Research Article

Effect of Slope Aspect and Land Use Types on Selected Soil Physicochemical Properties in North Western Ethiopian Highlands

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1. Introduction

Ethiopian highland areas are characterized by high rainfall and have continually practiced diversified cultivation with rapid land use changes [1]. Improper agricultural practices such as overgrazing, continuous tillage, poor soil, and water conservation practices and soil acidity affect the soil ecology and properties [2]. Rapid land use land cover change (LULCC), poor land and soil management practices, conventional cropping system, and other agricultural activities are the most important driving forces of land degradation and soil fertility declination in Ethiopia [3]. Besides the mountainous topography, the slope gradient combined with traditional agriculture has aggravated soil fertility depletion, soil acidity, and soil organic matter depletion [4].

Recent research findings implied the slope aspect has also a great impact on soil genesis, soil microbial function and diversity, biomass production and soil organic matter, soil hydrology, and microclimate regulation. These factors affect the soil physicochemical properties [5, 6]. The slope...
aspect can influence surface runoff and erosion due to the microclimate effect. Deviations due to topographic aspects brought diverse microclimates, causing differences in faunal abundance and diversity, soil moisture, temperature, and organic matter to affect soil fertility and ultimately soil quality [6]. Hydrological and solar energy systems of mountainous landscapes vary according to slope aspect, which leads to the variance in composition and distribution patterns of vegetation and soil biological properties [7].

Much research has been done on the effect of slope gradient and length; however the impact of slope aspect on soil geobiochemical processed research is still too limited in Ethiopia. This research was initiated to analyze the effect of slope aspect on selected soil physicochemical properties across different land use practices.

2. Research Methodology

2.1. Area Description. Gumara-Maksegnit watershed lies in the critical part of the Lake Tana basin which is the largest lake in Ethiopia under Megechi Catchment. This catchment drains into the Gumara-Maksegnit River, which ultimately drifts to Lake Tana (Figure 1). The biophysical processes in this catchment have a direct impact on the ecosystem of the Lake Tana. The Gumara-Maksegnit watershed is found in north Gondar zone of Gondar Zuria district with the geographical location which ranges between 12°23′53″N to 12°30′49″N and 37°33′39″ to 37°37′14″E. The watershed is located approximately 45 km southwest of Gondar town. The altitude of the survey area ranges from 1933 m to 2852 m above sea level. The topography of the area covers from a gentle slope to a very steep slope.

2.2. Soil Sampling Design and Soil Sample Collection. Soil samples were collected from three land use types (cropland, grazing land, and natural forest) within four slope aspects, eastward (Ew), northward (Nw), southward (Sw), and westward (Ww), using GPS within three-meter accuracy. From each land use, the types of representative soil samples with three replications were taken by a simple random sampling technique from the upper 20 cm of topsoil. Elevation, slope gradient, and management practices have been made as homogeneous as possible, and similar land uses within the four slope aspects were used during sample collection. In total, 36 undisturbed and 36 disturbed soil samples were taken from the four slope aspects and the three land use types.

2.3. Soil Laboratory Analysis. Soil texture, bulk density, electrical conductivity (EC), soil pH, available phosphorus (av. P), available potassium (av. K), total nitrogen (TN), and soil organic carbon (SOC) were analyzed. Soil texture was analyzed by the hydrometer method [8]. The 36 undisturbed soil samples were used to determine the bulk density (BD) [9] while the disturbed soil samples were used to determine other physical and chemical soil properties. Soil pH was measured using soil water: solution method at the ratio of 1:2.5 for soil: water solutions using a combined glass electrode pH meter [10]. For the determination of soil OM, wet oxidation titrated with 0.25 M ferrous sulfate solutions was used [11]. TN content was determined with the titration method following the Kjeldahl method as described by Jackson [12]. Av. K was measured by a flame photometer [13]. Available P was determined using the Olsen extraction method [14].

2.4. Statistical Analysis. Two-way ANOVA with Duncans’ multiple range test was employed to test the mean separation between land uses types, slope aspects, and the interaction effect. The Pearson correlation coefficient was employed to determine the relationship between soil properties. All the inferential statistics were conducted using statistical analysis software (SAS).

3. Results and Discussions

3.1. Descriptive Analysis of Selected Soil Properties. The descriptive analyses of the results revealed that there was a numerical difference among the selected physicochemical soil properties across the slope aspect and land use types, while soil organic carbon and bulk density showed similar patterns (Figure 2). Eastward and northward slope aspects showed lower clay percentage numerically (Figure 3) which might be as a result of surface runoff, microclimate, and soil management variation [7]. Soil chemical properties are highly influenced by geobiochemical processes including topography, slope aspect, and slope gradient; soil fauna, vegetation, and hydrologic process; and climatic factors such as temperature and rainfall. For example, surface runoff and downward leaching could affect soil nutrient content, soil pH, soil organic matter, soil respiration, and other soil biological characters. Table 1 confirms the effect of the slope aspect and land use types on selected soil properties.

3.1.1. Effect of Slope Aspect and Land Use Types on Soil Texture, Soil Bulk Density, and Soil Reaction. The significant difference in soil particle size distribution was observed between slope aspects. Eastward and northward slope aspects showed greater sand and silt contents while greater clay content was observed in the westward slope aspect (Table 2). Mären et al. [15] have reported the northward slope aspect has significantly more sand and silt content than the south face slope aspect but clay content was insignificant. In contrast, Bayat et al.’s [16] finding revealed that the north-facing slope has more clay and lower sand content than the south-facing slope. Such difference is due to the cumulative effect of microclimate and soil management variation including vegetation [7]. The difference in soil texture among the slope aspects has a great effect on soil biochemical processes such as mineralization and stabilization of soil organic matter [17]. There was no significant variation for soil pH and soil EC across slope aspects and land use types (Table 3). Regarding the bulk density lower bulk density was observed in Ww slope; hence, the westward watershed was
treated by soil and water conservation practices. This difference also could be associated with the variability of soil particle size distribution and SOC content among the slope aspects [6]. However, there was no significant variation with soil bulk density between Ww and Sw slope aspects (Table 4).

Forest land showed the greatest sand percentage, lowest clay percentage, and lowest bulk density. The reverse trend was observed in cropland (Table 2). Selassie et al. [18] reported higher clay percentage in a natural forest than both cropland and grazing land in contrast to this research finding. Meanwhile, Tufa et al. [19] documented that land use types do not have a significant effect on soil particle size distribution. The insignificant difference of soil particle sizes distribution between virgin forest soil and farming land was also reported in Morocco [20]. Higher bulk density in croplands might be due to lower soil organic matter content [21].

3.1.2. Primary Essential Nutrients and SOC across Slope Aspect and Land Use Types. Essential nutrient status is very important for analysis of the suitability of lands for agricultural productivity. Both land uses and slope aspects showed a significant effect on the primary macroessential nutrients even though the difference is not consistent (Table 3). A greater SOC was observed in Ww and NW slope aspects while the lowest was observed in Ew and Sw slope aspects (Table 3) in line with [22]. The north-facing sites are usually cool and moist and contain higher amounts of SOC, whereas south-facing slopes are usually hot and dry, with less vegetation, prone to erosion, and hence depleted in SOC [6]. Yuan et al. [21] also reported that the north- and southwest aspects of the watershed had a higher fraction of SOC than other aspects.

The lowest SOC and TN were observed under crop-land use type (Table 3) which might be due to the fast mineralization of soil organic matter and greater erosion than forest and grazing land [23]. The soil organic matter physical protection (stabilization) in conventionally
Tilled land is lower since the soil is more frequently disturbed than forest and grazing lands [24]. Tinker et al. [25] have also reported the factors contributing to the net decline of SOC during cultivation: erosion on sloping lands, lower litter inputs, and increased SOM oxidation caused by tillage as cited by Nandwa [26]. The effect of land use types on av. K was nonsignificant (Table 3). Av. P was the lowest in grazing land and was nonsignificant between cropland and forest lands. Application of DAP fertilizer in cropland might increase the av. P in croplands [27] while the mineralized phosphorus from organic matter might be the main reason for higher av. P in forest land [28].

The interaction effect of slope aspect and land use types was significant regarding soil pH, SOC, av. K, av. P, and TN (Table 4). Ww grazing land and forest land showed the
were positively correlated with line with the finding of Cao [29] which reported SOC and
a positive significant correlation between SOC and TN

lowest soil pH while Sw cropland and grazing lands showed the highest pH (Table 4).

3.2. Correlation between Soil Properties Measured. The person correlation result showed that there was a strong positive significant correlation between SOC and TN (r = 0.997; p ≤ 0.05 (Table 5 and Figure 4). This finding is in line with the finding of Cao [29] which reported SOC and TN were positively correlated with r = 0.869 at p ≤ 0.05. This might be because the main source for both SOC and soil TN is soil organic matter. Cusack et al. [30] also reported a significant positive correlation between C and N concentrations in forest soils with r = 0.93. A moderately positive correlation was observed between clay and sand

### Table 2: Main effect of slope aspect and land use types on selected soil properties.

| Treatment (DF = 30) | Sand (%) | Silt (%) | Clay (%) | BD (g/cm³) | pH | EC (dS/m) |
|---------------------|----------|----------|----------|------------|----|-----------|
| Ew                  | 47.1 ± 1.7a | 33.56 ± 2.2ba | 19.33 ± 3.1c | 1.29 ± 0.05a | 6.71 ± 0.08 | 6.92 ± 0.06 |
| Nw                  | 45.56 ± 2.1a | 38.89 ± 1.5a | 15.56 ± 1.2c | 1.30 ± 0.05a | 6.92 ± 0.06 | 6.92 ± 0.06 |
| Sw                  | 35.11 ± 1.5b | 35.11 ± 1.8c | 29.78 ± 3.3b | 1.25 ± 0.03ba | 6.93 ± 0.05 | 6.93 ± 0.05 |
| Ww                  | 34.00 ± 5.0b | 28.89 ± 2.1c | 37.11 ± 3.7a | 1.12 ± 0.06b | 6.42 ± 0.22 | 6.42 ± 0.22 |
| Sign. (0.05)         |          |          |          |          |    |           |

DF: degree of freedom; BD: bulk density; EC: electrical conductivity; Ew: eastward; Nw: northward; Sw: southward; Ww: westward; sign: significant; Fl: forest land; Cl: cropland; Gl: grazing land. The numbers indicated by ± are standard errors.

### Table 3: The main effect of slope aspect and land use types on SOC and primary macroessential nutrients.

| Treatment (DF = 30) | SOC (%) | Av. K (cmole/kg) | Av. P (ppm) | TN (%) |
|---------------------|---------|------------------|-------------|--------|
| Ew                  | 1.80 ± 0.3c | 722.7 ± 172b | 30.87 ± 6.6a | 0.14 ± 0.02c |
| Nw                  | 2.52 ± 0.3b | 1233.2 ± 108a | 35.76 ± 7.9a | 0.20 ± 0.02b |
| Sw                  | 1.99 ± 0.3c | 172 ± 30c | 10.28 ± 4.2b | 0.16 ± 0.03c |
| Ww                  | 3.04 ± 0.3a | 845.8 ± 172b | 15.95 ± 6.0b | 0.24 ± 0.02a |
| Sign. (0.05)         |          |          |          |        |
| Cl                  | 1.53 ± 0.17c | 741.7 ± 166 | 33.30 ± 6.4a | 0.11 ± 0.01c |
| Fl                  | 3.28 ± 0.24a | 792.8 ± 154 | 24.78 ± 6.2a | 0.25 ± 0.02a |
| Gl                  | 2.23 ± 0.23b | 694.3 ± 164 | 11.56 ± 6.8b | 0.17 ± 0.02b |
| Sign. (0.05)         |          |          |          |        |

DF: degree of freedom; SOC: in percent; Av. K: in centimole/kilogram; Av. P: by ppm; TN: in percent; Ew: eastward; Nw: northward; Sw: southward; Ww: westward; sign: significant; Fl: forest land; Cl: cropland; Gl: grazing land. The numbers indicated by ± are standard errors.

### Table 4: Interaction effect of slope aspect and LU on SOC and primary macroessential nutrients.

| Treatment (DF = 24) | Ph | SOC (%) | Av. K (cmole/kg) | Av. P (ppm) | TN (%) |
|---------------------|----|---------|------------------|-------------|--------|
| Ew * Cl             | 6.64 ± 0.18cba | 1.11 ± 0.17d | 343.3 ± 91c | 25.67 ± 3.5bc | 0.08 ± 0.01e |
| Ew * Fl             | 6.67 ± 0.06a | 2.77 ± 0.11a | 1307 ± 276.8a | 52.53 ± 4.7a | 0.22 ± 0.01b |
| Ew * Gl             | 6.82 ± 0.07b | 1.52 ± 0.23cd | 517.1 ± 50c | 14.4 ± 3.2bc | 0.12 ± 0.02cd |
| Nw * Cl             | 7.04 ± 0.19a | 1.35 ± 0.12d | 1116.8 ± 258b | 59.63 ± 0.83a | 0.11 ± 0.01e |
| Nw * Fl             | 6.93 ± 0.16a | 3.05 ± 0.37a | 1105.8 ± 45b | 25.87 ± 10.8bc | 0.23 ± 0.03b |
| Nw * Gl             | 6.78 ± 0.04a | 2.50 ± 0.12d | 1476.8 ± 168a | 21.77 ± 13.9bc | 0.25 ± 0.01b |
| Sw * Cl             | 7.02 ± 0.08a | 1.25 ± 0.14a | 186.9 ± 52c | 12.27 ± 9.0bc | 0.1 ± 0.01e |
| Sw * Fl             | 6.76 ± 0.05b | 3.08 ± 0.69a | 215.5 ± 70c | 15 ± 9.6bc | 0.24 ± 0.05b |
| Sw * Gl             | 7.02 ± 0.03a | 1.63 ± 0.14cd | 107.6 ± 15c | 3.57 ± 1.2c | 0.13 ± 0.03ced |
| Ww * Cl             | 6.92 ± 0.03ba | 2.40 ± 0.29c | 1319.7 ± 237a | 35.63 ± 10.8b | 0.19 ± 0.01cbd |
| Ww * Fl             | 6.23 ± 0.06bc | 4.22 ± 0.18a | 542 ± 251b | 5.7 ± 3.0c | 0.30 ± 0.01b |
| Ww * Gl             | 6.13 ± 0.34c | 2.59 ± 0.22b | 675.8 ± 261b | 6.51 ± 3.0c | 0.19 ± 0.03cb |
| Sign. (0.05%)        |          |          |          |        |        |

DF: degree of freedom; SOC: in percent; Av. K: in centimole/kilogram; Av. P: by ppm; TN: in percent; Ew: eastward; Nw: northward; Sw: southward; Ww: westward; sign: significant; Fl: forest land; Cl: cropland; Gl: grazing land. The numbers indicated by ± are standard errors.
Table 5: Correlation between observed soil physicochemical properties.

|          | pH   | EC   | Sand | Silt | Clay | Av. K | OC  | Total. N | Av. P | Bd   |
|----------|------|------|------|------|------|-------|------|----------|-------|------|
| pH       | 1    | -0.069ns | -0.21ns | 0.42*| -0.05ns | 0.12ns | -0.41*| -0.05ns | 0.15ns | 0.23ns |
| EC       | 1    | 0.23ns | 0.23ns | -0.32ns | 0.19ns | 0.03 | 0.03ns | 0.52* | 0.05ns |
| Sand     | 1    | -0.05ns | -0.84* | 0.14ns | 0.19ns | 0.20ns | 0.15ns | -0.002ns |
| Silt     | 1    | -0.50*    | 0.29ns | 0.06ns | 0.06ns | 0.27ns | 0.30ns |
| Clay     | 1    | -0.28ns | -0.20ns | -0.21ns | -0.28ns | -0.16ns |
| Av. K    | 1    | 0.24ns | 0.25ns | 0.58** | 0.13ns |
| OC       | 1    | 0.997* | -0.03ns | -0.38* |
| Total. N | 1    | -0.022ns | -0.38* |
| Av. P    | 1    | 0.22ns |
| Bd       | 1    |       |

Lu: land use types; Var: variables; DF: degree of freedom; BD: bulk density; EC: electrical conductivity; SOC: soil organic carbon; Av. K: available potassium; Av. P: available phosphorus; TN: total nitrogen; Ew: eastward; Nw: northward; Sw: southward; Ww: westward; sign: significant; Fl: forest land; Cl: cropland; Gl: grazing land. The numbers indicated by ± are standard errors.

4. Conclusion and Recommendations

In this research, we have investigated the effect of the slope aspect in different land use types. Based on our findings, EC and pH did not response to both slope aspect and land use types. Significantly higher clay content (37.11%) was observed in Ww slope croplands, which might be due to the cumulative effect of microclimate and long-term land management practices. The interaction effect of slope aspect and land use on SOC (4.22) and TN (0.33) was the highest in westward natural forest land while the lowest was observed in eastward cropland SOC (1.11) and TN (0.08), which is highly associated with the biochemical process depending on the microclimate condition. The highest av. K (1476.8 (centimole/kg)) and av. P (59.63 (ppm)) was found in Nw grazing land and Nw cropland while the lowest av. K (107.6

$(r = -0.84)$ and clay and silt percentage $(r = 0.50)$ at $p \leq 0.05$ (Table 5). Soil pH was negatively correlated with SOC and TN (Table 5). The scatter plot revealed again the data normality is very accurate when compared to other measured soil parameters which confirm that the soil organic matter and total nitrogen significantly correlate (Figure 4) and is affected by the interaction effect of land use and slope aspect.

![Figure 4: Linear regression between soil separates.](image)

![Figure 5: Linear regression between SOC and TN.](image)

![Figure 6: Linear regression of av. K versus av. P.](image)
and management. Use types need detailed characterization during soil surveys and management.

Data Availability
All raw and analyzed data are in the hands of the corresponding author and can be available based on the reasonable request of the publisher or any interested body.

Consent
The official letter was obtained and given to participants from the University of Gondar. All participants of the study fully agreed upon and were interested in the study.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

Authors’ Contributions
All the authors participated in every phase of this research. They all participated in proposal writing, data collection, analysis, and interpretation.

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