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Effectiveness of *Miraba* Soil Conservation Practices on Soil Erosion Control and Crop Yield in the Usambara Mountains, Tanzania

ABSTRACT

Indigenous soil conservation measures such as *miraba* have widely been used in Usambara Mountains for controlling soil erosion but with little success. On farm runoff experiments were set from 2011 – 14 on *Acrisols* in Majulai and Migambo villages with contrasting agro ecological conditions in the Usambara Mountains, Tanzania. The aim was to investigate the effectiveness of *miraba* in reducing runoff, soil and nutrient losses and productivity of maize (*Zea mays*) and beans (*Phaseolus vulgaris*). Results show that mean annual runoff coefficients (mm mm^{-1}) ranged from 0.72 for crop land with no soil conservation measure (control) to 0.15 for *miraba* with Tithonia (*Tithonia diversifolia*) mulching in Majulai village and respectively 0.68 to 0.13 in Migambo village. Soil loss was significantly ($p < 0.05$) higher under control and lowest under *miraba* with either *Tughutu* (*Vernonia myriantha*) or Tithonia mulching e.g. 184 vs 20 in Majulai and 124 vs 8 Mg ha^{-1} $year^{-1}$ for Migambo village in 2012. The *P*-factors were significantly ($p < 0.05$) higher 0.18 vs 0.11 under *miraba* sole than under *miraba* with mulching in Majulai and 0.10 vs 0.05 in Migambo villages. The annual nutrient losses in kg $ha^{-1}yr^{-1}$ were significantly ($p < 0.05$) higher under control and lowest under *miraba* with mulching 367 vs 37 total N, 0.8 vs 0.1 P and 14 vs 4 K for Majulai village; 474 vs 26 total N, 0.7 vs 0.1 P and 20 vs 1.2 K for Migambo village in 2012. Maize and beans yields were significantly ($p < 0.05$) highest under *miraba* with *Tughutu* mulching and lowest under crop land with no soil conservation measures (e.g 2.0 vs 0.7 Mg ha^{-1} for maize in Majulai in 2012). Thus *miraba* with *Tughutu* mulching was more effective in improving crop yields than *miraba* with Tithonia and *miraba* sole.

Key words: Runoff experiments, indigenous SWC, soil and nutrient losses, maize, beans

1.0 INTRODUCTION

Soil erosion has been reported as a serious problem to sustained agricultural production all over the world [1; 2; 3; 4, 5]. Soil erosion by water is a major factor causing land degradation in the Usambara highlands of Tanzania and severely affects soil functions resulting in low crop productivity [6; 7]. Soil erosion by water is defined as the detachment and displacement of soil particles by water, resulting in the development of rills and gullies [8]. To overcome the problem of soil deterioration, the Usambara farmers developed local soil and water conservation (SWC) measures such as *miraba*, micro ridges and stone bunds as an integral part of their farming systems while many of the introduced measures have often been rejected or minimally adopted [7; 9; 10]. Some of the reasons were due to the introduced measures such as bench and *Fanya Juu* terraces were expensive in terms of labour and money, while also their promoters paid little attention to indigenous practices.

Miraba are rectangular bound grass strips that do not necessarily follow contour lines [10] and are widely practised by farmers in the Usambara Mountains. *Miraba* as a SWC measure is traditionally characterized by a wide spacing of grass strips across the slope and usually the spacing depends on the size of farm plots. For decades these SWC technologies were never a

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subject of scientific writing so as to make improvements to effectively address problems of soil degradation and low crop productivity [9]. On the other hand, farmers have not been able to adjust these indigenous SWC techniques to rapidly changing farming systems and increasing intensity of land use [11; 9].

On steep slopes like in Usambara Mountains, bench terraces are highly recommended as the most effective soil and water conservation measure in crop land [12; 7; 9; 13). However, due to low adoption rates in Usambara Mountains the solution is to improve and use indigenous SWC technologies such as *miraba* for sustained agricultural productivity in the area.

In the Usambara Mountains *miraba* are established by using either Napier or Guatemala grass. Grass strips forming *miraba* serve as barriers which capture soil particles that have been detached and are transported with runoff from the cultivated land. Napier grass are mostly preferred because they are also used as forage for stall feeding, while Guatemala is appreciated for its drought resistance and to some extent is also used as forage for stall feeding.

Studies on effectiveness of some introduced SWC technologies such as bench terraces, *Fanya Juu* terraces and grass strips on soil erosion control and agricultural productivity have recently been carried out in western Usambara Mountains [7; 14]. However, the contribution of indigenous SWC technologies including *miraba* mostly practised in the study area have not fully been investigated for sustained agricultural productivity [9, 15]. Moreover, it has been reported that establishment of *miraba* is far cheaper than the construction of bench terraces. Therefore efforts towards improving this technique are warranted [14; 15].

This study investigated the effectiveness of *miraba* in reducing runoff, soil and nutrient losses and the productivity of maize and beans. Specifically, the study intendeds to: (i) quantify soil and nutrients losses under selected *miraba* practices (ii) determine rainfall-runoff responses under selected *miraba* practices (iii) select the best *miraba* practice using the Revised Universal Soil Loss Equation (RUSLE) and: (iv) determine the influence of *miraba* on crop yield.

2.0 MATERIAL AND METHODS

2.1 Description of the Study Sites

The study was conducted in Migambo and Majulai villages, Western Usambara Mountains, Lushoto District, Tanzania (Fig. 1) located between 38^0 15' to 38^0 24' E and 4^0 34' to 4^0 48' S. The rainfall characteristics are presented in (Table 1) Migambo is humid cold with mean annual air temperature of 12 − 17 ^{0}C and annual precipitation is 700 – 1800 mm. Majulai is dry and warm with mean annual air temperature between 16 and 21 ^{0}C and annual precipitation of 500 – 2100 mm. The monthly reference evapo-transpiration (ETo) as estimated by the local climate estimator software (New_LocClim) [16] ranges from 100 mm to 145 mm. The Usambara Mountains support a large population density more than 102 persons/km^2 [17].

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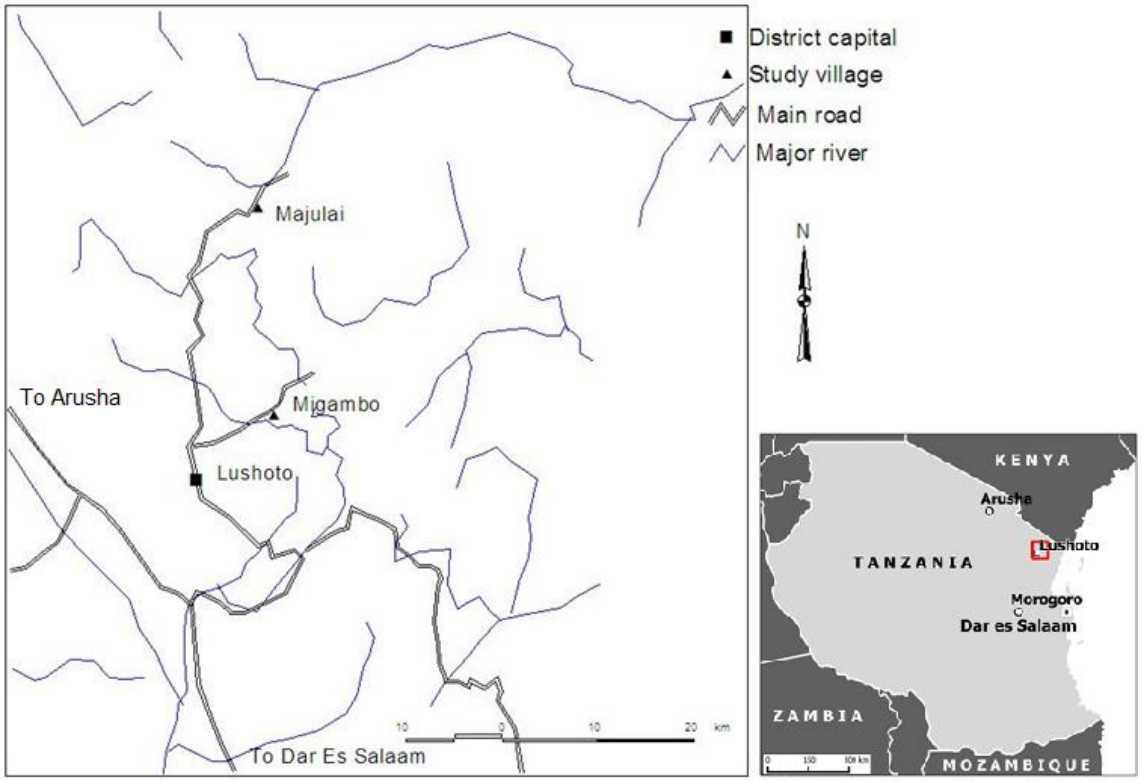

Fig. 1: Location Map of Migambo and Majulai villages, Lushoto District, Tanzania

According to the World Reference Base (WRB) [18], the soil type in Majulai site classifies as *Chromic Acrisol* (*Humic, Profondic, Clayic, Cutanic, Colluvic*) whereas in Migambo site the soil is *Haplic Acrisol* (*Humic, Profondic, Clayic, Colluvic*). The main land uses include cultivation on slopes and valley bottoms, 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 in valleys under rain fed or traditional irrigation. Beans are mainly grown during the long rainy season while maize is grown during the short rains. Round potatoes and fruits, namely peaches, plums, pears, avocado and banana are grown on ridge slopes under rain fed mixed farming. Round potatoes are also grown in valleys as sole crop or intercropped with maize.

Table 1: Rainfall characteristics (mm year^{-1}) in Majulai and Migambo village. Rainfall values for a dry and wet year have a 5 year return period

Village	**Annual rainfall (mm)**			**Rainfall erosivity (MJ mm ha^{-1} hr^{-1} year^{-1})**			
	Dry year	Average year	Wet year	Mean	Median	IQR	N
Majulai	900	1200	1500	12 354	10 156	9937	37
Migambo	800	1000	1300	6489	5973	2285	28

IQR = Interquartile range, N = number of years of continuous observation (Source: authors' calculation based on rainfall data from Lushoto (for Migambo) and Mlalo (for Majulai) rainfall gauges.

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2.2 *Miraba* establishment in runoff experiments

Miraba were established by using Napier grass (*Pennisetum purpureum*) barriers in runoff experiments in April 2011 about nine months before data collection started. Napier grass barriers forming *miraba* were established by planting tillers in a single row at 10 cm spacing perpendicular to slope and were maintained to about 50 cm wide strips. In the current study Napier grass barriers across the slope were spaced 5 m apart to mimic the recommended maximum effective width of hand made bench terrace [12]. It has been documented that soil conservation measures such as *Fanya Juu* and stone bunds tend to progressively form bench terraces when at a closer spacing [12; 19]. Moreover, the closer the grass strips are, the more effective they become [19]. Progressive bench terraces formation could also be possible under *miraba* when adjusted to appropriate spacing of grass strips. Natural bench terraces formations as a result of *miraba* implementation are much less expensive compared to mechanical bench terraces construction. Bench terraces are highly recommended for use in Usambara Mountains [20; 6; 7, 9]. On the other hand the spacing of Napier grass barriers forming *miraba* along the slope was set at 3 m apart.

2.3 Experimental Design

Closed runoff plots of 22 x 3 m in a randomized complete block design (RCBD) were set along lower ridge slopes at 50 % slope in Majulai and 45 % slope in Migambo village respectively. The plots were enclosed by *miraba* and bounded by pieces of wood that protruded 15 cm above the soil surface to prevent inflow and outflow from the plot boarders and that connected to three collector drums with hinged lids each drum having a volume of 220 litres. Maize (*Zea mays*) and beans (*Phaseolus vulgaris*) were planted in rotation as test crops in 2012 and 2013/14 rainy seasons. Maize was planted during short rains (*vuli*), while beans during long rains (*masika*)

The treatments included Runoff plots (Fig. 2) with: (i) *Miraba* with maize or beans (***MI***) (ii) *Miraba* with *Tithonia* mulching and planted with maize or beans (***MITH)*** (iii) *Miraba* with *Tughutu* mulching and planted with maize or beans (***MITG*)** (iv) plots without SWC measure and planted with maize or beans (Control) **(*CO*)** (v) Bare plots (***BA***), all replicated three times.

Mulching materials were the leaves of the readily available shrubs in both villages namely *Alizeti Pori* (*Tithonia diversifolia*) and *Tughutu* (*Vernonia myriantha*). Tithonia has frequently been reported as a good green manure while also *Tughutu* said to potentially contain NPK [21; 22; 23]. Samples were collected from each mulching material for determination of total N, available P, K^+, Mg^{2+}, Ca^{2+} and Na^+.

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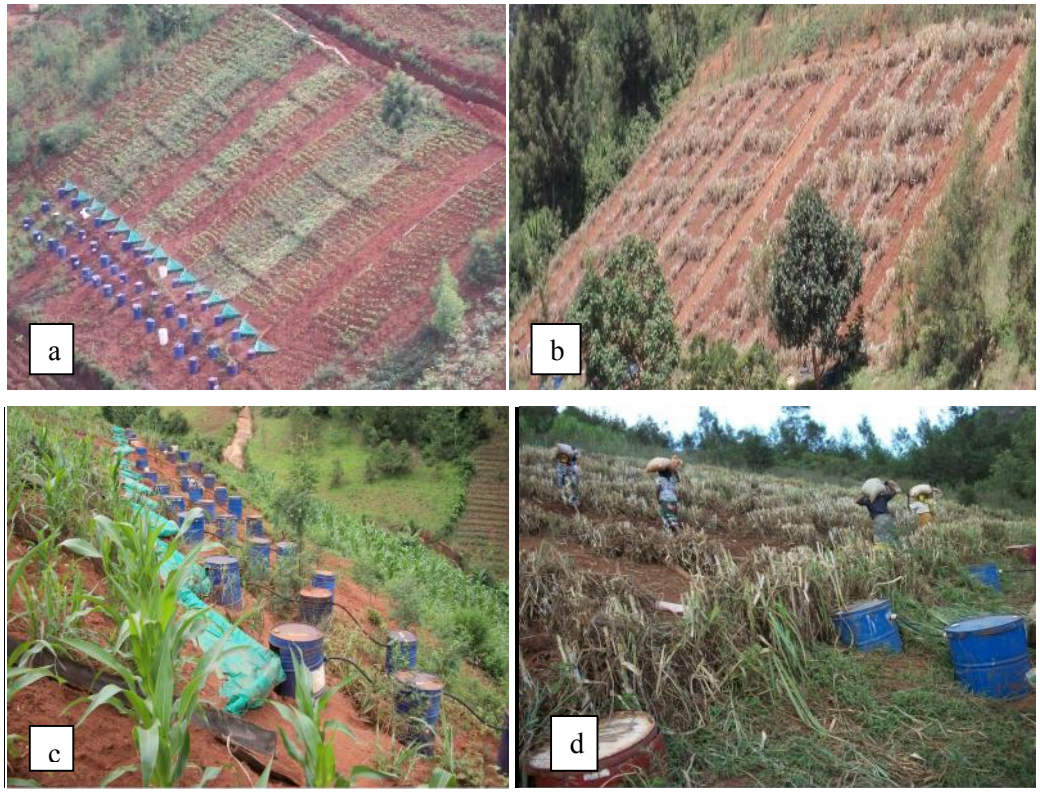

Fig. 2: Illustration of experimental plots a) Majulai plots layout b) Migambo plots layout c) Majulai plots with maize crop d) Migambo plots and application of farm yard manure

2.4 Rainfall data collection

Daily rainfall was measured from 1 January 2012 to 16 February 2014 using standard rain gauges and tipping buckets with a CR10 data logger (Campbell Scientific, Logan UT) installed at the experimental sites in Migambo and Majulai villages.

2.5 Runoff, Sediment and Nutrient Losses Determination

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 cm 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 done by lowering a one liter plastic bottle from the water surface to the bottom of the drum, and samples of about 100 ml were collected at the bottom, middle and upper part when runoff depth in the drum was above 25 cm. Heavy sediments in the drums were scooped out weighed and a 1 kg soil sample collected, oven dried for at least 24 hours at 105 ^{0}C and weighed for dry soil loss calculation. The suspended sediment samples were filtered using Whatman No. 42 filter paper and dried for at least 24 hours at 105 ^{0}C until constant weight was obtained [24] and the soil loss (Mg ha^{-1}yr^{-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. These losses were finally added to compute total soil loss per annumm. The soil

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samples for nutrient loss determination were collected by decanting the suspended sediment in buckets.

Where each runoff experimental site a soil profile was excavated and soil samples were collected from each horizon for characterization. Undisturbed core soil samples were taken at 0-5 cm, 45- 50 cm and 95-100 cm soil depth by Kopecky's core rings (100 cm^3) for bulk density, gravimetric moisture and available moisture determination. The soil was classified to level-2 according to the World Reference Base for Soil Resources WRB [18].

2.6 Crop yields

Maize (*Zea mays*) PANNAR 67 variety and beans (*Phaseolus vulgaris*) Kilombero variety were planted in runoff plots during the 2012 and 2013/14 rain seasons with maize in the short rains (*vuli*) and beans in the long rains (*masika*) 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 one month before the maize was harvested in Migambo and two weeks before harvesting maize in Majulai village. Farmyard manure with 1.7 % N, 0.4 % P and 1.9 % K was basal and spot applied at the rate of 3.6 Mg ha^{-1} air-dry weight, 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 and dried to about 13 % moisture content.

2.7 Soil analysis

Soil analysis was done following the [25] Laboratory Manual. Organic carbon (OC) was measured using the dichromate oxidation method, total nitrogen (TN) by 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.

2.8 Determination of the RUSLE factors

The RUSLE equation expresses average annual soil loss Mg ha^{-1} $year^{-1}$ caused by sheet and rill erosion [26]; $A = RKLSCP$……..…….....(1)

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

The equation developed by [27] was used to calculate R factor. Such that $R = 50.7\ MFI - 1405$……..……..….(2)

Where MFI is the Modified Fournier Index calculated from $MFI = \sum_{n=1}^{\infty}(p^2)/\mathrm{P}$……(3)

Where p is the 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, C and P factors are equal to 1. Thus K factor was calculated from $K = A_{bare\ plot}/(RLS)$……(4)

According to [28] $LS = [0.065 + 0.0456s + 0.006541s^2] \times (l/22)^{1/2}$…….....(5)

Where: s, is the slope gradient in %; l, is the plot length in m; constant ½, is used where slope steepeness is ≥ 5 %

The effectiveness of *miraba* on reducing soil loss was determined by the use of C and P factors when compared to the bare plots. The C factor in the long rain season was function of the bean crop cover; in the off season the C factor set by weed cover, while in short rains maize cover was considered. Therefore, the C factor was determined as the ratio between the seasonal or

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annual soil losses of the control plot to the seasonal or annual soil losses of the bare plot. While the *P* factor was determined as the ratio between the seasonal or annual soil loss under *miraba* plots to the seasonal or annual soil loss under control plots.

C (*CO* plot) = *A* (*CO* plot) / *A* (*BA* plot)…… (6)

P (MI plot) = *A (MI plot)* / *A* (*CO* plot)…….……..... (7)

P (MITH plot) = *A (MITH plot)* / *A* (*CO* plot)……..……..... (8)

P (MITG plot) = *A (MITG plot)* / *A* (*CO* plot)…….....……... (9)

Where: *A* (*CO* plot), is the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under control plots. *A* (*BA* plot), is the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under control plots. A ***(MI, MITH** or **MITG** plot),* is respectively the soil loss (Mg ha^{-1} $season^{-1}$ or Mg $ha^{-1}yr^{-1}$) under *miraba*, *miraba* with Tihtonia mulching and *miraba* with *Tughutu* mulching plots. The effectiveness of *miraba* on reducing soil loss was determined by the percent of *C* and *P* factors with reference to bare plots. The effectiveness of *miraba* on reducing nutrient losses was also calculated in percentages compared to bare plots.

2.9 Statistical analysis

Bartlett's test for homogeneity of variances was conducted to test data normality using GenStat software [29]. Rainbow software [30] was used to analyze the annual rainfall probabilities of exceedance frequencies at 20 % wet years, 50% for normal years and 80 % for dry years based on 37 years of observations (1975-2011) for Majulai and 28 years (1986-2013) for Migambo village. The relationships between daily rainfall and daily runoff were determined by Linear Regression Analysis with threshold runoff values obtained from the X-axis intercept. Analysis of Variance (ANOVA) in GenStat statistical software [29] was performed where Least Significant Difference ($LSD_{0.05}$) was used to detect mean differences between treatments.

3.0 RESULTS AND DISCUSSION

3.1 Rainfall erosovity between the two villages with contrasting climatic conditions

The annual and seasonal rainfalls recorded during the two consecutive years are presented in (Table 2), while rainfall distribution in (Fig. 3). It can be seen in Migambo village that 2012 was a dry year while 2013 corresponded to a normal year, whereas in Majulai village 2012 was a normal year while 2013 corresponded to a dry year. As the rainfall depth was higher in Majulai village than Migambo village in 2012 rainfall erosivity *R* factor is also higher in Majulai, while in 2013 the higher values of rainfall depth and *R* factor were observed in Migambo village (Table 2)

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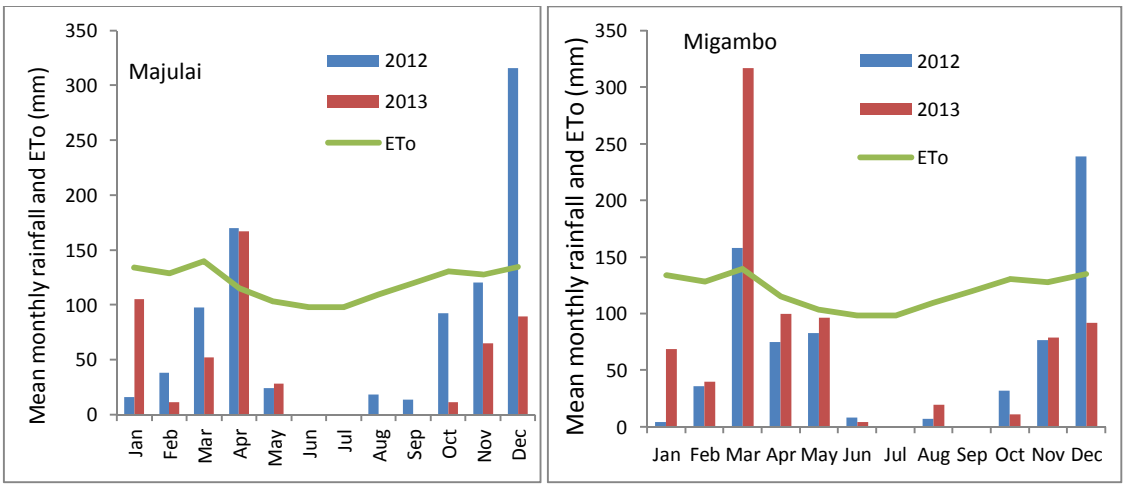

Fig. 3: Rainfall distribution in Majulai and Migambo villages and estimated reference evapo-transpiration (ETo) measured during 2012 and 2013; ETo determined according to New_LocClim estimator; [16].

3.2 Soil loss in relation to SWC measures and the two villages with contrasting climatic conditions

From our results (Table 2), Majulai village had significantly ($p < 0.001$) higher annual soil losses than Migambo in 2012, but in 2013 annual soil losses were significantly ($p < 0.001$) higher in Migambo than in Majulai village. The difference in soil losses between the two villages can partly be attributed to the rainfall depth (Table 2), 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 [31], where soil losses in Makonde plateau were much higher than inland plains and rainfall depth was spotted as the main contributing factor. The relatively steeper slope in Majulai than Migambo could also explain the soil loss differences. This is also spported by the work of [32] where slope gradients was found to be a strong determinant of soil loss. On the other hand soil losses differed significantly ($p < 0.001$) between SWC measures in both villages. Soil losses followed the trend that bare plots > crop land with no SWC measures > crop land with *miraba* sole > crop land with *miraba* and Tithonia or *Tughutu* mulching. The reduced soil losses under *miraba* and *miraba* with mulches could be explained by the effect of grass barriers forming *miraba* that captured some soil sediments that were with runoff. This observation is also supported by [33] in Lake Victoria Uganda who reported grass strips to effectively trap more than 70 % sediments under natural rainfall. Besides *miraba* were progressively forming bench terraces such that the terrace height reached about 1 m in Migambo and 0.7 m in Majulai village after two years of experimentation. The terraces that were formed cutoff the slope steepeness resulted into reduced runoff velocity and increased rate of infiltration which intern reduced runoff volume thus reduced sediment losses. On the other hand mulches tend to reduce runoff velocity, increased rate of infiltration and reduced runoff volume thus reduced sediment losses. Similarly the effectiveness of mulching in reducing soil losses were also reported by [34; 35] in Nepal where mulching was found to reduce annual soil loss by 60 to 90 percent in maize – mustard cropping system as compared to conventional farmers' practice.

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Table 2: Rainfall and annual soil losses measured in Majulai and Migambo villages Lushoto District, Tanzania

		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	7.1	23.4
Short rains (Oct. – Jan.)		636.9	165.1	415.8	222.7
Annual		906	528	718	826
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)		7774	3857	5859	7247
		Majulai		Migambo	
Soil loss Mg ha^{-1} $year^{-1}$		2012	2013	2012	2013
Bare plots	Replicates				
	1	254.6	100.6	175.6	177.1
	2	262.7	107.9	182.0	188.3
	3	266.9	105.7	183.6	186.6
	Mean	261.4	104.7	180.4	184.0
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	20.10	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 ($P \leq 0.05$)		4.14	4.06	4.14	4.06
SE		1.39	1.37	1.39	1.37

LSD: least significant different; SE: standard error of means

3.3 Rainfall-Runoff responses under *miraba* practices

The slope of the regression line was used as a measure of the rainfall-runoff response. The rainfall-runoff response varied between the villages and between soil conservation measures (Fig. 4a). The differences can strongly be explained by the influences of the studied soil conservation measures; bare plots had the highest annual runoff coefficient as for runoff depth, while *Miraba* with Tithonia and *Miraba* with *Tughutu* mulching had the lowest (Table 4 & Fig. 4). The rainfall threshold values to initiate runoff varied between the soil conservation measures and between the studied villages. These differences were also directly associated with the effects of soil conservation measures and the differences in climatic conditions between the villages (Fig. 3). The rainfall threshold values to initiate runoff follow the trend that *miraba* with Tithonia and *miraba* with *Tughutu* mulching > *miraba* sole > crop land with no SWC measures > bare land in both villages. *Miraba* with mulching had the highest rainfall threshold values e.g. 5.0 mm in

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Migambo village and lowest values under bare land e.g. 3.4 mm in Majulai village. The observed rainfall threshold values are very low; this implies that the soils of Usambara Mountains are very sensitive to runoff and therefore to soil loss, thus implementation of improved miraba could be very effective device agaist soil degradation by concentrated flow erosion in the area.

Table 3: Daily runoff (mm) (Y) response to daily rainfall (mm) (X) for Majulai and Migambo villages in Usambara Moutains, Tanzania

Village/Treatments	Regressions equations	Runoff threshol	R^2	No. of rainfall incedences	No. of runoff observations
Majulai					
Bare plots	Y=0.230X-0.79	3.4	0.87	118	353
Control	Y=0.190X-0.72	3.8	0.81	118	353
Miraba	Y=0.065X-0.26	4.0	0.66	118	353
Miraba+Tithonia	Y=0.038X-0.15	4.2	0.51	118	353
Miraba+Tughutu	Y=0.037X-0.16	4.2	0.52	118	353
Migambo					
Bare plots	Y=0.200X-0.76	3.8	0.93	122	365
Control	Y=0.160X-0.68	4.3	0.92	122	365
Miraba	Y=0.040X-0.19	4.7	0.81	122	365
Miraba+Tithonia	Y=0.030X-0.13	5.0	0.91	122	365
Miraba+Tughutu	Y=0.027X-0.15	4.9	0.89	122	365

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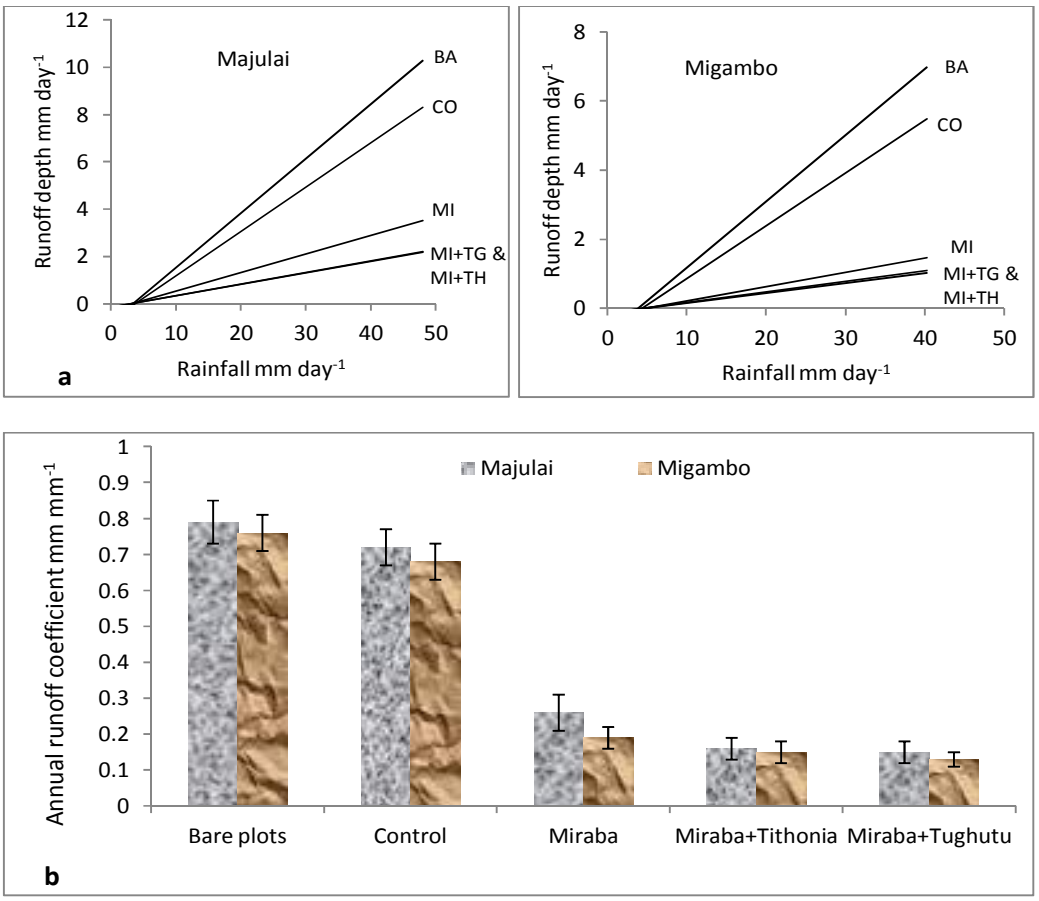

Fig. 4: a) Rainfall-runoff response curves b) runoff coefficients for different soil and water conservation measures in Usambara Mountains, Tanzania. (Key: BA= Bare plots; CO= Control; MI= *Miraba* sole, MI+TG= *Miraba* with *Tughutu* mulching and MI+TH= *Miraba* with Tithonia mulching).

3.4 Effectiveness of *miraba* in relation to RUSLE factors

The relative effectiveness of *miraba* practices with reference to soil losses from crop land with no SWC measures are presented in (Fig. 5). It can clearly be seen that *miraba* sole, *miraba* with Tithonia and *miraba* with *Tughutu* mulching were more effective in reducing soil loss in Migambo than in Majulai village. This can be attributed to the differences in rainfall distribution where there is poor rainfall distribution in Majulai village (Fig. 3) thus Napier grass in the *miraba* dies during dry spells, while the reliable rainfall in Migambo makes Napier grass barriers that form *miraba* to persist throughout the year and thus form more dense grass strips as compared to Majulai village. It is evident from (Fig. 4) that *miraba* reduced soil losses by about 80% in Majulai and 90% in Migambo village relative to soil losses from crop land with no SWC measures. On the other hand *miraba* with Tithonia and *Miraba* with *Tughutu* mulching reduced soil losses by 90% in Majulai and 95% in migambo village relative to soil losses from crop land with no SWC measures (Fig. 5).

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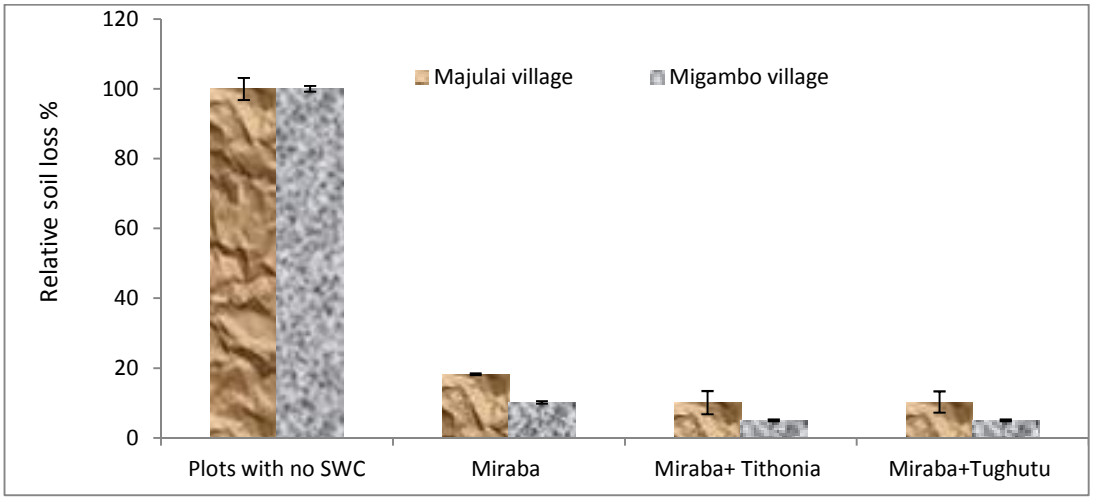

Fig. 5: The mean relative soil loss with STDEV from 3 replicates under *miraba* practices in Majulai and Migambo villages.

Based on the work by [31] RUSLE factors were found to provide better insight when assessing the effectiveness of soil conservation measures. The observed *K* factors were 0.0016 (Mg h MJ^{-1} mm^{-1}) for *Chromic Acrisol* (*Clayic*) in Majulai and 0.0018 (Mg h MJ^{-1} mm^{-1}) for *Haplic Acrisol* (*Clayic*) in Migambo village (Tabe 5). These *K* values are very low, which indicate the high susceptibility of the studied soils to erosion. More erodible soils such as silt loams have their *K* factor ranging from 0.03 – 0.05 (Mg h MJ^{-1} mm^{-1}) [e.g. 36; 37]. The *P* factor values are much higher in Majulai than in Migambo village (Table 4 & 5) indicating that *miraba* practices have stronger effect in Migambo than in Majulai village. This can be explained by the good rainfall distribution in Migambo as compared to Majulai village which experiences long dry spells (Fig. 3) resulting natural death of *miraba* Napier grass and, thus, reducing its effectiveness. Similarly significant differences were observed between *miraba* practices where *Miraba* with Tithonia and *Miraba* with *Tughutu* mulching were more effective in reducing soil loss than miraba sole and control (plots with maize or beans crop). This is due to the fact that grass barriers forming *miraba* and mulches tend to reduce runoff speed and thus increasing the rate of infiltration. This tendency was also reported by [38, 39, 33 and 40]. The most effective *miraba* practices in both villages are thus *miraba* with Tithonia and *miraba* with *Tughutu* mulching (*P* = 0.11 for Majulai and *P* = 0.002 for Migambo village).

Table 4: Annual RUSLE factors for the Majulai and Migambo villages in Usambara Mountains, Tanzania based on soil loss measurements on runoff plots for two years 2012-2013

RUSLE factors			Majulai		Migambo		
		n	2012	2013	2012	2013	Sig n.
R (MJ mm ha^{-1} h^{-1} $year^{-1}$)		1	7774	3857	5859	7247	ns
K (Mg h MJ^{-1} mm^{-1})		1	0.0018	0.0015	0.0020	0.0017	ns
C (dimensionless)							
	Maize and beans	3	0.71	0.70	0.70	0.70	ns
P (dimensionless)							
	Miraba	3	0.19	0.17	0.10	0.10	***
	Miraba+Tithonia	3	0.11	0.10	0.06	0.04	***
	Miraba+*Tughutu*	3	0.11	0.10	0.06	0.04	***
	LSD ($p \leq 0.05$)		0.03	0.03	0.03	0.03	

LSD: least significanr different; Sign. ns: not significant; ***: $p < 0.001$. Mann-Whitney U test for *R*, *K* and *C* factors; Nested ANOVA for *P* variables

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Table 5: RUSLE factors for the Majulai and Migambo villages in Usambara Mountains, Tanzania based on soil loss measurements on runoff plots from 2012-2014 rain seasons

	Majulai			Migambo			
RUSLE factors	Median	IQR	n	Median	IQR	n	Sign.
R (MJ mm ha^{-1} h^{-1} yr^{-1})	5816	1958	2	6553	694	2	ns
K (Mg h MJ^{-1} mm^{-1})	0.0016	0.0002	2	0.0018	0.0002	2	ns
C (dimensionless)	Mean	STDEV		Mean	STDEV		
Beans/weed/Maize	0.71	0.02	6	0.70	0.005	6	ns
P (dimensionless)	Mean	STDEV		Mean	STDEV		
Miraba	0.18	0.002	6	0.10	0.003	6	***
Miraba+Tithonia	0.11	0.03	6	0.05	0.002	6	***
Miraba+*Tughutu*	0.11	0.02	6	0.05	0.002	6	***
LSD ($p \leq 0.05$)	0.03			0.03			

LSD: least significant different; IQR: inter-quartile range; STDEV: standard deviation; n: number of observations; Sign. ns: not significant; ***: $p < 0.001$. Friedman test for *R*, *K* and *C* factors; Nested ANOVA for *P* variables

3.5 Estimates of nutrient losses under the studied SWC measures

Soil nutrient losses under *miraba* practices are presented in (Fig. 6). Soil nutrient losses were significantly ($p < 0.001$) differences between SWC practices. The differences in soil nutrient losses can directly be associated with the effects of *miraba* practices intervention (Table 6). Soil losses followed the trend that bare plots > crop land with no SWC measurecont > crop land with *miraba* sole > *miraba* with *Tughutu* and *miraba* with Tithonia mulching (Table 6). Similarly [15] in Migambo village, Tanzania reported lower losses of total N, P and K^+ in plots with *miraba*, Farmyard manure and Tithonia mulching than in crop land with no SWC measures.

The relative effectiveness of *miraba* practices with reference to soil losses from crop land with no soil conservation measures are presented in (Fig. 6). There are obvious differences in soil nutrient losses control between soil conservation measures. It is clear that *miraba* with mulching reduced most of soil nutrients losses by about 95% in Migambo and 85% in Majulai village, while *miraba* sole reduced nutrient losses by 90% in Migambo and about 80% in Majulai village (Fig. 6).

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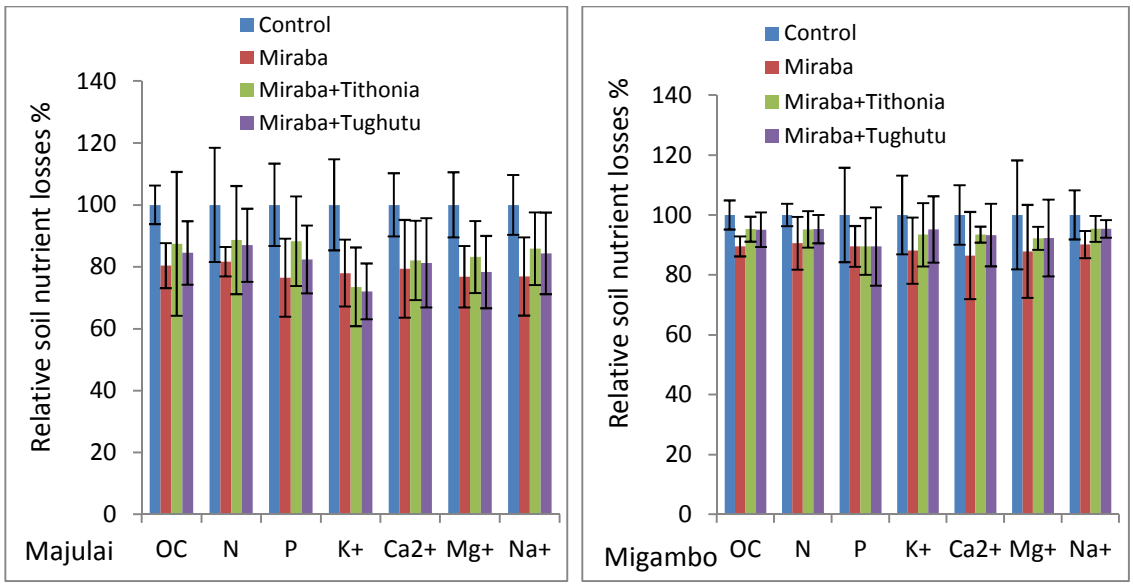

Fig. 6: The mean relative nutrient loss under *miraba* practices in Majulai and Migambo village

Table 6: Estimates of soil nutrient loss (kg ha^{-1} year^{-1}) under *miraba* in the two villages

Village	Treatments	n	OC	N	P	K^+	Ca^{2+}	Mg^+	Na^+
Majulai									
	Bare	72	4835.7	478.[illegible]	1.0	41.3	80.2	18.0	15.5
	Control	72	3049.7	306.[illegible]	0.8	13.6	62.7	18.3	8.8
	Miraba	72	632.7	59.2	0.2	2.7	12.8	4.0	2.3
	Miraba+Tithonia	72	414.7	36.6	0.1	3.8	8.2	2.9	1.4
2012	*Miraba+Tughutu*	72	518.3	42.5	0.1	4.1	11.5	4.0	1.5
	Bare	46	2024.3	176.[illegible]	0.7	5.9	23.9	8.4	6.5
	Control	46	1496.7	125.[illegible]	0.9	6.8	25.9	8.4	4.6
	Miraba	46	260.7	20.3	0.2	1.8	5.5	2.2	0.8
	Miraba+Tithonia	46	158.7	12.6	0.1	1.6	7.7	1.6	0.5
2013	*Miraba+Tughutu*	46	187.7	13.9	0.2	1.6	5.1	1.8	0.6
Migambo									
	Bare	51	6092.3	548.[illegible]	0.8	12.0	371.[illegible]	[illegible]	11.3
	Control	51	4908.7	474.[illegible]	0.7	19.7	262.[illegible]	46.3	8.8
	Miraba	51	450.0	40.7	0.1	1.9	30.7	4.9	0.8
	Miraba+Tithonia	51	251.7	27.2	0.1	1.7	20.3	4.5	0.5
2012	*Miraba+Tughutu*	51	276.7	26.0	0.1	1.2	20.2	[illegible]	0.5
	Bare	71	6308.7	525.[illegible]	1.2	15.9	437.[illegible]	74.4	12.6
	Control	71	4418.0	421.[illegible]	1.2	19.7	266.[illegible]	49.8	8.4
	Miraba	71	531	43.8	0.1	2.8	41.1	6.8	0.9
	Miraba+Tithonia	71	192.7	15.8	0.1	0.9	14.5	3.0	0.3
2013	*Miraba+Tughutu*	71	183	16.4	0.1	0.7	15.4	3.1	0.3

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3.6 Impact of *miraba* on crop productivity in the two studied villages

The yield of maize and beans are presented in (Table 7). The results show that there is a significant ($p < 0.05$) difference in crop yields between *miraba* practices and between the two studied years in both villages. In Majulai village maize grain yields were higher under *miraba* with *Tughutu* mulching than under miraba with Tithonia, *miraba* sole and control in 2012, but there was no maize yield in 2013 due to drought. The trend of beans grains yields followed the trend that: *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > under the control. The trends were similar in Migambo village where *miraba* with *Tughutu* > *miraba* with Tithonia > *miraba* sole > control for both maize and beans grain yields (Table 7). Maize grain yields were significantly ($p < 0.05$) higher in 2013 than in 2012, but there were no significant ($p > 0.05$) difference in beans grain yields between two years of study, however, the higher *p* values in 2013 than in 2012 indicates higher beans grain yields in 2013 than in 2012. There were also some differences in maize and beans yields between the two villages, with higher yields in Migambo than Majulai (Table 7). The observed crop yields under the studied SWC practices (Table 7) were higher than the average yields according to [41] of 1.5 Mg ha^{-1} for maize and of 0.7 Mg ha^{-1} for beans in Tanzania. It is clearly observed that the crop yield differences between treatments are highly influenced by *miraba* practices intervention (Table 7), while the crop yield differences between villages could partly be explained by differences in climatic condition in the two villages. The rainfall in Majulai is unreliable while Migambo village experinces reliable rainfall with a fair distribution in its growing seasons (Fig. 3).

In 2012 the average maize yield in Majulai village increased by 177 % under *miraba* with Tughutu, 128 % under *miraba* with Tithonia and 78 % under *miraba* sole while no maize yields in 2013 due to drought. A study by [15] reported increased maize yield by 57 % under *miraba* than under control in Migambo village, while beans yield did not differ, the maize yield differences were associated with the improved soil properties due to the effects of *miraba.* Beans grain yields in 2012 and 2013 respectively increased by 58 % and 85 % under *miraba* with *Tughutu*, 51 % and 76 % under *miraba* with Tithonia and 37 % and 44 % higher in plots with *miraba* sole than under control. Whereas in Migambo village during the same period the average maize yield increased by 149 % and 195 % under *miraba* with *Tughutu*, 109 % and 147 % under *miraba* with Tithonia and 70 % and 90 % higher under *miraba* sole than under control. [7] in Western Usambara Mountains reported an increased maize and beans yields respectively by 180 kg ha^{-1} and 20 kg ha^{-1} in plots with grass strips against an average yield of 1250 kg ha^{-1} and 150 kg ha^{-1} in plots without SWC measure. The crop yield increments were also associated with the effects of the intervened grass strips.

Beans grain yields in 2012 and 2013 respectively increased by 48 % and 70 % under *miraba* with *Tughutu*, 41 % and 58 % under *miraba* with Tithonia and 27 % and 37 % higher in plots with *miraba* sole than under control. It is clear that soil conservation measures contribute to higher crop yields by reducing the loss of plant nutrients and assuring a better water supply to the crop. The study by [13] in Usambara Mountains observed the average maize and beans yields of 270 % and 583 % higher in well managed farms with good quality terraces, well maintained grass strips, good quality seed for crops, adequate use of manure or fertilizer as compared to the control i.e the farms with no terracing, no grass strips, use of local seed material, little use of manure and no use of fertilizer and no tree cover. The yield differences was reported to be influenced by the sustainable land management categories studied.

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Table 7: Impact of *miraba* to crops yield in Majulai and Migambo villages

Village	SWC measures	N	Mean crop grains Yield (Mg ha^{-1}) in 2012		Mean crop grains Yield (Mg ha^{-1}) in 2013	
			Maize	Beans	Maize	Beans
Majulai						
	Plots with no SWC	3	0.71	0.59	0.0	0.59
	Miraba sole	3	1.26	0.81	0.0	0.85
	Miraba with Tithonia	3	1.62	0.89	0.0	1.04
	Miraba with *Tughutu*	3	1.97	0.93	0.0	1.09
	LSD (P ≤ 0.05)		0.15	0.15	0.0	0.15
	SE.		0.05	0.05		0.05
Migambo						
	Plots with no SWC	3	1.57	0.64	1.64	0.67
	Miraba sole	3	2.58	0.81	3.12	0.92
	Miraba with Tithonia	3	3.18	0.90	4.05	1.06
	Miraba with *Tughutu*	3	3.79	0.95	4.83	1.14
	LSD (P ≤ 0.05)		0.41	0.41	0.41	0.41
	SE		0.14	0.14	0.14	0.14

LSD: least significant different; SE: standard error of means

2.7 CONCLUSIONS AND RECOMMENDATIONS

Though miraba with either Tughutu or Tithonia mulching showed greater potential in reducing soil and nutrient losses than *miraba* soile, nevertheless, *miraba* with *Tughutu* mulching was more effective in improving crop yields than miraba with Tithonia while *miraba* sole was the least effective. The rainfall erosivity, assessed by the *R* factor, is clearly distinct in the two villages and this is linked to climatic condition differences. Though the soils of Usambara Mountains are susceptible to erosion, the *C* and *P* factors indicate that these soils are responsive to soil conservation measures. However, more local shrubs and grasses should be investigated for use as both green manure and soil conservation measure under *miraba*. Furthermore, researches need to be conducted to investigate effectiveness of the studied soil conservation practices on water-shed protection and avoiding river streams from sedimentation. It is strongly recommended that Tithonia and *Tughutu* shrubs be planted in the boarders of the farms plots along the slope for easy availability and sustainability. It is also recommended in Majulai village that drought resistant grasses such Guatemala be used for establishing *miraba* since Napier grass which are mostly preferred for (fooder) is sensitive to drought.

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