International Journal of Agriculture, Environment and Bioresearch

Vol. 2, No. 04; 2017

ISSN: 2456-8643

CONSERVATION TILLAGE METHODS FOR SOIL EROSION CONTROL ON STEEP SLOPES: CASE STUDY OF SOUTHERN ULUGURU MOUNTAINS, TANZANIA

***Mlengera, N[1,2]., Mtakwa, P. W[3]., Salim, B. A[2]., Mrema, G. C[2].**

[1]Uyole Agricultural Research Institute, P. O. Box 400, Mbeya, Tanzania

[2]Department of Engineering Sciences and Technology, Sokoine University of Agriculture, P. O. Box 3003 Chuo Kikuu, Morogoro, Tanzania,

[3]Department of Soil and Geological Sciences, Sokoine University of Agriculture, P. O. Box 3008 Chuo Kikuu, Morogoro, Tanzania, E-mail: petermtakwa@yahoo.com

ABSTRACT

Over 75 % of cultivated fields in the southern Uluguru Mountains, Tanzania, are situated on steep slopes exceeding 20 % resulting in high soil losses due to conventional farming practices. Conservation tillage methods of zero till, minimum tillage and soil cover were introduced on a 56 % slope to determine their effect on soil erosion. A factorial arrangement of treatments in a randomized complete block design (RCBD), comprising two factors i.e. tillage and soil cover was executed from 2013 to 2015. The best Conservation agriculture (CA) practice, i.e. strip tillage with cowpea intercrop (T3M3), significantly ($P < 0.05$) reduced soil loss by 50 (1.2 Mg ha-1) and 153 (0.2 Mg ha-1) times compared to the conventional practice (T1M1) (59.9 and 30.6 Mg ha-1) in the 2nd and 3rd years, respectively. It is concluded that CA technologies have the potential of controlling soil erosion on steep lands.

Keywords: Conservation agriculture, cover crops, shallow tillage, strip tillage

1. INTRODUCTION

Soil erosion is a major environmental problem facing agricultural production and is widespread across the world (Kimaro *et al*., 2008; Xiao *et al*., 2011; Onesimus *et al*., 2012). The ever-increasing population pressure, among other factors, is leading to increased cultivation of tropical steep lands, generally defined as “land with slope exceeding 20 %” (Presbitero *et al*., 2005; Haigh, 2006). Soil erosion by water in mountainous areas is leading to low productivity and increased poverty (Liu *et al*., 2012).

In Morogoro Region, Tanzania, soil loss and runoff are the main threats to soil and water conservation in the steep slopes of the Uluguru Mountains (UM) (Kingamkono *et al*., 2005). In parts of the UM rill and inter-rill soil erosion processes result in mean soil loss ranging from 91 to 258 Mg ha^{-1} $year^{-1}$ (Kimaro *et al*., 2008). Farmers in the southern UM are increasingly growing annual crops, especially maize (*Zea mays* L.), sorghum (*Sorghum bicolor* (L) Moench) and sesame (*Sesamum inducum* L.), on steep slopes of up to 80 % using traditional methods, mainly slash and burn followed by tillage using the hand hoe.

Plate 1. Conventional farming on 75 % slope at Kolero village.

This has resulted in accelerated soil erosion and low soil fertility. However, research on steep lands exceeding 20 % slope has generally been neglected because cultivation of these sites has traditionally been considered inappropriate and unsustainable (Juo and Thurow, 1998).

Worldwide, there have been efforts of promoting soil and water conservation (SWC) practices including the use of cross-slope live barriers of vetiver grass (*Vetiveria* spp.), stone and earth bunds, ridging, pitting, cut-off drains, bench terraces and contours (Shetto and Owenya, 2007) to control soil erosion on steep slopes, but with little effect in improving agricultural productivity (Haigh, 2006). Nevertheless, most of these physical structures are well suited for gentle slopes (< 10 %) and are associated with high construction and maintenance costs, and are time and labour consuming as well as lack of guaranteed soil fertility improvement (Tenge *et al*., 2005; Aku and Aiyelari, 2014; Mwango *et al*., 2015).

There are efforts of promoting conservation agriculture (CA) technologies in order to improve smallholder production systems which are faced with declining crop yields due to soil erosion (Shetto and Owenya, 2007). According to FAO (2015) conservation agriculture is an approach to managing agro-ecosystems for improved and sustained productivity as well as increased profits and food security, while preserving and enhancing the resource base and environment. Rainfall capture and retention is recognized as a major on-farm benefit of CA (Scott *et al*., 2010). However, studies on soil and water conservation technologies have been applied individually or taking into consideration only few variables (Haigh, 2006).

Efforts have been taken by a number of organizations including the Cooperative for Assistance and Relief Everywhere (Tanzania) (CARE(T)) a nongovernmental organization to promote strip digging and cover crops intercropping on the southern UM to control soil erosion caused by inappropriate farming practices (Mvena and Kilima, 2009). Nevertheless, the effectiveness of such technologies in controlling soil erosion and conserving soil moisture in the area are still undocumented.

Different CA technologies were introduced to area with 56 % slope, which is representative for most farms in the southern Uluguru Mountains, to determine their effectiveness in soil erosion control. Treatments under study included no-till, strip tillage/double digging, shallow tillage and cover crops (lablab and cowpea). The study intended to integrate different proven CA technologies in complex mountainous areas where soil erosion, particularly rill and inter rill erosion, is a serious problem (Kimaro, 2003) and yet farmers are using these steep lands for agricultural production.

2. MATERIALS AND METHODS

2.1 Research site description

The study was conducted at Kolero Village, that is 120 km from Morogoro town, on the southern foothills of the Uluguru Mountains located on longitude 37°48′0″ E and latitude 7°15′0″ S that was taken at CARE learning centre. The study area has an elevation ranging between 410 and

734 m.a.s.l. (Fig. 1). The Uluguru Mountains are part of a chain of mountains commonly known as the Eastern Arc Mountains (Kimaro *et al*., 2008; Mvena and Kilima, 2009).

The dominant soils on the foothills of these mountains where the study was undertaken based on FAO system of soil classification (FAO, 1998) are *Chromic Lixisols* and *Profondic Acrisols* associated with *Hypeferralic Cambisols* and *Endoleptic Cambisols* (Kimaro *et al*., 2005). The area has a bimodal rainfall pattern with over 1 200 mm per annum (Mvena and Kilima, 2009). The soil at the research site is sand clay loam and well drained.

Farming systems practised in the study area are unsustainable which ends up with land degradation (Bhatia and Ringia, 1996). Both food and cash crops are produced by farming households in the area, which in turn boosts income and employment (Mattee and Innocent, 2006). Main cereal crops grown are maize, rice and sorghum. Varieties of other food crops, vegetables and fruits are also grown (Bhatia and Ringia, 1996).

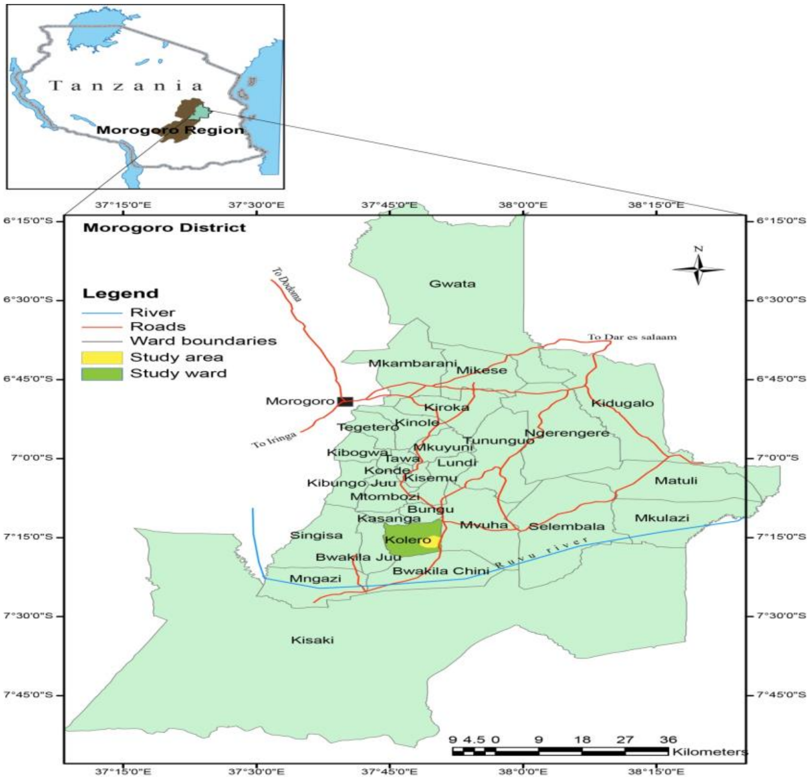

Figure 1: Location of the study area

Source: Arc GIS Map

2.2 Experimental design and treatments

A factorial arrangement of treatments in a randomized complete block design (RCBD) was laid out on a two-year grass fallowed site. The experiment comprised two factors i.e. tillage and soil cover each at three levels and replicated three times on runoff plots measuring 1.8 m × 10 m (Plate 2). The levels of the tillage factor were shallow tillage (T_1), zero till (T_2) and strip tillage (double digging) (T_3) whereas the soil cover factor comprised of slash and burn (M_1), lablab cover (M_2) and cowpea cover (M_3). The different treatment combinations are shown in Table 1. All treatments with lablab and cowpea intercrops as soil cover had crop residues retained as well.

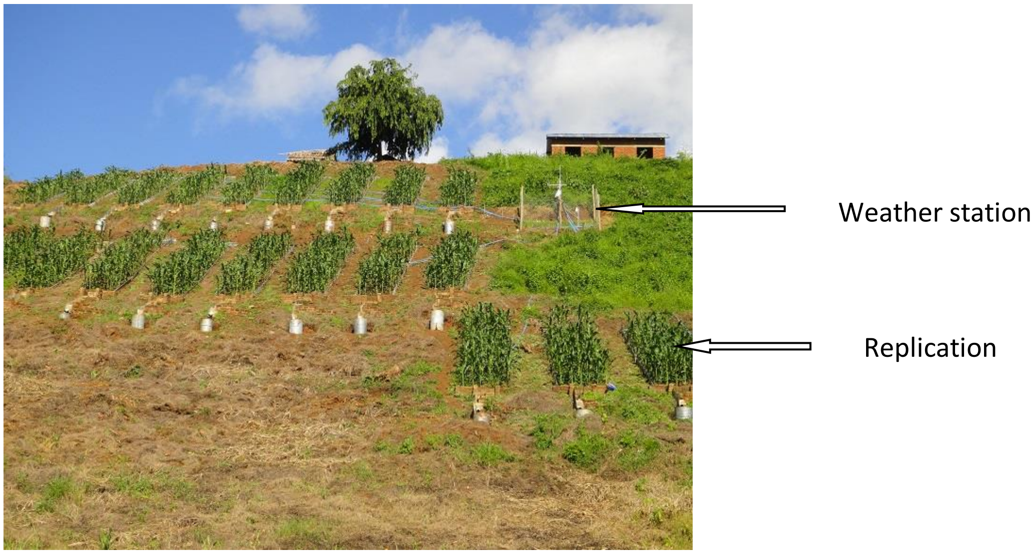

Plate 2: Experimental layout on 56 % slope at Kolero village

Table 1: Description of the experimental treatments

Treatments	**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

Shallow tillage involved tilling the land to a depth of 5 to 10 cm with a hand hoe. Strip tillage/double digging involved tilling a strip of about 20 cm wide and 30 cm deep on a seeding line only. No-till involved making a hole with a hand hoe for seed placement without primary tillage. Planting of *Situka* maize variety, which is early maturing, was done during the main rainy season from late February to early March each season at a spacing of 75 × 30 cm. Intercropping of lablab (*Lablab purpureus* L.) and cowpea (*Vigna unguiculata* L.) was done two weeks after planting maize at 75 × 25 cm spacing for those treatments requiring cover crops. The plots were bounded by corrugated iron sheets, buried to a depth of 20 cm and protruding 10 cm above the ground to prevent runoff water from outside the plots from entering the plots and that from runoff plots from flowing out unmonitored.

A three stage divisor system divided the runoff to one eighth by first splitting the runoff into a half, then into a quarter and finally to one eighth. Hence, an eighth (1/8) of the total runoff and sediment was collected in a 220 litre-drum at the bottom of each runoff plot. Drums had taps at the bottom for discharging the runoff water into a calibrated bucket for measuring of volume. The rest of the runoff was discharged into a drainage channel designed to remove the excess runoff (Plate 3).

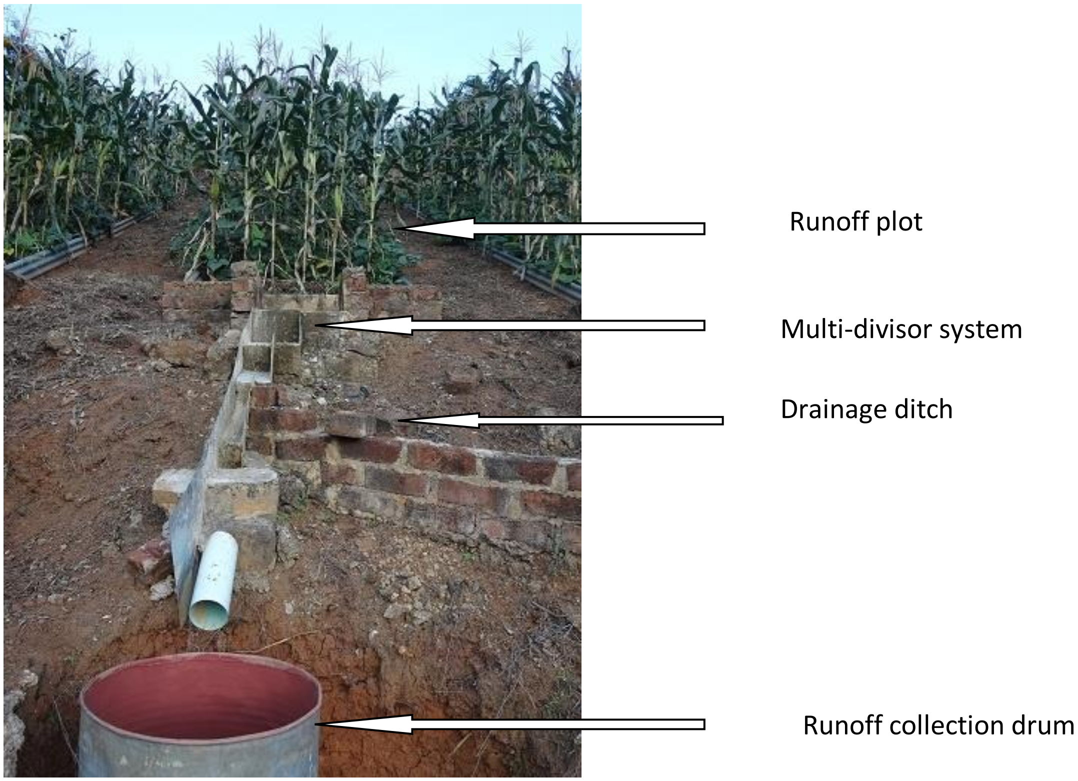

Plate 3: Multi-divisor system for runoff and sediment collection

2.3 Data Collection

2.3.1 Runoff measurement

The runoff and sediments in the drum were vigorously stirred and about 1 litre of the mixture of runoff and sediments was collected in a one litre bottle and the rest was volumetrically measured using calibrated buckets. Aluminium sulphate (Al_2SO_4) flocculating agent was used to separate water and sediments in the field by pouring off the water and then weighed before transporting the same to SUA laboratory. The sediment samples were filtered using Whatman No. 42 filter paper and oven dried for 24 h at 105 °C until constant weight was obtained (Yang *et al*., 2009), and the soil loss (Mg ha^{-1} y^{-1}) was determined.

The ground surface cover assessment was monitored once in a week using Quadrant Charting method (Plate 4) (Chikoye, 1999; Olmstead *et al*., 2004).

Plate 4: Soil surface cover measurement using a Quadrant frame

Data collected were processed using Microsoft Excel and statistically analyzed using GenStat statistical software package (GenStat, 2011), for analysis of variance (ANOVA) where treatment means for soil cover, runoff and soil loss were compared using Duncan Multiple Range Test (DMRT) at $P < 0.05$ level of significance.

3. RESULTS AND DISCUSSION

3.1 Rainfall amounts and percentage runoff

Seasonal rainfall (long rains) amount was recorded using automatic rain gauge installed at the experimental site and shown in Fig. 2. Runoff percentages for different treatments tested are also shown in Table 3. During the first two years, that is 2013 and 2014, the area experienced high amounts of rainfall during the growing season from February to June (main rainy season), compared with the year 2015 which experienced moderate rains with a very narrow sowing window (late February to mid March).

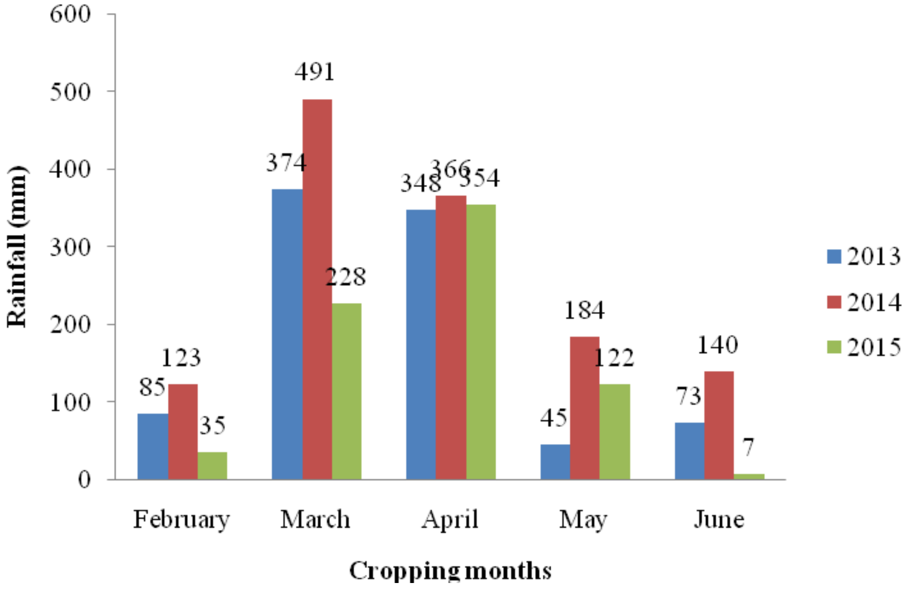

Figure 2: Monthly rainfall from 2013 to 2015 cropping seasons

Most erosive rains occurred in the first few weeks after the onset of rains recording 77.1 %, 65.8 % and 78.0 % for 2013, 2014 and 2015 seasons respectively between March and April. This was in most cases before soil cover establishment for treatments with cover crops intercrops.

Runoff results for the 2013 cropping season which involved leveling, de-stumping and construction of runoff plots indicated no any treatment effects observed to be very high from 15.4 to 51 % (Table 2). Results for 2014 and 2015 showed treatments effect that ranged between 4.4 and 26.7 %, conventional practice (T_1M_1) recording the highest runoff (Table 3). Conventional practice recorded the highest runoff of 16.2 and 26.7 for the 2014 and 2015 respectively (Table 2). Such runoff results resemble that reported by Rockstrom *et al*. (2001) for Eastern and Southern Africa who indicated that 10 to 25 % of rain water is lost to runoff on unprotected surfaces in the region. Conventional practice (T_1M_1) had two to six times runoff when compared to treatments with conservation agriculture options. Treatments with CA options had between 4.4 to 14 % runoff, strip and shallow tillage with soil cover observed to be more effective in runoff control. This could be attributed to the fact that tillage and soil cover resulted into increased water infiltration.

Table 2: Runoff percentage

			% Runoff for the Cropping Seasons		
Treatments	**Tillage**	**Soil cover**	**2013**	**2014**	**2015**
T_1M_1	Shallow tillage	Trash burned	22.3	16.2	26.7
T_1M_2	Shallow tillage	Lablab	32.4	12.3	5.3
T_1M_3	Shallow tillage	Cowpea	37.4	12.6	7.8
T_2M_1	Zero till	Trash burned	30.6	11.4	14.0
T_2M_2	Zero till	Lablab	51.0	10.6	14.0
T_2M_3	Zero till	Cowpea	30.3	11.3	14.1
T_3M_1	Strip tillage	Trash burned	31.5	13.1	13.1
T_3M_2	Strip tillage	Lablab	16.3	8.8	11.7
T_3M_3	Strip tillage	Cowpea	15.4	8.0	4.4
Mean			**29.7**	**11.6**	**12.3**

3.2 Soil loss for different treatments

Results on percentage soil cover, runoff and soil loss for the 2013 cropping season are indicated in Table 3. There was a significant difference ($P < 0.05$) among treatments in terms of soil cover between treatments which had lablab and cowpea cover crops and those without cover crops. Although such treatments had soil cover that was above the minimum 30 % recommended for CA practices, they did not show significant differences in runoff and soil loss control. Such results could be attributed to the fact that soil cover from lablab and cowpeas were established during mid season when most of the erosive storms were over.

Table 3: Percentage soil cover, runoff and soil loss for the 2013 cropping season

Treat	**Tillage**	**Cover**	**Soil Cover %**	**Runoff mm ha^{-1}**	**Soil loss Mg ha^{-1}**
T_1M_1	Shallow tillage	Trash burned	15.8 a	162.1 a	91.8 a
T_1M_2	Shallow tillage	Lablab	37.6 b	235.7 a	116.1 ab
T_1M_3	Shallow tillage	Cowpea	35.5 b	272.4 a	151.3 ab
T_2M_1	Zero till	Trash burned	15.9 a	222.9 ab	159.3 ab
T_2M_2	Zero till	Lablab	36.4 b	371.4 b	227.3 b
T_2M_3	Zero till	Cowpea	34.5 b	220.9 ab	129.0 ab
T_3M_1	Strip tillage	Trash burned	16.3 a	239.6 ab	118.3 ab
T_3M_2	Strip tillage	Lablab	35.6 b	200.0 a	112.3 ab
T_3M_3	Strip tillage	Cowpea	35.5 b	126.7 a	53.5 a
Mean			29.2	228.0	129.0
SE			6.9	68.3	60.5

CV (%)		28.9	36.7	108.0
F Prob.	Tillage	0.985	0.14	0.044
Cover		< 0.001	0.227	0.366
		< 0.999	≤ 0 .12	
Inter.				0.281

Mean values in the same column with the same letter are not significantly different at $P < 0.05$ (DMRT)

All CA treatments had no mulch during commencement of the trial due to land preparation that involved de-stumping and levelling of the runoff plots as well as construction of runoff plots. Only T_1M_1 and T_3M_3 (conventional tillage) treatment differed significantly ($P \leq 0.05$) from T_3M_3 (strip tillage with cowpea intercrop). The results for this cropping season, besides yielding many tonnes of soil loss, were not consistent with those of other seasons. Conventional practice (T_1M_1) recorded the least runoff and soil loss but one treatment (T_3M_3) among the nine treatments evaluated, different from the anticipated results. This can be attributed to the fact that commencement of the experiment did not allow for soil settlement as a result of soil loosening due to de-stumping and levelling of the runoff plots.

Soil loss results for the first year that involved leveling of runoff plots indicated losses ranging from 53.5 to 227.3 Mg ha^{-1}. This is in agreement with results by other researchers in the same Uluguru Mountains that have showed soil loss ranging from 91 to 258 Mg ha^{-1} y^{-1} (e.g. Kimaro, 2003), under traditional tillage practices. In central Kenya highlands, Gachene *et al*. (1997) reported soil losses of 247 Mg ha^{-1} y^{-1} on steep slopes of 18 % which is within the same range as that observed in the Uluguru Mountains.

Soil cover, runoff and soil loss results are shown in Table 4 for the 2014 cropping season. The results indicate that CA treatments were very effective in decreasing soil erosion rates.

Table 4. Percentage soil cover, runoff and soil loss for the 2014 cropping season

Treatments	**Tillage**	**Cover**	**Soil Cover %**	**Runoff mm**	**Soil loss Mg**

				ha^{-1}	ha^{-1}
T_1M_1	Shallow tillage	Trash burned	11.1 a	158.8 b	59.9 c
T_1M_2	Shallow tillage	Lablab	68.9 b	120.7 ab	2.0 a
T_1M_3	Shallow tillage	Cowpea	62.3 b	123.7 ab	21.6 b
T_2M_1	Zero till	Trash burned	13.0 a	111.0 ab	5.7 a
T_2M_2	Zero till	Lablab	67.6 b	103.3 ab	1.4 a
T_2M_3	Zero till	Cowpea	61.8 b	110.2 ab	2.0 a
T_3M_1	Strip tillage	Trash burned	11.3 a	128.2 ab	4.3 a
T_3M_2	Strip tillage	Lablab	66.9 b	86.5 a	1.7 a
T_3M_3	Strip tillage	Cowpea	60.2 b	78.1 a	1.2 a
Grand Mean			47.0	113.4	11.1
CV (%)			13.7	28.7	60.1
F Prob.		Tillage	0.882	0.063	< 0.001
		Cover	<0.001	0.107	< 0.001
		Inter	0.993	≤ 0.718	< 0.001

Mean values in the same column with the same letter are not significantly different at $P < 0.05$ (DMRT)

There was significant difference ($P \leq 0.05$) between conventional practice (T_1M_1) and all CA treatments in terms of soil loss control. Among the eight treatments with CA components (Table 4), five treatments, that is T_1M_2, T_2M_2, T_2M_3, T_3M_2, and T_3M_3, yielded soil losses that were within the tolerable range of 2 Mg ha^{-1} for sensitive areas where soils are thin or highly erodible like those in the southern Uluguru Mountains (Hudson, 1981).

Zero till and minimum tillage with lablab and cowpea cover crops as well as crop residue retention (T_1M_2, T_2M_2, T_2M_3, T_3M_2 and T_3M_3) were the most effective in soil erosion control

ranging from 30 (1.2 Mg ha^{-1}) to 50 (2.0 Mg ha^{-1}) times compared to conventional practice (T_1M_1) (59.9 Mg ha^{-1}). Soil loss results indicate that tillage, cover as well as their interaction had significant influence in terms of soil erosion control. Other researchers (Liu* et al.*, 2012) reported decreased soil loss due to straw mulching treatment versus non-mulched treatment. Thierfelder and Wall (2009) also observed greatest erosion and runoff in the conventional tillage practice when compared to CA treatments.

Although a significant difference ($P < 0.05$) was observed in terms of percentage soil cover between treatments with lablab and cowpea cover crops and those with sole maize (T_1M_1, T_2M_1 and T_3M_1), there was minimum effect on runoff control when compared to soil loss control. Only Strip tillage treatments T_3M_2 and T_3M_3 with lablab and cowpea soil cover, respectively, differed singnificanly ($P < 0.05$) from the traditional tillage practice (T_1M_1). This can be attributed to the influence of Strip tillage and soil cover.

During the 3rd cropping season, six out of eight treatments with CA components were able to control soil loss to tolerable range for shallow soils (Table 5). Soil loss results indicated that the two factors, i.e. tillage and cover, as well as their interaction had significant effect on soil loss control with CA treatments resulting in significantly lower ($P < 0.05$) soil loss than conventional treatment for the 2014 and 2015 cropping seasons.

Table 5. Percentage soil cover, runoff and soil loss for the 2015 cropping season

Treat	**Tillage**	**Cover**	**Soil Cover %**	**Runoff (mm ha^{-1})**	**Soil loss (Mg ha^{-1})**
T_1M_1	Shallow tillage	Trash burned	8.2 a	143.3 c	30.6 b
T_1M_2	Shallow tillage	Lablab	62.3 b	25.4 ab	0.3 a
T_1M_3	Shallow tillage	Cowpea	56.3 b	37.8 ab	4.6 a
T_2M_1	Zero till	Trash	17.3 a	78.1 abc	2.7 a

		burned			
T_2M_2	Zero till	Lablab	60.7 b	98.6 abc	1.0 a
T_2M_3	Zero till	Cowpea	60.0 b	100.8 bc	1.1 a
T_3M_1	Strip tillage	Trash burned	14.3 a	74.6 abc	1.8 a
T_3M_2	Strip tillage	Lablab	58.3 b	82.1 abc	1.2 a
T_3M_3	Strip tillage	Cowpea	54.3 b	20.9 a	0.2 a
Mean			43.6	73.5	4.8
CV			12.0	54.7	173.2
SE			5.7	32.86	6.82
F Prob.		Tillage	0.261	0.226	0.024
		Cover	<0.001	0.08	0.027
		Inter	0.399	0.029	0.031

Mean values in the same column with the same letter are not significantly different at $P < 0.05$ (DMRT)

The results in Table 5 show a significant ($P < 0.05$) tillage and cover interaction effect for the runoff. Shallow tillage with lablab and cowpea (T_1M_2, T_1M_3) as well as strip tillage with cowpea (T_3M_3) were more effective in runoff control compared to other treatments. Initial soil cover (crop residues) during the commencement of the cropping season plays a great role in controlling soil erosion. Soil cover establishment as a result of cover crops intercropping normally develop fully when most erosive rains have ceased hence reduced effect in runoff and soil loss control.

4. CONCLUSION AND RECOMMENDATIONS

Soil conservation on steep lands faced with increased conventional cultivation for crop production is important. Results of this study suggest that Conservation agriculture technologies have an influence on soil loss control on steep lands of the southern Uluguru Mountains. Shallow tillage, strip tillage, zero till and soil cover from cover crops and crop residues were observed to be effective 30 to 153 times in soil erosion control on steep lands compared to Conventional practice (T_1M_1). Furthermore, among the CA treatments themselves, those which had tillage and soil cover interacting (T_1M_2, T_1M_3, T_2M_2, T_2M_3, T_3M_2 and T_3M_3) were in most cases two to three times effective in soil loss control than those without soil cover (T_2M_1 and T_3M_1). The initial cover from crop residues is very useful in counteracting early erosive rains before cover crops and main crop canopy development.

5. ACKNOWLEDGEMENT

The authors gratefully acknowledge the Rockefeller Foundation and the Ministry of Agriculture, Livestock and Fisheries, Tanzania for funding this study. The cooperation from Kolero village government is also highly appreciated.

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