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Efficiency and interactive effects of Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture Retention in Semi-Arid Yatta Sub-County, Kenya

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Abstract

The study evaluated the efficiency and interactive of tillage practices, cropping systems and organic inputs (soil moisture conservation techniques) on soil moisture retention in semi-arid Yatta sub-county between October 2012 and February 2013 short rain season (SRS) and March to August 2013 long rain season (LRS). The experiment was laid out in Randomized Complete Block Design with a split-split plot arrangement. Main plots were; tillage practices (TP); Oxen plough (OP), tied ridges (TR) and furrows and ridges (FR). The Split-plots were; cropping systems (CS); mono cropping (MC), intercropping (IC) and crop rotation (CR) while the split-split plots were organic inputs; farmyard manure (FYM), Minjingu Rock Phosphate (MRP), combined MRP and FYM (MRP+FYM) and control. Sorghum and sweet potatoes were grown as intercrops or in rotation with Dolichos (*Dolichos lablab*) and chickpea (*Cicer arietinum* L.). Soil samples were taken at 0-30 cm depth at the start of the experiment and maturity of test crops for determination of soil moisture content (expressed as percentage) and efficiency of soil moisture conservation techniques. Significant ($p \leq 0.05$) increased in soil moisture content was recorded, across deasons, in TR with IC of dolichos and application of FYM (7.53% and 7.88%) for sorghum and sweet potato plots respectively. For enhanced efficiency of soil moisture conservation in the semi-arid Yatta district, TR with an intercrop of dolichos and sorghum and/or dolichos and sweet potato with application of FYM +MRP would be the soil moisture conservation technique of choice.

Keywords: cropping systems; tillage practices; organic inputs; Semi-arid; soil moisture conservation techniques

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1.0 Introduction

Agricultural production in Sub-Saharan Africa (SSA) primarily relies on rain-fed production that is climate sensitive (IITA, 1993). The most limiting factor to crop production in the arid and semi arid lands of Kenya especially Yatta Sub County is availability of soil moisture. The low rainfall together with its unreliability and poor distribution severely limits crop production (KARI, 1996). Additionally, the low quality of soil resource base which on one hand has been due to inherent and induced deficiencies of major nutrients N, P and K or low nutrient holding capacity and low organic matter (Okalebo *et al.,* 1992; Kaolo R. 2003) negatively affect crop production.

To ensure increased crop production and food security, farmers in the semi-arid tropics intercrop cereals with grain legumes, such as pigeon pea (*Cajanus cajan*), as a strategy for diversifying food production and household income since legumes are both cash and food crops (Mafongoya *et al.,*2006). The legume improves soil fertility and yields of associated cereals, as well, through atmospheric di-nitrogen fixation in association with rhizobia bacteria, nutrient pumping and incorporation of green manure (Chikowo *et al.,* 2004).

In addition to intercropping, farmers practice well-managed crop rotations with the aim of increasing soil organic matter to sufficient levels that help to moderate and retain soil moisture under dry conditions, and allow excess moisture to drain away in wet seasons thus recharging the ground water aquifers. The deep rooted crops following shallow rooted crops can access moisture reserves as well as capture any nutrients that have leached below the shallower root zones before they reach groundwater (Adam *et al.,* 2011).

Further, the application of manures to soil provide benefits such as fertility, structure, increased soil organic matter, better water holding capacity (Phan *et al.,*2002, Blay *et al.,*2001) and transmission properties.

Besides use of organic inputs to enhance and conserve soil moisture, various tillage practices; furrows and ridges and tied ridges, have been found to conserve soil moisture (Gebrekidan and Yohannes 2002) in semi-arid areas.

Tillage modifies soil surface structure by breaking the pan layer, total porosity and macro-porosity, pore continuity and pore size distribution and therefore has great influence on the hydrology of an agricultural catchment (Mwendera, 2002).

These have shown positive response in terms of yield increase in maize and other crops. These moisture conservation methods contribute to increased infiltration, reduction of run-off hence reduced erosion episodes and increasing rooting volume in shallow soils (Vogel *et al .,* 2001).

There is however a dearth of information on the efficiency and interactive effects of tillage practices, cropping systems and organic inputs (soil moisture conservation techniques) on soil moisture retention in the ASALs, thus necessitating the current study.

2.0 Materials and Methods

2.1 Study Site

Yatta sub-county, the study site, falls under agro- cological zone IV, which is, classified as semi-arid lands (Jaetzold and Schmidt, 2006). It lies at an altitude of 944m above sea level. The soils in Yatta Sub County are a combination of Acrisols and Luvisols with Ferralsols (WRB, 2006). In most places, they have topsoil that is loamy sand to sandy loam, sandy clay to clay with low nutrient availability (Kibunja *et al.,* 2010).

Yatta Sub County has a semi-arid climate with mean annual temperature varying from 18^{o}C to 24^{o}C and experiences bimodal rainfall with long rains season commencing early April to May (about 400 mm) and short rains season commencing from early October to December (500 mm). Most of the farmers in the sub county are small-scale mixed farmers. Crops grown in the area include maize, beans, pigeon pea, green grams, sorghum, and cowpea (Macharia, 2004).

2.2 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 laid out in a Randomized Complete Block Design with split-split plot arrangement. The main plots (150 x 60 m) were; tillage practices. Split plots (10 x 4 m) were cropping systems and split-split plots (2.5 x 1 m) were organic inputs. A control (no organic input applied) was also included as a split-split plot. The test crops were sweet potatoes (*i pomea batatas* L.lam) and sorghum (*sorghum bicolor L.*) intercropped and/or rotated with Dolichos (*Dolichos lablab)* and chickpea Chickpea (*Cicer arietinum* L.).

2.3 Field Practices

Land was prepared manually using oxen plough, for the oxen plough (OP) tillage practice and hand hoes were used to prepare tied ridges (TR) and furrows and ridges (FR), in late September and planted in October short rain season 2012 and April long rain season 2013.

Manure was broadcasted at a rate of $5tha^{-1}$ and minjingu rock phosphate (MRP) at 498 $Kgha^{-1}$ equivalent to 60 Kg P ha^{-1} and mixed thoroughly with the soil before the vines and seeds were placed in the holes. Sweet potatoes (wabolinge variety) were propagated through cuttings of 30 cm long at spacing of 90 cm between rows and 30 cm within rows. Weeding was done 5 weeks after planting and harvesting was done after 6 months when the leaves were yellow and dry. Harvesting was done using a sharp hoe by removal of all tubers. Sorghum (serendo variety) was sown at spacing of 75 cm by 30 cm and weeding done after 5 weeks of planting. Harvesting was done after three months when it had reached physiological maturity.

Chickpea and Dolichos were spaced 60 cm by 30 cm. Weeding was done after every 5 weeks and harvesting was done after three months when they had reached physiological maturity.

2.4 Soil Sampling and Analysis

Soil samples were taken in a zig-zag manner, from 0-30 cm depth, at the start of the experiment and composited. Thereafter soil samples were similarly taken, from each plot, at maturity of the test crops and thoroughly mixed to form one composite sample per treatment.

The soil moisture content (% volume) and efficiency of soil moisture conservation techniques (expressed as percentage) were determined as follows.

Soil moisture determination: soil moisture content (% volume) was determined using gravimetric method (RNAM, 1995).

$$C = \frac{(W_w - W_d)}{W_d} * 100$$

Where;

MC = Moisture content (%)
Ww = Weight of wet soil (g)
Wd = Weight of dry soil (g)

Efficiency of soil moisture conservation techniques: Performance of moisture conservation techniques was quantified by their efficiency in percentage. The efficiency of the techniques on moisture conservation was calculated from initial and final soil moisture content.

$$E = \frac{M_2}{(M_1 + R)} 100$$

Where;

E - Efficiency of moisture conservation
M_1 – moisture content at the beginning of cropping period;
M_2 – moisture content at the end of cropping period;
R - Rainfall received during cropping period

2.5 Statistical Analysis

Data was subjected to general analysis of variance using Genstat statistical software (Payne *et al.,* 2006). Means were separated using least significant difference and Duncan Multiple Range Test (where interactions occurred) at a probability level of 5%.

3.0 Results and Discussion

3. Interactive Effects of Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture *Retention*

An increased soil moisture content was recorded in all the tillage practices and cropping systems with application of FYM and MRP+FYM (Table 1).

Significant ($p \leq 0.05$) increase in soil moisture content was recorded in tied ridges with application of MRP+FYM under sorghum chickpea intercrop (8.37% and 8.44%) followed by chickpea –sorghum rotation (7.89% and 7.95% for the short rain season of 2012 and long rain season of 2013, respectively.

Table 1: Interactive Effects of Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture *Content* (%) in Sorghum Plots During Short Rain Season of 2012 and Long Rain Season of 2013

			Organic inputs SRS 2012				Organic inputs LRS 2013			
TP	CS		CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SOR	3.5^{fg}	5.26^{o}	4.38^{k}	4.73^{lm}	3.89^{jk}	5.3^{pqrs}	3.93^{jk}	4.91^{p}
	crop rotation	DOL-SOR	3.32^{f}	4.98^{n}	4.15^{ij}	4.48^{k}	3.58^{hi}	5.02^{pq}	3.72^{ij}	4.65^{o}
	inter cropping	SOR/DOL	3.01^{e}	4.51^{k}	3.76^{h}	4.06^{hi}	3.23^{eg}	4.55^{n}	3.37^{gh}	4.21^{m}
	inter cropping	SOR/CP	3.72^{h}	5.58^{p}	4.65^{kl}	5.02^{n}	4^{kl}	5.63^{t}	4.17^{m}	5.21^{pqr}
	mono cropping	SOR	3.05^{e}	4.58^{kl}	3.8^{1h}	4.12^{ij}	3.24^{eg}	4.62^{o}	3.42^{gh}	4.27^{m}
OP	crop rotation	CP-SOR	2.63^{b}	3.94^{h}	3.29^{f}	3.55^{fg}	2.92^{bc}	3.98^{kl}	2.95^{bd}	3.68^{ij}
	crop rotation	DOL-SOR	2.49^{b}	3.74^{h}	3.11^{e}	3.36^{f}	2.68^{ab}	3.77^{ij}	2.79^{bc}	3.49^{gh}
	inter cropping	SOR/DOL	2.26^{a}	3.38^{f}	2.82^{bc}	3.04^{e}	2.42^{a}	3.41^{gh}	2.53^{a}	3.16^{de}
	inter cropping	SOR/CP	2.79^{bc}	4.18^{ij}	3.49^{fg}	3.77^{h}	3^{cd}	4.22^{m}	3.13^{de}	3.91^{jk}
	mono cropping	SOR	2.29^{a}	3.43^{f}	2.56^{b}	3.09^{e}	2.43^{a}	3.46^{gh}	2.86^{bc}	3.21^{eg}
TR	crop rotation	CP-SOR	5.26^{o}	7.89^{x}	6.57^{s}	7.1^{uv}	5.83^{u}	7.95^{z}	5.89^{u}	7.36^{x}
	crop rotation	DOL-SOR	4.98^{n}	7.47^{w}	6.23^{r}	6.72^{s}	5.37^{pqrs}	7.54^{y}	5.58^{t}	6.98^{w}
	inter cropping	SOR/DOL	4.51^{k}	6.77st	5.64^{p}	6.09^{q}	4.85^{p}	6.82^{w}	5.06^{pq}	6.32^{v}
	inter cropping	SOR/CP	5.58^{p}	8.37^{y}	6.97^{tu}	7.53^{w}	5.99^{u}	8.44^{z}	6.25^{v}	7.81^{z}
	mono cropping	SOR	4.58^{kl}	6.86st	5.72^{p}	6.18^{r}	4.86^{p}	6.92^{w}	5.13^{pq}	6.41^{v}

Legend: SOR-sorghum, DOL-dolichos, CP-chickpea, MRP-minjingu rock phosphate, FYM-farm yard manure, TR-tied ridges, FR-furrows and ridges, SRS-Short Rain Season, LRS-Long Rain Season. Means per season followed by the same letter are not significantly different at $P \leq 0.05$

The increased in soil moisture content with combined application of MRP+FYM is attributable to addition of organic manure, which contributed to the maintenance of soil physical structure, and results in better soil moisture retention. These conformed to the study by Sugeet et al. (2011) and Lemlem (2012), who found that addition of Organic fertilizers improved soil water holding capacity.

Boateng et al. (2006) and Adeleye et al. (2010) also found out that higher levels of FYM increased the soil water content. Soil moisture is also known to enhance solubility of MRP. The P released, as a result of rock P dissolution, upon uptake by plants translates to better growth and thus adequate ground cover and subsequently Soil moisture retention. Dissolution of RP materials is generally thought to be higher in moist soils than in dry soils (Bolan *et al*., 1990). Thus, an increase in soil moisture level leads to enhanced PR dissolution (Kanabo and Gilkes, 198a).

Control had significantly ($p \leq 0.05$) lowest soil moisture and this was attributed to the soils of the study site being naturally low in organic matter. Due to low residue returns and high temperature causing fast decomposition as well as reduced rainfall hence the low water holding capacity.

This observation is in agreement with research by Cornelis, (2006) who found out that the soils of arid and semiarid zones are very susceptible of water erosion mostly due to the scarce vegetation cover, low organic matter content and the small resistance to the erosion forces.

Soil moisture reduced in the mono crop of sorghum in all tillage practices (Table 3) due to high evapotranspiration potential; on the contrary, soil moisture increased in the mono crop of sweet potato (Table 4) across all tillage practices due to low evapotranspiration potential. The sweet potato covers the ground adequately thus reducing direct losses from soil surface unlike in sorghum. According to Lusweti *et al.* (1999) Sweet potato provides good ground cover thereby reducing evapotransipiration and consequently enhancing moisture retention.

There were significant ($p \leq 0.05$) increases in soil moisture content under tied ridges following intercropping of sweet potato/Dolichos (8.44%), and sweet potato mono cropping (7.67%) with application FYM+MRP implying that the water evaporation at soil surface was low and soil moisture retention high compared to intercrop of chickpea (6.44%).

Table 2: Interactive Effects of Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture *Content* (%) in Sweet Potato Plots During Short Rain Season of 2012 and Long Rain Season of 2013

			Organic inputs SRS 2012				Organic inputs LRS 2013			
TP	CS		CTRL	FYM	MRP	MRP+FYM	CTRL	FYM	MRP	MRP+FYM
FR	crop rotation	CP-SP	3.5^{fg}	5.26^{o}	4.38^{k}	4.73^{lm}	3.89^{jk}	5.3^{pqrs}	3.93^{jk}	4.91^{p}
	crop rotation	DOL-SP	3.32^{f}	4.98^{n}	4.15^{ij}	4.48^{k}	3.58^{hi}	5.02^{pq}	3.72^{ij}	4.65^{o}
	inter cropping	SP/DOL	3.01^{e}	4.5^{1k}	3.76^{h}	4.06^{hi}	3.23^{eg}	4.55^{n}	3.37^{gh}	4.21^{m}
	inter cropping	SP/CP	3.72^{h}	5.58^{p}	4.65^{kl}	5.02^{n}	4^{kl}	5.63^{t}	4.17^{m}	5.21^{pqr}
	mono cropping	SP	3.05^{e}	4.58^{kl}	3.81^{h}	4.12^{ij}	3.24^{eg}	4.62^{o}	3.42^{gh}	4.27^{m}
OP	crop rotation	CP-SP	2.63^{b}	3.94^{h}	3.29^{f}	3.55^{fg}	2.92^{bc}	3.98^{kl}	2.95^{bd}	3.68^{ij}
	crop rotation	DOL-SP	2.49^{b}	3.74^{h}	3.11^{e}	3.36^{f}	2.68^{ab}	3.77^{ij}	2.79^{bc}	3.49^{gh}
	inter cropping	SP/DOL	2.26^{a}	3.38^{f}	2.82^{bc}	3.04^{e}	2.42^{a}	3.41^{gh}	2.53^{a}	3.16^{de}
	inter cropping	SP/CP	2.79^{bc}	4.18^{ij}	3.49^{fg}	3.77^{h}	3^{cd}	4.22^{m}	$3.13d^{e}$	3.91^{jk}
	mono cropping	SP	2.29^{a}	3.43^{f}	2.56^{b}	3.09^{e}	2.43^{a}	3.46^{gh}	2.86^{bc}	3.21^{eg}
TR	crop rotation	CP-SP	5.26^{o}	7.89^{x}	6.57^{s}	7.1^{uv}	5.83^{u}	7.95^{z}	5.89^{u}	7.36^{x}
	crop rotation	DOL-SP	4.98^{n}	7.47^{w}	6.23^{r}	6.72^{s}	5.37^{pqrs}	7.54^{y}	5.58^{t}	6.98^{w}
	inter cropping	SP/DOL	4.51^{k}	6.77^{st}	5.64^{p}	6.09^{q}	4.85^{p}	6.82^{w}	5.06^{pq}	6.32^{v}
	inter cropping	SP/CP	5.58^{p}	8.37^{y}	6.97^{tu}	7.53^{w}	5.99^{u}	8.44^{z}	6.25^{v}	7.81^{z}
	mono cropping	SP	4.58^{kl}	6.86^{st}	5.72^{p}	6.18^{r}	4.86^{p}	6.92^{w}	$5.13p^{q}$	6.41^{v}

Legend: SP-Sweet Potato, DOL-dolichos, CP-chickpea, MRP-minjingu rock phosphate, FYM-farm yard manure, TR-tied ridges, FR-furrows and ridges, SRS-Short Rain Season, LRS-Long Rain Season. Means per season followed by the same letter are not significantly different at $P \leq 0.05$

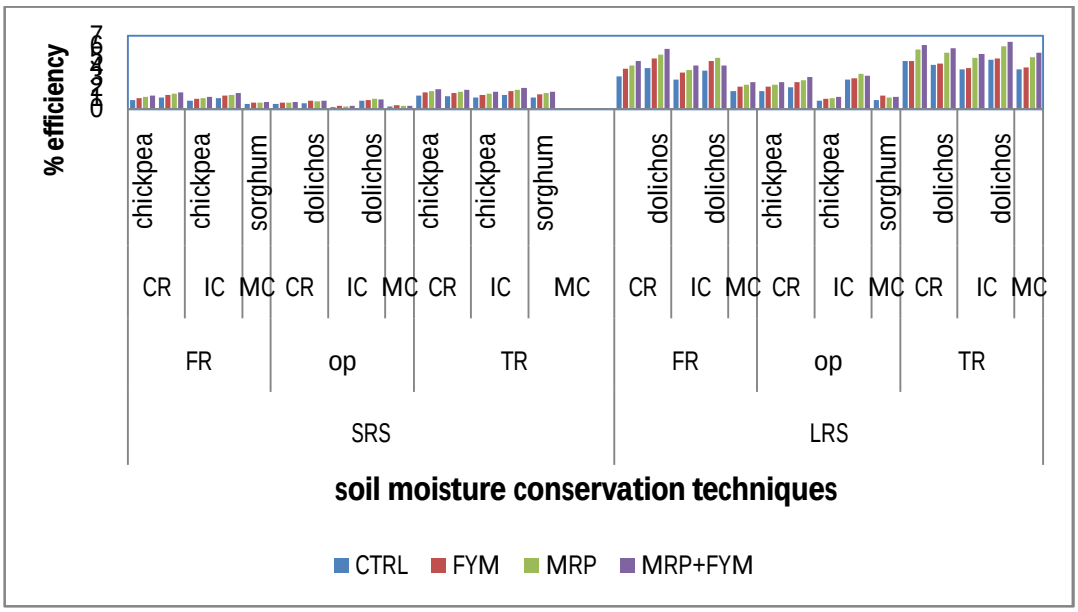
This is mainly due to the adequate ground cover provided by the sweet potato and dolichos. Additionally, distribution of root systems among species and cropping system influenced the soil moisture content in that when crops are intercropped the distribution of the roots in the soil is more intense as opposed to mono cropping. Ogindo and Walker (2005) also observed that under intercropping, water conservation was largely due to early high leaf area index and higher leaf area. Intercropping has also been reported to reduce water evaporation, and improve soil moisture conservation compared with sole cropping (Ghanbari *et al.,* 2010)

The high moisture retention recorded the soil moisture conservation techniques involving tied ridges further conforms to the findings of KARI (2005) who stated that there is a positive effect of the tied ridges and furrows and ridges in conservation of soil moisture and prolonged moisture availability in arid and semi-arid regions due to reduced soil loss through erosion and runoff. Vogel *et al. (*1994) similarly reported that moisture conservation method such as tied ridges and furrows and ridges contribute to increased infiltration, reduction of run-off and increasing rooting volume in shallow soils.

3.2 Interactive Effects of Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture Conservation Efficiency

Tied ridges with an intercrop of dolichos and sorghum (Fig. 1) and, dolichos and sweet potato (Fig 2) under tied ridges with application of FYM +MRP were the most efficient techniques for moisture conservation (Fig. 2) during the long rain season of 2013 whereas oxen plough showed very poor moisture efficiency (3.2%) (Fig. 1).

Figure 1: Efficiency of Combined Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture Retention Under Sorghum Based Plots



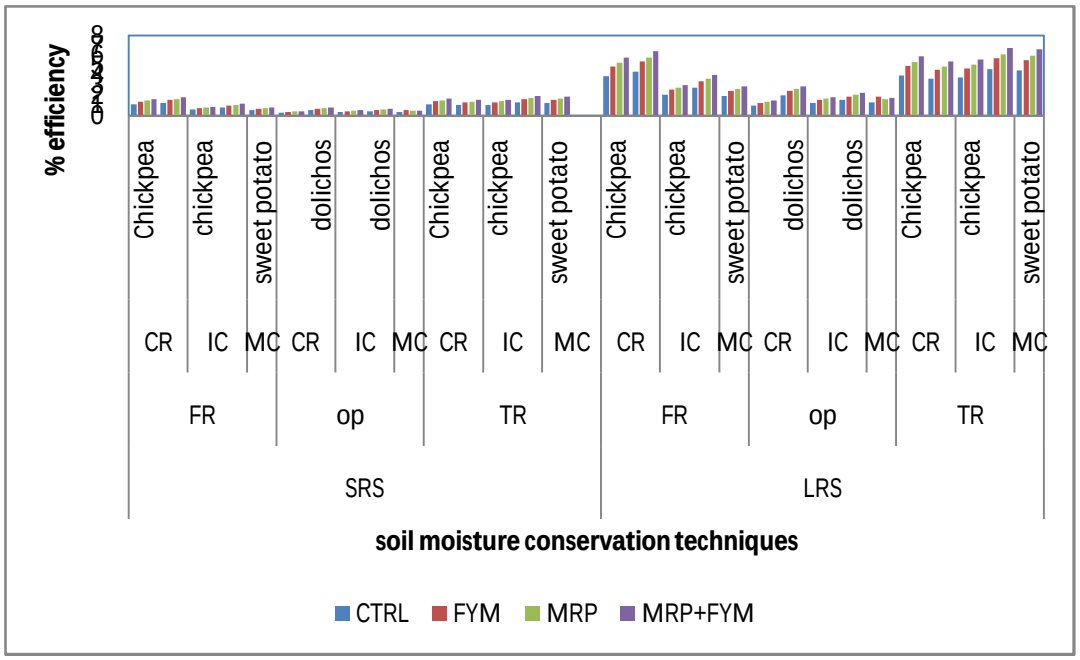
Legend: CR-crop rotation, IC-intercropping, Mc-Mono cropping, CTRL-control, FR-furrows and Ridges, FYM-farm yard, MRP-minjingu rock phosphate OP-oxen plough, LRS-long rain season, SRS-short rain season

The improved soil moisture conservation efficiency recorded in techniques involving tied ridges is due to the fact that they allow rainwater to be retained on the furrows for longer duration.

This is in addition to improved ground cover and increased amount of organic matter that results into improved soil structure and reduced water losses through soil erosion, reduced evapotranspiration following intercropping and moisture conservation by application of FYM.

Itabari *et al*. (2003) made similar observation that furrows and ridges and tied ridges favored prolonged rainwater infiltration and retention, thus raising the overall soil moisture retention and soil water holding capacity. Crusciol *et al.* (2005) also found that rotation and intercropping of crops with species that increase plant residues on the soil surface is fundamental to avoid erosion.

Figure 2: Efficiency of Combined Tillage Practices, Cropping Systems and Organic Inputs on Soil Moisture Retention Under Sweet Potato Based Plots



Legend: CR-crop rotation, IC-intercropping, Mc-Mono cropping, CTRL-control, FR-furrows and Ridges, FYM-farm yard, MRP-minjingu rock phosphate OP-oxen plough, LRS-long rain season, SRS-short rain season.

This was attributed to the improved ground cover and increased amount of organic matter in the soil ensuring reduced loss of soil moisture through evapotranspiration. In addition improved ground cover results into improved soil structure and reduced water losses through soil erosion.

The soil moisture conservation techniques were more efficient in the long rain season as compared to the short rain season but the same trend was observed with more efficiency under tied ridges; Intercrop of dolichos with the application of MRP+FYM as the most efficient techniques for moisture conservation. The high rainfall during the second season as opposed to the first season, may have led to increased soil moisture content. This resulted into an increased biomass, which further increased the moisture content by reducing the evapotranspiration and erosion, hence increased percolation.

4.0 Conclusion

Significant increase in soil moisture content was recorded in tied ridges following sorghum and dolichos and sweet potato and dolichos intercrops with application of FYM+MRP. The same treatments were similarly the most efficient techniques for moisture conservation. A combination of tied ridges and dolichos/sorghum and/or dolichos/sweet potato intercrops with application of MRP+FYM are viable methods for soil moisture conservation in the semi-arid areas of Yatta Sub County.

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