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Assessment of Improved Ladder Terraces in Controlling Soil Erosion on Uluguru Mountains-Tanzania

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Abstract

This study assesses effectiveness of improved ladder terraces in controlling soil erosion on steep slopes of Uluguru Mountains in Morogoro Region, where runoff collection tanks were located downstream of the divisor system were all runoff from the catchment upstream where improved ladder terraces were located. The soil properties percentage weight for sand, silt and clay were average 40, 10 and 50 respectively. Half of the terraces were left barely and half were planted with maize crop. Runoff and soil loss generated during every rainstorm was collected from six field plots of improved ladder terraces to the tanks. There was statistically significant different between reductions of soil loss in bare improved ladder terrace and cropped improved ladder terrace. The amount of runoff on the bare soil was high by 15% to 18% compare to runoff on cropped soils. It was found that cropped improved ladder terrace reduced soil loss by 74% while bare improved ladder terrace reduced soil loss only by 41%. Simple linear regression shows runoff water generated from rainfall amount with soil losses from different land cover. Bare soils behave with linear relationship ($r^2 = 0.85$) unlike cropped soil were $r^2 = 0.36$ because of gradual increase of crop canopy at every crop stage hence less impact to the soil. Soils losses from the bare soil ladder terrace and that of cropped soil ladder terrace was significantly difference with correlation coefficient of 0.863 at vegetative stage and 0.928 at the full booting stage.

Keywords: agricultural land, conservation agriculture, improved terrace ladder, soil erosion

1. Introduction

Soil erosion is a major soil degradation threat in most vulnerable ecological systems especially in the fragile semi-arid environments (where there is less biomass to sustain soil structural integrity). It is a serious problem associated with land use (Morgan, 1996). Soil erosion by water is commonly recognized as one of main reasons of land degradation worldwide (Beskow et al., 2009). Most of the involved areas are occupied by various agricultural activities but pastures, forestry, unpaved roads as well as construction sites are also endangered by water erosion (Ananda & Herath, 2003).

Different types of soil erosion have been discussed in the literatures which include soil erosion by water, wind and animals (Morgan, 2005). Soil erosion by water is affected by different factors which include climate, vegetation, land topography and soil (Morgan, 2005).

The factors controlling soil erosion are the erosivity of the eroding agent, the erodibility of the soil, the slope of the land and the nature of the plant cover (Morgan, 2005). Soil erosion by water is of three forms which are sheet, rill and gully and they differ in magnitude. The one with high magnitude of erosion effect is gully and normally interfere with the field machinery operation (Wall et al., 2003).

Soil erosion has been an environmental concern in countries such as China and those bordering the Mediterranean Sea for millennia (Morgan, 2005). In the United States the major impetus to scientific research on soil erosion and conservation came from H. Bennett, who led the soil conservation movement in the 1920s and 1930s (Morgan, 2005). In South Africa Soil erosion is a major problem confronting land resources throughout. Previous research indicates that over 70% of the country's surface has been affected by varying intensities and types of soil erosion (Le Rouxa et al., 2007). Depends on the kind of causative of the destruction the soil erosion can be classified in two, that is site and offsite erosion (Eaton, 1996). As soil erosion refers to a loss in soil productivity due to physical loss of topsoil, reduction in rooting depth, removal of plant nutrient and loss of water (Lal, 2001) the loss of soil productivity is the main onsite effect and sedimentation and eutrophication of waterways and reservoirs are offsite effects (Alfsen et al., 1996).

Several models have been developed to predict the extent of water induced erosion (Brady & Weil, 2008). These models include WEPP (Laen et al., 1991), EUROSEM (Morgan et al., 1992), GUEST (Ciesiolka et al., 1995; Rose et al., 1997) and In this way, the conditions at the start of each rainstorm are predicted USLE (Wischmeier & Smith, 1978) and RUSLE (Renard et al., 1997). WEPP is an American model based on a continuous simulation approach in which changing soil moisture conditions are modelled from daily calculations of the soil water balance. The model of interest in this study is the USLE/RUSLE as it puts all factors into consideration. The model deals with: the interception of rainfall by the plant cover; the volume and kinetic energy of the rainfall reaching the ground surface as direct through fall and leaf drainage; the volume of streamflow; the volume of surface depression storage; the detachment of soil particles by raindrop impact and by runoff; sediment deposition; and the transport capacity of the runoff (Morgan et al., 1992).

The Universal Soil Loss Equation (USLE) and its revised version-RUSLE have been useful in predicting the average rate of soil loss due to water erosion from agricultural lands (Wischmeier & Smith, 1978; Renard et al., 1997). In the early 1990s the basic USLE was updated and computerized to create an erosion prediction tool called the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). Amongst the USLE factors above, the erodibility (K) factor reflects the ease with which the soil is detached by splash during rainfall and/or by surface flow especially on sloping areas (Angima et al., 2003).

Mechanical erosion control measures include bunding, bench terraces and trenching. Terracing involves collecting surface runoff water thus increasing infiltration and controlling water erosion. The technique has an ancient history and has been used to transform landscape to agro-systems in many hilly or mountainous regions of the world (Zuazo et al., 2005).

Dorren and Rey (2005) reviewed the effect of terracing on soil erosion. They found that terraces can considerably reduce soil loss due to water erosion if they are well planned, correctly constructed and properly maintained. Stone terraces have been successful in Same and Lushoto districts in Tanzania in conserving soil and water. The benefits of terraces are greater in steep slope areas, where soil erosion due to runoff down the slope is high due to low infiltration and high runoff. In Lushoto district the Soil and Water Conservation (SWC) technologies most adopted include vegetation strips adopted by 55% of farmers, followed by bench terraces adopted by 26% and "fanyajuu" terraces adopted by 15% of farmers (Tenge et al., 2004).

According to Reij (1991) people in the Uluguru Mountains in Tanzania are believed were documented to have developed indigenous ladder terraces technique. The need for conducting research on indigenous SWC technologies in Africa is important due to the fact that many projects have failed as a result of ignoring indigenous SWC knowledge and project intervention (Critchley et al., 1994). Evaluation of the efficiency of bench terraces, "fanyajuu" terraces and grass strips done by Tenge et al. (2005) in the western Usambara Mountains showed that all the three SWC measures were effective in retaining soil moisture and reducing soil loss. The literature suggests, however that bench terraces are more efficiently than "fanyajuu" terraces and grass strips. According to Lingale (2013) these kind technologies of SWC are also practised on the steep slopes of Uluguru Mountains.

In Tanzania, the problem of soil erosion is increasingly becoming evident as a result of agricultural activities. Like many other parts of Tanzania and the world in general, the communities living in the Uruguru Mountains specifically are vulnerable to soil erosion. The impact of erosion is reflected in food crop production decline and accumulation of sediments in the downstream areas. Soil and water conservation measures are needed to control soil erosion and sustain agricultural production on steep slopes of the mountainous areas for enhanced of food security (Tumbo et al., 2010). According to Jones (2004), Uluguru Mountains were well known to have the problem of soil erosion since 1940s. However, since the failed attempts to implement bench terraces in the early 1950s little research has been undertaken in the area in order to alleviate the problem of erosion. Furthermore the effectiveness of improved ladder terraces on the slope of Uluguru Mountains has not been assessed bearing in mind the fact that locally developed ladder terrace are commonly practiced in Mgeta division within the Uluguru Mountains range (Lyamuya et al., 1994), and hence the need of this study.

2. Method

2.1 Study Area

An experiment was conducted in Morogoro region, located 200 km south west of the capital city of Dar es Salaam to achieve study objectives. The experimental fields were located Ukami village (latitude 37°39′26″E, and longitude 6°51′5″S) at an altitude of 510 m above mean sea level.

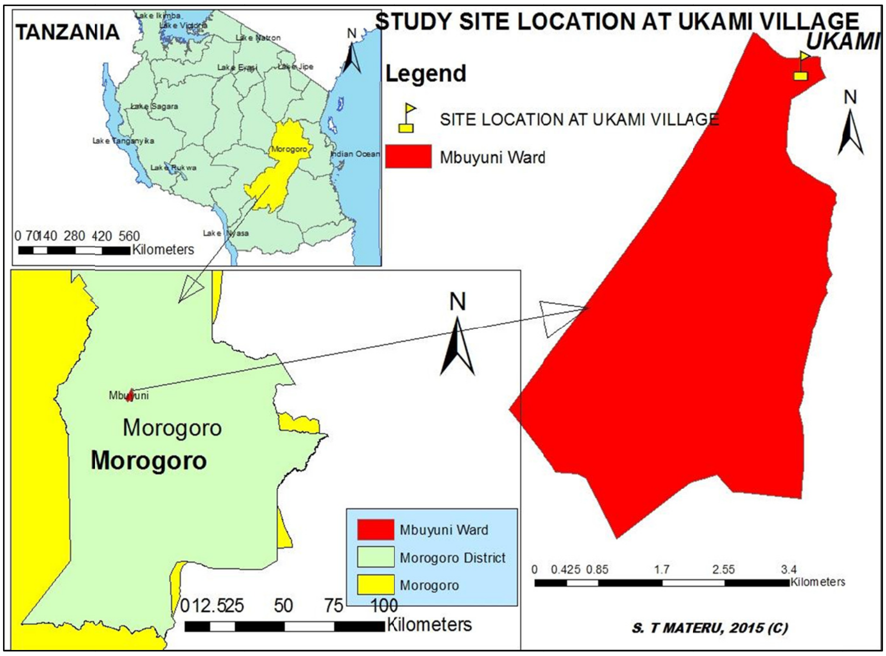


Figure 1. Map of Mbuyuni Ward showing the location of the study site (Ukami Village)

The climate of the Uluguru is very much influenced by the Indian Ocean from where wind laden with moisture blows on the eastern slopes. In general these slopes receive rainfall of 2000-4000 mm per year. The leeward (western) side of the mountains receives 890 mm to 2392 mm per year (Temple et al., 1972). The amount of rainfall increases and becomes more predictable with altitude (Lovett & Fjeldsa, 1995). Rainfall, in general, is bimodal with a dry season between May and late October, a short rainy season between October and the end of December and a long rainy season between March and May (Massawe, 1992).

2.2 Experimental Design

The preparations of the site started in early March, 2015. These included the general cleaning of the site and minor measurement of site boundaries. The layout of the experiment was a complete randomized block design (CRBD) with two treatments that was (i) Uncultivated bare soils and (ii) Cultivated cropped soils, in which each with three replications which make a total of six improved ladder terraces plots (Figure 2).

Uncultivated bare soils	Cultivated cropped soils	Uncultivated bare soils
Cultivated cropped soils	Uncultivated bare soils	Cultivated cropped soils

Figure 2. Experimental plots layout

Then after, installation of divisor system was followed for collection of runoff from the improved ladder terraces. Half of the terraces were left bare and half were with cropped maize. The bare and cropped terraces were arranged in triplicates with randomly located in the field plot. The centre terrace of each triplicate was used for data collection. All of the plots were left with no field boundaries but runoff from improved ladder terraces with reverse slope of about 1.5m width each were collected in tanks installed downstream of divisor system consisting of channels (Hudson, 1995).

The amount of rainfall was measured using standard rain gauge installed near the experimental site (RUHUNGO). The rain gauge was placed outside in the ground and each day rainfall was recorded in a notebook for analysis purposes. Runoff and soil data were collected and measured after every rainfall event. Run off volume was measured using a graduated wooden ruler. In order to have uniform mixture of water and soil particles of different size, the mixture in the collection tanks was stirred vigorously and one litre sample was scooped out. This sample was then filtered, dried at 105 °C for 24 hours and weighed for the calculation of the oven dried soil losses from the improved ladder terraces (Kingamkono et al., 2005).

Soil samples for texture were taken from different point of the field in order to insure the consistent of data. These samples were then taken to the laboratory for analysing textural class of the soil. Since soil structure affects soil resistance to erosion depending on the way it influences soil resistance to rain splash and water flow detachment and transport, resistance to dispersion by water, aggregate stability when wetted, porosity, proportion of micro pores, pore stability and continuity, water storage capacity and ability to transmit water through soil profile hence therefore it's very important to have the knowledge of the soil texture of the site.

The high erosivity of tropical rains is obviously an important factor responsible for widespread erosion. This is due to high detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff. Thus the erosivity of a rainstorm is a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops. To compute erosivity requires an analysis of the drop-size distributions of rain which basically varies with its intensity. The general relationships between kinetic energy and rainfall intensity, based on the work of Kinnell et al. (2002) and Brown and Foster (Salles et al., 2002) who obtained the following equation:

$$KE = 0.29233[1 - e - (0.0477I + 0.112)] \tag{1}$$

$$R = EI_{30} \tag{2}$$

Where, I_{30} is maximum 30 minutes rainfall storm intensity (mm h^{-1}) and E is the total storm energy (MJ/ha) given as

$$E = \Sigma(KE \times \Delta V) \tag{3}$$

Where, ΔV is the rainfall depth.

The predicted soil loss (A) is estimated using the following equation:

$$A = RKLSCP \tag{4}$$

Where, R = rainfall erosivity; K = soil erodibility index; L = slope length factor; S = slope gradient or steepness factor; C = cover and management factor which is the function of the cover crop development stages and P = erosion control practice factor/conservation practice factors. When all the unit plot conditions are met L, S, and P factors values in the RUSLE are equal to unity and soil erodibility index is calculated as follows,

$$K = \frac{A}{EI_{30}} \tag{5}$$

Where, A is soil loss and K is the soil erodibility index.

2.3 Data analysis

All statistical analyses were conducted using SAS (SAS, 1990). The data were analysed using Tukey-Kramer test for comparing pair wise differences of means (Somerville, 1993).

3. Results

3.1 Rainfall

The total amount of rainfall recorded at the experimental site during the study period (late March to May) was 533mm.The highest rainfall amount recorded was 50mm and mean rainfall during that period was 19 mm (Figure 3).

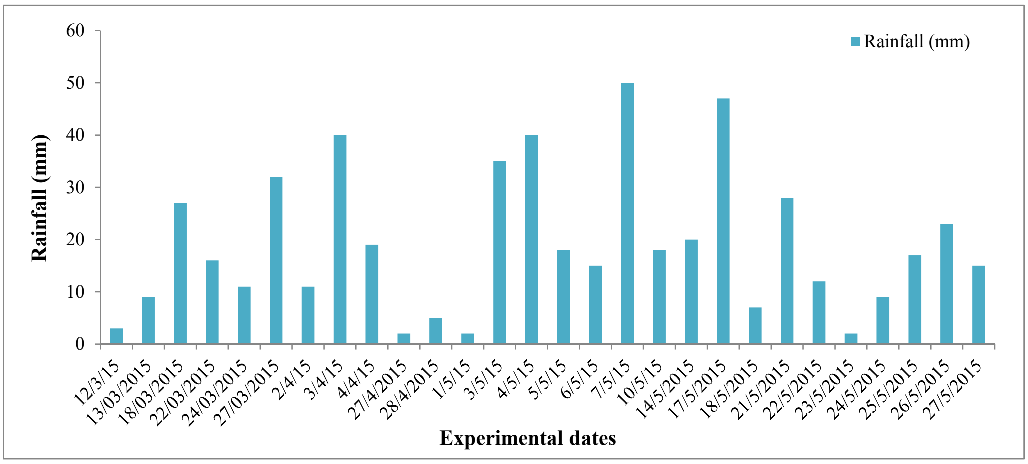


Figure 3. Daily rainfall events on respective dates during the experimental period

3.2 Soil Textural Class of the Site

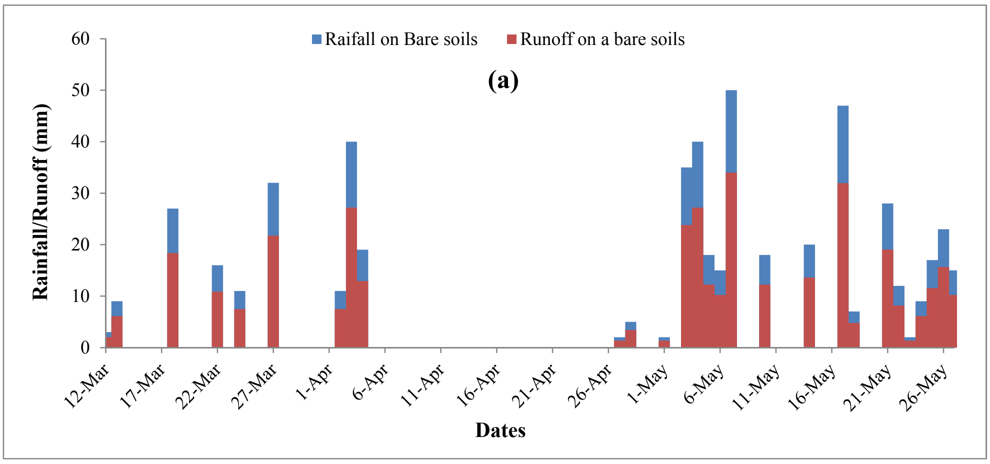
The soil samples were taken at different horizon within the experimental site (Table 1). After analysing soil sample in the laboratory, the results appear that average percentage weight for sand, silt and clay were 40, 10 and 50 respectively. From the soil triangle the class of soil was indicated as clay soil.

Table1. Physical properties of the soils in the site

Soil Profiles Depth (m)	Particle Size Analysis			
	% Sand	% Silt	% Clay	Textural class
0–0.15	48.24	5.64	46.12	Sandy clay
0.15–0.3	44.24	5.64	50.12	Clay
0.3–0.45	44.24	5.64	50.12	Clay
0.45–0.6	20.24	27.64	52.12	Clay

3.3 Runoff

Runoff from bare soils was significantly different ($p < 0.05$) from that of cropped soils. Infiltration rate on the cropped soil were significantly high compared to the bare soils (Figure 4). It was observed that at the beginning of the season the difference was statistically not significant but in the mid and end of the rain season the amount of runoff on bare soils was higher by 15% to 18% compared to that of cropped soils (Figure 4). Also the bare soils were somewhat compacted compared to cropped soils.



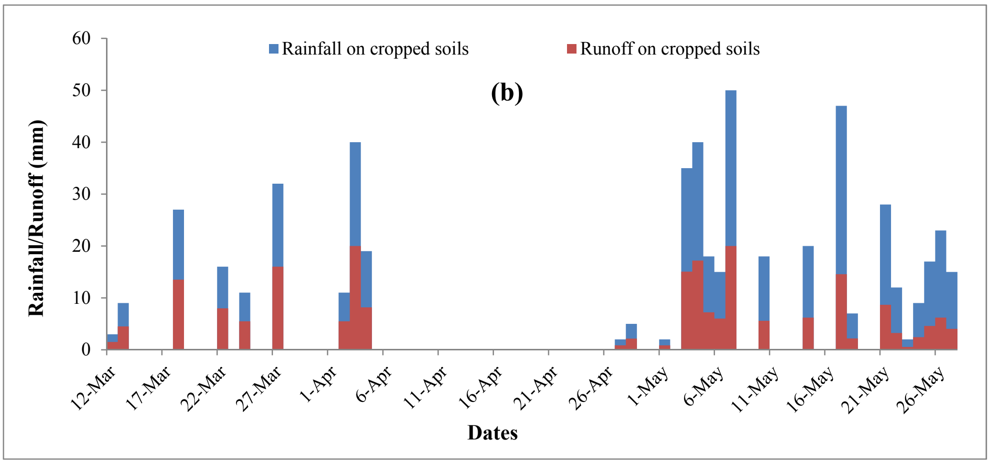


Figure 4. The relationship between rainfall and runoff for (a) bare soils and (b) cropped soils on the ladder terrace cropping systems

Amount of cropped soils loss from the field was not proportional to the runoff water that resulted from the rain because the impact of the rain drops and its intensity to the soil was not directly since the soil was covered with crops canopy. Progressively as the crop season continue the crop canopy cover become very high and that hinder direct impact of rain drop to the soil, hence less soil loss. It was found that the behavior of cropped soil loss were not proportional to the runoff with poor r^2 of 0.3561 (Figure 5). While the bare areas where soil, losses were directly proportional to the runoff water with r^2 of 0.8495. This indicates that the more runoff flow the soils were removed away from its original position to the downstream of the slope (Figure 6).

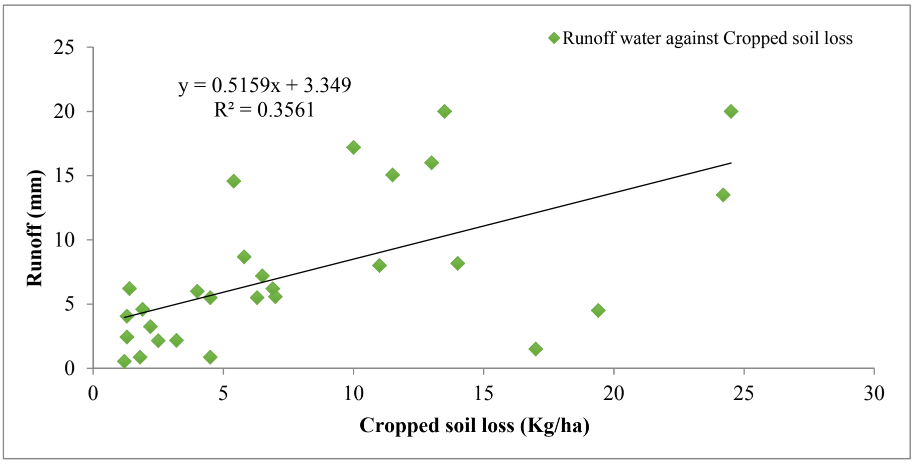


Figure 5. Soil losses on the cropped soils of ladder terrace system due to runoff water

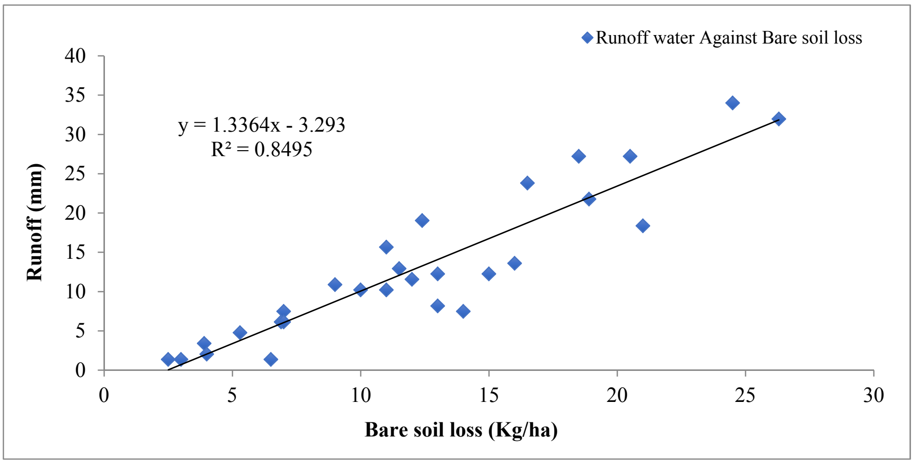


Figure 6. Soil losses on the bare soils of ladder terrace system due to runoff water

3.4 Soil Loss

The amount of soil losses recorded during the research period were 340.2 kg/ha for bare soil on improved ladder terrace system and 225.8 kg/ha for maize cropped soil on improved ladder terrace system. It was observed that before the seed germination in the beginning of the rain season, the cultivated cropped soils had high soil loss compared to the uncultivated bare soil (Figures 5, 6 and 7) due to the fact that the disturbed soils are easily moved by water with absence of cover crops compared to undisturbed soils. At the mid of vegetative stage the canopy cover shaded larger area of the plot hence amount of soil loss in the cultivated cropped soils were dramatically decreases regardless of the rain intensity (Figure 5). Soil loss in an uncultivated bare soil varies with the rain intensity from the beginning to the end of rain season (Figures 6 and 7).

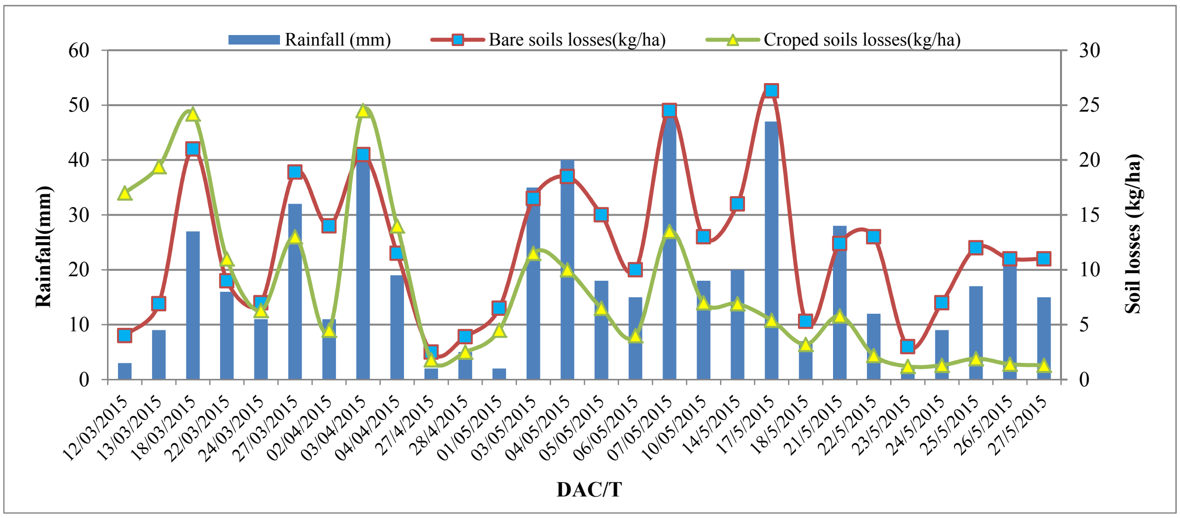


Figure 7. Amount of rainfall with the corresponding soil losses in both bare and cropped soils on ladder terraces cropping system (DAC/T is the Days after Cultivation/Tillage)

The analysis shows that the soil losses from third of May onwards between the bare and cropped soils were significant different at 5% the level (Figure 7). The amounts of soil losses from the bare soil affect significantly the crop growth and yield because of the nutrients removal that takes place continuous during the season. Crop nutrients such as Nitrogen (N), Phosphorus (P) and Potassium (K) are normal available on the top soil profile (0 to 20 cm).

On a monthly basis also soil losses in the categories were compared and the result show that bare soils had rapid increases in May compared to the cropped soils. This confirms the contribution of the canopy cover of the crop on reducing the splash event from rain by leaves intersection (Figure 8). For the month of May only, the amount of soil loss on cropped soil was only 40% of the soil loss on bare soils on the same month indicating that the more canopy cover prevent direct rain drop to the soil the less soil loss. In the beginning of the rain season the cropped soils somewhat show high soil loss compare to bare soil (which was not cultivated) because of the fact that the tillage process makes soil particle to be free and hence vulnerable to be swept by runoff water (Figure 8). Farmers need to ensure availability of cover crops on the field to avoid excessive water erosion that may negatively affect the future production.

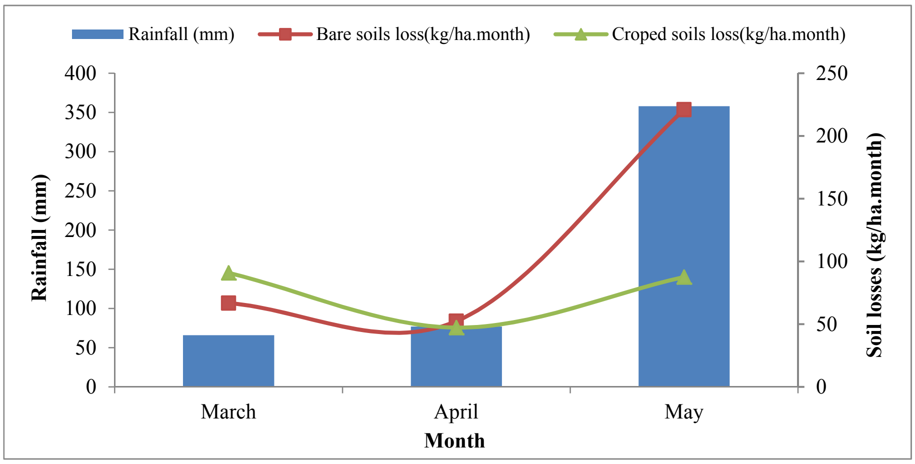


Figure 8. Monthly soil loss trend on bare and cropped soil on the ladder terraces system

Positive correlation was observed between bare soil loss and cropped soil loss under ladder terrace management system at the vegetative and full booting stage (Table 2). At the beginning of the season, cropped soil ladder terrace shows very high soil erodibility (K) compare to bare soil ladder terraces (Table 2). This was because of the tilling that had to take place for preparation of the seedbed before the maize seeds were planted in the field. After germination had taken place from 24 of March 2015, it can be observed that soil erodibility had somewhat reduced on the cropped soils. On the vegetative stage that was from 27th March 2015, bare soil loss and its erodibility were very high than that of the cropped soil (Table 2). This was because of the canopy cove increase on the cropped soils. Total cumulative soil loss for bare and cropped soils are 340.2 kg/ha and 225.8 kg/ha respectively under ladder terrace system. At the end of the season, bare soil loss was 34% higher than that of cropped soil (Table 2).

Table 2. Correlation between bare soil loss and cropped soil loss for different maize growth development stages

Growth stages	Soil Losses (n = 27)		Correlation coefficient
	Bare Soils Loss(kg/ha)	Cropped soils Loss (kg/ha)	
Early stage	51.9	60.6	0.082 NS
Vegetative stage	251.3	155.9	0.863*
Full booting stage	57	9.3	0.928*

Note. *: Significant at 5% level; NS: Not Significant.

4. Conclutions and Recommendations

4.1 Conclusions

High rates of soil loss have major impact on agriculture through decrease in yield as a result of impoverished soil with sustainable production at stake. Despite a number of soil erosion studies conducted in Tanzania, only a handful have dealt with erosion vis-a-vis mechanical control methods of erosion. There is scanty information on studies done to assess the effect of soil erosion under long-term variable management. The current study attempted to redress the shortfall. It is anticipated that, erosion results from this study coupled with more studies of similar nature would be useful in the assessment of erosion hazards.

The following tentative conclusions can be drawn as a result of the present study:

- It is difficult to assess the effectiveness of mechanical control methods (such as terraces) in controlling soil erosion and getting good results if the ground slope is not uniform. This is due to the fact that the dimensions of erosion control method (terrace) will also not be uniform.
- Results from this study indicate very low mean difference between bare and cropped improved ladder terraces (terrace with reverse slope) as an outcome of high interception of runoff, shortening of slope length, slowing down runoff flow velocity and improving infiltration.

4.2 Recommendations

Mechanical measures alone cannot prevent the detachment of soil particles; their main role is in supplementing agronomic measures in controlling the flow of any excess water and wind that may arise. Unless the soils are deep, terrace construction exposes the less fertile subsoil and may therefore result in lower crop yields. Technically suitability of a mechanical soil erosion control technique is largely determined by slope steepness of the area and targeted allowable or tolerable soil losses, hence, their significance in controlling soil erosion on steep slope should be studied from time to time to monitor their feasibility and applicability on the field level. Further research is required on the relationship between erosion and productivity in an attempt to incorporate the soil moisture conservation techniques with the existing terrace technique as well as developing predictive equations that should be able to predict yield levels without necessarily undertaking runoff studies which are time consuming and expensive.

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