The Influence of Selected Soil Conservation Practices on Soil Properties and Crop Yieldsin the Usambara Mountains, Tanzania

S. B. Mwango[1*], B. M. Msanya[1], P. W. Mtakwa[1], D. N. Kimaro[2], J. Deckers[3], J. Poesen[3], I. Nzunda[1], S. Ringo[1]

[1]Department of Soil Science, Sokoine University of Agriculture, P.O. Box 3008 Chuo Kikuu, Morogoro, Tanzania.
[2]Department of Agricultural Engineering and Land Planning, Sokoine University of Agriculture, P.O. Box 3003 Chuo Kikuu, Morogoro, Tanzania.
[3]Department of Earth & Environmental Sciences, KU Leuven, Celestijnenlaan 200 E, B-3001 Heverlee, Belgium

Authors' contributions

This work was carried out in collaboration between all authors. SB designed the study, wrote the protocol, conducted field work, performed statistical analysis,and wrote the first draft of the manuscript. BM designed the study, conducted field work, managed the literature searches and edited drafts. PW designed the study, conducted field work and edited drafts. DN, JDandJP designed the study and edited drafts.IN and SR conducted field work. All authors read and approved the final manuscript

ABSTRACT

The Usambara Mountains in Tanzania are severely affected by soil erosion which has led to deterioration of soil properties and reduced crop productivity. Indigenous soil erosion control measures such as *miraba*which arewidelypractised in the areahave yielded little success. Field plot experiments were laid down in Majulai and Migambo villages from 2011 – 2014 on typical soils of the area (*Acrisols)*.The aim was to single out soil properties developedunder the studiedsoil conservation practicesand their impact on crop productivity with reference to maize (*Zea mays*) and beans (*Phaseolus vulgaris*).Results showed thattotal N, OC, available P, Ca^{2+}, Mg^{2+}, K^+ and pHwere powerful (*P* = .05) attributes that discriminated conservation measures. Magnitudes of the discriminating attributes followed the trend:*miraba* with *Tughutu*(*Vernoniamyriantha*) mulching >*miraba* with Tithonia (*Tithoniadiversifolia*)mulching >*miraba* sole > cropland with no'Soil and Water Conservation'(SWC) measures (control).Contents ofmicro-nutrients did not differ significantly with SWC measures except for Zn which was significantly (*P* = .05)lowin the control. Bulk density and available moisture content (AMC) were also strong descriminitorsof conservation measures. Maize and bean grain yields differed significantly (*P* = .05)with the trend:*miraba* with *Tughutu*>*miraba* with Tithonia>*miraba* sole > control in both villages. Crop yields under *miraba*were a function of AMC and pH (R^2= 0.71); AMC, available P, Ca^{2+} and K^+ (R^2= 0.89) under *miraba* with Tithonia mulching; AMC, available P, Ca^{2+} and K^+ (R^2= 0.90) under *miraba* with *Tughutu* mulching. These findings imply

*Corresponding Author: E-mail: sibawaymwango@yahoo.com

that *miraba* with *Tughutu*mulching had greater potential in improving soil properties and crop yields than *miraba* with Tithonia mulching and *miraba* sole.

Key words: Soil erosion, miraba, Tithonia, Tughutu, maize yields, bean yields

1.0 INTRODUCTION

The problem of soil erosion is global, and has been reported all over the world to affect agricultural sustainability [1; 2; 3]. For example the Usambara Mountains of Tanzania whichare characterized by a high population density of about 120.4 persons/km^2, and practise farming on steep slopes of more than 40 % due to land scarcity, suffer fromsevere soil degradation by water erosion[4; 5]. Soil loss,nutrient depletion and reduced capacity of the soil to retain water are major forms of soil degradation in the area. These have lead to deterioration of soil properties and reduced crop productivity[6]. Population pressure in the area has led to increased land use intensity and expansion of cultivation offood and cash crops in valleys and sloping land [4; 5].

There is a growing concern that land use practices in the Usambara Mountains may not be sustainable because of their detrimental effects on soil properties[4; 7]. To address the problem of soil degradation by water erosion, Usambarafarmers developed indigenous 'Soil and Water Conservation'(SWC) measures such *miraba*(rectangular grass bound strips that do not necessarily follow contour lines),micro-ridges and stone bunds as integral part of their farming systems, while introduced measures have often been rejected or minimally adopted because they were expensive interms of money and labour[9; 8].Surprisingly however,theindigenous soil erosion control measures implemented in the area have remained poorly documented[8].Besides,farmers' efforts to conserve the degrading landhaveyielded very little success,and deterioration of some soil properties are activeevenin places where SWC measures are practised [9; 4; 7; 10]. This is partly due to limited knowledge on the effectiveness of theindigenous SWC practices. Moreover, indigenous SWC measures in the area have been for decades left traditional with little scientific intervention for improvement [9; 10].

Indigenous SWC measures have been documented to play a considerable role in controlling soil erosion and improving crop yield. For example,stone bunds in Ethiopia have been reported byVancampenhout*et al*.[11]to be effective in increasingyields from 632 to 683 kg ha^{-1} for cereals, from 501 to 556 kg ha^{-1} for *Eragrostistef* and from 335 to 351 kg ha^{-1} for *Cicerarietinum* as compared to the situation without stone bunds.Likewise the study byMsita[10] in UsambaraMoutains, Tanzania revealed *miraba* to have some contribution in controlling soil erosion and increased maize yield form 0.7 Mg ha^{-1} in cropland with no soil conservation measures to 1.1 Mg ha^{-1} in farms with *miraba*.

Although studies on the effectiveness of some introduced SWC technologies on soil erosion control and agricultural productivity have recently been carried out in Western Usambara Mountains [9; 7], the contribution of indigenous SWC measures including *miraba*which is the most preferred in the study areahave not fully been investigated [4; 10]. Even when investigated, not a single studyhas attempted to explain the linkages that exist between soil propertiesand crop productivity associated with SWC technologies.Furthermore, land use planners, agricultural managers and extension officers need sound information to guide implementation of SWC practices within the context of improved soil properties and maximized crop production;yet, at present such information does not exist.

The study reported herein,wastherefore aimed at establishing the linkages between identifiedsoil properties associated with soil conservation practices namely*miraba* and *miraba* with various mulching matrerialswith reference to productivity of maize (*Zea maize*) and beans (*Phaseolus* *vulgaris*) under smallholder farming conditions in Usambara Mountains. The objectives of this study were (i) to identify soil properties that discriminate between selected SWC practices (ii) to test whether the identified soil properties correlated with crop yield and (iii) to investigate the relation between the identified soil properties and crop yield.

2.0 MATERIAL AND METHODS

2.1 Description of the Study Sites

Migambo and Majulai villages in Western Usambara Mountains, Lushoto District, Tanzania (Fig. 1) are located between 38^{0}15’ to 38^{0}24’ E and 4^{0}34’ to 4^{0}48’ S. Migambo is humid cold with mean annual air temperature of 12 ^{0}C−17 ^{0}C and an annual precipitation ranging from 800–2300 mm. Majulai is dry warm with mean annual air temperature between 16 ^{0}C and 21 ^{0}C and annual precipitation of 500–1700 mm.The annual evapo-transpiration (ETo) as estimated by the local climate estimator software (New_LocClim) [12] ranges from 100 mm to 145 mm. The UsambaraMountains support a large population density ofmore than 120.4 persons/km^2[5].According to theWorld Reference Base (WRB) for Soil Resources[13] the soils in Majulai site classified as *ChromicAcrisols* (*Humic, Profondic, Clayic,Cutanic,Colluvic*) whereas in Migambo site the soilsare*HaplicAcrisols*(*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 grown mainly during long rains and 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 or intercropped with maize.

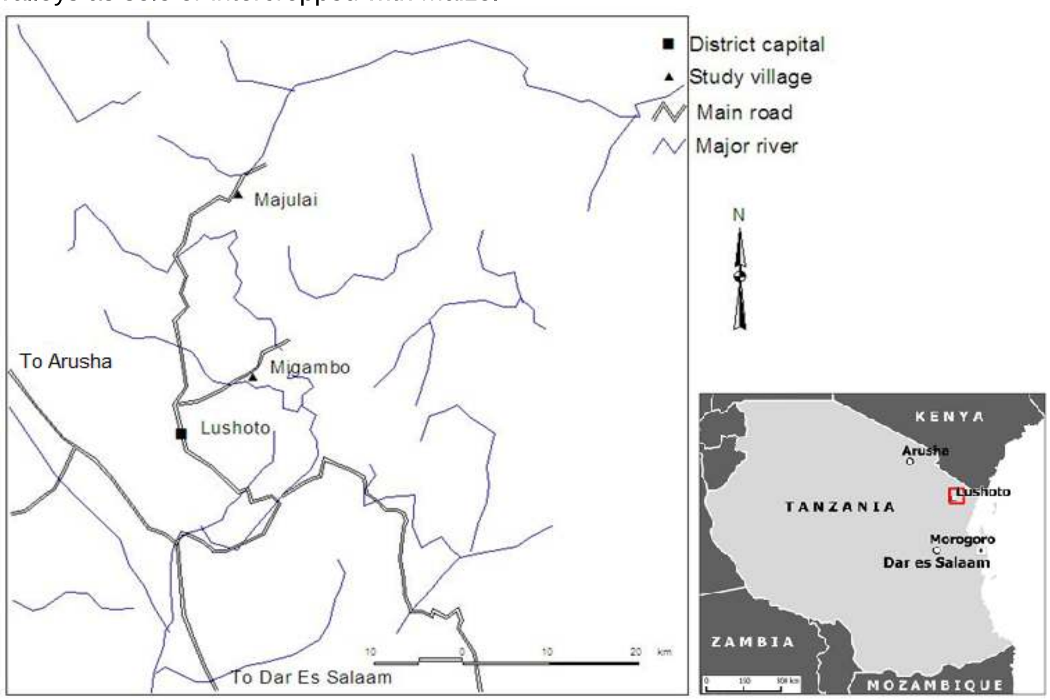

Fig.1: Location Map of Migambo and Majulai villages, Lushoto District, Tanzania

2.2 Establishment of *Miraba* in Field Plots

Miraba were established using Napier grass (*Pennisetumpurpureum*) barriers in field plots in April 2011 about nine months before crops were grown. Tillers ofNapier grass were planted in single rows 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 to mimic the recommended maximum effective width of hand made bench terraces[14]. On the other hand, the spacing of Napier grass barriers forming *miraba* along the slope was set at 3 m apart.

It has been documented that soil conservation measures such as *Fanya*Juu (hillside ditches made by throwing excavated soil on the upslope of the ditch, built along contour lines at appropriate intervals depending on slopegradient)and stone bunds tend to progressively form bench terraces when at closespacing [14; 15]. Moreover, the closer the grass strips are the more effective they become in controlling soil erosion [15]. Progressive bench terrace formation is also possible under *miraba* when adjusted to appropriate spacing of grass strips. Natural bench terraceformation as a result of *miraba* implementation is much less expensive compared to mechanical bench terraceconstruction which isfeared by farmers. Bench terraces are highly recommended for use in Usambara Mountains [16; 17; 9; 4].

2.3 Experimental Design

Miraba plots 22m x 3 m in a randomized complete block design (RCBD) were set in the lower ridge slopes at 50 % slope in Majulai and 45 % slope in Migambo village (Fig. 2). Maize and beans were planted in rotation as test crops in 2012 and 2013/14 rain seasons, where maize was planted during short rains (*vuli*) and beans during long rains (*masika*). The treatments included plots with (i) *Miraba* and planted 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) No SWC measures (***CO***) (Control) and planted with maize or beans, all replicated three times.

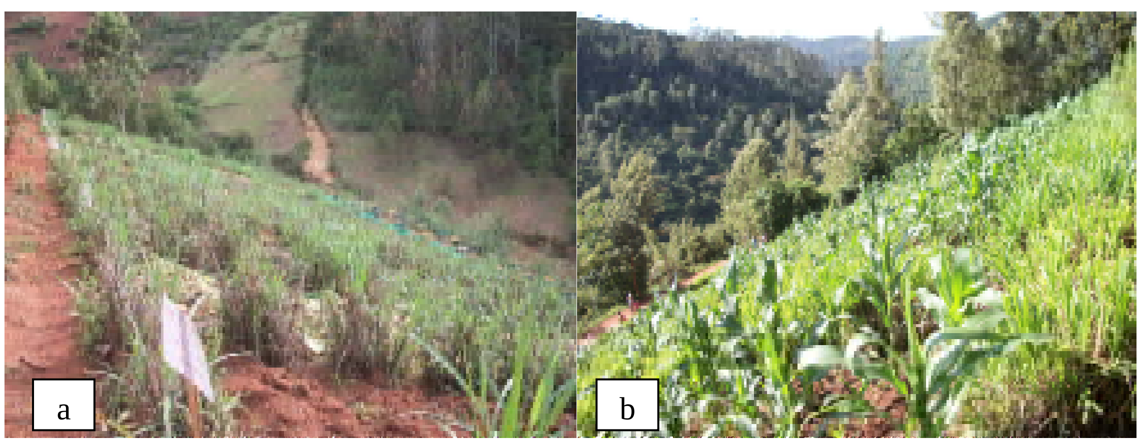

Fig.2:a) Majulai experimental plots b)Migamboexperimental plots with maize crop

2.4 Mulching Materials

Mulching materials used included the leaves of *Tithoniadiversifolia* (*Alizeti Pori*) and *Vernoniamyriantha* (*Tughutu*) in both villages. The mulch was applied under *miraba* two weeks after crops germinated at the rate of 3.6 Mg ha^{-1} dry weight. These shrubs were chosen as mulches because the plants are readily available in the area and have been documented to contain appreciable amounts of N, P and K [18; 6]. Samples from each mulching material were collected for determination of total N, available P, K^+, Mg^{2+}, Ca^{2+} and Na^+.

2.5 Determination of Soil Chemical and Physical Properties

The impact of SWC measures on soil chemical and physical properties was determined by taking composite topsoil samples (0 - 30 cm depth) from each treatment for the analysis of pH, OC, total N, available P, K^+, Ca^{2+}, Mg^{2+}, Na^+, Fe, Cu, Zn, Mn and soil texture. Undisturbed core soil samples were also collected from 0 – 5 cm depth for bulk density and available moisture content determination. Soil samples were collected after every cropping season i.e. long rains and short rains from 2012 to 2013/14.In each runoff experimental site a representative soil profile was excavated and described, and soil samples collected from each horizon for pedologicalcharacterization. Undisturbed core soil samples were taken from 0-5 cm, 45- 50 cm and 95-100 cm soil depths by Kopecky's core rings (100 cm^3) for bulk density and available moisture determination for further characterization of the representative soil profiles.The soil profiles were classified to tier-2 according to WRB for Soil Resources [13].

2.6 Crop Yield Determination

Maize (*Zea mays*) variety PANNAR 67 and beans (*Phaseolus vulgaris*) Kilombero variety were planted in runoff plots during the 2012 and 2013/14 rainy seasons with maize in short rains (*vuli*) and beans during the long rains (*masika*). The spacing was 75 cm× 30 cm for maize and 50 cm× 25 cm for beans. Beans were always planted three weeks before maize was harvested in Migambo and two weeks in Majulai village. Farmyard manure with 0.6% N, 0.4% P, 0.5 % K and 15 % OC was basal and spot applied at the rate of 3.6 Mg ha^{-1} air-dry weight, DAP 18: 46: 0 NPK ratio and Urea46 % N were applied at the rate of 80 kg ha^{-1}, but Urea was not applied for beans. At maturity maize and bean grains were harvested and dried to about 13% moisture content.

2.7 Soil and Plant Samples Analysis

Soil analysis was done following Moberg'sLaboratory Manual[19]. 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.The available Fe, Mn, Zn and Cu were extracted using buffered DTPA (Diethylenetriaminepentaacetic acid) method and the DTPA extract was analysed in an Atomic Absorption Spectrophotometer (AAS). Soil texture was determined by Hydrometer method. Bulk density was determinedbyoven drying and weighing method.Soil moisture retention characteristics were studied using sand kaolin box for low suction values and pressure plate apparatus for higher suction values [20].

2.8 Statistical Analysis

Bartlett's test for homogeneity of variance was conducted to test data normality usingGenStat software [21]. All data were subjected to Analysis of Variance (ANOVA). GenStat statistical analysis software [21] was used for the analysis and significant differences were tested by the Least Significant Difference ($LSD_{0.05}$). Correlationand multiple linear regressions were performed using Minitab software [22] to determine the relationship between soil properties and crop yield under the studied SWC measures.

3.0 RESULTS AND DISCUSSIONS

3.1 Selected Chemical Properties of Mulching Materials

Chemical properties of mulching materials are presented in (Table 1). It can clearly be seen that *Tughutu* had higher nutrient contents than Tithonia (Table 1). This situation is also supported by other researchers[18] who also found higher NPK contents in *Tughutu* than in Tithonia shrub.

Table1: Chemical Properties of mulching materials and farm yard manure applied in Majulai and Migambo villages

	Plant nutrients content %					
Mulching materials	N	P	K	Ca	Mg	Na
Tithonia	3.3	0.3	6.1	1.2	0.7	0.04
Tughutu	3.6	0.3	6.3	1.4	0.9	0.04
Farm yard manure	1.7	0.4	1.9	0.9	0.6	0.07

3.2 The Influence of SWC Measures on Selected Soil Physico-chemical Properties

Variability of soil chemical and physical properties betweenSWC measures are presented inTables2&3.Considering the soil chemical properties in relation to the SWC measures, most of the properties were significantly(P = .05) different between treatments. The differences can be explained by the influences of the SWC measuresapplied. It was revealed in both villages that the contents of all studied macro nutrientsfollowed the trend that:*miraba* with *Tughutu*mulching >*miraba* with Tithonia mulching>*miraba* sole >cropland with no SWC measures (Table 2) except for Na^{+} which did not significantly (P = .05)differ. Similarly pH followed the same trend. It was therefore concluded that total N, OC, P, Ca^{2+}, Mg^{2+}, K^{+} and pH were powerful attributes thatdifferentiatedSWC measures. Studies byTenge and Kyaruzi[9; 7] revealed similar observations where terracing such as bench and *FanyaJuu* terraceseffectively control runoff and soil losses, thus improving soil physical and chemical properties in Usambara Mountains. The higherpH and macro nutrient status under *miraba* with *Tughutu* mulching than under *miraba* with Tithonia mulching can be explained by the higher nutrient contents of *Tughutu* as compared with Tithonia mulching material (Table 1). The higher NPK contents in *Tughutu* than in Tithonia shrub was also reported by Wickama and Mowo[18]. It is also well known thatexchangeable bases have strong positive correlation with soil pH [23; 24]. In the case of micro nutrients, it was found that there were no significant(P = .05) differences between SWC measures exept for Zn which was significantly low undercropland with no SWC measures. Therefore Zn was spotted as the best micronutrient differentiatingSWC measures. These differences can be explained by the influences of the tested SWC measures. Kyaruzi[7] in Usambara Mountains, also reportedbench terraces and grass strips tohave an influence on soil chemical properties such as pH, total N, OC, CEC, Ca^{2+} and $Mg^{2+}$when compared to control. Similar observations were reported byTenge[9] and Wickama *et al*. [25] in Usambara Mountains, where soil conservations measures suchas bench terraces, *FanyaJuu* terraces and grass strips were found to have a big influence on soil chemical and physical properties as compared with cropland with no SWC measures.

Table 2: The influence of the studied SWC practices on soil chemical properties

Village	SWC	N	pH	OC	N	P	K+	Ca2+	Mg+	Na+	Fe	Mn	Zn	Cu
				%	%	Mg kg-1	cmol (+) kg-1				Mg kg-1			
Majulai														
	Control	12	4.5	2.2	0.19	10.6	0.15	1.1	0.72	0.32	36.4	44.4	1.5	3.2
	Miraba sole	12	4.5	2.4	0.22	14.4	0.17	1.5	0.95	0.33	41.2	42.0	2.1	3.6
	Miraba with Tithonia	12	4.5	2.6	0.26	23.1	0.31	1.4	1.17	0.32	42.5	47.2	1.7	3.1
	Miraba with *Tughutu*	12	4.9	2.9	0.28	26.7	0.45	2.2	1.93	0.34	41.6	51.7	2.2	3.9
Migambo														
	Control	12	5.2	3.4	0.33	5.6	0.13	4.3	1.22	0.31	42.3	157.6	3.5	2.6
	Miraba sole	12	5.5	3.7	0.36	7.5	0.19	6.1	1.79	0.32	41.7	187.6	4.7	3.5
	Miraba with Tithonia	12	5.7	4.1	0.38	10.1	0.42	6.4	2.38	0.34	44.6	155.0	4.4	3.2
	Miraba with *Tughutu*	12	5.7	4.4	0.42	13.0	0.46	7.3	2.78	0.35	47.9	164.4	5.1	3.5
	LSD (P = .05)		0.3	0.5	0.03	4.0	0.13	1.3	0.6	0.09	6.5	30.9	1.1	1.5
	SE		0.1	0.2	0.01	1.4	0.05	0.5	0.2	0.01	2.3	11.0	0.4	0.5

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

On the other handsoil physical properties were significantly (P = .05) different between SWC measures except for soil texture which did not differ (Table 3). The available moisture contents (AMC) were higher under *miraba* with mulching than under *miraba* sole and cropland with no SWC measures. Bulk density (BD) values were significantly lower under *miraba* with mulching than under *miraba* sole and cropland with no SWC measures. Thus AMC and BD were powerfull soil physical properties that discriminated SWC measures. The higher AMC and lower bulk density under *miraba* with mulching can be explained by the increased organic carbon contents due to the application of mulches (Table 2 & 3). It has been established that the higher the organic carbon contents in the soil the lower the bulk density while also the higher the capacity of the soil to retain moisture available to plants [26].

The improvements of the aforementioned soil physical and chemical properties under *miraba* can also be explained by the fact that,apart from the ability of grass barriers forming *miraba*of retaining soil sediments and nutrients,*miraba* were alsoprogressively forming bench terraces such that the terrace height was raised to about 1 m in Migambo and 0.7 m in Majulai village after three years of experimentation. The terraces so formed cut down the slope steepeness resulting reduced runoff velocity and increased rate of infiltration which inturn reduced runoff volume thus reducing soil and nutrient losses. Observations byGilley *et al*.[27] reported grass hedge to effectively reduce runoff and nutrient loads following manure application as compared with cropland with no grass hedge. A similar observation was madebyWanyama *et al*.[28] who reportedelephant grass, lemon grass, paspalum and sugarcane to effectively trap sediments and reduce runoff from cropland in Uganda.

Table 3: The influence of the studied SWC practices on soil physical properties

Village	SWC practises	N	AMC %	BD g/cc	Sand %	Silt %	Clay %
Majulai							
	Control	12	23.2	0.98	34	9	56
	Miraba sole	12	29.2	0.97	33	9	58
	Miraba with Tithonia	12	32.9	0.93	34	9	57
	Miraba with *Tughutu*	12	32.9	0.91	33	12	55
Migambo							
	Control	12	17.6	0.95	35	13	52
	Miraba sole	12	22.7	0.89	35	15	51
	Miraba with Tithonia	12	25.9	0.88	35	16	50
	Miraba with *Tughutu*	12	29.3	0.83	35	13	52
	LSD (P = .05)		3.6	0.06	5.1	3.0	4.6
	SE		1.3	0.02	1.8	1.1	1.6

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

3.3The Influence of Selected SWC Practices on Crops Yield in Majulai and Migambo Villages

Maize and bean yields under the studied SWC practices in the Majulai and Migambo villages are presented in (Table 4). Significant (P = .05) differences in crop yields between SWC practices were observed. Maize and bean grain yields followed the trend:*miraba* with*Tughutu*>*miraba* with Tithonia>*miraba* sole > control in both villages (Table 4). Maize grain yields were significantly (P = .05) higher in 2013 than in 2012, but there were no significant (P = .05)differences in bean grain yields between thetwo years of study. It was clearly observed that crop yield differences between treatments were highly influenced by the SWC practices (Table 4), while the higher crop yields under*miraba* with Tithonia and *miraba* with *Tughutu* mulches couldbe explained by the improved soil properties especially of AMC, OC, N, P, K, Ca^{2+}, Mg^{2+}, pH and BD (Table 2 & 3). Similar observations were reported byTenge[9] where *FanyaJuu* terraces had significantly higher maize and bean yields than under bench terraces and grass strips while control was the least; likewise the study by Msita[10] found *miraba* with farmyard manure and mulching to have higher maize and bean yields than *miraba* sole and control had the least.The higher yields were associted with improved soil fertility. The observed crop yields under the studied SWC practices (Table 4) were higher than the average yields according to FAO[29]of 1.5 Mg ha^{-1} for maize and of 0.7 Mg ha^{-1} for beans in Tanzania.

When considering variability of crop yields within the studied SWC practices, it can be seen from Table 4 that, cropgrain yields did not significantly(P = .05) varied within SWC measures except under cropland with no SWC measureswhere lower parts had higher maize grain yields than the upper parts. It can easily be noted that maize crop is more sensitive to the effect of gradients than bean crop; this is probably due to the ability of bean to fix nitrogen for its consumption as opposed to maize crop. Tenge[9]reported similar observations where bean crop performance was found not to besensitive to slope gradients as opposed to maize. The evenly distributed crop yields within the studied SWC practices can partly be explained by the effect of reducing spacing of grass barriers that form *miraba* from thetraditionally very wide to 5 m apart. This spacing was close enough to limit runoff velocity and thus reduced soil nutrients that could move with it down the slope to the lower parts. Besides, with this spacing,*miraba* were progressively forming bench terraces which cut down the slope and thus reducetranslocation of soil nutrients by runoff. On the other hand mulching was also contributing to the reduced soil nutrient movement from the upper to the lower parts, allowing crops to respond evenly within the studied SWC practices.

Table 4: Crop yields under selected SWC practices in Majulai and Migambo villages

			Mean crop grains yield Mg ha^{-1} in 2012		Mean crop grains yield Mg ha^{-1} in 2013	
Village/SWC measures	Parts within plots	N	Maize	Beans	Maize	Beans
Majulai village						
Plots with no SWC	Upper		0.51	0.56		0.57
	Lower		0.91	0.62		0.61
	Mean	**3**	**0.71**	**0.59**	0.0	**0.59**
Miraba sole	Upper		1.24	0.80		0.85
	Lower		1.28	0.82		0.85
	Mean	**3**	**1.26**	**0.81**	0.0	**0.85**
Miraba with Tithonia	Upper		1.61	0.89		1.04
	Lower		1.63	0.89		1.04
	Mean	**3**	**1.62**	**0.89**	0.0	**1.04**
Miraba with *Tughutu*	Upper		1.96	0.93		1.09
	Lower		1.98	0.93		1.09
	Mean	**3**	**1.97**	**0.93**	0.0	**1.09**
LSD (*P* = .05)			0.15	0.15	0.0	0.15
SE.			0.05	0.05		0.05
Migambo village						
Plots with no SWC	Upper		1.07	0.62	1.33	0.65
	Lower		1.97	0.66	1.95	0.69
	Mean	**3**	**1.57**	**0.64**	**1.64**	**0.67**
Miraba sole	Upper		2.53	0.81	3.10	0.92
	Lower		2.63	0.81	3.14	0.92
	Mean	**3**	**2.58**	**0.81**	**3.12**	**0.92**
Miraba with Tithonia	Upper		3.14	0.90	4.00	1.06
	Lower		3.22	0.90	4.10	1.06
	Mean	**3**	**3.18**	**0.90**	**4.05**	**1.06**
Miraba with *Tughutu*	Upper		3.75	0.95	4.82	1.14
	Lower		3.83	0.95	4.84	1.14
	Mean	**3**	**3.79**	**0.95**	**4.83**	**1.14**
LSD (*P* = .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

3.4Relation between Soil Properties and Crop Yields underthe DifferentSWC Measures

Correlation between soil properties (that descriminatedSWC measures)and crop yields are presented in Table5.It can be seen that all the descriminator soil properties were positively correlated with crop yields except bulk density which was negatively correlated. The negative correlation of bulk density with crop yields can be explained by the fact that, bulk density is greatly influenced by soil organic carbon contentssuch that low the OC contents high the bulk density of the soils and vice versa (Table 2 & 3).Similar relationship was also reported by Aticho[26]. Soil OC has been acknowledged to be an important cushion for many soil nutrients, thus thehigher the OC content the higher the soil nutrients in the soil [23; 24].A multiple linear regression model was fitted through the descriminatorsoil properties that were correlated with crop yields under SWC measures (Table 6).It was found that maize grain yieldswere significantly (*P* = .05) a function of $Ca^{2+}$and Mg^{2+} with (R^2= 0.85)under *miraba* and (R^2= 0.79) forcropland with no SWC measures. However, under *miraba* with Tithonia mulching maize grainyields werea function of K^+ and Mg^{2+}(R^2= 0.89),whereas under *miraba* with *Tughutu* mulching maize grain yields werea function of AMC, K^+ and Mg^{2+} (R^2= 0.97).Bean grain yields were significantly (*P* =.05)afunction of Mg^{2+} and Mn(R^2= 0.68) under control; AMC and pH (R^2= 0.71) under *miraba*; AMC, available P, Ca^{2+} and K^+ (R^2= 0.89) under *miraba* with Tithonia mulching; while under *miraba* with *Tughutu* mulching bean grain yields werestronglya function of AMC, available P, Ca^{2+} and K^+(R^2= 0.90). These observations imply that AMC and pHhad greater potential ofinfluencing maize and bean grain yields under *miraba*, while AMC, available Pand K^+ had greater potential of influencing maize and bean grain yields under*miraba* with Tithoniaand*miraba* with *Tughutu*mulching. The enhanced ability of *miraba* to availsoil water to plants and increasesoil pH can be explained by the improved soil OC and exchangeable bases under *miraba* (Table 2& 3). Similarpositive correlations of exchangeable bases with pH and AMC with OC were also reported byMwango, Msanya *et al*. and Shelukindo *et al*.[23; 24; 30].The improved P and K^+were greatly due to the influences of mulching materials applied which have high contents of available P and K^+ (Table 1).This is strongly supported by the findings that applications of organic materials in soils reduce P sorption capacities and increase P availability [31], while also application of high quality organic materials with P content equal to or greater than 3.0 g P kg^{-1} in the soil decreases P adsorption[32],a tendence that improves P availability in the soil.

Table 5: Soil properties that correlated with crop yield under the studied SWC measures

Crop	SWC measure	Soil properties										n
Maize												
	Control	Ca*	Mg**	Zn*								24
	Miraba	Ca***	Mg***	TN***	OC**	pH***	Zn***	Mn***				24
	Miraba with Tithonia	Ca***	Mg***	TN***	OC***	K***	pH***	Zn*	Mn*			24
	*Miraba*with *Tughutu*	Ca***	Mg***	TN***	OC***	K***	pH***	Zn*	Mn*	AMC**		24
Beans												
	Control	Ca*	Mg*	Mn*								24
	Miraba	Ca*	Mg*	pH*	K*	AMC**						24
	Miraba with Tithonia	Ca*	Mg***	K***	P*	pH*	AMC***	-BD*				24
	Miraba with Tughutu	Ca**	Mg***	K***	P*	pH***	TN**	OC*	Zn**	AMC**	-BD*	24

Key: *** = significant at *P*< .001, ** = significant at *P* = .01 and * = significant at *P* = .05

Table 6: Relation betweensoil properties and crop yield (Mg ha^{-1}) (Y) under the studied SWC measures

Crop	SWC measure	Regression equations	R^2	*P*	n
Maize	Control	$Y = 0.152 + 0.104\ Ca^{2+}$cmol/kg$+ 0.793\ Mg^{2+}$cmol/kg^{-1}	0.85	0.003	24
	Miraba				
		$Y = 0.314 + 0.139\ Ca^{2+}$cmol/kg $+ 0.038$ OC% $+ 0.716\ Mg^{2+}$ cmol/kg	0.80	0.000	24
		$Y = 0.376 + 0.03$ TN% $+ 0.141\ Ca^{2+}$cmol/kg $+ 0.752\ Mg^{2+}$cmol/kg	0.80	0.000	24
		$Y = 0.381 + 0.142\ Ca^{2+}$cmol/kg $+ 0.754\ Mg^{2+}$cmol/kg	0.79	0.000	24
	Miraba with Tithonia				
		$Y = -0.70 + 5.67\ K^{+}$cmol/kg $+ 0.703\ Mg^{2+}$cmol/kg$+ 0.191$ pH	0.90	0.000	24
		$Y = -0.040 + 5.62\ K^{+}$cmol/kg $+ 0.732\ Mg^{2+}$cmol/kg $+ 0.85$ TN%	0.90	0.000	24
		$Y = 0.004 + 5.71\ K^{+}$cmol/kg $+ 0.714\ Mg^{2+}$cmol/kg $+ 0.069$ OC%	0.90	0.000	24
		$Y = 0.134 + 5.96\ K^{+}$cmol/kg $+ 0.762\ Mg^{2+}$cmol/kg	0.89	0.000	24
	Miraba with Tughutu				
		$Y = -1.98 + 0.0319$ AMC% vol $+ 0.848\ Mg^{2+}$cmol/kg $+ 3.04\ K^{+}$ cmol/kg $+ 1.63$ TN%	0.98	0.000	24
		$Y = -2.70 + 0.0238$ AMC % vol $+ 0.313$ pH $+ 0.886\ Mg^{2+}$ cmol/kg $+ 3.35\ K^{+}$cmol/kg	0.98	0.000	24
		$Y = -1.37 + 0.0259$ AMC% vol $+ 0.970\ Mg^{2+}$cmol/kg$+ 3.51\ K^{+}$ cmol/kg	0.97	0.000	24
Beans	Control	$Y = 0.456 + 0.000629$ Mn mg/kg $+ 0.0872\ Mg^{2+}$cmol/kg	0.68	0.006	24
	Miraba				
		$Y = -1.18 + 0.0197$ AMC% vol $+ 0.156$ pH	0.71	0.000	24
	Miraba with Tithonia				
		$Y = -0.496 + 0.0175$ AMC% vol $+ 0.00569$ P mg/kg$+ 0.0470\ Ca^{2+}$cmol/kg $+ 0.242\ K^{+}$cmol/kg	0.89	0.000	24
	Miraba with Tughutu				
		$Y = -0.224 + 0.0123$ AMC% vol $+ 0.00839$ P mg/kg $+ 0.0474\ Ca^{2+}$Cmol/kg $+ 0.219\ K^{+}$cmol/kg	0.90	0.000	24

4.0 CONCLUSIONS AND RECOMMENDATIONS

Most of the studied chemical and physical soil properties were significantly (P = .05)influenced by the studied SWC measures. The trend for total N, OC, available P, Ca^{2+}, Mg^{2+}, K^{+} and pH was:*miraba* with *Tughutu*>*miraba* with Tithonia>*miraba* sole >cropland with no SWC measures (Control), while Na^{+} did not differ. Micro nutrients Fe and Cu did not differ between SWC measures except for Zn and Mn which were significantly(P = .05)low in cropland with no SWC measures. Likewise,*miraba* with *Tughutu* mulching had the highest AMC and lowest BD, whereas cropland with no SWC measures had the lowest AMC and highest BD.Maize and bean grain yields differed significantly(P = .05)in the following trend:*miraba* with*Tughutu*>*miraba* with Tithonia>*miraba* sole > control in both villages.Crop grain yields did not significantly (P = .05) varied within SWC measures except for control which had higher crop grain yields in the lower parts than the upper parts.AMC and pH had the greatest potential ininfluencing maize and bean grain yields under *miraba*, while AMC, available P and K^{+} had the greatest potential in influencingmaize and bean grain yields under *miraba* with Tithonia or *miraba* with *Tughutu* mulching.Further researches are recommended to investigate the potentials of these mulching materials to influencethe production of vegetables such as cabbage, tomatoes, onions and carrots which are widely cultivated in the Usambara Mountains.

ACKNOWLEDGEMENTS

The authors are grateful to the VLIR-UOS supported RIP-DSS SUA Project “Enhancing Indigenous Knowledge on Conservation Agriculture for Poverty Alleviation and Sustainable Livelihood, Usambara Mountains, Lushoto, Tanzania”, for providing financial and logistical assistance to the research. The first author is grateful to the Tanzania Commission of Science and Technology (COSTECH) for sponsoring PhD programme that contributed to production of this paper.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

6.6 REFERENCES

1. Faucette LB, Risse LM, Nearing MA, Gaskin JW, West LT. Runoff, erosion, and nutrient losses from compost and mulch blankets under simulated rainfall. Journal of Soil and Water Conservation. 2004;59: 154 -160.
2. Kimaro DN, Poesen J, Msanya BM, Deckers J. Magnitude of soil erosion on the northern slope of the UluguruMountsins, Tanzania: Interrill and rill erosion. Catena. 2008;75: 38-44.
3. Jiao P, Xu D, Wang S, Wang Y, Liu K, TangG. Nitrogen loss by surface runoff from different cropping systems. Soil Research. 2012;50: 58–66 Journal compilation - CSIRO 2012 http://dx.doi.org/10.1071/SR11152.
4. Vigiak O, Okoba BO, Sterk G, Stroosnijder L. Water erosion assessment using farmers' indicators in the Western Usambara Mountains, Tanzania. CATENA. 2005; 64(2-3):307–320
5. National Bureau of statistics. The 2012 population and housing census. Central statistical office of Tanzania, Dar es Salaam. 2012. http://www.nbs.go.tz/. (Accessed 09/08/2014).
6. Mowo JG, Janssen BH, Oenema O, German LA, Mrema JP, Shemdoe RS. Soil fertility evaluation and management by smallholder farmer communities in northern Tanzania. Agriculture, Ecosystems and Environment. 2006; 116: 47-59.
7. Kyaruzi LA. Relationship between Soil and Landform Derived Land Qualities and Conservation Agriculture Practices in West Usambara Mountains, Tanzania. MSc. Dissertation Sokoine University of Agriculture. 2013; 140 pp.
8. Msita HB, Kimaro DN, Deckers J, Poesen J. Identification and Assessment of Indigenous Soil Erosion Control Measures in the Usambara Mountains, Tanzania. In: 166 Earl T. Nardali (Ed.), No Till Farming: Effect on Soil, Pros and Cons and Potential. Nova Science Publishers, Hauppauge, NewYork. 2010; 49-74.
9. Tenge AJM. Participatory appraisal for farm-level soil and water conservation planning in West Usambara Highlands, Tanzania. Dissertation for Award of PhD Degree at Wageningen University, Netherlands. 2005; 195 pp.
10. Msita HB. Insights into Indigenous Soil and Water Conservation Technologies in Western Usambara Mountains, Tanzania. PhD dissertation KU Leuven Belgium. 2013; 198 pp.
11. Vancampenhout K, Nyssen J, Desta Gebremichael, Deckers J, Poesen J, Mitiku Haile, Moeyersons J. Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. Soil & Tillage Research. 2006; 90: 1-15.
12. FAO (Food and Agriculture Organization). New_LocClim, Local Climate Estimator software, Agro meteorology group FAO/SDRN, Rome, Italy. 2006.
13. FAO (Food and Agriculture Organization). World Reference Base for soil resources.A framework for International classification, correlation and communication. World Soil Resources Reports 106 FAO, Rome, Italy. 2014; 182 pp.
14. Sheng TC. Bench Terrace Design Made Simple. Department of Earth Resources Colorado State UniversityFort Collins, CO 80523, USA. 2002; 500 -504.

15. Kaswamila AL. Assessment of the Effectiveness of Soil Erosion Control Measures Using Soil Surface Micro topographic Features in the West Usambara Mountains, Tanzania.International Journal of Marine, Atmospheric & Earth Sciences. Florida, USA.2013; 2327-3356.
16. Shelukindo H. Technical recommendations for soil and waterconservation measures and agroforestry systems. SECAP and TIP, DALDO, Lushoto. 1995.
17. AHI (African Highlands Initiative). Annual Report. District Agricultural Office Lushoto, Tanzania. 2001.
18. Wickama JM, Mowo JG. Indigenous nutrient resources in Tanzania. Managing African Soils. Issue Paper No. 21. International Institute for Environment and Development, London. 2001; 1560 – 3520.
19. Moberg JP. Soil and Plant Analysis Mannual. The Royal Veterinary and Agricultural University, Chemistry Department, Copenhagen, Denmark. 2001; 133 pp.
20. National Soil Service. Laboratory procedures for routine analysis, 3rd edition. Agricultural Research Institute, Mlingano, Tanga, Tanzania. Miscellaneous. 1990; 212 pp.
21. Genstat. Introduction to Genstat 14 for Windows. Statistical service centre, University of Reading, UK. 2011; 41 pp.
22. Minitab. Minitab Statistical Software for Quality Improvement. Meet Minitab: Minitab User Guide. Minitab Inc. Pennsylvania State University, USA: 2004; 134 pp.
23. Mwango SB. Automated Land Evaluation for Alternative Uses in South Western Part of Uluguru Mountains, Morogoro Rural District, Tanzania. MSc. Dissertation Sokoine University of Agriculture. 2000; 182 pp.
24. Msanya BM, Kimaro DN, Kileo EP, Kimbi GG, Mwango SB. Land suitability evaluation for the production of food crops and extensive grazing: A case study of Wami Plains in Morogoro Rural District, Tanzania. Soils and Land Resources of Morogoro Rural and Urban Districts, Volume 1. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania. Printed by Mzumbe Book Project, Mzumbe, Tanzania. 2001; ISBN 9987 605 26 5.
25. Wickama J, Okoba B, Sterk G. Effectiveness of sustainable land management measures in West Usambara highlands, Tanzania. CATENA. 2014; 118: 91–102.
26. Aticho A. Evaluating organic carbon storage capacity of forest soils. Case study in Kafa zone Bita District, South eastern Ethiopia. American Eurasian Journal of Agriculture and Environmental Sciences. 2013; 13 (1): 95-100.
27. Gilley JE, Durso LM, Eigenberg RA, Marx DB, Woodbury BL. Narrow grass hedge control of nutrient loads following variable manure applications. American Society of Agricultural and Biological Engineers. 2011; 54(3): 847-855.
28. Wanyama J, Herremans K, Maetens W, Isabirye M, Kahimba F, Kimaro D, Poesen J, Deckers J. Effectiveness of tropical grass species as sediment filters in the riparian zone of Lake Victoria. Soil Use and Management. 2012; 28: 409 - 418.
29. FAO (Food and Agriculture Organization). Food and Agriculture Organization of the United Nation, 2010 FAOSTAT database, Production: Crops. 2010; Available: http://faostat.fao.org/site/567/DesktopDefault.aspx (accessed 16/01/2014).
30. Shelukindo HB, Msanya BM, Semu E, Mwango SB, Singh B, Munishi P. Characterization of Some Typical Soils of the Miombo Woodland Ecosystem of Kitonga Forest Reserve, Iringa, Tanzania: Physico-Chemical Properties and Classification.Journal of Agricultural Science and Technology. 2014; A 4: 224-234.
31. Ikerra ST. Use of Minjingu phosphate rock combined with different organic inputs in improving phosphorus availability and maize yields on a chromic Acrisol in Morogoro, Tanzania. PhD thesis Sokoine University of Agriculture, Morogoro, Tanzania. 2004; 263 pp.
32. Lyamuremye F, Dick RP. Organic materials and phosphorus sorption by soils. Advances in Agronomy. 1996; 56: 139-185.