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Effect of Slope Position on Soil Physico-Chemical Properties with Different Management Practices in Small Holder Cultivated Farms of *Abuhoy Gara Catchment*, Gidan District, North Wollo

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Abstract The research work was conducted on eroded soil at the Abuhoy Gara Catchment, which is located in the Gidan District of North Wello Zone in the Amhara National Regional State to determine the effect of slope position on soil physico-chemical properties. Soil samples were collected from higher-slope, middle slope, intermediate slope and lower slope positions at two depths, surface (0-15 cm) and subsurface (15-30 cm) soil layers. Results showed a significant difference among the physicochemical properties of higher, middle, intermediate and lower slope soils. Clay fraction of the lower slope (27.08%) was the highest followed by middle slope (26.67%), intermediate slope (23.34%) and higher slope (22.92%). Conversely, sand (60%) was highest at higher slope and followed by middle slope (57.08%), intermediate slope (51.67%) and lower slope (49.58%), respectively. Likewise, Ca (8.41 cmol$^{(+)}$/ kg), Mg (3.19cmol$^{(+)}$/ kg), K (1.43cmol$^{(+)}$/ kg), CEC (17.58cmol$^{(+)}$/ kg), total nitrogen (0.104%), organic carbon (1.88%) and Available phosphorous (9.52 ppm) at higher slope followed by middle slope, intermediate slope and lower slope, respectively. The deterioration in chemical properties of lower slope as compared to other slopes were presumed to be due to continuous cultivation for longer period of time and past soil erosion effect that removed the soil organic matter and other plant nutrients. This study results concluded that increasing extent of continuous and intensive cultivation with minimum conservation practices and erosion due to slope effect can further deteriorate soil properties. The control of such damaging effects would require proper soil conservation strategies such as proper land leveling, afforestation, crop rotation, fallowing, terracing and inclusion of restorative crops in cropping systems on these lands.

Keywords: *Topography, Slope position, Soil physico-chemical properties, Eroded soils*

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1. Introduction

1.1. Background of the Study

Securing food and a livelihood is inextricably linked to the exploitation of the natural resource base (land, water and forest) in Ethiopia [3]. The pressure of intense human activity and improper farming and management practices pose serious threats to the sustainability and the suitability of soil for crop production which is based on the quality of the soil’s physical, chemical and biological properties.

Land degradation, mainly due to soil erosion and nutrient depletion, has become one of the most important environmental and economic problems in the highlands of Ethiopia; and it was estimated that half of the Ethiopian highlands’ arable lands are moderately to severely degraded and nutritionally depleted due to over cultivation, over grazing, primitive production techniques, and over dependent on rainfall [16]. According to World Bank [36], Ethiopia high lands including the study area are most seriously affected by land degradation. As a result, soil fertility has declined and it is perceived to be widespread and is recognized as an important constraint to increased food production and farm incomes in many parts of sub-Saharan Africa including Ethiopia [30].

The topography of the study catchment is mountainous having steep slopes; full of hills, mountains and deeply dissected gorges. The topography of the area, both in terms of slope and ruggedness, is difficult for cultivation, infrastructure development and irrigation. The area is known for intensive agricultural production having two distinct growing season *viz., ‘Ganna’* (March-July) and *‘Bona’* (August-December). Nejad and Nejad [24] reported the effect of topography on soil genesis and development of soils and observed that slope gradient and slope length had direct and indirect effect on calcification Nutrient removal results in decline soil fertility when replenishment with inorganic or organic nutrient inputs is inadequate.

1.2. Statement of the Problem

For small scale farming households, declining soil productivity and ever-growing pressure on land leading to declining farm sizes, and the need to produce enough to secure the survival of the household stand in the foreground [7]. The complex inter-linkages between environmental degradation, poverty and fast population growth have brought several changes [8]: farm holdings have become smaller and more fragmented, fallow periods become shorter, farmers cultivate fragile margins on steep slopes previously hold in pasture and woodlot, many households particularly those with large family rent in land.

However the need for better understanding on the status of soil fertility is increasing to provide information used for designing management policies and programs that promote and improves farmers' economic sustainability and profitability of the farm land, little information is currently available to farmers and extension workers on soil fertility status and nutrient management [4]. Assessing soil fertility status in different slope positions is difficult because most soil chemical properties either change very slowly or have large seasonal fluctuations; in both cases, it requires long-term research commitment.

1.3. Objective of the Study

- To determine or characterize the effect of slope position on soil physico-chemical properties in the study area.

1.4. Significance of the Study

As soil quality has emerged as a leading concept in natural resource conservation and protection, stronger emphasis is now being placed on the relationship between specific dynamic soil properties and soil performance. Although public and private sectors, extension workers, non-governmental organization, policy-makers need information to develop appropriate fertility management technologies to enhance these dynamic soil properties, soil fertility status information within Gidan district is still lacking.

Therefore, research findings in relation to soil fertility status in line with slope position can provide information on soil suitability for crop production, diagnosing soil constraints for agriculture and improve effective technique for future rehabilitation program and, and as a basis for fertilizer recommendations. The results also can provide some guidelines for future research on the development of promising conservation technologies and implementation approaches.

2. Research Methods

2.1. Description of the Study Area

The study was conducted at *Abuhoy Gara* catchement in *Gidan* district (Figure 1) which is found in North Wollo Zone of Amhara National Regional State. Gidan is bordered by Tigray Region in the North; Gubalafto district in the North east; Meket district in the south east and Lasta district in the south and south west. Astronomically, it is located between 11^{0}53’-12^{0}16’ North and 39^{0}10’_39^{0}35’ east39^{0}10’_39^{0}35’ East. Muja is the administrative town of the district and is situated at about 595km from the capital city, Addis Ababa. According to the district agricultural office report, the population of the study catchment is 580 people of whom 420 are male and 160 are female. The total area of *Abuhoy Gara* catchment is about 615 hectares (250 hectares cultivated and 365 hectares none cultivated lands).The altitude ranges from 3089 to 3559 m.a.s.l. The annual mean rainfall is 1100 mm with the annual mean maximum and minimum temperature of 21.23°C and 9.57°C, respectively.

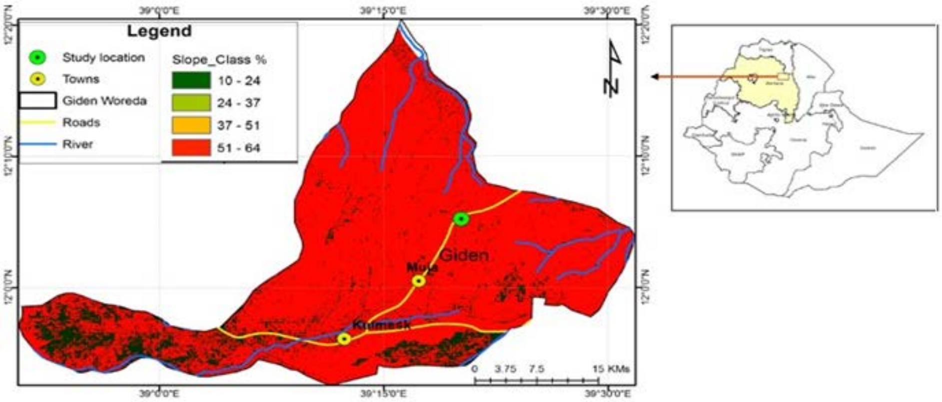

Figure 1. Location map of the study area

2.2. Methods of Data Collection

At the beginning, a general visual field survey of the area was carried out to have a general view of the study area. Global Positioning System readings were used to identify the geographical locations and the coordinate system where data could be taken, and clinometers were used to identify slopes of the sampling sites. In order to capture the farming practices on the study site, participatory rural appraisal tools were conducted using namely direct observation, formal and informal discussion, focus group interviews and key informants. Therefore, data and information on farmers’ knowledge about the management practices of their fields were collected at watershed village (higher, middle, intermediate, and lower slopes). The 30 sampled households were randomly selected from a list of total households of each village. To increase the validity and reliability of data, focus group discussions (composed of elders, male and female farmers and community leaders) and informal interviews with developmental agents and district agricultural experts were carried out.

Soil samples were collected from higher slope, middle slope, intermediate slope and lower slope positions from two soil depths. Totally, sixty composite soil samples from 0-15 cm and 15-30 cm were collected using flexible grid survey method of 1:30,000 scales (Table 1). Each composite sample was made from a pool of 15 point samples and from the 60 composite soil samples major soil fertility parameters were analyzed. Before sampling, forest litter, grass, dead plants and any other materials on the soil surface were removed; and during collection of samples, field/terrace edges, furrow, old manures, wet spots, areas near trees, compost pits, fields used as kitchen gardens and fertilizer bands were excluded.

Table 1. Number of composite samples in each slope positions

Slope percentage	Number of composite soil samples
-Higher slope (51-64%) ------------------------	12
-Middle slope (37-51%) ------------------------	16
-Intermediate slope (24-37%) -----------------	16
-Lower slope (10-24%) ------------------------	16

2.3. Method of Data Analyses

2.3.1. Soil Laboratory Analysis

The collected samples were air-dried, homogenized and sieved to pass a 2 mm mesh sieve for physical and chemical analyses. Particle-size distribution was determined using the pipette methods or hydrometer method [14]. Soil pH was determined in water and 1M KCl in a soil to solution ratio of 1: 2.5 soil water solution [20] using glass electrodes after reciprocal shaking for 1 hour. The exchangeable acidity was extracted with 1M KCl and it can be determined by the titration method using 0.01M NaOH [32]. Organic matter and total organic carbon were determined using loss-on-ignition method [5]. Total nitrogen was determined using Kjeldahl method [26] and total carbon in soil was determined by the wet digestion method of Walkley and Black [25]. Olsen method was used to determine available phosphorous content of the soil [27]. Exchangeable cations (K, Ca, Mg and Na) were extracted with 1M NH4OAc buffered atpH 7. The concentrations of K, Ca, Mg and Na in the solutions were measured by AAS (Shimadzu AA-6800). Cation Exchange Capacity (CEC) was determined by0.05M K_2SO_4 using the soil used for the basic exchangeable cation determination or by the neutral ammonium acetate (CH3COONH4) saturation method [29]. The exchangeable bases in the ammonium acetate filtrates collected above were measured by atomic absorption spectrophotometer [29].

2.3.2. Data Analysis

Analysis of variance (ANOVA) using the general linear model procedure of the statistical analysis system (SAS) was performed to detect effect of slope position on soil physico-chemical properties on the surface soils (0-15 cm) and subsurface soil (15-30 cm). The least significance difference (LSD) test was used to separate significantly difference after main effects were found.

3. Results and Discussions

3.1. Soil Texture

There were no significant (p<0.05) differences in clay and sand content among the slope positions and between the soil depths ,whereas silt content was significantly higher at lower slope (23.75%) than intermediate slope (17.08 %) positions (Table 2).

Table 2. Evaluation of soil texture under different land slope position and soil depth

Variables	Sand %	Silt%	Clay%	Textural class
		Slope Category		
10-24%	49.58a	23.75a	27.08a	SCL
24-37%	51.67a	21.25ab	26.67a	SCL
37-51%	57.08a	17.08b	23.34a	SCL
51-64%	60.00a	19.58ab	22.92a	SCL
LSD (0.05)	**NS**	**5.9423**	**NS**	
SEM (+)	**28.1473**	**23.02827**	**55.50595**	
CV (%)	**19.05232**	**23.50422**	**29.80093**	
		Soil Depth		
0-15 cm	55.42a	22.71a	23.54a	SCL
15-30 cm	53.75a	18.13b	26.45a	SCL
LSD (0.05)	**NS**	**4.2018**	**NS**	
SEM (+)	**18.147**	**23.0283**	**55.5059**	

*Means with the same letter are not significantly different (P≤0.05).

*LSD = Least Significance Difference; SEM = Standard Error of Mean; CV = Coefficient of Variation; NS = Non Significance.

Considering the four slope categories, the highest clay fraction (27.08%) was found at the lower slope (10-24 %), while the highest sand fraction (60%) was found at the higher slope (51-64%).This may be due to recent crop cultivation encroachment to the top of the land topography which brings less weathered sandy soil; and the intensive and continuous cultivation at the bottom of land which might cause compaction on the surface that reduces translocation of clay particles in agreement with the findings reported by Gebeyaw [12] and Jaiyeoba [17].

Conversely, the suspended finer particles are transported down the slope where they accumulate at the bottom thus increasing the clay and silt contents. It was further, noted (Table 2) that sand and silt contents decreasing with increasing soil depth while clay content increased with increased soil depth. The reason can be, during the erosion processes, the suspended clay particles also leach down the profile along with percolating water and accumulate there in the subsurface layer. Unlike to sand and clay content, silt content was significantly affected by soil depth; and the highest (22.71%) was found at surface layer of the soil.

3.2. Soil Reaction (pH)

The soils pH-H_2O value was significantly ($P \leq 0.05$) affected by both slope and soil depth (Table 3). For instance, the minimum (6.01) and (6.04) soil pH-H_2O values were recorded under the higher slope (51-64%) and lower slope (10-24%), respectively.

Table 3. Effects of slope position and soil depth on selected chemical properties of the soils in the catchment

Variables	Exchangeable Cation, Acidity and CEC (cmol$^{(+)}$/ kg)									
	Ca	**Mg**	**K**	**Na**	**Exa.A**	**CEC**	**pH**	**TN %**	**OC%**	**Av.P(ppm)**
	Slope Category in percentage									
10-24 %	**6.63c**	**1.91c**	**0.66c**	**0.19c**	**0.29a**	**14.60c**	**6.04 b**	**0.091c**	**0.650d**	**6.33c**
24-37%	**7.02b**	**2.65b**	**0.86b**	**0.41a**	**0.22d**	**15.03c**	**6.14a**	**0.094c**	**1.061c**	**7.58b**
37-51%	**7.23b**	**2.74b**	**0.88b**	**0.33ab**	**0.24c**	**16.47b**	**6.14a**	**0.099b**	**1.326b**	**8.08b**
51-64%	**8.41a**	**3.19a**	**1.43a**	**0.27bc**	**0.27b**	**17.58a**	**6.01b**	**0.104a**	**1.880a**	**9.42a**
LSD (0.05)	0.246	0.127	0.109	0.084	0.009	0.7314	0.060	0.0035	0.1213	0.9607
SEM (±)	0.0395	0.0100	0.0078	0.00460	0.000	0.3488	0.002	0.0000	0.0096	0.6020
CV (%)	2.7168	3.8068	9.2261	22.6715	2.9035	3.7102	0.801	2.8729	7.9672	9.8785
	Soil Depth									
0-15cm	**6.81b**	**2.45b**	**0.73b**	**0.25b**	**0.27a**	**15.66b**	**6.06b**	**0.1001a**	**1.221a**	**7.75a**
15-30cm	**7.83a**	**2.79a**	**1.18a**	**0.35a**	**0.25b**	**16.18a**	**6.11a**	**0.094b**	**1.237a**	**7.96a**
LSD (0.05)	**0.1741**	**0.0874**	**0.0771**	**0.0594**	**0.0065**	**0.5171**	**0.0427**	**0.0024**	**NS**	**NS**

*Means with the same letter are not significantly different ($P \leq 0.05$).

*Exa.A = exchangeable Acidity; CEC = Cation Exchange Capacity; TN = Total Nitrogen; OC = Organic carbon; Av.P = Available Phosphorous; LSD = Least Significance Difference; SEM = Standard Error of Mean; CV = Coefficient of Variation; NS = Non Significance.

The lowest value of pH at the higher slope may be due to no fertilizer application because the farmers expectation of recent land for cultivation. Moreover, the soil in higher slope had low pH values, perhaps suggesting the washing out of solutes (Na+) from these parts which is evident from previous works [1,11,22]. Whereas, the lowest pH value at lower slope can be due to intensive and continues cultivation that cause depletion of basic cations in crop harvest and depletion of basic cations drainage to streams in runoff generated from accelerated erosions. Secondly, application of inorganic fertilizer might be the reduction of pH at lower slop position [2,23]. Generally, the pH values observed in the study area are within the ranges of slightly reactions (6.0-6.6) as indicated by Foth and Ellis [10] and Tekalign [33]. Considering the two soil depths, the higher mean value of pH-H_2O (6.11) was observed within the sub soils (Table 3). The increase in soil pH down the soil depth could be attributed to the downward movement of Ca and Mg and accumulation therein the subsurface soil layer.

Previous researches also reported a sharp increase in soil pH with increasing soil depth [19,35] due to higher accumulation of Ca^{2+} in the sub-surface soil [18]. Hao and Chang [15] reported similar results and revealed that in irrigated soils Ca^{2+} decreased in surface soil (0-15 cm) but increased at depths below 30 cm due to the downward movement of lime with peculating water to subsurface soil that cause an increase in soil pH.

3.3. Soil Organic Carbon (SOC)

As stated in Table 3, the lowest SOC (0.650%) was recorded in continuous and intensive lower slope cultivated fields, whereas the highest SOC (1.88%) in recently cultivated higher slope as compared to other slopes might be due to addition of soil organic matter (SOM) foliage. The lowest SOC in the lower slope cultivated land, on the other hand, could be due to reduced inputs of organic matter, reduced physical protection of SOC as a result of tillage and increased oxidation of SOM. In this study continuous and intensive cultivation reduced the organic matter content of the soil to a larger extent and increasing SOM decomposition rates similar results reported by Riezebos, *et al* and Gebyaw [12].

3.4. Total Nitrogen (TN)

Total nitrogen was increased with increased slope percentage. The highest (0.104%) and the lowest (0.091%) TN values were observed at higher slope (51-64%) and lower slope (10-24%), respectively (Table 3). The content of TN was almost in very low range (<0.1) and these refers that TN content is lower in continuously and intensively cultivated and highly weathered soils of the humid and sub humid tropics due to leaching and low OM content [34]. In other words, the TN content of a soil is directly associated with its OC content [21,34].

3.5. Available Phosphorus (Available P)

Available P contents were increasing with increasing slope percentage (Table 3). The main sources of plant available P are the weathering of soil minerals, the decomposition and mineralization of SOM and commercial fertilizers. Previous researchers [28] argued that the amount of SOM in the semi-arid region is the main factor of controlling P and other soil fertility parameters. Thus, increased in SOM content at higher slope with less erosion hazards might have increased the available P in soil at higher slope position.

3.6. Cation Exchange Capacity (CEC)

The CEC values of the soils in the study area were significantly ($P \leq 0.05$) affected by slope percentage and soil depth (Table 3). Considering the slope percentage, the highest (17.58 cmol$^{(+)}$/kg) and the lowest (14.60cmol$^{(+)}$/kg) values of CEC were observed at the higher and lower slope position of the land, respectively. Considering the soil depth, the highest CEC value (16.18 cmol$^{(+)}$/ kg) was recorded at the sub surface layer of the land (Table 3). It is a general truth that both clay and colloidal OM have the ability to absorb and hold positively charged ions. Soils with large amount of clay and OM have higher CEC than sandy soil low in OM. Thus, soils containing high clay at the subsurface layer and organic matter contents at the higher slope have high cation exchange capacity.

3.7. Exchangeable acidity

The exchangeable acidity was significantly ($P \leq 0.01$) affected by slope percentage and soil depth (Table 3). The highest (0.29cmol $^{(+)}$/kg) exchangeable acidity were recorded at the lower slope. These results show that deforestation, intensive cultivation and application of inorganic fertilizers leads to the higher exchangeable acidity content under the crop field.

3.8. Basic Exchangeable Cations

The content of exchangeable bases were significantly ($P \leq 0.05$) affected by slope and soil depth (Table 3). The Ca content was 6.63 cmol$^{(+)}$/kg at the lower slope compared with 8.41 cmol$^{(+)}$/kg at higher slope, and progressively decreased with increased year of cultivation period. The Ca content (6.81 cmol$^{(+)}$/kg) in comparison the Ca content (7.83 cmol$^{(+)}$/kg) at 15-30 cm depth showed that decreased from surface to subsurface layers. The results in Mg and K content showed the same trends compared with those of Ca (Table 3). The Mg and K content were 1.91 cmol$^{(+)}$/kg and 0.66 cmol$^{(+)}$/kg at lower slope as compared with 3.19 cmol$^{(+)}$/kg and 1.43cmol$^{(+)}$/kg at higher slope, respectively. Data regarding exchangeable bases increased with increased slope percentage. The lowest value obtained at the lower slope could be also be related to influence of intensity of cultivation and abundant crop harvest with little or no use of input as reported by Singh *et al*. [31] and He *et al*.. Similarly, higher cations at subsurface soil layer might be due to leaching and accumulation factor.

4. Summary and Conclusion

The maximum clay fraction (27.083%) and the minimum (22.92%) were found on the bottom (10-24 %) and top (51-64%) slopes, whereas the highest (60%) and lowest (49.58%) mean sand fractions were found on the top and bottom positions, respectively. The results show that the loss in clay and silt contents, which was of about the same magnitude as the gain in sand content, was probably due to erosion and illuviation.

Soil organic carbon (SOC), TN, Ca, Mg, K, CEC and Available P contents declined consistently with decreasing slope percentage. According to Hazelton and Murphy, FAO [9] and Tekalign [33] rate classifications, even then, being eroded soils with minimum soil conservation practices, the concentration of Ca (6.63-8.41cmol$^{(+)}$/kg), Mg (1.91-3.19cmol$^{(+)}$/kg), CEC (14.60-17.58cmol$^{(+)}$/kg) were under moderate rage, whereas K (0.66-1.43cmol$^{(+)}$/kg) was in high range while SOC (0.65 - 1.326%), TN (0.091-0.104%) and Available P(6.33-9.42ppm) were in low range.

Despite the fact that previous researchers (Pruess *et al*., 1992) argued that the amount of soil organic matter is the main factor of controlling P and other soil fertility parameters, the soil organic carbon was observed in the study area implying the degradation soil organic matter as a result of continuous cultivation. The clearing of forests and grasslands for annual crop production invariably resulted in a loss of soil organic matter because of the removal of large quantities of biomass during land clearing, a reduction in the quantity and quality of organic inputs added to the soil. Therefore, the control of such damaging effects would require proper soil conservation strategies such as proper land leveling, afforestation, crop rotation, fallowing, terracing and inclusion of restorative crops in cropping systems on these lands.

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