Article

Effects of Tillage Systems and Cropping Patterns on Soil Physical Properties in Mozambique

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Abstract: Conservation agriculture (CA) practices are advocated to reduce soil degradation, resulting in more sustainable food production as compared to conventional tillage (CT). In this study, the short-term effects of two tillage systems in combination with cropping patterns on selected soil physical parameters on four experimental sites in Mozambique were studied. The study sites differ according to their climatic conditions, soil types, and crop adaptation. Tillage systems evaluated were CA and CT, while the cropping pattern had four levels of sole cropping and three levels of intercropping. In general, soil physical properties showed significant changes due to the tillage systems, but the cropping pattern and their interaction with tillage systems did not yield significant impacts on the soil physical properties. CA increased bulk density, penetration resistance, and saturated hydraulic conductivity as compared to CT. A significant difference due to the tillage system was observed across the four sites, and in general, evaporation was higher in CT compared to CA. The presence of crop residues in CA contributed to lower evaporation. Thus, in the short term, CA practices could be a sustainable option to conserve soil water through higher infiltration and less evaporation.

Keywords: Bulk density; cropping pattern; evaporation; hydraulic conductivity; penetration resistance; tillage system

1. Introduction

In sub-Saharan Africa (SSA), unsustainable farming practices, such as excessive soil tillage with no soil cover, have led to a decrease in soil fertility, accelerated erosion, and degradation of arable land. In Mozambique, around 68% of the population live in rural areas, and up to 90% are smallholder farmers [1]. The most common tillage system practiced by smallholder farmers in Mozambique is where hand hoes are used to till the soil, with crop residue collection and burning during land preparation. This is referred to as conventional tillage (CT) throughout this study. The use of inappropriate tillage systems (i.e., CT) has led to the deterioration of soil quality through decay in organic matter, disruption of soil structure, and decrease in aggregate stability. This resulted in lower macroporosity, thus promoting soil erosion, organic matter loss, and fertility depletion [2–5]. The development of sustainable management practices to reduce the physical degradation of soil should, therefore, be a high priority. Conservation agriculture (CA) practices are proposed to minimize soil degradation and improve soil quality. CA is defined as a tillage system where at least 30% of crop residues are left on the field surface, and it is a conservation practice to reduce soil erosion, improve water use efficiency, and regulate upper soil temperature [6,7]. CA integrates three principles, namely minimal soil disturbance, crop residue retention, and crop diversification through rotation or intercropping [6,8,9]. These CA practices are advocated to increase the microporosity in relation to macroporosity, consequently

restoring soil aggregate stability [5,8,10]. Fortunately, to reduce soil degradation there is increased adoption of CA practices by smallholder farmers, as this is an attractive solution.

Crop production management practices cause changes in the physical attributes of soil, mainly due to changes in soil structure that disrupt the distribution and continuity of pores. Bulk density (Db), penetration resistance (PR), saturated hydraulic conductivity (Ks), available soil water, evaporation, and aggregate stability are the most vulnerable parameters used to assess the impact of tillage systems on soil physical quality (e.g., Zarnoza et al. [7], Busari and Salako [11]). The impact of different tillage operations on the physical properties is, however, controversial. The aim of CT is generally to loosen soil, resulting in higher macroporosity, and thus lowered bulk density and penetration resistance even over the short term [12]. Intensive use of CT practices can, however, promote subsurface compaction through the reduction of pore sizes, which coincides with an increase in Db and decrease in Ks . On the contrary, short-term impacts of CA can also lead to higher Db and PR values and a reduction in Ks under CA when compared to CT systems, mainly due to the absence or reduction of soil disturbance [2,13,14]. In the long term, the accumulation of organic matter under CA practices is expected to decrease the Db and PR and increase Ks , all of which are associated with increased macroaggregation in the top soil [14]. Furthermore, the presence of crop residues in CA practices will promote surface infiltration rates, reduce the impact of raindrops (sealing), and reduce evaporation [14,15].

The consortia between cereals and legumes under CA practices allow for higher organic matter accumulation. Biomass productions from cereal and legume associations are a critical source of organic carbon input that improves physical attributes [16] and decreases soil degradation. Organic matter maintains aggregate stability and improves soil physical quality by improving water storage through higher infiltration and lower runoff and evaporation. Thus, soil loss by water erosion is minimized, while the lower bulk density and penetration resistance promote root growth and development [3,17,18].

Although the literature suggests that physical attributes (e.g., Db , PR , and Ks) are improved under CA practices over the long term, it is often the short term impacts and benefits that promote adoption. These impacts must, therefore, be understood and optimized. In Mozambique, research on the individual effects of tillage systems and cropping patterns on soil physical properties has been conducted [19–21], but the information is scanty on the combined effects of tillage systems and cropping pattern on soil physical properties. Therefore, this study is conducted at four sites over two growing seasons to evaluate the impact of tillage systems and cropping patterns and their interactions on selected soil physical properties. This study hypothesizes that the tillage system and cropping pattern have significant impacts on selected soil physical properties, such as bulk density, penetration resistance, hydraulic conductivity, and evaporation in the short term.

2. Materials and Methods

2.1. Site Description

This study was conducted at four research stations of the Agricultural Research Institute of Mozambique (IIAM). These are the Nhacoongo station in the Inhambane province in the southern region, Gurúè station in the Zambézia province in the central region, Mutuali station in the Nampula province in the northern region, and Lichinga station in the Niassa province in the northern region of Mozambique (Figure 1). Some characteristics of the research stations are given in Table 1.

Figure 1. Locations of the Lichinga (a), Gurue (b), Mutuali (c), and Nhacoongo (d) research stations in Mozambique where the study was conducted.

Table 1. Selected characteristics of the Nhacoongo, Mutuali, Lichinga, and Gurúè research stations [22–25] where the experiments were conducted.

Research Station	Agroecological Zone	Province	District	Location	Annual Rainfall (mm)	Temperature °C	Altitude (M.A.S.L.)	Soil Type *	Textural Class **
Nhacoongo	R2	Inhambane	Inharrime	24°19′49.00″ S 35°12′55.00″ E	1000–1200	18–33	68	Luvic Arenosols	Loamy sand
Mutuali	R7	Nampula	Malema	14°52′14.02″ S 37°00′15.98″ E	300–1300	15–36.6	574	Orthic Ferralsols	Sandy loam
Lichinga	R10	Niassa	Lichinga	13°18′46.01″ S 35°14′26.02″ E	1200–1400	16.1–32.9	1396	Orthic Ferralsols	Sandy clay loam
Gurúè	R10	Zambézia	Gurúè	19°09′05.00″ S 36°42′43.90″ E	1800–2000	15–23	678	Humic Nitisols	Sandy loam

* Based on FAO soil classification (FAO, [26]). ** Based on USDA textural soil classification (USDA, [27]).

2.2. Experimental Design and Layout

The trials were conducted over two cropping seasons, i.e., 2016–2017 to 2017–2018, to evaluate the response on soil physical properties (Table 2). At each location, a field experiment was set up as a two factor split-plot experiment in a randomized complete block design and replicated four times. The first order factor was tillage systems, i.e., two levels—conventional tillage (CT) and conservation agriculture (CA), with 26 m × 37.5 m (975 m², including 2 m buffer zones between blocks and 1 m buffer zones between plots) main plots, and the second order factor was cropping patterns (seven levels; see Table 2) with 5.0 m × 4.5 m (22.5 m², excluding any buffer zones) subplots (see Figure 2). The four sites had the same experimental design, and the treatments were applied to the same plots during the two years of study. For the CA system, glyphosate was applied at a rate of 2.5 L ha^{−1} (480 g L^{−1} of isopropylamine salt active ingredient) two weeks before planting. Under the CA system, the soil was disturbed only with a dibble stick planter when the seeds were planted, while under the CT system, soil was disturbed with a hand hoe to a depth of approximately 15 cm for seedbed preparation and planting. For the CT system, crop residues were removed, and for the CA system, the surface area was covered with at least 30% of the previous season harvested crop residues (2–3 t ha^{−1}). No fertilizers were applied, since this is not common practice amongst the smallholders.

The sowing and harvesting dates were respectively in November and May every year for all crops, except for pigeon pea, due to a longer growing period, which was harvested in July of each year. Maize and pigeon pea seed were sown in rows at the recommended spacing of 75 cm between rows and 30 cm within rows, while the other legumes varied from 50 cm × 30 cm for common beans, cowpea, and groundnut, and 50 cm × 10 cm for soybean. The arrangement of row intercropping was 1:1 (one row of maize alternated by one row of legume). Maize and legumes were sown simultaneously as a sole crop or intercropped in alternative rows. Two seeds were sown per hill and later thinned to one per hill; gapping was done five days after emergence. Postemergence weeds were controlled with hand hoeing.

Table 2. Details of tillage systems and cropping pattern at each of the four study sites.

	Tillage System: Conservation Agriculture (CA)/Conventional Tillage (CT)			
	Nhacoongo	Mutuali	Lichinga	Gurùè
Cropping pattern at each study site	Sole maize (Matuba) *	Sole maize (Matuba)	Sole maize (Matuba)	Sole maize (Matuba)
	Sole groundnut (JL24)	Sole pigeon pea (00554)	Sole pigeon pea (00554)	Sole cowpea (IT16)
	Sole pigeon pea (00554)	Sole cowpea (IT16)	Sole soybean (TGX 1937-1F)	Sole soybean (TGX 1937-1F)
	Sole cowpea (IT16)	Sole soybean (TGX 1937-1F)	Sole common beans (Nua 45)	Sole common beans (Nua 45)
	Maize–groundnut intercropping	Maize–pigeon pea intercropping	Maize–pigeon pea intercropping	Maize–cowpea intercropping
	Maize–pigeon pea intercropping	Maize–cowpea intercropping	Maize–soybean intercropping	Maize–soybean intercropping
	Maize–cowpea intercrop	Maize–soybean intercrop	Maize–common beans intercropping	Maize–common beans intercropping

* Crops planted: maize (*Zea mays* L.), cowpea (*Vigna unguiculata* L.), groundnut (*Arachis hypogaea* L.), pigeon pea (*Cajanus cajan* L.), soybean (*Glycine max* L.), and common beans (*Phaseolus vulgaris* L.).

Codes: ML1 = Maize legume 1; ML2 = Maize legume 2; ML3 = Maize legume 3; LEGUME_1 = Sole legume 1; LEGUME_2 = Sole legume 2 and LEGUME_3 = Sole legume 3

Figure 2. Experimental layout for both conservation agriculture or conventional tillage treatments (buffers between plots and blocks are 1 and 2 m, respectively).

2.3. Measurement of Soil Properties

Soil physical properties were measured at the end of the second growing season (July 2018). Undisturbed core samples were collected from randomly located points in all plots for bulk density determination. Disturbed samples were collected at the same locations to measure particle size distribution. Saturated hydraulic conductivity, penetration resistance, and evaporation were determined in situ using methods discussed below.

2.3.1. Particle Size Distribution and Gravel

Disturbed composite soil samples of 50 g were from topsoil horizon of selected plots, oven-dried at 105 °C, and passed through a 2 mm sieve. The hydrometer method was used for the determination of particle size distribution [27]: sand (2.0–0.05 mm); silt (0.05–0.002 mm), and clay (<0.002 mm). This method is based on the contrasting settling velocities of the particle sizes within a water column. The textural class was deducted using the United States Department of Agriculture (USDA) textural triangle [27]. The gravel retained on the 2 mm sieve was used to estimate the percentage gravel in a composite soil sample.

2.3.2. Bulk Density

Undisturbed core samples were collected at the end of the second growing season (July 2018) from four randomly located points in all subplots. Cores with a 2.5 cm radius and 5 cm in length were used for sampling at Lichinga, Mutuali, and Gurùè, while slightly larger cores (3.5 cm radius and 12 cm length) were used in Nhacoongo. Bulk density was determined using the undisturbed core sampling method of Okalebo et al. [28]. Bulk density, Db ($\text{g}\cdot\text{cm}^{-3}$), was calculated as the relationship between dry soil mass and total ring volume using the equation below:

$$b \left(\text{g}\cdot\text{cm}^{-3} \right) = \frac{M}{V} \quad (1)$$

where:

Db = Bulk density ($\text{g}\cdot\text{cm}^{-3}$);

M = Dry weight of the core sample (g);

V = Volume of the soil core (cm^3).

2.3.3. Penetration Resistance

At the end of the second cropping season (July 2018), penetration resistance of the soil of each plot at all four sites was measured using a manual cone penetrometer (hand penetrometer Eijkelkamp 06.01.14). This instrument measures the soil resistance to penetration in Newton (N). Measurements were taken at 10 randomly selected points per plot within each plot to a depth of 15 cm, and the average value was calculated. The penetration resistance measurements were made by the same person in all four sites to ensure that the pressures were applied consistently on the penetrometer from one place to another using the equation below.

$$PR(\text{kPa}) = \frac{F}{A} \quad (2)$$

where:

PR = penetration resistance ($\text{N}\cdot\text{cm}^{-2}$ then converted to kPa);

F = normal force (N);

A = base area of the cone (cm^2).

2.3.4. Saturated Hydraulic Conductivity

Saturated hydraulic conductivity was determined using the double-ring falling head infiltrometer method. The double ring infiltrometer method consisted of a 10 cm inner ring diameter and a 30 cm

outer ring diameter inserted approximately 10 cm into the soil at two randomly selected points in selected plots at the experimental sites. Both the outer and inner rings were then saturated with water. The water level in the outer ring was kept above that of the inner ring to avoid lateral drainage from the inner ring. The time for water to infiltrate 2 cm was then recorded (from 10 to 8 cm above the soil surface). The infiltration test was repeated until the infiltration time became nearly constant (or less than a 5% decline from the previous infiltration time). The saturated hydraulic conductivity (K_s) was then calculated using the modified Bouwer and Rice [29] equation below.

$$K_s = \frac{L}{t} \times \ln \frac{(h_0 + L)}{(h_1 + L)} \quad (3)$$

where:

K_s = saturated hydraulic conductivity;

L = thickness of horizon (L);

t = time until constant infiltration rate was obtained (T);

h_0 and h_1 = head of water above the surface before and at the start of the test and after t , respectively.

2.3.5. Evaporation

Evaporation (E) was measured using microlysimeters (MLs) following the second cropping season (August, September, October, and November of 2018) according to the method proposed by Flumignam et al. [30]. The MLs (Figure 3B) consist of rigid polyvinyl chloride (PVC) pipes that were 15 cm long with 10 cm inner diameter. The wall thickness of the pipes was 0.25 cm. One of the sides was sharpened to ease penetration into the soil. A cap was inserted at the bottom to prevent deep drainage (Figure 3A). A slightly larger envelope was then inserted into the soil used for hosting the MLs (Figure 3C). The bottom of the MLs was sealed and raised 0.5 cm to eliminate the effects of drainage and runoff.

Figure 3. Components of a microlysimeter system for measurement of evaporation: (A) Cap to avoid drainage, (B) microlysimeter, (C) outer envelope, and (D) installed microlysimeter. Source: Flumignam et al. [30].

The MLs were saturated with water (approximately 100 mL), and the wet soil was weighed on a 2 g resolution electronic scale. Water evaporation was measured as the reduction in weight from the wet soil in the MLs on a daily basis for a week. This was repeated four times aligned to the site visits. The difference in weight between measurements was attributed to evaporation and was calculated using the equation below.

$$E \text{ (mm)} = \frac{\Delta M_{MLs}}{A_{MLs}} \quad (4)$$

where:

E = water evaporation from the MLs (mm);

ΔM_{MLs} = MLs variation in mass (kg);

A_{MLs} = MLs surface area with a fixed value of 0.0785 m².

2.4. Data Analysis

Data collected were tested for normality with the Shapiro–Wilk test and for homogeneity with the Levene test before analysis of variance (ANOVA) with XLSTAT v 17.3 software for Excel [31]. Treatment means were separated by Tukey’s multicomparison test, and differences were reported at the 5% probability level. The interaction between the tillage system and cropping pattern was given separately for those attributes that had a significant influence, and these were described accordingly.

3. Results

3.1. Particle Size Distribution and Gravel Content

The particle size distribution and resulting textural classes of the soil samples from the Nhacoongo, Mutuali, Lichinga, and Gurúè experimental sites are presented in Table 3. Soil texture is unlikely to be influenced by the treatments. It is, however, important to consider the texture when the impact on other physical properties are assessed. It is also important to consider the texture if recommendations and extrapolations are made to other sites. Soils from Nhacoongo are loamy sand, Mutuali and Gurúè are sandy loam, and Lichinga is sandy clay loam. In general, the highest gravel content was observed in Gurúè (5.00%), followed by Lichinga (3.28%), Mutuali (1.20%), and Nhacoongo (0.50%).

Table 3. Average particle size distribution and gravel content of the soil at the four experimental sites.

Location	Clay (%)	Silt (%)	Sand (%)	Textural Class *	Gravel (%)
Nhacoongo	8.8	5.3	85.9	loamy sand	0.5
Mutuali	14.3	14.4	71.3	sandy loam	1.2
Lichinga	31.5	13.5	54.7	sandy clay loam	3.3
Gurúè	12.0	8.8	79.2	sandy loam	5.0

* Based on USDA soil textural classification (USDA, [26]).

3.2. Bulk Density

The Db was influenced significantly by the tillage system at Nhacoongo, Mutuali, and Lichinga but not at Gurúè (Table 4). However, at all four sites, CA was associated with increases in Db of 1.29% for Nhacoongo, 2.63% for Mutuali, 7.50% for Lichinga, and 1.92% for Gurúè in comparison to under CT. On the other hand, the cropping pattern had no significant influence on Db at all four sites varying from 1.03 to 1.57 g·cm^{−3}. The interaction between the tillage system and cropping pattern significantly influenced Db only in Nhacoongo and Lichinga but not in Mutuali and Gurúè.

Table 4. Effect of tillage systems on soil physical properties at Nhacoongo, Mutuali, Lichinga, and Gurúè experimental sites.

Tillage System	<i>Db</i> (g·cm ⁻³)				<i>PR</i> (kPa)				<i>Ks</i> (mm h ⁻¹)			
	Nhacoongo	Mutuali	Lichinga	Gurúè	Nhacoongo	Mutuali	Lichinga	Gurúè	Nhacoongo	Mutuali	Lichinga	Gurúè
CA	1.57 a	1.17 a	1.29 a	1.06 a	1055 a	1989 a	1861 a	2692 a	743 a	517 a	619 a	669 a
CT	1.55 b	1.14b	1.20 b	1.04 a	554 b	1903 a	1805 a	2399 b	648 b	454 a	374 b	384 b
L.S.D.	0.01	0.03	0.04	0.03	61	137	220	162	89	196	137	228
CP	ns	ns	ns	ns	ns	*	ns	ns	ns	ns	ns	ns
CP x TS	*	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	2.47	7.74	8.92	6.91	14.05	13.08	22.21	11.82	23.75	37.35	44.63	53.07

CA, conservation agriculture; CT, conventional tillage; CP, cropping pattern; TS, tillage system; *Db*, bulk density; *PR*, penetration resistance; *Ks*, saturated hydraulic conductivity; L.S.D., least significant difference at $p \leq 0.05$; ns, not significantly different at $p \leq 0.05$; *, significantly different at $p \leq 0.05$. Means followed by different letters within a column are significantly different at $p \leq 0.05$.

3.3. Penetration Resistance

The effect of tillage systems on *PR* was significant only at Nhacoongo and Gurùè (Table 4). However, *PR* values across the four study sites were consistently higher under the CA system (Nhacoongo = 90.4%, Mutuali = 4.5%, Lichinga = 3.1%, and Gurùè = 12.2%) compared to the CT system. Cropping patterns, however, had a significant influence on *PR* only in Mutuali (Figure 4). The interaction effects between tillage systems and the cropping patterns had no significant influence on *PR* in Mutuali, Lichinga, and Gurùè. Overall, the interaction produced a higher *PR* under CA than under CT.

Figure 4. Cropping pattern in Mutuali; Maize, sole maize, Ppea, sole pigeon pea; Sbean, sole soybean; Cpea, sole cowpea; M_Ppea, maize–pigeon pea intercropping; M_Cpea, maize–cowpea intercropping; M_Sbean, maize–soybean intercropping. Means followed by different letters within a column are significantly different using Tukey’s test at $p \leq 0.05$.

3.4. Saturated Hydraulic Conductivity

The *Ks* was significantly affected ($p \leq 0.05$) by the tillage system in Nhacoongo, Lichinga, and Gurùè but not in Mutuali (Table 4). Generally, average *Ks* values were higher under the CA system (Nhacoongo = 14.7%, Mutuali = 13.9%, Lichinga = 65.5% and Gurùè = 74.2%) than under the CT system. The current study did not show any significant cropping pattern on *Ks* across the four sites ranging from 335 to 773 mm h^{−1}. This was also the case with the interaction of tillage systems by cropping patterns.

3.5. Evaporation

A significant effect of tillage system on evaporation was obtained in some months at Nhacoongo, Mutuali, Lichinga, and Gurùè (Figure 5a–d). Significant differences in evaporation were at Nhacoongo and Gurùè, recorded in September, October, and November; at Lichinga in August, September, and November; and at Mutuali only in November. In most cases, evaporation was higher under CT than CA. Across the four sites, lower evaporation was recorded in the sandy loam soils of Gurùè (CA = 3.42 and CT = 3.61 mm) and Mutuali (CA = 6.22 and CT = 6.57 mm) than in the loamy sand soil of Nhacoongo (CA = 8.60 and CT = 11.27 mm) and the sandy clay loam soil of Lichinga (CA = 11.10 and CT = 10.98 mm). Unexpectedly, in August, higher evaporation values were obtained under CA than CT in Nhacoongo, Mutuali, and Gurùè.

Figure 5. Evaporation at Nhacoongo (a), Mutuali (b), Lichinga (c), and Gurúè (d) experimental sites. Bars represent means values and error bars one standard error; bars followed by different letters are significantly different using Tukey's test at $p \leq 0.05$.

4. Discussion

4.1. Bulk Density

Measurements made in the four experimental sites showed significant differences in Db as a result of tillage system. The CA system increased Db , resulting in increased compaction and less aeration compared to the CT system. Several studies (Fabrizzi et al. [2], Rashidi and Keshavarzpour [12], Malecka et al. [13], and Dembele [32]) reported greater Db values under CA than CT. Management practices adopted for CT (ploughing) tend to disturb the soil to a 30 cm depth, creating more pore space. Furthermore, the absence of tillage (CA system) increases Db because the soil becomes more compacted after only two cropping seasons. In the long term, decomposition of crop residues and organic matter accumulation might result in a decrease in Db [33,34]. It is clear that the expected long-term benefit associated with the higher organic matter has not yet been obtained. Across the four sites, the highest Db was recorded in the loamy sand soil of Nhacoongo (CA = 1.57 and CT = 1.55 g·cm⁻³), followed by sandy clay loam soil of Lichinga (CA = 1.29 and CT = 1.20 g·cm⁻³), sandy loam soil of Mutuali (CA = 1.17 and CT = 1.14 g·cm⁻³), and the sandy loam soil of Gurúè (CA = 1.06 and CT = 1.04 g·cm⁻³). This was not unexpected and can be attributed to the fact that soil texture (loamy sand with >80% sand) differed from that in Mutuali and Gurúè (sandy loam with less than 75% sand). Sandy loam soils tend to have higher Db than more clayey variants [35]. At Lichinga, the soil was sandy clay loam with an average of 45% clay. Lower clay contents contribute to higher compaction, which explains the high Db in Nhacoongo (clay content < 9%) compared to other sites (clay content > 14%). Increased Db in sandy soil as compared to clayey soils was also recorded [36]. This can be ascribed firstly to the relatively high clay contents, which are not prone to compaction, and secondly to the short study period.

Cropping pattern (CP) had no significant influence on Db at all four sites. It was expected that plots with legumes and with more crop residues accumulation would have a positive effect on soil physical quality by improving the structure and decreased Db . However, no clear trends were observed between different cropping patterns. Similarly, Oliveira et al. [37] found no significant difference between beans and millet intercropping effects on Db .

A significant interaction effect between the tillage systems and CP on Db was recorded in Nhacoongo and Lichinga but not in Mutuali and Gurúè. The significant differences could be attributed to single outliers, and no clear trend was observed. Several other researchers have reported similar contradictory results. Nabanita [38] and Alam et al. [39] found insignificant interaction effects on Db between tillage systems and cropping patterns, whereas Rusu et al. [40] obtained significant interaction effects. The overall trend of tillage systems and cropping pattern interaction effects on Db under CA was higher than that under CT.

4.2. Penetration Resistance

PR values across the four study sites were consistently higher under CA systems compared to the CT system. Therefore, the CA system offered more resistance to root development than CT. This concurs with the results of Rashidi and Keshavarzpour [12] and Çelik [41]. The higher PR under CA can be due to almost no soil disturbance, which causes compaction and a decrease of macropore volume on the surface. Ploughing loosens the soil, leading to a lower PR. Across the four sites, the highest PR was recorded in Gurúè (CA = 2692 and CT = 2399 kPa) followed by Mutuali (CA = 1989 and CT = 1903 kPa) and Lichinga (CA = 1861 and CT = 1805 kPa), and unexpectedly, the loamy sand soil of Nhacoongo (CA = 1055 and CT = 554 kPa), despite that it recorded higher Db (CA = 1.57 and CT = 1.55 g·cm⁻³) than Mutuali (CA = 1.17 and CT = 1.14 g·cm⁻³), Lichinga (CA = 1.29 and CT = 1.20 g·cm⁻³) and Gurúè (CA = 1.06 and CT = 1.04 g·cm⁻³). Sandy soils (Gurúè and Mutuali) are more prone to compaction and surface crusting than clayey soils (Lichinga), thus explaining the difference in results obtained at the various sites.

The cropping pattern influenced *PR* significantly in Mutuali only. The interaction effects between tillage systems and CP had no significant influence on *PR* in Mutuali, Lichinga, and Gurúè. Across the four sites, higher *PR* values were observed under the CA system with CP interaction than under the CT system with CP interaction. According to some literature, the interaction between tillage systems and CP significantly influences *PR* [42]. At the same time, other researchers reported insignificant interaction effects, especially with short term studies [36].

4.3. Saturated Hydraulic Conductivity

In general, the hydraulic conductivity on all the sites was high ($>300 \text{ mm h}^{-1}$), which exceeds typical rainfall intensity. The *K_s* values were higher under CA systems than CT. Across the four sites, higher *K_s* values were recorded in the loamy sand soil of Nhacoongo ($CA = 743$ and $CT = 648 \text{ mm h}^{-1}$), while the lowest *K_s* values were recorded in the sandy loam soil of Mutuali ($CA = 517$ and $CT = 454 \text{ mm h}^{-1}$). Singh et al. [43] emphasized that the lower *K_s* values recorded under CT could be ascribed to the destruction of aggregates and reduction of macroporosity in ploughed soils. The positive impact of CA on *K_s* was somewhat surprising, as the general theory is that an increase in compaction and bulk density is typically associated with lower conductivity. The accumulation of organic matter associated with reduced physical aeration and accumulation of crop residues could be attributed to the increased conductivity. Organic matter and continuous root channels will increase the macroporosity under the CA, thereby increasing *K_s*. These results are consistent with those reported by McGarry et al. [44] and Kumar et al. [45], who found an increase in *K_s* under CA, probably due to the retention of crop residues that modified soil structure, hence aggregate stability. Although our study sites had high inherent *K_s*, the short term impact of CA in increasing *K_s* can be beneficial in other areas with low infiltration rates.

4.4. Evaporation

The tillage system had a significant influence on evaporation in some months at Nhacoongo, Mutuali, Lichinga, and Gurúè: Significant differences in evaporation were recorded at Nhacoongo and Gurúè in September, October, and November; at Lichinga in August, September, and November; and at Mutuali only in November. In most instances, evaporation was higher under the CT system than CA. These results are in agreement with those of Dembele [32], Singh et al. [46], and Thierfelder et al. [47], who reported improved water use efficiency due to the application of CA instead of CT. The higher evaporation under the CT system reflects the disadvantages of ploughing, which increases soil aeration and decay of soil aggregates, leading to enhanced water loss by evaporation. Conservation agriculture systems are effective in reducing evaporation and increase water holding capacity due to the presence of crop residues, which act as a protective skin for the soil by intercepting a great part of the incident solar radiation, creating thus a wetter microclimate at the soil surface, which enhances crop water availability. These findings are in agreement with those of Hobbs et al. [8], Alam et al. [39], and van Donk et al. [48], who reported that soils dry slowly on the surface due to the presence of crop residues under the CA system. The reduced evaporation is ascribed to shading, which moderates surface soil temperature and wind effects. Crop residues in CA systems also prevent the impact of direct rainwater on the soil, thus avoiding the formation of surface sealing, in turn maintaining water conductivity. Crop residues can reduce evaporation by 10–20% [49]. However, contradictory results were noted in Nhacoongo and Gurúè in August, Mutuali in August and October, and Lichinga in August, with higher evaporation recorded under CA than CT. The inconsistent trends recorded in August can be attributed to the fact that crop residues delay heat loss from the surface during winter, and this could promote warming during summer, leading to increased evaporation [50,51]. The inconsistency in the results could also be attributed to the use of microlysimeters, since they might not contain sufficient soil water to maintain realistic evaporation.

5. Conclusions

This study revealed some significant differences related to the tillage system across the four experimental sites in Mozambique after two years of employing different cultivation practices. Higher values of *Db*, *PR*, and *Ks* were recorded under the CA system when compared to the CT system. A change in soil physical properties usually requires a significant accumulation of organic matter, which requires a long time to achieve. The increased compaction, as indicated by *Db* and *PR*, is ascribed to the absence of tillage of the soil, whereas the increase in conductivity related to increased macroporosity is associated with the accumulation of organic matter through reduced tillage and crop residues. Evaporation at the soil surface is higher in the CT system than in the CA system. The decline in evaporation under CA, when compared to CT, is a short term benefit of CA that should be explored in the future to promote CA adoption under smallholder farmers. In the present study, tillage methods that significantly affected the soil physical properties due to decreased evaporation by reducing water loss were noted. Therefore, smallholder farmers should be encouraged to adopt CA practices to increase water availability in the soil during the crop growth period. Two years of experimentations were not enough to develop clear trends of sole cropping compared to intercropping. Thus, there is a need to conduct long-term studies to quantify cropping pattern effects on soil physical properties.

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