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EVALUATION OF FARMING SYSTEMS EFFECTS ON SPATIAL AND TEMPORAL VARIABILITY OF SOIL MOISTURE, ORGANIC CARBON AND BULK DENSITY IN RAIN-FED LOWLANDS OF LAIKIPIA COUNTY, KENYA

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ABSTRACT

A study to determine the effects of farming systems on spatial and temporal variability of soil bulk density, soil organic carbon and soil moisture was carried out in lowland areas of Laikipia during 2019 and 2020 cropping seasons. Soil sampling was carried out from 3m x 3m plots, demarcated in 30 selected farms practicing conservation agriculture (CA), conventional farming(CF) and from a bordering fallow reference land (RL). Ten soil samples/cores from each plot were collected at 20cm depth, using metallic soil augers of 5cm diameter and core ring samplers of 5cm diameter and 10cm height, air dried taken for lab analysis to determine the soil attributes. Findings indicated that the percentage soil moisture in farms adopting conventional farming was significantly lower than that adopting conservation agriculture. The mean soil bulk density under convention farming was 1.35 ± 0.06 g/cm^3, while farms under conservation agriculture had a mean bulk density of 1.78 ± 0.04 g/cm^3 and 1.13 ± 0.04 g/cm.^{3} in uncultivated reference land. Overall, the highest levels of total soil organic carbon were 61.9gkg^{-1} under CA and 35.3gkg^{-1} under CF. These findings could show that the adoption of CA can substantially affect the selected soil physical properties and potentially enhance soil quality and productivity in the study area.

Key Words: *Farming Systems, Conservation Agriculture, Soil carbon, Soil moisture, Soil quality*.

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INTRODUCTION

The average annual rainfall received in arid and semi-arid lands (ASAL) makes these regions have major water supply challenges (Wang *et al.*, 2017; Teame *et al.*, 2017). Majority of farmers in ASAL areas depend on rainfall for farming, since productivity has only been based on annual cumulative rainfall (Huho *et al.*, 2012; Huho and Kosonei, 2013). Rainfall water is lost mainly by direct surface runoff and inadequate water harvesting strategies (Sousa *et al* 2016; Abadi *et al*., 2018). This situation is further exacerbated by soil degradation from farming systems leading to decline in crop productivity (Tanveera *et al*., 2016).

Packham, (2010), defines farming systems as the collection of principles applied in farm production processes to improve agricultural performance. Climate smart farming systems approach has been used as one way to address soil degradation in semi-arid areas. Farming systems can affect plant available water, cause soil compaction and impede free root penetration (Packham, 2010; Sousa *et al*., 2016). It can also affect the distribution and supply of soil organic carbon by directly altering soil properties from different levels and intensity of management practices (Abadi, 2018).

Adoption of climate smart farming practices by farmers can substantially reduce land degradation; improve soil bulk density, soil organic carbon and soil moisture retention in arid farming (Tanveera *et al*., 2016; Kaufman *et al.*, 2010; Sousa *et al.*, 2016). Farming practices such as weed control, minimum soil tillage, increased use of organic biomass retention and water conservation can improve soil properties (Araz, 2014; Ngetich *et al.*, 2014). Conservation agriculture involving; minimum soil disturbance, permanent organic soil cover and crop rotation (Sousa *et al*., 2016; FAO, 2019), was introduced in Laikipia in 1997 with the aim of enhancing crop productivity and resilience (Kaumbutho and Kienzle, 2007). This farming model has subsequently been promoted among farmers through capacity development (Abadi *et al*., 2018; Sousa *et al*., 2016). However, after many years of implementation in the study area, empirical data to show effects of CA on soil attributes is lacking (Kuria, 2022; Kaumbutho and Kienzle, 2007).

The current study evaluated the effects of CA systems on temporal and spatial variation of soil moisture, bulk density and organic carbon in lowland farming areas of Laikipia County. Soil moisture, soil organic carbon and soil bulk density are among key biophysical factors associated with crop productivity as they affect soil tilth, crop anchorage, buffering of soil pH and exchange of plant nutrients (Kissel *et al*, 2012; Teame *et a*l., 2017).

MATERIALS AND METHODS

Description of the Study Area

The study area is located in two sub-counties in Laikipia north and East, between (N00.04423-N00.08516;E037.06823- 037.20538; and S00.07958-S00.13260; E036.57029-E036.946990), and is classified as semi-arid area, where water for production is inadequate, thereby compromising on food production (Sousa *et al*., 2016; Pound, 2014). The selected study areas consisted of Umande, Thingithu, Tigithi, Ngobit and Mukogodo East (Figure 1). It is characterized by undulating terrain with elevation from 1,300 to 2,010 masl and interspersed with acacia trees and savanna open grasslands. The average annual rainfall is between 400-700mm, with 80% of the annual precipitation occurring in mid-March to mid-May and in mid-October to mid-December with a dry season lasting about 4-5 months and varying in amount and distribution (Huho *et al.*, 2012; Sébastien *et al*., 2018). Maize (*Zea mays* L) is the dominant staple crop and is often intercropped with common bean (*Phaseolus vulgaris*) or black beans/dolichos (*Lablab purpureus*). The time at which these crops are planted is determined by the onset of rainfall season (Abadi, 2014). The soils were formed on gneisses and magmatites metamorphic rocks are well drained, moderately deep to deep, consisting of sandy-clay-loam to clay-loam separates, classified as Chromic Cambisols and Chromic Luvisols (Jaetzold and Schimidt, 2006). The area represents a wide range of climatic and agro-ecological conditions with areas of high as well as areas of low agricultural potential.

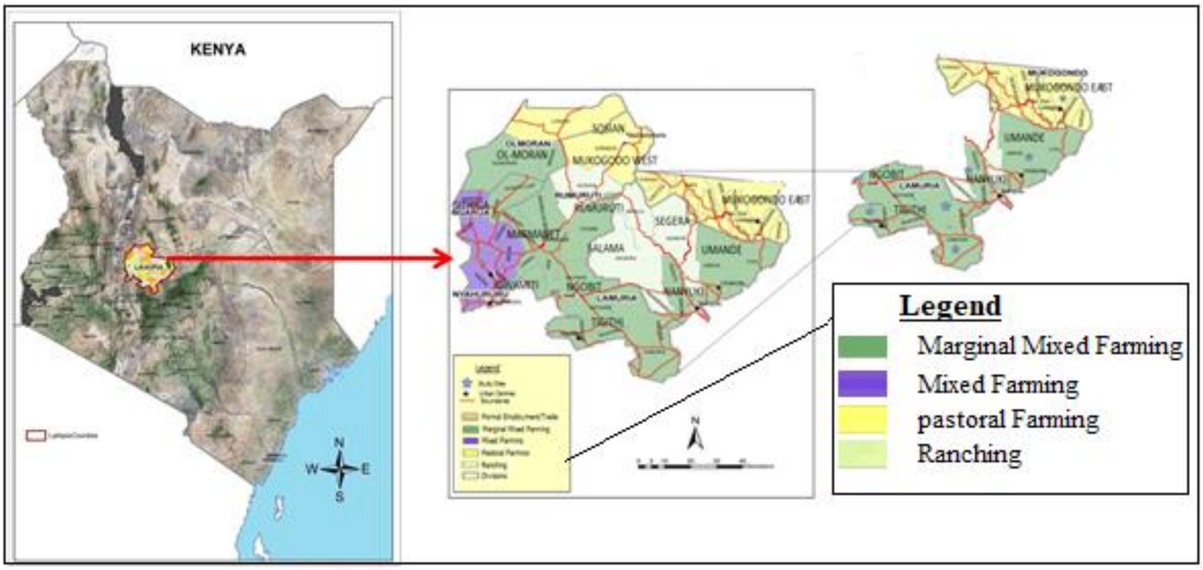

Figure 1: Map of Laikipia showing the study areas in Laikipia north and Laikipia East sub counties, where the study was carried out.

Farm Selection, Experimental Design, Soil Sampling and Analysis

The study area was purposively selected to include Laikipia East and north sub-counties where conservation agriculture had historically been introduced and consistently practiced. Four sites (wards) in Laikipia East sub-county (Umande, Tigithi, Thingithu and Ngobit) and one site in Laikipia north sub-county (Mukogodo East) were sampled. Random sampling was used to obtain the initial 332 farmers who had been registered as adopting CA with Ministry of Agriculture. Further screening of farmers was based on the following criterion; (i) farmers who received training on CA curriculum (ii) farmers who were actively practicing all the three principles of CA (minimum soil disturbance, crop rotation and soil cover), as outlined by FAO (2019); and (iii) farmers who were practising CA alongside conventional farming. A final sample of 30 farmers was selected by proportionate stratified random sampling method (Haque, (2010), facilitating proportioning of farmers in each ward according to their population in each sampling stratum (ward) (Table 1).

Table 1. Stratified Random Sampling of Farmers Based on Population of Farmer field schools

Ward	Farmers' who met selection criteria/ward	PSRS= Stratum population/total population *total	Sample size	% Population
Mukogodo East	30	2.6	3	9.5
Umande	52	4.5	5	15.9
Thingithu	25	2.2	2	8.4
Ngobit	87	7.5	8	23.4
Tigithi	138	12.0	12	42.8
Totals	332		30	100.0

Soil sampling

Mixed research design was adopted to determine effect of farming systems on soil moisture, bulk density and carbon in the five study sites. Sampling locations on the Conservation Agriculture (CA) and Conventional farming (CF) fields within each farm and a bordering reference (RL) that had been fallow for at least 3 years were done. For each location, soil samples were collected from ten randomly selected points within 3 x 3 m subplots, and bulked together to form composite samples. To reducing farm variability, three composite replicate samples of homogeneous soil types, similar crops and farming management practices in CA, CF and RL were collected. A 5-cm diameter soil auger was used to take soil samples at a depth 20 cm depth which is the rooting zone of most annual crops grown in the study area. Except for the soil samples determining soil moisture which were collected during wet and dry seasons, all other soil samples were collected during the dry season of 2019 and 2020. A total of 270 composite soil samples from 30 farms were collected, air dried and transported to the laboratory for analysis.

Determination of Bulk Density and particle size

The collection of soil samples for determination of soil bulk density was done during the dry season just before the onset of the April - May, 2019 long rainy (LR) season. Undisturbed soil samples were collected from the three sampling locations on each farm adopting CA, CF and RL, using a metal core ring sampler of 5cm diameter and 10cm height. The metal ring core sampler was driven into the soil to a depth of 0-20 cm using a wooden block and then excavated using a trowel. Excess soil was removed with a flat bladed knife, and then the core contents for each depth emptied in a separate paper bag, labeled and delivered to the laboratory. Bulk density was determined from moisture free samples after drying the samples at 105°C for 24 hours or until a constant dry weight was attained. Soil bulk Density (BD) was determined using the formula;

$BD\ (g/cm^3) = Wt(g) / Vol(cm^3)$ …… (1)

Where; BD = bulk density (g/cm^3); wt = weight of soil in the sampler (g), Vol = Volume (cm^3) of the dry soil sample.

Laboratory analysis

Soil organic carbon (SOC) was determined at the plant and soil analysis laboratory at the Kenya agricultural and Livestock Research Organization (KALRO) Nairobi by the wet oxidation method (Okalebo *et al*., 2002). Soil particle size distribution (sand, silt, and clay content) was analyzed using hydrometer method (Gee and Bauder 1986) and bulk density (BD) using core method (Blake and Hartge 1986), at the Plant and Soil laboratory, Kenya Agricultural and Livestock Research Organization (KALRO) Nairobi.

Soil Moisture Monitoring

Soil moisture was monitored during the wet and dry seasons, using gravimetric method. Top soil (0–20 cm depth) was sampled from ten sampling points in each sampling location using a 5-cm diameter soil auger and bulked into composite sample. The samples were then transported to the laboratory for drying and moisture determination. Two hundred and seventy sampling points were selected for the monitoring of soil moisture ensuring; (i) minimal human disturbances on the field, (ii) uniform crop and agricultural practices; (iii) uniform slope. Sampling was done on three occasions at 25, 50 and 70 days after seeding. The sampling intervals for soil moisture determination was justified since beans and maize crops grown in the region require adequate soil moisture condition at the time of planting, and during flowering and grain filling stages, which occurs around 50 days after seeding (Kenya Seed Co, 2010). Maize crop is especially sensitive to moisture stress at 45-60 days after germination (Kenya Seed Co, 2010; Jaetzold and Schimidt, 2006). In view of this, soil moisture availability to crops should coincide with this critical stage of water requirement. The crop farming calendar from planting to harvesting in the study area is shown in Table 1.

Table 1: Crop farming calendar.

Dry ←→		Wet ←→ Long Rains			Dry ←→				Wet ←→ Short Rains		
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
H	LP_1	P_1 W_1 W_2			H	N-A	N-A	LP_2	P_2 W_1 W_2		

***Key*:** LP_1, LP_2= Land preparation for 1st and 2nd cropping cycles; W1, W_2 = Weeding for first and second cropping cycles; H = crop Harvesting; Wet = Wet period and N-A = No Activity. (*Adopted with modifications from Huho et al., 2012*).

Soil moisture content was determined by the gravimetric method according to Okalebo *et al*., (2002). Soil samples were first weighed to record the weight of wet soil samples. The soil samples were then oven dried at 105°C in an oven for 24 hours and then reweighed to determine soil moisture content on a dry basis. The soil moisture content was calculated as: -
$\%MC = (WTw - WTd)/WTd * 100 \ldots\ldots$ (2)
Where %MC = Percentage Moisture Content, WTw = Weight of field wet sample, WTd = Weight of oven dry sample.

Statistical Analysis
Statistical analyses were performed with SPSS 21.0 software and MS Excel, 2019 office. Differences in soil parameter levels in different farms under CA, CF and RL were compared using two-way analysis of variance (ANOVA) followed by Tukey's post hoc multiple test analysis for significance of soil carbon, soil bulk density and soil moisture content. Findings were considered to be significant if $p<0.05$.

RESULTS

General agronomic practices employed by farmers in the study area
Analysis of farmer's agronomic activities and farm management practices in the study area are shown in (Table 2). Findings showed that, the average farm size is 2.8 acres, with 74% cultivating maize, 8% sorghum and 18% wheat respectively. On legumes, 75% of farmers cultivated beans. Findings indicate that, 75% of farmers utilized commercial fertilizers while 25% utilized manure, 79% of farmers practiced mono cropping, while 21% cultivated diverse crops. On crop residue management, 58% of farmers retained crop residues on soil, 37% fed crop residue to livestock, while 5% of farmers burnt it. Majority (75%) of farmers retaining crop residue on soil were from Ngobit ward. In weed control, findings show 79% of farmers used manual weeding while 21% used chemical control (herbicides). For land preparation and tillage, 78% of farmers utilized moldboard ploughs, 17% utilized chisel ploughs while 5% used other equipment. Findings indicated that, farming in the study area is majorly rain fed with 92% of farmers relying on rainfall and only 8% using irrigation.

Table 2. Agronomic Practices Carried Out By Farmers In The Study Area.

	Tigithi (n=138)	Ngobit (n=87)	Umande (n=52)	Mukogodo E. (n=30)	Thingithu (n=25)	*% Av*
Average farm size (acres)	4	4	2	2	2	*2.8*
Cultivation of Cereal Crops						
Maize *(%)*	70	70	80	70	80	*74*
Sorghum *(%)*	10	10	10	5	5	*8*
Wheat	20	20	10	25	15	*18*
Cultivation of Legume Crops						
Beans *(%)*	65	75	80	75	80	*75*
Peas *(%)*	35	25	20	25	20	*25*
Soil Fertility Management						
Use of Fertilizer (%)	65	60	75	90	85	*75*
Use of Manure (%)	35	40	25	10	15	*25*
Crop Diversification						
Pure Stand *(%)*	75	70	80	90	80	*79*
Mixed Cropping *(%)*	25	30	20	10	20	*21*
Crop Residue Management						
Incorporated into soil *(%)*	65	75	60	50	40	*58*
Fed to livestock *(%)*	31	23	35	45	52	*37*
Burnt *(%)*	4	2	5	5	8	*5*
Weed Control Management						
Manual weeding *(%)*	75	65	80	85	90	*79*
Chemical weeding *(%)*	25	35	20	15	10	*21*
Use of Tools for Ploughing and Tillage						
Moldboard Plough *(%)*	70	65	83	80	90	*78*

Chisel Plough *(%)*	25	30	15	10	5	*17*
Others *(%)*	5	5	2	10	5	*5*
Source of Water For Farming						
Rain fed *(%)*	82	86	97	98	99	*92*
Rain fed + Irrigation *(%)*	18	14	3	2	1	*8*

Rainfall Patterns in The Studied Sites

Rainfall distribution during the study period is shown in Figure 2. Results show that the amount of rainfall received in 2020 was generally higher than in 2019, with significant levels in Mukogodo East and Umande sites. The period between January-February, June-September represent a period of dry season, in both 2019 and 2020. The highest amount of rainfall received in 2019 rainy season occurred in the months of April and November at Ngobit, Tigithi and Thingithu. Seasonal rainfall patterns indicate that much of the rainfall is received in the 1st and the 2nd months after the onset of rainfall season. Rainfall pattern show rainfall amount diminishes in approximately 75 days after seeding following onset of rainfall season.

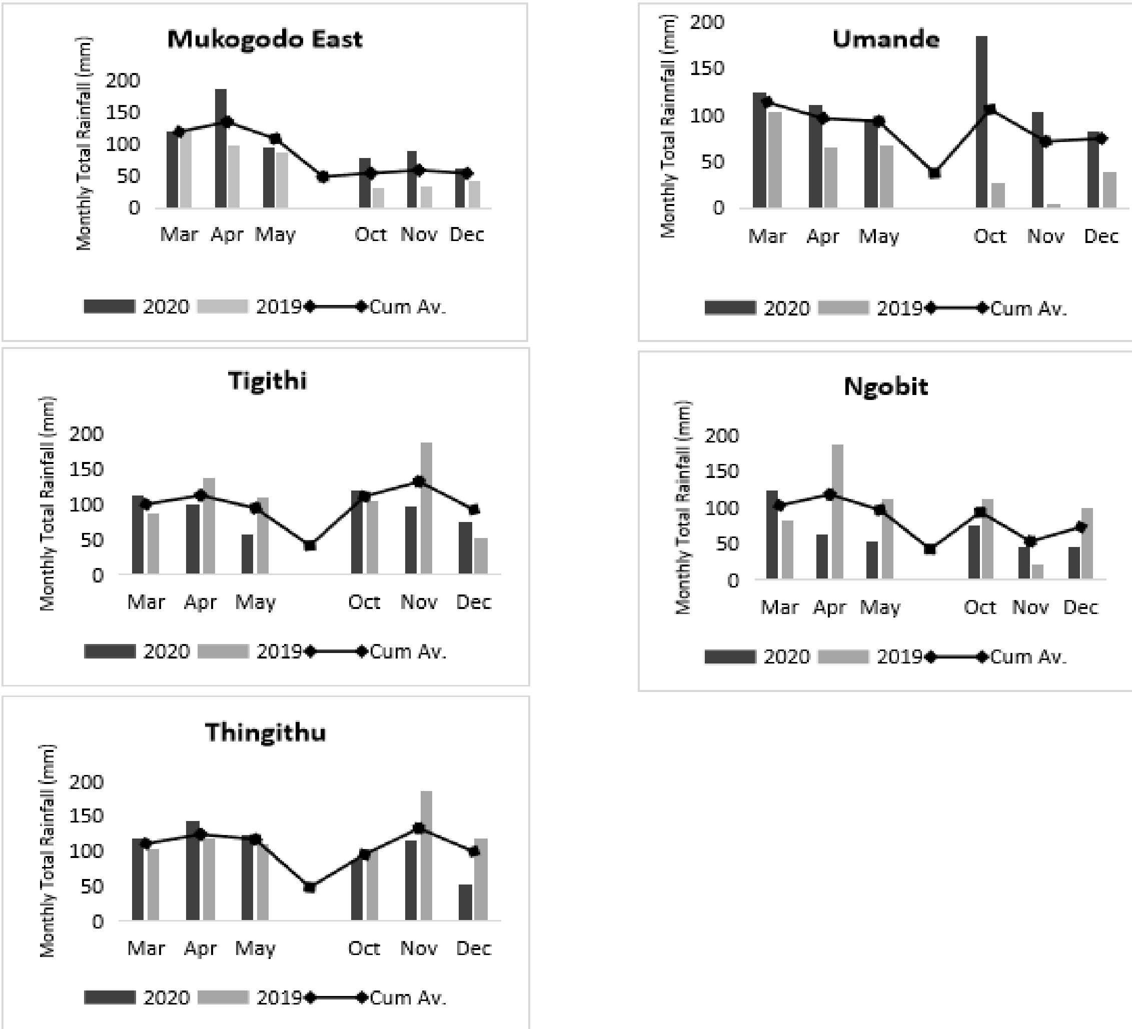

Figure 2: Rainfall distribution in the study area showing amounts received and patterns during long rain (LR) and short rains (SR) seasons in 2019 and 2020, against cumulative average.

Soil Textural Characterization of the Surveyed Farms

The results of soil textural classification in the studied farms showed that the dominant soil texture was sandy clay loam (SCL) (Table 3). The mean percentage of sand ranged between 56-59%; that of clay separate ranged between 26-33%, while that of silt separate ranged between 12-15%.

Table 3. Characterization of soil textural classes in the study sites

	Soil separate	Max	Min	Mean	SD	CV	K	S	Pr(>F)	Textural class
Umande (n = 5)	Sand (%)	78	50	56	5.8	1	3.9	1.9	0.8	Sandy clay loam
	Clay (%)	45	14	33	5.6	1.7	1.4	-1	0.59	
	Silt (%)	20	6	11	2.8	2.3	1.1	0.1	0.62	
Mukogodo East (n = 3)	Sand (%)	78	54	59	4.5	0.8	16	3.8	0.62	Sandy clay loam
	Clay (%)	36	16	28	4.1	1.6	1.7	-1	0.75	
	Silt (%)	18	6	13	3.2	2.9	-1	0.1	0.67	
Ngobit (n = 8)	Sand (%)	78	54	58	4	0.5	8	2.3	0.51	Sandy clay loam
	Clay (%)	36	14	29	3.5	1.1	-1	0	0.53	
	Silt (%)	18	6	13	2.7	2.7	-1	0.5	0.73	
Tigithi (n = 12)	Sand (%)	72	50	58	3	0.6	5.6	0.5	0.69	Sandy clay loam
	Clay (%)	40	18	29	3.5	1.4	1.7	0	0.7	
	Silt (%)	18	6	12	2.4	2.5	0	0.8	0.68	
Thingithu (n = 2)	Sand (%)	78	53	59	4.4	0.7	5.1	1.9	0.43	Sandy clay loam
	Clay (%)	36	12	26	4.2	1.7	3.6	1.8	0.74	
	Silt (%)	18	10	15	2.7	2.2	0	-1	0.62	

Variations in Soil Organic Carbon Under Different Farming Systems In Five Sites

Findings of 2019/2020 temporal variations in total soil organic carbon under different farming systems in five sites are shown in Figure 3.

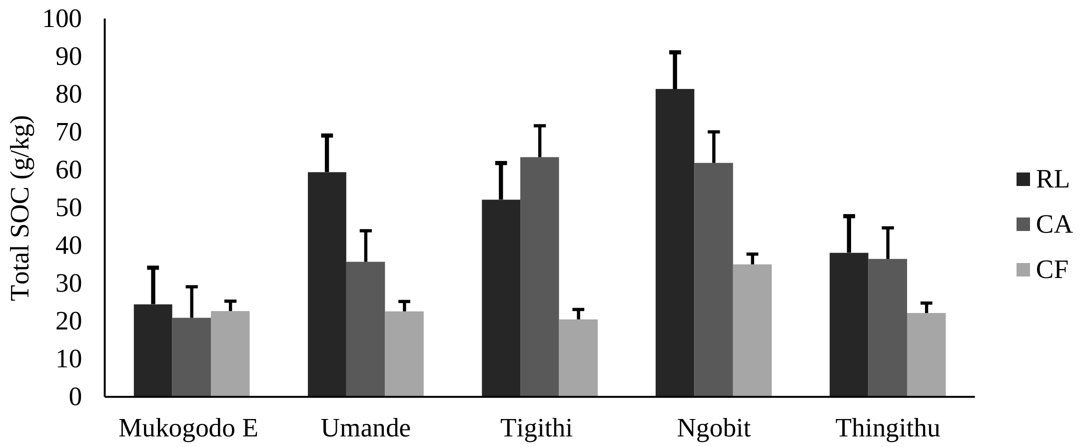

Figure 3. Soil Organic Carbon in Different Farms And Farming Systems During 2019/2020 Cropping Seasons.

Individual farms and sites reported differing findings with significantly higher levels of SOC under CA at Umande (35.7gkg^{-1}) and Ngobit (61.9gkg^{-1}) sites in 2019/2020 season.

Findings also indicate significant levels of SOC in the RL at Umande (59.4gkg^{-1}) and Ngobit (81.4gkg^{-1}) wards. Overall, the farms in Ngobit ward had the highest levels of total soil organic carbon in farmed soils; with an average of 61.9gkg^{-1} under CA and 35.3gkg^{-1} under CF. The higher levels in SOC findings reported in selected wards are postulated to be due to the effects of agronomic practices presented earlier in Table 2. Although the percentage ratios of farmers adopting climate smart agronomic practices is still low (75%:25%), a significant number of farmers in Ngobit, Tigithi and Umande wards had adopted agronomic practices that can enhance SOC. These practices included; the use of farm yard manure (40%, 35%, 25%), retention of crop residue on farm (75%, 65%, 60%), use of chemical weed control (35%, 25%, 20%) and use of chisel ploughing (30%, 25%, 15%), in Ngobit, Tigithi and Umande respectively.

Variations in Soil Moisture under Different Farming Systems in Five Sites

Soil moisture variation during the 2019 and 2020 cropping season is shown in Figure 4. Soil moisture in farms adopting CA and those from the reference land (RL) varied significantly ($p>0.05$) at '25DAS' and '50DAS' as compared to those farms adopting CF. Studies on farming systems, according to (Ngwira *et al*., 2014) show that, CF as compared to CA can retain more soil moisture at the start of the season due to the opening up of soils during ploughing at the start of a rainy season, but loses that moisture faster than CA when the temperature rises, while the rainfall amount reduced in amount and intensity. This period is marked by high initial downpour of rainfall occurring at the start of the season (Figure 2), contributing to differences in soil moisture levels in soils under different farming systems. Soil moisture did not differ significantly at '25DAR' for farmers adopting CF in Thingithu, Ngobit and Mukogodo East. Soil moisture differed significantly at '75DAS' in farms adopting CA except in Tigithi site.

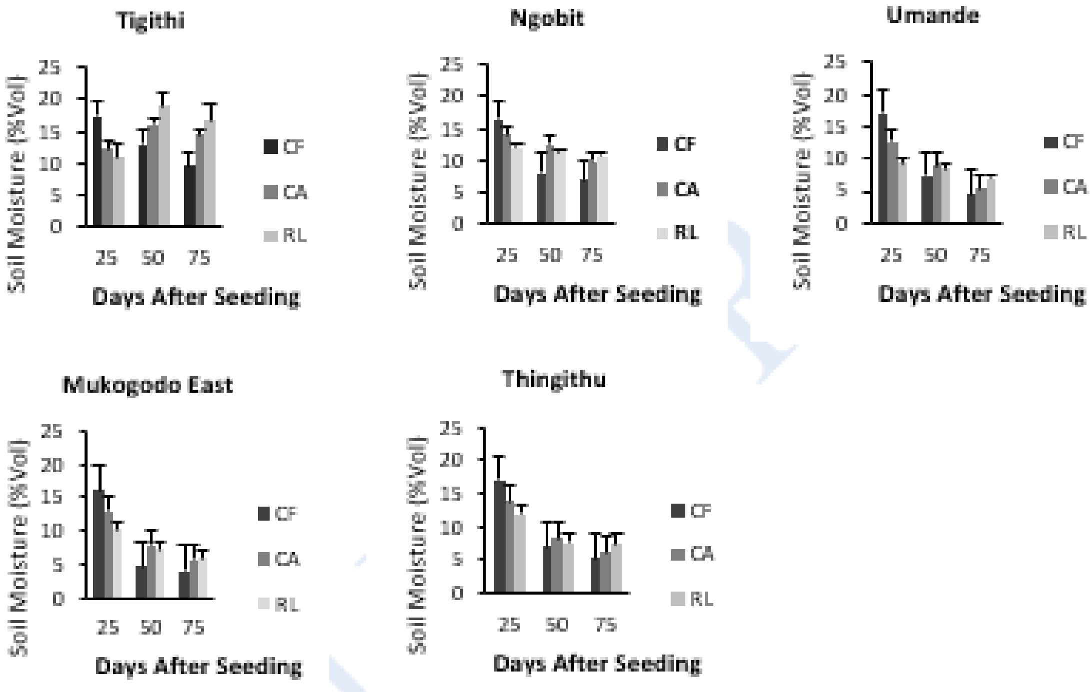

Figure 4. Histograms showing soil moisture (%vol) at 25, 50 and 75 days after seeding (DAS), in different farming systems. Error bars in the same DAS that don't overlap at all, are significantly different ($p < 0.05$).

Variations in Soil Bulk Density Under Different Farming Systems in Five Sites

Results in Table 4 show mixed effects on cumulative soil bulk density in the farms adopting CA, CF and the reference land in Tigithi, Ngobit, Umande, Mukogodo East and Thingithu sites during 2019/2020 cropping seasons. Bulk density (BD) in farms adopting CA were significantly higher ($p \leq 0.05$) in 2 farms in Tigithi ward, 4 farms in Ngobit, 1 farm in Umande ward and 3 farms in Mukogodo East ward. Findings on farms adopting CF showed significantly higher soil bulk density in 1 farm in Tigithi ward, 2 farms in Ngobit ward, 3 farms in Umande ward and 1 farm in Mukogodo East. Most of samples from CA and the RL, had significantly higher soil bulk density, compared to those from CF. These findings are in consistent with those by Kaufman *et al*., (2010) and Tanveera *et al*., (2016), that showed varying effects on soil BD under different farming systems.

The highest mean soil bulk density in farms adopting CF was 1.35 ± 0.05 g/cm^3 and was recorded in Ngobit ward, while the mean soil bulk density in farms adopting CA was 1.78 ± 0.04 g/cm^3, recorded in Mukogodo East ward. Soil samples collected from RL had highest mean bulk density of 1.82 ± 0.02 g/cm^3 and was recorded in Umande ward.

Table 4. Results of soil bulk density (gcm^{-3}) under different farming systems in five study sites

Farm no.	Farming system		Tigithi			Ngobit			Umande			Mukogodo East			Thingithu		
		df	Mean	SE	pr>F	Mean	SE	pr>F	Mean	SE	pr>F	Mean	SE	pr>F	Mean	SE	pr>F
1	CA	2	1.23a	0.04	0.102	1.36b	0.06	0.047	1.76b	0.04	0.054	1.78b	0.04	0.054	1.21a	0.07	*0.059*
	CF		1.04a	0.05		1.14a	0.02		1.04a	0.03		1.01a	0.03		1.30a	0.06	
	RL		1.28a	0.06		1.28b	0.05		1.44b	0.2		1.54b	0.2		1.29a	0.06	
2	CA	2	1.32a	0.05	0.443	1.50a	0.02	0.111	1.22a	0.09	0.189	1.02a	0	0.189	1.32a	0.06	0.0*
	CF		1.35a	0.05		1.14a	0.06		1.06a	0		1.06a	0.02		1.09b	0.01	
	RL		1.43a	0.02		1.35a	0.10		1.82a	0.02		1.22a	0.09		1.43a	0.02	
3	CA	2	1.31a	0.02	0.054	1.56a	0.01	0.00*	1.38a	0.05	0.064	1.38ab	0.05	0.01*			
	CF		1.17b	0.04		1.11b	0.01		1.15a	0.06		1.15a	0.06				
	RL		1.35a	0.02		1.37c	0.05		1.57b	0.03		1.57b	0.03				
4	CA	2	1.34b	0.06	0.03*	1.32a	0.07	0.054	1.19a	0.05	0.058	1.29b	0.05	0.054			
	CF		1.13a	0.04		1.13a	0.01		1.07a	0.03		1.07a	0.03				
	RL		1.33b	0.06		1.42b	0.04		1.32b	0.04		1.32b	0.04				
5	CA	2	1.23a	0.04	0.053	1.24a	0.05	0.579	1.24a	0.04	0.617						
	CF		1.25b	0.05		1.15a	0.02		1.07a	0.13							
	RP		1.33b	0.01		1.20a	0.05		1.13a	0.04							
6	CA	2	1.25a	0.08	0.231	1.10a	0.03	0.04									
	CF		1.11a	0.02		0.99a	0.03										
	RL		1.31a	0.03		1.22b	0.09										
7	CA	2	1.40b	0.04	0.02*	1.25a	0.01	0.00*									
	CF		1.13a	0.06		1.13a	0.01										
	RL		1.53b	0.06		1.34b	0.09										
8	CA	2	1.31a	0.03	0.182												
	CF		1.11a	0.01													
	RL		1.37a	0.03													
9	CA	2	1.26a	0.02	0.00*												
	CF		1.11a	0.01													
	RL		1.36b	0.04													
10	CA	2	1.28a	0.01	0.189												
	CF		1.15a	0.05													
	RL		1.37b	0.04													
11	CA	2	1.38a	0.05	0.01												
	CF		1.15a	0.06													
	RL		1.57b	0.03													
12	CA	2	1.02a	0	0.189												
	CF		1.06a	0.02													
	RL		1.22a	0.09													

*Analysis of Variance (ANOVA), Tukey's multiple family-*wise *comparisons of soil bulk density between farming system at 95% confidence level. Different letters indicate significant differences in bulk density between farming systems. Group values with the same letter are not significantly different at 95% confidence level.* KEY: CA= Conservation Agriculture; CF= Conventional Farming; and RL= Reference Land.

DISCUSSIONS

Site Characterization and Farming Management Practices

To reduce crop-weed competition for soil moisture and improve soil nutrients in the dryland rain fed farming, most farmers carry out weed control in the first week of weed germination (Kivuva *et al*., 2014). Studies have continued to show the vital role played by leaving crop residues on the soil surface, which serve to protect soil against erosion and improve surface aggregation, thereby reducing crusting and surface compaction of the soils (Kamiri *et al*., 2022). As outlined by (Teame *et al*., 2017, soil compaction happens due to farming practices, (Wang *et al.*, 2017), moisture stress in crops especially during the sensitive stages of flowering and grain filling can lead to major drop in crop yield performance (Kenya Seed Co, 2010).

Rainfall patterns in the studied sites

Findings demonstrated how rainfall trend in amounts and intensity received are distributed throughout the season, and which has implication on soil moisture levels (Huho *et al*., 2012). From these patterns, it is evident that there are high chances of the crops depleting the available soil moisture as the season advances leading to moisture deficit and crop failure. In this case proper timing of the rainfall onset by adhering to the seasonal rainfall calendar and encouraging farmers to plant early are necessary for the crops to utilize rain water.

Soil textural characterization of the surveyed farms

The major soil texture in the studied farms consistently remained sandy clay loam. Soil texture being an inherent factor (USDA-NRCS, 2015), the study did not provide evidence of significant effects of farm management practices on the soil texture. Soil texture affects pore space distribution, water infiltration and can also lead to moisture loss at the crop root levels (Tanveera *et al*., 2016). The sandy-loamy nature of the soil in the study area, facilitate water movement through its large pores as compared to other soils with small pore spaces. In this case, the adoption of CA farming system and management practices according to Packham, (2010), can consistently improve soil physical properties.

Variations in soil organic carbon under different farming systems in five sites

Adoption of agronomic practices such as zero tillage and retention of crop residues employed in CA has been found to contribute to increased soil carbon sequestration (Luo *et al*., 2010). These findings are consistent with those by Kadiri *et al*., (2021) and Araz, (2014). Retention of crop residues by farmers in farming practices in this study is consistently associated with improved soil water infiltration providing additional organic biomass and acting as soil mulch during dry seasons. This practice is further associated with enhancing SOC and improved soil physical properties in farms adopting CA, which is in line with studies by Teame e*t al*., (2017) and Alavaisha *et al.*, (2019). Such agronomic practices if maintained over a long duration can be expected to improve SOC levels at 20cm soil depth and the overall soil physical properties in the area. Maintaining grasslands biomass and use of farm yard manure is postulated to be the reason behind increased levels of SOC in Ngobit and Tigithi wards (Kamiri *et al*., 2022). Although none of the tested farming practices provided adequate levels of SOC sequestration in soils, long term practice and adherence to the principles of CA has the potential to substantially increasing SOC in farms.

Variations in soil moisture under different farming systems in five sites

The results portray similar findings by Teame, *et al.,* (2017) and Sousa *et al.*, (2016), that showed variations in soil moisture, usually leading to crop failure in dryland farming due to inadequate supply of water. The study found that moisture stress to crops occurred at 75"DAS", which coincided with the critical crop moisture requirement period, usually at crop flowering and grain filling stages, as experimented by Kenya Seed Co. 2010. Findings on the use of supplemental irrigation during dry season by farmers in Laikipia are also consistent with those by Teame, *et al.,* (2017). Overall, the percentage soil moisture in farms adopting CF system was lower than those from farms adopting CA and the reference land at '75DAR', in all the five sites.

Variations in soil bulk density under different farming systems in five sites

It is speculated that "zero tillage" and lack of regular soil ripping by farmers as recommended in CA principles by FAO, (2019), is the main reason for high soil BD in majority of farms under CA. Reliance on 'biological tillage' in farms adopting CA, rather than 'physical tillage' as applied in CF farming system makes the soils in CA farms get compacted resulting in possible higher BD level, consistent with findings by Sousa *et al*., (2016). Soil texture, particle size and organic matter content can also affect soil BD (Kaufman *et al*., 2010). Soil bulk density of between 1.2 - 1.55gcm^{-3}, has been found to enhance soil porosity, root penetration, moisture absorption and nutrient availability (Tanveera *et al*., 2016; Ngetich *et al*., 2014).

Recommendations

Adoption of CA farming system can substantially and gradually affect soil BD, SOC and soil moisture which are major soil physical properties with the potential for increasing productivity in dryland farming. We recommend increased use of crop residue in farms, regular soil ripping using soil rippers and continuous adjustment of plough depth by farmers consistent with CA and CF farming principles, which is expected to reduce the development of soil hard pans and high bulk density. Rain water harvesting and storage at the farm level can substantially provide additional water for use in supplementing irrigation in times of inadequate soil moisture that can sustain crop growth to maturity. Farmers are advised to adopt early land preparation, dry land planting, water and soil conservation, use of agroforestry and proper weed management to up-scale climate smart farming technologies, innovations and management practices that improve soil properties. Government policies that strengthen farmers' capacity and promote resilient food systems should be put in place. Further studies are required to establish other factors beyond this study that contributed to inconsistencies in findings from similar farming systems and soil types.

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