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Research Article

Effects of Physical Soil and Water Conservation Structures and Slope Gradients on Soil Physicochemical Properties in West Oromia, Ethiopia

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Abstract

Background and Objective: Soil degradation resulted from water erosion is quite common in mountainous area where the land cover is depleted and cultivated for long time without applying proper land management practices. The objective of the study was to evaluate the effects of soil and water conservation structures (terraces) on selected soil physical and chemical properties. **Materials and Methods:** The treatments used for comparison were cultivated land treated by soil and water conservation structures, adjacent non-conserved cultivated land and slope gradients. The slope gradients were gentle (3-15%), moderately steep (15-30%) and steep slope (>30%). A total of 18 composite soil samples were collected from the top 0-20 cm soil depth replicated three times for each treatment. Selected soil physical and chemical properties were analyzed in the laboratory by using standard procedures. Data was analyzed using statistical software. **Results:** The results of the study revealed that most of investigated soil physical and chemical properties showed significant different between conserved and not conserved farms except for soil pH value, sand and available phosphorous content. For slope gradients result of the study indicated that soil pH value, sand and available phosphorous content were significantly different among treatments. **Conclusion:** It can be concluded that implementation of proper soil and water conservation measures on moderate to steep sloped degraded farm lands could reclaim the land through improving selected soil physical and chemical properties. This implies that crop production on degraded sloppy land without implementation of appropriate soil and water conservation measures could not be maintained and sustainable.

Key words: Terraces, soil physical properties, soil chemical properties, hillside farming, slope gradients

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Land degradation caused by soil erosion is one of the most serious environmental problems affecting resource-poor tropical hillside farmers¹. Land degradation is a major cause for poverty in rural areas of developing countries particularly in sub-saharan Africa². The immediate consequence of land degradation is reduced soil fertility and crop yield followed by economic decline and social stress³. Agriculture is the main source of livelihood for more than 75% of the Ethiopian population. However, the agricultural sector and hence the livelihood of farmers are under continuous threat from the effects of land degradation mainly caused by soil erosion and soil nutrient depletion⁴. Soil fertility depletion due to erosion is one of the most important challenge of Ethiopian farmers that led to very low productivity of agricultural lands. In densely populated highlands of Ethiopia farmers face twin problems of increasing population pressure which forced farmers to continuously farm on limited croplands and marginal areas. Increased deforestation and continuous hillside cultivation combined with limited agricultural inputs led to degradation processes such as; declining soil fertility, accelerated soil erosion by water and siltation of irrigation and hydropower reservoirs^{5,6}.

Owing to the fact that land degradation is severe in Ethiopia, government is investing huge financial and labor resources to tackle the problems. Nevertheless, farmers investments in soil and water conservation practices remain limited⁷. Lack of participation and a top down approach have been reported as the main causes for the observed low level of investment in physical soil and water conservation practices⁸. Moreover, household and field characteristics are often mentioned as major factors affecting farmers investments in physical soil and water conservation practices^{9,10}. In addition, farmers investments in soil and water conservation practices are affected by the effectiveness of these practices on improving soil fertility and crop yield¹¹. Given that there is severe and widespread land degradation in the study area soil and water conservation measures mainly terraces, bunds and tree planting introduced.

Taking into consideration impacts of soil and water conservation structures on soil properties is vital to inform farmers on the effectiveness of the measures and persuade them to invest on its implementation. Although it was reported that soil and water conservation practices decreased loss of soil, runoff and increased crop yield in some regions of the country, no study was conducted in Ya'ee Chabo watershed, in western Ethiopia. The effectiveness of soil and water conservation structures on soil properties and crop yield

are generally site specific and highly variable¹². Therefore, this study was conducted with the objective of assessing the impacts of soil and water conservation structure (terraces) and slope gradients on soil physical and chemical properties.

MATERIALS AND METHODS

Description of the study area: The study was conducted at Ya'ee Chabo Watershed which is found in Ambo district, Oromia region, Ethiopia. It is 15 km far from Ambo town and 130 km from Addis Ababa, capital of Ethiopia. Geographically, it is located between 8°49'26"-8°55'22"N and 37°51'57"-37°54'08"E. The total land area of the Ya'ee Chabo watershed is about 1091 ha. The watershed has an altitude range of 2380-3170 m.a.s.l. The area is characterized by undulating, rugged and hilly topography.

The area belongs to moist agro-climatic zone with bimodal rainfall. The main rainy occurs from June to mid-September and the short rainy season extending from February to April. The mean annual rainfall recorded over the last 10 years ranges from 1500-1700 mm while the mean minimum monthly temperature of the area varies from 11.89-17°C and the mean maximum monthly temperature ranges from 20.5-27°C. From total area of the watershed about 59% is cultivated land predominantly used for cereal crop production, 6% is covered by enset (*Ensete ventricosum*) plantation, 15% remnant natural forests, while 18% is occupied by settlement and 2% grazing land.

Site selection and soil sampling: Reconnaissance field survey was carried out in the watershed to select appropriate site for the study were cultivated lands on which soil and water conservation measure. Sampling sites were selected from farm plots where land terraces for soil and water conservation had been constructed and maintained for more than 10 years and farm plots not treated with physical soil and water conservation measures as control. Both farm lands have similar land form and land use/cover. From terraced plots, soil samples were collected from the area between the two successive terraces. In the case of non-terraced plots, soil samples were collected from the area in between successive farm boundaries.

In the area land terrace has been recommended as suitable physical soil and water conservation measure and implemented on land with slope between 3-45%. The slope gradient was divided into three slope ranges of which 3-15% as gentle slope, 15-30% as moderately steep and 30-50% steep slope¹³.

Based on slope gradients the sampling plots were grouped into two categories. Accordingly, 4 plots representing 2 plots from each slope categories were identified. From each sampling plot a total of 15 sub-samples were collected in zigzag movement across the slope gradients to make one composite sample. By repeating those procedures on all selected croplands with terrace and adjacent non-conserved croplands, a total of 18 composite samples (2 treatments × 3 slope gradients × 3 replications) were collected by using auger from a depth of 0–20 cm.

Preparation and laboratory analysis: The samples were mixed thoroughly in a plastic bucket to form a composite sample. Except for soil bulk density, collected soil samples were air-dried at room temperature, homogenized and passed through 2 mm sieve before laboratory analysis. For determination of soil organic carbon and total nitrogen, the samples were passed through 0.5 mm sieve. Moreover, undisturbed samples were taken with a core sampler of height (10 cm) and diameter (7.2 cm) for soil bulk density determination.

Selected soil physical and chemical properties that were determined in the laboratory, include texture, bulk density, pH, organic carbon, available phosphorus, total nitrogen, CEC, exchangeable acidity and exchangeable bases (Ca, Mg, K and Na). The particle size distribution of the soils were analyzed with the help of the hydrometer method¹⁴. The bulk density of the soil was estimated from undisturbed soil samples collected by using a core sampler (which is weighted at field moisture) after drying pre-weighted soil core samples in an oven¹⁵ at 105°C.

Determination of soil pH was conducted using pH meter in the supernatant suspension of 1:2.5 soils to water ratio. Organic carbon of the soils was determined following the wet digestion method¹⁶. While percentage organic matter of the soils was determined by multiplying the percent organic carbon value by 1.724. Available P was determined by the Bray II extraction method¹⁷. Total nitrogen was determined titrimetrically following the Kjeldahl method¹⁸. The ammonium acetate method was employed to determine the Cation Exchange Capacity (CEC) and exchangeable cations (Ca, Mg, K and Na). The exchangeable cations Ca and Mg in the

leachate were determined by Atomic Absorption Spectrometer, whereas K and Na were measured by flame photometer¹⁹. Exchangeable acidity was determined by saturating the soil samples with potassium chloride (1 MKCl) solution and titrated with 0.02 M NaOH²⁰.

Statistical analysis: Soil and water conservation practice (terrace) and adjacent control farm plots and slope gradient were used as independent variables and the soil parameters as dependent variables. All the collected data of the soil physical and chemical properties for terraced and their corresponding control sites and slope gradients were tested by using analysis of variance following General Linear Model (GLM) procedure of the statistical analysis system. When significant differences were observed, comparisons of means were performed using Tukey's Least Significant Difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Soil physical properties

Soil particle size distribution: The result revealed that the content of silt and clay were significantly influenced by the soil and water conservation structures and slope gradients. Soils of the non-conserved land had the highest percent clay content compared to the soils of conserved one (Table 1). Highest clay content in the control treatment may due to the exposure of the soil by tillage and soil erosion by water eventually exposes the sub-soil, which is naturally high in clay content. Complete removal of top soil at loss zone causes the sub-soil dominated by clay material to move down slope and deposited on the fertile accumulation²¹. The average silt content recorded under conserved field were significantly higher.

The highest mean (31.97%) value of sand content was recorded in un-conserved farm plot (Table 1). The content of sand and silt particles showed irregular variation along the slope gradient (Table 2). Sand dominant soil textures are common on higher slope position of the watershed²². This indicated that it is the inherent soil property and the slope gradient which cause the variation in texture than the

Table 1: Impact of conservation structure on soil particle size distribution and bulk density

Treatments	Particle size distribution (%)			Textural class	Bulk density (g cm ⁻³)
	Clay	Silt	Sand		
Terraced area	33.30 ^b	36.60 ^a	29.98 ^a	Clay loam	1.00 ^b
Control	40.17 ^a	28.20 ^b	31.97 ^a	Clay	1.03 ^a
LSD (5%)	5.37	2.19	Ns		0.02
CV (%)	13.92	6.44	15.49		2.48

Same alphabet represents that values are significantly different

Table 2: Impact of slope gradient on soil particle size distribution and bulk density

Slope gradients	Particle size distribution (%)			Textural class	Bulk density (g cm ⁻³)
	Clay	Silt	Sand		
3-15%	41.03 ^a	34.15 ^a	25.92 ^b	Clay	0.98 ^b
15-30%	39.44 ^b	36.45 ^a	24.21 ^b	Clay loam	1.01 ^b
>30%	29.73 ^b	26.60 ^b	42.79 ^a	Sandy clay loam	1.05 ^a
LSD (5%)	8.77	10.89	6.07		0.04
CV (%)	19.47	28.65	15.94		3.63

Same alphabet represents that values are significantly different

Table 3: Impact of conservation structure on selected soil chemical properties

Treatments	pH	OM (%)	TN (%)	Av. P (mg kg ⁻¹)	Exchangeable basic cations (Meq/100 g)				Ex. acidity (Meq/100 g)	CEC (Meq/100 g)
					Na ⁺	K ⁺	Mg ⁺²	Ca ²⁺		
Conserved	5.36 ^a	2.22 ^a	0.07 ^b	12.95 ^a	0.13 ^a	0.07 ^b	22.50 ^a	13.44 ^a	0.07 ^b	22.50 ^a
Un-conserved	5.29 ^a	1.99 ^b	0.09 ^a	11.82 ^a	0.12 ^b	0.09 ^a	20.86 ^b	12.05 ^b	0.09 ^a	20.86 ^b
LSD (5%)	NS	0.15	0.01	NS	0.01	0.01	1.29	1.34	0.01	1.29
CV (%)	6.56	6.90	8.19	16.13	8.54	8.19	5.74	9.63	8.19	5.70

Same alphabet represents that values are significantly different, OM: Organic matter, TN: Total nitrogen, Av. P: Available phosphorous, CEC: Cation exchange capacity, NS: Not significant

structures. With steep landscapes, transportation and translocation of fine particles are expected.

This result also confirmed the presence of higher clay fraction in the lower slope gradient due to deposition from the upper slope. The content of clay particles showed regular variation from 41.03-29.73% along the slope gradient when slope is 3-15% and >30%, respectively (Table 2). Similar result was reported previously that fine textured soil particles are dominated on flat land areas whereas coarser textured classes are mainly dominated on the steeper slopes²².

Soil bulk density: The non-conserved farm plot was found to exhibit the highest mean value of bulk density than conserved farm plots. The mean bulk density value in conserved plot was significantly lower (1.00) than un-conserved farm plot (1.03) (Table 1). The higher bulk density values in the un-conserved farm plots may be caused by the exposure of the sub-soil by erosion and the removal and oxidation of the organic carbon from the top soil. Soil erosion due to runoff and the decomposition of relatively small amount of organic carbon resulted in the decline of soil structural properties, resulting in the increased bulk density.

The mean values of soil bulk density also showed significant difference ($p \leq 0.05$) with the slope gradients. The mean value of bulk density showed regular variation from 0.98 to 1.05 when the slope position is 3-15% and >30%, respectively (Table 2). The results indicated that soil bulk density has a direct relation with slope gradient which might be attributed to the corresponding decline in soil organic carbon content with the increase in slope gradient/steepness. The lower bulk density in on the lower slope position could be due to high accumulation of organic matter in the lower slope position.

Soil chemical properties

Soil reaction (pH): The soil pH was not significantly varied within treatments ($p > 0.05$). The mean soil pH in un-conserved farmland was lower (5.29) and higher (5.36) on conserved farmlands (Table 3). This could be due to leaching of cations in un-conserved farm plots. The higher amount of soil loss due to erosion might have removed the top soil and exposed the sub-soil to the surface resulting in lower soil pH values.

The result also revealed that there was significant difference ($p \leq 0.05$) of soil pH mean values along slope gradients. The result indicated that soil pH value showed regular variation from 4.93 to 5.58 when the slope gradient is >30% and 3-15%, respectively (Table 4). This could be due to the fact that the high rainfall in the area and steepness of the slope increased soil erosion and leaching of basic cations leading to decreased pH values.

Soil organic matter: The non-conserved plots had significantly lower (1.99) organic matter content than mean value (2.22) conserved plots (Table 3). Soils having less than 0.8% organic matter are rated as very low, between 0.8 and 2.6% as low, between 2.6 and 5.20% as medium and greater than 5.20% as high²³. In accordance with this rating, the soil of the study area has low organic matter content. The results indicated that soil organic matter content showed regular variation from 1.90-2.37% when slope gradient is >30% and 3-15%, respectively (Table 4). Soil organic matter accumulation might be higher at the bottom of hills for the fact that it would be transported to the lowest point in the landscape through run off and erosion.

Table 4: Impact of slope gradients on selected soil chemical properties

Slope gradients (%)	pH	OM (%)	TN (%)	Av. P (mg kg ⁻¹)	Exchangeable basic cations (Meq/100 g)				Ex. acidity (Meq/100 g)	CEC (Meq/100 g)
					Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺		
3-15	5.58 ^a	2.37 ^a	0.15 ^a	14.63 ^a	0.15 ^a	0.76 ^a	5.72 ^a	14.95 ^a	0.07 ^b	22.70 ^a
15-30	5.47 ^a	2.05 ^b	0.14 ^b	11.60 ^b	0.12 ^b	0.65 ^b	5.65 ^b	13.52 ^a	0.07 ^b	21.44 ^{ab}
>30	4.93 ^b	1.90 ^b	0.12 ^c	10.93 ^b	0.11 ^b	0.63 ^b	5.57 ^c	11.27 ^b	0.10 ^a	20.91 ^b
LSD (5%)	0.41	0.29	0.02	4.06	0.01	0.18	0.13	2.25	0.01	2.01
CV (%)	6.26	11.45	12.44	26.63	10.10	21.47	2.00	13.82	18.06	7.57

Same alphabet represents that values are significantly different, OM: Organic matter, TN: Total nitrogen, Av. P: Available phosphorous, CEC: Cation exchange capacity

Total nitrogen The mean of total nitrogen content in soils under un-conserved farm plots was significantly lower (0.12) than mean value (0.15) in conserved plot (Table 4). Total nitrogen content of soils are categorized as <0.1 very low, 0.1-0.2 low, 0.2-0.5 medium, 0.5-1 high and >1 as very high²⁴. Accordingly, total nitrogen content of the soil in study area is categorized under low. The variation in total nitrogen content was significant (p<0.05) with slope gradient. The mean value of total nitrogen content also showed regular variation along slope gradient. It was higher (0.15) in the area with slope between 3-15% than the value recorded (0.12) on the site where slope is >30% (Table 4). The mean total nitrogen content for both conserved and non-conserved farm plots could probably be related to the rapid mineralization of existing low organic matter content.

Available phosphorous: The mean value of available phosphorous content in soils under un-conserved farm plots was lower (11.82) than the value recorded (12.95) in conserved plots (Table 3). The available phosphorous content of the soil is categorized as <4 very low, 5-7 low and >8 very high²⁴. Accordingly, the available phosphorous content of the soil of study area can be categorized under very high (>8). This possibility might be due to intensive application of P-containing fertilizer by the farmers in the past years. The highest amount of available phosphorous content was observed in the conserved plots compared to un-conserved plots. The mean soil content of available phosphorous showed regular variation along the slope gradient (Table 4). The higher (14.63) value of av. phosphorous content was also recorded on lower 3-15% slope than content of the area with slope >30%.

Exchangeable basic cations and exchangeable acidity: The exchange complexes of the soil in all observations are dominated by calcium followed by magnesium, potassium and sodium. The prevalence of Ca²⁺ followed by Mg²⁺, K⁺ and Na⁺ in exchange sites of soil is favorable for crop production²⁵. The mean exchangeable Ca²⁺ recorded was higher (13.44) in conserved plot than mean value recorded (12.05) in un-conserved plots. The mean values of exchangeable Mg²⁺,

K⁺ and Na⁺ content were higher 5.74, 0.07 and 0.13, respectively, in conserved plots than mean values of 12.5, 0.09 and 0.12, respectively, in un-conserved plot (Table 3). The lower exchangeable basic cations value on un-conserved farm plot could be due to leaching and higher rate soil erosion compared to conserved field.

The highest exchangeable bases of soil were observed in the area with slope between 3-15% and the lowest exchangeable basic cations value was recorded on the upper (>30%) slope position (Table 4). Significant differences in the values for different slope positions of the watershed could be attributed to erosion, deposition and leaching processes. The mean value of exchangeable acidity content in soils under un-conserved farm plots was significantly higher (0.09) and lower (0.07) in the conserved plots (Table 3). The mean values of exchangeable acidity content of the soil was significantly higher (0.10) when the slope is >30% and lower (0.07) where the slope is between 3-15%. This could be due to the fact that the high rainfall coupled with steeper slopes might have increased leaching of basic cations from steeped slope area.

Cation exchange capacity: The analysis of variance revealed that the CEC of the soil of the study area showed significant variation (p<0.05) with respect to treatments. The mean value of CEC content in soils under un-conserved farm plots was lower (20.86) than the value recorded (22.50) in conserved farm plots (Table 3). The lower CEC mean value recorded in un-conserved farm plots was similar with the lower CEC value of the soils under un-conserved plot²⁶. According to rating suggested of CEC as >40 very high, 25-40 high, 15-25 medium, 5-15 low and <5 very low. The soils of the study area had medium CEC. The mean of CEC content of the soil also regularly varied from 20.91-22.70 when the slope is >30% and 3-15%, respectively (Table 4). The trend of mean values of CEC recorded indicates that the CEC of the soil of the study area was inversely related with the slope gradients. This might be due to when the slope increases the content of organic matter and clay decreases and resulted in decrease of soil CEC value²⁷.

The results of this study revealed that there was significant differences for most of mean values of selected soil

physical and chemical properties in un-conserved and conserved farmlands. Similarly, results of slope gradients depicted significant differences among studied soil properties. From this study results, it is possible to recognize that application of land terracing on degraded hillside farmlands for soil and water conservation can be recommended. The results of this study showed that most of selected soil chemical properties contents were in low to medium ranges for both conserved and un-conserved farmlands. Thus, in order to improve land productivity and sustain crop production of the area implementation of economically and social viable integrated soil fertility management is crucial and need immediate action of land users.

CONCLUSION

For almost all soil physicochemical properties investigated that there was significant variation among conserved, un-conserved plots and slope gradients. The highest mean values of sand and clay content were observed in un-conserved farm plot than in conserved farm plots. Higher mean value of silt content was recorded in conserved plots than un-conserved farm plots. Whereas, mean value of bulk density recorded in conserved plots was lower than the value recorded in un-conserved plots. Contents of soil organic matter, pH value, total nitrogen, available phosphorus, cation exchange capacity and exchangeable basic cations were higher in conserved farmland and similarly in gentle sloped sites compared to un-conserved and steep slope sites. The exchangeable acidity contents of the soil were higher in un-conserved farmland than conserved farm and it was higher in steep sloped site than gentle sloped site.

Thus, from the results of this study it can be concluded that soil physical and chemical properties were relatively in better condition when physical soil and water conservation is practiced for ten years. Similarly, soil on gentle sloped sites has contained relatively higher nutrients and physical properties compared to steep sloped sites. Eventually, these results indicated the presence of relatively higher rate of detachment and transportation of solid materials from un-conserved land compared to conserved plots and from steep sloped site than gentle sloped sites.

SIGNIFICANCE STATEMENT

This study discovers the impact of soil and water conservation practices on reclaiming degraded hillside farmlands in moist highland agro-ecology. Soil and water conservation have been practiced in the study area in the last 3 decades, but the effects of these practices on soil physicochemical properties were not studied yet in the study

area. Therefore, this study will generate information that fill gap of knowledge that can benefit local farmers, researchers and soil conservation experts operating in the area.

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