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Effects of Tillage Practices, Cropping Systems and Organic Inputs on Soil Nutrient Content in Machakos County

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Abstract

Low use efficiencies of inorganic fertilizers coupled with their rising costs has diverted attention of farmers towards organic sources. A study was conducted in Yatta sub-county between October 2012 to February 2013 short rains and April-August 2013 long rainy seasons to evaluate the how tillage, cropping and organic inputs influenced soil nutrient status. A Randomized Complete Block Design with a split-split plot arrangement replicated three times was used. The main plots were tillage practices (TP): Split-plots comprised the cropping systems (CS) while split-split plots were organic inputs, plus the Control. The test crops were sorghum and sweet potatoes (*Impomea batata*) with Dolichos (*Dolichos lablab*) and chickpea (*Cicer arietinum* L.) added either as intercrops or in rotation. Soil was randomly sampled at 0-30cm depth at the onset of the experiment and at maturity of test crop for NPK and % OC analysis. Significant ($P \leq 0.05$) high level of K (1.91 Cmol/+kg), available P (51.45 ppm), Total N (0.19%) and OC (2.19%), in combined TR, intercrop sorghum/chickpea with application of MRP+FYM during SRS of 2012 compared to the other treatment combinations was observed. Comparing different organic inputs, tillage practices and cropping systems combined TR, intercrop of sorghum/chickpea and MRP+FYM and FYM increased the soil nutrients status. In conclusion, soil organic inputs such as MPR and FYM are viable alternatives to inorganic fertilizers for improving the soil nutrient status. The study therefore recommends incorporation of the organic inputs in combination with TR, intercropping with legumes in their cropping systems to improve soil health and resilience.

Key words: Cropping systems; tillage practices; organic inputs; Semi-arid; soil nutrients

INTRODUCTION

Low soil fertility and moisture deficits are major constraints to crop production in the semi-arid areas of Kenya. Many interrelated factors, both natural and managerial, lead to soil fertility decline either through leaching, erosion, and crop harvesting (Donovan and Casey, 1998). The low soil fertility is majorly contributed by agriculture intensification particularly in developing countries (Rezig *et al.,* 2012) due to the ever-increasing food demand for the rising population. Unless the nutrients are replenished using organic or mineral fertilizers, partially returned through crop residues or rebuilt more comprehensively through traditional fallow systems that allow restoration of nutrients and reconstruction of soil organic matter, soil nutrient levels will decline continuously. Therefore, the use of species different from the main crop such as legumes contributes to the nutrient balance, which may consequently increase soil fertility level over time. Leguminous species are known for their capacity to fix atmospheric di-nitrogen in association with rhizobia bacteria and hence narrow the C: N ratio, resulting in faster residue decomposition (Aita and Giacomini, 2003) with consequent release of accumulated N, P and K to the soil (Borkert *et al.,* 2003). Legume green manures are also efficient at mobilizing P from the soil (Knight and Shirtliffe, 2005) pool through decomposition and release in a labile form that enhances P nutrition of succeeding crops (Cavigelli and Thien, 2003).

Farmers in the Eastern part of Kenya use farmyard manure (FYM) as a cheaper alternative source of plant nutrients as opposed to the more expensive inorganic fertilizers (Gichangi *et al.,* 2007).Farmyard manure acts as an alternative source of fertility enhancement as they release nutrients more slowly and steadily over a period of time and also improve the soil fertility status by activating the soil microbial biomass (Belay *et al.,* 2001; Karuku and Mochoge, 2016). Consequently, inputs from organic sources such as FYM, play a pivotal role in the productivity of many farming systems by providing nutrients through decomposition and substrate for the synthesis of soil organic matter (SOM). SOM has been shown to improve crop growth and yield by supplying nutrients or by modifying soil physical properties (Rees *et al.*, 2000; Karuku *et al.*, 2012 and 2014) and environment.

Furthermore, SOM acts as a bonding and dispersing agent by increasing inter-particle hydrophobicity and cohesion within aggregates (Mullins 2000; Abiven *et al*., 2009). It is well known that manures are sources of all-necessary macro- and micro-nutrients in available forms, thereby improving the physical, chemical and biological properties of the soil (El-Magd *et al*., 2005; Zhang, 2005). Due to the slow process of decomposition, manures are usually applied at higher rates, relative to that of inorganic fertilizers, to meet crop nutrient requirements and the excess have positive residual effects on the growth and yield of succeeding crops (Makinde and Ayoola, 2008). Application of manures to soil similarly provide other potential benefits such as improved fertility and structure, increased soil organic matter buildup and improved water holding capacity (Phan *et al.*, 2002; Blay *et al.*, 2002). In addition tillage practices such as; Tied ridges and Furrows and Ridges may allow rainwater retention on open furrows for longer duration as the water infiltrates into the soil or soil management techniques that favor prolonged rainwater infiltration and retention thus raising the overall soil moisture availability and hence improved crop production in ASALs (Itabari, 2003).This study evaluated effects of tillage practices, cropping systems and organic inputs on NPK and organic carbon in Yatta sub County.

METHODOLOGY

Study Site:

The study was carried out in Yatta sub County, Kenya, coordinates-1.4667°S and 37.8333°E at 944m asl. The sub-county falls under agro-ecological zones IV, classified as semi-arid lands (Jaetzold and Schmidt, 2006). Yatta Sub County comprises a suite of soils that includes Acrisols and Luvisols in association with Ferrallisols (WRB, 2015). In most places, the topsoil is loamy sand to sandy loam, sandy clay to clay with low nutrient availability (Kibunja *et al*., 2010).

The mean annual temperature vary from 18 to 24^{o}C and the area experiences bimodal rainfall with long rains in early April to May (about 400 mm) and short rains commencing from early October to December (500 mm). Most farmers in the Sub County practice small-scale mixed farming with crops grown ranging from maize (*Zea mays)*), beans (*Phaseolus vulgaris*), pigeon pea (*Cajanus cajan*), green grams (*Vigna radiata*), sorghum (*Sorghum bicolor*), and cowpea (*Vigna unguiculata*) (Macharia, 2004).

Initial soil analysis indicated that the soils at the site were acidic sandy clay, low in fertility, with low amounts of TN, OC and available P (Table 1). This was attributed to farmers' reliance on one continuous cropping systems without application of organic inputs. Continuous cropping of land with little or no nutrient returns lead to their depletion hence decline in soil fertility (Smalling *et al*., 1 997).

Table 1: initial soil physical and chemical properties

Soil chemical properties	*% OC*	*% TN*	*P (ppm)*	*K (Mol/Kg)*	*PH H$_2$0*	*PH CACL$_2$*	*CEC*
	1.86	*0.1*	*26.84*	*1.91*	*5*	*5.63*	*14.65*
Soil physical properties	*%Clay*	*% loam*	*% sand*	*Textural class*			
	54	*22*	*24*	*Sand clay*			

Farm yard manure used in the study was slightly alkaline at a pH of 8.2, OC of 18.6 %, TN at 2.1 % and P and K contents of 0.4 % and 2.7 %, respectively. The Ca content was 3.4 % (Table 2).

Table 2: Salient properties of FYM used in the study

chemical properties of FYM	% OC	% Total N	% P	% K	% Ca	% Na	PH H_20
	18.6	2.1	0.4	2.7	3.5	0.8	8.2

Treatments and Experimental design

The treatments were tillage practices (Oxen plough, Tied ridges and, Furrows and ridges), cropping systems (mono cropping, intercropping, and crop rotation) and organic inputs (farmyard manure, rock phosphate, and combined Farmyard manure and rock phosphate) and control. The experiment was in a Randomized Complete Block Design with split-split plot arrangement. The main plots (150m x 60m) were; tillage practices (Oxen plough, tied ridges and furrows, and ridges). Split plots (10m x 4m) were cropping systems (mono cropping, intercropping, and crop rotation) and split-split plots (2.5m x 1m) were organic inputs (farmyard manure, rock phosphate and combined Farmyard manure and rock phosphate). A control (no organic inputs applied) was also included as a split-split plot. The test crops were sweet potatoes (*Ipomea batatas* lam) and sorghum (*sorghum bicolor l.*) with Dolichos (*Dolichos lablab)* and chickpea (*Cicer arietinum* L.) either as intercrops or in rotation.

Field Practices

Land was prepared manually using oxen plough in late September and planted in October short rain of 2012 and April long rain season 2013.Manure was broadcasted at a rate of 5tha^{-1}, Minjingu rock phosphate (MRP) at 498kgha^{-1} equivalent to 60kgP ha^{-1}, thoroughly mixed with the soil before the vines and seeds were placed in the holes. Sweet potatoes (wabolinge variety) were propagated through 30cm long cuttings at a spacing of 90cm between rows and 30cm within rows. Weeding was done 5 weeks after planting and harvesting after 6 months when the leaves turned yellow and dry. The harvesting was done using a sharp hoe to remove all tubers (Mureithi, 2005). Sorghum (serendo variety) was sown at spacing of 75cm by 30cm while Dolichos and chickpea were planted at a spacing of 30cm within the sorghum and sweet potato rows. Weeding was done after 5 weeks of planting and harvesting after three months when it had reached physiological maturity.

Soil sampling and analysis

Soil samples were collected in a transect (in a zigzag manner from one edge of the field) for initial soil analysis. Soil samples were later taken at maturity of sweet potato and sorghum as main crops, at three samples per treatment which were then composited into a single sample and mixed thoroughly. The sample was air-dried by spreading it out in a clean, warm, dry area for two days before being analyzed for N by micro-Kjeldahl method as described by Bremner (1996); P by double acid method; K by flame photometry and organic carbon determined following Walkley and Black (1934) as described by Nelson and Sommers (1996). Soil pH-H2O and pH-CaCl2 was determined with a pH meter in a 1:2.5 ratio extract. Electrical conductivity (ECe) was measured on a 1:2.5 ratio extract with an EC meter.

Statistical analysis

Data was subjected to general analysis of variance using GenStat statistical software (Payne *et al.*, 2005) version 18. Means were separated using least significant difference at a probability level of 5%.

RESULTS AND DISCUSSION

Effects of tillage practice, cropping systems and organic inputs on soil nutrients status.

Potassium (K) content was significantly ($P \leq 0.05$) affected by the organic inputs as increased level were recorded with application of MRP + FYM in all tillage practices and cropping systems, compared to the other organic inputs MRP, FYM and their controls. Increased K content was observed under combined oxen plough (OP), sorghum mono cropping with application of MRP+FYM (3.37Cmol+/Kg) and intercropping sweet potato/dolichos (3.08Cmol+/Kg) as compared to other tillage practices, combined furrows and ridges, intercropping sorghum/dolichos with application MRP+FYM (2.01Cmol+/Kg) and intercropping sweet potato/dolichos (2.14Cmol+/Kg) and tied ridges with intercropping of sorghum/chickpea (1.91Cmol+/Kg) and intercropping of sweet potato /chickpea (2.06Cmol+/Kg).

Increased K content under MRP+FYM application was attributed to the fact that when farmyard manure and Minjingu rock phosphate are mixed, it enhances release of other nutrients such as K through increased microbial activity in the soil. Same applies when FYM was applied. Low K content under Tied ridges (1.91Cmol+/Kg); Furrows and ridges (2.11Cmol+/Kg) compared to OP (2.95Cmol+/Kg) could be attributed to increased soil moisture content leading to loss of the nutrients down the profile due to leaching of K in the upper profile as compared to OP. Under different cropping systems, increased K content was observed under intercrop and crop rotation of both chickpea and dolichos in all tillage practices. This was attributable to the effects of exudates such as H^+ and other organic acids released by the legumes in the rhizosphere and works on the organic materials applied thus mineralizing more nutrients to the soil. Root-secreted chemicals mediate multi-partite interactions in the rhizosphere, where plant roots continually respond to and alter their immediate environment. Increasing evidence suggests that root exudates initiate and modulate dialogue between roots and soil microbes. For example, root exudates serve as signals that initiate symbiosis with rhizobia and mycorrhizal fungi. In addition, root exudates maintain and support a highly specific diversity of microbes in the rhizosphere of given particular plant species, thus suggesting a close evolutionary link (Dayakar and Jorge, 2009; Sunita, 2017). Moreover, inclusion of legumes in crop rotations protects the fragile soil surface by restoring the organic matter content and organic fertility of these soils and this would also help to restore the natural fertility of these soils (Ahmad *et al*., 2010; Liu *et al*., 2006).

Increased potassium level under intercropping and crop rotation of chickpea and dolichos was also reported by Ahmad *et al.*(2010) who found out that use of green manure especially legumes in a cropping pattern could help restore crop productivity. In addition Aziz *et al.* (2010) reported that manure application significantly increases soil K contents due to increased microbial activity in the soil. Another similar observation was made by Suge *et al.*(2011), who found that addition of organic fertilizers improve soil water holding capacity as well as the CEC and nutrients are released slowly to crop plants thus impacting on nutrients availability. The inclusion in a rotation of cover crops or green manures can also enhance the efficient use of nutrients by plants, mainly owing to the increase in soil microbial population and activity (Watson *et al.*, 2002).

Changes in potassium content Cmol+/Kg across the seasons (SRS 2012 and LRS 2013)

Changes in potassium content across the two season was observed with increase during the LRS (3.65Cmol+/Kg) and (3.39Cmol+/Kg) as compared to the SRS (3.37Cmol+/Kg) and (3.09Cmol+/Kg) under oxen plough in sorghum mono cropping and intercropping of sweet potato/ dolichos with the application of MRP+FYMin sorghum and sweet potato plots respectively (Table 3 and 4). During the LRS of 2013 the soil moisture content increased as a result of prolonged rainfall as opposed to SRS of 2012. Soil moisture content affects the availability of K in soil, with greater efficiency of K fertilizer with increasing soil moisture (Kuchenbuch *et al.*, 1986) since it influence microbial activities responsible for decomposition for release of potassium.

Decomposition of organic matter is chiefly carried out by heterotrophic microorganisms. This process is influenced by temperature, moisture and ambient soil conditions leading to the release and cycling of plant nutrients, especially nitrogen (N), potassium and phosphorus (Murphy *et al.*, 2007; Sunita, 2017).

Available phosphorous

The soil available P level increased significantly ($P \leq 0.05$) in plots with MRP+FYM compared to other treatments FYM, MRP and control. Accordingly, combined TR, intercropping sweet potato and sorghum/dolichos with application of MRP +FYM had highest P levels (51.45 ppm and (46.31 ppm), respectively in the SRS of 2012 (Table 5 and 6). Increased available P with application of MRP+FYM was due to the enhanced release from MRP when mixed with FYM since decomposition of FYM releases humic acid which further promote the release of P from the rock. Organic exudates of soil microbes and roots of grain legume crops can mobilize phosphorus from unavailable soil-P pool and increase its availability for P inefficient plant species grown in inter-cropping or crop rotation. Legume crops adopt different strategies such as development of cluster roots, exudation of carboxylates, protons and acid phosphatase to render the P available from inorganic and organic P sources (Hawkins *et al*., 2005; Lambers *et al*., 2006; Sunita, 2017). Thus, inter-cropping or crop rotation of cereal crops with such legumes that have improved mechanisms to gain access to this fixed P will contribute toward more sustainable agriculture (Sunita, 2017). In addition it implies that MRP underwent considerable dissolution leading to release of Pin the MRP applied. Addition of FYM results into an increased microorganism decomposition rates and thus release phosphorous into the soil. Organic manures after decomposition may also provide organic acids and increase P-bioavailability after dissolution of MRP when combined with FYM. Sunita (2017) reported similar findings in India. This also conforms to a study by Mengel and Kirkby (2001); Marschner (2011) who noted an increase in P contents with addition of FYM and attributed it to mineralization and increased water holding capacity, thus making P readily available to crops. A study by Kari (1996) stated that application of FYM affect available P content considerably. In addition FYM increase soil moisture content (Boateng *et al.*, 2006), increase microbial activity and resultant biochemical transformations of P in soil. The added organic manures may lead to mineralization of more recalcitrant P fraction (Nziguheba *et al.*, 1998) as also reported by Maerere *et al.* (2001) and Odedina *et al.* (2011) in their studies.

There was a significant difference (p≤0.05) across the tillage practices with increased available content under Tied ridges (51.45ppm) compared to Furrows and ridges (48.24 ppm)and Oxen plough (38.59ppm) under intercropping sorghum/chickpea and with the application of MRP+FYM during the SRS of 2012.The increased P under Tied ridges and Furrows and ridges was attributed to the increased soil moisture content harvested under Tied ridges and Furrows and ridges resulting in reduced runoff hence less soil loss by erosion and hence reduced P losses in soil is less mobile and most losses are due to soil erosion. Kaushik and Gautam (1997) found out that increased soil water retention reduces nutrients losses through erosion. Oxen ploughed plots may have had lower P due to increased loss through erosion and leaching. Use of the oxen plough tillage practice could increase erosion due to the inappropriate width adjustment on the plough which led to formation of plough furrows acceleration the rate of rill erosion, especially in sloping lands causing nutrients losses as documented by Kaumbutho and Simalenga (1999).

There was also a significant difference (p≤0.05) across all the cropping systems with increased P content under the intercropping of chickpea (51.45 ppm) and dolichos (46.88ppm) in Tied ridges with the application of MRP+FYM during SRS 0f 2012.This was due to enhanced release of the nutrients from the organic inputs as presence of the legumes enhanced release, fixation of nutrients and increased biological activity rotation (Sunge *et al.*, 2011; Larkin, 2008). Suge *et al*. (2011) who attributed increased available P to crop while Larkin (2008) indicated that crop rotation help in pests and diseases control thus increasing soil biological activity. Christen and Sieling (1995) observed increased water use efficiency which in turn increased P content in the soil under crop rotation. This conforms to a study that crop rotation along with increasing soil organic matter increased biodiversity and soil biological community (Kamkar and Damghani (2009).

Table 3: Effects of tillage practice, cropping systems and organic inputs on soil potassium Cmol+/Kg sorghum based plots during SRS of 2012 and LRS of 2013

			SRS 2012				*LRS 2013*			
TP	*CS*	*CROP*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*
FR	*crop rotation*	*CP-SOR*	1.29^{bc}	1.4^{de}	1.48^{def}	1.67^{gh}	1.4^{bc}	1.52^{de}	1.6^{def}	1.81^{gh}
	crop rotation	*DOL-SOR*	1.08^{a}	1.13^{a}	1.18^{ab}	1.34^{cd}	1.17^{a}	1.22^{a}	1.28^{ab}	1.45^{cd}
	inter cropping	*SOR/DOL*	1.62^{gh}	1.7^{ghi}	1.77^{ghi}	2.01^{k}	1.75^{gh}	1.84^{ghi}	1.92^{ghi}	2.18^{k}
	inter cropping	*SOR/CP*	1.55^{defg}	1.72^{gh}*i*	1.87^{ghi}	2.11^{k}	1.68^{defg}	1.84^{ghi}	1.92^{ghi}	*l*2.18^{k}
	mono cropping	*SOR*	1.19^{ab}	1.29^{bc}	1.36^{cd}	1.54^{defg}	1.29^{ab}	1.4^{bc}	1.47^{cd}	1.67^{defg}
OP	*crop rotation*	*CP-SOR*	2.54^{m}	2.66^{mn}	2.78^{o}	3.15^{q}	2.75^{m}	2.88^{mn}	3.01^{o}	3.41^{q}
	crop rotation	*DOL-SOR*	2.64^{mn}	2.77^{o}	2.9^{p}	3.28^{qr}	2.86^{mn}	3^{o}	3.14^{p}	3.56^{q}
	inter cropping	*SOR/DOL*	2.54^{m}	2.66^{mn}	2.78^{o}	3.15^{q}	2.75^{m}	2.88^{mn}	3.01^{o}	3.41^{q}
	inter cropping	*SOR/CP*	2.37^{ln}	2.49^{m}	2.6^{mn}	2.95^{p}	2.57^{l}	2.69^{m}	2.82^{mn}	3.19^{p}
	mono cropping	*SOR*	3.08^{q}	3.82^{t}	3.22^{qr}	3.37^{s}	3.33^{q}	4.14^{t}	3.49^{qr}	3.65^{s}
TR	*crop rotation*	*CP-SOR*	1.45^{def}	1.58^{defg}	1.66^{gh}	1.88^{ghij}	1.58^{def}	1.71^{defg}	1.8^{gh}	2.04^{ghij}
	crop rotation	*DOL-SOR*	1.16^{a}	1.26^{bc}	1.33^{cd}	1.51^{def}	1.26^{a}	1.37^{bc}	1.44^{cd}	1.63^{def}
	inter cropping	*SOR/DOL*	1.33^{cd}	1.44^{de}	1.52^{def}	1.72^{ghi}	1.44^{cd}	1.56^{de}	1.64^{def}	1.86^{ghi}
	inter cropping	*SOR/CP*	1.47^{def}	1.61^{gh}	1.68^{gh}	1.91^{ghij}	1.6^{def}	1.75^{gh}	1.82^{gh}	2.07^{ghij}
	mono cropping	*SOR*	1.13^{a}	1.23^{ab}	1.29^{bc}	1.46^{def}	1.22^{a}	1.33^{ab}	1.4^{bc}	1.59^{def}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system. Under rotation legumes were harvested during the short rain season 2012 whereas sweet potatoes and sorghum were harvested during the long rain season 2013. Means followed by the same letters in the same season in a column are not significantly different at P ≤ 0.05.

Table 4: Effects of tillage practice and organic cropping systems on soil potassium Cmol+/Kg sweet potato based plots during SRS of 2012 and LRS of 2013

			SRS 2012				LRS 2013			
TP	CS	CROP	CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SP	1.58^{h}	1.66^{hi}	1.73^{hij}	1.96^{m}	1.74^{h}	1.82^{hi}	1.91^{hij}	2.16^{m}
	crop rotation	DOL-SP	1.04^{a}	1.09^{b}	1.14^{b}	1.29^{bcd}	1.14^{a}	1.2^{b}	1.25^{b}	1.42^{bcd}
	inter cropping	SP/DOL	1.73^{hij}	1.81^{k}	1.89^{l}	2.14^{o}	1.9^{hij}	1.99^{k}	2.08^{l}	2.36^{o}
	inter cropping	SP/CP	1.13^{b}	1.19^{bc}	1.24^{bcd}	1.41^{ef}	1.25^{b}	1.31^{bc}	1.37^{bcd}	1.55^{ef}
	mono cropping	SP	1.09^{b}	1.18^{bc}	1.24^{bcd}	1.41^{ef}	1.19^{b}	1.3^{bc}	1.37^{bcd}	1.55^{ef}
OP	crop rotation	CP-SP	2.28^{q}	2.38^{r}	2.49^{s}	2.82^{v}	2.5^{q}	2.62^{r}	2.74^{s}	3.11^{v}
	crop rotation	DOL-SP	1.19^{bc}	1.24^{bcd}	1.3^{bcde}	1.47^{efg}	1.31^{bc}	1.37^{bcd}	1.43^{bcde}	1.62^{efg}
	inter cropping	SP/DOL	2.48^{s}	2.6^{t}	2.72^{u}	3.08^{w}	2.73^{s}	2.86^{t}	2.99^{u}	3.39^{w}
	inter cropping	SP/CP	1.29^{bcd}	1.36^{ef}	1.42^{efg}	1.61^{h}	1.42^{bcd}	1.49^{ef}	1.56^{efg}	1.77^{h}
	mono cropping	SP	2.21^{p}	2.75^{u}	2.32^{q}	2.42^{r}	2.43^{p}	3.02^{u}	2.55^{q}	2.67^{r}
TR	crop rotation	CP-SP	1.27^{bcd}	1.38^{ef}	1.45^{efg}	1.65^{hi}	1.4^{bcd}	1.52^{ef}	1.6^{efg}	1.81^{hi}
	crop rotation	DOL-SP	1.02^{a}	1.11^{b}	1.16^{bc}	1.32^{bcde}	1.12^{a}	1.22^{b}	1.28^{bc}	1.45^{bcde}
	inter cropping	SP/DOL	1.57^{h}	1.71^{hij}	1.8^{k}	2.04^{n}	1.73^{h}	1.88^{hij}	1.98^{k}	2.24^{n}
	inter cropping	SP/CP	1.58^{h}	1.73^{hij}	1.81^{k}	2.06^{n}	1.75^{h}	1.89^{hij}	1.99^{k}	2.26^{n}
	mono cropping	SP	1.03^{a}	1.12^{b}	1.18^{bc}	1.34^{bcde}	1.13^{a}	1.23^{b}	1.3^{bc}	1.47^{bcde}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at P ≤ 0.05.

Table 5: Effects of tillage practice and organic inputs on soil available phosphorous sorghum based plots during SRS of 2012 and LRS of 2013

TP	*CS*	*CROPS*	*SRS 2012*				*LRS 2013*			
			CTRL	*FYM*	*MRP*	*MRP+FYM*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*
FR	*crop rotation*	*CP-SOR*	*27.1^{g}*	*29.04^{j}*	*30.25^{k}*	*34.28^{p}*	*30.97^{g}*	*33.19^{j}*	*34.57^{k}*	*39.18^{p}*
	crop rotation	*DOL-SOR*	*30.78^{l}*	*32.98^{lmn}*	*34.35^{p}*	*38.93^{s}*	*35.18^{l}*	*37.69^{lmn}*	*39.26^{p}*	*44.5^{s}*
	inter cropping	*SOR/DOL*	*34.75^{p}*	*37.23^{r}*	*38.78^{s}*	*43.95^{x}*	*39.71^{p}*	*42.55^{r}*	*44.32^{s}*	*50.23^{x}*
	inter cropping	*SOR/CP*	*38.14^{s}*	*40.86^{v}*	*42.56^{v}*	*48.24^{y}*	*43.58^{s}*	*46.7^{v}*	*48.64^{v}*	*55.13^{y}*
	mono cropping	*SOR*	*25.17^{ef}*	*26.96^{g}*	*31.83^{lm}*	*28.09^{ghi}*	*28.76^{ef}*	*30.82^{g}*	*36.38^{lm}*	*32.1^{ghi}*
OP	*crop rotation*	*CP-SOR*	*21.68^{b}*	*23.23^{d}*	*24.2^{e}*	*27.42^{gh}*	*24.78^{b}*	*26.55^{d}*	*27.66^{e}*	*31.34^{gh}*
	crop rotation	*DOL-SOR*	*24.62^{e}*	*26.38^{g}*	*27.48^{gh}*	*31.15^{l}*	*28.14^{e}*	*30.15^{g}*	*31.41^{gh}*	*35.6^{l}*
	inter cropping	*SOR/DOL*	*27.8^{gh}*	*29.78^{k}*	*31.03^{l}*	*35.16^{q}*	*31.77^{gh}*	*34.04^{k}*	*35.46^{l}*	*40.19^{q}*
	inter cropping	*SOR/CP*	*30.51^{k}*	*32.69^{lmn}*	*34.05p*	*38.59^{s}*	*34.87^{k}*	*37.36^{lmn}*	*38.91^{p}*	*44.1^{s}*
	mono cropping	*SOR*	*20.13^{a}*	*22.47^{c}*	*21.57^{b}*	*25.47^{ef}*	*23.01^{a}*	*25.68^{c}*	*24.65^{b}*	*29.1^{ef}*
TR	*crop rotation*	*CP-SOR*	*28.91^{j}*	*30.97^{l}*	*32.26^{lm}*	*36.57^{r}*	*33.04^{j}*	*35.4^{l}*	*36.87^{lm}*	*41.79^{r}*
	crop rotation	*DOL-SOR*	*32.83^{lmn}*	*35.18^{q}*	*36.64^{r}*	*41.53^{v}*	*37.52^{lmn}*	*40.2^{q}*	*41.88^{r}*	*47.46^{v}*
	inter cropping	*SOR/DOL*	*37.07^{r}*	*39.71^{t}*	*41.37^{v}*	*46.88^{y}*	*42.36^{r}*	*45.39^{t}*	*47.28^{v}*	*53.58^{y}*
	inter cropping	*SOR/CP*	*40.68^{u}*	*43.58^{w}*	*45.4^{x}*	*51.45^{z}*	*46.49^{u}*	*49.81^{w}*	*51.89^{x}*	*58.8^{z}*
	mono cropping	*SOR*	*26.84^{g}*	*28.76^{j}*	*33.95^{o}*	*29.96^{k}*	*30.68^{g}*	*32.87^{j}*	*38.81^{o}*	*34.24^{k}*

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Table 6: Effects of tillage practice and organic inputs on soil available phosphorous sweet potato based plots during Short Rain Season 2012 and Long Rain Season 2013

			SRS 2012				*LRS 2013*			
TP	*CS*	*CROPS*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*
FR	*crop rotation*	*CP-SP*	24.39^{f}	26.13^{fghi}	27.22^{fghij}	30.85^{m}	27.88^{f}	29.87^{fghi}	31.11^{fghij}	35.26^{m}
	crop rotation	*DOL-SP*	27.7^{fghij}	29.68^{jkl}	30.92^{m}	35.04^{p}	31.66^{fghij}	33.92^{jkl}	35.33^{m}	40.05^{p}
	inter cropping	*SP/DOL*	31.27^{m}	33.51^{o}	34.9^{p}	39.56^{u}	35.74^{m}	38.29^{o}	39.89^{p}	45.21^{u}
	inter cropping	*SP/CP*	34.32^{p}	36.77^{r}	38.31^{t}	43.41^{x}	39.23^{p}	42.03^{r}	43.78^{t}	49.62^{x}
	mono cropping	*SP*	22.65^{de}	24.27^{f}	28.65^{jkl}	25.28^{fgh}	25.89^{de}	27.73^{f}	32.74^{jkl}	28.89^{fgh}
OP	*crop rotation*	*CP-SP*	19.51^{b}	20.91^{bc}	21.78^{d}	24.68^{fg}	22.3^{b}	23.89^{bc}	24.89^{d}	28.21^{fg}
	crop rotation	*DOL-SP*	22.16^{d}	23.74f	24.73^{fg}	28.03^{jk}	25.33^{d}	27.14^{f}	28.27^{fg}	32.04^{jk}
	inter cropping	*SP/DOL*	25.02^{fg}	26.81^{fghi}	27.92^{jk}	31.65^{mn}	28.59^{fg}	30.64^{fghi}	31.91^{jk}	36.17^{mn}
	inter cropping	*SP/CP*	27.46^{fghij}	29.42^{jkl}	30.65^{m}	34.73^{p}	31.38^{fghij}	33.62^{jkl}	35.02^{m}	39.69^{p}
	mono cropping	*SP*	18.12^{a}	20.22^{bc}	19.41^{b}	22.92^{de}	20.71a	23.11^{bc}	22.19^{b}	26.19^{de}
TR	*crop rotation*	*CP-SP*	26.02^{fgh}	27.88^{jk}	29.04^{jkl}	32.91^{o}	29.73fgh	31.86^{jk}	33.19^{jkl}	37.61^{o}
	crop rotation	*DOL-SP*	29.55^{jkl}	31.66^{mn}	32.98^{o}	37.38^{rs}	33.77^{jkl}	36.18^{mn}	37.69^{o}	42.72^{rs}
	inter cropping	*SP/DOL*	33.36^{o}	35.74^{pq}	37.23^{r}	42.2^{w}	38.12^{o}	40.85^{pq}	42.55^{r}	48.22^{w}
	inter cropping	*SP/CP*	36.61^{r}	39.23^{u}	40.86^{v}	46.31^{y}	41.84^{r}	44.83^{u}	46.7^{v}	52.92^{y}
	mono cropping	*SP*	24.16^{f}	25.89^{fgh}	30.56^{m}	26.96^{fghij}	27.61^{f}	29.58^{fgh}	34.92^{m}	30.82^{fghij}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

Changes in phosphorous content ppm across the season (SRS 2012 and LRS 2013)

Changes in P content across the two season indicated an increase during the LRS (58.8 ppm) and (52.92 ppm) compared to the SRS (51.45 ppm) and (46.31 ppm) under OP in intercropping of sorghum/chickpea and sweet potato/ chickpea with the application of MRP+FYM in sorghum and sweet potato plots, respectively (Table 7 and 8).The higher amounts of soil available P in the LRS 2013 than SRS 2012 was attributed to the residual effects of the organic inputs applied (MRP, MRP+FYM and FYM). According to Rowell (1994), the rapid adsorption of P onto soil particle is followed by a slower conversion into less available forms including mineral phosphates, thus P in the MPR and most phosphate fertilizers is available in the first season after application but the rest remains over long periods of time hence their residual effects.

Total Nitrogen

Total N increased significantly ($P \leq 0.05$) through application of FYM in all the tillage practices and cropping systems compared to other treatments. Significant ($P \leq 0.05$) increased % TN (0.19) was recorded under FYM with the intercrop of dolichos/sorghum in Furrows and ridges (Table 7 and 8). The increase in soil TN after FYM application was due to addition of N by decomposing FYM. These results conforms to the findings of Thamaraiselvi *et al*. (2012) who reported an increases in soil TN with FYM application. Nyambati (2000) also reported that MRP and organics (FYM) combinations provide cheap N sources. Also solubilization of MRP through formation of favorable acid environments that result when organics are in contact with MRP decompose in soils releasing N to the soil. Ref

Percent TN content increased significantly ($p \leq 0.05$) across cropping system with crop rotation dolichos/sorghum at 0.21% and intercrop sorghum/chickpea at 0.19% under Tied ridges and application of FYM (Table 7). This same trend was observed under Furrows and ridges (0.19% and 0.17%) and OP (0.15% and 0.13%) under crop rotation of dolichos/sorghum and intercrop though the content was lower compared to sorghum planted plots. The increased in TN under dolichos intercrop and rotation was attributed to the legumes ability to fix Nitrogen and the amount obtained from the legumes residues which led to increased soil organic matter (SOM) as opposed to the mono-cropping. Aita and Giacomini, (2003) observed that leguminous species have capacity to fix atmospheric nitrogen and narrow the C/N ratio, resulting in faster residue decomposition and consequent release of accumulated N and other nutrients such as P and K, to the soil. Crop rotations usually increase organic matter and prompt changes in N sources, affecting their availability to plants and, as a consequence, the N efficiency is greater when a crop rotation is adopted (Montemurro and Maiorana, 2008). In this study, it was observed that ridges and furrows enhanced infiltration thus reducing runoff and consequently prevented nutrient losses, a fact consistent with FAO (1993). The lower TN content in OP compared to ridges & furrows and Tied ridges was attributed to higher soil erosion and runoff (Kaumbutho and Simalenga, 1999) leading to their loss.

Changes in Total Nitrogen across the season

Changes in % TN across the two season was observed to increase during the LRS at 0.23&0.21% compared to SRS at 0.19&0.19% under Tied ridges of intercropped sorghum/ chickpea and crop rotation of dolichos/sweet potato with the application of MRP+FYM in sorghum and sweet potato plots, respectively (Table 7and 8). This implies that TN increased with increased soil moisture during the LRS of 2013 hence mineralization was dictated by soil moisture content. The study therefore show a correlation between soil moisture and soil N mineralization, which agree with previous studies (Li *et al.*, 1995; Zhou and Ouyang, 2001).

Organic Carbon

The level of organic carbon increased significantly (P≤0.05) across all cropping system and tillage practices compared to initial soil analysis where FYM and MRP +FYM were added. An increase % OC (2.45) and (3.15) was observed in combined OP, intercrop of sorghum/chickpea and dolichos/sweet potato rotations, respectively where FYM was applied (Table 9 and 10). This was due to high carbon content present in applied FYM as opposed to MRP application alone plus additional residue from legumes that further raised the carbon content. Across the cropping systems, increased % OC was observed under sorghum/dolichos intercropping (2.45%), then rotation of sorghum/chickpea (2.26%) and rotation of sorghum/dolichos (2.19%) under oxen plough with the application of FYM. Cover crops are generally grown to provide soil cover thus preventing soil erosion by wind and rainwater, which increases organic matter content in the long run (Karuku *et al.*, 2014; Karuku, 2018). Komatsuzaki (2004) indicated that cover crop utilization is a technique that limits nutrient leaching, scavenging the soil residual N and making it available for subsequent cultivation.

Among the three tillage practices, a significant difference (p≤0.05) was observed with improved % OC under OP followed by furrows and ridges though under different cropping systems and application of FYM. The observed %OC level conform to the study by Bayu *et al*. (2006) who noted that FYM application increased soil SOC content by up to 67% over the control. The crop residues from the legumes further act as manures thus increasing % OC and other nutrients. This agrees Knight and Shirtliffe, (2005) where legume green manure increased benefits such as atmospheric N_2fixation and P mobilization from the soil, facts also observed in this with study.

Changes in % organic carbon across the season (SRS 2012 and LRS 2013)

Data on % OC changes across seasons indicate an increase during the LRS (2.28%) and (2.27%) compared to the SRS (2.1 %) and (2.51%) under Tied ridges with intercropping sorghum/ dolichos and intercropping sweet potato/ dolichos applied with MRP+FYM in sorghum and sweet potato plots, respectively (Table 8 and 9).The higher % OC observed during LRS is attributed to higher biomass production, which upon decomposition releases CO_2 thus raising carbon levels. Devi *et al*. (2006, 2009) in earlier studies had reported that high rate of CO_2 release during the LRS could be due to a congenial environment for microorganisms dwelling in the soil decomposing organic matter. The low % OC in the SRS seen in the study is attributed to low soil moisture content, temperature and relative humidity, thereby inhibiting the microbial activity (Devi *et al*., 2006; Kosugi *et al*., 2007). Ginting *et al.* (2003), for example, found out that4 years after the last application of FYM the residual effects resulted in 20 to 40% higher soil microbial biomass C.

Table 7: Effects of tillage practices and organic cropping systems on soil total N on sorghum based plots during SRS of 2012 and LRS of 2013

			SRS-2012				*LRS-2013*			
TP	*CS*	*CROPS*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*	*CTRL*	*FYM*	*MRP*	*MRP+FYM*
FR	*crop rotation*	*CP-SOR*	0.1^{c}	0.13^{f}	0.1^{c}	0.11^{d}	0.1^{d}	0.14^{h}	0.11^{e}	0.12^{f}
	crop rotation	*DOL-SOR*	0.15^{h}	0.19^{l}	0.16^{i}	0.16^{i}	0.16^{j}	0.2^{n}	0.17^{k}	0.18^{l}
	inter cropping	*SOR/DOL*	0.09^{b}	0.12^{e}	0.09^{b}	0.1^{c}	0.09^{c}	0.13^{g}	0.1^{d}	0.11^{e}
	inter cropping	*SOR/CP*	0.13^{f}	0.17^{j}	0.14^{g}	0.15^{h}	0.14^{h}	0.18^{l}	0.15^{i}	0.16^{j}
	mono cropping	*SOR*	0.09^{b}	0.11^{d}	0.12^{e}	0.15^{h}	0.1^{d}	0.12^{f}	0.13^{g}	0.16^{j}
OP	*crop rotation*	*CP-SOR*	0.08^{a}	0.11^{d}	0.08^{a}	0.09^{b}	0.08^{b}	0.12^{f}	0.09^{c}	0.1^{d}
	crop rotation	*DOL-SOR*	0.12^{e}	0.15^{h}	0.12^{e}	0.13^{f}	0.13^{g}	0.16^{j}	0.14^{h}	0.14^{h}
	inter cropping	*SOR/DOL*	0.07^{a}	0.1^{c}	0.07^{a}	0.08^{a}	0.07^{a}	0.11^{e}	0.08^{b}	0.09^{c}
	inter cropping	*SOR/CP*	0.1^{c}	0.13^{f}	0.1^{c}	0.11^{d}	0.11e	0.14^{h}	0.12^{f}	0.12^{f}
	mono cropping	*SOR*	0.08^{a}	0.12^{e}	0.09^{b}	0.09^{b}	0.08^{b}	0.13^{g}	0.09^{c}	0.1^{d}
TR	*crop rotation*	*CP-SOR*	0.11^{d}	0.15^{h}	0.11^{d}	0.13^{f}	0.12^{f}	0.16^{j}	0.12^{f}	0.14^{h}
	crop rotation	*DOL-SOR*	0.16^{i}	0.21^{m}	0.17^{j}	0.18^{k}	0.18^{l}	0.23^{o}	0.19^{m}	0.2^{n}
	inter cropping	*SOR/DOL*	0.1^{c}	0.14^{g}	0.1^{c}	0.12^{e}	0.12^{f}	0.16^{j}	0.12^{f}	0.14^{h}
	inter cropping	*SOR/CP*	0.14^{g}	0.19^{l}	0.15^{h}	0.16^{i}	0.18^{l}	0.23^{o}	0.19^{m}	0.2^{n}
	mono cropping	*SOR*	0.11^{d}	0.12^{e}	0.13^{f}	0.16^{i}	0.11^{e}	0.13^{g}	0.14^{h}	0.18^{l}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OI-Organic Inputs OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at P ≤ 0.05.

Table 8: Effects of tillage practices and organic cropping systems on soil total N sweet potato based plots during SRS of 2012 and LRS of 2013

TP	*CS*		*SRS 2012*				*LRS 2013*			
			CTRL	*FYM*	*MRP*	*MRP+ FYM*	*CTRL*	*FYM*	*MRP*	*MRP+ FYM*
FR	*crop rotation*	*CP-SP*	0.08^{c}	0.12^{g}	0.09^{d}	0.1^{e}	0.09^{c}	0.13^{g}	0.09^{c}	0.11^{e}
	crop rotation	*DOL-SP*	0.13^{h}	0.17^{l}	0.14^{i}	0.15^{j}	0.14^{h}	0.19^{m}	0.15^{i}	0.16^{j}
	inter cropping	*SP/DOL*	0.07^{b}	0.11^{f}	0.08^{c}	0.09^{d}	0.08^{b}	0.12^{f}	0.08^{b}	0.1^{d}
	inter cropping	*SP/CP*	0.11^{f}	0.15^{j}	0.12^{g}	0.13^{h}	0.12^{f}	0.17^{k}	0.13^{g}	0.14^{h}
	mono cropping	*SP*	0.08^{c}	0.09^{d}	0.1^{e}	0.13^{h}	0.09^{c}	0.1^{d}	0.11^{e}	0.14^{h}
OP	*crop rotation*	*CP-SP*	0.07^{b}	0.11^{k}	0.08^{c}	0.09^{d}	0.08^{b}	0.12^{f}	0.09^{c}	*0.1d*
	crop rotation	*DOL-SP*	0.12^{g}	0.16^{k}	0.13^{h}	0.14^{i}	0.13^{g}	0.18^{l}	0.14^{h}	0.15^{i}
	inter cropping	*SP/DOL*	0.06^{a}	0.1^{e}	0.07^{b}	0.08^{c}	0.07^{g}	0.11^{e}	0.08^{b}	0.09^{c}
	inter cropping	*SP/CP*	0.1^{e}	0.14^{i}	0.11^{f}	0.12^{g}	0.11^{e}	0.16^{j}	0.12^{f}	0.13^{g}
	mono cropping	*SP*	0.07^{b}	0.12^{g}	0.08^{c}	0.09^{d}	0.08^{b}	0.13^{g}	0.09^{c}	0.1^{d}
TR	*crop rotation*	*CP-SP*	0.09^{d}	0.13^{h}	0.09^{d}	0.11^{f}	0.1^{d}	0.14^{h}	0.1^{d}	0.12^{f}
	crop rotation	*DOL-SP*	0.14^{i}	0.19^{m}	0.15^{j}	0.16^{k}	0.16^{j}	0.21^{n}	0.17^{k}	0.18^{l}
	inter cropping	*SP/DOL*	0.08^{c}	0.12^{g}	0.08^{c}	0.1^{e}	0.09^{c}	0.13^{g}	0.09^{c}	0.11^{e}
	inter cropping	*SP/CP*	0.12^{g}	0.17^{l}	0.13^{h}	0.14^{i}	0.14^{h}	0.19^{m}	0.15^{i}	0.16^{j}
	mono cropping	*SP*	0.09^{d}	0.1^{e}	0.11^{f}	0.14^{i}	0.09^{c}	0.16^{j}	0.12^{r}	0.11^{e}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OI-Organic Inputs, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in column are not significantly different at P ≤ 0.05.

CONCLUSIONS

Soil organic inputs, MPR and FYM are viable alternatives to the expensive inorganic fertilizers for improving the soil nutrient status in Matuu, Yatta sub County. Combined TR, intercropping of sorghum and sweet potato with dolichos and with application of MRP +FYM significantly increased soil K and P whereas combined TR, intercropping of dolichos with sorghum and sweet potatoes and with application of FYM led to an increase in soil % OC and TN. Moreover, the MRP, FYM are locally available, thus making it an ideal source of nutrients for smallholders economically.

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Table 9: Effects of tillage practices and organic cropping systems on % soil Carbon sorghum based plots during SRS of 2012 and LRS of 2013

			Organic Inputs-SRS 2012				*Organic Inputs -LRS 2013*			
TP	*CS*		*CTRL*	*MRP+FYM*	*MRP*	*FYM*	*CTRL*	*MRP+FYM*	*MRP*	*FYM*
FR	*crop rotation*	*CP-SOR*	1.2^{a}	1.29^{b}	1.34^{bc}	1.52^{de}	1.74^{m}	1.87^{o}	1.94^{opq}	2.2^{tu}
	crop rotation	*DOL-SOR*	$1.51d^{e}$	1.62^{f}	1.69^{g}	1.91^{ghijk}	1.35^{fg}	1.45^{hi}	1.51^{hij}	1.71^{m}
	inter cropping	*SOR/DOL*	1.74^{g}	1.87^{ghij}	1.95^{ghijkl}	2.21^{p}	1.9^{op}	2.03^{r}	2.12^{t}	2.4^{w}
	inter cropping	*SOR/CP*	1.82^{ghi}	1.95^{ghijkl}	2.03^{lmn}	2.3^{pqr}	1.47^{hi}	1.58^{k}	1.64^{l}	1.86^{o}
	mono cropping	*SOR*	1.93^{ghijkl}	2.06^{lmn}	2.14^{p}	2.43^{s}	1.16^{cde}	1.25^{f}	1.3^{fg}	1.47^{hi}
OP	*crop rotation*	*CP-SOR*	1.78^{gh}	1.91^{ghijk}	1.99^{lm}	2.26^{pq}	2.06^{s}	2.21^{tu}	2.3^{tuv}	2.61^{y}
	crop rotation	*DOL-SOR*	2.52^{t}	2.7^{u}	2.81^{v}	2.19^{p}	0.89^{a}	0.95^{b}	0.99^{b}	1.12^{cd}
	inter cropping	*SOR/DOL*	1.94^{ghijkl}	2.08^{lmn}	2.16^{p}	2.45^{s}	2.25^{tuv}	2.41^{w}	2.51^{x}	2.84^{z}
	inter cropping	*SOR/CP*	0.97^{b}	1.04^{c}	1.08^{cd}	1.23^{f}	1.63^{f}	1.74^{g}	1.82^{ghi}	2.06^{lmn}
	mono cropping	*SOR*	1.7^{m}	2.16^{t}	1.83^{o}	1.9^{op}	2.67^{y}	2.38^{w}	2.87^{w}	2.98^{x}
TR	*crop rotation*	*CP-SOR*	1.47^{d}	1.52^{de}	1.6^{f}	1.82^{ghi}	1.29^{fg}	1.33^{fg}	1.4^{h}	1.59^{k}
	crop rotation	*DOL-SOR*	1.17^{a}	1.21^{a}	1.27^{b}	1.44^{d}	1.02^{c}	1.06^{c}	1.11^{cd}	1.26^{f}
	inter cropping	*SOR/DOL*	1.7^{g}	1.76^{gh}	1.85^{ghij}	2.1^{lmno}	1.85^{o}	1.91^{op}	2.01^{r}	2.28^{tuv}
	inter cropping	*SOR/CP*	1.77^{gh}	1.83^{ghi}	1.93^{ghijk}	2.19^{p}	1.45^{hi}	1.48^{hij}	1.56^{k}	1.77^{mn}
	mono cropping	*SOR*	1.88^{ghij}	1.95^{ghijkl}	2.05^{lmn}	2.33^{pqr}	1.13^{cd}	1.17^{cde}	1.23^{f}	1.4^{h}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at P ≤ 0.05.

Table 10: Effects of tillage practices and organic cropping systems on % soil Carbon sweet potato based plots during SRS of 2012 and LRS of 2013

			Organic Inputs-SRS 2012				*Organic Inputs-LRS 2013*			
TP	*CS*		*CTRL*	*MRP+ FYM*	*MRP*	*FYM*	*CTRL*	*MRP+ FYM*	*MRP*	*FYM*
FR	*crop rotation*	*CP-SP*	1.3^{a}	1.39^{b}	1.45^{bc}	1.65^{de}	1.91^{m}	2.05^{o}	2.14^{opq}	2.43^{tu}
	crop rotation	*DOL-SP*	1.64^{de}	1.75^{f}	1.83^{g}	2.07^{ghijk}	1.48^{fg}	1.59^{hi}	1.66^{hij}	1.88^{m}
	inter cropping	*SP/DOL*	1.89^{g}	2.02^{ghij}	2.11^{ghijkl}	2.39^{p}	2.09^{op}	2.24^{r}	2.33^{t}	2.64^{w}
	inter cropping	*SP/CP*	1.97^{ghi}	2.11^{ghijkl}	2.2^{lmn}	2.5^{pqr}	1.62^{hi}	1.74^{k}	1.81^{l}	2.05^{o}
	mono cropping	*SP*	2.1^{ghijkl}	2.25^{lmn}	2.34^{p}	2.66^{s}	1.28^{cde}	1.37^{f}	1.43^{fg}	1.62^{hi}
OP	*crop rotation*	*CP-SP*	1.93^{gh}	2.07^{ghijk}	2.16^{lm}	2.44^{pq}	2.26^{s}	2.42^{tu}	2.53^{tuv}	2.87^{y}
	crop rotation	*DOL-SP*	2.73^{t}	2.92^{u}	3.05^{v}	3.15^{y}	0.98^{a}	1.05^{b}	1.09^{b}	1.24^{cd}
	inter cropping	*SP/DOL*	2.11^{ghijkl}	2.26^{lmn}	2.35^{p}	2.67^{s}	2.47^{tuv}	2.65^{w}	2.76^{x}	3.13^{z}
	inter cropping	*SP/CP*	1.76^{f}	1.89^{g}	1.97^{ghi}	2.23^{lmn}	1.06^{b}	1.14^{c}	1.19^{cd}	1.35^{f}
	mono cropping	*SP*	1.87^{m}	2.37^{t}	2.01^{o}	2.09^{op}	2.89^{u}	3.66^{z}	3.1^{w}	3.23^{x}
TR	*crop rotation*	*CP-SP*	1.59^{d}	1.65^{de}	1.74^{f}	1.97^{ghi}	1.41^{fg}	1.47^{fg}	1.54^{h}	1.75^{k}
	crop rotation	*DOL-SP*	1.27^{a}	1.31^{a}	1.38^{b}	1.56^{d}	1.12^{c}	1.16^{c}	1.23^{cd}	1.39^{f}
	inter cropping	*SP/DOL*	1.84^{g}	1.9^{gh}	2^{ghij}	2.27^{lmno}	2.03^{o}	2.1^{op}	2.22^{r}	2.51^{tuv}
	inter cropping	*SP/CP*	1.92^{gh}	1.99^{ghi}	2.09^{ghijk}	2.37^{p}	1.57^{h}	1.63^{hij}	1.72^{k}	1.95^{mn}
	mono cropping	*SP*	2.04^{ghij}	2.11^{ghijkl}	2.23^{lmn}	2.52^{pqr}	1.24^{cd}	1.29^{cde}	1.36^{f}	1.54^{h}

Legend: SP-sweet potato, DOL-dolichos, CP-chickpea, TP-tillage practice, TR-tied ridges, FR-furrows and ridges, OP-oxen plough, FYM-farm yard -manure, MRP-Minjingu rock phosphate, CTRL-control, LRS-long rain season, SRS-short rain season, CS-cropping system.. Means followed by the same letters in the same season in a column are not significantly different at $P \leq 0.05$.

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