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Research article

Soil nutrients and crop yield response to conservation-effective management practices in the sub-humid highlands agro-ecologies of Kenya

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ABSTRACT

Crop productivity in most smallholder farming systems in Sub-Saharan Africa experience low use of soil amendment resources, low and erratic rainfall, frequent dry spells, and droughts. Rain-fed agriculture has a high crop yield potential if rainfall and soil nutrient input resources are utilized effectively. Thus, in 2011, we set up an on-farm experiment in Meru South (sub-humid) and Mbeere South (marginal sub-humid) sub-counties in upper Eastern Kenya to assess conservation-effective management (CEM) practices effects on maize (*Zea Mays* L.) yields response and soil nutrients. The CEM practices were; tied ridging (TR), mulching (MC), and minimum tillage (MT), with conventional tillage (CT) as a control. There were frequent dry spells and droughts during the experimental period. The experiment ran for four seasons, from the long rains season of 2011 (LR11), short rains seasons of 2011 (SR11), long rains season of 2012 (LR12), short rains 2012 (SR12), and long rains season of 2013 (LR13). In Meru South, TR and MT treatments had significantly higher phosphorus content (100% and 66%, respectively) than the control. Also, in the same site, Cu and Zn were high in MT than in CT treatments. In the Mbeere South site, the aboveground biomass yield was significantly higher in TR treatment (by 71%) than CT during SR11, while in LR12 season, it significantly increased by 72% and 46% under MC and TR treatments, respectively, than the control. The TR treatment had significantly higher aboveground biomass than the control (84% and 115%) in the SR12 and LR13 seasons. In Meru South, MC treatment had significantly higher aboveground biomass, which was significantly higher, by 39%, during the SR11 season and 46% in TR treatment in SR12 season than the control. This study highlighted tied ridging as the best-fit practice for enhancing maize crop aboveground biomass production in rain-fed farming systems of marginal lands and sub-humid regions receiving unreliable rainfall. Further, we recommend longer-term experimentation to explore CEM effects on soil nutrients.

1. Introduction

Due to the low use of soil nutrient inputs and water conservation practices, declining food production is a major concern for most rain-fed dependent smallholder farming systems of sub-Saharan Africa (SSA) (Graaff et al., 2011). Yet, 'farmers' farming on less than 2 ha in total landholding dominate agriculture in SSA. Conservation management practices offer potential benefits such as sustainable farm food productivity and food security to the smallholders (Giller et al., 2011; Naab et al., 2017). Specifically, they aid in rectifying soil degradation and climate change/variability-related effects – such as soil erosion, soil fertility decline, runoff losses, labor unavailability, and adverse effects – on agricultural productivity (Jat et al., 2012). According to Tully et al. (2015), high population growth in SSA has resulted in the expansion and intensification of agriculture, one of the main causes of soil degradation. In the study area, Central Highlands of Kenya, soil fertility and crop production have been decreasing over time due to continuous soil plowing and the inadequate amount of soil nutrients coupled with increased population size (Mucheru-Muna et al., 2014). Crop performance and soil fertility can be altered by continuous cultivation and the absence of soil cover. The low, erratic, and unreliable rainfall amounts in the Central Highlands of Kenya aggravate the adverse alteration of soil properties and crop performance (Ngetich et al., 2014a). To enhance food security for the growing population in the study area, it is important to ensure the conservation of soil nutrients and enhance rainwater use.

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Soil fertility improvement can be enhanced through the application of soil amendment resources, e.g., mineral fertilizers. However, the smallholder farmers in the study region hardly afford the mineral fertilizers' right quantities (Macharia et al., 2014). Soil and water conservation-effective management practices have been found to cause soil properties changes (Palm et al., 2014). The changes could either be positive or negative. For instance, the CEM practices enhanced soil pH, organic matter, and available nutrient content compared to conventional tillage in the study of Mousques and Friedrich (2007). Additionally, Abolanle et al. (2015) observed that minimum tillage could significantly increase SOC than does conventional tillage. Crop residue retention is recommended as a source of SOC and overall soil quality enhancement (Lal et al., 2004; Hiel et al., 2018). Consequently, Dalal (1992) observed a reduction in total N loss under no-tillage practice. On the other hand, N availability is sometimes reported to be low under conservation agriculture systems with residue retention due to low decomposition rates and higher N immobilization than in conventional practice (Boddey et al., 2010). Practices of different conservation techniques and cropping sequences also lead to variation in soil "micronutrients" behavior (Fe, Mn, Zn, and Cu). Micronutrients are required in micro quantities, but their lack can cause severe crop performance challenges (Tully et al., 2015). Soil nutrients concentration is typically higher on the topsoil layer in CEM practices such as minimum tillage, mulching, and tied ridging than under tilled soil (Giller et al., 2009). Soil nutrient decline is a major constraint towards productivity in the study region. Thus, the need to explore the potential of the CEM practices to enhance soil properties.

Although maize (*Zea Mays* L.) production is the predominant farming enterprise in the study area, the grain yields have declined to below 1.0 Mg ha^{-1} against a probable of 6–8 Mg ha^{-1} (Kiboi et al., 2019). Maize stover yields have also been reported to be lower under conventional farmers' practices compared to mulching and tied ridging practices under on-station trials in the study region (Okeyo et al., 2014). Maize crop is widely used as human food (grain yield), animal feed, fuel (gas, solid, or liquid), and mulch (cobs and stover). According to Pordesimo et al. (2004) and Ion et al. (2015), maize is a vital source of biomass for producing biogas, high dry matter yield, and is easy to cultivate. Thus, all output (i.e., total aboveground biomass) from maize crop is essential. One of the requirements to produce biomass efficiently is using the most appropriate CEM techniques such as reduced tillage (Ion et al., 2015), mulching, and tied ridging. There is limited information on quantities of aboveground biomass produced under CEM practices than with conventional practices under on-farm conditions under sub-humid agroecologies of Kenya. Higher demands for agriculture to provide food, feed, fiber, and fuel have led to an intensification of production practices on farm 'lands' (Sanderson et al., 2013). However, changing from conventional tillage agriculture to practicing CEM practices requires 'shifts' in conventional thinking and attitudes on how the farmers should undertake agriculture. Implementation of the CEM practices under on-farm conditions could facilitate the transition of their benefits to the implementing farmers, their neighbors, the nation at large, and future generations (FAO, 2001).

As defined by Kiboi et al. (2017), conservation-effective management practices as "strategies that enhance soil conservation, soil water-holding capacity, crop yield increase, and stability under the smallholder rainfed farming system" – are widely accepted ways of improving crop yields in rain-fed agriculture. Thus, under rainfed production, the first strategy to reduce crop production risks would involve enhancing soil water retention and conservation through surface management approaches such as tied ridging, mulching, and reduced tillage. Studies conducted in the study region suggest that to improve management of natural resources, especially soils, training is an important constituent of imparting skills that build the target group's capacity (Macharia et al., 2014). Implementation of CEMs practices under researcher-designed farmer-managed trials would be of greater advantage in facilitating their uptake. Therefore, this study's objective was to assess the selected CEM practices' effects on soil nutrients and aboveground biomass yields of maize in small-hold farmers' fields in sub-humid and marginal sub-humid agro--ecologies. The research questions we set out to answer were (i) how does the implementation of CEM practices influence soil nutrients in farmer's fields? (ii) what is the effect of CEM practices on total maize crop aboveground biomass yield?

2. Materials and methods

2.1. Description of the study sites

The areas were Mbeere South (marginal sub-humid site) and Meru South (sub-humid site) sub-counties (Kiboi et al., 2017) in the South-Eastern slopes of Mt Kenya. The region experiences bimodal rainfall patterns; long rains (LR) in March, April, and May (MAM)and short rains (SR) from October, November, and December (OND) (Jaetzold et al., 2007). The main food crop is maize (*Zea Mays* L.) produced under limiting conditions as most farmers apply less amounts or no external soil fertility amendment resources.

Mbeere sub-county receives an average yearly rainfall of 800 mm with an annual average temperature of 21.6 °C, thus high evapotranspiration rates. It lies at an altitude of 700–1200 m above sea level (a.s.l.). Sandy clay loam Cambisols is the predominant soil type (FAO, 1988; Ngetich et al., 2014b). The main cropping system is maize-based and intercropping with the common beans (*Phaseolus vulgaris* L.).

Meru South receives an average yearly rainfall of about 1200 mm with an annual average temperature of 20 °C. It lies at an altitude of 1500 m a.s.l. Maize cropping is the predominant cropping system practiced by smallholder farmers with farm sizes ranging from 0.1 to 2 ha – an average of 1.2 ha per household (Shisanya et al., 2009). The predominant soil type is *Humic Nitisols* (Jaetzold et al., 2007), with clayey soil texture (Ngetich et al., 2014b). O.

2.2. Experimental design and implementation of the CEM practices

The on-farm experimental design was an incomplete randomized block design with the CEM practices replicated four times in each sub-county. Twelve farmers (each considered an incomplete block) were selected to implement the trials for four cropping seasons consecutively from each sub-county. The willingness to implement the experiment, similarity of farms in soil type and continuous tillage and nearness to automatic rain gauges (1 km radius) installed in nearby public schools were the criteria used in selecting the farmers. Each selected farmer practiced a different CEM practice beside a nearby conventional practice. Maize was the test crop; DH04 and H515 varieties for Mbeere South and Meru South, respectively. Both varieties were from Kenya Seed Company Limited. The plot size varied in each site: 6 × 6 m in Mbeere South and 6 × 4.5 m in Meru South. The plant spacing (between and within rows spacings) for Mbeere South was 0.90 m × 0.60 m, while for Meru South, it was 0.75 m × 0.50 m. The adopted spacing was as per the recommendation of the Ministry of Agriculture in Kenya.

The implemented CEM practices in both sites were: (1) minimum tillage, (2) tied ridging (3) mulching, and (4) a control (farmers' practice). In the conventional treatment plots, the farmers removed the crop residues before plowing the plots to roughly about 15 cm deep. The conventional treatment plots were maintained weed-free through weeding using hand hoes. For the mulching treatment, the land was prepared just like conventional treatment, and mulch was applied soon after crop emergence. The mulching rate was 5 Mg ha^{-1} (dry matter basis), and the mulching material used was the previous season's maize stover (residue). In the tied ridging treatment, ridges were made using a hand hoe during the establishment of the experiment (Short rains season of 2011) and seasonally mended on a need basis. The ridges were constructed with a height of 0.2 m and interchanged ties of 0.15 m apart. Under minimum tillage, farmers removed the crop residues and did not plow the plots. Instead, they only dug planting holes for seed sowing. While the maize crop was not affected by any disease, Bulldock pesticide (manufactured by Bayer East Africa Ltd) was used on a need basis to control pests such as stem borers. Before the onset of each season, the farmers were re-trained on implementing the CEM practices. The experiment was established in 2011 and ended in 2013, thus implemented during the short rains season of 2011 (SR11), long rains season of 2012 (LR12), short rains season of 2012 (SR12), and long rains season of 2013 (LR13). The distinction between the long and short rains season is the period (rainy length) the rains are received. The long rains period is March, April, May to Early June (approximately three and half months), while the short rains season runs from October November to mid-December (about two and half months, on average) (Ngetich et al., 2014a).

2.3. Crop management and yield measurement

Three maize seeds were planted per hill during sowing and thinned to two seedlings a week after emergence. The approach was used in order to achieve the recommended plant population (as per plant spacing) per site. Mineral fertilizers were band-applied during planting at the recommended rates of 60 kg N ha^{-1} and 90 kg P ha^{-1} per cropping season (FURP, 1987). The mineral fertilizers were from the Yara company manufactured Chapa Meli® 23-23-0 NPK and Triple Super Phosphate (TSP) (in granular form). The TSP was used to achieve the 90 kg P ha^{-1} rate. The total crop aboveground biomass determined was the combination of maize stover, cobs, and grains. At maturity, harvesting was done from 24 m^2 and 21 m^2 net plots in Mbeere South and in Meru South, respectively. During harvesting, maize plants in the guard rows and the first and last maize plants in each row were excluded in order to account for the edge effects. After harvesting, we separated the cobs from stover and determined the fresh weight in each treatment. The stovers were subsampled and oven-dried to constant weight, after which the total stover weight was derived by correcting the fresh field weight. Maize cobs were air-dried at about 26–28 °C for about a month, hand-shelled and weighed. Immediately after weighing, the grain moisture content was determined using a Dickey-john MiniGAC® moisture meter (with a moisture range of 5–45%, ±0.02% moisture precision). Then the grain weight was corrected against the measured moisture content to standard 12.5% moisture content. The total aboveground biomass yield was derived from cumulative weights of stover, cobs, and grains and presented on a per hectare basis to assess the CEM practices.

2.4. Soil sampling

From each farmer's field, soil samples were obtained from the CEM treatment plot and conventional tillage plot at the end of the study using an Edelman auger from a depth of 0–15 cm. Samples were randomly collected from six spots in each plot and mixed to make a composite sample for each plot. The soil samples were put in plastic bags with marked tags, bulked, and transported to the laboratory.

2.5. Rainfall measurement and the amount received during the experimental period

Daily rainfall amounts were measured using an automatic tipping-bucket rain gauge. The rain gauge was launched at the start of the experiment and relaunched after every readout. Using HOBOware Pro Version 3.2.2 software, data was exported in comma-separated version (.csv) file format and processed further in MS Excel. To obtain the daily rainfall amount, the rain gauge's daily tips were multiplied with the rain gauge's tipping bucket resolution (0.2 mm). The rain gauge status was checked regularly to ensure proper functioning, and whenever necessary, we promptly replaced exhausted batteries to ensure a consistent and accurate record of rainfall.

During the experimental period, Mbeere South received a cumulative rainfall amount of 1263 mm with 357 mm received in SR11, 297 mm in LR12, 334 mm in SR12, and 275 mm in LR13 seasons (Figure 1a). Meru South received a cumulative rainfall amount of 2489 mm, with 875 mm during SR11, 644 mm during LR12, 499 mm during SR12, and 471 mm during LR13 season (Figure 1b).

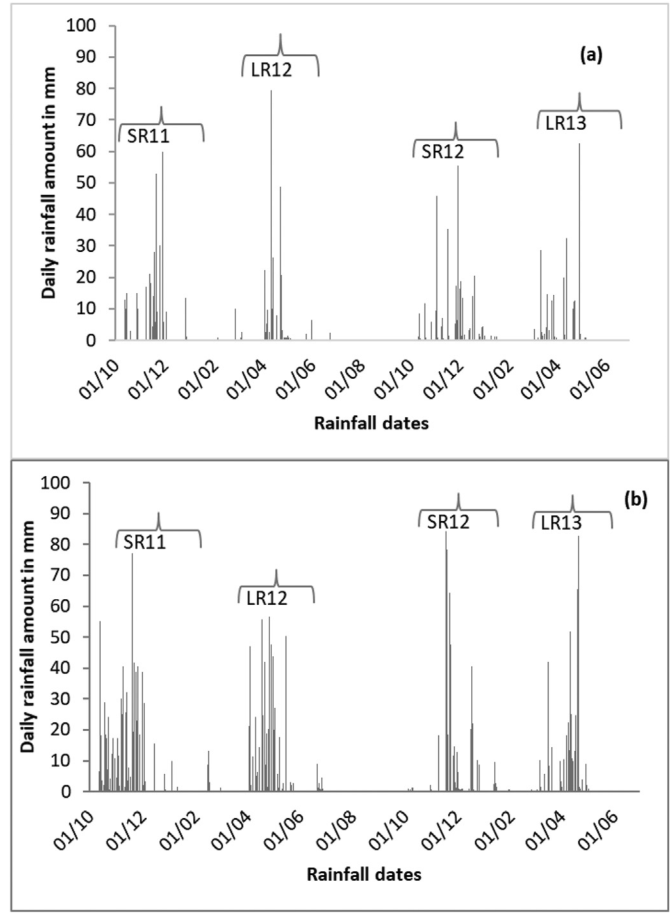

Figure 1. Rainfall amount and distribution as observed in Mbeere South a) and Meru South b) during SR11, LR12, SR12, and LR13 seasons.

Cumulatively during the SR12 and LR13 seasons, both sub-counties received lesser amounts of rainfall than the SR11 and LR12 seasons. Different durations of dry spells occurred in the two sites during the cropping seasons. Dry spells of 12 and 23 days during the SR11, a 25-days during LR12, and ten days during the SR12 season were experienced in Mbeere South (Figure 1a). There was a 10-day dry spell in Meru South during the SR11 and 15 days during the SR12 season (Figure 1b). The two sites also experienced agricultural droughts [(soil water stress occurring at a critical crop-growth stage during the experimental period (Rockström, 2003; Sileshi et al., 2011)]. Meru South experienced an agricultural drought at the emergence and flowering stages (30 days after planting) during the LR12 season. During the LR13 season, an agricultural drought was experienced during the grain formation/filling stages in both sites (Mbeere South 55 days and 57 days in Meru South).

2.6. Laboratory analyses

Soil analyses were conducted following the recommended methods in the soil laboratory. Soil pH water (1:1, soil: water) was measured using pH meter; N using Kjeldahl method, potassium was extracted using Ammonium Acetate Solution (NH_4OAc), and emission readings taken on a flame photometer (Ryan et al., 2001). Available phosphorus determination was done using Mehlich 3 method (Mehlich, 1984) while organic carbon, modified Walkley, and Black method was used. Exchangeable calcium and magnesium, and micronutrients, i.e., Copper, Iron, Manganese, and Zinc (extracted following Lindsay and Norvell, 1978) were determined using atomic absorption spectrophotometer.

2.7. Data analyses

Soil nutrients and aboveground biomass data were subjected to the analysis of variance (ANOVA) using the Mixed Procedure Model in SAS 9.3 software (SAS Institute, 2004) to obtain an F value of the effect of the model. The data was first sorted chronologically by season because of a repeat statement in the Mixed procedure. Tukey Kramer's honestly significant difference (HSD) test at $p = 0.05$ was used to compare the CEM practices.

3. Results and discussion

3.1. Soil nutrients

At the end of the experiment, in Mbeere South, soil pH was significantly lower ($p = 0.04$) in MT by 10% than in the CT (Table 1). On the other hand, phosphorus was significantly higher by about 200% in MT than CT in the same site. The CEM practices did not significantly influence nitrogen, organic carbon, and exchangeable cations (calcium, potassium, and magnesium). At the end of the experiment in Meru South, phosphorus was significantly higher by 100% and 66% in TR and MT, respectively, than the CT (Table 1). Potassium was markedly higher in TR by 44% compared with CT in Meru South. Also, the CEM practices did not significantly influence the soil pH, nitrogen, organic carbon, calcium, and magnesium at the end of the experiment Meru South experiment.

In Mbeere South, the CEM practices had no significant effects on soil micronutrients (Table 2). In Meru South Cu was significantly ($p = 0.002$) higher in MT by 83% than CT (Table 2). Zinc was significantly ($p < .0001$) higher in MT and TR by 67 and 55%, respectively, than the control in Meru South.

Tillage is often reported to have no impact on soil pH (Rasmussen, 1999); however, lower soil pH, was observed under MT in the marginal sub-humid site. This could be ascribed to higher runoff due to the soil type in Mbeere South, leading to erosion of soil nutrients that are primarily found on the topsoil layer. Erosion of the topmost soil layer results in reduced SOC, which in turn increases soil acidity. Soil type is one factor that significantly affects soil pH (Busari et al., 2015). The soil texture in Mbeere South is predominantly sandy clay loam with low nutrient levels (Ngetich et al., 2014b). Soils with such characteristics have a shallow surface layer and a hardpan that causes decreases permeation of rainwater and increases surface runoff. In their study, Fuentes et al. (2013) also found increased acidity under no-tillage in the top layer (15 cm) of sandy clay soils compared to conventional tillage. Lal (1997) also observed increased soil acidity in NT plots compared to the tilled plots.

Higher available P content under MT in the two sites could be attributed to reduced P mobilization due to minimal soil disturbance hence decreased mineralization, leading to increased residual P. Phosphorus is an immobile element and has a high residual effect; thus, the elevated amount in soils under MT. This was consistent with Gosai et al. (2010) study, which found higher values of available P in shallow tillage and no-tillage at 15–20 cm depth in a site with loamy, sandy soil texture. According to Fuentes et al. (2013), the intrinsically limited mobilization of P under no-tillage restricts its distribution to a few centimeters near the plant seedling. The use of mulch did not affect phosphorus in both sites. This could be due to the low P content in maize crop residues, as Damon et al. (2014) found.

Generally, CEM practices influence soil macronutrients (e.g., nitrogen, phosphorus, potassium in the soil organic matter positively due to reduced sediment transport (Adimassu et al., 2014). However, this was contrary to what this study found. The CEM practices did not significantly influence most soil nutrients (N, OC, Ca, and Mg) in the two sites after the four cropping seasons (Table 1). The lack of significant changes was attributed to the short duration we conducted the research and the use of mineral fertilizers that have readily available nutrients hence the slow build-up of SOC. In their review, Wolka et al. (2018) indicated that the influence of CEM practices for increased soil organic carbon (SOC) and soil nutrients are not seen everywhere (insignificant changes). Hulugalle et al. (1990) found no change in SOC under tied-ridges in Burkina Faso. After eight years of experimentation, Hiel et al. (2018) found no considerable nitrate differences and total organic carbon under mulching. However, Chivenge et al. (2007) found a noteworthy increase in SOC under tied ridging after experimenting for ten years. The use of mulch did not affect the soil chemical properties throughout the experimental period in the two sites. This could be due to the low nutrient content of maize stover applied. Surface retention of high quantities of cereal residues with a high C: N ratio (e.g., maize stover) temporarily causes net immobilization of mineral N in the soil (Jat et al., 2012).

Table 1. Soil macronutrients under CEM practices after four consecutive cropping seasons in Mbeere South and Meru South sub-counties.

Treatment	pH	N%	P g/kg	OC%	K	Ca	Mg
					cmol/kg		
Mbeere South							
CT	7.11^{a}	0.06^{a}	0.01^{b}	0.59^{a}	0.56^{a}	2.48^{a}	0.39^{a}
MC	7.02^{a}	0.07^{a}	0.02^{ab}	0.66^{a}	0.61^{a}	2.55^{a}	0.38^{a}
MT	6.42^{b}	0.07^{a}	0.03^{a}	0.58^{a}	0.51^{a}	1.98^{a}	0.37^{a}
TR	7.38^{a}	0.06^{a}	0.01^{b}	0.57^{a}	0.57^{a}	2.43^{a}	0.41^{a}
LSD	0.6	0.02	0.02	0.25	0.17	0.71	0.16
p	0.04	ns	0.04	ns	ns	ns	ns
Meru South							
CT	5.44^{a}	0.17^{ab}	0.03^{b}	1.68^{ab}	0.52^{bc}	2.43^{a}	0.59^{a}
MC	5.18^{a}	0.19^{a}	0.02^{b}	1.87^{a}	0.62^{b}	2.48^{a}	0.58^{a}
MT	5.57^{a}	0.16^{b}	0.05^{a}	1.45^{b}	0.43^{c}	2.48^{a}	0.53^{a}
TR	5.63^{a}	0.18^{ab}	0.06^{a}	1.71^{ab}	0.75^{a}	3.13^{a}	0.59^{a}
HSD	0.82	0.04	0.02	0.32	0.12	0.89	0.11
p	ns	ns	0.004	ns	0.0006	ns	ns

CT = Conventional tillage; MC = Mulching; MT = Minimum tillage; TR = Tied ridging. HSD = Honestly significant difference, ns = not significant.

Table 2. Soil micronutrients under CEM practices after four consecutive cropping seasons in Mbeere South and Meru South sub-counties.

Treatment	Mbeere South				Meru South			
	Mn cmol/kg	Cu	Fe	Zn	Mn cmol/kg	Cu	Fe	Zn
		mg/kg				mg/kg		
CT	0.42[a]	0.95[a]	6.96[a]	3.26[a]	1.53[a]	1.68[b]	9.84[ab]	19.37[b]
MC	0.51[a]	1.22[a]	7.12[a]	3.89[a]	1.56[a]	1.01[b]	6.68[b]	14.25[b]
MT	0.33[a]	0.70[a]	6.59[a]	2.43[a]	1.64[a]	3.08[a]	10.52[ab]	32.40[a]
TR	0.43[a]	1.11[a]	8.57[a]	3.23[a]	1.55[a]	1.70[b]	10.86[a]	30.05[a]
HSD	0.18	0.53	4.12	1.66	0.54	0.79	3.91	5.31
p	0.25	0.17	0.77	0.39	0.95	0.002	0.12	<.0001

CT = Conventional tillage; MC = Mulching; MT = Minimum tillage; TR = Tied ridging. CT = Conventional practice, MC = Mulching, MT = Minimum tillage, TR = Tied ridging. Different letters indicate significant differences in Tukey's HSD test performed if the model's effects were significant (p = 0.05).

Essential soil micronutrient dynamics and transformations are affected by organic matter accumulation (leads to increased microbial activity) (Chen, 1996; Dhaliwal et al., 2019). Thus, significantly high Cu under MT and Zn under MT and TR in Meru South site could be attributed to the already higher SOC content in the *Humic Nitisols* of Meru South than the *Cambisols* in Mbeere South (Table 2). Jaetzold et al. (2007) and Okeyo et al. (2014) studies corroborate the higher SOC content in *Humic Nitisols* of Meru South and low SOC in *Cambisols* of Mbeere South scenario. Continuous tillage under CT is also known to result in SOM decline. Additionally, corn and cereals respond more to Zn and Cu content (Gupta et al., 2008). de Santiago et al. (2008) also found high Cu and Zn content under conservation tillage due to increased organic matter compared to conventional tillage. Insignificant changes in all the micronutrients at Mbeere South and in Mn and Fe in Meru South could be due to no significant effect (increase) of the CEMs on SOC (Table 2). According to Gupta et al. (2008), micronutrient responses often occur in soil with high organic carbon content. High increase and maintenance of SOC require organic inputs, unlike the mineral fertilizers used in this study.

3.2. Maize aboveground biomass

During the SR11 season, the aboveground biomass was significantly higher ($p = 0.002$) in TR by 71% compared with CT in Mbeere South (Figure 2a). During the LR12 season, aboveground biomass significantly increased by 72 and 46% under TR and MC, respectively, compared to the CT. During the SR12 ($p = 0.02$) and LR13 ($p = 0.0004$) seasons, it is only tied ridging treatment that significantly increased aboveground biomass by 84 and 115%, respectively, compared with the CT in Mbeere South (Figure 2a). In Meru South, aboveground biomass was significantly higher ($p = 0.05$) in MC by 39% compared with CT during the SR11 season (Figure 2b). Aboveground biomass significantly increased ($p = 0.02$) in TR by 46% compared with the CT during the SR12 season (Figure 2b). The CEM practices had no significant influence on aboveground biomass during LR12 and LR13 seasons in Meru South. Generally, aboveground biomass was higher in Meru South compared to Mbeere South. Aboveground biomass yield was higher during short rain seasons in both sites compared to the long rains seasons.

The influence of the CEM practices on maize aboveground biomass yields during the experimental period was similar to the influence observed on maize grain yields in both sites (Kiboi et al., 2017). Overall, Thierfelder et al. (2015) reported an over 80% increase in maize productivity under soil water conservation systems than the conventional systems in target communities in the Southern Africa region; Malawi, Mozambique, Zambia, and Zimbabwe. On the simulation of grain and biomass using the APSIM model, Mkoga et al., 2010 predicted that conservation tillage increased maize yield.

Tied ridging emerged as the best practice in increasing aboveground biomass in the marginal sub-humid site. This could be due to the ridges' ability to capture rainfall, thus improve soil moisture (Korodjouma et al., 2006; Branca et al., 2013). The positive effect agreed with the results of Jensen et al. (2003), who reported positive impacts of tied ridging practice on biomass production and harvest index in a marginal sub-humid site. Conversely, in the sub-humid site, tied ridging had a significant influence on the yield only during the SR12 season (Figure 2b). This was because the region received sufficient rainfall amount for maize crop growth. Practicing tied-ridging in regions receiving above-average rainfall and high rainfall conditions of >700–900 mm per year has no benefit to crops (Wiyo et al., 2000; Araya and Stroosnijder, 2010). Thus, in areas receiving sufficient rainfall,

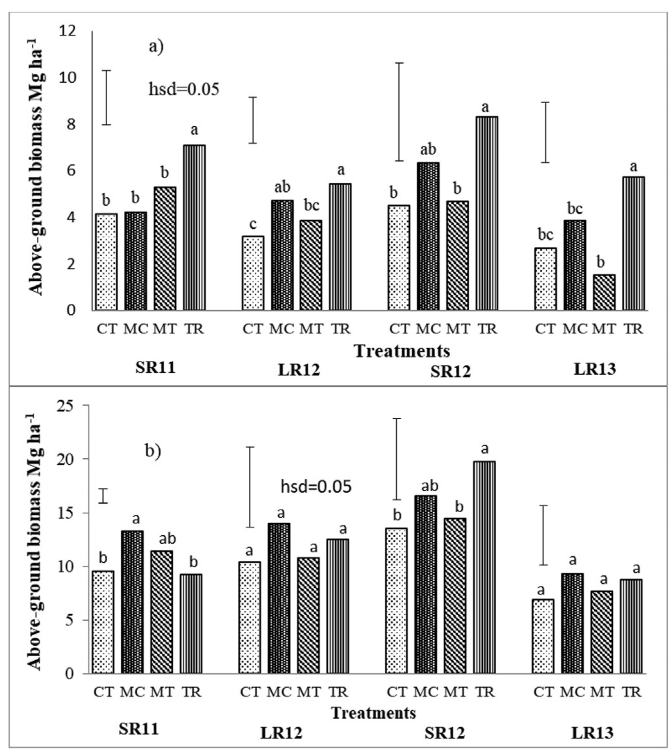

Figure 2. Aboveground biomass (Mg ha^{-1}) under CEM practices during the SR11, LR12, SR12, and LR13 seasons in Mbeere South (a) and Meru South (b) sub-counties. CT = Conventional practice, MC = Mulching, MT = Minimum tillage, TR = Tied ridging. Different letters indicate significant differences in Tukey's HSD test performed if the model's effects were significant (p = 0.05).

moisture stress may not affect crop productivity. Mulching practice significantly increased the biomass compared to conventional tillage only during the first cropping season (SR11) in Meru South. The increase could be due to enhanced physical protection of the topsoil layer and water retention. However, mulching treatment had no influence on the biomass for the rest of the seasons in Meru South and throughout the experiment period in Mbeere South. Cereal crop residues have a high C:N ratio, which causes N immobilization resulting in decreased crop production. Thus the lack of mulch effect was attributed to nutrients immobilization since maize residue is known to have low decomposition rates (Palm et al., 2001).

Higher aboveground biomass in Meru South compared with Mbeere South was attributed to the favorable intrinsic soil characteristics, especially total N content (Table 1) and higher rainfall (Figure 1). Meru South is a higher agricultural potential area than Mbeere South (Okeyo et al., 2014). Greater aboveground biomass yield observed during the short rains seasons in the two sites was ascribed to better rainfall distribution observed during the seasons (Kiboi et al., 2017). Generally, the Central Highlands of Kenya receives higher rainfall amounts during short rainy seasons than in the long rainy seasons (Mucheru-Muna et al., 2014). Significant differences in the aboveground biomass yields between the CEM practices and conventional tillage during the experimental period were ascribed to the short study duration and continuous use of mineral fertilizer whose nutrients easily mineralize, thus failing to synchronize with crop demand.

Additionally, N availability is usually reduced under conservation practices with surface application of residues due to slower decomposition and higher N immobilization (Boddey et al., 2010). Mutuku et al. (2020) found similar findings in their on-farm trials conducted in the same study area for four cropping seasons. Other authors, for example, Paul et al. (2013) have also reported no influence or even a decline in crop yields in the initial years of practicing soil and water conservation practices.

4. Conclusion

The conservation effective management practices did not influence most of the soil nutrients in the two sites. However, minimum tillage led to higher phosphorus content in both sites compared with conventional tillage. It also had higher copper and zinc content in Meru South. Tied ridging significantly improved maize crop aboveground biomass yield in marginal sub-humid areas (Mbeere South). In the sub-humid tropical regions (Meru-South), mulching and tied ridging practices performed relatively well in increasing aboveground biomass. Thus, to increase aboveground biomass for smallholder farming systems under declining rainfall conditions, we recommend tied ridging for the marginal sub-humid region and mulching and tied ridging for the sub-humid areas. Longer-term experimentation on the impacts of the treatments on soil nutrients is recommended.

Declarations

Author contribution statement

Kiboi M.N.; Ngetich, F.K.: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mucheru-Muna, M. W.; Diels, J.; Mugendi, D.N.: Contributed reagents, materials, analysis tools or data; Wrote the paper

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Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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