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Effects of Graded Stone Bunds on Selected Soil Properties in the Central Highlands of Ethiopia

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Abstract: Land degradation is one of the major challenges in agricultural production in many parts of the world, especially in developing nations like Ethiopia. To combat the problem different Soil and Water Conservation (SWC) measures were introduced in the country. This research was conducted in the Harowerke micro-watershed, West Showa Zone, Oromia Regional State to assess effect of conservation measures on selected soil properties. Graded stone bunds are one of the conservation measures in study area. It included a comparison between farm plots with six-year graded stone bund and non conserved ones. A total of 48 surface soil samples were collected and analyzed for soil bulk density (BD), moisture content (MC), organic matter (OM), total nitrogen (TN), hydrogen ion concentration (pH) and cation exchange capacity (CEC) of soil. Results showed that soil BD and soil MC were significantly ($p \leq 0.05$) affected by the soil conservation measures and slope gradients. Soil OM, TN, and CEC also showed significant differences between conserved and non conserved as well as slope gradients. Soil pH did not show significant difference. The non conserved plots had the lowest soil OM, TN and CEC. The soil OM content of the plots were positively correlated to soil MC (R^2=0.86), total N (R^2=0.73), CEC (R^2=0.65) and inversely correlated to soil BD (R^2=0.68). The contribution of conservation measure to improve soil properties is significant in the study site. Additional soil fertility management practices, those including biological measures, could be added for better effect. Moreover, further research need to be conducted on socio-economic aspects for a better understanding of the sustainable use of the land.

Keywords: Soil Erosion, Soil and Water Conservation, Graded Stone Bund, Non Conserved, Soil Fertility

1. Introduction

The reason for the poor performance of agriculture in many developing countries is believed to be partly the deterioration of the natural resource base [19]. Land degradation due to soil erosion and nutrient depletion is considered as the main problem constraining the development of the agricultural sector. In Ethiopia, cultivation of marginal land, rugged topography and steep slopes is common in highlands, which characterized by intense rainfall and growing human and animal populations [3]. Land degradation in the form of soil erosion, sedimentation, depletion of nutrients, deforestation and overgrazing are the major challenges for agricultural development. Erosion has been threatening the agricultural sector of the country and has become one of the causes of the current drought and famine [4]. Soil erosion limits farmer's ability to increase agricultural production and reduce poverty and food insecurity. Erosion by water is the major cause for the rapid degradation of the highlands. As measurements from experimental plots and micro-watershed showed, the annual loss due to erosion by water from croplands is about 42t ha^{-1} $year^{-1}$ [41]. In area of steep slopes the rate reach up to 300 t ha^{-1} $year^{-1}$, where vegetation cover is inadequate [43]. With this rate of loss, much of the slopes of the highlands will be totally naked of the top soil layer in less than two centuries [42]. Estimates also show that 3.7% of the highlands had been so seriously eroded that they could not support cultivation, while a further 52% had suffered various levels of degradation [25].

This clearly shows the extent to which soil erosion is causal factor to the country's food security problem. Furthermore, many research results confirmed that soil nutrient depletion caused by erosion is the major cause for decline of agricultural production [6]. Soil erosion can reduce crop production by reducing organic matter content, plant nutrients, rooting depth and water holding capacities of soil [36]. Hence, land degradation in Ethiopia is becoming a matter of serious concern for its negative implications on the livelihood of the rural population and the environment from which they largely depend. The current trend of land degradation by soil erosion is a threat to food security and Adaa Berga district is not an exception. The undulating landscape coupled with unwise management of natural resource has aggravated the soil erosion in the study area.

Soil and water conservation measures (SWC) can change the physical conditions of the soil like soil organic matter content, soil structure, water holding capacity, soil bulk density, soil porosity, soil pH and its workability [18]. They also provide a stable drainage network to transport excess rainfall.

Since 2005, SWC measures have been promoting agricultural production through environmental rehabilitation in the Harowerke micro-watershed with collaboration of Oromia Agricultural Sector Support Project (ASSP) and Africa Developmental Bank. Graded stone and soil bunds have been the major program activities on croplands of the watershed. In the study area SWC measures have achieved considerable success in coverage. However, apart from monitoring and evaluation reports, no substantive studies made on their performances of improving both physical and chemical soil properties so far. Hence, it is valuable to investigate the effects of SWC measures on selected soil properties to evaluate the benefit of treating lands with physical SWC measures.

Therefore, the objective of this research is to assess the effects of graded stone bunds on selected soil properties and come up with recommendations for future SWC interventions. The finding can then be used to improve land management practices in the hilly areas of the watershed as well as in similar agro-climatic zones in the country.

2. Materials and Methods

2.1. Description of the Study Area

The study area is situated in Oromia regional state of Ethiopia at West Shewa Zone, Adaa Berga district. Geographically, it lies between the coordinates of 9°12" to 9°37" north latitude and 38°17 to 38°36 east longitude. It is at about 83km North West of Addis Ababa, capital city of Ethiopia. Topography is characterized by undulating and rugged mountainous. The entire area of the study district is characterized by high relief in the upper watershed of the Blue Nile River system.

The study area lies between 2501 to 2789 m above sea level and receives an annual average precipitation of 1290mm [17]. The minimum and maximum annual average temperature lies between 12 and 25°C [17]. The soil parent material of the study site is Mesozoic sedimentary rocks which itself lies under tertiary basalts and tuffs of the Trapp series that include rare rhyolites [17]. The soil types fall in to the three major categories of Vertisols, Nitosols and Lithosols [16]. Nitosols and Vertisols are the dominant soil types at the upper and lower streams of the watershed, respectively.

Soils in depressions and at the foot of the watershed tend to be black and liable to water logging during the rainy season, while those on upper streams are likely to be brown to reddish brown.

The entire area of the study is believed to have been covered by natural forest. But today almost all of them have disappeared due to rapid increase of population and high deforestation in order to obtain more land for cultivation, grazing and settlement. Natural Vegetation like *Juniperus procera, Afrocarpus falcatus, Oeleaa fricana, Corton macrostachyus*, Ficus and Acacia are visible sparsely. Mixed farming is the major economic activity which involves crop-livestock production systems.

Livestock production is an essential part of the farming system as nearly all land preparation is done with ox-drawn ploughs. They provide also farmers with transport, manure and fuel. They are an important insurance during hardship times and wealth ranking is mainly based on the ownership of livestock. Oxen, cows, sheep, goats, horse and donkeys are the types of livestock kept by the farmers. The major crops grown are wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), faba bean (*Vicia faba*.), teff (*Eragrostis tef*), chickpeas (*Cicer arietinum*), and highland maize (*Zea mays*). Fallow is a common practice in much of the upper micro watershed as means of soil fertility improvement methods. Other fertility enhancing practices such as crop rotation are applied, while green manure, mulching, and plowing under crop residues are not known in the area.

2.2. Methodology

Before the start of the experimental research, a field survey was conducted in consultation with key informants, local development agents and *kebele* leaders to harmonize ourselves with area and locate representative sample plots within the selected slope gradients. The experiment was done on the most upper slope of the study area where erosion is assumed to be severe and has above 15% slope percentage. Three slope gradients each containing graded stone bund of 6 years and adjacent farm plots without conservation measures were selected at an interval of 50 m from each other. The experiments were laid down in RCBD (randomized complete block design) with factorial arrangement. The experimental plots containing each treatment (terraced and non terraced farms) were replicated four times in the selected farm plots which were systematically located across the slope gradient. Altogether (4 replication x 3 slopes position x 2 treatment x 2 positions of farm plot = 48 sampling plots) were established. From each representative experimental plot soil samples were taken from four corners and center of a plot of 10m x10m size using an "X" sampling design [29] with sharp edged knife and mixed thoroughly in a clean plastic bucket to form a composite sample for analysis of the various soil properties. In the case of the conserved farm plots, the sampling plots refer to the area between the two consecutive structures where as in the non terraced plots, the sampling plots refer to the area under cultivation which is found adjacent to the terraced one. For BD determination after clearing the top surface crop residues and others, undisturbed soil were taken from the center of each sampling plots at depth of 0-15 cm topsoil with a core sampler.

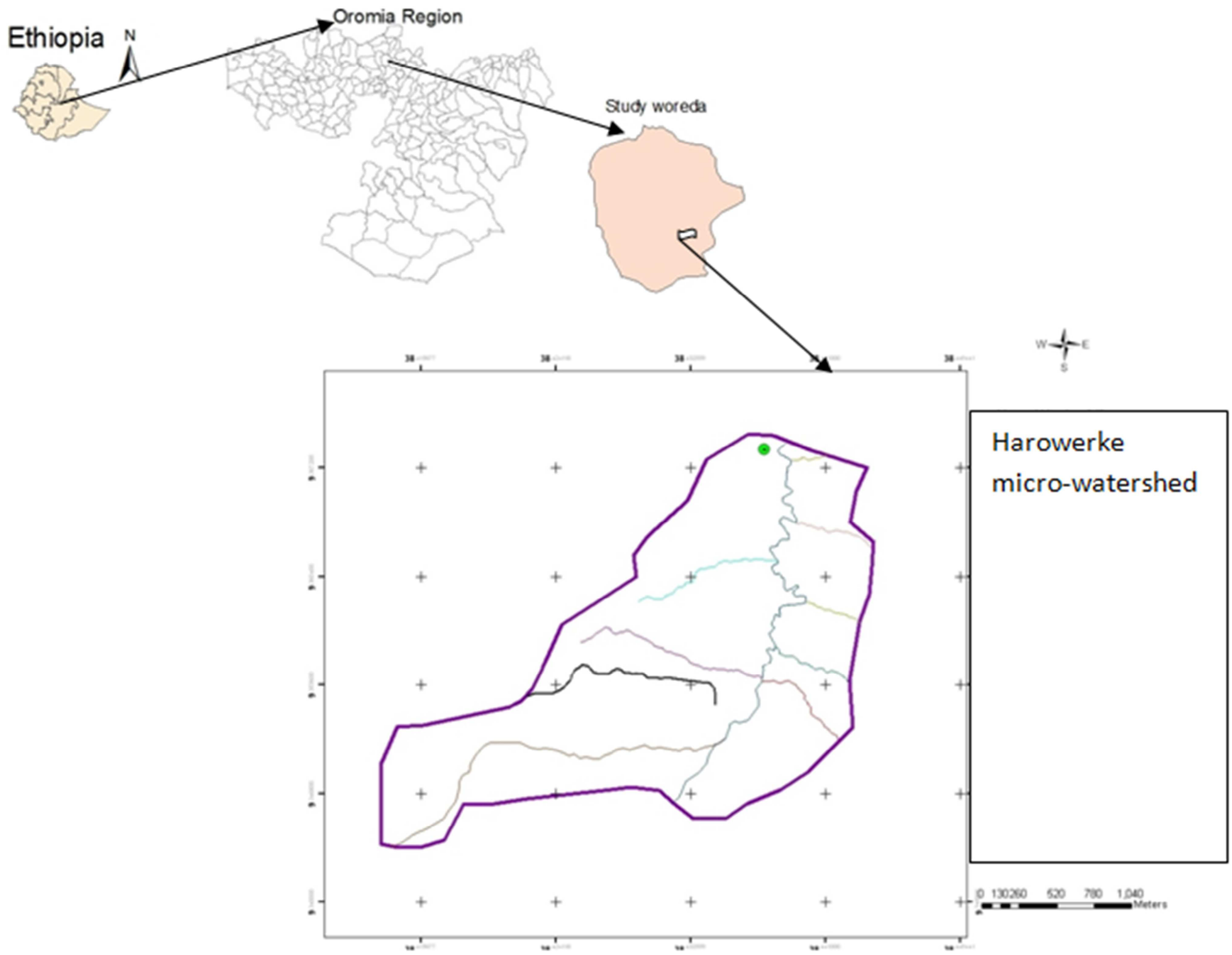

Figure 1. *The location map and the study area.*

Finally, each soil samples were air-dried at room temperature, homogenized and passed through a 2 mm sieve before laboratory analysis for different soil parameters including OM content, CEC, TN and soil pH. Organic carbon was determined according to Walkley & Black method [37], and it was converted to OM by multiplying the percentage of carbon by 1.72; total nitrogen was analyzed by the Kjeldahl method [11]; CEC was measured by using 1M Ammonium acetate and pH was measured in distilled water using a 1:2.5 (soil: water) suspension at the Institute of Oromia Agricultural Research at Ziway soil laboratory Center. Soil BD and soil MC were determined by the core method [8] at nearby Holleta Agricultural Research Center.

SWC practice (graded stone bund of 6 years of age and adjacent non conserved farm plots) and slope gradient were used as independent (fixed) variables and the soil parameters as dependent variables. The effect of SWC practice and slope gradient on some physical and chemical properties of soil were tested by two way analysis of variances. The soil physical properties (MC and BD) and chemical properties (pH, TN, OM and CEC) were subjected to analysis of variance using the general linear model procedure of the statistical analysis system (SAS, version 9.0). When the analysis of variance (ANOVA) showed significant differences (at $p \leq 0.05$) due to SWC practice and slope gradient for each parameter, a mean separation for each parameter was made using least significant difference (LSD).

3. Results

3.1. Soil Bulk Density (BD)

Significant differences in soil BD (g/cm^3) were observed between terraced and non-conserved and among slope gradients at ($p \leq 0.05$) (Figure 2). Significantly lower soil BD

(1.13) occurred in terraced farm plots as compared to non-conserved farm plots (1.21) (Table 1). With respect to slope, lower soil BD (1.14) was observed in middle slope (20-25%) than the higher slope gradient ≥25% (1.21) (Table 1). Middle and lower slope positions were not statistically different among each other.

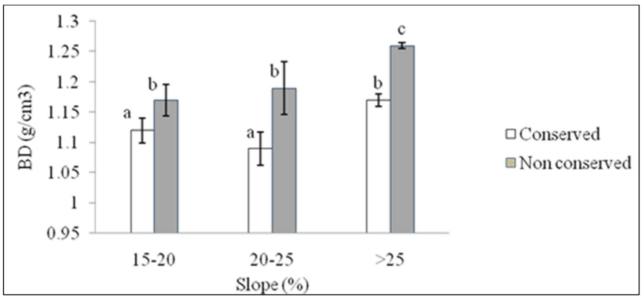

Figure 2. *Soil bulk density (BD) with respect to conservation practices and slope position.*

Graphs with similar letters are not significant at (p≤0.05). Bars indicate standard error of the mean.

3.2. Soil Moisture (MC %)

Soil moisture showed significant variation at (p≤0.05) with respect to treatment (Figure 3). Higher soil MC (19.6%) was observed in farm plots with SWC measures as compared with non-conserved farm plots (17.6%) (Table 1). In respect to slope gradients there was a significant variation (p≤0.05) between upper and middle slope (figure 3). The higher soil moisture (19.7%) was observed in the middle slope (20-25%) than in the higher slope gradient ≥25% (17.2%) whereas lower slope gradient was found to be between the two (18.7%) (Table 1). But slope-treatment interaction effect didn't show any significant variation at (p≤0.05).

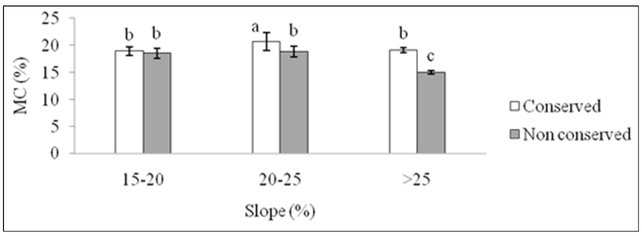

Figure 3. *Soil Moisture content (%) with respect to conservation practices and slope position of the top 0-15cm soil depth.*

Graphs with similar letters are not significant at (p≤0.05). Bars indicate standard errorof the mean.

3.3. Soil Organic Matter (OM)

Results of the experiment indicated that there was significant difference in soil OM (%) content between the treatments. There were also significant variations with slope gradient as well as slope-treatment interaction effects at (p≤0.05) (Figure 4). The significantly lowest SOM occurred in non-conserved (2.9%), while soil OM showed the highest (3.4%) in farm plot which was conserved with graded stone bunds (Table 1). In respect to slope position higher SOM (3.5%) was observed in the lower slope (15-20%) than at both higher (≥25%) and middle `slope gradients (20-25%) which were (2.7%) and (3.2%) respectively (Table 1). Soil OM was positively and significantly correlated with MC (R^2=0.86**), TN (R^2=0.73**), CEC (R^2=0.65**) while it was inversely and significantly correlated with soil BD (R^2=0.68**) (Table 2).

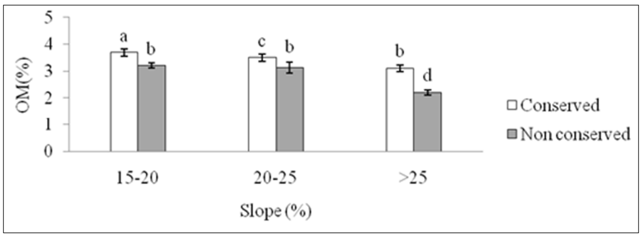

Figure 4. *Soil Organic matter content (%) with respect to conservation practices and slope position of the top 0-15cm soil depth.*

Graphs with similar letters are not significant at (p≤0.05). Bars indicate standard error of the mean.

3.4. Total Nitrogen (TN)

Total nitrogen (%) differed significantly between the treatment, slope positions and also between the treatment slope interaction at (p≤0.05), matching the soil OM distribution (Table 2). The overall TN content in soils under non-conserved farm plots was significantly lower (0.17%) than the content under graded stone bund 6 years of age (0.24%) (Table 1). With relation to slope position higher TN (0.25%) was observed in the lower slope (15-20%) followed by middle slope (20-25%) and upper slope position (≥25%) with value of (0.21%) and (0.16%), respectively (Table 1).

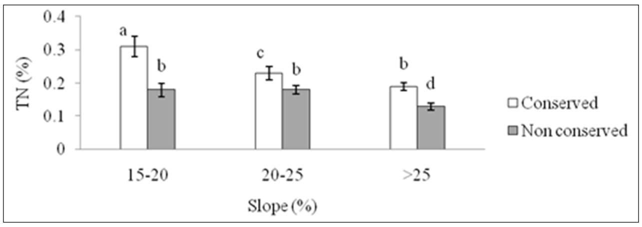

Figure 5. *Total Nitrogen (%) with respect to conservation practices and slope position of the top 0-15cm soil depth.*

Graphs with similar letters are not significant at (p≤0.05). Bars indicate standard error of the mean.

3.5. Soil pH

The soil pH did not show significant variation between treatments, slope gradient and slope-treatment interaction effect at (p≤0.05). The pH values of the study site varied from 5.57 to 5.61. Soil pH was positively correlated with MC (R^2=0.06), OM (R^2=0.12) and CEC (R^2=0.09) while it was inversely correlated with soil BD (R^2=0.19) and TN (R^2 =0.01) (Table 2). The correlation of soil pH was not statistically significant with each parameter.

3.6. Cation Exchange Capacity (CEC)

Results of the experiment indicated that there was significant difference in CEC (meq/100gm of soil) between the treatments and with respect to slope gradients at ($p\leq0.05$). The CEC of the soils was lower (30.1) in non-terraced farm plots and higher (38.2) in farm plots with SWC practices (Table 1). With respect to slope gradient the highest CEC (36.08) was observed in the lower slope (15-20%) though there were no statistically significant difference with that of middle slope (20-25%) whose value was (34.6). The lowest value was observed in the upper slope positions (≥ 25%) with (31.8) (Table 1).

Table 1. *Soil BD (g/cm³), MC (%), OM (%), TN (%), CEC (meq/100g) and soil pH of the top 0-15cm soil depth, in relation to slope position and conservation practices (mean±SE).*

Variables	slope percentage			conservation practices	
	15-20%	20-25%	≥25%	conserved	non conserved
BD	1.15±0.02a	1.14±0.03a	1.21±0.01b	1.13±0.02a	1.21±0.03b
MC	18.71±0.59ab	19.76±0.95a	17.22±0.51b	19.57±0.60a	17.55±0.55b
OM	3.49±0.13a	3.24±0.14b	2.71±0.11c	3.42±0.13a	2.87±0.12b
TN	0.25±0.03a	0.21±0.02b	0.16±0.01c	0.24±0.02a	0.17±0.01b
CEC	36.08±1.14a	34.59±1.43a	31.78±1.16b	38.24±0.49a	30.07±0.79b
pH	5.57±0.06a	5.56±0.05a	5.59±0.07a	5.55±0.04a	5.61±0.06a

Means followed by the same letter(s) horizontally for each variable are not significantly different at (p ≤ 0.05) with respect to treatments and slope gradients.

Table 2. *Pearson's correlation matrix for various soil physical and chemical properties.*

Parameters	MC	BD	TN	OM	CEC	pH
MC	1	-0.73**	0.622**	0.866**	0.699**	0.059
BD		1	-0.59**	-0.687**	-0.76**	-0.192
TN			1	0.734**	0.682**	-0.004
OM				1	0.655**	0.119
CEC					1	0.097
pH						1

** Significant at the 0.01 level,* significant at the 0.05 level; MC=moisture content, BD=bulk density, TN=total nitrogen, OM=organic matter and CEC=cation exchange capacity

4. Discussions

4.1. Soil Bulk Density (BD)

Lower mean value of BD was recorded in farm plots with SWC practices compared to non terraced farm plots. This is due to the presence of higher OM as a result of conservation measures. This is in line with the findings of [44, 31] which indicated conserved micro watershed was found to exhibit significantly lower mean value of BD than non conserved. This result was different with the study of [35], which reflected that the soil BD of terraced land was higher than that of non conserved land. Thus, there is a general pattern of non conserved farm plots to be associated with soil compaction due to removal of top soil and plant residues, which has implications for the moisture and air that would be available to plant root and microorganisms in the soil system.

The finding of the experiment indicated that soil bulk density declined as soil moisture content increased along the slope gradient. This may be attributed to soil textural class due to deposition and leaching along the slope gradients. As report by [13], the overall soil textural class of both terraced and non conserved farm plot of the study site falls under clay type with fraction of (42% clay, 35% sand and 24% silt). As it was reported by the same author, silt fraction slightly increase as one move to higher slope gradient whereas clay percentage is contrary. Hence, the differences were mainly due to SWC practice. The significance difference in soil organic matter which governs soil property in the study area is also the possible reason for soil compaction at higher slope gradient. Similarly, [28] reported decrease in bulk density on cultivated farm plots in the lower slope gradients than higher gradients. On other hand this results was different with the study by [45], which reported that slope position did not have a significant effect on surface BD, although a slight higher BD at the top position than other slope positions. This could be attributed to the removal of crop roots, debris and crop residue from upper area and deposited at lower position and thereby increase in soil organic matter. The decrease in soil BD due to SWC practices at lower slope gradient would result in greater water infiltration rates which in turn minimize runoff velocity, thus, sediments and organic matter removal. As a consequence OM accumulation improves a soil physical structure which promotes crop root abundance, crop stand, crop production and better crop residues at the lower slope. In doing so, it promotes OM accumulation in the area in addition to transported from eroded area and accumulated at deposited area.

4.2. Soil Moisture (MC %)

The results revealed that SWC measures significantly improved the soil MC. Soil MC, which is a key factor affecting agricultural production in water limited environments, was higher in farm plots with SWC practices compared to non conserved farm plots. This could be attributed to the presence of significantly higher OM and reduced runoff velocity and enhanced infiltration as a result of SWC measures than the faster runoff flow down the slope for non conserved farm plots. Since the soil textural class of the study site is of clay type [13], we can say that, the only variable that is affecting the soil moisture is the SWC practice. Soil OM improves the soil structure and thus affects the stocking of the soil water reserves [26]. In this study soil MC showed that strong correlation to that of soil OM contents.

In respect to slope gradient there is a significant variation between upper and middle slope gradients. The result revealed that middle slope position do have more soil MC. It seems that the middle receives higher amounts of additional moisture from upper positions compared with lower slope gradients. This may be associated with the relative amounts of the soil at that slope position. This is in line with findings of [33] which found out that the mid slope position has higher values of moisture content than the bottom and upper slope positions.

The fertile topsoil moved down the slope by water erosion processes and sediment deposition took place at middle slope positions, which in turn might have contributed to increased soil depth and consequently improved the water content of the soil. Similar to the results on the soil MC, [20] on their report also confirmed that soils that lie at the middle and lower positions receive more moisture than upper slope. These increases in soil MC also may be attributed to an additional water supply from upslope to down slope as catchment area increase.

4.3. Soil Organic Matter

Soil OM, which is considered as a key soil attribute as it affects many physical, chemical and biological properties, that control a soil's productivity and resistance to degradation, was highly significant between the treatments. Higher SOM were observed in plots with SWC measures than non conserved farm plots. This could probably be attributed to accumulated and retained OM due to bund construction, whereas the lowest OM may be attributed to the loss in the form of decaying leaves, stems and roots from surface soil due to lack of physical barriers. [31, 2] also reported that soil under non conserved treatment was found to exhibit lower soil OM than plots treated by SWC structures. A study conducted by [24] in the Amhara region, Enebsie Sar Mider woreda, also showed that the OM content of non conserved land for a slope range between 10 and 15% were lower (mean = 1.12%) than the conserved land of corresponding slope class (mean=2.33%).

Soil OM content was the highest at lower positions for non conserved farm plots which directly related to higher amounts of available soil MC. Upper positions had the lowest OM that may indicate the severity of soil erosion on these sites and transportation to the lower point in the landscape through runoff and erosion. According to [9], OM accumulation is often favored at the bottom of hills for two reasons: one is they are wetter than at mid or upper slope positions, and the other is OM would be transported to the lowest point in the landscape through runoff and erosion. The same holds true for conserved land where soils are actively eroded from the soil loss zone and deposited to the soil accumulation zone, creating spatial variability in terms of moisture and nutrient availability within the inter-conserved space.

Some parameters found in this study were significantly correlated with each other (Table 2). Soil OM was positively and significantly correlated with MC, TN and CEC (at $p \leq 05$). Because of this close link, soil organic matter has an influence on soil properties. Hence, declines in soil OM contributes to the loss of grain production and results in food insecurity. According to the soil classification of soil OM ranges suggested by [5], the mean values of organic matter of both terraced and non-terraced farm plots were found to be medium. This may be attributed to erosion before the structures built and linked to poor soil fertility management practices conducted by the land users after the structures. In the study area, soil OM depletion needs special attentions in the future.

4.4. Total Nitrogen (TN %)

Significant differences were observed between the treatments. The farm plots treated with SWC measures within the watershed was found to exhibit higher TN than the non conserved watershed. Similarly, [31] also reported that farmland with physical SWC measures have high TN as compared to the non conserved land. [2, 44] also found that the mean TN contents of the conserved sites were higher as compared to the average TN contents of the corresponding non conserved sites.

The variation in TN was also significant with slope gradient, where TN was, higher in the lower slope than in the higher slope gradients. This might be due to the removal of OM from the higher or steep slopes as a result of soil erosion and leaching to the down slope. Following the rating of TN greater than 1% as very high, 0.5 to 1%as high, 0.2 to 0.5% as medium, 0.1to 0.2% as low and less than 0.1% as very low nitrogen status as indicated by [27], TN of conserved and non conserved farm plots of the study area were found between low to medium. These may be attributed to less physical protection against water erosion, intensive tillage, due to leaching and limited nutrient amendments [39]. Generally, the lowest TN in the study site might be associated with the use of crop residues and stocks for fuel and animal feed rather than leaving in the farm to decompose and enrich the soil OM content.

In this study TN content of a soil is directly associated with its soil OM contents. Therefore, if OM input from crop residues, manure and any other sources were not equal to the rate of decomposition, without take into account the rate of output, the TN depletion is faster. These in turn make the situation more problematic along with soil erosion and contribute to the loss of grain production.

4.5. Soil PH

The variations for soil pH, which affects nutrient availability and toxicity, microbial activity and root growth [10] both under conserved and non conserved farm plots were generally small. No significant differences were detected either between treatments or between slope positions. The laboratory result of sampled soils is in agreement with the reports of other similar studies. For instance [2, 17, 31] also found that stone bunding had no significant effect on soil pH when compared to the control treatment (non conserved plots). [40], also reported pH values did not vary with position in the plots between consecutive stone terraces. The report by [23] indicated soil pH significantly differed, which was not in agreement with results of this study in that 4 years level soil bunds and six years level stone bunds compared to non conserved

Soil pH was positively correlated with MC, OM and CEC while it was inversely correlated with soil BD and TN. The inversely correlation probably suggest that the washing out of solutes from upper slope positions where soil BD is higher and application of acid forming fertilizers like Urea.

According to [34], rating of surface soil pH (4.5 as very acidic, 5.0 as acidic, 5.5 as moderately acidic and 6.0 as slightly acidic) the pH value of both the conserved and the non conserved farm plots in study area can be classified as moderately acidic. It may be attributed to the application of acid forming fertilizers, continuous intensive cultivation, intense erosion and leaching of basic nutrients like calcium, potassium and magnesium as excess rainfall passes through the soil [12, 38]. The other reason could be related to the parent material of the Trapp series that include rare rhyolites of the sampled soils [17]. As explained by [34], soils developed from acidic rocks (parent materials) such as granite and rhyolite contain an excess of quartz or silica and these, combined with various proportions of water, form acids such as silicic acid, and trisilicic acid. As a result, most soils in high rainfall area have the problem of nutrient availability for the production of agricultural crops such as potassium, calcium, magnesium and phosphorous. This is one of the problems mentioned by many researchers [15, 38] that make the tropical countries poor and unable to feed themselves in most cases in addition to other problems related to agricultural production and productivity.

4.6. Cation Exchange Capacity (CEC)

The value of CEC in the soil samples collected and analyzed showed that the results obtained were statistically significant. CEC was higher in plots treated with SWC compared to non conserved farm plots. This is in line with research conducted by [2], where conserved area with original slope of 25 and 35% were found to have mean CEC value of 6 and 49%, respectively, higher than the average CEC of the corresponding non conserved slopes. Contradictory to this [23, 31] found that statistically insignificant mean value of CEC in their comparison of conserved and non conserved farm plots. Following [27] the rating of CEC greater than 40 as very high, 25 to 40 as high, 15 to 25 as medium, 5to 15 as low and less than 5 as very low, soils of the study area could be regarded as high CEC. Similar to soil OM, soil CEC showed an increment with decrease in slope gradient both in farm plots with SWC practices and without conservation measures.

In this study there was a positive and significant correlation between soil CEC and OM (Table 2). This finding implies, that improving soil OM content can significantly increase soil CEC. The high clay fraction along with soil OM may also attribute to high rate of soil CEC in the study site. Hence, processes that affect soil OM due to soil erosion, intensive cultivation and land use changes can affect CEC of soil [32, 31, 14], which in turn affects soil fertility and can cause severe yield decrease.

5. Conclusions and Recommendations

Soil erosion seriously restricts land productivity in Adaa Berga areas as other areas of the Ethiopian highlands. In the study area, graded stone bunds have shown significant improvement in soil physical properties such as soil MC and BD and chemical properties such as soil OM, TN, pH, and CEC. Moreover, the high OM content of farm plots with SWC practices affect more positively the soil properties as compared to the non conserved farm plots.

The variation was also significant along slope gradient for some soil physical properties and chemicals properties. Higher BD was found in steep slope gradient (≥25%) whereas lower was found in middle slope gradient. Unlike soil bulk BD, higher MC was observed in middle slope (20-25%) whereas lower was observed in higher slope gradient. Soil OM and TN were negatively correlated with soil BD, while they were positively correlated with soil MC. This implies that SWC measures have affected positively the productivity of agriculture in conserved lands.

Soil pH was found not significantly affected by both SWC measures and slope gradient. The similarity of soil pH in conserved and non conserved farm plots suggested that there is an intense leaching as excess rainfall passes through the soil. Generally, the effects of graded stone bunds on some selected soil physical and chemical properties at Adaa Berga district were found to have pronounced positive effects. Soil properties are relatively better on the conserved farm plots than on the non conserved one. Conservation measures such as terraces were found to be important not only to reduce soil erosion but also to maintain the soil fertility such as soil OM, TN and CEC. This implies that SWC measures positively affected the productivity of agricultural lands although farmers' future adoption could be challenged by poor perception of farmers.

However, there is a need for awareness creation and follow up on proper management and regular maintenance of structures. Integration of biological conservation measures is vital for better effective and sustainability of SWC efforts. If SWC practice is not intensively continued, more land will become unsuitable for crop production in the future.

Finally, since this study focused on the analysis of some physical and chemical soil properties without incorporating socio-economic and institutional aspects of biological and physical SWC approach due to various limitations, further research such as impacts of terracing on crop yield are required to get a comprehensive conclusion. The difference in soil properties between the loss zone and accumulation zone within the terraced plot should also be evaluated further for complete understanding.

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