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Short-Term Impact of Conservation Agriculture on Soil Strength and Saturated Hydraulic Conductivity in the South African Semiarid Areas

Godwin Iloabuchi Nebo ^{1,*} , Alen Manyevere ¹, Tesfay Araya ¹  and Johan van Tol ² 

¹ Department of Agronomy, University of Fort Hare, Private Bag X1314, Alice 5700, South Africa; AManyevere@ufh.ac.za (A.M.); TWeldeslassie@ufh.ac.za (T.A.)

² Department of Soil-and Crop-and Climate Sciences, University of the Free State, Bloemfontein 9301, South Africa; Vantoljj@ufs.ac.za

* Correspondence: ilowynn@gmail.com; Tel.: +27-784-642-250

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Abstract: The severe limitation of agricultural land productivity induced by physical soil degradation has become a major concern in semiarid climates, especially in the Eastern Cape Province, South Africa. A randomized complete block design in a split-split-plot arrangement was used to evaluate the short-term (2012–2015) effects of tillage (no-till (NT) and conventional tillage (CT)), rotation (maize-fallow-maize (MFM); maize-fallow-soybean (MFS); maize-wheat-maize (MWM) and maize-wheat-soybean (MWS)) and residue management (residue removal (R−) and residue retention (R+)) on bulk density (BD), penetration resistance (PR), soil hydraulic conductivity (Ks) and macroporosity hydraulic conductivity. The interaction of tillage × crop rotation × residue management was not significant ($p > 0.05$) with respect to BD, PR, Ks and macroporosity. The MFM rotation had the highest BD (1.40 g cm^{-3}), followed by MWM rotation (1.36 g cm^{-3}), and the least BD was observed in the MFS rotation (1.29 g cm^{-3}). Penetration resistance was significantly higher in CT (2.43 MPa) compared to NT (1.46 MPa). The study concludes that inclusion of MFS and MWS rotations can potentially reduce BD in the short term. Similarly, conversion from CT to NT reduces soil resistance.

Keywords: soil bulk density; soil penetration resistance; soil moisture; macroporosity

1. Introduction

South African soils are extremely fragile and have low resilience [1]. This is especially true in the Eastern Cape Province, where most soils are low in soil organic matter (SOM) ($<10 \text{ g C kg}^{-1}$) [2,3], which has contributed to lowering their productivity and continues to create high crop production challenges [4]. The smallholder farmer's unsustainable farming practices such as repeated tillage, maize monoculture and burning/removal of crop residues further reduce SOM levels, worsening the degradation of the fragile lands [3,5,6]. Soil degradation is linked to poverty as it reduces soil productivity and potential economic returns for the smallholder farmers. Identifying and developing suitable land-management strategies that can help smallholder farmers adapt and mitigate these challenges is therefore imperative. Conservation agriculture (CA) based on no-till (NT), viable crop rotations and permanent soil cover [7] aims to produce crops in a sustainable manner without any compromise on the current and future of soil productivity or resource availability. Adoption of the technology in the province is low, however, owing to lack of knowledge on the technology as well as socioeconomic and biophysical factors [8].

The perception amongst most smallholder farmers is that non-tilled soils are compacted, harder to work on and more resistant to root penetration and water infiltration than tilled soils [9]. Soil compaction

is recognized as one of the major threats to soil quality [10]. In fact, Moraes et al. [11,12] reported that soil compaction is a major drawback to productivity in the farming sectors because of its ability to reduce porosity, which restricts root distribution and growth as well as inhibiting water and air transmission and circulation. The knowledge of effects of CA on soil compaction and hydraulic properties would help increase adoption of the technology and, potentially, improve both soil and crop productivity amongst the smallholder farmers in the Eastern Cape Province. Bulk density (BD) and soil penetration resistance (PR) are the most common variables used to measure soil compaction.

The ideal BD for plant growth varies for different soil and types of crops. A low BD results in poor soil–root interplay or contact, whereas a high BD decreases aeration and increases soil compaction [9]. Soils with high bulk density and low porosity have a negative influence on saturated hydraulic conductivity (Ks) and infiltration rate [13–15]. Mwendera and Feven [16] found that Ks can decrease directly as a result of an increase in soil compaction associated with reductions in soil macroporosity. Soil strength, which is usually measured as PR, is an essential parameter of soil structure. Soil strength is closely associated with increased bulk density and decreased soil porosity [17] as well as soil moisture content. Nevertheless, studies report that PR is highly sensitive to agronomic practices relative to BD [18]. Soil PR is an ideal soil parameter used for the investigation of the influence of different agronomic operations on soil strength and shows the resilience of roots to navigate the soil volume. According to Pias et al. [19], soil penetration resistance determines the level of soil layer restriction to root growth. The interaction among crop type, soil texture, SOM, mass wetness and particle and aggregate sizes influences the response of soil strength to various crop sequences [20]. Most studies on soil strength have been done in other areas [10,11]; a few have been done in the Eastern Cape Province in south Africa [21].

Various studies have reported the benefits of CA on soil compaction and hydraulic properties, but the results are inconsistent. For example, BD was found to be high under NT compared to CT [9,22,23], while no significant differences were observed [24–26], and reduced BD under NT compared to CT [27–29]. Similar inconsistencies were also reported for PR. Ferreras et al. [30] observed a higher PR in NT at the top 10 cm of soil depth relative to CT. Rusu et al. [31] observed a higher PR in the NT at 20 cm of soil compared to the CT. The same authors reported that tillage effects on PR were because the PR determination is hinged on the state of soil settlement and its humidity.

The inconsistent observations on soil compaction are due to the fact that soil responses to management practices are also influenced by soil type, crop rotation, tillage types and climate [32]. Furthermore, studies that focused on the combined effect of conservation agriculture on soil compaction and soil hydraulic properties are still limited in the Eastern Cape Province context. Spatial variability of soil properties is inherent in nature due to geologic and pedologic soil forming factors, but some of the variability may be induced by tillage and other management practices [33]. Investigating the response of a physical properties of a Haplic Cambisol to management practices of smallholder farmers is vital to understand changes that occur at the local scale. According to Gulser et al. [33], all soil physical properties are weakly spatially dependent for the 6–9 cm soil depth, and moderately spatially dependent for the 27–30 cm soil depth. The study therefore focused on the 0–10 cm depth. The study can be used to apply to a wider scale using applications such as geostatistical tools. Therefore, the objective of this study was to examine the impact of different tillage, crop rotation and crop residue management systems on selected soil physical properties, such as soil BD, PR, soil hydraulic conductivity and macroporosity, on a Haplic Cambisol three years after CA inception in the Eastern Cape region of South Africa. The study hypothesized that in the short-term, the use of CA practices will decrease soil strength and increase soil hydraulic conductivity.

2. Materials and Methods

2.1. Site Selection

The study was carried out at the University of Fort Hare Research Farm (32°46' S and 26°50' E), located at 535 m above sea level. The climate is warm temperate semiarid. According to the South African classification system, the soil is in the Oakleaf soil form [34] and is a Haplic Cambisol according to International Union of Soil Sciences working group [35]. The field is on flat land. Initial soil tests indicated that the soils had 1.57% soil organic carbon and a BD of 1.53 g cm⁻³. The soil type is clay-loam with a texture of 44%, 22% and 34% for sand, silt and clay, respectively. Prior to the establishment of the trial, the field was under lucerne (*Medicago sativa*).

2.2. Trial Layout and Treatments

The experiment was set up in October 2012, and sampling was done after harvesting maize in April 2015, i.e., after a 3-year period. The experiment had a split-split-plot experimental design replicated 3 times (Table 1). The main plots were tillage (no-till (NT) and conventional tillage (CT)), the subplots were crop rotation (maize-fallow-maize (MFM), maize-fallow-soybean (MFS), maize-wheat-maize (MWM) and maize-wheat-soybean (MWS)), while the sub-subplots were crop residue management (residue removal (R−) and residue retention (R+)). The main plot area was 325 m², while the subplots and sub-subplots measured 70 m² and 35 m², respectively.

Table 1. A summary of the treatment factors for the split-split-plot field experiment.

Factor	Treatment	Level
Main plot factor	Tillage	Conventional tillage (CT) No-till (NT)
Subplot factor	Crop rotation	Maize-fallow-maize (MFM) Maize-fallow-soybean (MFS) Maize-wheat-maize (MWM) Maize-wheat-soybean (MWS)
Sub-subplot factor	Residue management	Residue retained (R+) Residue removed (R−)

2.3. Trial Management

The agronomic practices were as described by Mtyobile et al. [26] and Gura and Mnkeni [36]. Before the establishment field was ploughed, it was disked to make a fine tilth to create uniform conditions before the initial crop establishment. Tillage in the CT plots was done at the beginning of the winter and summer seasons every year (Table 2). Ploughing was done to a depth of 20 cm of using a disk plough and subsequently harrowed to make a fine tilth at planting. The maize cultivar BG 5785BR and soybean cultivar PAN 5409RG were sown in the summer seasons, both targeting plant populations recommended for dry land crop production in the province, of 25,000 and 250,000 plants ha⁻¹, respectively [36]. An early maturing, dryland spring wheat cultivar (SST015) was planted in winter (May–August) at a seeding rate of 100 kg ha⁻¹. An inorganic fertiliser 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 the plots. A compound basal fertilizer (6.7% N; 10% P; 13.3% K + 0.5% Zn) was applied at planting to supply all the K and P and a third of the N. The rest of the N was applied as lime ammonium nitrate (28), at 6 weeks after planting. The soybean crop was inoculated with *Rhizobium leguminosarium* before sowing. In the winter seasons, an early maturing wheat cultivar (SST 015) was planted at a seed rate of 100 kg ha⁻¹. At harvest, crop residues were left as surface covers in plots having the residue retention treatment only. All crops were rain-fed.

Table 2. Summary of crops grown in the experiment (2012–2015).

Rotation	Summer 2012/13 (Nov–April)	Winter 2013 (May–Oct)	Summer 2013/14 (Nov–April)	Winter 2014 (May–Oct)	Summer 2014/15 (Nov–April)
MFM	Maize	Fallow	Maize	Fallow	Maize
MFS	Maize	Fallow	Soybean	Fallow	Maize
MWM	Maize	Wheat	Maize	Wheat	Maize
MWS	Maize	Wheat	Soybean	Wheat	Maize

2.4. Measurements

Soil sampling for bulk density, porosity, saturated hydraulic conductivity and water-conducting macroporosity was done at the end of the 2014/15 summer season. Soil bulk density was determined using the core method as described by Okalebo et al. [37]. Undisturbed samples were collected from a depth of 10 cm by driving open-ended plastic core rings made of polyvinyl chloride pipe (11 cm in diameter and 7.7 cm in height) into the soil. Two soil samples were randomly taken in the middle of the net plot in each sub-subplot. The soil sample was dried at 105 °C for 48 h. Bulk density was then calculated as shown in Equation (1):

$$BD = \frac{m}{v} \quad (1)$$

where BD is the bulk density (g cm^{-3}), m is the mass of oven-dried soil (g) and V is the volume of the core (m^3).

The hammer-type dynamic cone penetrometer (DCP) was used to measure penetration resistance as described by Herrick and Jones [38] to assess the impact of the different tillage, crop rotation and crop residue management practices on soil strength. The hammer-type dynamic cone penetrometer was fitted with a 30° hard steel cone with a 20.3 mm diameter shaft. The shaft had a striking plate attached on it. This striking plate forces the steel cone into the soil, while the shaft serves to guide the 2 kg hammer onto the plate. A predetermined drop height of the hammer to ensure uniformity and repeatability was achieved through an adjustable collar. The penetrometer cone was placed onto the soil surface with the shaft in a vertical position. The cone base was made to be at the same level with the soil surface while in contact with soil. The required number of blows to reach a penetrating depth of 0–0.15 m was recorded. Every strike had an equivalent kinetic energy of 12.74 joules. Five measurements per plot (sub-subplot) were done.

Macropores in this study were considered to be pores which would be emptied at a suction head of 3 cm with an equivalent pore radius (r) larger than 0.5 mm, following Watson and Luxmoore [39]. Briefly, a 100 mm mini-graduated ring was placed on top of the undisturbed core sample. The ring was slightly pressed into the core to allow water conduction, at the same time minimising soil disturbance. The ring was ponded to approximately 50 mm with water. Macroporosity was calculated using the Watson and Luxmoore [39] approach from the difference between the ponded (double ring) infiltration rate and the infiltration rate at a tension of 3 cm. The theory behind this approach is that the capillary rise equation (Equation (2)) can be used to calculate the maximum pore size (r in cm) that is filled with water at a certain suction head (h in cm) [40]:

$$r = \frac{2\gamma \cos(\vartheta)}{\rho gh} \sim \frac{0.15}{h} \quad (2)$$

where γ is the surface tension of water (M T^{-2}), ϑ the contact angle between the water and pore wall (assumed to be 0), ρ the density of water (M L^{-3}) and g the gravitational force (L T^{-2}). Equation (1) predicts that all pores with a radius smaller than 0.5 mm will remain water filled at a suction (h) of 3 cm and are therefore responsible for water flux at that suction. Under these conditions, pores with a radius larger than 0.5 mm will not be conducting water.

Saturated hydraulic conductivity was measured using a tension infiltrometer under laboratory conditions to assess the effects of the different tillage, crop rotation and crop residue management practices. For this experiment, undisturbed soil samples were collected using core samplers as described for soil bulk density. The core samples were placed on the top of a gauze and were saturated with water. The calculation of saturated hydraulic conductivity (mm h^{-1}) was done using the modified falling head equation shown in Equation (3) [41]:

$$k_s = \left(\left(\frac{L}{t} \right)^* \frac{L + h_0}{L + h_1} \right) \quad (3)$$

where K_s is the hydraulic conductivity, L the length of soil column (L); h_0 the height of water above surface at time 0, h_1 the height of water above surface at the end and t the time until the water level changed from h_0 to h_1 .

2.5. Data Analysis

A three-way analysis of variance (ANOVA) was performed on all variables using JMP version 14 (SAS Institute, Inc., Cary, NC, USA). Significant differences among treatments of the measured selected soil physical properties that included bulk density, porosity, penetration resistance, saturated hydraulic conductivity, texture and water-conducting macroporosity were identified at $p < 0.05$.

3. Results

3.1. Soil Bulk Density

Three-way interactions of tillage \times crop rotation \times residue management were not significant ($p > 0.05$) with respect to bulk density (Table 3). Similarly, the two-way interactions of tillage \times crop rotation, tillage \times residue management and crop rotation \times residue management had no significant effect ($p > 0.05$) on bulk density in the study. Only the main effects of crop rotation influenced BD ($p < 0.01$) in the short-term study. The rotation of MFM (1.40 g cm^{-3}) had a significantly higher BD relative to MFS (1.29 g cm^{-3}) (Figure 1).

Table 3. p -values of three-way ANOVAs evaluating the effect of tillage (T), residue management (R) and crop rotation (CR) on bulk density (BD), soil resistance (PR), hydraulic conductivity (Ks) and macroporosity after 3 years of cropping in Haplic Cambisol in Alice, Eastern Cape.

Source of Variation	BD	PR	K _s	Macroporosity
Tillage (T)	0.096	0.001	0.374	0.077
Residue management (R)	0.228	0.098	0.908	0.404
Crop rotation (CR)	0.009	0.098	0.787	0.497
T \times R	0.092	0.215	0.136	0.155
T \times CR	0.112	0.654	0.830	0.935
CR \times R	0.935	0.823	0.746	0.063
T \times CR \times R	0.468	0.509	0.733	0.788
CV	15.9	27.8	10.5	11.8

In bold are statistically significant values ($p \leq 0.05$); CV is the coefficient of variation.

The descriptive statistics of BD, PR, and Ks are shown in Table 4.

Table 4. Descriptive statistics of the parameters measured in the study.

	Bulk Density	Penetration Resistance	Hydraulic Conductivity
	(g cm ⁻³)	(MPa)	(mm h ⁻¹)
Minimum	1.16	10.56	1.10
Maximum	1.51	29	210.54
Mean	1.34	18.94	45.10
Coefficient of variance	6.81	25.4	105
Standard deviation	0.09	4.80	47.5

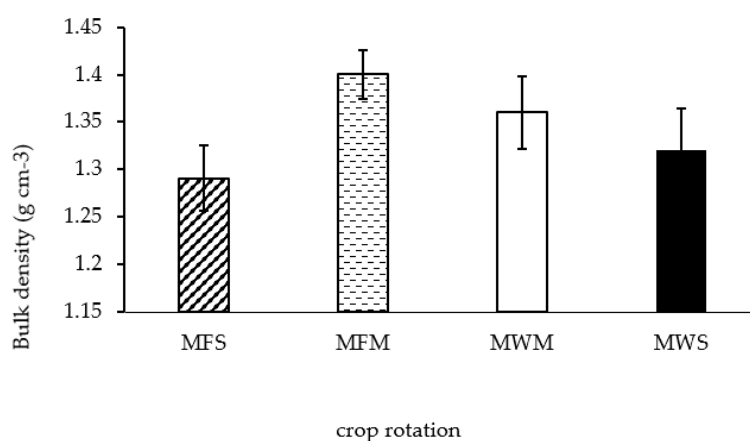


Figure 1. Effects of crop rotation on bulk density after 3 years of cropping. MFM is maize-fallow-maize; MWM is maize-wheat-maize; MWS is maize-wheat-soybean; MFS is maize-fallow-soybean. Error bars indicate standard deviation.

3.2. Penetration Resistance

The interaction of tillage \times crop rotation \times residue management had no effect ($p > 0.05$) on the PR (Table 1). Likewise, the interactions of tillage \times crop rotation, tillage \times residue management and crop rotation \times residue management were not significant ($p > 0.05$) with respect to PR (Table 1). Tillage main effects were significant ($p < 0.001$), while crop rotation and crop residue management were not significant ($p > 0.05$) with respect to PR. Penetration resistance was 40% higher under CT compared to NT (Figure 2).

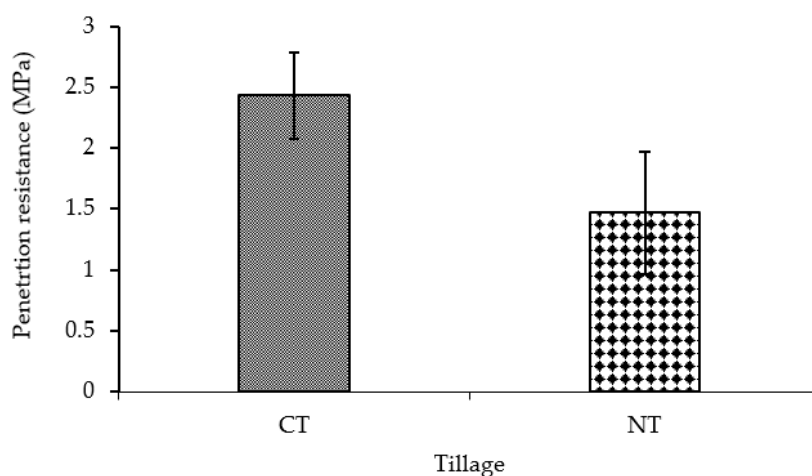


Figure 2. Effects of tillage on to penetration resistance at the 0–0.15 m depth after 3 years of cropping. CT is conventional tillage and NT is no-till. Error bars indicate standard deviation.

3.3. Soil Saturated Hydraulic Conductivity and Water-Conducting Macroporosity

There were no three-way interaction effects ($p > 0.05$) on either soil K_s or water-conducting macroporosity. Two-way interactions of tillage \times crop rotation, tillage \times residue management and crop rotation \times residue management had no effect ($p > 0.05$) on soil hydraulic conductivity and water-conducting macroporosity. Although hydraulic conductivity was higher under NT (58.4 mm h^{-1}) compared to CT (32.8 mm h^{-1}), the difference between the tillage treatments was not statistically significant (Figure 3).

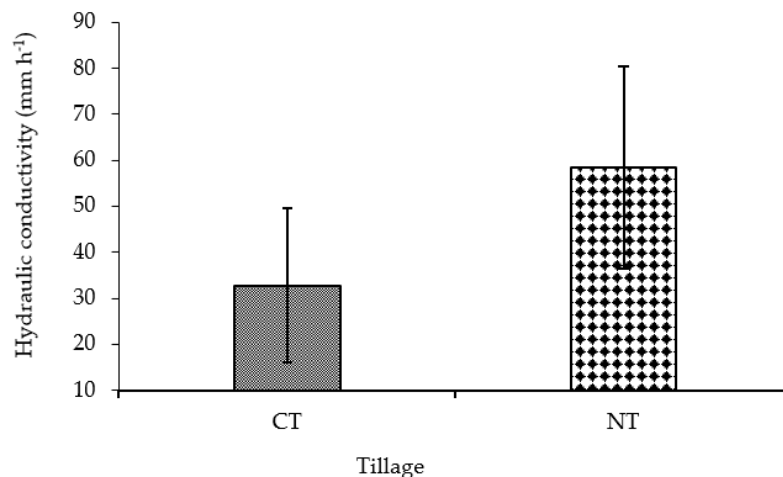


Figure 3. Effects of tillage on hydraulic conductivity at the 0–0.15 m soil depth after 3 years of cropping. Error bars indicate standard deviation. CT is conventional tillage and NT is no-till.

4. Discussion

4.1. Soil Bulk Density

Low BD under MFS relative to MFM rotation could be explained by the rooting system and the differences in decomposition of soybean and maize crop residues. Kavdir et al. [42] reported that the presence of the soybean in a rotation system has the potential to create macropores after decomposition and hence decrease BD. Bulk density is one of the sensitive soil quality indicators which assists to assess the situation with regard to the ease of root penetration, water movement and soil strength [43,44]. A soil BD exceeding 1.3 Mg m^{-3} in a silty soil could adversely disrupt soil aeration through the reduction of air-filled pore spaces [45]. Lower BD under MFS compared to MWM and MWS can possibly be attributed to greater aggregate stability due to greater residue accumulation from maize and wheat compared to soybean. The results from this study indicated no significant differences ($p > 0.05$) in BD between NT (1.42 Mg m^{-3}) and CT (1.34 Mg m^{-3}). The results of the study show that changes in BD in the Eastern Cape Province are visible in the short term (after 3 years), but are likely to occur only under different crop rotations. These findings were similar with other studies which established that BD requires a long period to be impacted by conservation soil management practices. For example, Gura and Mkeni [36] observed no significant difference between NT and CT under similar environmental conditions. Similarly, Ferreras et al. [30] reported no significant difference in BD between tillage systems in a study done on moderately well-drained Chernozemic loam soils in the southern Pampas of Argentina. Soil BD changes take time, but not with a consistent tendency [46].

4.2. Penetration Resistance

The measurement of soil PR ensures a quick and easy way of determining soil strength. Soil strength on a larger scale determines the index and momentum of soil productivity [47] and other soil

hydrological processes [48]. According to the Cornell Soil Health Manual [49], soil with PR of 2.07 MPa inhibits good root growth. The higher PR in this under CT relative to NT in this study could be attributed to soil crusting. A soil PR range of 2.0–3.5 MPa was found to be critical [50]. The findings from this short-term study were inconsistent with studies done elsewhere. Findings by Wilkins et al. [51] asserted that in a long-term study on well-drained loess (Walla Walla silt loam) soils, NT has a higher compaction than CT. In a study done on Albic Luvisols developed on loamy sands, Malecka et al. [52] reported significantly higher PR under NT (1.56 MPa) compared to tilling practices (1.19 MPa) at the 0–0.10 m depth. However, Castellini et al. [53] observed that surface soil compaction can actually occur during springtime regardless of the tillage system adopted in the past season.

4.3. Soil Saturated Hydraulic Conductivity and Water-Conducting Macroporosity

The lack of differences in soil hydraulic properties could be because of the short duration of the CA experimental study. More so, it has been observed that under a continuous NT system, it takes about five years for soil properties to fully stabilize [54,55]. However, numerous factors such as soil type, climate and machinery as well as crop types have been found to influence major changes in soil physical properties on a short-term basis [56]. Research has also found contradictory trends without a definite pattern in the effects of CA treatments on saturated hydraulic conductivity [56]. According to Kodesova et al. [57] and Kargas et al. [58], the higher average saturated hydraulic conductivity under NT is because of a good soil structure, and higher total porosity increased SOM and plant root influences. Moreno et al. [59] posited that the presence of preferential flow paths due to earthworm activities was the reason for higher saturated hydraulic conductivity under NT compared to CT. The biological actions of earthworms affect soil structure and influence soil properties such as porosity and water content [60]. However, Six et al. [61] reported that lower saturated hydraulic conductivity in CT was due to mechanical breakdown of aggregates during tillage, leading to structural degradation in the CT plots. Fuentes [62] and Hu et al. [56] noted that hydraulic properties are prone to temporal surface changes, which could sometimes be a result of the tillage operations and practices employed. In contrast, in an 8-year-long study, Raczkowski et al. [63] found out that a no-till system resulted in lower macroporosity and higher microporosity as compared to conservation tillage. Drees et al. [64] also observed less macroporosity on a silty clay loam under NT for 17 years than under convention tillage. They were able to observe significant differences among the tillage treatments because of the long duration of their experiments. In another experiment, Zhang et al. [65] found, after 24 years, significantly greater macropores (more than 11%) under no-till with residue retention than under conventional tillage with residue burnt. In the 0–3 cm layer of a silt loam soil, Blanco-Canqui and Lal [66] found that the macropores in the treatments where residues were retained were about twice the volume in the treatments where the residues were removed. This study, therefore, demonstrated that crop rotations have little impact on the macroporosity on the short-term basis (3 years).

The lack of significant interactions ($p < 0.05$) with respect to PR and bulk density and soil hydraulic properties reiterates that changes in soil physical properties require time. Changes in soil physical properties are not immediate, and when they change, this is not in a consistent tendency. Seasonal changes in soil properties can be due to factors such as volume and intensity of rainfall, drying and wetting of soil, land position and crop type, among others [67]. Furthermore, the interannual and intra-annual changes in properties such as BD are determined by tillage-induced loosening and soil aggregate fragmentation, soil resettling and aggregation under the impact of biological activity including root growth and rainfall [68]. The scope of this study did not cover seasonal variations, only changes after 3 years.

5. Conclusions

The study of the effects of CA components on BD and PR is very important because of the dynamics of these parameters in influencing farming, crop production and hydrological processes. Lack of significant effects suggests that soil compaction and hydraulic properties in the Eastern Cape

Province are not affected in the short term (after 3 years). The study also concludes that inclusion of MFS and MWS rotations can potentially reduce BD in the short term compared to the traditional MFM cropping system. Conversion from CT to NT reduced soil resistance; therefore, no-till can possibly ensure good soil conditions in the Eastern Cape Province.

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References

1. Njaimwe, A.N.; Mnkeni, P.N.S.; Chiduzza, C.; Muchaonyerwa, P.; Wakindiki, I.I.C. Sensitivity of selected chemical and biological soil quality parameters to tillage and rotational cover cropping at Zanyokwe Irrigation Scheme, South Africa. *S. Afr. J. Plant Soil* **2018**, *35*, 321–328. [[CrossRef](#)]
2. Meadows, M.E.; Hoffman, M.T. The nature, extent and causes of land degradation in South Africa: Legacy of the past, lessons for the future? *Area* **2002**, *34*, 428–437. [[CrossRef](#)]
3. Mandiringana, O.T.; Mnkeni, P.N.S.; Mkile, Z.; Van Averbek, W.; Van Ranst, E.; Verplancke, H. Mineralogy and fertility status of selected soils of the Eastern Cape Province. *S. Afr. Commun. Soil Sci. Plan.* **2005**, *36*, 2431–2446. [[CrossRef](#)]
4. Hoffman, M.T.; Todd, S.; Ntshona, Z.; Turner, S. Land degradation in South Africa. In *A National Review of Land Degradation in South Africa*; South African National Biodiversity Institute: Pretoria, South Africa, 1999. Available online: www.sanbi.org/landdeg (accessed on 18 February 2013).
5. Mkile, Z. The Use and Agronomic Effectiveness of Kraal Manures in the Transkei Region of the Eastern Cape, South Africa. Master's Thesis, University of Fort Hare, Alice, South Africa, 2011.
6. Nyambo, P.; Chiduzza, C.; Araya, T. Carbon input and maize productivity as influenced by tillage, crop rotation, residue management and biochar in a semiarid region in South Africa. *Agronomy* **2020**, *10*, 705. [[CrossRef](#)]
7. FAO (Food and Agriculture Organization). Conservation Agriculture—Matching Production with Sustainability. Available online: www.fao.org/ag/agl/agll/prtcons.stm (accessed on 24 March 2020).
8. Nyambo, P.; Cornelius, C.; Araya, T. Carbon Dioxide Fluxes and Carbon Stocks under Conservation Agricultural Practices in South Africa. *Agriculture* **2020**, *10*, 374. [[CrossRef](#)]
9. Lampurlanes, J.; Cantero-Martinez, C. Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. *Agron. J.* **2003**, *95*, 526–536. [[CrossRef](#)]
10. Tonui, W.; Ndiema, C.; Mutai, E.K. Determination of soil compaction levels by agricultural machinery in cultivated fields using dynamic cone penetrometer. *Int. J. Res. Appl. Sci. Eng. Technol.* **2016**, *4*, 494–500.
11. Moraes, M.T.; Debiasi, H.; Franchini, J.C.; Da Silva, V.R. Correction of resistance to penetration by pedofunctions and a reference soil water content. *Revista Brasileira de Ciência do Solo* **2012**, *36*, 1704–1713. [[CrossRef](#)]
12. Moraes, M.T.; Debiasi, H.; Franchini, J.C.; Da Silva, V.R. Soil penetration resistance in a rhodic eutrudox affected by machinery traffic and soil water content. *Engenharia Agrícola* **2013**, *33*, 748–757. [[CrossRef](#)]
13. Miriti, J.M.; Kironchi, G.; Esilaba, A.O.; Gachene, C.K.K.; Heng, L.K.; Mwangi, D.M. The effects of tillage systems on soil physical properties and water conservation in a sandy loam soil in Eastern Kenya. *J. Soil Sci. Environ. Manag.* **2013**, *4*, 146–154. [[CrossRef](#)]
14. Gicheru, P.T.; Gachene, C.; Mbuvi, J.; Mare, E. Effects of soil management practices and tillage systems on soil surface soil water conservation and crust formation on a sandy loam in semi-arid Kenya. *Soil Tillage Res.* **2004**, *75*, 173–184. [[CrossRef](#)]

15. Bhattacharyya, R.; Prakash, V.; Kundu, S.; Gupta, H.S. Effect of tillage and crop rotations on pore size distribution and soil hydraulic conductivity in sandy clay loam soil of the Indian Himalayas. *Soil Tillage Res.* **2006**, *86*, 129–140. [[CrossRef](#)]
16. Mwendera, E.J.; Feyen, J. Predicting tillage effects on infiltration. *Soil Sci.* **1993**, *155*, 229–235. [[CrossRef](#)]
17. Kilic, K.; Ozgoz, E.; Akba, F. Assessment of spatial variability in penetration resistance as related to some soil physical properties of two fluvents in Turkey. *Soil Tillage Res.* **2004**, *76*, 1–11. [[CrossRef](#)]
18. Fabrizzi, K.P.; Garcia, F.O.; Costa, J.L.; Picone, L.I. Soil water dynamics, physical properties and corn and wheat responses to minimum and no-tillage systems in the southern Pampas of Argentina. *Soil Tillage Res.* **2005**, *81*, 57–69. [[CrossRef](#)]
19. Pias, O.H.D.C.; Cherubin, M.R.; Basso, C.J.; Santi, A.L.; Molin, J.P.; Cimélio, B. Soil penetration resistance mapping quality: Effect of the number of subsamples Acta Scientiarum'. *Agronomy* **2018**, *40*. [[CrossRef](#)]
20. Reichert, J.M.; Da Silva, V.R.; Reiner, D.J. Soil moisture, penetration resistance, and least limiting water range for three soil management systems and black beans yield. In Proceedings of the ISCO 2014—13th International Soil Conservation Organisation Conference, Brisbane, Australia, 4–8 July 2004.
21. Mupambwa, H.A.; Wakindiki, I.I.C. Winter cover crops effects on soil strength, infiltration and water retention in a sandy loam Oakleaf soil in Eastern Cape, South Africa. *S. Afr. J. Plant Soil* **2012**, *29*, 121–126. [[CrossRef](#)]
22. Unger, P.W.; Jones, O.R. Long-term tillage and cropping systems affect bulk density and penetration resistance of soil cropped to dryland wheat and grain sorghum. *Soil Tillage Res.* **1998**, *45*, 39–57. [[CrossRef](#)]
23. Villamil, M.B.; Bollero, G.A.; Darmody, R.G.; Simmons, F.W.; Bullock, D.G. No till corn/soybean systems including winter cover crops: Effects on soil properties. *Soil Sci. Soc. Am. J.* **2006**, *70*, 193–194. [[CrossRef](#)]
24. Logsdon, S.D.; Cambardella, C.A. Temporal changes in small depth-incremental soil bulk density. *Soil Sci. Soc. Am. J.* **2000**, *64*, 710–714. [[CrossRef](#)]
25. Huggins, D.R.; Allmaras, R.R.; Clapp, C.E.; Lamb, J.A.; Randall, G.W. Corn-soybean sequence and tillage effects on soil carbon dynamics and storage. *Soil Sci. Soc. Am. J.* **2007**, *71*, 145–154. [[CrossRef](#)]
26. Mtyobile, M.; Muzangwa, L.; Mnkeni, P.N.S. Tillage and crop rotation effects on soil carbon and selected soil physical properties in a Haplic Cambisol in Eastern Cape, South Africa. *Soil Water Res.* **2020**, *15*, 47–54. [[CrossRef](#)]
27. Nyamadzawo, G.; Chikowo, R.; Nyamugafata, P.; Giller, K.E. Improve legume tree fallows and tillage effects on structural stability and infiltration rates of a kaolinite sandy soil from central Zimbabwe. *Soil Tillage Res.* **2007**, *96*, 182–194. [[CrossRef](#)]
28. Da Veiga, M.; Reinert, D.J.; Reichert, J.M.; Kaiser, D.R. Short and long-term effects of tillage systems and nutrient sources on soil physical properties of a Southern Brazilian Hapludox (1). *Revista Brasileira de Ciência do Solo* **2008**, *32*, 1437–1446. [[CrossRef](#)]
29. Abiven, S.; Menasseri, S.; Chenu, C. The effects of organic inputs over time on soil aggregate stability—A literature analysis. *Soil Biol. Biochem.* **2009**, *4*, 1–12. [[CrossRef](#)]
30. Ferreras, L.A.; Costa, J.L.; Garcia, F.O.; Pecorari, C. Effect of no-tillage on some soil physical properties of a structural degraded Petrocalcic Paleudoll of the southern “Pampa” of Argentina. *Soil Tillage Res.* **2000**, *54*, 31–39. [[CrossRef](#)]
31. Rusu, T.; Bogdan, I.; Marin, D.I.; Moraru, P.I.; Pop, A.I.; Duda, B.M. Effect of conservation agriculture on yield and protecting environmental resources. *AgroLife Sci. J.* **2015**, *4*, 2015.
32. Bescansa, P.; Imaz, M.J.; Virto, I.; Enrique, A.; Hoogmoed, W.B. Soil water retention as affected by tillage and residue management in semi-arid Spain. *Soil Tillage Res.* **2006**, *87*, 19–27. [[CrossRef](#)]
33. Gülser, C.; Ekberli, I.; Candemir, F.; Demir, Z. Spatial variability of soil physical properties in a cultivated field. *Eurasian J. Soil Sci.* **2016**, *5*, 192.
34. Soil Classification Working Group. *Soil Classification—A Taxonomic System for South Africa*, 2nd ed.; Memoirs oor die natuurlike landbouhulpronne van Suid-Afrika No. 15; Department of Agricultural Development: Pretoria, South Africa, 1991.
35. WRB, Iuss Working Group. *World Reference Base for Soil Resources 2014, Update 2015: International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*; FAO Rome: Rome, Italy, 2015.
36. Gura, I.; Mnkeni, P.N.S. Crop rotation and residue management effects under no-till on the soil quality of a Haplic Cambisol in Alice, Eastern Cape, South Africa. *Geoderma* **2019**, *337*, 927–934. [[CrossRef](#)]
37. Okalebo, J.R.; Gathua, K.W.; Woomer, P.L. *Laboratory Methods of Soil Analysis: A Working Manual*, 2nd ed.; TSBR-CIAT and SACRED Africa: Nairobi, Kenya, 2002.

38. Herrick, J.E.; Jones, T.L. A dynamic cone penetrometer for measuring soil penetration resistance. *Soil Sci. Soc. Am J.* **2002**, *66*, 1320–1324. [[CrossRef](#)]
39. Watson, K.W.; Luxmoore, R.J. Estimating Macroporosity in a Forest Watershed by use of a Tension Infiltrometer. *Soil Sci. Soc. Am. J.* **1986**, *50*, 578–582. [[CrossRef](#)]
40. Bear, J. *Dynamics of Fluids in Porous Media*; Elsevier: New York, NY, USA, 1972.
41. Bouwer, H.; Rice, R.C. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. *Water Resour. Res.* **1976**, *12*, 423–428. [[CrossRef](#)]
42. Kavdir, Y.; Rasse, D.P.; Smucker, A.J.M. Specific contributions of decaying alfalfa roots to nitrate leaching in a Kalamazoo loam soil. *Agric. Ecosyst. Environ.* **2005**, *109*, 97–106. [[CrossRef](#)]
43. Grossman, R.B.; Reinsch, T.G. Bulk density and linear extensibility. In *Methods of Soil Analysis Part 4*; Dane, J.H., Topp, G.C., Eds.; SSSA: Madison, WI, USA, 2002; pp. 201–228.
44. Nyambo, P.; Taeni, T.; Chidzuza, C.; Araya, T. Effects of Maize Residue Biochar Amendments on Soil Properties and Soil Loss on Acidic Hutton Soil. *Agronomy* **2018**, *8*, 256. [[CrossRef](#)]
45. Landon, J.; Booker, R. *Tropical Soil Manual: A Handbook of Soil Survey and Agricultural Land Evaluation in the Tropics and Subtropics*; Longman Scientific & Technical; Wiley, Booker/Tate: Hoboken, NJ, USA; Routledge: London, UK, 1991.
46. Ordoñez-Morales, K.D.; Cadena-Zapata, M.; Zermeño-González, A.; Campos-Magaña, S. Effect of tillage systems on physical properties of a clay loam soil under oats. *Agriculture* **2019**, *9*, 62.
47. Bergamin, A.C.; Vitorino, A.C.T.; Franchini, J.C.; Souza, C.M.A.; Souza, F.R. Induced compaction of a Rhodic Acrustox as related to maize root growth. *Revista Brasileira de Ciência do Solo* **2010**, *34*, 681–691. [[CrossRef](#)]
48. Silva, V.R.; Reichert, J.M.; Reinert, D.J.; Bortoluzzi, E.C. Soil water dynamics related to the degree of compaction of two Brazilian Oxisols under no-tillage. *Revista Brasileira de Ciência do Solo* **2009**, *33*, 1097–1104. [[CrossRef](#)]
49. Cornell Soil Health Manual. *Physical Indicator: How Penetration Resistance Relates to Soil Function: Field Penetration Resistance*; Cornell University: New York, NY, USA, 2016; pp. 28–29. Available online: https://www.canr.msu.edu/foodsystems/uploads/files/cornell_soilhealth.pdf (accessed on 18 March 2016).
50. De Moraes, M.T.; Debiassi, H.; Carlesso, R.; Franchini, J.C.; Silva, V.R. Critical limits of soil penetration resistance in a rhodic eutrudox. *Revista Brasileira de Ciência do Solo* **2014**, *38*, 288–298. [[CrossRef](#)]
51. Wilkins, D.E.; Siements, M.C.; Albrecht, S.L. Changes in soil physical characteristics during transition from intensive tillage to direct seeding. *Trans. ASAE* **2002**, *45*, 877–880. [[CrossRef](#)]
52. Małecka, I.; Bleharczyk, A.; Sawinska, Z.; Dobrzeńiecki, T. The effect of various long-term tillage systems on soil properties and spring barley yield. *Turk. J. Agric. For.* **2012**, *36*, 217–226.
53. Castellini, M.; Niedda, M.; Pirastru, M.; Ventrella, D. Temporal changes of soil physical quality under two residue management systems. *Soil Use Manag.* **2014**, *30*, 423–434. [[CrossRef](#)]
54. Alvarez, C.R.; Taboada, M.A.; Gutierrez-Boem, F.H.; Bono, A.; Fernandez, P.L.; Prystupa, P. Topsoil properties as affected by tillage systems in the rolling pampa region of Argentina. *Soil Sci. Soc. Am. J.* **2009**, *73*, 1242–1250. [[CrossRef](#)]
55. Moreira, W.H.; Tormena, C.A.; Karlen, D.L.; da Silvad, A.P.; Keller, T.; Betioli, E., Jr. Seasonal changes in soil physical properties under long-term no-tillage. *Soil Tillage Res.* **2016**, *160*, 53–64. [[CrossRef](#)]
56. Hu, W.; Shao, M.A.; Wang, Q.J.; Fan, J.; Horton, R. Temporal changes of soil hydraulic properties under different land uses. *Geoderma* **2009**, *149*, 355–366. [[CrossRef](#)]
57. Kodešová, R.; Vignozzi, N.; Rohošková, M.; Hájková, T.; Kočárek, M.; Pagliai, M.; Kozák, J.; Šimůnek, J. Impact of varying soil structure on transport processes in different diagnostic horizons of three soil types. *J. Contam. Hydrol.* **2009**, *104*, 107–125. [[CrossRef](#)]
58. Kargas, G.; Kerkides, P.; Poulouvasilis, A. Infiltration of rain water in semi-arid areas under three land surface treatments. *Soil Tillage Res.* **2012**, *120*, 15–24. [[CrossRef](#)]
59. Moreno, F.; Pelegrin, F.; Fernandez, J.E.; Murillo, J.M. Soil physical properties, water depletion and crop development under traditional and conservation tillage in southern Spain. *Soil Tillage Res.* **1997**, *41*, 25–42. [[CrossRef](#)]
60. Medina-Sauza, R.M.; Álvarez-Jiménez, M.; Delhal, A.; Reverchon, F.; Blouin, M.; Guerrero-Analco, J.A.; Cerdán, C.R.; Guevara, R.; Villain, L.; Barois, I. Earthworms building up soil microbiota, a review. *Front. Environ. Sci.* **2019**, *7*, 81. [[CrossRef](#)]

61. Six, J.; Elliott, E.T.; Paustian, K.; Doran, J.W. Aggregation and soil organic matter accumulation in cultivated and native grassland soils. *Soil Sci. Soc. Am. J.* **1998**, *62*, 1367–1377. [[CrossRef](#)]
62. Fuentes, J.P.; Flury, M.; Bezdicsek, D.F. Hydraulic properties in a silt loam soil under natural prairie, conventional tillage and no-till. *Soil Sci. Soc. Am. J.* **2004**, *68*, 1679–1688. [[CrossRef](#)]
63. Raczkowski, C.W.; Mueller, J.P.; Busscher, W.J.; Bell, M.C.; McGraw, M.L. Soil physical properties of agricultural systems in a large-scale study. *Soil Tillage. Res.* **2012**, *119*, 50–59. [[CrossRef](#)]
64. Drees, L.R.; Karathanasis, A.D.; Wilding, L.P.; Blevins, R.L. Micromorphological characteristics of long-term no-till and conventionally tilled soils. *Soil Sci. Soc. Am. J.* **1994**, *58*, 508–517. [[CrossRef](#)]
65. Zhang, S.L.; Simelton, E.; Lovdahl, L.; Grip, H.; Chen, D.L. Simulated long-term effects of different soil management regimes on the water balance in the Loess Plateau, China. *Field Crop. Res.* **2007**, *100*, 311–319. [[CrossRef](#)]
66. Blanco-Canqui, H.; Lal, R. Impacts of long-term wheat straw management on soil hydraulic properties under no-tillage. *Soil Sci. Soc. Am. J.* **2007**, *71*, 1166–1173. [[CrossRef](#)]
67. Alletto, L.; Coquet, Y. Temporal and spatial variability of soil bulk density and near-saturated hydraulic conductivity under two contrasted tillage management systems. *Geoderma* **2009**, *152*, 85–94. [[CrossRef](#)]
68. Karunatilake, U.P.; Van Es, H.M. Rainfall and tillage effects on soil structure after alfalfa conversion to maize on a clay loam soil in New York. *Soil Tillage Res.* **2002**, *67*, 135–146. [[CrossRef](#)]



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