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ONE-TIME CONVENTIONAL TILLAGE, CROP DIVERSIFICATION AND MULCHING ENHANCED HYDRO-PHYSICAL PROPERTIES OF A TROPICAL SANDY LOAM SOIL

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ABSTRACT

Effective soil management is crucial to sustainable crop production in the Anthropocene characterized by intensive and mechanized agrarian activities. This study analyzed integrated measures involving one-time conventional or mechanical tillage followed by no tillage and cereal-legume rotation in the context of conservation agriculture. The aim was to improve the hydro-physical properties of a sandy loam soil located in the semi-deciduous forest zone of Ghana. Twelve treatments arranged in factorial viz. (a) two levels of tillage (continuous conventional tillage of ploughing and harrowing, and one-time conventional to no tillage), (b) three levels of cropping sequence (maize monoculture, cowpea monoculture and cowpea-maize rotation) and (c) two levels of crop residue management (no mulch and mulch) were evaluated. Soil aggregate size distribution and stability, penetration resistance and some hydraulic properties, namely, saturated hydraulic conductivity, infiltration rate and sorptivity, were measured. Interaction between one-time conventional tillage and maize-cowpea rotation increased soil aggregate stability by 34%, with greater proportions in the macro aggregate size range than the interaction of same cropping sequence with continuous conventional tillage. Integrating surface mulch with tillage and maize-cowpea sequence increased mean weight diameter of water stable aggregates from 0.66 to 0.85 mm compared to similar integrated system without mulch. One-time conventional tillage increased cumulative infiltration amount by 45% and sorptivity from 7.51 to 12.24 cm h^{-1} over continuous conventional tillage. Generally, the interaction of one-time conventional tillage with maize-cowpea rotation or maize monoculture and mulch improved grain yield and the soil hydraulic properties of cumulative infiltration, steady state infiltrability and sorptivity. Diversifying tillage operations within the framework of conservation agriculture holds promise for improving soil hydraulic properties and crop yield in sub-Saharan Africa in the era of climate change.

Key words: conservation agriculture, infiltration, soil management, sorptivity, stable aggregates

INTRODUCTION

In this era of climate change, climate-smart agriculture is becoming increasingly important globally with keen concerns for low crop yields in the tropics confronted with erratic rainfall patterns (Logah *et al*., 2024). Thus, soil management measures aimed at enhancing soil moisture retention and other hydro-physical properties are needed. A number of conservation practices such as crop rotation, cover cropping, and mulching have been proposed (Bashagaluke *et al*., 2019) to enhance resilience of tropical cropping systems. Cropping practices impose direct and indirect effects on the condition and productivity of the soil (Norris and Congreves, 2018). For example, tillage influences soil compaction, aggregation and aggregate stability, infiltration rate, moisture storage, erosion and runoff (Kuhwald *et al.,* 2017; Shah *et al.,* 2017; Yadav *et al.,* 2020) whereas monoculture has been noted to upset ecological balance with negative implications for soil health (Thomas *et al*., 2020; Faye and Braun, 2022), Thus, cropping practices that create favourable soil condition for crop growth and yield may prove beneficial in the era of climate change.

Tillage, crop rotation and mulching have received enormous research attention (Fuentes *et al.,* 2009; Curaqueo *et al.,* 2010; Nyamangara *et al.,* 2013; Ezenne *et al.,* 2019) with most studies comparing the impact of conventional and conservation practices on soil properties and crop yield (Liebig *et al.,* 2004; Obalum *et al.,* 2011; Khan *et al.,* 2014; Obalum *et al.,* 2020). The tendency for crop farmers in sub-Saharan Africa to combine different soil management practices suggests that the many scientific reports on unilateral practices may not necessarily contribute to explaining the impact and effects of mingled practices on the soil. Recent studies on merging conventional and conservation agricultural practices have focused on rotational tillage (Wang *et al.,* 2018), one-time conventional tillage (Liu *et al.,* 2016), occasional tillage (Blanco-Canqui and Wortmann, 2020) and conversion of previous tillage practice to no-till. In this context,

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rotational tillage involves following one tillage type with different tillage operation in subsequent cropping season whereas one-time conventional tillage implies tilling the land mechanically once with no further tillage in subsequent season(s). Occasional tillage consists of using some method of soil tillage viz. chiseling, subsoiling, plowing and harrowing in no tillage to mitigate potential problems of soil compaction, weed management, stratification of organic matter and nutrients associated with the no till system (Blanco-Canqui and Wortmann, 2020).

However, there is limited information on the interactive effect of such tillage practices within the framework of conservation agriculture on dynamic soil hydro-physical properties. This is despite the importance of such information in climate-driven crop production in the Anthropocene. In this paper, we hypothesized that one-time conventional tillage followed by no-tillage could offset soil degrading effect from continuous conventional tillage and provide a realistic benefit from no-tillage practice for sustainable soil management. We thus aimed at examining the appropriateness of alternative cropping practices such as one-time conventional tillage and its combination with cereal-legume rotation and mulching for improving soil aggregate stability and infiltration characteristics. We also assessed the effect thereof on maize grain yield.

MATERIALS AND METHODS

Description of Study Area

The study was conducted at the Agricultural Research Station, Anwomaso (6° 41′ 21.68″ N, 1° 30′ 53.97″ W) of the Faculty of Agriculture (Figure 1), Kwame Nkrumah University of Science and Technology, Ghana. Climatic condition of the area is of the tropical monsoon (http//nationalgeographic.com) with a bimodal rainfall pattern and mean monthly temperature ranging from 24 to 28°C. The annual rainfall during the experiment was low (averaging 168.32 mm) compared to the overall average of the semi-deciduous forest zone of about 1500 mm. Humidity during the period ranged between 67.20 and 83.40%. The soil the study area was classified as a Haplic Plinthosol (FAO, 1998). Its sand, silt and clay distributions were 66-82%, 4-11%, and 12-30%, respectively. The texture varied from sandy loam to loamy sand. The bulk density ranged from 1.36 to 1.78 Mg m^{-3} with soil organic matter content of 0.41-2.68%. The field was laid fallow for one year prior to the experiment.

Experimental Design

The experiment was carried out in four consecutive cropping seasons on same plots. Two levels of tillage, three levels of cropping sequence, and two levels of crop residue management were factorially combined to give twelve treatment combinations. The tillage treatments comprised continuous conventional (Ct) and one-time conventional (Cs) tillage. The cropping sequence consisted of maize monoculture (Mm), cowpea monoculture (Cm) and cowpea-maize rotation (CMr) with the two levels of crop residues management designated as no mulch (R–) and mulch (R+). The experimental design was split-split arrangement replicated three times, with tillage as main plot factor, cropping sequence as sub-plot factor, and crop residue management as sub-sub-plot factor. Each of the main plots measured 7.90 × 15 m, sub-plots, 7.90 × 4 m, and sub-sub plots, 3.20 × 4 m. The main and sub-plots were 2 m and 1.50 m apart, respectively.

The Ct involved disc or tractorized ploughing to 20-25 cm depth followed immediately by disc harrowing. In the first season of the experiment, all plots were tractor-tilled and harrowed, no mulch was applied, and maize (variety Omankwa) and cowpea (variety Asontem) were cultivated especially for the CMr plots. In the second to the fourth seasons, Ct was carried out on three randomly selected main plots labeled while others were left untilled. Again, crops were cultivated in the subplots. Similarly, crop residues (maize stover, maize husk, cowpea haulm and emptied pods) harvested from the previous season were used in mulching designated sub-sub plots.

The major cropping seasons spanned from April to July. Minor season cropping was carried out between September and November. Maize residue was applied to plots cultivated to maize and cowpea residue to plots cultivated to cowpea. In the case of plots cultivated to maize and cowpea in rotation, the residues of both crops were applied in rotation. Even amount of either maize or cowpea residue was allocated per plot by dividing the total residue dry matter (of maize or cowpea) with the number of plots cultivated. Crop residues were applied to plots after land preparation before planting. For maize residues, 3.00, 7.20 and 6.30 kg plot^{-1} equivalent to 2.34, 5.63 and 4.92 Mg ha^{-1} dry matter, respectively were applied consecutively in the second, third and fourth seasons. For cowpea, 6.50, 1.56 and 6.08 kg plot^{-1} equivalent to 5.07, 1.22 and 4.75 Mg ha^{-1} dry matter, respectively were used.

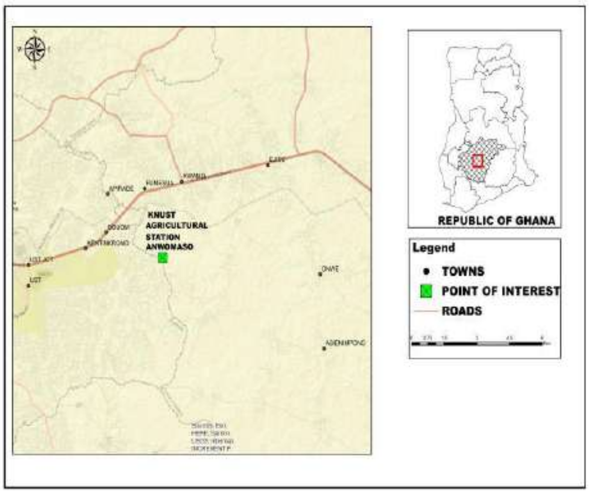


Figure 1: Map of the study area

Soil Sampling and Analysis

Disturbed and undisturbed soil samples were collected from the 0-15 and 15-30 cm depths before treatment application after the last crop harvest. Triplicate disturbed soil samples were collected diagonally across the field at 1 m intervals with the aid of auger and core samplers and were composited and transported in zipper polybags to the laboratory. Also, after crop harvest, the disturbed and undisturbed samples were collected in triplicates from the base of plants in the middle rows within 6 m^2 of each sub-sub plot. The disturbed samples were composited for each plot, air-dried and sieved for analysis of soil chemical properties. Core sampler was used to collect undisturbed soil samples which were subsequently oven-dried at 105°C for 48 h and used for the determination of soil bulk density (Blake and Hartge, 1986) and volumetric moisture content (ϴv cm^3 cm^{-3}).

Measurement of Penetration Resistance and Infiltration Test

Penetration resistance and infiltration rate were measured *in situ*. Penetration resistance was measured in the field using a spring-type proctor penetrometer (Wagtech® International) penetrating to a maximum depth of 12 cm with a cone diameter of 1.654 cm to assess the pressure required to penetrate the soil. The penetrability of the soil was measured at 2 cm intervals from the top 2 cm to 10 cm depth. Soil moisture at the time of measurement was 0.05-0.11 cm^3 cm^{-3} (v/v). Soil resistance to penetration was measured in triplicates at an angle of 60º in each sub-sub plot near the base of plants. At each insertion, measurement was made to 10 cm depth (Blanco-Canqui *et al.*, 2011). Penetration resistance was recorded in kg cm^{-2} and converted to kPa (Khan *et al.,* 2014; Tanveer *et al.,* 2014).

Infiltration test was conducted *in situ* after crop harvest using the constant head method (Klute and Dirksen, 1986) at an initial moisture content of 0.09-0.10 cm^3 cm^{-3}. A 10-cm diameter and 30-cm height single ring infiltrometer (made from PVC pipe) was inserted into the soil to the depth of 15 cm. A thin layer of crop residue was used to cover the soil surface within the infiltrometer to minimize the agitation of soil particles and the tendency for pore blockage. A constant head of 5 cm was maintained in the infiltrometer with water added from a graduated measuring cylinder. The infiltration measurement continued for 60 min. at pre-determined time intervals. A graph of cumulative infiltration amount (*I*) as a function of time (*t*) was plotted. Sorptivity (*S*) which represents the soil's ability to absorb/desorb water by capillary processes (Ogban, 2017; Ezenne *et al.,* 2019), was obtained from the plot of cumulative infiltration amount and square root of time at the first 5 min. (Philip, 1957).

Saturated Hydraulic Conductivity

Core samplers, 10 cm in diameter were used to collect undisturbed soil to 10 cm depth after crop harvest. The falling head method as described by Bonsu and Laryea (1989) was followed. The soil was initially saturated and subsequently ponded to a 10 cm height. The time taken for a drop in height of water by 2 cm interval was recorded. The fall of the hydraulic head from the initial at the soil surface was measured as a function of time using a stopwatch and a manometer. The saturated hydraulic conductivity was calculated as:

$$Ks = \left(\frac{\mathrm{AL}}{\mathrm{A1t}}\right) \mathrm{In}\left[\frac{\mathrm{H_o}}{\mathrm{H_t}}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1);$$

where K_s is saturated hydraulic conductivity, A is surface area of the cylinder, AL is surface area of the soil, $\mathrm{H_o}$ is initial hydraulic head, t is time in seconds, and L is length of the soil sample (mm). A graph of In $\left[\frac{\mathrm{H_o}}{\mathrm{H_t}}\right]$ against t gave a slope of $b = \frac{\mathrm{KsA1}}{\mathrm{AL}}$ with K_s estimated as the product of the slope (b) of the ratio of natural log of initial and new hydraulic head over time and the length of soil column (L).

Aggregate Size Distribution

Three set of sieves 2 mm, 1 mm, and 0.25 mm were used in assessing water stable aggregates (Kemper and Rosenau, 1986). A 100 g of air-dry soil was gradually moistened to avoid spontaneous rupture of aggregates. The moistened soil was transferred onto the first sieve and sieving was done sequentially. Wet sieving of soil was done in a 2-L basin for 10 min. at 30 rpm. Soil remaining on each sieve was quantitatively transferred into re-weighed containers and oven dried at 105℃. Subsequently, the stability of soil aggregates was measured using the mean-weight diameter of soil aggregates (Kemper and Rosenau, 1986):

$$\mathrm{MWD\ (mm)} = i\sum_{=1}^{n} \overline{\mathrm{x_i}}\ \mathrm{w_i} \ldots\ldots\ldots\ldots. (2);$$

where MWD is mean-weight diameter of soil aggregates, $\overline{\mathrm{x_i}}$ is the mean diameter of each size fraction, and w_i is proportion of the total sample weight occurring in the corresponding fraction.

Statistical Analysis

The data were entered in Microsoft Excel and exported to GenStat version 12.10 (VSN International Ltd, UK) for statistical analysis. The data were initially examined for satisfaction of the assumptions of analysis of variance (ANOVA). The ANOVA for split-split design was used to assess the main effects of treatments and their interactions on the measured soil parameters. Significant treatment effects were observed at $P_{0.05}$. The second order treatment interactions, which were more reflective of farmer practice alongside the main effects, are presented in this paper.

RESULTS

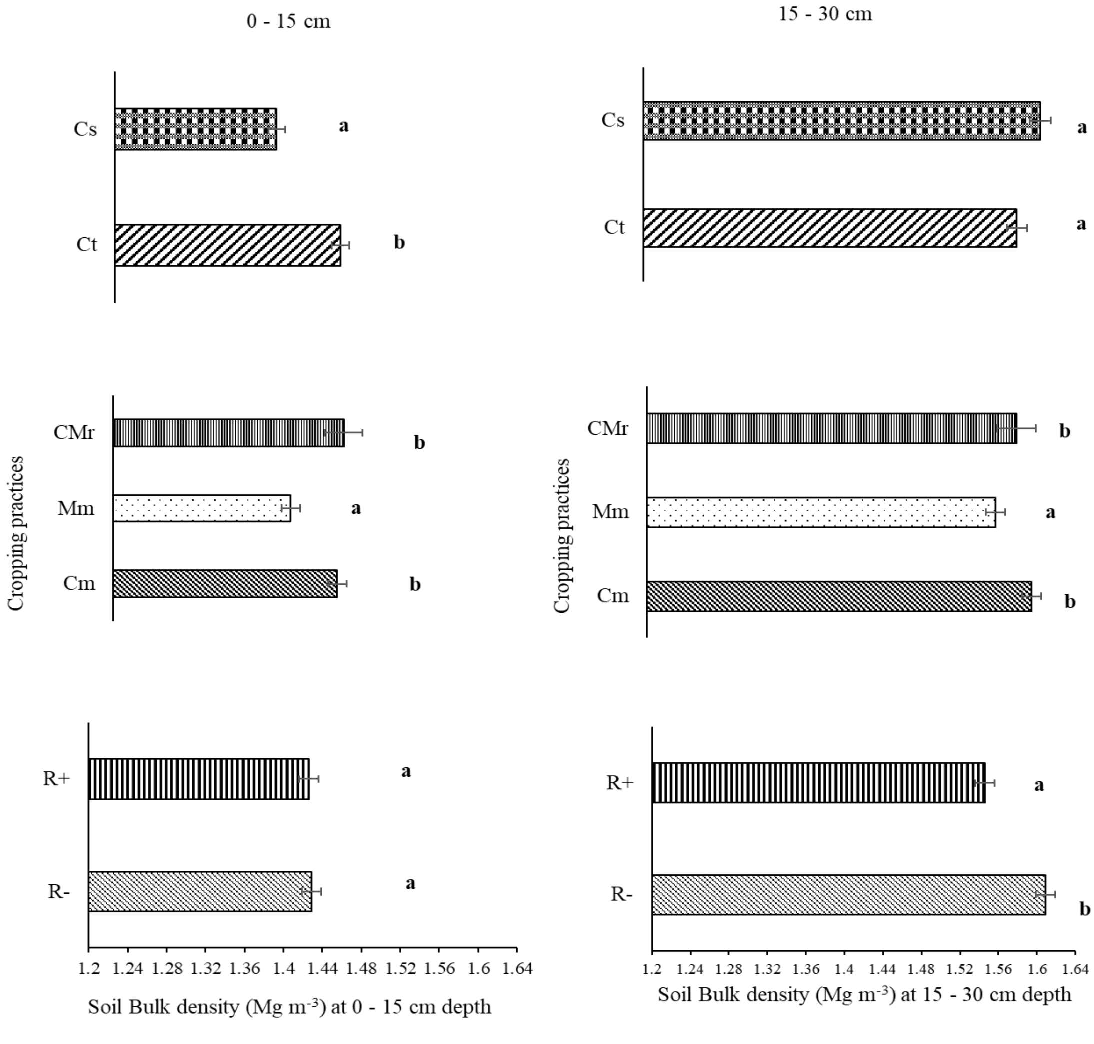
Dry Bulk Density

The results of soil bulk density, an indicator of soil compaction suggested that one-time tractorized or conventional tillage (Cs), maize monoculture (Mm) or sometimes cowpea-maize rotation (CMr) and mulch (R+) were very important soil management practices. Soil bulk density was significantly lower ($p < 0.05$) in the topsoil (0-15 cm) under one-time conventional tillage (1.46 Mg m^{-3}) than continuous conventional tillage (1.38 Mg m^{-3}) (Figure 2).

At the 15-30 cm depth however, ρb was lower under Ct (1.58 Mg m^{-3}), but the difference was not significant ($p = 0.245$) from Cs (1.56 Mg m^{-3}). Meanwhile, the effect of cropping sequence on bulk density was significant at both soil depths. Maize monoculture (Mm) was the sole practice that produced the lowest significant effect ($p < 0.05$) on bulk density in both the top- (1.392 ± 0.015 Mg m^{-3}) and subsoils (1.558 ± 0.015 Mg m^{-3}). Bulk density values recorded under cropping sequence were in the order: Mm < Cm < CMr in the topsoil and Mm < CMr < Cm in the subsoil. Crop residue management had no significant effect ($p = 0.676$) on bulk density in the topsoil (Figure 2). Notwithstanding, in the subsoil, bulk density was significantly lower ($p < 0.05$) under mulch (R+) than no mulch (R–). Treatments interacted significantly at both soil depths to affect bulk density. In the topsoil, the lowest significant ($p < 0.05$) bulk density was obtained under Cs x Mm x R+ (Figure 3) whereas in the subsoil, the least significant value ($p < 0.05$) was recorded under Ct × CMr × *R*+ (Figure 3).

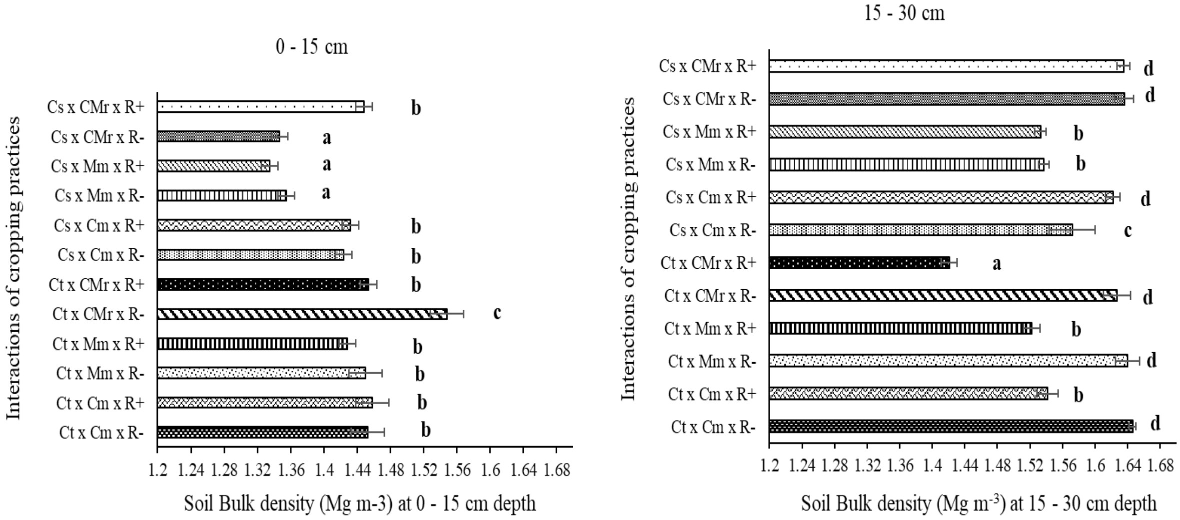
Penetration Resistance

The penetration resistance (PR) was generally lower under Cs (ranging between 6 and 15%). As soil depth increased above 4 cm, Cs showed significantly lower soil penetration resistance than Ct (Figure 4A). No clear differences were observed among cropping sequence (Figure 4B). At all the soil depths, PR was significantly lower for mulched soils than no-mulch soils (Figure 4C). In most cases, treatment interactions that recorded lower ($p < 0.05$) PR values (Figure 5) were also often better than their main effects. Penetration resistance was positively associated with bulk density mostly at 15-30 cm soil depth under cropping practices except Cm, even though the degree of association was not statistically significant (Table 3).



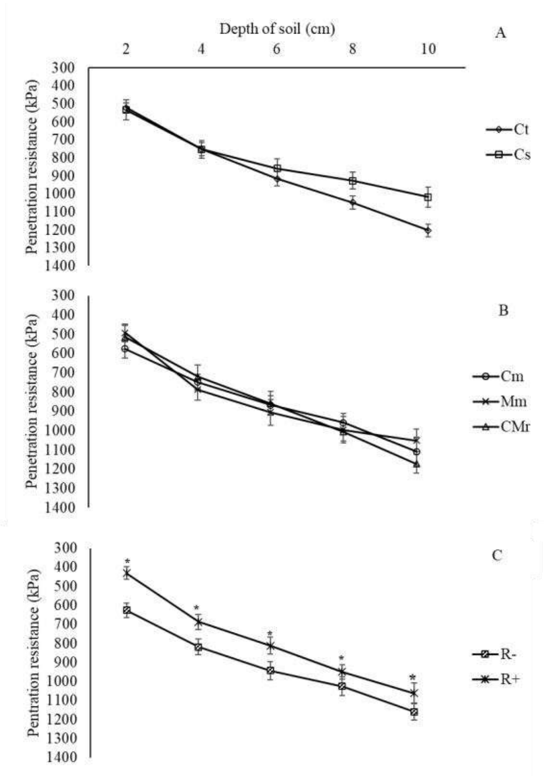
CMr is cowpea-maize rotation, Mm is maize monoculture, Cs is one-time conventional tillage,
Ct is continuous conventional tillage; significant differences were measured at $p < 0.05$.

Figure 2: Main effects of cropping practices on soil bulk density at the 0-15 cm and 15-30 cm depths



CMr is cowpea-maize rotation, Mm is maize monoculture, Cs is one-time conventional tillage,
Ct is continuous conventional tillage, R+ is mulch, R– is no mulch; significant differences were measured at $p < 0.05$.

Figure 3: Interaction effects of cropping practices on soil bulk density at the 0-15 cm and 15-30 cm depths



CMr is cowpea-maize rotation, Mm is maize monoculture, Cs is one-time conventional tillage, Ct is continuous conventional tillage, R+ is mulch, R– is no mulch; significant differences were measured at $p < 0.05$.

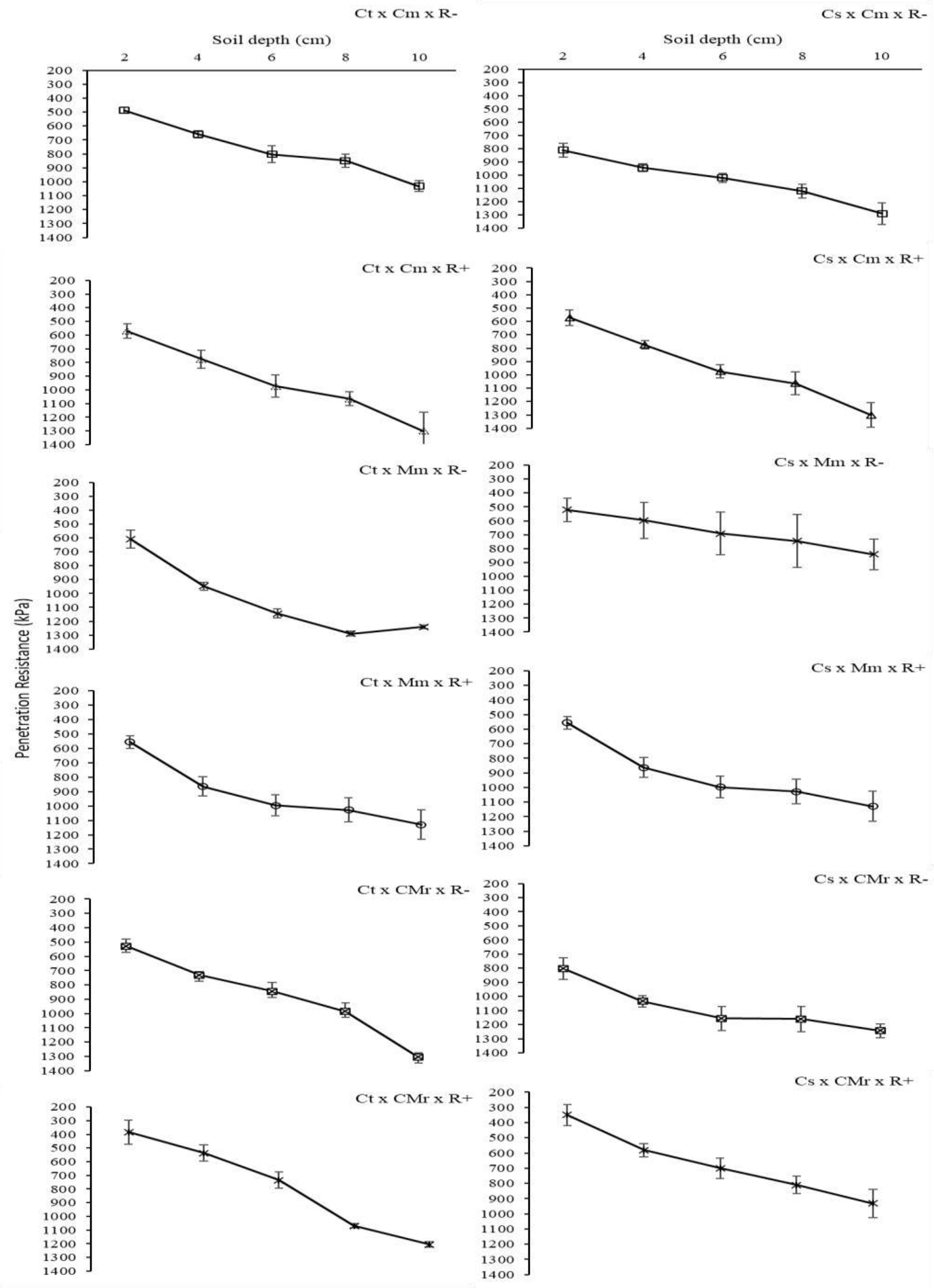
Figure 4: Main effects of tillage (A), crop rotation (B), and mulching (C) on penetration resistance at 2 to 10 cm depth

Soil Hydraulic Properties

Results point to significant influence of tillage, cropping sequence and crop residue management on soil hydraulic properties (Table 1). One-time conventional or tractorized tillage followed by no tillage increased cumulative infiltration and saturated hydraulic conductivity by 45 and 63%, respectively over continuous conventional tillage. Maize in rotation with cowpea (CMr) increased cumulative infiltration amount and sorptivity more by 48% and 14%, respectively than maize monoculture (Mm). Similarly, mulch application increased cumulative infiltration amount, sorptivity and steady-state infiltrability by 91%, 5%, and 45% than no mulch. The interactions of cropping practices (Table 2) pointed to a greater tendency to significantly impact the hydraulic properties of the soil when the interaction included Cs, Mm or CMr and R+. This is evidenced by the significantly ($p < 0.05$) higher values of cumulative infiltration amount (2823 mm), sorptivity (167.12 mm $s^{-1/2}$) and steady state infiltrability (0.53 mm s^{-1}) under Cs × CMr × R+ usually followed by Cs × Mm × R+ (1947 mm, 148.24 mm $s^{-1/2}$, 0.38 mm s^{-1}, respectively). A significantly ($p < 0.05$) higher K_s (16.74 cm h^{-1}) was observed under Cs × Mm × R. Notwithstanding, the effect under Cs × Mm × R– was statistically similar to Cs × Mm × R+ and Cs × CMr × *R*+. Regarding their association, K_s was always negatively associated with ρb and PR (Table 3).

Soil Aggregate Size Distribution and Aggregate Stability

In the surface soil (0-15 cm), one-time conventional tillage under maize-cowpea rotation and mulch increased soil aggregate stability with greater proportions of 79.71% in the macro aggregate size range (> 0.25 mm) than continuous conventional tillage under same cropping system with 61.42%, which had more micro-aggregates (Table 4). As expected, continuous conventional tillage increased soil micro-aggregate stability by 28% more than conventional tillage-no tillage in the surface soil. Maize monoculture enhanced stable macro-aggregate distribution better than continuous cowpea cultivation in both surface and subsoil (Tables 4 and 5).



CMr is cowpea-maize rotation, Mm is maize monoculture, Cs is one-time conventional tillage,
Ct is continuous conventional tillage, R+ is mulch, R– is no mulch; significant differences were measured at $p < 0.05$.

Figure 5: Interaction effects of cropping practices on penetration resistance at 2 cm to 10 cm soil depth

Table 1: Main effects of cropping practices on selected soil hydro-physical properties

Cropping practices		K_s (cm h^{-1})	I (mm)	S (mm s$^{-1/2}$)	K_o (mm s^{-1})
Tillage	Ct	7.51	920.00	49.60	0.23
	Cs	12.24*	1338.00	96.10	0.26
	$LSD_{0.05}$	*1.87*	*401.80*	*ns*	*ns*
Cropping sequence	Cm	9.08	760.00	50.10	0.19
	Mm	11.09*	1060.00	78.90	0.23
	CMr	9.45	1567.00*	89.60	0.32
	$LSD_{0.05}$	*ns*	*188.10*	*12.34*	*0.02*
Crop residue management	R–	10.31	774.00	57.90	0.20
	R+	9.44	1485.00	87.80	0.29
	$LSD_{0.05}$	*ns*	*156.10*	*15.80*	*0.02*

* - statistically significant at $p < 0.05$, K_s - saturated hydraulic conductivity, I - cumulative infiltration amount, S - sorptivity, K_o - steady state infiltrability, CMr - cowpea-maize rotation, Mm - maize monoculture, Cs - one-time conventional tillage, Ct - continuous conventional tillage, R+ - mulch, R– - no mulch, ns - not statistically significant at $p < 0.05$, $LSD_{0.05}$ - least significant difference

Table 2: Interactions effect of cropping practices on selected soil hydro-physical properties

Interaction effects	K_s (cm h^{-1})	I (mm)	S (mm s$^{-1/2}$)	K_o (mm s^{-1})
Ct × Cm × R–	10.44	377.00	24.67	0.19
Ct × Cm × R+	7.74	1152.00	59.41	0.24
Ct × Mm × R–	7.56	568.00	43.90	0.22
Ct × Mm × R+	6.48	1032.00	62.07	0.23
Ct × CMr × R–	7.44	1144.00	68.14	0.25
Ct × CMr × R+	5.40	1249.00	39.65	0.24
Cs × Cm × R–	9.50	807.00	65.93	0.14
Cs × Cm × R+	8.64	706.00	50.32	0.16
Cs × Mm × R–	16.74	693.00	61.48	0.14
Cs × Mm × R+	13.60	1947.00	148.24	0.32
Cs × CMr × R–	10.20	1054.00	83.50	0.27
Cs × CMr × R+	14.76	282.00	167.12	0.53
CV (%)	14.20	19.00	29.90	10.30
$LSD_{0.05}$	2.36	384.00	39.20	0.04

CMr - cowpea-maize rotation, Mm - maize monoculture, Cs - one-time conventional tillage, Ct - continuous conventional tillage, R+ - mulch, R– - no mulch, K_s - saturated hydraulic conductivity, I - cumulative infiltration amount, S - sorptivity, K_o - steady state infiltrability, $LSD_{0.05}$ - least significant difference, CV - coefficient of variation

Table 3: Correlation of selected soil hydro-physical parameters

Cropping practice	Parameters	$\rho b_{0\text{-}15\ cm}$	$\rho b_{15\text{-}30\ cm}$	K_s
Ct	kPa at 2 cm	–0.0620 (0.8069)	0.3480 (0.1570)	0.1621 (0.5025)
	kPa at 4 cm	–0.0788 (0.7561)	0.4289 (0.0758)	0.1160 (0.6468)
	kPa at 6 cm	–0.2132 (0.3956)	0.3088 (0.2125)	0.0265 (0.9169)
	kPa at 8 cm	–0.1271 (0.6152)	–0.0354 (0.8890)	–0.2562 (0.3049)
	kPa at 10 cm	0.3843 (0.1153)	–0.0738 (0.7712)	–0.1166 (0.6449)
	K_s	–0.0012 (0.9962)	0.6890 (0.0016)*	
Cs	kPa at 2 cm	–0.1180 (0.6409)	0.2401 (0.3371)	–0.4386 (0.0686)
	kPa at 4 cm	–0.3264 (0.1862)	0.1838 (0.4654)	–0.5196 (0.0271)*
	kPa at 6 cm	–0.2958 (0.2334)	0.2382 (0.3412)	–0.4318 (0.0735)
	kPa at 8 cm	–0.2496 (0.3178)	0.2419 (0.3335)	–0.4642 (0.0523)
	kPa at 10 cm	–0.2263 (0.3665)	0.1913 (0.4469)	–0.3562 (0.1468)
	K_s	–0.2688 (0.2807)	–0.4425 (0.0660)	
Cm	kPa at 2 cm	–0.2159 (0.5004)	–0.4013 (0.1960)	0.2747 (0.3875)
	kPa at 4 cm	–0.0299 (0.9265)	–0.5288 (0.9265)	0.1407 (0.6628)
	kPa at 6 cm	0.0859 (0.7907)	–0.5964 (0.0407)*	–0.0822 (0.7994)
	kPa at 8 cm	0.0419 0.8971)	–0.5457 (0.0665)	–0.0725 (0.8228)
	kPa at 10 cm	0.1009 (0.7549)	–0.5398 (0.0701)	0.0468 (0.8852)
	K_s	–0.1136 (0.7251)	0.4130 (0.1821)	
Mm	kPa at 2 cm	0.5089 (0.0911)	0.4105 (0.1851)	–0.5007 (0.0973)
	kPa at 4 cm	0.5156 (0.0862)	0.5420 (0.0687)	–0.7754 (0.0030)*
	kPa at 6 cm	0.6176 (0.0324)*	0.6394 (0.0252)*	–0.7921 (0.0019)*
	kPa at 8 cm	0.5732 (0.0514)	0.7301 (0.0070)*	–0.7347 (0.0065)*
	kPa at 10 cm	0.4865 (0.1087)	0.5546 (0.0613)	–0.7400 (0.0059)*
	K_s	–0.7300 (0.0070)*	–0.3663 (0.2415)	
CMr	kPa at 2 cm	–0.4984 (0.0991)	0.3735 (0.2317)	–0.0691 (0.8311)
	kPa at 4 cm	–0.5568 (0.0600)	0.5265 (0.0787)	0.0897 (0.7817)
	kPa at 6 cm	–0.5751 (0.0504)	0.3624 (0.2471)	0.0261 (0.9358)
	kPa at 8 cm	–0.4153 (0.1795)	–0.1956 (0.5425)	–0.4238 (0.1698)
	kPa at 10 cm	0.1124 (0.7281)	–0.1269 (0.6942)	–0.5896 0.0436)*
	K_s	–0.3335 (0.2895)	0.6292 (0.0284)*	
R–	kPa at 2 cm	–0.4457 (0.0638)	0.0404 (0.8737)	–0.1973 (0.427)
	kPa at 4 cm	–0.1920 (0.4453)	0.3654 (0.1359)	–0.5412 (0.0204)*
	kPa at 6 cm	–0.1278 (0.6132)	0.4664 (0.0510)	–0.5707 (0.0134)*
	kPa at 8 cm	0.0443 (0.8614)	0.4806 (0.0435)*	–0.6673 (0.025)*
	kPa at 10 cm	0.3949 (0.1048)	0.5510 (0.0178)*	–0.8400 (< 0.001)*
	K_s	–0.6177 (0.0063)*	–0.6401 (0.0042)*	
R+	kPa at 2 cm	0.3867 (0.1129)	–0.0681 (0.7883)	–0.4915 (0.0383)*
	kPa at 4 cm	–0.2213 (0.3775)	0.0049 (0.9846)	–0.1285 (0.6112)
	kPa at 6 cm	–0.0450 (0.8594)	–0.1927 (0.4435)	–0.2810 (0.2586)
	kPa at 8 cm	0.0627 (0.08047)	–0.5605 (0.0155)*	–0.4191 (0.0834)
	kPa at 10 cm	0.1592 (0.5281)	–0.5278 (0.0244)*	–0.3255 (0.1874)
	K_s	0.5533 (0.0727)	0.5533 (0.0172)*	

* - statistically significant at $p < 0.05$, p values are shown in parentheses, Ct - continuous conventional tillage, Cs - tillage rotation, Cm - cowpea monoculture, Mm - maize monoculture, CMr - cowpea-maize rotation, R– - no residue mulch, R+ - residue mulch retained, $\rho b_{0\text{-}15\ cm}$ - soil bulk density at 0-15 cm depth, $\rho b_{15\text{-}30\ cm}$ - soil bulk density at 15-30 cm depth, K_s - saturated hydraulic conductivity

Table 4: Aggregates size distribution and aggregates stability obtained by wet sieving at 0-15 cm and 15-30 cm soil depth for main cropping practices

Practice	% Distribution of the different aggregate size ranges (mm)				MWD (mm)
	4-2	2-1	1-0.25	< 0.25	
Tillage	0-15 cm depth				
Ct	13.27	14.52	36.48	37.73	0.69
Cs	14.35	16.41	39.73	29.51	0.76
CV (%)	29.40	16.40	22.70	39.80	19.30
$LSD_{0.05}$	1.58	0.35	2.80	3.51	0.03
Crop rotation					
Cm	10.07	15.36	29.48	45.08	0.59
Mm	17.44	15.96	43.67	22.93	0.83
CMr	13.91	15.07	41.16	29.86	0.75
CV (%)	19.00	17.80	15.70	28.40	13.70
$LSD_{0.05}$	2.47	1.95	4.96	6.83	0.07
Mulching					
R–	12.69	13.58	36.62	37.10	0.67
R+	14.92	17.35	39.59	28.14	0.77
CV (%)	28.50	12.00	22.80	38.40	18.60
$LSD_{0.05}$	1.27	0.76	0.87	1.13	0.01
Tillage	15-30 cm depth				
Cs	14.91	14.50	36.30	34.29	0.71
CV (%)	41.00	24.60	14.80	35.90	18.50
LSD0.05	ns	2.47	ns	ns	ns
Crop rotation					
Cm	7.91	12.56	32.81	46.72	0.57
Mm	16.68	17.30	36.82	29.20	0.76
CMr	18.01	18.60	37.35	26.04	0.80
CV (%)	24.60	21.20	13.90	22.30	11.50
$LSD_{0.05}$	3.49	2.70	5.58	3.83	0.04
Mulching					
R-	12.47	14.63	33.48	39.43	0.65
R+	15.93	17.68	37.85	28.54	0.77
CV (%)	39.20	25.00	13.40	31.60	16.30
$LSD_{0.05}$	0.99	1.76	1.12	2.38	0.02

Ct - continuous conventional tillage, Cs - tillage rotation, Cm - cowpea monoculture, Mm - maize monoculture, CMr - cowpea-maize rotation, R– - no residue mulch, R+ - residue mulch retained, MWD - mean weight diameter, CV - coefficient of variation, LSD - least significant difference, ns - not significant at *F* probability 0.05

Table 5: Aggregates size distribution and aggregates stability obtained by wet sieving at 0-15 cm and 15-30 cm soil depth for cropping practices interactions

Practice interactions	Aggregate size range (mm)				MWD (mm)
	4-2	2-1	1-0.25	< 0.25	
	0-15 cm depth				
Ct × Cm × R-	8.66	13.15	31.43	46.75	0.57
Ct × Cm × R+	10.45	17.66	34.67	37.23	0.67
Ct × Mm × R-	14.66	13.40	39.53	32.41	0.73
Ct × Mm × R+	20.59	16.17	45.00	18.24	0.88
Ct × CMr × R–	12.10	12.18	33.54	42.18	0.62
Ct × CMr × R+	12.14	14.57	34.71	37.58	0.67
Cs × Cm × R–	9.61	13.39	24.72	52.24	0.51
Cs × Cm × R+	11.55	17.25	27.12	44.07	0.60
Cs × Mm × R–	15.15	14.81	44.22	25.82	0.80
Cs × Mm × R+	19.37	19.46	45.93	15.24	0.91
Cs × CMr × R–	15.98	14.55	50.08	23.17	0.82
Cs × CMr × R+	14.44	18.97	46.30	16.51	0.90
Mean	13.81	15.46	38.10	32.62	0.72
CV (%)	12.70	6.80	3.20	4.80	2.30
$LSD_{0.05}$	3.44	2.48	5.91	8.09	0.08
	15-30 cm depth				
Ct × Cm × R–	5.62	12.49	28.99	52.91	0.51
Ct × Cm × R+	7.16	14.13	33.31	45.40	0.59
Ct × Mm × R–	14.31	16.63	23.08	35.98	0.69
Ct × Mm × R+	17.29	21.27	37.57	23.86	0.82
Ct × CMr × R–	16.77	19.24	36.93	27.07	0.79
Ct × CMr × R+	19.79	23.09	40.27	16.85	0.90
Cs × Cm × R–	8.06	10.23	33.63	48.08	0.56
Cs × Cm × R+	10.80	13.39	35.32	40.49	0.64
Cs × Mm ×R–	16.27	13.49	36.82	33.42	0.72
Cs × Mm × R+	18.84	17.79	39.83	23.55	0.82
Cs × CMr × R–	13.79	15.67	31.41	39.13	0.66
Cs × CMr × R+	21.71	16.40	40.79	21.10	0.85
Mean	14.20	16.15	35.66	33.99	0.71
CV (%)	9.60	15.00	4.30	9.70	5.00
$LSD_{0.05}$	6.30	4.21	9.60	7.07	0.07

Abbreviations and notations are as explained in Table 4.

Grain and Stover Yields

Tillage had no impact on maize grain yield in the first year of cropping but with yield differing significantly ($p < 0.05$) between the Ct and Cs in the second year (Table 6) where Cs produced grain yield of 4.01 t ha^{-1}. Stover yields did not differ significantly under Ct and Cs in both years. Similarly, maize monoculture or maize in rotation with cowpea had no significant impact on maize grain and stover yields. Mulching produced greater grain yield and stover yields. In the major season of the first year of cropping, mulching increased grain yield by 50% over no mulch; in the second year, the corresponding increase was 23%. Treatment interactions showed significant variations in maize grain and stover yields with tillage rotation combined with maize-cowpea rotation and mulching producing greater yields (Table 7).

DISCUSSION

Tillage Effect on Selected Soil Properties

Bulk density generally increased after cultivation compared to the initial value. The increase ranged from 2-12%, pointing to tillage as a potential contributor to soil compaction (Irmak *et al.,* 2018; Cavalcanti *et al.,* 2020). This showed that soil disturbance by tillage can increase bulk density days after the disturbance as a result of gradual compaction, resulting from re-settling of soil particles and rainfall impact (Osunbitan *et al*., 2005). In view of this, tillage practices that minimize increase in bulk density may create favourable soil condition for crop growth and yield. Thus, the lower bulk density ($p < 0.05$) observed under Cs especially in the top 0-15 cm depth (Figure 2) suggests that Cs could be a tillage practice with potential to minimize the impact of cultivation on soil bulk density. The principle of one-time conventional tillage entails completely skipping the use of mechanical tillage implements on cropping fields for some period. The benefits of the practice are embedded in its ability to carefully blend mechanical or tractorized tillage and no-tillage on the cropping field. By skipping mechanical tillage, the compaction, pulverization and soil structure disrupting effects that would have been imposed by the mechanical implements are for that period, missing. This can enhance soil structure stability and reduction of soil compaction, explaining the fairly lower penetration resistance observed under Cs than Ct (Figure 4).

Bulk density and penetration resistance are often useful indicators of soil structure (DuPont *et al.,* 2021). Well-structured soils are more likely to increase infiltration, moisture storage and reduce runoff. Increase in penetration resistance and bulk density as observed under Ct (Figure 4) adversely affects soil infiltrability, hydraulic conductivity, aeration, seedling emergence, plant root and shoot growth and hence crop yield. Any tillage practice that reverses these negative trends as observed in Cs (Figure 4) tends to create favourable soil conditions for crop growth. The lower penetration resistance of the Cs can be alluded to reduced wheel traffic, tillage intensity and the presence of vegetal material that minimized soil compaction, the impact forces of raindrops and surface sealing (Shi *et al*., 2012). Values of penetration resistance in this study were below the critical level (2000-2500 kPa) at which root growth restriction could occur (Shi *et al.,* 2012). These low values suggest a good basis for skipping subsequent soil mechanical disturbance.

The increase in K_s observed under Cs than Ct (Tabel 1) suggested that even though continuous conventional tillage immediately loosens the soil to allow rapid transmission of water, such benefits disappear with time as particles resettle (Osunbitan *et al*., 2005). Thus, it appears that the frequent soil disturbance and mixing under the continuous conventional tillage diminished the proportion of preferential flow paths (created by plant roots and soil organisms). Tillage systems that decrease the volume of macropores also reduce water transmission through the soil profile (Blanco-Canqui and Ruis, 2018). The cutting action of tillage

Table 6: Grain yields under tillage, crop rotation and mulch

Practice	Grain yield		Stover	
	Year 1	Year 2	Year 1	Year 2
	(Mg ha^{-1})			
Tillage				
Ct	2.58	3.74	6.76	5.82
Cs	3.30	4.01	6.95	6.49
CV (%)	32.50	14.40	30.20	22.80
$LSD_{0.05}$	ns	0.15	ns	ns
Crop rotation				
Mm	2.59	3.72	6.88	6.47
CMr	3.29	4.02	6.83	5.84
CV (%)	32.70	14.20	30.20	22.90
$LSD_{0.05}$	ns	ns	ns	ns
Mulching				
R–	2.35	3.47	5.46	5.12
R+	3.53	4.28	8.25	7.19
CV (%)	27.40	9.40	20.40	14.80
$LSD_{0.05}$	0.37	0.32	1.19	0.38

Ct - continuous conventional tillage, Cs - tillage rotation,
Mm - maize monoculture, CMr - cowpea-maize rotation,
R– - no residue mulch, R+ - residue mulch retained,
CV - coefficient of variation, LSD - least significant difference,
ns - not significant at *F* probability 0.05

Table 7: Interaction effect on maize grain and stover yields

Interactions	Grain yield		Stover	
	Year 1	Year 2	Year 1	Year 2
	(Mg ha^{-1})			
Ct × Mm × R-	1.83	3.32	4.98	5.59
Ct × Mm × R+	2.61	3.90	8.72	6.63
Ct × CMr × R-	2.37	3.42	5.56	4.42
Ct × CMr × R+	3.50	4.31	7.78	6.65
Cs × Mm × R-	2.02	3.46	5.54	6.26
Cs × Mm × R+	3.89	4.21	8.28	7.39
Cs × CMr × R-	3.16	3.66	5.78	4.23
Cs × CMr × R+	4.13	4.69	8.21	8.08
CV (%)	13.50	8.90	14.70	6.60
$LSD_{0.05}$	1.45	0.55	ns	0.96

Abbreviations are as explained in Table 6.

implement breaks the connectivity and continuity of soil pores, disrupts macroaggregates, reduces the macropore fraction (Pires *et al.*, 2017) and changes the pore geometry. These effects decrease the ability of the soil (under continuous conventional tillage) to transmit water to deeper layers, causing reduction in time to incipient ponding and consequently increasing surface runoff and soil erosion. However, the greater K_s obtained under one-time conventional tillage followed subsequently by no-tillage may be due to the greater tendency for more water transmission pores due to the lesser disruption of soil aggregates. Reduced tillage frequency in addition to the implied preservation of biopores probably enhanced the formation and stabilization of macroaggregates as well as macro-and mesopores (Pires *et al*., 2017) thereby contributing to the greater K_s under Cs. The larger MWD observed under the no tillage suggests its greater binding effects on soil particles (Obalum and Obi, 2010).

Crop Rotation Effect on Selected Soil Hydro-Physical Properties

The potential of cropping sequence(s) to alter soil bulk density at the two soil depths and over time was inconsistent. However, cowpea-maize rotation (CMr) and continuous maize monoculture (Mm) appeared to decrease bulk density more than continuous cowpea monoculture (Cm). Lower bulk density was previously reported under rotations systems including legumes (Grant and Lafond, 1993) and under continuous maize monoculture (Perez-Brandan *et al.,* 2014). Meanwhile, the effects of plants on soil physical properties may vary depending on the root mass or weight, root length, as well as the quality and amount of exudates. Therefore, differences in plant root characteristics (for maize and cowpea) appear to be implicated in the observations made in this study. More so, the alternation of cowpea and maize on the same land might have enhanced the benefits associated with each crop (that is, rotational benefit).

The sequences of crops assessed varied significantly ($p < 0.05$) in their impact on aggregate size distribution and stability. The results showed CMr and Mm with greater aggregate stability and percentage aggregate distribution in the macro size range (> 0.25 mm) than Cm, which had more of the microaggregates. The role of root biomass, its attributes in aggregate formation and stability, contribution to SOC, organic cementing agents are all important considerations in this observation. Field observations at six weeks after sowing showed the dry root biomass of maize to be 90.10% greater than that of cowpea at the 0-15 cm depth. Besides contributing to increased SOC, maize roots are also known to produce exudates, which instantaneously bind soil aggregates (Six *et al.,* 2004); thus, maize and legume systems in rotation as in CMr, enhanced macroaggregate stability more than cowpea monoculture (Tables 4 and 5). Some studies reported association of macroaggregates with soil organic carbon content (Six *et al.,* 2000; Curaqueo *et al.,* 2010; Bougma, *et al.,* 2022; Mesele *et al.,* 2024). In consonance with the significantly ($p < 0.05$) greater macroaggregates fraction and stability under wet soil condition, greater sorptivity, cumulative infiltration amount, steady state infiltration and saturated hydraulic conductivity were produced under Mm and CMr than Cm.

Mulch Effect on Selected Soil Hydro-Physical Properties

Similar to its effect on soil bulk density and penetration resistance, mulch produced significantly ($p < 0.05$) greater macroaggregates and aggregate stability at both soil depths (0-15 and 15-30 cm) than no-mulch, which appeared to increase microaggregate fraction. The observation suggests that retaining crop residue mulch on the soil surface will promote the formation and stabilization of soil aggregates, similar to the findings of Linden *et al.* (2000), Masciandaro *et al.* (2004) and Gaudin *et al.* (2013). The cushioning effect of crop residue mulch on the soil surface and the likely addition of organic matter due to decomposition may explain the differences in aggregate formation and stabilization observed under mulch and no-mulch. Mulch intercepts and reduces the aggregate disintegrating and dispersing force of raindrop. Also, by increasing the surface roughness, mulch hinders the rapid flow of water accumulation over the surface (Scopel *et al.,* 2005; Diop *et al.,* 2021) thereby limiting the transport and collision of soil particles, which contribute to aggregate breakdown. On the other hand, the decomposition of crop residue mulch provides the organic substrates, which aid in the binding and stabilization of soil aggregates (Mulumba and Lal, 2008; Curaqueo *et al.,* 2010). This has implications for sustainable soil management within the framework of conservation agriculture in sub-Saharan Africa. Higher sorptivity, cumulative infiltration amount, steady state infiltrability were observed under mulch than no mulch (Table 1). While surface sealing and crusting can increase under no-mulch resulting in reduction in water infiltration and increased runoff (Le Bissonnais and Arrouays, 1997; Bhardwaj and Sarolia, 2012), the tendency for improved burrowing action of soil organisms and organic matter under mulch (Agbede *et al.,* 2013) can explain the greater infiltration recorded under this practice. Also, mulch effectively controls soil surface characteristics (Scopel *et al.,* 2005) by reducing unproductive loss of soil water and structural characteristics by improving aggregation and infiltration (Flerchinger *et al.,* 2003).

Interaction Effects on Soil Hydro-Physical Properties

In practice, crop farmers generally integrate different cropping practices in their production schemes. The type and diversity of activities employed by crop farmers tend to produce varied impacts on the soil. The results of this study suggest that often, the interaction of tillage, crop rotation and mulching improved soil condition more than their individual effects. In most instances, significant effect of practice interactions was noted also at the second order interaction hence these were reported herein rather than the first order interaction. The lower ($p < 0.05$) soil bulk density and penetration resistance produced under Cs × CMr × *R*+ and Cs × Mm × R+ interactions point to complementary benefit associated with the individual practices involved. The reduction in penetration resistance and bulk density under these combinations could be due to the increased soil organic matter content in plots under this treatment (results not shown). The foregoing also explains the significantly ($p < 0.05$) higher aggregate stability, saturated hydraulic conductivity and infiltration produced under these practice interactions. The study also provides evidence that one-time conventional tillage when combined with CMr or Mm and *R*+ is able to improve soil condition in the short term and suggests that the interactions thereof possess the potential for sustainable soil management in the long term in sub-Saharan Africa. In general, the impact of the treatment interactions appeared to be dependent on the level of the individual practices involved in the interaction. Thus, the adoption of the Cs practice in addition to CMr or Mm and R+ has the potential to promote the sustainable management of the sandy loam textured soil in the study area.

Maize Yield

Crop yield is an important indicator of successful soil and agronomic interventions in agro-ecosystems. The significantly greater grain yields observed under Cs than Ct in the second year of cropping was due to improved soil condition (i.e., improved hydrological characteristics and soil fertility). In this study, most of the soil physical, hydrological and chemical parameters assessed were superior under CT-NT similar to earlier findings by Obalum *et al.* (2012) in Nigeria. We observed that 70% (results not shown) of the variation in maize grain yield was explained by the cumulative effect of physical and hydrological conditions of the sandy loam soil. Thus, soil physical and hydrological conditions significantly influenced maize grain yield. However, when tillage was integrated with mulch, significant differences were observed even in the first year of cropping. This may be due to additional advantages conferred by mulching as increased infiltration and moisture storage. More so, retention of mulch has been reported to increase soil biological activity (Zamir *et al.*, 2013) for sustainable soil productivity and increased yield (Ahmad *et al.,* 2022).

CONCLUSION

One-time conventional tillage under cereal-legume rotation increased soil aggregate stability by 34% with greater proportions in the macro aggregate size range than continuous conventional tillage under same cropping system. One-time conventional tillage with cowpea-maize rotation or maize monoculture and mulch improved through complementary effect, cumulative infiltration, steady state infiltrability and sorptivity. We also observed increases in grain yield as a result of the improvement in the soil hydro-physical condition. Diversifying tillage practices within the framework of conservation agriculture holds promise for sustainable soil management in the tropics in the era of mechanized agriculture.

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AUTHORS CONTRIBUTION

Conceptualization, Parker and Quansah; methodology, Parker, Logah and Quansah; software, Parker; validation, Logah and Opoku; formal analysis, Parker; investigation, Parker, Logah, Opoku and Quansah; data curation, Parker, Logah and Opoku; writing-original draft, Parker and Logah, writing-review and editing, Parker and Logah; visualization, Parker, Logah and Opoku; supervision, Quansah, Logah and Opoku; correspondence, Logah. All authors read and agreed to the published version of the manuscript.

REFERENCES

Agbede T.M., Adekiya A.O. and Ogeh J.S. (2013). Effects of *Chromolaena* and *Tithonia* mulches on soil properties, leaf nutrient composition, growth and yam yield. *West Afr. J. Appl. Ecol.,* **21 (1),** 15-29

Ahmad A., Yaseen M, Hussain H. *et al.* (2022). Effects of mulching on crop growth, productivity and yield. In: Akhtar K., Arif M., Riaz M. and Wang H. (eds.), *Mulching in Agroecosystems: Plant, Soil and Environment* (pp. 215-229). Springer, Singapore. https://doi.org/10.1007/978-981-19-6410-7

Bashagaluke J.B., Logah V., Opoku A., Tuffour H.O., Sarkodie-Addo J. and Quansah C. (2019). Soil loss and runoff characteristics under different soil amendments and cropping systems in the semi-deciduous forest zone of Ghana. *Soil Use Manage*., **35 (4),** 617-629. https://doi.org/10.1111/sum.12531

Bhardwaj R.L. and Sarolia D.K. (2012). Effect of mulching on crop production under rainfed condition: A Review. *Int. J. Res. Chem. Environ.,* **2 (2),** 8-20

Blake G.R. and Hartge K.H. (1986). Bulk density. In: Klute A. (ed.), *Methods of Soil Analysis Part 1. Physical and Mineralogical Methods* (2nd ed., pp. 363-382). Am. Soc. Agron., Soil Sci. Soc. Am*.,* Madison, Winsconsin

Blanco-Canqui H. and Ruis S.J. (2018). No-tillage and soil physical environment. *Geoderma*, **326,** 164-200. https://doi.org/10.1016/j.geoderma.2018.03.011

Blanco-Canqui H. and Wortmann C.S. (2020). Does occasional tillage undo the ecosystem services gained with no-till? A review. *Soil Till. Res.,* **198,** 104534. https://doi.org/10.1016/j.still.2019.104534

Blanco-Canqui H., Mikha M.M., Presley D.R. and Claassen M.M. (2011). Addition of cover crops enhances no-till potential for improving soil physical properties. *Soil Water Manag. Conserv.,* **75 (4),** 1471-1482. https://doi.org/10.2136/sssaj2010.0430

Bonsu M. and Laryea K.B. (1989). Scaling saturated hydraulic conductivity of an Alfisol. *J. Soil Sci.,* **40,** 731-742. https://doi.org/10.1111/j.1365-2389.1989.tb01313.x

Bougma A.B., Ouattara K., Compaore H. (2022). Soil aggregate stability of forest islands and adjacent ecosystems in West Africa. *Plant Soil,* **473,** 533-546. https://doi.org/10.1007/s11104-022-05302-x

Cavalcanti R.Q., Rolim M.M., de Lima R.P., Tavares U.E., Pedrosa E.M. and Cherubin, M.R. (2020). Soil physical changes induced by sugarcane cultivation in the Atlantic Forest biome, northeastern Brazil. *Geoderma*, **370,** 114353. http://dx.doi.org/10.1016/j.geoderma.2020.114353

Curaqueo G., Acevedo E., Cornejo P., Seguel A. and Borie F. (2010). Tillage effect on soil organic matter, mycorrhizal hyphae and aggregates in a Mediterranean Agroecosystem. *RC Suelo Nutr. Veg.,* **10 (1),** 12-21. http://dx.doi.org/10.4067/S0718-27912010000100002

Diop M., Quansah C., Logah V. and Dembele G. (2021). Soil fertility erosion on cropland: Impact of tillage and soil amendments in Ghana. *J. Ghana Sci. Assoc.,* **20 (1),** 33-41

DuPont S.T., Kalcsits L. and Kogan C. (2021). Soil health indicators for Central Washington orchards. *PLoS ONE,* **16 (10),** e258991. https://doi.org/10.1371/journal.pone.0258991

Ezenne G.I., Obalum S.E. and Tanner J. (2019). Physical-hydraulic properties of tropical sandy-loam soil in response to rice-husk dust and cattle dung amendments and surface mulching. *Hydrol. Sci. J*, **64 (14),** 1746-1754. https://doi.org/10.1080/02626667.2019.1662909

FAO (1998). FAO/UNESCO soil map of the world revised legend, with corrections. World Soil Resources Report 60. Rome. Technical Paper 20, ISRIC, Wageningen

Faye J.B. and Braun Y.A. (2022). Soil and human health: Understanding agricultural and socio-environmental risk and resilience in the age of climate change. *Health Place* **77,** 102799. https://doi.org/10.1016/j.healthplace.2022.102799

Flerchinger G.N., Sauer T.J. and Aiken R.A. (2003). Effects of crop residue cover and architecture on heat and water transfer at the soil surface. *Geoderma,* **116 (1-2),** 217-233. https://doi.org/10.1016/S0016-7061(03)00102-2

Fuentes M., Govaerts B., De León F. *et al.* (2009). Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. *Europ. J. Agron.,* **30 (3),** 228-237. http://dx.doi.org/10.1016/j.eja.2008.10.005

Gaudin A.M., Westra S., Loucks C.S., Janovicek K., Martin R. and Deen W. (2013). Improving resilience of northern field crop systems using inter-seeded red clover: A Review. *Agron.,* **3,** 148-180. https://doi.org/10.3390/agronomy3010148

Grant C.A. and Lafond G. (1993). The effects of tillage systems and crop sequences on soil bulk density and penetration resistance on a clay soil in southern Saskatchewan. *Canad. J. Soil Sci.,* **73,** 223-232. https://cdnsciencepub.com/doi/pdf/10.4141/cjss93-024

Irmak S., Sharma V., Mohammed A.T. and Djaman K. (2018). Impacts of cover crops on soil physical properties: Field capacity, permanent wilting point, soil-water holding capacity, bulk density, hydraulic conductivity, and infiltration. *Transact. ASABE*, **61 (4),** 1307-1321. https://doi.org/10.13031/trans.12700

Kemper W.D. and Rosenau R.C. (1986). Aggregate stability and size distribution. *Methods of Soil Analysis, Part 1* (2nd edn, Vol. 9, pp. 425-442). Am. Soc. Agron., Madison

Khan G.D., Din S., Ud-Din S., Ramzan M., Hanif M. and Hameed M. (2014). Influence of tillage and mulching practices on soil physical properties under semi-arid environment. *J. Environ. Earth Sci.,* **4 (9),** 120-124

Klute A. and Dirksen C. (1986). Hydraulic conductivity and diffusivity: Laboratory methods. In: Klute A. (ed.), *Methods of Soil Analysis: Part I* (pp. 687-734). Am. Soc. Agron., Madison, WI. https://doi.org/10.2136/sssabookser5.1.2ed.c28

Kuhwald M., Blaschek M., Brunotte J. and Duttmann R. (2017). Comparing soil physical properties from continuous conventional tillage with long-term reduced tillage affected by one-time inversion. *Soil Use Manage.,* **33 (4),** 611-619. https://doi.org/10.1111/sum.12372

Le Bissonnais Y. and Arrouays D. (1997). Aggregate stability and assessment of soil crustability and erodibility II: Application to humic loamy soils with various organic carbon contents. *Europ. J. Soil Sci.,* **48**, 39-48. https://doi.org/10.1111/j.1365-2389.1997.tb00183.x

Liebig M., Tanaka D. and Wienhold B. (2004). Tillage and cropping effects on soil quality indicators in the northern Great Plains. *Soil Till. Res.,* **78 (2),** 131-141

Linden D., Clapp C. and Dowdy R. (2000). Long-term corn grain and stover yields as a function of tillage and residue removal in East Central Minnesota. *Soil Till. Res.,* **56 (3–4),** 167-174

Liu H., Carvalhais L.C., Rincon-Florez V. *et al.* (2016). One-time strategic tillage does not cause major impacts on soil microbial properties in a no-till Calcisol. *Soil Till. Res.,* **158**, 91-99. https://doi.org/10.1016/j.still.2015.12.007

Logah V., Abubakari F., Issifu H. *et al.* (2024). Soil carbon, nutrient and vegetation dynamics of old Anogeissus groove in Mole National Park, Ghana. *Biotropica,* in press. https://doi.org/10.1111/btp.13299

Masciandaro G., Ceccanti B., Benedicto S., Lee H.C. and Cook H.F. (2004). Enzyme activity and C and N pools in soil following application of mulches. *Canad. J. Soil Sci.,* **84,** 19-30. https://doi.org/10.4141/S03-045

Mesele S.A., Melenya C., Bougma A. *et al.* (2024). Soil mineralogical and nutrient characteristics of forest islands and surrounding ecosystem types in West Africa suggest anthropogenic soil improvement. *Plant Soil,* **495,** 157–175. https://doi.org/10.1007/s11104-023-06042-2

Mulumba L.N. and Lal R. (2008). Mulching effects on selected soil physical properties. *Soil Till. Res.,* **98 (1),** 106-111. http://dx.doi.org/10.1016/j.still.2007.10.011

Norris C.E. and Congreves K.A. (2018). Alternative management practices improve soil health indices in intensive vegetable cropping systems: A review. *Front. Environ. Sci.,* **6 (50),** 1-18. https://doi.org/10.3389/fenvs.2018.00050

Nyamangara J., Nyengeral K., Masvaya E.N. *et al.* (2013). Effect of conservation agriculture on maize yield in the semi-arid areas of Zimbabwe. *Exp. Agric.,* **2,** 159-177. http://dx.doi.org/10.1017/S0014479713000562

Obalum S.E. and Obi M.E. (2010). Physical properties of a sandy loam Ultisol as affected by tillage-mulch management practices and cropping systems. *Soil Till. Res.,* **108 (1-2),** 30-36. https://doi.org/10.1016/j.still.2010.03.009

Obalum S.E., Igwe C.A. and Obi M.E. (2012). Soil moisture dynamics under rainfed sorghum and soybean on contrasting tillage–mulch seedbeds in a mineral sandy loam at derived savanna of south-eastern Nigeria*. Arch. Agron. Soil Sci.,* **58 (11),** 1205-1227. ttps://doi.org/10.1080/03650340.2011.575065

Obalum S.E., Igwe C.A., Obi M.E. and Wakatsuki T. (2011). Water use and grain yield response of rainfed soybean to tillage-mulch practices in southeastern Nigeria. *Scientia Agricola*, **68** (**5**), 554-561. https://doi.org/10.1590/S0103-90162011000500007

Obalum S.E., Ogumba P.O. and Uzoh I.M. (2020). Influence of tillage-seedbed and manure-NPK-micro-nutrient management options on selected soil properties of sandy-loam Ultisols evaluated using sweet potato. *Nigerian Journal of Soil Science,* **30 (3),** 117-125

Ogban P.I. (2017). Effect of land use on infiltration characteristics of soils in northern akwa ibom state, south-eastern Nigeria. *Agro-Science,* **16 (3),** 29-36. https://doi.org/10.4314/as.v16i3.5

Osunbitan J.A., Oyedele D.J. and Adekalu K.O. (2005). Tillage effects on bulk density, hydraulic conductivity and strength of a loamy sand soil in southwestern Nigeria. *Soil Till. Res.,* **82,** 57-64. http://dx.doi.org/10.1016%2Fj.still.2004.05.007

Perez-Brandan C., Arzeno J.L., Huidobro J. *et al.* (2014). The effect of crop sequences on soil microbial, chemical and physical indicators and its relationship with soybean sudden death syndrome complex of *Fusarium* species. *Span. J. Agric. Res.,* **12 (1),** 252-264. https://doi.org/10.5424/sjar/2014121-4654

Philip J.R. (1957). The theory of infiltration I: The infiltration equation and its solution. *Soil Sci.,* **83,** 345-357. http://dx.doi.org/10.1097/00010694-195705000-00002

Pires L.F., Borges J.A.R., Rosa J.A. *et al*. (2017). Soil structure changes induced by tillage systems. *Soil Till. Res.,* **165,** 66-79. http://dx.doi.org/10.1016/j.still.2016.07.010

Scopel E., Findeling A. Chavez Guerra E. and Corbeels M. (2005). Impact of direct sowing mulch-based cropping systems on soil carbon, soil erosion and maize yield. *Agron. Susutain. Dev.,* **25,** 425-432. https://doi.org/10.1051/agro:2005041

Shah A.N., Tanveer M.B. Shahzad G. *et al*. (2017). Soil compaction effects on soil health and cropproductivity: An overview. *Environ. Sci. Poll. Res.,* **24 (11),** 10056-10067. https://doi.org/10.1007/s11356-017-8421-y

Shi X.H., Yang X.M., Drury C.F., Reynolds W.D., McLaughlin N.B. and Zhang X.P. (2012). Impact of ridge tillage on soil organic carbon and selected physical properties of a clay loam in southwestern Ontario. *Soil Till. Res.,* **120,** 1-7. http://dx.doi.org/10.1016/j.still.2012.01.003

Six J., Elliott E. and Paustian K. (2000). Soil macro-aggregate turnover and micro-aggregate formation: a mechanism for C sequestration under no-tillage agriculture. *Soil Biol. Biochem.,* **32 (14),** 2099-2103. https://doi.org/10.1016/S0038-0717(00)00179-6

Six J., Bossuyt H., Degryze S. and Denef K. (2004). A history of research on the link between (micro) aggregates, soil biota, and soil organic matter dynamics. *Soil Till. Res.,* **79 (1),** 7-31. https://doi.org/10.1016/j.still.2004.03.008

Tanveer S.K., Zhang J., Lu X. *et al.* (2014). Effect of corn residue mulch and N fertilizer application on nitrous oxide (N_2O) emission and wheat crop productivity under rain-fed condition of Loess Plateau, China. *Int. J. Agric. Biol.,* **16 (3),** 505-512

Thomas E., Kurieni V.T., Prabha S.V. and Thomas A.P. (2020). Monoculture vs. mixed-species plantation impact on the soil quality of an ecologically sensitive area. *J. Agric. Environ. Int. Dev.,* **114 (2),** 41-62. https://doi.org/10.12895/jaeid.20202.1360

Wang S., Wang H., Zhang Y. *et al.* (2018). The influence of rotational tillage on soil water storage, water use efficiency and maize yield in semi-arid areas under varied rainfall conditions. *Agric. Water Manage.,* **203,** 376-384. http://dx.doi.org/10.1016/j.agwat.2018.03.007

Yadav G.S., Lal R. and Meena R.S. (2020). Vehicular traffic effects on hydraulic properties of a Crosby silt loam under a long-term no-till farming in Central Ohio, USA. *Soil Till. Res.,* **202,** 104654. https://doi.org/10.1016/j.still.2020.104654

Zamir M.S.I., Javeed H.M.R., Ahmed W. *et al.* (2013). Effect of tillage and organic mulches on growth, yield and quality of autumn planted maize (*Zea mays* L.) and soil physical properties. *Cercet. Agron. Mold.,* **46 (2),** 17-26. http://dx.doi.org/10.2478/v10298-012-0080-z