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Can Conservation Agriculture Technologies Mitigate Intra-Seasonal Drought Effects on Crop Yields in Steep Lands? Case of the Southern Uluguru Mountains, Tanzania

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Abstract
This study was conducted in the 2015 and 2015/16 rain seasons at Kolero village, in the southern Uluguru Mountains, Tanzania. The aim was to investigate the effectiveness of different Conservation Agriculture (CA) practices on runoff control and soil moisture retention as well as its implication on rainfall use efficiency (RUE) and crop production and environmental conservation on the steep slopes. Two factors (tillage practice and soil surface cover mulches, i.e. crop residues and cover crops) each at three levels, were combined to form a 3 x 3 factorial experiment and tested in a Randomized Complete Block Design (RCBD) with three replications each. Levels of tillage were shallow tillage, zero tillage and strip tillage; and those for cover crop were slash and burn, lablab and cowpea cover crops with residue retention. Moisture readings were taken at 0 - 20 cm, 20 - 40 cm, 40 – 60 cm, 60 – 80 cm and 80 - 100 cm soil depths. Results showed that there were significant differences ($P<0.05$) among treatments in runoff, at which conventional tillage recorded 26.7% and 42.2% runoff for 2015 and 2015/16 rain seasons respectively, while CA treatments had between 3.5 to 22.2 % runoff. There was also numerically higher volumetric moisture content for most of the cropping months in CA treatments at 0 to 45 cm soil depths. Soil temperature was high in conventional practices from 0 to 100 cm soil depths as compared to CA treatment for most of the cropping months. Conventional practice also showed significant difference ($P<0.05$) as it recorded the lowest RUE (4.2 kg ha^{-1} mm^{-1}) compared to CA treatments whose RUE ranged between 5.8 and 6.3 kg ha^{-1} mm^{-1} for the 2015/16 rain season which had erratic rainfall and prolonged dry spells. Most CA treatments were observed to be more effective in runoff control, moisture conservation as well as provision of high RUE at fragile foothills of southern Uluguru Mountains. CA treatments have shown to be effective in mitigating intra-season dry spells.
Keywords: conservation agriculture, runoff, soil moisture, soil temperature, slash and burn

1. Introduction

Soil erosion adversely affects crop productivity by reducing the availability of water, nutrients and organic matter. Reduction in the water available to plants is erosion's most harmful effect. In soils degraded by erosion, water infiltration may be reduced by as much as 90 percent (Pimentel, 1993). Such a situation is worsened by traditional cultivation, characterized by slash and burn, which leaves the land bare. Due to soil erosion problems, moisture is normally not enough for plant growth. Efficient use of the limited amount of moisture available for crop production on steep slopes is, therefore, essential.

The Uluguru Mountains (UM) are one of the thirteen mountain ranges that form the Eastern Arc Mountains (EAM), recognized as part of a Global Biodiversity Hotspot as well as an important water catchment area in the country (URT, 2005). The UM are faced with a host of human population pressure causing rapid land use changes (Coll Besa *et al*., 2010). Smallholder farmers in the area practice shifting cultivation characterized by slash and burn followed by tillage and sowing on bare steep slopes. Land and water resources have deteriorated due to increased soil erosion that result in decreased crop yields (Coll Besa *et al*., 2010).

In fragile areas like the southern Uluguru Mountains, Conservation Agriculture (CA), which is an agro-ecological approach to sustainable crop production intensification, (Kassam *et al*., 2014), would be appropriate. CA improves soil water-use efficiency, enhances water infiltration, and increases insurance against drought (Scott *et al*., 2010; Colmenero *et al*., 2013). Reduced soil disturbance and crop residues retention leads to both increased water infiltration rates and soil moisture retention helping crops cope with intra-seasonal dry spells (Thierfelder *et al*., 2012) and use rain water more efficiently (Kimaro *et al*., 2015). CA has the potential of making a difference in situations of erratic rainfall distribution characterized by mid-season dry spells where higher moisture conservation during critical crop phases may increase crop yields at harvest or at least reduce the risk of complete crop failure (Thierfelder and Wall, 2010; Mupangwa *et al*., 2012).

There is also increasing evidence that soil mulch cover is critical for maintaining the local water cycle through suppression of surface temperatures, in turn preventing drying, run-off and increased erosion (Kravcik *et* *al*., 2008). Tilled bare soils also experience quick heating due to high temperatures during the day that have negative influence on biological soil processes and increased soil moisture loss.

Although considerable knowledge on the advantages of conservation tillage practices as dry spell mitigation and productivity enhancement measures exists (Barron *et al*., 2003), very little is known about the comparative advantages of the different conservation methods in controlling runoff on steep slopes and mitigating dry spells (Mkoga, 2010).

A study was undertaken in the foothills of the southern Uluguru Mountains in Morogoro, Tanzania, to evaluate the interactive effects of different CA technologies in controlling runoff, moderating soil moisture and temperatures for improved maize productivity.

2. Materials and Methods

2.1. Study site description

The research was conducted at Kolero village, situated at 37°48'E, 07°15'S in the southern Uluguru Mountains. Elevation in the Kolero area ranges from 260 to 1250 m.a.s.l. The area experiences bi-modal rainfall, with the long rains (*Masika*) starting from mid-February to June and the short rains (*Vuli*) starting from mid-October to December (Kimaro *et al*., 2015). The economy of Uluguru Mountains area is dominated by agriculture as the main source of income. Farmers cultivate maize, rice, sorghum and simsim using slash and burn followed by tillage. At Kolero, maize is the main cereal crop while cash crops are sorghum (*Sorghum bicolor*) and sesame (*Sesamum inducum*).

2.2. Treatment description

The study was established on about 56% slope, whereby three replications with 9 treatments each (Table 1) were established on runoff plots of 1.8 m × 10 m in RCBD with factorial design.

Table 1: Description of the experimental treatments

Treatment	Description
T_1M_1	Shallow tillage + slash and burn (control)
T_1M_2	Shallow tillage + crop residue + lablab
T_1M_3	Shallow tillage + crop residue + cowpea
T_2M_1	Zero till + slash and burn
T_2M_2	Zero till + crop residue + lablab
T_2M_3	Zero till + crop residue + cowpea
T_3M_1	Strip tillage (double digging) + slash and burn
T_3M_2	Strip tillage (double digging) + crop residue + lablab
T_3M_3	Strip tillage (double digging) + crop residue + cowpea

Note: The main crop was maize

Two factors employed were tillage and soil cover which included crop residues and cover crops. Shallow tillage involved tilling the land to a depth of 5 to 10 cm with a hand hoe. Strip tillage/double digging was done on a seeding strip of about 20 cm width and 15 to 20 cm deep only. No-till involved seeding on un-ploughed soil with a hand hoe. Planting of *Situka* maize variety which is early maturing was done during the long and short rainy seasons of 2015 and 2015/16 respectively at 75 × 30 cm spacing. Intercropping of lablab (*Lablab purpureus* L.) and cowpea (*Vigna unguiculata* L.) was done two weeks after planting maize.

2.3. Precipitation, soil moisture and temperature measurements

Daily weather data, that is wind speed (km h^{-1}), solar radiation (MJ m^{-2}), relative humidity (%), air and soil temperature (˚C) and precipitation (mm), were measured using an automatic weather station installed at the experimental site during the 2015 growing season. Average volumetric soil moisture content was measured using water content reflectometers (WCR) with two rods having 12 cm length; model CS 655, Campbell Scientific Inc (McCoy *et al*., 2006) (Plate 1).

Plate 1. Soil moisture sensors installed at different depths

In soil, the moisture sensitivity volume extended approximately 7.5 cm from the rods along their length and 4.5 cm beyond the end of the rods. Soil temperature was measured using a thermistor that was in contact with one of the stainless steel rods at the base of the epoxy probe body. The sensors were installed at 0 – 20 cm, 20 – 40 cm, 40 – 60 cm, 60 – 80 cm and 80 – 100 cm soil depths for the representative treatments in replicates (T_1M_1, T_2M_3, T_3M_1 and T_3M_2). Except for the 0 to 20 cm depth at which sensors were installed inclined to avoid air effect in soil moisture measurement, sensors were installed vertically at all other depths (Roy, 2014).

2.4. Soil moisture calibration

Volumetric soil moisture readings from soil moisture sensors were calibrated using gravimetric soil moisture content derived from different soil depths at different levels of soil moisture regimes. The calibration equation for volumetric soil moisture content was:

$$y = 1.0437x - 5.196 \quad (1)$$

Where: y = calibrated volumetric moisture content ($m^3 m^{-3}$)
x = direct volumetric moisture content ($m^3 m^{-3}$) reading

2.5. Soil cover measurements

The ground surface cover was measured using a 50 cm by 50 cm frame made of timber and nylon ropes. It consisted of 25 squares of 10 cm by 10cm. During recording, a square that is covered to more than a half was considered as full (Stocking, 1988).

Plate 2a: Sole maize

Plate 2b: Maize-cowpea intercrop

Three observations were made per treatment, close to plot ends as well as at the middle, and the average taken and then converted into percentage cover.

2.6. Research site soil characteristics

Soils at the study site are well drained sandy clay at the surface horizon and clay dominated at the sub surface (Table 2).

Table 2. Soil profile characteristics at the experimental site

Soil depth (cm)	% Sand	% Clay	% Silt	Texture	% OC	CEC	LL	DUL	SAT	BD
0-20	54	36	11	SC	1.55	12.8	0.227	0.335	0.437	1.28
20-40	44	46	11	C	0.98	11	0.281	0.397	0.457	1.32
40-60	40	54	7	C	0.69	10	0.324	0.438	0.47	1.38
60-80	36	52	9	C	0.53	9.2	0.323	0.438	0.478	1.33
80-100	38	50	9	C	0.49	9.2	0.323	0.428	0.474	1.37

Generally, organic carbon was observed to be very low, while CEC rating was low (Metson, 1961). Such results could be attributed to lack of prior conservation measures as the field was experiencing traditional farming practice on steep slope.

2.7. Calculation of maize equivalent yield

The grain yield of lablab and cowpea were converted into maize equivalent yield (MEY) (Ghosh *et al*., 2015). The MEY was used to determine rainfall use efficiency with respect to maize-legume intercropping as compared to sole maize. It is the yield of maize plus the yield of lablab/cowpea expressed as maize yield that was determined through respective crop prices. MEY was used to calculate Rainfall Use Efficiency (kg ha^{-1} mm^{-1}) determined from seasonal rainfall.

2.8. Data analysis

Analysis of variance (ANOVA) in GenStat statistical software (GenStat, 2011) was performed whereby Least Significant Difference (LSD 0.05) was used to detect mean differences between treatments. Excel software was used in drawing moisture graphs.

3. Results and Discussion

3.1. Rainfall amount at the study site

Figures 1 and 2 show monthly rainfalls for the 2015 and 2015/2016 rain seasons.

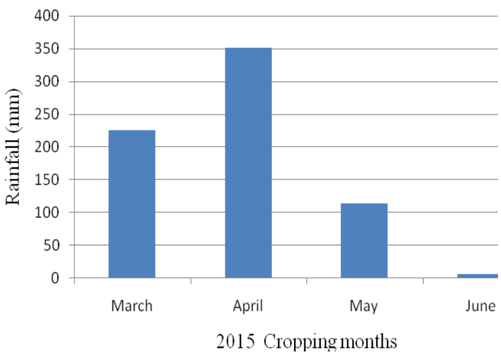

Fig. 1. Monthly rainfall for the 2015 long rainy season

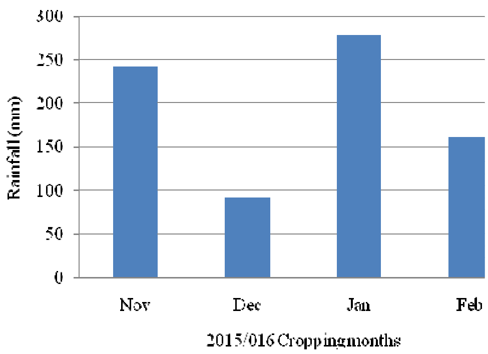

Fig. 2. Monthly rainfall for the 2015/2016 short rainy season

The amount of rainfall in the study area for the 2015 long rainy season was moderate with a narrow sowing window (Fig. 1). During 2015/16 short rainy season, the rains were erratic with prolonged dry spells (Fig. 2). For example, November had 242.6 mm of rainfall of which 198.1 mm (81.7%) rained in two consecutive days. In 2015 seasonal precipitation recorded at the experimental site was 703.8 mm (Fig. 1). The number of storms for the season was 48 of which 19 were able to cause runoff. The total amount of rainfall that resulted in runoff was 560.3 mm, representing 79.6% of the seasonal precipitation.

3.2. Effects of treatments on runoff control

Results in Table 3 show the ability of CA technologies in runoff control (less runoff amount) for the 2015 and 2015/16 rain seasons.

Table 3. Treatment's runoff (mm ha^{-1}) and percentage runoff

Treatment	2015 long rainy season		2015/16 short rainy season	
	Runoff (mm ha^{-1})	% Runoff	Runoff (mm ha^{-1})	% Runoff
T_1M_1	130.5 d	26.7	327.2 b	42.2
T_1M_2	26 ab	5.3	27.2 a	3.5
T_1M_3	37.9 abc	7.8	63.7 a	8.2
T_2M_1	68.6 c	14.0	172.2 ab	22.2
T_2M_2	68.2 c	14.0	172.3 abc	22.2
T_2M_3	69.1 c	14.1	143.7 a	18.5
T_3M_1	64.1 c	13.1	168.1 a	21.7
T_3M_2	57.0 bc	11.7	62.1 a	8.0
T_3M_3	21.6 a	4.4	59.6 a	7.7
GM	60.3		133	
CV	30.6		65.7	
F Prob. Tillage	0.062		0.293	
Cover	< .001		0.006	
Inter	< .001		0.082	

Means in the same column with similar letter(s) are not statistically different at P > 0.05

Most CA treatment options had significant difference (P<0.05) on runoff control compared to the control (T_1M_1) as shown in Table 3. This can be attributed to the presence of soil cover (Table 4).

Treatments T_3M_3 (strip tillage with cowpea intercrop), T_1M_2 (shallow tillage with lablab intercrop) and T_1M_3 (shallow tillage with cowpea intercrop) (Table 3) had the lowest runoff percentages (3.5 to 7.8), while T_1M_1 (slash and burn plus shallow tillage), which was the traditional tillage practice, had the highest runoff of 130.5 mm (26.7%) and 327.2 mm (42.2%). This is above 10 to 25% runoff from unprotected soil surface for the Eastern and Southern Africa as reported by Rockstrom *et al.* (2001). Thierfelder and Wall (2009) also reported high runoff in Zimbabwe (545.1 mm) which was approximately 50% of all precipitation for conventional practice as compared to 30% for CA practice.

Table 4. Monthly average soil cover percentage for 2015 rain season

Treatments	Monthly Percentage Soil Cover				
	March	April	May	June	July
T_1M_1	3.8 a	6.7 a	12.0 a	6.4 a	5.0 a
T_1M_2	22.2 bc	21.9 b	62.7 c	90.0 e	85.3 c
T_1M_3	19.1 bc	23.1 b	59.8 c	80.7 cde	66.0 b
T_2M_1	6.7 a	12.0 a	24.6 b	17.3 b	12.2 a
T_2M_2	27.3 c	24.7 b	57.4 c	87.0 de	76.0 bc
T_2M_3	26.7 bc	24.2 b	60.0 c	79.8 cd	83.5 c
T_3M_1	5.7 a	9.9 a	20.9 ab	12.8 ab	10.0 a
T_3M_2	18.7 b	21.3 b	53.4 c	87.7 de	81.6 bc
T_3M_3	20.0 bc	23.8 b	54.8 c	75.1 c	66.2 b
GM	16.7	18.6	45.1	59.6	54.0
CV	26.1	28.3	14.2	8.5	17.0
LSD	7.6	9.11	11.04	8.72	15.85
SED	4.3	4.3	5.21	4.12	7.48
F Prob. Tillage	0.03	0.478	0.379	0.458	0.445
Cover	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Inter	0.554	0.942	0.123	0.137	0.141

Means in the same column with similar letter(s) are not statistically different at P > 0.05

3.3. Conservation agriculture and soil moisture and soil temperature dynamics

Soil moisture is one of the most important factors that determine crop production. Availability of optimum soil moisture in the root zone has great influence on crop performance. Soil tillage and cover have indicated to influence ability of the soil to hold moisture and moderate soil temperature (Patil *et al*., 2013). Available soil cover and interaction between soil cover and tillage methods showed significant difference (P<0.001) in runoff control (Table 3), which could have contributed to the differences in soil moisture among tested treatments (Fig. 2a to 6a). There were also differences in soil temperature among tested CA options (Fig. 2b to 6b), soil cover observed to have great influence.

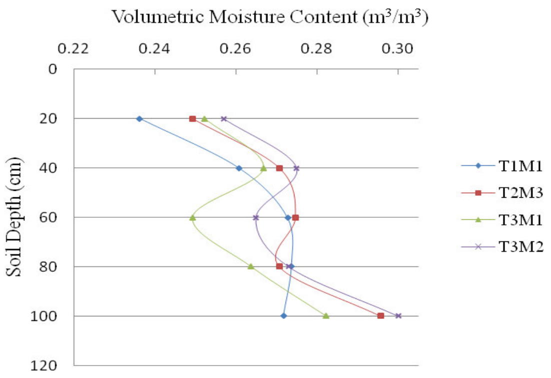

Fig. 2a. VMC for March 2015

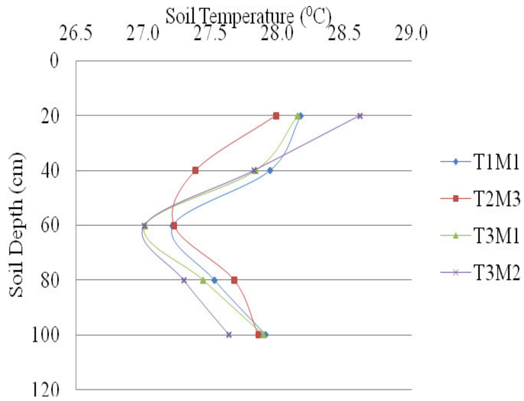

Fig. 2b. Soil temperature in March 2015

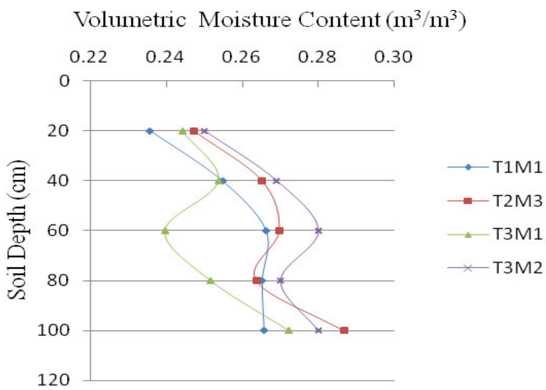

Fig. 3a. VMC for April 2015

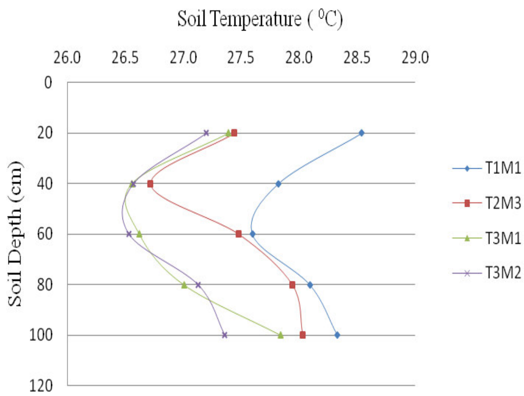

Fig. 3b. Soil temperature for April 2015

Treatments T_2M_3, T_3M_1 and T_3M_2, which had CA components, were observed to have higher soil volumetric moisture content from March to April (Fig. 2a and 3a) compared to traditional tillage (T_1M_1) from 0 to 45 cm soil depth that could be attributed by soil cover. During heavy storms in March and April, T_1M_1 recorded the lowest soil moisture at 0 to 45 cm soil depth; this could be attributed to soil surface sealing, which results into poor infiltration and high runoff losses. Junge *et al*. (2008) reported high soil moisture content (14.5 to 14.7%) for the top 20 cm depth for plots with maize intercropped with melon and yams compared to sole maize plots that had low moisture content (12.7 to 14.2%).

During the month of May when cowpea was at flowering stage, T_3M_2 recorded the lowest soil moisture content at 0 to 40 cm depth (Fig. 4a), which can be an indication of presence of competition for soil moisture between the main crop maize and the intercropped legume.

There were no more storms as from June after 2nd weeding that involved hand hoe shallow tillage for T_1M_1 control treatment (Fig. 5a and 6a). The treatment was observed to have high soil moisture content, coming 2nd behind T_3M_2 which had well established lablab cover crop. In the absence of heavy storms, the hand hoe tillage practice tended to temporarily improve water infiltration.

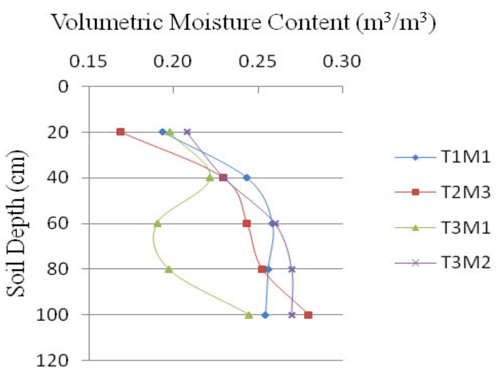

Fig. 4a. VMC May 2015

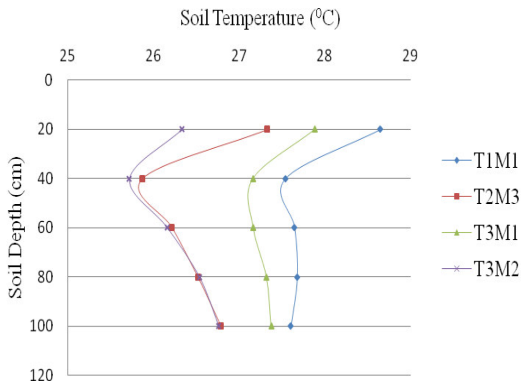

Fig. 4b. Soil temperature May 2015

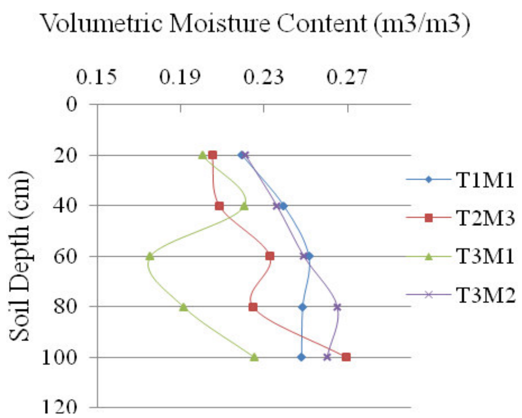

Fig. 5a. VMC for June 2015

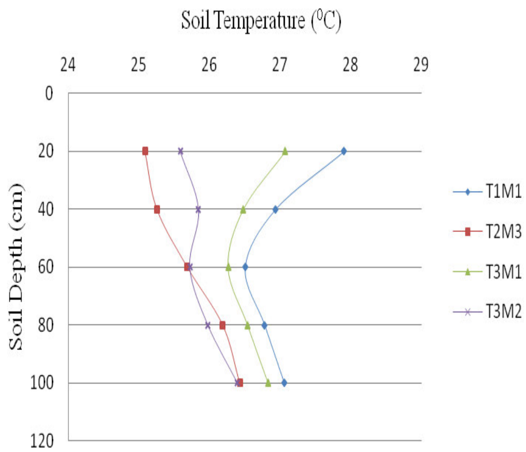

Fig. 5b. Soil temperature for June 2015

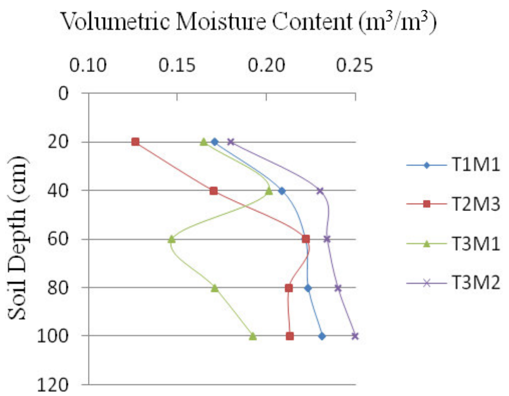

Fig. 6a. VMC for July 2015

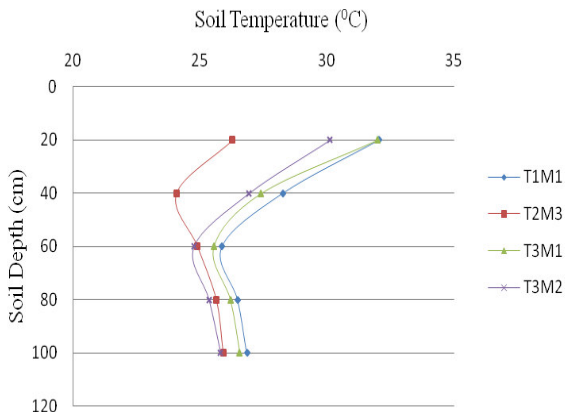

Fig. 6b. Soil temperature for July 2015

Soil temperature was also assessed with respect to the treatments employed. Throughout the season, treatments with crop residues and cover crop mulches (T_2M_3 and T_3M_2) were observed to record moderate soil temperature (Fig. 3b – 6b) compared to those without mulch. Simmons and Nafziger, (2008) reported similar results whereby strip tillage had the lowest soil temperature followed by no-till while conventional practice had the highest soil temperature. On average soil temperature was observed to be high for T_1M_1 and T_3M_1 treatments without soil surface mulch, therefore experiencing direct solar radiation effect.

3.4. Influence of conservation agriculture on rainfall use efficiency

Table 5 shows results of Rainfall Use Efficiency (RUE) with respect to different treatments that were tested for the 2015 and 2015/2016 rain seasons. In determining RUE, legume grain yields for intercropped treatments were translated to maize yield equivalent through respective crop prices as all contributed to yields per unit area with respect to resources used. While 1 kg of maize was sold at TShs 555.56, both lablab and cowpea grains fetched TShs 1,000 per kg. During the short rain season with erratic rains and prolonged dry spells, all CA treatment options except (T_2M_1) recorded significantly higher RUE ranging between 5.8 to 6.3 kgha^{-1}mm^{-1} than 4.2 kgha^{-1}mm^{-1} for the conventional practice (P<0.05). Kimaro *et al*. (2015) reported similar results of high RUE in CA treatments compared to the conventional practice.

Table 5. Rainfall Use Efficiency (RUE)

Treat	2015 long rainy season		2015/16 short rainy season	
	MEY (kg ha^{-1})	**RUE (kg ha^{-1} mm^{-1})**	**MEY (kg ha^{-1})**	**RUE (kg ha^{-1} mm^{-1})**
T_1M_1	4.2 a	6.0 a	3.2 a	4.2 a
T_1M_2	5.1 a	7.3 a	4.8 b	6.2 b
T_1M_3	5.1 a	7.2 a	4.8 b	6.2 b
T_2M_1	4.5 a	6.3 a	4.2 ab	5.4 ab
T_2M_2	4.9 a	7.0 a	4.8 b	6.2 b
T_2M_3	5.1 a	7.3 a	4.6 b	5.9 b
T_3M_1	4.8 a	6.8 a	4.5 b	5. 8 b
T_3M_2	4.5 a	6.4 a	4.8 b	6.3 b
T_3M_3	5.1 a	7.2 a	4.6 b	5.9 b
GM	4.8	6.83	4.48	14.0
CV	12.8	12.8	14.7	14.0
SE	0.614	0.872	0.537	0.659
F Prob. Till	0.984	0.984	0.493	0.462
Cover	0.162	0.162	0.030	0.023
Inter	0.582	0.582	0.364	0.320

Means along same column with similar letter(s) are not statistically different at P > 0.05

Although the short rainy season had high rainfall amount (Fig. 2) compared to the long rain season (Fig. 1), it had low RUE (Table 5). The 2015 long rain season recorded 703.8 mm of rainfall with short dry spells and reasonable rainfall distribution that showed no significant difference among treatments. Mkoga (2010) concluded that minimum tillage (ripping) with surface crop residues, with or without cover crops, is more effective in mitigating dry spells and enhancing crop productivity in locations that receive seasonal rainfall below 770 mm. However, in this study, CA technologies were more effective in mitigating dry spells and improving crop productivity compared to the conventional practice (T1M1) during the short rain season which had high amount of seasonal rainfall (776.2 mm) that was very erratic with prolonged dry spells.

4. Conclusion and Recommendation

Soil cover from crop residues and cover crops as well as interaction between soil cover and tillage i.e. shallow, minimum and zero tillage were effective in runoff control. They resulted in increased infiltration which helps to minimize the effects of intra-seasonal drought effects on crop yields. Intercropping of legumes has shown increased RUE with respect to production per unit area when compared to sole maize farming practice. It is recommended that CA technologies that involve minimum soil disturbance and retention of crop residues plus intercropping of legume cover crops be promoted in steep lands receiving erratic rains with frequent dry spells as well as runoff problems.

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