at UFH experimental site

Treatments	SOC (%)	NH_4-N(mg/kg)	NO_3-N (mg/kg)	Total Mineral-N (mg/kg)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Zn (mg/kg)	pH	EC (μS/cm)
0–5 cm											
CT	1.17b	0.82b	1.09b	1.70b	51.07	172.08b	2248.58	503.83	0.94b	5.50	118.73a
No-till	1.36a	1.21a	1.28a	2.11a	55.85	265.33a	2303.58	515.83	1.51a	5.40	112.30b
$LSD_{0.05}$	0.08	0.04	0.03	0.08	ns	19.13	171.2	ns	0.09	ns	2.9
MFM	1.08b	0.96b	1.02c	1.85c	46.96b	254.33a	2056.67c	410.17c	1.45a	5.45	114.53ab
MFS	1.28a	1.07a	1.19a	1.99a	55.28ab	266.50a	2559.50a	501.67b	1.57a	5.47	116.90a
MWM	1.30a	1.06a	1.14b	1.91b	48.77ab	204.5 b	2136.50b	555.50a	1.05b	5.38	112.30b
MWS	1.40a	0.98b	1.18ab	1.89bc	62.81a	149.50c	2352.17ab	582.0 a	0.83c	5.50	118.33a
LSD0.05	0.11	0.06	0.04	0.05	14.76	27.05	242.1	33.09	0.13	ns	4.13
CV %	11.72	4.50	4.85	14.14	11.97	8.47	7.80	8.57	8.60	7.94	8.62
5–10 cm											
CT	1.06b	0.74b	0.88b	1.42b	42.67b	133.75	1221.92b	460.42	0.85	5.40	112.80
No-till	1.25a	0.96a	1.00a	1.81 a	48.92a	148.58	2121.08a	468.83	0.93	5.50	112.59
LSD0.05	0.04	0.04	0.06	0.07	6.03	ns	150.7	ns	ns	ns	ns
MFM	1.0 c	0.72d	0.85	1.58c	39.33b	169.17a	604.67 d	454.0b	0.90	5.46	113.62
MFS	1.22 a	1.01a	0.88	1.89a	49.50ab	127.83b	1447.83c	455.67ab	0.90	5.53	113.62
MWM	1.15 b	0.87 bc	0.87	1.73b	41.0 b	129.17b	2657.17a	449.33b	0.83	5.46	111.47
MWS	1.25 a	0.81bc	0.86	1.65bc	53.33a	134.50b	1776.33b	499.50a	0.93	5.55	112.06
$LSD_{0.05}$	0.05	0.06	ns	0.10	8.53	23.66	213.2	44.56	ns	ns	ns
CV %	11.11	8.70	7.14	11.69	13.04	8.18	7.86	9.50	7.50	7.54	8.01
10–20 cm											
CT	1.09b	0.32 b	0.85	1.12b	36.47b	108.42	1002.50	349.83	0.28	5.50	82.18
No-till	1.28a	0.51 a	0.86	1.33a	41.81a	109.83	1073.75	349.92	0.28	5.60	76.08
LSD0.05	0.03	0.01	ns	0.05	3.16	ns	ns	ns	ns	ns	ns
MFM	1.02b	0.29 c	0.89	1.09b	33.6 b	110.17	829.83b	345.17	0.27	5.47	88.48a
MFS	1.19a	0.36 b	0.89	1.17b	42.31a	111.17	920.33b	354.67	0.28	5.66	89.37a
MWM	1.16a	0.31 c	0.86	1.12b	35.04b	104.83	1539.67a	345.17	0.28	5.57	74.6 b
MWS	1.18a	0.51 a	0.90	1.33a	45.58a	110.33	836.67b	357.67	0.27	5.68	67.01b
LSD0.05	0.15	0.02	ns	0.06	4.47	ns	469.7	ns	ns	ns	9.46
CV %	7.89	6.20	5.80	7.69	13.04	7.19	4.13	5.18	6.23	4.0	10.15

MFM, maize-fallow-maize; MFS, maize-fallow-soybean, MWM, maize-wheat-maize and MWS, maize-wheat-soybean
Different letters in each column and factor indicate significant differences amongst the treatments
LSD, Least Significant Difference; ns - treatment not significant at $p \leq 0.05$ probability level
CT-conventional tillage; CV–coefficient of variation

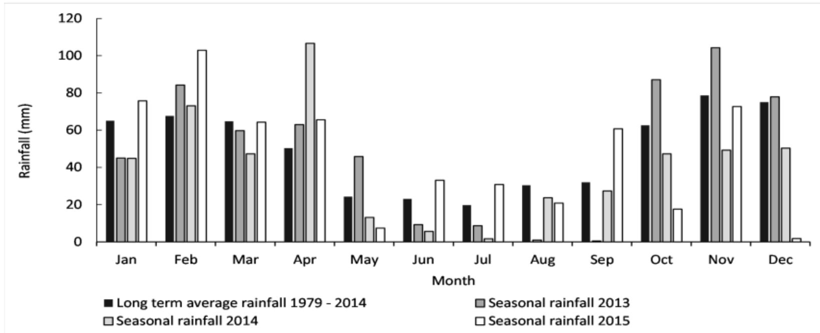

Fig. 1: Long-term monthly average rainfall (1979-2014) compared to the 2013, 2014 and 2015 rainfall at UFH experimental site

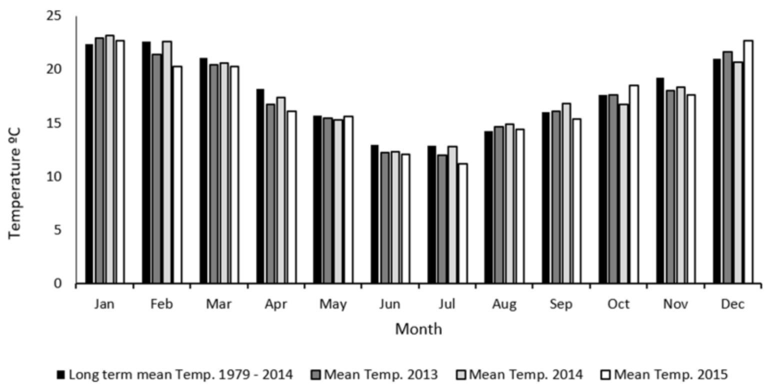

Fig. 2: Long-term monthly mean temperature (1979–2014) compared to the 2013, 2014 and 2015 seasonal mean temperature at UFH experimental site

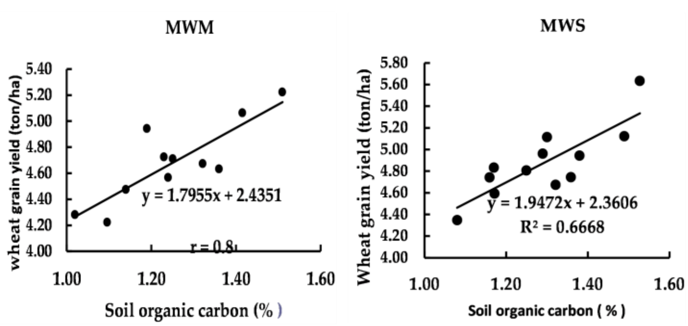

Fig. 3: Relationship between wheat grain yield (ton/ha) and soil organic carbon (%) under maize-wheat-maize (MWM) and maize-wheat-soybean (MWS) rotations

However, a better correlation was observed under MWM rotation (r=0.84) than under the MWS rotation (r=0.82). Wheat grain yield was highly correlated with total mineral-N under the two rotations. However, a better correlation was observed under the MWS rotation (r=0.98) than under the MWM rotation (r=0.93) (Fig. 4). The correlation of wheat grain yield with soil P differed considerably under the two rotations. A very high correlation was observed under the MWS rotation (r=0.90) while a weak correlation was observed under the MWM rotation (r=0.74) (Fig. 5).

Discussion

The higher SOC observed from no-till than CT plots is consistent with the findings by Ghimire *et al.* (2012) who attributed this to the lack of soil turnover under no-till as opposed to the mix-up of crop residues and soil under CT.

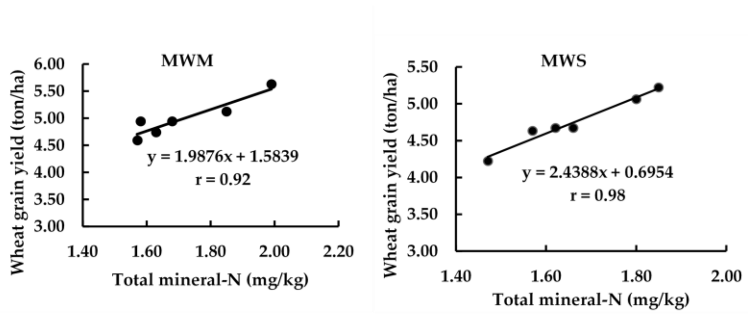

Fig. 4: Relationship between wheat grain yield (ton/ha) and total mineral-N (mg/kg) under maize-wheat-maize (MWM) and maize-wheat-soybean (MWS) rotations

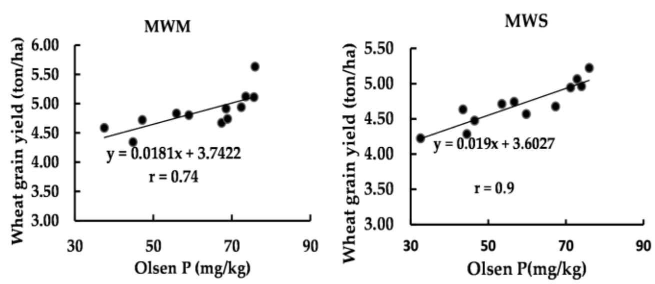

Fig. 5: Relationship between wheat grain yield (ton/ha) and Olsen P (mg/kg) under maize-wheat-maize (MWM) and maize-wheat-soybean (MWS) rotations

Intensive tillage commonly practised with CT, reduces the storage of SOC because it disturbs soil aggregates, increases soil aeration and decomposition of residues. The observed lower SOC in the maize monoculture was in agreement with the studies of Gregorich *et al*. (2001) who reported a large increase in SOC level for cereal-legume rotation compared to a maize monoculture system. In contrast to our findings, Omay *et al.* (1997) reported more SOC under continuous maize than maize-soybean rotation. Greater NH_4-N content observed under no-till than CT and decreased with soil depth and could be due to higher organic material on soil surface. Crop residues have been reported to increase soil organic fertility, which can improve microbial activity, nutrient supply and overall soil health (Saha *et al*., 2010). Total mineral-N was greater in no-till than CT as a result of the build-up of organic material on the soil surface in the no-till system with residue retention.

Reduced soil disturbance and inclusion of a leguminous crop in rotation appeared to increase Zn concentration. The observation of higher P levels in the top soil, decreasing with soil depth was in agreement with findings by Selles *et al*. (1997) that no-till practices increases total P in the topsoil by 15% compared to CT. A study by Njaimwe (2010) revealed that high P stratification on soil surface under no-till was attributed to limited soil mixing with no-till as opposed to tilled soils. Residue retention under no-till could have caused an increase in P availability by decreasing the adsorption of P to mineral surfaces. According to Zibilske *et al*. (2002), CA is designed to retain crop residues and thus should impact the P status of soils. The low mobility of P downwards in the soil profile also contributed to this response. The lower soil P found in MFM was in contrast with the findings by Hickman (2002) who reported higher P in the maize-soybean (MS) rotation than MFM and soybean-soybean rotations (SS). Okpara and Igwe (2013) obtained similar results to our findings where P was higher in a legume–maize rotation. The higher K concentration under no-till compared to CT was as reported by Houx *et al*. (2011) for the upper soil layer in a long term tillage experiment. Hickman (2002) also observed that K tended to be reduced in the CT plots compared to no-till. An increase in K levels in continuous maize plots is in agreement with findings by Reeves (1997).

Results revealed that soil pH was not affected by tillage irrespective of soil depth levels similar to the findings of Rasmussen (1999). This is however in contrast to other reports of decreased pH in no-till systems compared to CT (Rahman *et al*., 2008). The higher EC under CT compared to no-till and the decrease of EC values with an increase in soil depth was consistent with the findings of Botha (2013). Botha (2013) attributed this to a plough pan created as a result of many years of mouldboard ploughing which limits water infiltration into deeper layers and thus resisting salt leaching.

Table 4: Tillage and crop rotation effect on wheat grain yield (tons/ha) 2013, 2014 and 2016 winter seasons at UFH experimental site

Characteristics	No-till	CT	Means
2013 winter season			
MWM	3.13	3.35	3.24
MWS	3.33	3.18	3,26
Means	3.23	3.27	3,25
$LSD_{0.05}$	0.48		
ANOVA	p-value		
Tillage	0.77^{ns}		
Crop rotation	0.91^{ns}		
Tillage × crop rotation	0.16^{ns}		
CV %	9. 47		
2014 winter season			
MWM	2.94	2.79	2.86
MWS	3.13	3.03	3.08
Means	3.04	2.91	3.25
$LSD_{0.05}$	0.48		
ANOVA	p-value		
Tillage	0.56^{ns}		
Crop rotation	0.33^{ns}		
Tillage × crop rotation	0.89^{ns}		
CV %	17.70		
2016 winter season			
MWM	3.29	3.15	3.22
MWS	3.47	3.30	3.39
Means	3.38	3.22	3.30
$LSD_{0.05}$	0.30		
ANOVA	p-value		
Tillage	0.25^{ns}		
Crop rotation	0.22^{ns}		
Tillage × crop rotation	0.90^{ns}		
CV %	6.58		

Crop rotation treatments were MFM, maize-fallow-maize; MFS, maize-fallow-soybean, MWM, maize-wheat-maize and MWS, maize-wheat-soybean

CT-conventional tillage; CV–coefficient of variation

High salt release from rapidly decomposing crop residues under MWS and MFS enhanced EC relative to MFM and MWM rotation in the 0-5 cm depth under no-till. Hati *et al*. (2007) reported an increase in soil EC in soybean-wheat-maize rotation over a period of 28 years.

Total mineral-N, SOC and extractable P were consistently correlated to wheat yield suggesting a link between grain yield and the aforementioned essential soil elements. According to Oelofsea *et al*. (2015), SOC is recognised as an important parameter affecting soil quality, and can therefore contribute to improving a number of soil properties that influence crop yield. Inclusion of legume (MWS) in crop rotation produced maximum average wheat grain yields than the summer and winter cereal-based rotation (MWM) in season 4 and 6. Many researchers have found out that a wheat-legume rotation systems tend to use the limited rainfall efficiently especially when residues are retained on the surface (Pala *et al*., 2007). The enhanced soil-N content observed in the MWS rotation appeared to have influenced the yield of the season 4 and 6 wheat crop that followed the soybean rotation. This is an important observation considering that there was no fertilizer applied onto wheat crop and it relied only on residual nutrients from the summer crop. According to Mohammad *et al*. (2012), nitrogen is the most important limiting factor in wheat production and biological nitrogen fixation is considered as an extremely important N source, which contributes to yield improvement.

Phosphorous is also regarded as one of the essential soil elements limiting crop production in the Eastern Cape (Mandiringana *et al*., 2005). A number of studies have reported that inclusion of legumes in rotation with cereal crops may increase P availability to the cereal crops resulting in an increase in crop growth and production (Rehmut *et al*., 2013). Legumes such as soybeans have the ability to solubilize P from less labile P pools in the soil (Hassan *et al*., 2012). This could explain the high correlation between wheat grain yield and Olsen extractable P under the MWS rotation as contrasted to a much lower correlation under the MWM rotation.

Conclusion

The combined effect of no-till and crop rotations was critical in improving soil chemical properties in this short-term study. Soil nutrient elements accumulated at the upper soil level and decreased with soil depth. No-till consistently resulted in higher soil chemical properties relative to CT. The MWS proved to be the most effective crop rotation in improving soil available nutrients. It was evident that no-till combined with MWS crop rotation would likely be a better option in improving SOC, soil fertility, and overall soil health. When soil nutrients levels are inadequate, wheat cannot grow and produce normally and therefore to ensure profitable production of wheat, crop rotation involving soybean should be encouraged. The results indicate that rotation of cereal with legumes under no-till hold the key in ensuring wheat yield stability and can be promoted as an entry point for the farmers who wish to practice CA in the Eastern Cape, South Africa.

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