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Effects of selected soil and water conservation technologies on nutrient losses and maize yields in the central highlands of Kenya

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ABSTRACT

Mitigating nutrient loss is a prerequisite of sustainable agriculture in the tropics. We evaluated three soil and water conservation technologies (mulching, minimum tillage and tied ridging) for two cropping seasons (long rains 2011, short rains 2011) at two sites in the central highlands of Kenya. The objectives were: to determine effects of the technologies on runoff, sediment yield and nutrient loads in sediment, and to assess influence of the technologies on maize yields. Experimental design was a randomized complete block with 3 treatments replicated thrice. At the beginning of experiment, soil was sampled at 0–15 cm depth and analyzed for pH, N, P, K, C, Ca and Mg. Mulch was applied at a rate of 5 t ha^{-1}. Runoff was sampled, sediments extracted by drying in oven at 105 °C, and analyzed for NPK and C loads. Data were subjected to analysis of variance using SAS 9.1.3 and means separated using Fishers' LSD at 5% level of significance. Results showed reduced nutrient losses with the technologies. In Meru South, sediment yield was reduced by 41 and 7% during long rains 2011 (p = 0.03), and by 71 and 68% during short rains 2011 (p = 0.01) under mulching and minimum tillage, respectively. Runoff and maize yields were positively influenced by mulching. In Mbeere South, sediment yield was lower under soil and water conservation technologies. Runoff was reduced by 52 and 49% during long rains 2011 and by 51 and 30% during short rains 2011 under tied ridging and mulching respectively, compared with control. Total crop failure occurred during long rains 2011 due to erratic rains. During short rains 2011 tied ridging and mulching increased maize yield by 94 and 75%, respectively, compared with control. This study highlights the importance of analyzing soil and water conservation technologies within rain-fed farming systems perspective in response to declining food production and supports a focus on tied ridging and mulching.
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1. Introduction

Nutrient management is a key challenge for global food production (Powlson et al., 2011). Per capita food availability in Sub-Saharan Africa (SSA) has decreased over time leading to wide spread food insecurity (Beintema and Stads, 2006). Over 80% of agriculture in SSA is rain-fed with the bulk under smallholder farming (Rockström, 2000). Small-scale farmers are faced with challenges of increasing population pressure, food insecurity, very low levels of agricultural productivity and rapid natural resource degradation associated with nutrient depletion through soil erosion and excessive runoff (Rockström, 2000). Majority of the small-holder farmers in the central highlands of Kenya depend on rain-fed agriculture (Mugwe et al., 2009). Maize productivity in the area has declined in the recent past leading to poor crop yields (Mucheru-Muna et al., 2007). The decline is attributed to inadequate use of external inputs, poor agricultural water management, degraded soil quality and erratic rainfall. Therefore, the challenge of solving the problem of food insecurity in the area involves addressing soil nutrient and water depletion in the region.

Erosion by water is the primary cause of soil quality degradation in the central highlands of Kenya (Okoba and Sterk, 2006). Negative impact of erosion on topsoil depth, soil organic carbon content, nutrient status, soil texture and structure, available water holding capacity and water transmission characteristics was long recognized by Lal (1997). Sanchez and Jama (2002) identify soil fertility depletion resulting from soil erosion as the fundamental biophysical cause for declining per capita food production on smallholder farms. Further to erosion, there are risks related to rainfall variability in the study area (Schreck and Semazzi, 2004). Extreme rainfall variability characterized by high rainfall intensities, few rain events, and poor spatial and temporal distribution

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have a direct impact on soil productivity especially nutrient levels, runoff and soil water holding capacity (Brouder and Volenec, 2008). These impacts have the potential to severely affect people's livelihoods, particularly, due to dependency on rain-fed agriculture and limitations of technological capabilities (Osman-Elasha, 2007).

Apart from soil nutrient loss, water deficit is a significant factor that hinders crop productivity (Bossio et al., 2010). Increased soil moisture availability through reduced runoff and soil loss is hence important (Ngigi et al., 2006). Water scarcity is more pronounced in semi arid regions of Sub Saharan Africa where agriculture is rainfed and faces threat from frequent dry spells and droughts (Rockström, 2000). Mbeere south sub-county is such an area. There is therefore an urgent need to increase nutrient and water availability to crops grown by smallholder farmers in developing countries. According to Bossio et al. (2010), soil erosion, nutrient depletion and other forms of land degradation reduce water productivity, nutrient use efficiency and hence agricultural productivity. Stroosnijder (2009) emphasizes that plant production suffers because water is not available due to deteriorated physical properties of soil.

In order to overcome biophysical constraints causing low yields in rain-fed farming systems in the central highlands of Kenya, there is need for appropriate soil and water management technologies. Mulching, tied ridging and minimum tillage technologies have been used in different parts of the world (Araya and Stroosnijder, 2010). In the study area, studies by Mugendi et al. (2006), Okoba and Sterk (2006), Mucheru-Muna et al. (2007), Mugwe et al. (2009) and Shisanya et al. (2009) have focused on integrated soil fertility management. However, little attention has been given to the potential of soil and water conservation technologies in combating soil degradation and enhancing agricultural water management. Soil erosion and runoff have been approached from environmental perspective and off site effects rather than plot scale. For these practices to be recommended to smallholders in the area, they have to be tested. In this paper, we report on a study investigating the potential of mulching, tied ridging and minimum tillage on combating runoff, soil and nutrient loss, and increasing maize yields.

2. Materials and methods

2.1. Experimental site description

This study was conducted in Meru South sub-county, Tharaka-Nithi County and Mbeere South sub-county, Embu County (Fig. 1). The two sites in the Central Highlands of Kenya have contrasting soil fertility and highly variable rainfall patterns (Mucheru-Muna et al., 2010). In Meru South, experimental site was Kigogo primary school (00°23′ S, 37°38′ E) while the site in Mbeere South was Machang'a secondary school (00°47′26.8″ S; 37°39′45.3″ E). Kigogo lies in Upper Midland Agro-ecological Zones 2 and 3 (Jaetzold et al., 2007) on eastern slopes of Mount Kenya at an altitude of 1500 m above sea level (a.s.l.). It is majorly a maize growing zone with smallholdings of 1.2 ha per household on average. Population pressure (569 inhabitants km^{-2}) pushed people to marginal areas (Mucheru-Muna et al., 2010) such as Mbeere South. Agriculture is characterized by smallholder mixed farming activities comprising of cash crops, food crops, trees and livestock (Shisanya et al., 2009). Kigogo was representative of high potential areas while Machang'a represented low potential areas of the central highlands of Kenya. Machang'a is situated in Lower Midland Agro-ecological Zones 3, 4 and 5 and Inner Lowland 5 on the eastern slopes of Mount Kenya at an altitude between 700 and 1200 m a.s.l (Jaetzold et al., 2007). Cropping systems are maize-based with beans as the preferred legume intercrop although cowpea, groundnut and green grams are gaining importance. Rapid population growth has resulted in expansion into fragile area and low-potential lands being taken under cultivation, reduced fallow periods and systematic degradation (Mucheru-Muna et al., 2010).

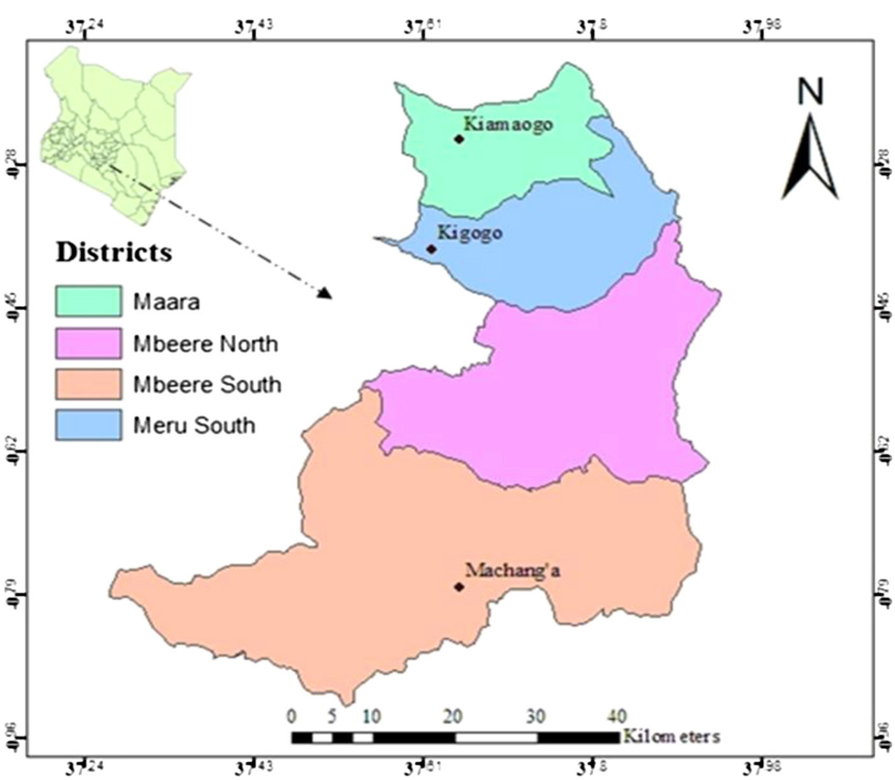

Fig. 1. Map of the study area.

Table 1
Soil chemical properties at Kigogo and Machang'a experimental sites.

Parameter	Kigogo	Machang'a
pH	4.93	5.68
Exchangeable Ca (cmol/kg)	4.73	2.13
Exchangeable Mg (cmol/kg)	1.73	0.75
Exchangeable K (cmol/kg)	0.48	0.37
Organic C (g/kg)	15.22	4.03
Total N (g/kg)	2.00	0.58
Total P (g/kg)	0.13	0.05

2.2. Site description and measurement

2.2.1. Soils

The soils of Kigogo are humic Nitisols; a typical deep weathered soil with moderate to high inherent fertility (Jaetzold et al., 2007). On the contrary, soils of Machang'a are mostly plinthic Cambisols (FAO and UNESCO, 1998). These are brown young soils with cambic B horizons as a major feature. Cambisols are less weathered than most soils of the humid tropics. The soils are poor hence require intensive fertilization (Jaetzold et al., 2007). Selected soil properties are presented in Table 1. Soil sampling was carried out before start of relay cropping in order to determine baseline status of the soil.

2.2.2. Climate

Daily rainfall and temperatures were obtained from a tipping-bucket rain gauge with 0.2 mm resolution and built-in data logger installed at the sites at a distance of about 12 m from experimental plots (Plate 1).

Total rainfall and its distribution showed large differences among seasons (Fig. 2) and sites. Long rains define the rainy/cropping season that occurs from March to June while short rains fall from October to December. The 2011 refers to the experimental year. Cumulative rainfall at Kigogo for the experimental period was 1451 mm, whereby 541 mm was received during long rains 2011 and 910 mm received during short rains 2011. In Machang'a, cumulative rainfall was 516 mm with 157 mm received during long rains and 359 mm received during short rains 2011 respectively. There were intra-seasonal dry-spells of various degrees during the cropping seasons. Reference evapotranspiration (ETo) was calculated from FAO Penman–Monteith equation (Allen et al., 1998). The ETo in Kigogo ranged between 1.8 and 4.7 mm d^{-1} during long rains 2011 and between 2.6 and 6 mm d^{-1} during short rains. In Machang'a, ETo was between 4.1 and 7.4 mm d^{-1} during long rains 2011 and 3.2–6.9 mm d^{-1} during short rains 2011.

2.3. Runoff plots

Field plots were positioned on varying slopes between 4 and 5% in Machang'a and 9.5–12% in Kigogo. Runoff plots of same lengths were constructed: 3 m × 12 m (36 m^2) on a larger plot (20 m × 76 m) and bounded on three (top and sides) sides with a galvanized metal sheet buried at least 25 cm in the ground. At the bottom end of the plot, a gutter designed to slope towards one end of the drainage tube was installed to collect and convey runoff into a 200 L storage tank. Given the limited storage capacity, the tank was modified to collect excess runoff. The storage tanks were perforated using 8.43 mm (3/8″) drill bits at intervals of 2.25 cm apart and a constant height from the bottom in order give a uniform maximum water height. One hole was fitted with hose pipe that drained to a smaller (20 L) container (Plate 1). The tanks were calibrated following dynamic calibration procedure described by Okoba and Sterk (2006). Runoff coefficient (Rc) refers to the portion of rainfall lost as runoff and was expressed in percent (%).

$$Rc\,\% = \frac{\text{Runoff (mm)}}{\text{Runoff (mm)}} \times 100$$

where Rc is runoff coefficient, runoff (mm) is runoff generated during a rainfall event and rainfall (mm) is total rainfall received in a given rainfall event. Small Rc value means little runoff and therefore is more desirable in terms of agricultural water management.Experimental design with treatments

The experiments adopted a randomized complete block design (RCBD) with four treatments replicated thrice giving a total of twelve plots per site. The technologies were implemented in runoff plots. Maize (*Zea mays* L.) was the test crop. Weeding was done twice using a hand hoe. The experiment consisted of mulching, tied ridging and minimum tillage. The fourth treatment, conventional tillage, was the control, representing farmers in lower cadre of resource endowment. Mulching and control were implemented in both sites. In contrast to minimum tillage in Kigogo, tied ridging was tested in Machang'a. Planting was done two days after onset of rains in Machang'a while in Kigogo dry planting was done. Dry maize stover was used for mulching at a rate of 5 t ha^{-1}. For tied ridging technology, ridges were constructed at the beginning of the first cropping season and damages repaired accordingly for the following season. Distance between ties alternated at 0.50 m, 1.5 m and 1.0 m while the height of ridges was 0.15 m.

2.4. Runoff, sediment and nutrient load measurement

Runoff volume was determined by multiplying the height of water in the storage tank by the base area of the tank. Runoff

a) b)

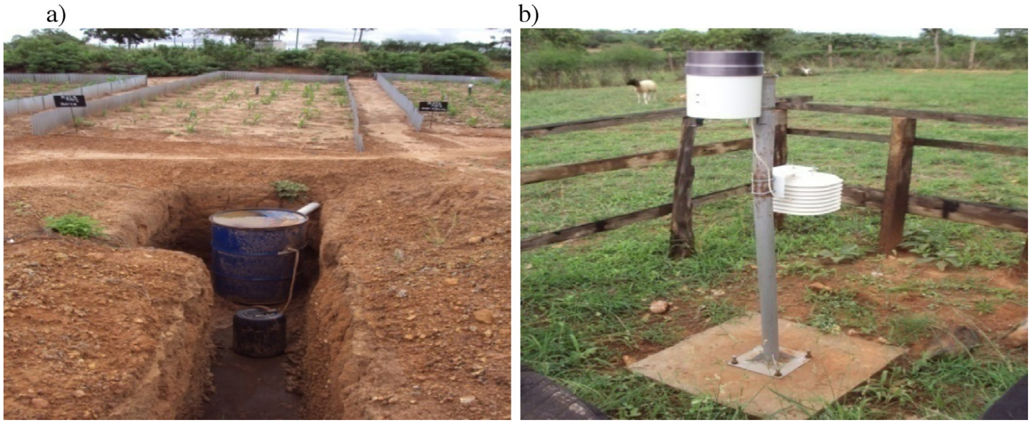

Plate 1. Runoff plot and collection tank (a) and an automatic rain gauge (b).

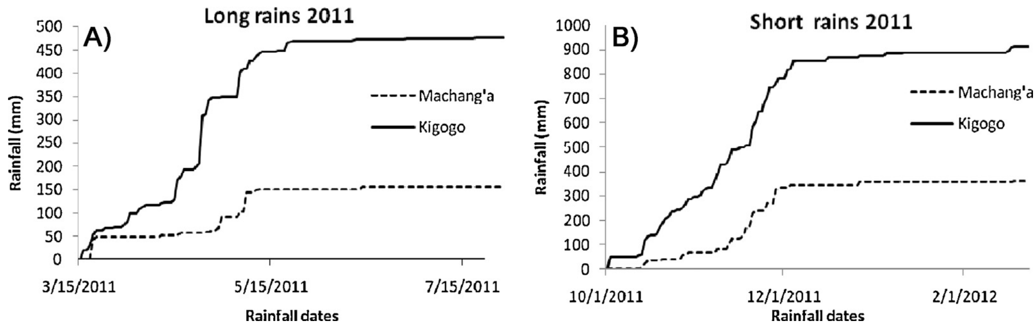

Fig. 2. Cumulative rainfall at Kigogo and Machang'a experimental stations during long rains 2011 (a) and short rains 2011 (b) seasons.

was then sampled in runoff bottles for sediment determination. At the laboratory, runoff samples were placed in aluminium metal bowls. After thoroughly shaking and mixing, the suspension was poured into bowls and oven dried at a temperature of 105 °C. All information on labels, volume of suspension in the runoff bottles, can weight, weight of can + soil (after oven drying) was carefully recorded. Sediment yield was calculated using total volume of suspension in the major drum. Sediment yield gave an estimate of total soil loss from each runoff plot. Sediments extracted from runoff were analyzed to determine load of N, P, K and organic carbon using standard methods described by Ryan et al. (2001). Ammonium (NH_4^+) Nitrogen was analyzed by Kjeldahl method, available phosphorus by Olsen method, available Potassium by flame photometer and total Organic carbon by Walkley and Black method.

2.5. Crop management and crop parameters

In Kigogo, maize variety Hybrid 513 was planted at a spacing of 0.75 and 0.5 m inter- and intra-row, respectively, with two seeds per hill (53,333 plants ha^{-1}). In Machang'a, maize variety DH04 was planted at a spacing of 0.9 and 0.6 m inter and intra-row, respectively, with two seeds per hill (37,037 plants ha^{-1}). Fertilizers Triple Super Phosphate (TSP) and Nitrogen Phosphorus and Potassium (NPK) was spot applied at planting to supply 90 kg ha^{-1} P and 60 kg ha^{-1} N. Top dressing was done with calcium ammonium nitrate (CAN) at a rate of 60 kg ha^{-1} N four weeks after germination. Dates of emergence, heading and maturity were recorded. Yield parameters used for evaluating effectiveness of the technologies were dry grain weight at 13.5% moisture content.

2.6. Data analysis

ANOVA was used to compare effects of the technologies on runoff, sediment and nutrient loss, and grain yield performance with the help of SAS 9.1.3. (SAS Institute Inc., 2004). Mean separation was done using Fisher's LSD at 5% level of significance.

3. Results

3.1. Runoff and sediment yield

In Kigogo, compared with control, mulching reduced runoff by 26% ($p = 0.04$) while minimum tillage increased runoff by 17% during short rains 2011 season. In Machang'a, runoff was reduced by 52 and 49% during long rains 2011, and by 51 and 30% during short rains 2011 under tied ridging and mulching respectively, compared with control.

In Kigogo, sediment yield was reduced by 41 and 7% during long rains 2011 ($p = 0.03$), and by 71 and 68% during short rains 2011 ($p = 0.01$) under mulching and minimum tillage respectively, compared with control (Table 2). In Machang'a mulching and tied ridging reduced sediment yields by 78 and 71% during long rains 2011 ($p = 0.01$) and by 53 and 64% during short rains 2011 ($p = 0.02$) respectively, compared with control. From the results, sediment yield was generally lower under the soil and water conservation treatments than the control except for minimum tillage during long rains season (Table 3).

3.2. Nutrient load

In Kigogo, N load was reduced by 29 and 18% during long rains 2011 and by 61 and 46% during short rains 2011 under mulching and minimum tillage, respectively, compared with control. Potassium load was reduced by 56 and 44% during short rains 2011 season under mulching and minimum tillage respectively, compared with control ($p = 0.02$). Organic carbon load was reduced by 54 and 46% during long rains 2011 and by 54 and 39% during short rains 2011 under mulching and minimum tillage respectively, compared with control.

In Machang'a, Potassium load was reduced by 53 and 47% during long rains 2011 and by 33 and 54% during short rains 2011 season under mulching and tied ridging, respectively, compared with control. Organic carbon load was reduced by 54 and 50% under mulching and tied ridging respectively, during long rains 2011 season. Mulching reduced organic carbon load by 58% compared with control during short rains 2011. Sediment under tied ridging was insufficient for analysis of organic carbon during short rains 2011. Nutrient loss was directly proportional to soil loss. Low nutrient loads were therefore recorded where there was low runoff and low sediments.

Table 2
Runoff coefficients and sediment yield in Kigogo and Machang'a during the experimental period.

Treatment	Kigogo		Machang'a	
	LR11	SR11	LR11	SR11
Runoff coefficient in %				
CT	2.7[ba]	2.3[ba]	14.9[a]	10.5[a]
MC	2.2[b]	1.7[b]	7.6[b]	7.4[b]
MT	3.4[a]	2.7[a]	–	–
TR	–	–	7.2[b]	5.1[c]
p	0.09	0.04	0.001	0.001
LSD	0.9	0.8	4.5	1.9
Sediment in kg ha^{-1} $season^{-1}$				
CT	452[a]	1020[a]	959[a]	500[a]
MC	267[b]	292[b]	209[b]	234[b]
MT	482[a]	323[b]	–	–
TR	–	–	278[b]	179[b]
p	0.03	0.01	0.01	0.02
LSD	128	333	384	176

CT, conventional tillage; MC, mulching; MT, minimum tillage; TR, tied ridging. Same superscript letters in the same column denote no significant difference between the treatments.

Table 3
Nutrient and organic carbon load in the sediment. in kg ha^{-1} at Kigogo and Machang'a during LR11 and SR11 seasons.

Nutrient and organic carbon loads in kg ha^{-1}								
	Long rains 2011 season				Short rains 2011 season			
Nutrient	N	P	K	Organic_C	N	P	K	Organic_C
Treatment				Kigogo				
CT	1.7[a]	8.0[a]	3.7[b]	195.2[a]	17.8[a]	9.6[a]	53.9[a]	175.1[a]
MC	1.2[b]	7.2[a]	5.2[a]	90.5[d]	7.0[c]	7.6[a]	24.3[b]	80.2[d]
MT	1.4[a]	6.7[a]	4.9[ba]	111.8[c]	9.7[cb]	7.8[a]	30.1[b]	106.1[c]
p	0.02	0.5	0.14	<0.01	<0.01	0.23	0.02	<0.01
LSD	0. 4	2.2	1.5	27.9	2.8	3.1	17.0	10.0
				Machang'a				
CT	0.7[a]	12.2[a]	6.2[a]	25.0[a]	0.2[a]	9.7[a]	3.9[a]	25.9[a]
MC	0.3[a]	5.6[b]	2.9[c]	11.6[d]	0.1[a]	7.5[a]	2.6[bc]	11.0[b]
TR	0.3[a]	11.6[a]	3.3[c]	12.5[c]	0.0[a]	9.4[a]	1.8[c]	–
p	0.3	0.11	<0.01	<0.01	0.45	0.70	0.01	<0.01
LSD	0.6	5.8	1.1	10.0	0.3	4.8	1.1	10

CT, conventional tillage; MC, mulching; MT, minimum tillage; TR, tied ridging. N = ammonium nitrogen (NH_4^+N); P = available phosphorus; K = available potassium; organic C = total organic carbon. Superscript letters in the same column denote no significant difference between the treatments.

Table 4
Maize grain yield (Mg ha^{-1}) under different technologies during 2011 long rains and 2011 short rains at Kigogo and Machang'a.

Grain yield Mg ha^{-1}				
Treatment	Kigogo		Machang'a	
	LR11	SR11	LR11	SR11
CT	5.8[b]	2.5[a]	0.0	1.6[b]
MC	6.1[b]	2.6[a]	0.0	2.8[a]
MT	6.2[b]	2.3[a]	–	–
TR	–	–	0.0	3.1[a]
p	0.001	0.5	0.0	0.003
LSD	0.7	0.7	0.0	0.8

CT, conventional tillage; MC, mulching; MT, minimum tillage; TR, tied ridging). Same superscript letters in the same column denote no significant difference between the treatments.

3.3. Maize yield

At Kigogo, maize yield was increased by 7 and 5% under minimum tillage and mulching respectively, during long rains 2011, compared with control. During short rains 2011, maize grain yields were in the descending order of mulching, conventional tillage and minimum tillage. The differences were, however, not significant ($p = 0.50$) (Table 4).

In the lower potential area, Machang'a, total crop failure occurred during long rains 2011 season. Maize development was adversely affected by erratic rains at planting which led to poor germination, sudden cessation of rains at the critical flowering stage and subsequent severe meteorological drought stress (Fig. 2). During short rains 2011 tied ridging and mulching increased maize grain yields by 94 and 75% respectively, compared with control.

4. Discussion

Reduced runoff, sediment and nutrient loss means an improvement in the soil water status and a reduction in soil loss, which in turn leads to reduced land degradation and increased crop water (Temesgen et al., 2009). High runoff, sediment and nutrient loss under control treatment might be attributed to the beating action of rain drops which causes breakdown of aggregates and clay dispersion (McHugh et al., 2007). These subsequently lead to soil surface sealing with decreased infiltration. Research has demonstrated that soil and water conservation technologies are effective in reducing nutrient load in runoff thereby improving soil fertility and crop yields (Naudin et al., 2010). Effectiveness and efficacy of mulching in managing runoff, sediment and nutrient loss arises from protection provided against rain-splash. Wang et al. (2009) attributes the effectiveness of soil surface mulching to slowed soil erosion. Cairns et al. (2012) attributes reduced runoff under mulching to the improved infiltration capacity and soil transmission characteristics. According to Uwah and Iwo (2011), mulch provides a better soil environment, increases soil porosity and water infiltration rate during intensive rain. These results corroborates findings of Liu et al. (2012) who reported significant decrease in sediment yield under straw mulch treatment by 18–22% compared with control. Babalola et al. (2007) reported best performance with vetiver grass mulch over control in reducing soil, water and nutrient losses in Nigeria. Good maize yields under mulching can be associated with high soil moisture under mulching which enhances efficient use of fertilizer while the excellent regulated solar radiation during the growth seasons encourages higher photosynthetic rates which culminate in greater yields. Bhatt et al. (2006) and Khurshid et al. (2006) highlighted that mulching with crop residue at a rate of 4–6 t ha^{-1} helps to maintain good grain yield.

High runoff and sediment yield under minimum tillage could be attributed to the firm soil surface limiting infiltration of water into the soil at the initial stage of the experiment. This is consistent with the findings of Liu et al. (2011) who observed that runoff and sediment yields were 0.2% and 56.1% higher under minimum tillage compared with control. Reduced soil organic carbon load under minimum tillage could be attributed to absence of the physical action of tillage which incorporates residue into the soil and often causes increased decomposition of previously stable soil organic matter. Puustinen et al. (2005) indicated reduction of losses in soil and organic carbon through runoff in conservation tillage practices. Initial performance of minimum tillage might be insignificant. For instance, Das and Bauer (2012) indicated that annual predicted maize yields from conventional cropping were higher than that from minimum tillage in initial years. However, yield under conventional cropping declined gradually due to diminishing soil fertility caused by the loss of soil nutrients and organic matter over time. Runoff and sediment loss was higher in Machanga than in Kigogo. This was partly attributed to the nature of soils in the two sites. Cambisols of Machang'a have low water holding capacity while nitisols of Kigogo have the ability to hold water hence reducing runoff.

Reduced runoff, sediment and nutrient losses by tied ridging could be attributed to impoundment and increased infiltration, water harvesting effect of bunds under tied ridging technology, and improved soil physical properties (McHugh et al., 2007). The findings are in agreement with that of Araya and Stroosnijder (2010)

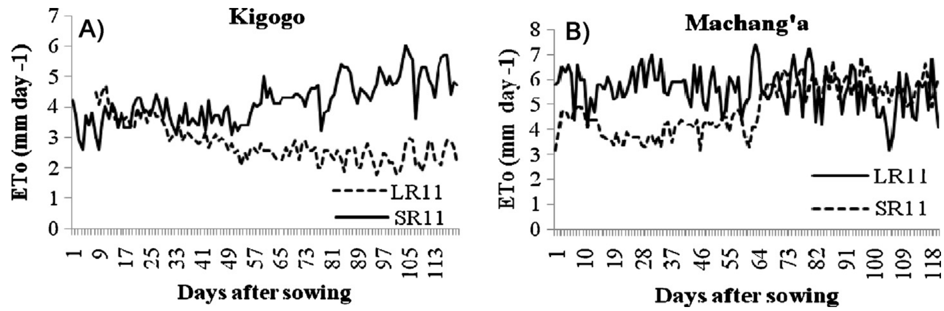

Fig. 3. Daily evapotratranspiration rates at Kigogo (a) and Machang'a (b) during long rains 2011 (LR11) and short rains 2011 (SR11) seasons.

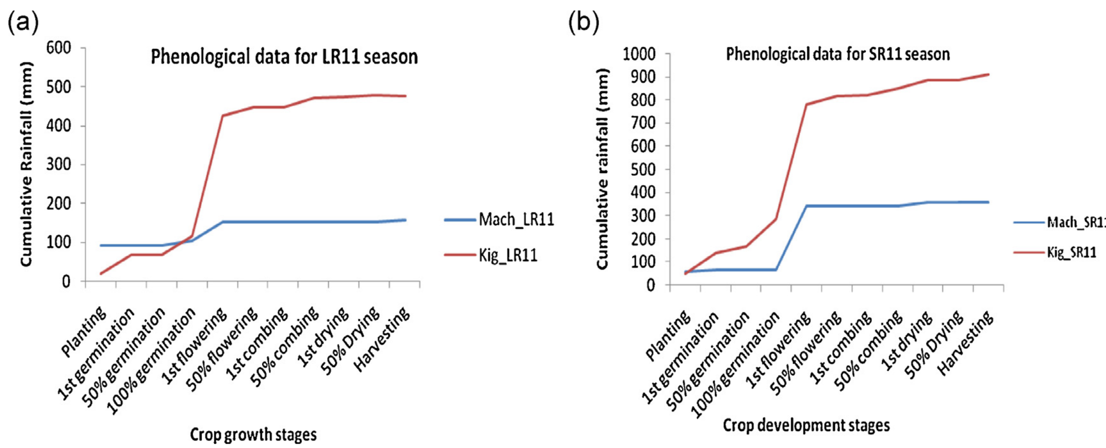

Fig. 4. Crop growth stages and rainfall distribution during the experimental period.

who indicated that runoff from a wheat field with tied ridges was far lower than that from the control treatment. Similar studies in semi-arid Ethiopia by McHugh et al. (2007) have indicated that tied ridging on slopes less than 3% reduced the runoff by more than 75% compared with control practice. Low runoff under ridges leads to increased water infiltration and storage in the profile, to be made available to the crop during later stages of crop growth (Nuti et al., 2009). Good maize yields under tied ridging might be ascribed to conservation of soil moisture which ultimately influences grain yield (Araya and Stroosnijder, 2010). Higher moisture status enhances availability of nutrients to crops (Sarkar, 2005). Tied ridging can enhance response of crops to rainfall and fertilizer, the soil supply of available N, positive effect on yield, and the harvest index. The combined response to seasonal rainfall, and N, P and K fertilizer under tied-ridged conditions accounts for 86% in the variance of yields (Nuti et al., 2009). This is consistent with the findings of Araya and Stroosnijder (2010) who stated that maize grain yield under tied ridging could be increased by at least 44% over the control during below average rainfall years. Enfors et al. (2011) reported that conservation treatments such as tied ridging and mulching increased maize yield by at least 65%, with exceptional amounts of rainfall of about 549 mm. Miriti et al. (2012) found that maize grain yields were generally greater under tied-ridge tillage compared with control treatment in semi arid region of Eastern Kenya.

Crop failure during the LR11 season at Machang'a could be linked to a severe meteorological drought (32 days) experienced during the critical crop development stage of flowering (Fig. 2) and coupled with high evapotranspiration rates ranging between 4.1 and 7.4 mm d^{-1} (Fig. 3). Rainfall distribution received during this season was quite erratic with 157 mm (Fig. 4b) distributed among eleven pentads. Two days after full germination of crops, a major rainfall event (41 mm) occurred after which a meteorological drought (32 days) was experienced in the remaining part of the season. This observation is concurrent with the statement of Ngigi et al. (2006) that in a semi-arid context, especially in a coarse-textured soil with low moisture storage capacity, *in situ* water conservation may offer no guarantee against poor rainfall distribution. Thus the risk of crop failure is only slightly lower than that without any measures. A study by Rowhani et al. (2011), examining the relationships between seasonal climate and crop yields focusing on maize, sorghum and rice in Tanzania has indicated that both intra- and inter-seasonal changes in temperature and precipitation influence cereal yields. Semenov and Porter (1995) have reported the negative impacts of climate variability on crop growth, especially if it happens at specific crop development stages.

The differences in maize grain yield under the various treatments were due to a combination of water availability and fertility status of the soil as induced by treatments. Although the total rainfall received in SR11 was slightly higher, the occurrence of prolonged dry spells within the season (Fig. 2) affected final yields. Generally yields at Kigogo were higher than those of Machang'a. This is attributed to the contrasting environmental conditions in the two experimental sites with regard to soil chemical and physical characteristics (Table 1), rainfall (Fig. 1) and evapotranspiration rates (Fig. 3). Kigogo is considered to be better than Machang'a in terms of agricultural potential.

5. Conclusion

Mulching and tied ridging technologies were the best in Kigogo and Machang'a respectively, in reducing runoff, sediment yield and nutrient load in sediment and improving maize yield. The study highlights the possibility of improving grain yields with erratic rainfall through implementation of technologies which promote water availability and retention within the field and improve soil status, and recommends mulching for Kigogo and tied ridging for Machang'a. Emerging from the study is, however, the difficulty in promoting SWC technologies in semi-arid lands such as Machang'a. For instance, total crop failure occurred during long rains 2011 despite the implementation of soil and water conservation technologies. Small scale farmers in such environments are faced with difficult task of producing sufficient food.

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