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EFFECTIVENESS OF MULCHING UNDER *MIRABA* IN CONTROLLING SOIL EROSION, FERTILITY RESTORATION AND CROP YIELD IN THE USAMBARA MOUNTAINS, TANZANIA

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ABSTRACT

Soil erosion is a major threat to food security in rural areas of Africa. Field experiments were conducted from 2011 to 2014 in Majulai and Migambo villages with contrasting climatic conditions in Usambara Mountains, Tanzania. The aim was to investigate the effectiveness of mulching in reducing soil erosion and restoring soil fertility for productivity of maize (*Zea mays*) and beans (*Phaseolus vulgaris*) under *miraba*, *a unique* indigenous soil conservation measure in the area. Soil loss was significantly higher ($p < 0{\cdot}05$) under *miraba* sole than under *miraba* with mulching, for example, 35 versus 20 and 13 versus 8 Mg ha^{-1} y^{-1} for Majulai and Migambo villages, respectively, in 2012. Soil fertility status was significantly higher ($p < 0{\cdot}05$) under *miraba* with *Tughutu* mulching than under *miraba* sole, for example, 0·35 versus 0·25% total N, 37 versus 22 mg kg^{-1} P and 0·6 versus 0·2 cmol(+) kg^{-1} K for the Majulai village; and 0·46 versus 0·38 total N, 17·2 versus 10·2 mg kg^{-1} P and 0·50 versus 0·2 cmol(+) kg^{-1} K for the Migambo village. Maize and bean yields (Mg ha^{-1}) were significantly higher ($p < 0{\cdot}05$) under *miraba* with *Tughutu* mulching than under *miraba* sole, 2·0 versus 1·3 for maize and 0·9 versus 0·8 for beans in Majulai; and 3·8 versus 2·6 for maize and 1·0 versus 0·8 for beans in the Migambo village in 2012. This implies that *Tughutu* mulching is more effective in improving crop yield than Tithonia, although both could potentially protect the arable land from degradation caused by water erosion under *miraba*. Copyright © 2014 John Wiley & Sons, Ltd.

KEY WORDS: SWC practices; runoff experiments; Tithonia; *Tughutu*; maize; beans

INTRODUCTION

Soil erosion is affecting all the continents and has been accelerated by human use and abuse of the land (Mandal & Sharda, 2013; Ligonja & Shrestha, 2013; Zhao *et al*., 2013; Lieskovsky & Kenderessy, 2014). Soil erosion by water and tillage in Mountainous areas of Sub-Saharan Africa, including the Usambara Mountains in Tanzania, have been identified as a major constraint to generating enough food to feed the escalating population, whereas cropland is becoming scarce and no longer productive owing to soil erosion (Pimentel *et al*., 1987; Kimaro *et al*., 2008). Many soil control measures ranging from indigenous ones such as *miraba* (rectangular grass bound strips that do not necessarily follow contour lines; Msita, 2013), micro-ridges, stone bunds and introduced ones such as bench terraces, *Fanya Juu* terraces (hillside ditches made by throwing excavated soil on the upslope of the ditch, built along contour lines at appropriate intervals depending on slope gradient), grass strips and agroforestry have been implemented in the Usambara Mountains to combat the problems of soil erosion. *Miraba* is the most preferred and widely practised indigenous technology by farmers in the Usambara Mountains. *Miraba* is an indigenous soil and water conservation (SWC) measure unique in the Usambara Mountains, established by using either Napier (*Pennisetum purpureum* Schumach.) or Guatemala (*Tripsacum andersonii* J.R. Gray) grass barriers. In this study, *miraba* was established using Napier grass because it is mostly preferred as it is also used as fodder.

Currently, there is a growing interest and recognition of indigenous SWC technologies on soil erosion control; however, the effectiveness of such technologies is not fully understood. Furthermore, these technologies have, for decades, been left traditional in the absence of scientific interventions such as mulching for improvements (Vigiak *et al*., 2005; Huenchuleo *et al*., 2012; Bizoza, 2014; Tesfaye *et al*., 2014). Mulching has been frequently documented to play an important role in controlling soil erosion (Giménez Morera *et al*., 2010; Fernández *et al*., 2012; Lee *et al*., 2013; Xu *et al*., 2012). A study by Bajracharya *et al*. (2005) in Nepal reported mulching to reduce annual soil loss by 60% to 90% as compared to conventional farmers' practice. Moreover, it reduced annual soil nutrient losses such as soil organic matter by 52%, total nitrogen (TN) by 46%, available P_2O by 32% and exchangeable K_2O by 53% in maize–mustard cropping system. Similarly, in maize + soybean–mustard cropping system, the annual losses of organic matter, TN, available P_2O and exchangeable K_2O were reduced by 58%, 49%, 26% and 60%, respectively. Lal (1997) in western Nigeria reported beneficial effects of mulching on agronomic productivity and increased maize

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grain yield due to improvements in soil quality. A study by Msita (2013) in a humid and cold part of the Usambara Mountains revealed *miraba* to be effective in reducing runoff, soil and nutrient losses and increasing maize yields when combined with farmyard manure and *Tithonia* mulching. However, the contribution of mulching on controlling soil erosion and improving crop yield was not singled out as a separate variable. Besides, the study by Msita (2013) was carried out in a humid and cold climate; thus, the results could not be directly applied in other areas with different soils and climatic conditions.

In the current study, two types of shrubs, namely *Tithonia diversifolia* (Hemsl.) A. Gray (*Alizeti Pori*) and *Vernonia myriantha* Hook f. (*Tughutu*), were used as mulching materials. These shrubs were chosen because they are readily available in the respective villages and Usambara Mountains in general. Besides, they have been documented to be potential local resources of NPK and organic carbon (OC; Wickama & Mowo, 2001; Mowo *et al*., 2006). Moreover, *Tughutu* is a local shrub that is perceived by farmers in Usambara Mountains as a wonderful plant for its ability of improving soil fertility and increasing crop yields around it; thus, it was innovative to include it as a mulching material under *miraba* and compare its effectiveness with that of Tithonia shrub that was promoted by Msita (2013). Furthermore, the effectiveness of *Tughutu* and Tithonia mulching was tested and compared in different climatic conditions for explicit conclusive remarks. Maize and beans were used as test crops because these are the main food crops in the study area and they are mainly cultivated on the slopes. The objectives of this study were as follows: (i) to quantify runoff and soil losses under mulching in *miraba*- maize/beans land utilization; (ii) to establish relationship between runoff, rainfall depth and mulching cover in *miraba*-maize/beans land utilization; (iii) to determine the effect of mulching materials on soil fertility restoration under *miraba*; and (iv) to select the best mulching material for controlling soil erosion and improving crop yield.

MATERIAL AND METHODS

Study Area

Migambo and Majulai villages are located in Western Usambara Mountains, Lushoto District, Tanzania (Figure 1) between latitudes 4°34′S to 4°48′S and longitudes 38°15′E to 38°24′E. Migambo is humid cold with mean annual air temperature of 12–17 °C, and annual precipitation is 800–2300 mm. Majulai is dry warm with mean annual air temperature between 16 °C and 21 °C, and annual precipitation is 500–1700 mm. The Usambara Mountains support a large population density of more than 120·4 persons km^{-2} (National Bureau of Statistics, 2012). Salient features of the study aera are presented in Table I. According to World Reference Base for Soil Resources (FAO, 2014), the soils in the Majulai site classified as *Chromic Acrisols* (*Humic*, *Profondic*, *Clayic*, *Cutanic* and *Colluvic*), whereas in the Migambo site, the soils are *Haplic Acrisols* (*Humic*, *Profondic*, *Clayic* and *Colluvic*). The main land uses include cultivation on slopes and in valleys, settlements on depressions, lower ridge summits and slopes and forest reserves on ridge summits and upper slopes. Vegetables such as carrots, onions, tomatoes, cabbages and peas are grown as sole crops

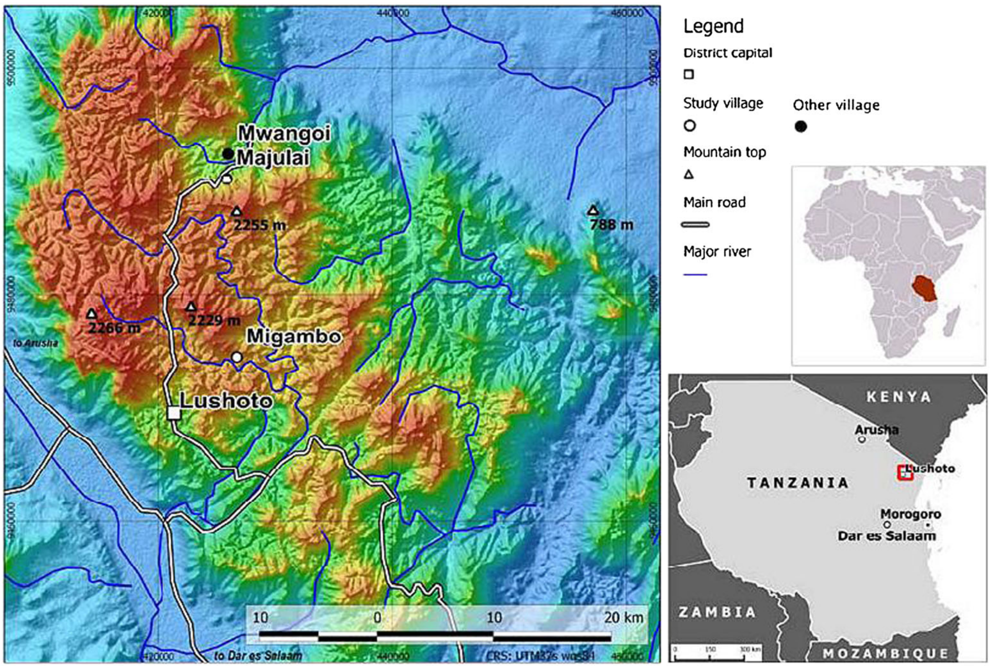

Figure 1. Location map of Migambo and Majulai villages, Lushoto District, Tanzania (adapted from Msita, 2013). This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

Table I. Soil and topographical properties of the study area

Village	Altitude (m asl)	Slope (%)	Soil horizon	BD (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	Textural class	AMC (%)	GMC (%)
Majulai village	1402	50	Ap	1·14	45	7	48	C	20	52
			Bt1	1·26	31	7	62	C	17	60
			Bt2	1·30	21	15	64	C	16	62
Migambo village	1682	45	Ap	1·15	33	14	53	C	19	53
			Bt1	1·28	22	10	66	C	16	61
			Bt2	1·33	12	16	72	C	15	64

BD, bulk density; AMC, available moisture content; GMC, gravimetric moisture content; asl, above sea level.

in valleys under rain-fed conditions or traditional irrigation. Beans are mainly grown during long rains whereas maize in short rains; Irish potatoes and fruits namely peaches, plums, pears, avocado and banana are grown on ridge slopes under rain-fed mixed farming. Irish potatoes are also grown in valleys as sole crop or intercropped with maize.

Experimental Design and Data Collection

The establishment of *miraba* in runoff experiments was carried out in April 2011 about 9 months before data collection started, the time that allowed *miraba* to be well formed. Napier grass barriers forming *miraba* were established by planting tillers in a single row at 10-cm spacing perpendicular to the general slope and were maintained to about 50-cm-wide strips. Napier grass barriers across the slope were spaced 5 m apart. Along the slope, the spacing of Napier grass barriers was set at 3 m apart.

Closed runoff plots of 22 m × 3 m in a randomized complete block design were established in Majulai and Migambo villages. The plots were enclosed with *miraba*, and the sides were supported by pieces of wood that protruded about 15 cm above the soil surface and that connected to the 120-l collector drums with hinged lids. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) were planted in rotation as test crops in 2012 and 2013/2014 rain seasons, and maize was planted during short rains (*vuli*) whereas beans in long rains (*masika*). The treatments included plots with (i) *Miraba* and planted with maize or beans (control) *MI*; (ii) *Miraba* with *Tithonia* mulching and planted with maize or beans *MITH*; and (iii) *Miraba* with *Tughutu* mulching and planted with maize or beans *MITG*; all were replicated three times.

The leaves of *T. diversifolia* (*Alizeti Pori*) and *V. myriantha* (*Tughutu*) shrubs were used as mulching materials in both villages. The chemical properties of these mulching materials were as follows: Tithonia had 3·3%, 0·3%, 6·1%, 1·2%, 0·7% and 0·04% whereas *Tughutu* had 3·6%, 0·3%, 6·3%, 1·4%, 0·9% and 0·04% of N, P, K, Ca, Mg and Na, respectively. The mulches were applied at the rate of 3·6 Mg ha^{-1} dry weight. The percent mulch cover was estimated by the line transect method proposed by Nill *et al*. (1996) where the presence or absence of soil surface contact cover was recorded. The recording was carried out by lay down along the diagonals in each plot with a marked thread at 10-cm intervals (Nill *et al*., 1996). This procedure was carried out after every rainstorm throughout the year. Samples were collected from each mulching material for determination of total N and available P, K^+, Mg^{2+}, Ca^{2+} and Na^+.

Daily rainfall was measured from 1 January 2012 to 16 February 2014 using standard rain gauges and an automatic rain gauge with a CR10 data logger (Campbell Scientific, Logan, UT) installed at the experimental sites in Migambo and Majulai villages. Runoff and sediment was collected daily from 1 January 2012 to 16 February 2014. Beans were grown during the long rains, weeds were left to grow in the field during off season and maize was grown in short rains. Runoff volume was estimated by measuring the depth of water in centimetre in the collecting drums and then converted to volume of water in litres. Sediment load was estimated by sampling water in collecting drums after vigorously stirring the suspension. The water sampling was carried out by lowering a 1-l plastic bottle from the water surface to the bottom of the drum, and samples of about 300 ml were collected at the bottom, middle and upper parts when runoff depth in the drum was above 25 cm. Heavy sediments in the drums were scooped out and weighed; and a 1-kg soil sample was collected, oven dried for 24 h at 105 °C and weighed for dry soil loss calculation. The suspended sediment samples were filtered using Whatman No. 42 filter paper and 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. Soil losses from heavy sediments and from suspended materials from each runoff event were added to compute total soil loss for the events. Soil losses from all runoff events were finally added to compute total soil loss per annum. The soil samples for nutrient loss determination were collected by decanting the suspended sediments in buckets.

The effectiveness of mulching materials under *miraba* on soil fertility restoration was determined by taking composite top soil samples to 30-cm-depth plough layer from each treatment for the analysis of pH, OC, total N, available P, K^+, Ca^{2+}, Mg^{2+} and Na^+. Undisturbed core soil samples were collected at depth of 0–5 cm for bulk density, gravimetric moisture content and available water content determination. Soil samples were collected at the end of every cropping season, that is, long rains and short rains from 2012 to 2013/2014. Soil analysis was carried out following Moberg's (2001) laboratory manual. OC was measured using the dichromate oxidation method, TN by the Kjeldahl method, available phosphorus (Bray-I), exchangeable bases (Ca^{2+} and Mg^{2+}) by atomic absorption spectrophotometer, exchangeable Na^+ and K^+ by flame photometer, and pH water by normal laboratory pH meter.

Maize (*Z. mays*) variety PAN 67 and beans (*P. vulgaris*) Kilombero variety were planted at a recommended spacing of 30 cm within rows and 75 cm between rows for maize, and 25 cm within rows and 50 cm between rows for beans. Beans were always planted 3 weeks before the maize was harvested in Migambo and 2 weeks before harvesting maize in the Majulai village. Farmyard manure was basal and spot applied at the rate of 3·6 Mg ha^{-1} air-dry weight, and diammonium phosphate (DAP) 18:46:0 NPK ratio and urea 46% N were applied at the rate of 80 kg ha^{-1}, but urea was not applied for beans. At maturity, maize and beans grains were harvested, dried to about 13% moisture content and weighed.

RUSLE Factors Determination and Statistical Analysis

The Revised Universal Soil Loss Equation (RUSLE) equation expresses average annual soil loss (Mg ha^{-1} y^{-1}) caused by sheet and rill erosion (Renard *et al*., 1996);

$$A = RKLSCP \tag{1}$$

Where: A is the average soil loss (Mg ha^{-1} y^{-1}), R is rainfall erosivity factor (MJ mm ha^{-1} h^{-1} y^{-1}), K is the soil erodibility factor (Mg ha MJ^{-1} mm^{-1}), LS is dimensionless factor combining slope steepness (S) and slope length (L), and C and P are dimensionless factors accounting respectively for crop cover and management and conservation practices.

The equation developed by Vrieling *et al*. (2010) was used to calculate R factor. Such that

$$R = 50.7\,MFI – 1405 \tag{2}$$

Where: MFI is the modified Fournier index calculated from

$$MFI = \sum_{n=1}^{\infty}\left(p^2\right)/P \tag{3}$$

Where: p is the long-term average monthly rainfall (mm) and P is the average annual rainfall (mm). In the absence of any cover crop or soil protection measure, as for the bare plot (plot with no *miraba*, no mulches, no crops and no weeds, i.e. left bare throughout), C and P factors are equal to 1. Thus, the K factor was calculated from

$$K = A_{\text{bare plot}}/(RLS) \tag{4}$$

According to Mitchell & Bubenzer (1980)

$$LS = \left[0.065 + 0.0456s + 0.006541s^2\right] \times (l/22)^{1/2} \tag{5}$$

Where: s is the slope gradient in %; l, is the plot length in metre; the constant 1/2 is used where the slope steepness is ≥ 5%.

The effectiveness of mulching materials under *miraba* on reducing soil loss was determined by the use of C factors when compared to the *miraba* plots without mulching. Therefore, the C factor was determined as the ratio between the seasonal or annual soil losses under *miraba* plots with mulching to the seasonal or annual soil loss under *miraba* plots without mulching.

$$C(MITH \text{ plot}) = A(MITH \text{ plot})/A(MI \text{ plot}) \tag{6}$$

$$C(MITG \text{ plot}) = A(MITG \text{ plot})/A(MI \text{ plot}) \tag{7}$$

Where: A (*MI* plot) is the soil loss (Mg ha^{-1} season^{-1} or Mg ha^{-1} y^{-1}) under *miraba* plots without mulching. A (*MITH* plot) is the soil loss (Mg ha^{-1} season^{-1} or Mg ha^{-1} y^{-1}) under *miraba* plots with *Tithonia* mulching. A (*MITG* plot) is the soil loss (Mg ha^{-1} season^{-1} or Mg ha^{-1} y^{-1}) under *miraba* plots with *Tughutu* mulching. The effectiveness of mulching materials under *miraba* on reducing soil loss was determined by the percent of C factor with reference to *miraba* plots without mulching. The effectiveness of mulching materials under *miraba* on reducing nutrient losses was also calculated in percentages compared to that of *miraba* plots without mulching.

Bartlett's test for homogeneity of variances was conducted to test data normality using the GENSTAT software (GenStat, 2011). Regression analysis was used to determine the rainfall and mulch cover-runoff responses, where the rainfall and percent mulch cover threshold values to initiate runoff were obtained at the X-axis intercept. Analysis of variance in GENSTAT statistical software (GenStat, 2011) was performed to compare the crop yield differences where least significant difference ($LSD_{0·05}$) was used to detect mean differences between treatments. Box-and-whisker plots were used to visualize the effectiveness of mulching on soil fertility restoration.

RESULTS AND DISCUSSION

Soil Loss in Relation to the Studied SWC Practices and the Two Villages with Contrasting Climatic Conditions

The Majulai village had significantly higher ($p < 0·001$) annual soil losses than Migambo in 2012, whereas in 2013, Migambo experienced significantly ($p < 0·001$) higher annual soil losses than Majulai. The difference in soil losses between the two villages can partly be attributed to the rainfall depth (Table II), as it can clearly be seen that the higher the rainfall depth, the higher the soil losses in the studied villages. Similar observations were reported by Kabanza *et al*. (2013), where soil losses in Makonde plateau were much higher than those in inland plains, and rainfall depth was spotted as the main contributing factor. The relatively steeper slope in Majulai than in Migambo could also explain the soil loss differences. On the other hand, soil loss differed significantly ($p < 0·001$) between SWC measures. The soil losses followed the following trend: cropland with no SWC measures > cropland with *miraba* sole > cropland with *miraba* and Tithonia or *Tughutu* mulching. A similar observation was reported by Bajracharya *et al*. (2005) in Nepal where mulching was found to reduce annual soil loss by 60% to 90% in maize–mustard cropping system as compared to conventional farmers' practice.

Table II. Rainfall and annual soil losses measured in the Majulai and Migambo villages, Lushoto District, Tanzania

	Replicates	Majulai		Migambo	
		2012	2013	2012	2013
Rainfall (mm)					
Long rains (Feb–May)		329·3	258·0	359·4	552·1
Offseason rains (Aug–Sept)		28·7	0·0	7·1	23·4
Short rains (Oct–Jan)		636·9	165·1	415·8	222·7
Annual		906	528	718	826
Soil loss Mg ha^{-1} $year^{-1}$					
Plots with maize or beans	1	179·6	72·9	124·1	133·3
	2	183·3	76·8	124·3	129·8
	3	187·8	77·2	124·4	131·6
	Mean	183·6	75·6	124·3	131·6
Miraba with maize or beans	1	34·7	12·2	13·3	14·9
	2	35·9	11·7	13·4	13·4
	3	33·6	14·3	13·5	14·3
	Mean	34·7	12·7	13·4	14·2
Miraba with Tithonia and maize or beans	1	17·58	5·42	8·02	5·30
	2	20·03	8·20	7·58	4·76
	3	20·05	9·09	7·97	5·18
	Mean	19·22	7·57	7·86	5·08
Miraba with *Tughutu* and maize or beans	1	18·47	5·62	7·97	5·47
	2	20·01	9·34	7·43	5·18
	3	20·02	9·33	7·24	5·27
	Mean	19·50	8·10	7·55	5·31
LSD ($p \leq 0{\cdot}05$)		2·75	2·61	2·75	2·61
SE		0·91	0·86	0·91	0·86

LSD, least significant difference; SE, standard error of means.

Runoff Responses to Rainfall and Mulching Cover under the Studied SWC Measures

The rainfall threshold values to initiate runoff varied between the studied SWC measures in both villages (Table III). From Table III, it can clearly be seen in both villages that *miraba* sole with only crop residues is more susceptible to runoff than *miraba* under mulching. Therefore, implementation of mulches under *miraba* in the Usambara Mountains could effectively protect arable land from degradation caused by water erosion.

Effectiveness of Mulching Covers in Relation to RUSLE Factors

The relative effectiveness of mulching covers with reference to soil losses from plots with no mulching cover presented in Figure 2. There were no significant ($p < 0{\cdot}05$) soil loss differences between mulching covers. However, the soil

Table III. Daily runoff (mm) response (Y) to mulching cover (%) ($X1$) and rainfall (mm) ($X2$) for Majulai and Migambo villages in Usambara Mountains, Tanzania

Village/ treatments	Regression equations	Runoff thresholds vs $X1$	Runoff thresholds vs $X2$	R^2	Sign. mulch cover	Sign. rainfall	Cover observations	Rainfall occasions
Majulai								
Miraba	$Y = -0{\cdot}30 - 0{\cdot}015X$ $1 + 0{\cdot}2X2$	20	1·5	0·57	ns	***	318	106
Miraba + Tithonia	$Y = -0{\cdot}20 - 0{\cdot}0055X$ $1 + 0{\cdot}069X2$	36	2·8	0·57	***	***	318	106
Miraba + *Tughutu*	$Y = -0{\cdot}20 - 0{\cdot}0055X$ $1 + 0{\cdot}071X2$	36	2·9	0·56	***	***	318	106
Migambo								
Miraba	$Y = -0{\cdot}25 - 0{\cdot}013X$ $1 + 0{\cdot}16X2$	19	1·5	0·75	*	***	327	109
Miraba + Tithonia	$Y = 0{\cdot}15 - 0{\cdot}0045X$ $1 + 0{\cdot}05X2$	33	3·0	0·77	***	***	327	109
Miraba + *Tughutu*	$Y = 0{\cdot}16 - 0{\cdot}0048X$ $1 + 0{\cdot}051X2$	33	3·0	0·74	***	***	327	109

ns, not significant.
*Significant at $p < 0{\cdot}05$.
***Significant at $p < 0{\cdot}001$.

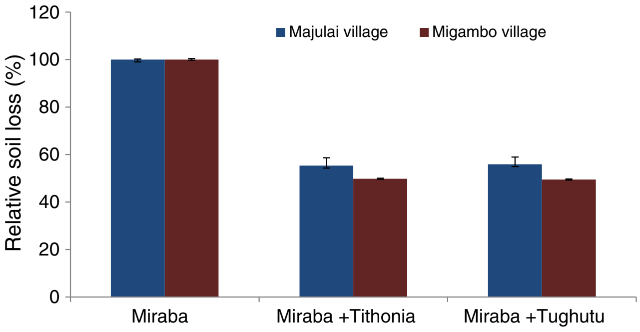

Figure 2. The mean relative soil loss with STDEV from three replicates under mulching cover in Majulai and Migambo villages. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

losses under mulching cover were higher in the Majulai village than in the Migambo village. As the surface soil texture between the two village was similar, the differences in soil loss were greatly be influenced by the steeper slopes in the Majulai village than in the Migambo village (Table I). This observation is supported by Ziadat & Taimeh (2013) who also observed slope to explain about 89% of the variation in runoff and soil loss. Relative to soil losses from cropland with *miraba*, it can be seen that Tithonia mulch reduced soil losses by 55% in the Majulai village and 50% in the Migambo village, whereas *Tughutu* mulch reduced soil losses by 56% in the Majulai village and 50% in the Migambo village.

The observed *K* factors were 0·002 ($Mg\,h\,MJ^{-1}\,mm^{-1}$) for *Chromic Acrisol* in the Majulai village and *Haplic Acrisol* in the Migambo village (Tables III and IV). The *K* value is very low, which indicate the high susceptibility of the studied soils to erosion. More erodible soils such as silt loam soils reported to have *K* factor ranging from 0·03 to 0·05 ($Mg\,h\,MJ^{-1}\,mm^{-1}$) (e.g. Poesen, 1992). The *C* factor values did not significantly differ between the villages, although were much higher in the Majulai village than in the Migambo village (Table IV), indicating that mulches have slightly stronger effect in the Migambo village than in the Majulai village. This can be explained by the steeper slopes in the Majulai village than in the Migambo village, which accelerate the speed of running water and thus increased rate of soil erosion (Liu *et al*., 1994; Morgan & Duzant, 2008). On the other hand, *miraba* with Tithonia and *miraba* with *Tughutu* mulching were significantly more effective in reducing soil loss than *miraba* sole (control). This is because mulches tend to reduce runoff speed and thus increases rate of infiltration. This observation was also supported by Lal (1997), Duran Zuazo *et al*. (2006), Birru *et al*. (2012) and Fernández *et al*. (2012) who reported reduced soil losses as a result of improved infiltration and soil structure stability under mulching.

However, the effectiveness of Tithonia and *Tughutu* mulching materials in reducing runoff and soil losses did not differ but was significantly much more effective than maize or beans cover in both villages (Table IV).

Influence of Mulching Cover to Soil Fertility Restoration

The mean values of soil nutrients are summarized in Table V, whereas the median, inter-quartile range, minimum and maximum values are presented by box-and-whisker plots in Figures 3 and 4, where the boxes represent inter-quartile ranges with median values dividing the boxes, and whiskers represent the minimum and maximum values. It was found that most of the studied soil nutrients were significantly ($p < 0{\cdot}05$) different between SWC practices and between the two villages except for Ca^{2+} and Na^{+}. The contents of P, K^{+} and Mg^{2+} were significantly higher at $p < 0{\cdot}001$, and OC and total N at $p < 0{\cdot}003$. All the studied soil nutrients were significantly ($p < 0{\cdot}05$) higher under *miraba* with *Tughutu* and Tithonia mulching than under *miraba* sole except for Ca^{2+} and Na^{+}, which did not significantly ($p > 0{\cdot}05$) differ in both villages. Although most of soil nutrients were not significantly different, the general trend was as follows: *miraba* with Tughutu > *miraba* with Tithonia > *miraba* sole. The higher soil fertility status under mulching than under *miraba* sole can directly be associated with the intervention of *Tughutu* and Tithonia mulching. This observation is

Table IV. RUSLE factors for the Majulai and Migambo villages in Usambara Mountains, Tanzania, based on soil loss measurements on runoff plots from 2012 to 2013 rain seasons

RUSLE factors	Mulching and maize cover	Majulai Median	Majulai IQR	Majulai *n*	Migambo Median	Migambo IQR	Migambo *n*	Sign.
R ($MJ\,mm\,ha^{-1}\,h^{-1}\,y^{-1}$)		5816	1958	2	6553	694	2	ns
K ($t\,h\,MJ^{-1}\,mm^{-1}$)		0·0016	0·0002	2	0·0018	0·0002	2	ns
P (dimensionless)	*Miraba*	0·18	0·002	6	0·10	0·003	6	***
C (dimensionless)		Mean	STDEV		Mean	STDEV		
	Beans/weed/maize	0·71	0·02	6	0·70	0·005	6	ns
	Tithonia	0·55	0·14	6	0·50	0·02	6	ns
	Tughutu	0·55	0·13	6	0·50	0·02	6	ns
	LSD ($p \leq 0{\cdot}05$)	0·14			0·14			

Friedman test for *R*, *K* and *P* factors; nested ANOVA for *C* variable
LSD, least significant difference; IQR, inter-quartile range; STDEV, standard deviation; *n*, number of observations, i.e. 2 years for *R* and *K* factors, and three replications for each year for *P* and *C* factors; ns, not significant; ANOVA, analysis of variance; RUSLE, Revised Universal Soil Loss Equation.
***$p < 0{\cdot}001$.

Table V. The influence of mulching to topsoil (0–30 cm) fertility status after 2 years of mulching application

Village/year	Treatments	*N*	OC (%)	Total N (%)	P (mg kg^{-1})	K^+	Ca^{2+}	Mg^{2+} (cmol(+) kg^{-1})	Na^+
Majulai	*Miraba* sole	9	2·26	0·24	22·00	0·20	2·71	0·44	0·31
	Miraba with Tithonia	9	2·60	0·31	34·70	0·50	2·30	0·90	0·30
	Miraba with *Tughutu*	9	2·60	0·35	37·42	0·60	3·45	1·30	0·41
Migambo	*Miraba* sole	9	3·84	0·38	10·16	0·20	9·12	1·42	0·30
	Miraba with Tithonia	9	4·70	0·42	15·00	0·38	9·50	1·83	0·31
	Miraba with *Tughutu*	9	5·10	0·46	17·20	0·50	11·37	2·63	0·30
	LSD ($p \leq 0·05$)		0·54	0·06	8·3	0·16	2·30	0·43	0·11
	SE		0·17	0·02	2·6	0·05	0·80	0·19	0·03

LSD, least significant difference; SE, standard error of means.

strongly supported by the fact that *Tughutu* and Tithonia mulching materials revealed to contain appreciable amount of N, P and K. Upon decomposition, mulches release nutrients to the soil, thus leading to restored soil nutrients. This observation was strongly supported by Xu *et al.* (2012) where terraced orchard with grass cover was found more effective in improving soil fertility especially soil organic matter, available N, P and K and bulk density, saturated hydraulic conductivity and aggregate stability than terraced orchard without grass cover. Besides, mulches were found to be effective in reducing soil nutrient losses; thus, in this study, cropland under mulches had higher soil fertility than those without. A similar observations was reported by Bajracharya *et al.* (2005) in Nepal where mulching was found to reduce annual nutrient losses such as organic matter by 52%, TN by 46%, available P_2O by 32% and exchangeable K_2O by 53% in maize–mustard cropping system as compared to conventional farmers' practice.

Impact of Mulching to Crop Productivity in the Two Studied Villages

The yield of maize and beans is presented in Figure 5. The results show that maize grain yields in 2012 in the Majulai village were significantly ($p < 0·05$) different between SWC practices. The crop yield followed the trend: *miraba* with *Tughutu* mulching > *miraba* with Tithonia mulching > *miraba*

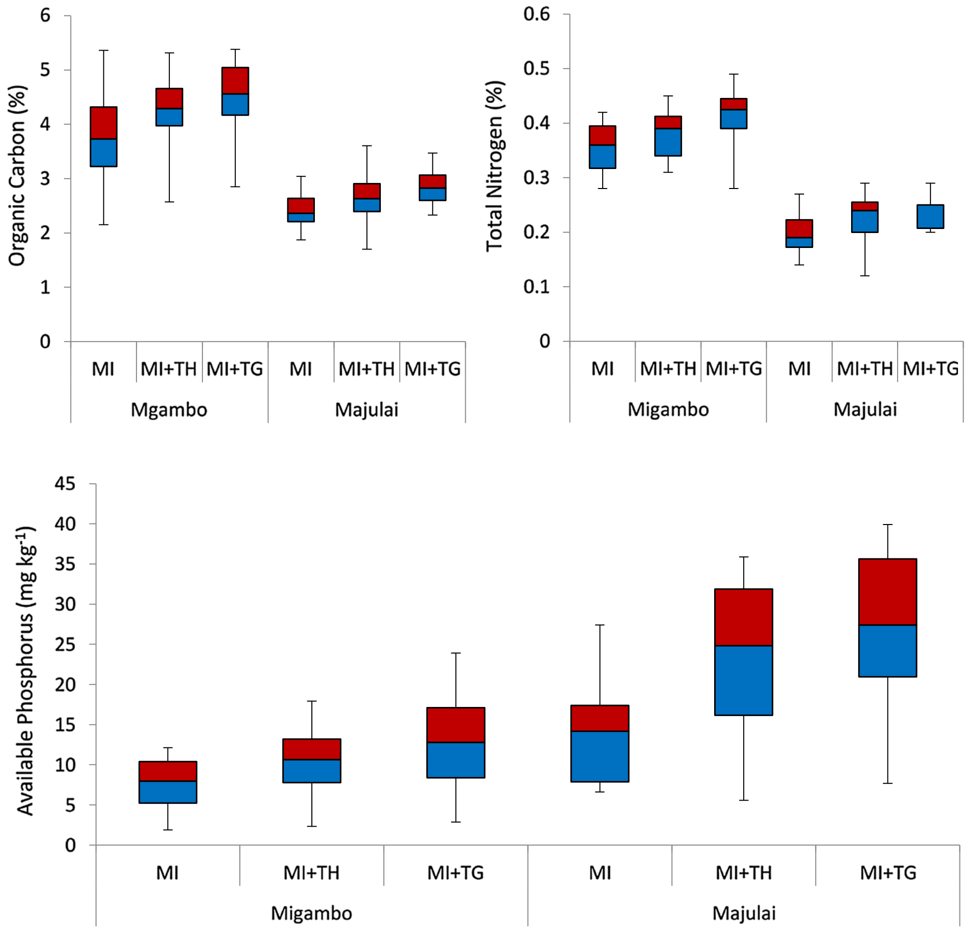

Figure 3. The influence of soil conservation measures on the status of OC, total N and P in the studied villages. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

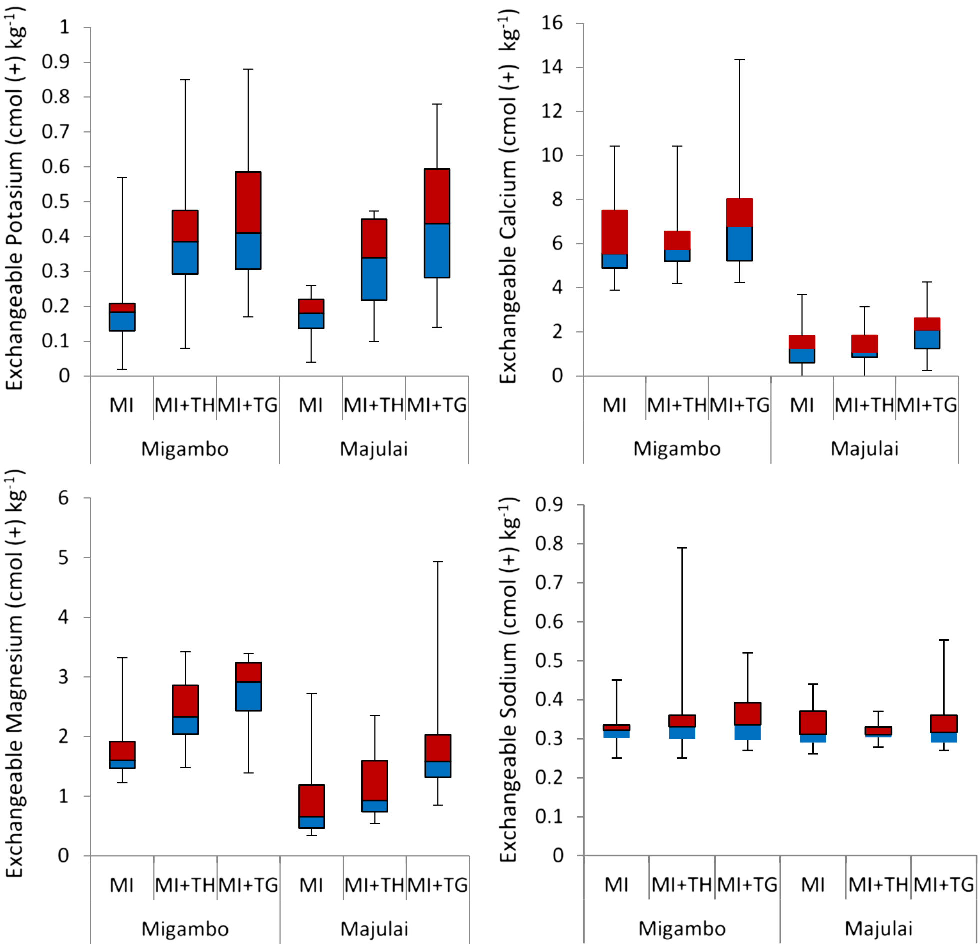

Figure 4. The influence of soil conservation measures on the status of K^+, Ca^{2+}, Mg^{2+} and Na^+ in the studied villages. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

sole (Figure 5). Beans grain yield did not significantly differ between SWC practices. But owing to drought, there was no maize grain yield in 2013. In the Migambo village, maize and beans grain yields were significantly ($p < 0{\cdot}05$) different with the following trend: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole. Maize grain yields were significantly higher ($p < 0{\cdot}05$) in 2013 than in 2012, whereas beans grain yields did not differ, but they were higher in 2013 than in 2012. The observed crop yields under the studied SWC practices were higher than the average yields according to FAO (2010) of 1·5 Mg ha^{-1} for maize and of 0·7 Mg ha^{-1} for beans in Tanzania. There were also some differences in maize and beans yields between the two villages, with higher yields in Migambo than in Majulai. The crop yield differences between SWC practices can be explained by the influences of mulching application that lead to improved soil fertility, whereas the crop yield differences between villages could partly be caused by the reliable rainfall for crop production in the Migambo village, whereas in the Majulai village, rainfall was not reliable in its growing seasons.

Mulching materials increased maize grain yield in the following order: *Tughutu* mulching increased maize grains yield by 56% and Tithonia mulching by 29%, and there were no maize grains yield in 2013 owing to drought. Beans grain yields increased by 15% owing to *Tughutu* and 10% owing to Tithonia mulching in 2012, whereas in 2013, *Tughutu* increased by 28% and Tithonia by 22% as compared to plots with *miraba* sole in the Majulai village. In the Migambo village, the trend was similar where maize grains yield respectively increased by 47% and 24% under *Tughutu* and Tithonia mulching in 2012, whereas in 2013, *Tughutu* and Tithonia increased maize grains yields by 55% and 30%, respectively, as compared to plots with *miraba* sole. Beans grains yield was increased by 17% under *Tughutu* and 11% under Tithonia, whereas in 2013, *Tughutu* increased beans grains yield by 24% and 15% by Tithonia mulching as compared to plots with *miraba* sole. The higher grain yield under mulching was also reported by Lal (1997) in western Nigeria who found an increased maize grain yield due to soil quality improvements as a result of mulching. Similarly, Lee *et al*. (2013) observed an improved plant germination and growth under coir geotextile mulching.

The higher crop yields under *Tughutu* than under Tithonia mulching can be explained by the higher nutrients contents in *Tughutu* than in Tithonia mulching material. Moreover, studies by Wickama & Mowo (2001) and Mowo *et al*. (2006) reported the rate of decomposition of *Tughutu* to be

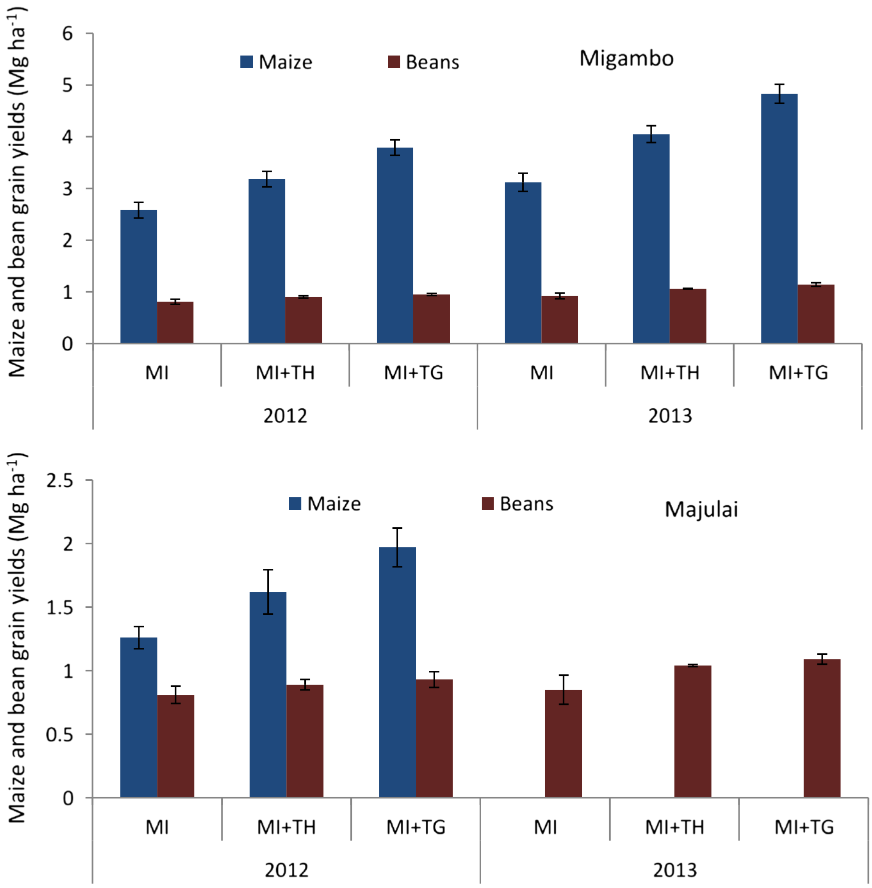

Figure 5. Impact of mulching on crop yields in Majulai and Migambo villages. This figure is available in colour online at wileyonlinelibrary.com/journal/ldr.

much faster than that of Tithonia. It has been revealed that the faster the rate of decomposition of organic materials, the better the supply of nutrients as compared to slow decomposing materials (Palm *et al*., 2001; Giller *et al*., 2006). This implies that the intervention of *Tughutu* mulching under *miraba* could sustainably and effectively improve crop yields in Usambara Mountains.

CONCLUSIONS

Although both *Tughutu* and Tithonia mulches showed great potential in reducing runoff, soil and nutrient losses under *miraba*, *Tughutu* mulching was more effective in improving crop yield than Tithonia mulching. The rainfall erosivity, assessed by the *R* factor, is clearly distinct in the two villages, and this is linked to climatic condition differences. Despite the fact that the soils of Usambara Mountains are susceptible to erosion, the *C* factors indicate these soils are responsive to mulching.

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