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Evaluation of the effectiveness of soil and water conservation practices on improving selected soil properties in Wonago district, Southern Ethiopia

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Accelerated soil erosion remains the major challenge that is adversely affecting the agricultural performance in Ethiopia. Efforts towards soil and water conservation (SWC) goal were started since the mid-1970s and 80s to alleviate soil erosion and low crop productivity. However, the effectiveness of SWC practices on improving soil properties remains less studied. Soil physical analysis (%sand, silt and clay) and chemical analysis (pH, exchangeable potassium (K^+), available phosphorous (P), total nitrogen (TN), soil organic carbon (SOC) and cation exchange capacity (CEC)) were analyzed. A total of 36 soil samples from two sub watersheds (SWs) with SWC and without SWC practices (Elmo without, Elmo with, Hobene without and Hobene with) from three landscapes with three landscape positions (upper slope, middle slope, and bottom) were studied. The results showed that soil pH, K^+, P, TN, SOC, %clay and CEC were significant ($p \leq 0.05$) for SWC practices. The sand and silt fractions were not significant ($p < 0.05$) for SWC practices. P, SOC, %silt and CEC were significantly different for landscape position. The study indicated the effectiveness of SWC practices in improving the soil properties. There should be a continuous awareness creation for technically efficient implementation and proper maintenance of SWC practices for optimum improvement of soil properties.

Key words: Soil erosion, soil and water conservation (SWC) practices, landscape position, sub watershed.

INTRODUCTION

Land degradation by accelerated soil erosion remains one of the biggest environmental problems worldwide, threatening both developed and developing countries (Lal, 2014). It is considered one of the main problems constraining the development of the agricultural sector in Ethiopia (Amsalu and Graaff, 2007; Kirubel and Gebreyesus, 2011; Kebede and Mesele, 2014). As agriculture is the backbone of the Ethiopian economy, it is given special attention by the government to spearhead the economic transformation of the country (Woldeamlak, 2003). However, land degradation in general and soil erosion in particular still remain the major challenges that are adversely affecting the agricultural performance of the country. The majority of the farmers in rural areas of Ethiopia are subsistence-oriented, cultivating impoverished soils on sloppy and marginal lands that are generally highly susceptible to soil erosion and other degrading forces (Shimelis, 2012).

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The severity of this land degradation process makes large areas unsuitable for agricultural production, because the topsoil and even part of the sub-soil in some areas has been removed, and stones or bare rock are left at the surface (Esser et al., 2002). The land degradation problem has had serious consequences in Ethiopia such as occurrence of persistent food insecurity, economic losses and various environmental hazards such as recurrent drought (Bekele and Holden, 1999). As noted by Pimentel et al. (1995), erosion adversely affects crop productivity by reducing water availability, water-holding capacity of the soil, nutrient levels, soil organic matter and soil depth. Research results confirmed that soil nutrient depletion caused by erosion is the major cause for decline of agricultural production (Bekele and Holden, 1998; Abay et al., 2016). Deforestation and conversion of marginal land to agriculture has been followed by severe soil erosion that has caused crop production losses, which in turn result in economic losses (Bojö and Cassels, 1995). For example, due to soil and nutrient loss through erosion, Ethiopia has been annually losing about US$ 106 million (Bojö and Cassels, 1995).

In Ethiopia, coping with these problems, efforts towards soil and water conservation goal were started since the mid-1970s and 80s to alleviate both problems of erosion and low crop productivity (Shimelis, 2012). As a result, government implemented soil and water conservation (SWC) practices to reduce erosion-induced land degradation (Hurni, 1993; Bekele and Holden, 1999). Since then, various mechanical (bunds, terraces, check dams, cutoff drains and waterways) and biological (homestead and communal tree plantations and enclosures) SWC measures have been implemented in drought-prone areas (Amsalu and de Graaff, 2007). The implementation of sustainable land management practices may help to increase agricultural productivity, improve ecosystem functions and enhance resilience to adverse environmental impacts. SWC practices undoubtedly have affected positively the productivity of agriculture where agriculture is hampered by drought, erosion; low soil fertility and moisture stress (Mulugeta and Stahr, 2010; Kirubel and Gebreyesus, 2011).

Recognizing land degradation by accelerated soil erosion as major environmental and socio-economic problems and the importance of SWC, the Wenago district agricultural office has made considerable efforts to improve food security by rehabilitating degraded land and preventing further degradation. As a result, different degraded watershed areas have been, covered by physical and biological soil and water conservation measures. Some of the implemented soil and water conservation practices in the SWs include soil bunds, check dams, cut-off drains, waterways, area closure, trenches and plantation of tree seedlings.

However, the effectiveness of SWC practices on improving soil properties remains under studied. Although, many resources in terms of money and labor, have been invested in the construction of SWC structures in sub-watersheds, their impact on improving soil properties is not well studied. Comparing changes with soil properties between two SWs (both SWs have areas with and without SWC adjacently) could contribute to further improvement of design, implementation and sustainable maintenance of SWC practices. Therefore, the main objective of the study was to evaluate the effectiveness of SWC on improving the selected soil properties.

MATERIALS AND METHODS

Description of the study area

The research was conducted in Wenago district (Figure 1), Gedeo Zone, Southern Ethiopia, located at 375 km South of Addis Ababa, the capital of Ethiopia. The Wenago district lies in geographical coordinates between 6°20'30" and 6°15'0˝North - 38°15' 30" and 38°21'0" East. Total area coverage is estimated to be about 13.7 km^2, and the district is sub divided into 17 administrative rural kebeles (villages) (GZFES, 2005). Topographic feature of the district generally shows that there is a decreasing altitude from east to west and north to south. The physical features of land are dissected and undulating and each hillside or mountain is followed by plateau and then by short or long slopping to flat land. Erratic and irregular rainfall of the study area is bi-modal including the spring (short rainy season) from March to May (60 - 90 days), while the main rainy season is from July to September (90 - 120 days). According to CSA (2007), the climate of Wenago district is characterized by annual rainfall and temperature of 1001 - 1800 mm and 12 to 25°C, respectively. The soil types that dominantly occur in the study area include chromic luvisol, eutric fluvisol and dystric nitisol in decreasing order.

Data collection

Delineation of watershed

The study was conducted April 2015 to March 2016 in Elmo SW (Figure 2) with an area of 233.74 ha area in Karasodity village and Hobine SW (Figure 3) with an area of 167.43 ha in Dako village (Figure 1). The SWs have both SWC practices and degraded areas without SWC practices. Lakew et al. (2005) noted sub-watershed units prioritized for key interventions. The SWs were delineated by using digital elevation model (DEM). The topographic transect walk method was employed for the assessment of existing SWC measures in the sub watersheds. Transect walk was made to identify the major SWC practices implemented in the study area. The slope of the SWs is indicated in Figures 2 and 3.

Soil data collection and analysis

Soil physical and chemical analysis (%sand, silt, clay, and organic carbon, total nitrogen (TN), available phosphorus (P), exchangeable potassium (K) and cation exchange capacity (CEC) were analyzed to evaluate the effectiveness of SWC measures on improving soil properties at the two sub watershed. The two SWs were characterized by having both conserved and non-conserved areas adjacently. A total of 36 soil samples from two SWs with SWC practices and without SWC practices (Elmo without SWC, Elmo with SWC, Hobene without SWC, and Hobene with SWC) from three landscapes (replications) with three landscape positions

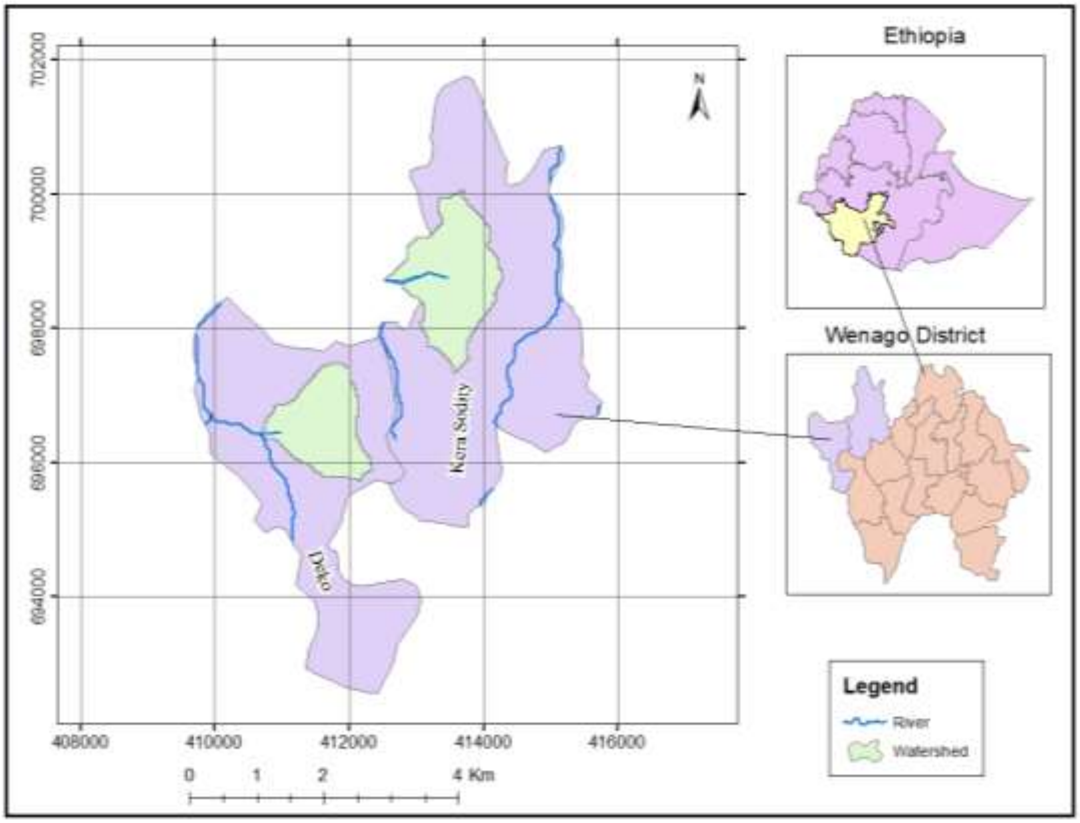

Figure 1. Location of the study area.

(upper, middle and bottom slopes) were taken at one depth (0-30 cm). There were two treatments (SWC practices and land positions) and three landscapes (replications). The study followed factorial randomized complete block design (RCBD). The soil physical and chemical properties were analyzed based on their standard methods. The particle size distribution of the soil was done using the Bouyoucos hydrometric method (Bouyoucus, 1962). For this, disturbed soil samples from representative locations (transect) were collected from a depth of 0-30 cm with the help of soil auger.

Soil organic carbon (%) was determined by potassium dichromate wet combustion procedure (Walkly and Black, 1934). The pH of the soil was measured in water suspension in a 1:2.5 (soil: liquid ratio) potentiometrically using a glass-calomel combined electrode (Van Reeuwijk, 2002). TN content was determined by wet oxidation procedure of the Kjeldahl method (Mostara and Roy, 2008). The available P content was determined by 0.5 M sodium bicarbonate extraction procedures (Olsen et al., 1954). Flame photometer (Toth and Prince, 1949) was used for determination of K^+. CEC was determined by extraction with ammonium acetate method (Chapman, 1965)

Statistical analysis

The impact of independent variables (SWC practices and landscape positions) on the dependent variables (soil properties) was statistically tested. For each measured response, analysis of variance (ANOVA) was performed. Data was analyzed for variability using General Linear Model of SAS version 9.1 statistical software (SAS institute, 2008). The mean separation was made using least significant difference ($LSD_{0.05}$) method.

RESULTS AND DISCUSSION

Characterization of the SWC practices in the study

Based on detailed inquiry on two SWs (sub watersheds) along the transect line, different SWC practices were implemented since 2009. The SWC measures in the SWs were installed for the purpose of land rehabilitation and to control further soil erosion in agricultural areas. Majority of the physical SWC practices constructed were soil bunds (Figure 4), fanyajuu, half-moons, trenches (Figure 5) and micro basins (Figure 6), and cut off drain in area closures on grazing and fallow land. Similarly, the commonly practiced biological SWC include maintaining natural vegetation and tree plantation in area closures, plantation of valley bottoms, and stabilization of physical structures using natural vegetations, vetiver grass and elephant grass. Implementation of conservation practices may keep the soil in place and reduce both the on-site and off-site effects of soil erosion (Blanco and Lal, 2008). The field observations revealed that most of the SWC measures have been widely implemented are stabilized with some irregularities in dimensions and lack of maintenance. Stability of SWC structures depend on various factors such as slope of the land, construction quality, construction material, support of physical structures by biological measures, and appropriateness

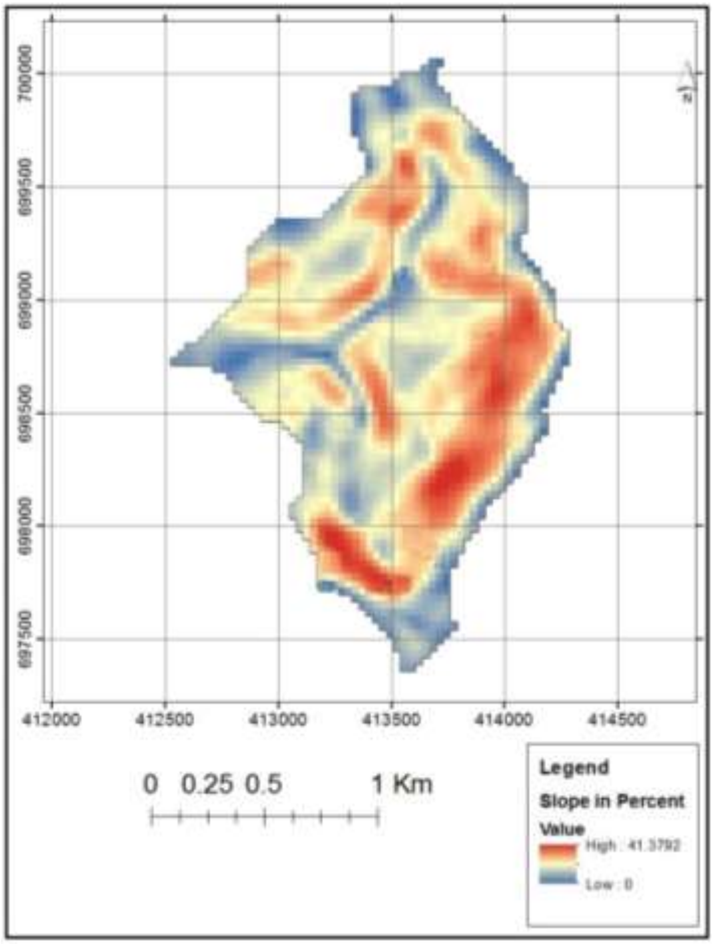

Figure 2. Elmo sub watershed with slope (%).

of structure to the site conditions (Olarieta et al., 2008).

The SWC practices improve the biophysical change by reducing soil and water loss, discharge of springs (Figure 7), improved micro climate, greening the area (Figure 5), supplying grass for cut and carry (Figure 5), modifying terrain, improving soil depth, stabilizing active gullies. Even though the above benefits, there are limitations in the design and installation of the practices. The study of Kirubel and Gebreyesus (2011) indicated that there has been success in maintaining and improving land resources, viz. soil, water, vegetation and humidity due to the implementation of SWC practices. Most the SWC practices did not follow the site specific design criteria of vertical interval and dimension of the structures based on the soil depth, slope and rainfall. Simeneh (2016) reported that most of the existing physical SWC structures were not constructed according to the standards in Wyebla Watershed. The SWC technologies introduced by both government extension system and nongovernmental organizations (NGOs) working at grassroots level is predominantly biased to standard structural SWC technologies (Mitiku et al., 2006).

Effectiveness of soil and water conservation practices on improving soil properties

Sand, clay and silt fractions

According to ANOVA sand and silt fractions were not significantly different ($p < 0.05$) for SWC practices and %sand and %clay were not significant landscape position and their interaction (Table 1). This result confirms findings by Lemma et al. (2015). The maximum sand of 22.45% at Elmo without SWC and minimum of 19.56% at Elmo with SWC were observed (Table 1). The variation may be due to the steep landscapes; transportation and translocation of fine particles are expected. The analysis also showed significant variation of clay for SWC practices with maximum clay of 48.49% at Hobene with SWC and lower 39.53 at Elmo without SWC with variation on effect of SWC practices. The maximum value of silt observed was 38.61% at Elmo without SWC and the lower content was 29.50% at Hobene with SWC. The non-significant difference in texture may be due to the young age of SWC practices that cannot make

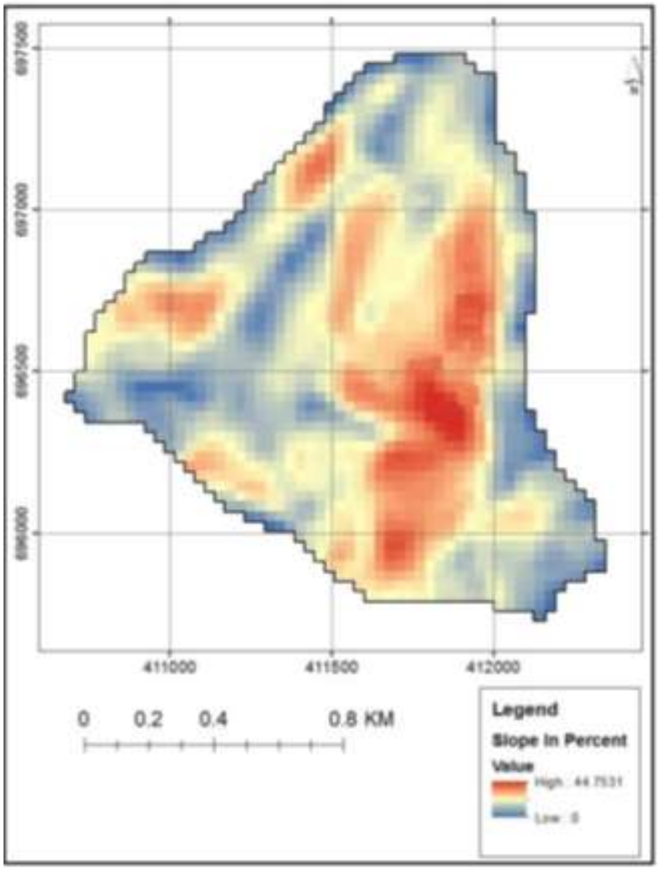

Figure 3. Hobene sub watershed with slope (%).

Figure 4. Stabilized soil bund.

significant change on soil weathering (Lemma et al., 2015). For landscape position, maximum sand content of 22.78% was indicated at middle and lower position, value of 20.13% at bottom, maximum clay content of 47.43% was indicated at upper and lower position, value of 41.07% was indicated at middle position, maximum silt content of 38.67% was indicated at bottom position and lower value of 30.95% was indicated at upper position

Figure 5. Water harvested in area closure with trench .

Figure 6. Micro water harvesting structure.

with variation due to position. The highest silt content measured at bottom may result to erosion and sedimentation processes, as there could be a balance between soil particle detachment, runoff velocity and deposition. This may be due to soil particles resistance to detachment, and susceptibility to transportation. Gebremichael et al. (2005) reported that selective removal of soil particles to steeper slopes leave behind coarser materials (sand, gravel and stones), while the transported material is deposited as the slope steepness decreases. Sandy soils are less cohesive than clayey soils and thus aggregates with high sand content are more easily detached; silty soils derived from loess parent material are the most erodible type of soil (Blanco and Lal, 2008).

Soil pH

The soil pH in the experimental area varied from 5.0 to 7.3 with an average value of 6.06 which is moderately acidic (Tekalign and Haque, 1991). The pH was not significantly different at $p<0.05$ level of significance for landscape position and for interaction, and highly

Figure 7. Discharge of water below area closure.

Table 1. SWC practices and landscape position effects on soil properties.

Treatment		pH (H_2O)	K^+ (ppm)	P (ppm)	TN (%)	SOC (%)	Particles size distribution (%)			CEC (meq/100 g
							Sand	Clay	Silt	
SWC practices	Elmo without SWC	6.23^b	3.70^b	4.196^b	0.139^b	1.9^c	22.45^a	39.53^b	38.01^a	25.81^c
	Elmo with SWC	6.75^a	5.19^b	5.73^a	0.320 ^{a}	3.42^{ab}	19.56^a	41.82^{ab}	38.61^a	43.18^a
	Hobene without SWC	5.48^c	5.09^b	4.21^b	0.163^b	2.69^b	22.02^a	44.44^{ab}	33.54^a	25.88^c
	Hobene with SWC	5.78^{bc}	7.00^a	5.55 ^{a}	0.272^a	3.61^a	22.01^a	48.49^a	29.50^a	38.22^b
	$LSD_{0.05}$	0.49	1.72	0.56	0.096	0.74	4.77	8.09	8.4	4.12
Landscape position	Upper	5.90^a	4.53^a	4.41^b	0.237^a	2.85^b	21.62^a	47.43^a	30.95^b	29.51^b
	Middle	6.14^a	5.50^a	4.83^b	0.223^a	2.37^b	22.78^a	41.07^a	35.14^{ab}	36.70^a
	Bottom	6.13^a	5.70^a	5.53^a	0.211^a	3.49^a	20.13^a	41.21^a	38.67^a	33.61^a
	$LSD_{0.05}$	0.43	1.49	0.48	0.08	0.64	4.13	7.00	7.27	3.64
CV (%)		8.38	13.55	11.63	23.94	26.07	22.36	18.98	24.61	12.91

K^+ = Exchangeable potassium; P = available phosphorous; TN = total nitrogen; SOC = soil organic matter; CEC = cation exchange capacity.

significant for SWC practices. Maximum pH value of 6.75 was obtained from areas with SWC practices at Elmo and relatively lower pH value of 5.48 at Hobene without SWC practice. This indicates that SWC practices increase the pH of the soil and then reduces soil acidity. Similarly, pH value did not vary for landscape positions. Maximum pH value of 6.27 was found on bottom landscape with SWC and pH value of 5.65 found on upper. This study agreed with Tadele et al. (2013) who found relatively lower pH mean value for the loss zone (without SWC) which may be attributed due to the relatively lower base saturation percentage and lower soil organic matter content while the highest pH value in the accumulation zone (with SWC). This could be attributed to the presence of higher exchangeable cations due to reduced erosion. Similarly, Shimelis (2012) reported that pH values on the farmland terraces decreased with increase in slope of the terrain.

Exchangeable (K^+)

The soil K^+ value in the experimental area varied from 0.6 to 8.7 ppm with an average value of 5.24 (Table 1) which is lower based on standard values of nutrients by Marx et al. (1999). Results of Mulugeta and Stahr (2010) also indicated that tropical soils are deficient in K^+. The exchangeable K^+ is significantly different for SWC practices (p=0.0065) and for interaction (p=0.0489), but not significant for landscape position at 5% level. Even though it is not significantly different, a maximum K^+ value of 5.7 ppm was obtained from bottom position. Area with SWC practices at Hobene showed higher K^+ value of 7.00 ppm and relatively lower K^+ value of 3.7 ppm at Elmo without SWC. Similarity, average K^+ value of 5.7, 5.50 and 4.53 ppm were found from bottom, middle and upper position of the field, respectively (Table 1). The interaction effect also showed significance with maximum K^+ value of 8.03 ppm found on lower position with SWC at Hobene and lower K^+ value of 3.53 ppm found on Elmo without SWC at the middle position. This may be due to the fact that erosion and leaching remove soluble salts from upper-slope and accumulate these at the down-slope erosion (*Pimentel* et al., 1995). Olarieta et al. (2008) reported that at the lower slope positions, water has a relatively longer residence time and as a result, soluble materials precipitate down.

Available P

Available phosphorus (P) was significantly different between the areas with SWC and without SWC (p<0.0001), among the landscape positions (p =0.0004) and their interaction (p<0.0001). Maximum available P value of 7.78 ppm found on lower position with SWC at Hobene and lower available P value of 4.05 ppm was measured on Hobene without SWC at middle terrain. Similar finding was obtained by Mulugeta and Stahr (2010). This may be due to the fact that organic sources of P are important for amending the agricultural land for a better land productivity. Higher available P of 5.73 ppm was found at Elmo with SWC and lower available P of 4.196 ppm was determined at Elmo without SWC. The lower P from areas without SWC was possibly due to the difference in the past land degradation resulting from continuous cultivation, extractive plant harvest and soil erosion. Bottom position showed higher available P of 5.73 ppm and a lower value of 4.41 ppm was observed at upper position (Table 1). P contents increased from upper to bottom position. Even though comparatively higher P found from areas with SWC, it was found at the lower range of medium based on London (1991) which is ≤ 5ppm as lower, 5-15 ppm as medium and >15 ppm as higher content of P. The lower plant available P could be attributed to inherent soil properties such as P fixation by iron and aluminum, while the differences between the terraces across slope of the terrain could be related to organic matter (OM) input differences (Shimelis, 2012).

Total nitrogen (TN)

The plots treated with SWC practices within the sub watersheds was found to exhibit higher total nitrogen (TN) than the non-conserved parts of the sub watersheds. TN was significant (p = 0.0018) for SWC practices and the highest content was found from the conserved parts with SWC practices than adjacent part without SWC practices. Mulugeta and Stahr (2010) also reported that the lands with SWC measures have high TN as compared to the non-conserved land. Abay et al. (2016) found TN (%) differed significantly between conserved and non-conserved, slope positions and also with their interactions (p≤0.05). This indicates the positive impacts of SWC practices in improving the nutrient status of farms treated by structures (Hailu et al., 2012). Lemma et al. (2015) also reported the overall total nitrogen (TN) was higher under closed area with SWC than in soil under closed area without SWC. Similar to exchangeable K and soil pH, no significant differences were found for TN in the landscape positions. Following the rating of TN greater than 1% as very high, 0.5 to 1% as high, 0.2 to 0.5% as medium, 0.1 to 0.2% as low and less than 0.1% as very low nitrogen status as indicated by (London, 1991), TN of conserved and non-conserved farm plots of the study area were found between low and medium. These may be attributed to less physical protection against water erosion, intensive tillage, due to leaching and limited nutrient amendments.

Soil organic carbon (SOC)

Based on ANOVA result, soil organic carbon differences between the conserved and non-conserved SWs were statistically significant (p = 0.0003 and p = 0.0052) with respect to landscape position, with higher values at Hobene and at bottom. This reveals the physical structures stabilized with vegetative practices have a better effect in soil OM accumulation. This finding agrees with Mulugata and Stahr (2010) who assessed the effect of integrated SWC measures on key soil properties with higher soil organic matter (SOC) (3.69%) in conserved catchment as compared to non-conserved (2.24%). As compared to sites without SWC practices, the implementation of SWC practices in this erosion-prone landscape resulted in the recovery of SOC. Moreover, SWC measures may hold great potential for increasing SOM levels since the areas where these are implemented are often heavily degraded.

This variation in SOC could be attributed due to the erosion reduction effects of SWC measures implemented and biomass accumulation (Tadele et al., 2013; Abay et al., 2016; Lemma et al., 2016). This implies SWC practices can bring current land use systems to a higher above and below ground biomass (and hence SOC) level by enhancing better ground cover. Kebede et al. (2011) on crop field also reported that the non-conserved fields had lower SOC as compared to the conserved fields with different conservation measures. Lal and Bruce (1999) also generally indicated technologies for restoration of degraded soils by establishing ecological-based vegetation cover, using appropriate soil and water conservation measures, adopting water harvesting measures, enhancing nutrient recycling mechanisms, and controlling stocking rate. Because soil organic matter is highly concentrated at the top layers of soils, it is highly affected by erosion. At the bottom slope position, higher organic carbon content was due to lower erosion rate and higher biomass production at bottom position (Tadele et al., 2013.)

Cation exchange capacity (CEC)

Statistical analysis revealed that the soils had statistically significantly different CEC ($p < 0.001$), SWC practices ($p= 0.0019$), and landscape position ($p=0.0003$) for their interaction, CEC was higher in parts of SWs treated with SWC as compared to without SWC adjacent parts. The conserved area at Elmo was found to have higher mean CEC value of 48.18 meq/100 g and lowest value of 25.81 meq/100 g at Elmo without SWC (Table 1). This is in line with research conducted by Abay et al. (2016) who revealed significant difference in CEC (meq/100 g) between the treatments and with respect to slope gradients ($p \leq 0.05$). The mean CEC (meq/100 g) did not vary (p=5%) between middle and bottom positions with 36.5 and 33.6, respectively and the lower different value of 29.51 at upper position. This result is similar to Abay et al. (2016) who found that the highest CEC (36.08 meq/100 g) was observed in the bottom, although there was no significant difference with that of middle slope whose value was 34.6 meq/100 g. The lowest value was observed in the upper slope positions with 31.8 meq/100 g. Similarly, according to a study conducted by Mulugata and Stahr (2010), areas with SWC showed higher CEC than areas without SWC. Lal et al. (1999) discussed that CEC of a soil can be reduced by soil erosion through the loss of soil OM. By the rating of London (1991), CEC greater than 40 meq/100 g is very high, 25 to 40 meq/100 g is high, 15 to 25 meq/100 g is medium, 5 to 15 meq/100 g is low and less than 5 meq/100 g is very low; soils of the study area could be regarded as high CEC.

CONCLUSION AND RECOMMENDATION

This study showed that the effectiveness of soil and water conservation at both SWs improved significantly the soil qualities (soil pH, K^+, available P, SOC, TN, clay and CEC) than in the adjacent without SWC treatment, in the same SW. This indicates the positive impacts of SWC practices in improving the nutrient status. Further the results of the soil analysis showed that most of the soil chemical properties had significant variations with respect to landscape positions. It would be possible to conserve more soil if the technical characteristics of the SWC practices and the maintenance systems were improved. Variability in soil types, slope gradient and landscapes (upper, middle and bottom slopes) affect the efficiency of different SWC measures and should be considered when designing and placing such measures for maximizing the benefit from that conserved. Bearing in mind, the effectiveness of SWC practices towards improving the soil quality and thereby sustainable agricultural productivity, there should be a continuous awareness creation mechanism for technically efficient implementation and a follow up process on the proper maintenance for optimum soil properties improvement.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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