Research Article

Effect of Soil Management Practices and Slope on Soil Fertility of Cultivated Lands in Mawula Watershed, Loma District, Southern Ethiopia

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Soil degradation is a serious problem challenging food security in Ethiopia. To halt degradation and restore impoverished soils, the government has initiated soil management practices in the affected areas. Still, there is little information on the impact of these practices in terms of improvement in soil fertility of cultivated lands under different soil and climatic conditions. Accordingly, the study was carried out to study the effect of soil management practices, viz, soil bund (SB), application of farm yard manure (FYM), soil bund integrated with FYM (SBFYM), and vis-a-vis no management practice (NM), on soil fertility under upper (20%–30%) and lower (2%–10%) slope ranges at Mawula watershed, Loma district, Southern Ethiopia. Twenty-four composite soil samples (4 practices × 2 slope ranges × 3 sites) drawn from the surface layer (0–20 cm) were analysed for different physical and chemical properties indicative of soil fertility. The data were analysed statistically in a randomized complete block design. All the soil management practices improved significantly the different aspects of physical and chemical fertility (soil texture, bulk density, total porosity, moisture content, organic carbon, and contents of macro and micronutrients, viz, N, P, K, Na, Ca, Mg, Fe, Mn, Zn, and Cu). The practice SBFYM was significantly superior to FYM and SB. The order of performance was SBFYM > FYM > SB > NM. The usefulness of soil management practices was further corroborated by the farmers’ response (based on semistructured questionnaires), as 83% of them perceived the practices well and opted for their adoption. As such, the soil management practices, notably SBFYM, merit their implementation on a large scale to improve fertility and productivity of degraded lands.

1. Introduction

Land degradation, implying deterioration of soil in terms of its quality and productivity due to improper use, is a major global issue and will remain high on the international agenda in the 21st century due to its effects on agronomic productivity, the environment, and food security [1]. Various sources suggest that 5-6 million hectares of arable land worldwide are being lost annually to severe degradation [2]. Due to severity of land degradation, Africa as a whole has become a net food importer since Saharan Africa because 65% of the population is rural, and the main livelihood of about 90% of the population is agriculture [3]. Land degradation is one of the major causes of low and declining agricultural productivity, continued food insecurity, and rural poverty in Ethiopia [4–6]. Every year, the country is losing billions of birrs in the form of soil, nutrient, water, and agrobiodiversity losses [7]. As a result, poverty and food insecurity are concentrated in rural areas [8]. Although estimates vary considerably, the direct losses of productivity from land degradation in Ethiopia may be put minimally at 3% of agriculture GDP [9]. The Ethiopian highlands covering a sizeable landmass are particularly more severely degraded, eroding the valuable soil resource base and aggravating drought and repeated food shortages [10, 11].

Among various biophysical, socioeconomic, and political factors of soil degradation, poor land management is thought to be playing an overriding role in the overall
degradation process in many regions [12]. The increased anthropogenic influence on land resources evident in increased cultivation of marginal land with steep gradients and low-input or fertility-mining methods of subsistence agriculture accelerates soil erosion and cause sharp decline in soil fertility [13]. The MoARD and WB [14] reported that cultivation on steep and fragile lands with inadequate investments in soil conservation or vegetation cover, erratic and erosive rainfall patterns, declining use of fallow, and limited recycling of dung and crop residues to the soils are largely responsible for continued soil degradation in Ethiopia. The cultivated lands in Ethiopia, particularly in steeply sloping areas, are reported to have very high rates of soil erosion ranging from 20 to 237t·ha⁻¹·year⁻¹ [15–18]. Majority of Ethiopian soils are, therefore, poor in soil fertility [19–21]. As a consequence of declining soil fertility, the crop productivity has been low, and average cereal yield at the national level is still less than 2t·ha⁻¹.

To cope up with the soil erosion problem, Ethiopian Government had launched massive soil conservation programs throughout the country in the middle of 1970s [22], involving different nongovernmental organizations (NGOs) and mobilizing local people. The different programs under food-for-work program comprised land leveling programme (LLP), sustainable land management (SLM), United Nations Development Program (UNDP), and Productive Safety Net Program (PSNP). The programs aimed at transforming agriculture through conservation of soils, reducing soil erosion, and restoring soil fertility. One of the programs was in steeply sloping areas for rehabilitation of degraded lands by introducing mechanical conservation measures, use of perennial crops, plantation of forest areas, and use of organic manures. The commonly followed soil management practices included (a) use of a soil bund, (b) use of only manure, and (c) use of integrated bund and manure. The management practices ought to influence differentially the soil characteristics and attendant soil fertility regimes.

Recent studies [23, 24] have indicated usefulness of these conservation practices in improvement of soil fertility. Such studies need to be taken up under different soil and climatic conditions influencing the performance of soil conservation measures. Monitoring and evaluation of soil management programs is essential to have their continuity, reinforcement, and corrections to make them compatible with socioeconomic environment imperatives. It becomes all the most important in Ethiopia, as about 18% of the rainfed croplands have so far been treated with soil and water conservation measures, and 60%, i.e., nearly 12 million ha, still need to be treated [25].

Management-induced changes in soil can be evaluated by assessing soil’s physical and chemical properties, such as texture, water holding capacity, bulk density, porosity, soil organic carbon, total nitrogen, available phosphorus, exchangeable potassium, soil pH, and electrical conductivity [23, 24, 26, 27]. Accordingly, this study was envisaged to evaluate the effect of three soil management practices under two slope ranges on the improvement of soil fertility (reflected in indicative soil properties) of cultivated lands in Mawula watershed, Loma district, Southern Ethiopia. The usefulness of the practices was also assessed by conducting a questionnaire-based survey on perception and adoption of soil management practices by farmers in the watershed.

2. Materials and Methods

2.1. General Description of Study Area

2.1.1. Location and Physiography. The study was conducted at the Mawula watershed (Figure 1), which is located in Loma district of Dawro Zone in the Southern Nations and Nationality Regional State (SNNPRS). It is located between 6°57′00″N–6°59′30″N latitude and 37°11′00″E–37°17′00″E longitude, with an altitude ranging from 1779 to 2361 meters above sea level. It is at about 365 km from Hawassa city in the southern direction and at about 546 km southwest of Addis Ababa. It is one of the 108 watersheds in Loma district and covered 937 ha out of the total area of 117,043 ha in the district. The area is marked by 15.9% gentle slope, 43.4% moderate slope, 26.5% moderately steep slope, 10.5% steep slope, and 3.7% mountainous terrain [28]. About 54% of total area in the watershed was managed under different conservation practices.

2.1.2. Land Use and Farming System. The cultivated, forest, and grazing lands covered 78.3%, 11.4%, and 3.8% of area in the watershed. Agriculture is characterized by the subsistent mixed crop-livestock farming system. The important cereal crops were maize (Zea mays), sorghum (sorghum bicolor), barley (Hordeum vulgare), and wheat (Triticum aestivum). The vegetables grown were potato (Solanum tuberosum L.), tomato (Solanum lycopersicum), cabbage (B. oleracea var. capitata), onion (Allium cepa), carrot (Daucus carota), green pepper (Capsicum spp.), fava bean (Vicia faba L.), pea (Arachis hypogea), and haricot bean (Phaseolus vulgaris). Most of the area around the homestead was covered with perennial enset (Enset ventricosum), which is a staple food and income source. Coffee (Coffee arabica) and fruit trees such as false banana (Musa species), avocado (Persea americana), and mango (Mangifera indica) were also among the widely cultivated crops [28].

2.1.3. Climate and Agroecology. The district is divided into three climatic zones on the basis of altitudinal and annual rainfall variations, as “Dega,” “Woyna Dega,” and “Wet Kola.” The study site belonged to “Woyna Dega.” The mean monthly rainfall and maximum and minimum temperatures for eleven years (2000–2010) are presented in Figure 2. The mean annual rainfall was 1720 mm, and mean minimum and maximum temperatures were 11.7 and 23.5°C, respectively. The rainfall distribution was bimodal. The medium rainy season (Belg) occurs from March to May, while the main rainy season (Kremt) occurs from June to September. Also, there is small rain in October and November. The Mawula watershed is drained into the Manstha River, which is a part of the Omo Gibe River basin.
2.1.4. Soil Type. The soil of the area is grouped as Orthic Acrisols [29]. These soils have a distinct argillic B horizon and a low base saturation. These soils are chemically poor. The content of weatherable minerals is generally low, the pH is less than 5.5, and available $P$ is low. The rooting depth might be limited by the argillic B horizon or by rock at shallow depth. The moisture storage capacity of soil is moderate to good.

2.2. Soil Sampling. The soil sampling was performed at three sites of the watershed (Table 1) for four soil management practices being followed by farmers for about 8 years (no management, soil bund, manure application, and soil bund integrated with manure) at two slope ranges (20–30% slope as upper range and 2–10% slope as lower range).

About 15 subsamples each for the different soil management practices were drawn from 0–20 cm depth at a particular site for two slope ranges from the cultivated fields. The subsamples for each practice were composited. Thus, a total of 24 composite samples (four practices× two slope ranges× three sites as replications) were obtained for laboratory analyses. Soil core samples from the 0–20 cm depths were taken with a sharp-edged steel cylinder forced manually into the soil for bulk density determination.
Global positioning system (GPS) and clinometers were used to know the geographical location and slope of the sampling sites, respectively.

2.3. Soil Analyses. The analyses for physical fertility parameters (soil texture, bulk density, and moisture content) and chemical fertility parameters (pH, organic carbon, total nitrogen, cation exchange capacity, and available phosphorus) were performed at SNNPR State Agricultural Bureau Sodo Soil Laboratory. The analyses for macro and micronutrients (Ca, Mg, K, Na, Fe, Mn, Cu, and Zn) were performed at Arba Minch University, Abaya Campus Environmental and Soil Laboratory. 

The particle size distribution was determined by the Bouyoucos hydrometric method [30]. Soil bulk density was determined using undisturbed core samples as described by Black [31]. Total porosity was calculated using general equation relating bulk density and particle density. Soil moisture content was expressed on mass basis (\(\text{Black}\) [31]). Total porosity was calculated using undisturbed core samples as described by Boycouos hydrometric method [30]. Soil bulk density was determined using undisturbed core samples as described by Black [31]. Total porosity was calculated using general equation relating bulk density and particle density. Soil moisture content was expressed on mass basis (\(\text{Black}\) [31]).

2.4. Farmers’ Survey. Semistructured questionnaires were used to gather information from watershed people about soil management practices and their adoption. The general discussions and interviews were made with 72 randomly sampled respondents taken from a total of 362 household people in watershed according to the sampling formula of Glenn [38]:

\[
n = \frac{N}{1 + N(e^2)}
\]

where \(n\) = sample size, \(N\) = total population, and \(e\) is the precision level chosen (10% confidence level).

Accordingly, \(n = 362/1 + 362(0.1)^2 = 362/1 + 3.62 = 362/4.62 = 362/5 = 72.\)

The respondents belonged to community elder groups, development/extension agents, watershed management planning committee, male and female household heads, and water development committee.

2.5. Statistical Analysis. The soil physical and chemical properties were subjected to analysis of variance using the general linear model procedure of the statistical analysis system version 9.1 [39]. The least significance difference (LSD) was used to separate significantly differing treatment means after main effects were found significant at \(P < 0.05\). Simple correlation analyses were executed to reveal the magnitudes and directions of relationships between selected soil physicochemical parameters. The farmers’ perception and the adoption of soil management practices were analysed using IBM SPSS statistics software version 20.

3. Results and Discussion

3.1. Effect of Soil Management Practices on Soil Physical Properties

3.1.1. Soil Texture. The soil texture was significantly affected \((P < 0.05)\) by soil management practices and slope range. The proportion of sand in soil under no management practice (NM) was significantly higher compared to soil management practices (Table 2). It decreased progressively under SB (soil bund), FYM (farm yard manure application), and SBFYM (soil bund coupled with farm yard manure application). Conversely, the clay fraction was significantly higher under SB, FYM, and SBFYM compared to NM by 7%, 14%, and

| Site name | Slope range | Coordinate point | Altitude (masl) | Slope (%) | Aspect |
|-----------|-------------|-----------------|----------------|-----------|--------|
| Borthe    | Upper       | 6°57′00″–6°57′21″ | 6°57′15″–7°15′38″ | 2153–2156 | 20–30  | Southern |
|           | Lower       | 6°57′00″–6°57′21″ | 6°57′15″–7°15′38″ | 1658–1855 | 2–10   | Southern |
| Fulasa    | Upper       | 6°57′21″–6°57′38″ | 6°57′15″–7°15′38″ | 2153–2156 | 20–30  | Southern |
|           | Lower       | 6°57′21″–6°57′38″ | 6°57′15″–7°15′38″ | 1658–1952 | 2–10   | Southern |
| Xossa wora| Upper       | 6°58′30″–6°58′40″ | 6°57′15″–7°15′38″ | 2153–2156 | 20–30  | Southern |
|           | Lower       | 6°58′30″–6°58′40″ | 6°57′15″–7°15′38″ | 1658–1952 | 2–10   | Southern |
### Table 2: Effect of soil management practices and slope range on physical properties of soils in Mawula watershed.

| SMP  | Sand (%) | Silt (%) | Clay (%) | STC  | BD (Mg·m⁻³) | PD (Mg·m⁻³) | MC (%) | TP (%) |
|------|----------|----------|----------|------|-------------|-------------|--------|--------|
| NM   | 50.7ᵃ    | 21.5ᵇ   | 27.7ᵈ   | SCL  | 1.16ᵃ       | 2.5ᵇ       | 12.2ᵈ  | 56.2ᵃ  |
| SB   | 47.2ᵇ    | 23ᵇ      | 29.7ᶜ   | CL   | 1.0ᵇ        | 2.6ᵇ       | 22.4ᶜ  | 57.4ᵇ  |
| FYM  | 41.7ᶜ    | 26.5ᵃ    | 31.7ᵇ   | CL   | 1.0ᵇ        | 2.6ᵇ       | 27.6ᵇ  | 58.8ᵇ  |
| SBFYM| 38.5ᵈ    | 27ᵃ      | 34.5ᵃ   | CL   | 0.9⁹ᶜ       | 2.6ᵃ       | 32.5ᵃ  | 62.3ᵃ  |
| LSD (0.05) | 1.25 | 1.86 | 1.67 | 0.06 | 0.01⁴        | 4.3⁹       | 2.26   |
| SEM (±) | 0.50 | 0.07 | 0.57 | 0.01⁴ | 0.00⁴       | 1.3⁰       | 0.6⁰   |
| CV%  | 2.3⁴     | 6.1⁹     | 4.0¹    | 4.7⁹  | 2.8⁵        | 16.5²      | 3.7⁴   |
| LSD (0.05) | 1.25 | 1.86 | 1.67 | 0.06 | 0.01⁴       | 4.3⁹       | 2.26   |
| SEM (±) | 0.50 | 0.07 | 0.57 | 0.01⁴ | 0.00⁴       | 1.3⁰       | 0.6⁰   |
| CV%  | 2.3⁴     | 6.1⁹     | 4.0¹    | 4.7⁹  | 2.8⁵        | 16.5²      | 3.7⁴   |

Means within a column followed by the same letter are not significantly different from each other at P ≤ 0.05; SMP, soil management practices; STC, soil texture class; SCL, sandy clay loam; CL, clay loam; BD, bulk density; PD, particle density; MC, moisture content; TP, total porosity; US, upper slope; LS, lower slope.

24.5%, respectively. The proportion of silt was significantly higher under FYM and SBFYM practices compared to NM and SB. From the foregoing, it is clear that soil with any of the management practices is having higher amounts of finer fractions, viz., clay and silt, and lower of coarse sand fraction. Such a situation is desirable from the soil fertility point of view, as it is the finer soil fraction that retains nutrients and water. The soil with no management practice is subject to soil erosion and removal of finer soil fraction with runoff water. Accordingly, the texture of soil with conservation practices was better (clay loam) compared to no conservation practice (sandy clay loam). Although, soil texture being a basic soil property is not subject to change as it was loam under both the categories of the upper slope and lower slope. However, proportion of sand was significantly higher under the upper slope (45.7%) than the lower slope (43.3%) and proportion of silt higher under the lower slope (25.2%) than the upper slope (23.9%). The higher silt content in the lower slope might be due to reduced soil erosion and more deposition of fine fractions of soil.

#### 3.1.2. Bulk Density and Total Porosity

The bulk density of soil was significantly higher under soil with no conservation practice (1.17 Mg·m⁻³) compared to soils with soil conservation practices, viz., soil bund (1.08 Mg·m⁻³), farm yard manure (1.08 Mg·m⁻³), and soil bund combined with farm yard manure (0.99 Mg·m⁻³) (Table 2). The total porosity, having negative relationship with bulk density, was significantly lower in soil with no conservation practice (56.2%) compared to soils with conservation practices. The highest value of porosity (62.3%) was obtained with the practice of soil bund + farm yard manure. Such a trend of bulk density and total porosity values under different management practices could be explained to their level of protection against the processes of soil erosion, viz., dispersion, transportation, and deposition of soil particles. The practice with no conservation practice will have removed the finer soil fraction, raising the value of bulk density. Conversely, the soils having conservation practices will have less erosion and more proportion of clay and silt, lowering the value of bulk density. A similar decrease in the bulk density of soil treated with management practice of SB + FYM compared to no management has been reported by Selassie et al. [23] in Zikre watershed, northwestern Ethiopia. Also, Agele et al. [40] found soil amended with FYM to be having lower bulk density and higher total porosity, possibly due to increases in the proportion of macroaggregates and soil organic matter. Husen et al. [41] indicated that soil bund had a significant effect on soil bulk density.

The interaction effect of soil management and slope range (Table 3) indicated better textural composition of soil provided with management practices of SBFYM at both slope ranges.

The slope condition was found to affect bulk density and total porosity significantly. The upper slope had significantly higher bulk density (1.11 Mg·m⁻³) compared to the lower slope (1.05 Mg·m⁻³). The total porosity was significantly higher for the lower slope (59.7%) compared to the upper slope (57.6%). Actually, when soil erosion takes place, finer particles get suspended in the accumulating water and are transported down the slope, leaving coarser material at the top slope positions that raise bulk density and lower pore spaces. On the other hand, the suspended finer particles transported down the slope get accumulated at the bottom.
slopes, thus, lowering bulk density and raising total porosity of lower slopes. Similar results were reported by Selassie et al. [23] who found a significant reduction in bulk density from the upper slope (28%) to the lower slope (8%). Likewise, Khan et al. [42] found bulk density to be decreased with decrease in the slope. Based on soil volume functions, the performance of land management practices could be in the order of SBFYM > FYM = SB > NM.

The interaction between soil management practices and slope (Table 3) indicated BD to be highest with NM at the upper slope (24.8%) and lowest with SBFYM at the lower slope (1.01 Mg m\(^{-3}\)). The porosity was highest (62%) with SBFYM at the lower slope and lowest with NM at the upper slope (53.2%). The interaction effect, therefore, further established the superiority of management practice of SBFYM in maintaining physical soil environment.

### 3.1.3. Soil Moisture Content

There was a significant effect (\(P < 0.05\)) of soil management practices on soil moisture content. The soil with no conservation practice contained significantly lower amount of moisture (12.2%) compared to soils having soil conservation practices (22.5–32.6%) (Table 2). The highest moisture content was obtained with the practice of SBFYM followed by FYM and SB. The percentage increases in moisture content were 84, 126, and 167 under SB, FYM, and SBFYM, respectively, over NM. Such a marked increase in soil moisture by the practice of SBFYM followed by FYM and SB. The highest mean value of 6.6 was at the lower slope range and minimum with NM at the upper slope.

| SMP          | Sand (%) | Silt (%) | Clay (%) | BD (Mg m\(^{-3}\)) | PD (Mg m\(^{-3}\)) | MC (%) | TP (%) |
|--------------|----------|----------|----------|---------------------|---------------------|--------|--------|
| US           | LS       | US       | LS       | US                  | US                  | US     | US     |
| NM           | 54.7 \(a\) | 52.3 \(b\) | 22.3 \(c\) | 24 \(b>d\)          | 22.6 \(d\)          | 23.6 \(d\) | 1.21 \(a\) | 1.12 \(a\) | 2.58 \(a\) | 2.59 \(a\) | 14.4 \(b\) | 15.37 \(d\) | 53.2 \(d\) | 56.7 \(d\) |
| SB           | 49 \(e\) | 47 \(f\) | 22.6 \(e\) | 23.3 \(d\)          | 29 \(c\)            | 30.3 \(c\) | 1.12 \(b\) | 1.07 \(b\) | 2.61 \(b\) | 2.62 \(b\) | 21.7 \(b\) | 23.17 \(c\) | 57.1 \(c\) | 59.2 \(c\) |
| FYM          | 44 \(a\) | 41.3 \(b\) | 25.3 \(b\) | 27.6 \(a\)          | 31.6 \(b\)          | 31.6 \(b\) | 1.11 \(b\) | 1.04 \(d\) | 2.62 \(b\) | 2.63 \(b\) | 26.4 \(b\) | 28.83 \(a\) | 57.3 \(c\) | 60.2 \(b\) |
| SBFYM        | 40 \(a\) | 39 \(b\) | 26.3 \(a\) | 26.2 \(a\)          | 34.3 \(a\)          | 35 \(a\) | 1.04 \(cd\) | 1.01 \(d\) | 2.64 \(a\) | 2.65 \(a\) | 31.1 \(b\) | 34.07 \(a\) | 60.7 \(b\) | 62.03 \(a\) |

Means for specific soil parameter followed by the same letter(s) are not significantly different from each other at \(P < 0.05\); SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure; SBFYM, soil bund integrated with farm yard manure; BD, bulk density; PD, particle density; MC, moisture content; TP, total porosity; US, upper slope; LS, lower slope.

### 3.1.4. Soil pH

The pH was significantly lower with no management practice (5.2) compared to soils having management practices such as soil bund (5.9), farm yard manure (6.2), and combination of soil bund and farmyard manure (6.5) (Table 4). The depression in soil pH in soils without any conservation practice was probably due to removal of basic cations along with the eroding fine soil fractions. To the contrary, the soils protected with certain conservation practice would retain the basic cations along with fine fraction, raising the soil pH.

A significant increase in soil pH with provision of soil and water conservation measures have also been reported elsewhere. For instance, Wolka et al. [13] reported increase in soil pH with the construction of level stone and soil bunds in Bokole watershed, Ethiopia. Likewise, Tugizimana [44] indicated increase in soil pH with the adoption of soil and water conservation measures in Rwanda.

The upper slope range indicated significantly lower pH (5.8) than the lower slope range (6.1) (Table 4). This is obvious as upper slopes have more loss of basic cations that causes lowering of pH, while lower slopes have gain of basic cations raising the soil pH.

The interaction effect of soil management practices and the slope range was significantly different (\(P < 0.05\)). The three soil management practices at both upper and lower slope ranges showed significantly higher soil pH compared to no practice. The highest mean value of 6.6 was at the lower slope under SBFYM and lowest of 5.1 was under NM at the upper slope (Table 5). The practices of FYM and SBFYM had similar pH, but significantly higher than rest of the treatment.
combinations. As per rating of Tekalign [45], the non-managed soil in upper and the lower slope was strongly acidic (pH of 5.1–5.3). The soil with practice of SB in the upper slope was moderately acidic (pH of 5.6) and in the lower slope was slightly acidic (pH of 6.0). The soil with FYM alone and with SB+FYM was also slightly acidic (pH of 6.4 and 6.6).

### 3.2.2. Organic Carbon (OC)

The organic carbon content was significantly (P ≤ 0.05) affected by soil management practices. It was significantly lower under no management practice (0.51%) compared to soil bund (2.08%), farm yard manure application (2.62%), and soil bund combined with farm yard manure application (2.97%) (Table 4). The percentage increase in OC content for SB, FYM, and SBFYM over NM were 308, 414, and 482 percent, respectively. A very low content of OC under NM was due to the fact that soils are subject to inexorable processes of soil erosion, leaving soils devoid of organic fraction. On the other hand, the lands with management practices that provide mechanical barriers to the runoff water would have reduced the loss of fine soil fractions and organic carbon. The clay particles have substantial exchange surface areas and, therefore, adsorb and stabilize OC in soils [46, 47]. The soil management practices such as FYM and SBFYM would also add organic matter to the soils through manure application besides controlling soil erosion.

It is interesting to note that physical soil conservation measure SB complemented with organic manure application could raise soil SOC content better than soil bund alone. Similar increase in organic carbon content (over 120 percent) under SBFYM compared to NM has been reported by Selassie et al. [23] in Zikre watershed, Ethiopia. Likewise, farm land with SWC measure significantly improved soil organic carbon compared to farm land without SWC [24, 48]. As organic matter is the main supplier of nutrients in low input farming systems, a continuous decline in the soil OC content of the soils is likely to affect the soil productivity and sustainability.

Considering the main effect of two slope ranges (Table 4), the OC content was significantly higher under the lower slope (2.17%) than the upper slope (1.93%). The increase in former was due to deposition of eroded sediments and organic fraction from the upper slope and less intense soil erosion due to reduction in degree of the slope. The similar results on the effect of the slope range on OC content in soils have been reported by Wolka et al. [13], Tadele et al. [49], and Selassie et al. [23].

**Table 4**: Effect of soil management practices and slope range on soil chemical properties in Mawula watershed.

| SMP       | pH  | OC (%) | TN (%) | C: N | AP (mg/kg) |
|-----------|-----|--------|--------|------|------------|
| NM        | 5.20d | 0.51d | 0.09d | 5.89c | 7.50d |
| SB        | 5.91e | 2.08e | 0.15e | 13.59a | 13.30c |
| FYM       | 6.17b | 2.62b | 0.21b | 12.54b | 17.83b |
| SBFYM     | 6.52a | 2.97a | 0.26a | 11.6b | 21.16b |
| LSD (0.05) | 0.16 | 2.87  | 0.02  | 1.02  | 1.02   |
| SEM (±)   | 0.02 | 0.02  | 0.01  | 0.68  | 76.70  |
| CV%       | 2.18 | 6.95  | 9.64  | 7.57  | 6.29   |

Slope range

| Upper     | Lower     | Upper     | Lower     |
|-----------|-----------|-----------|-----------|
| pH        | OC (%)    | TN (%)    | C: N      |
| 5.80b     | 1.93b     | 0.17b     | 10.76     |
| 6.10a     | 2.17a     | 0.19a     | 11.04     |
| LSD (0.05) | 0.11 | 0.12  | 0.01  | 0.72  |
| SEM (±)   | 0.02 | 0.02  | 0.001 | 0.68  |

Means within a column followed by the same letter are not significantly different from each other at P ≤ 0.05; SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure; SBFYM, soil bund integrated with farm yard manure; OC, soil organic carbon; TN, total nitrogen; C: N, carbon to nitrogen ratio; AP, available phosphorus; US, upper slope; LS, lower slope.

**Table 5**: Interaction effect of soil management practices and slope ranges on chemical properties of soils in Mawula watershed.

| SMP       | pH  | OC (%) | TN (%) | C: N | AP (mg/kg) |
|-----------|-----|--------|--------|------|------------|
| NM        | 5.1f | 0.44d | 0.07c | 10.0f | 6.0d |
| SB        | 5.6e | 0.59d | 0.14d | 14.8e | 12.67f |
| FYM       | 6.2dc | 0.21c | 0.21c | 15.26c | 17.6c |
| SBFYM     | 6.4ba | 0.27c | 0.27c | 11.11c | 20.3b |
| LSD       | 0.227 | 0.476 | 1.650  |
| SEM (±)   | 0.075 | 0.009 | 0.476  |

Means for specific soil parameter followed by the same letter(s) are not significantly different from each other at P ≤ 0.05; SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure; SBFYM, soil bund integrated with farm yard manure; SEM, standard error of mean; US, upper slope; LS, lower slope.
management practices such as FYM and SBFYM, the same level of OC could be maintained at upper and lower slopes. The amount of OC in soils rated according to Tekalign [45] was found to be low under nonmanaged land and medium under three management practices.

3.2.3. Total Nitrogen (TN) and C:N Ratio. Total nitrogen (TN) amount was significantly affected ($P < 0.05$) by different soil management practices and slope conditions. It was significantly lower with no management (0.086%) compared to soil bund (0.153%), farmyard manure application (0.210%), and soil bund integrated with FYM (0.258%) (Table 4). The increase in N under SB, FYM, and SBFYM over NM was 58%, 144%, and 200%, respectively. The increase in N content under soil management practices were due to less loss of fertility bearing soil fractions such as clay and silt and addition of farm yard manure. The N enrichment was more marked under management practices adding farm yard manure. The soil management practices reducing runoff and soil loss and enhancing profile water storage would enhance crop growth and contribute to OM and N input in the soil. The significance of soil management in enhancing soil fertility has been highlighted by some studies. For instance, nonconserved land had the smallest mean value of TN compared to the conserved land [26]. In another study [13], soil and water conservation increased the total soil N in Bokole watershed in Ethiopia. Similarly, the soil management practices of farm yard manure complemented with soil bund increased the total nitrogen content by 107% over nonconserved land [23].

The mean N content decreased considerably from 0.188% in the bottom slope to 0.166% in the upper slope soil (Table 4), revealing a reduction of about 12%. The difference in N content may be due to deposition of eroded sediments from the upper to the lower slope. A similar decrease in total N on the upper slope compared to the bottom slope has been reported by Dagnachew et al. [24].

Considering the interaction of soil management practices by the slope range (Table 5), the significantly highest N (0.27%) compared to other treatment combinations was recorded with the practice of soil bund integrated with farm yard manure at the lower slope, followed by the same practice at the upper slope (0.24%). The significantly lowest concentration of N compared to other treatment combinations was shown by NM practice both at upper (0.07%) and lower (0.10%) slope ranges.

Following the rating of total N [45], the soil under no management was low in N, the soil under management practices, viz., soil bund alone and farm yard manure alone was moderate in N status, and the soil under integrated soil management of soil bund + farm yard manure was high in N status. As the OC and total N contents showed strong association ($r^2 = 0.811^{**}$), the reduction in the total N contents of the soils both with nonmanagement practice and the upper slope was possibly due to reduction of soil OM content. The increase of total N at the lower slope might be due to the downward movement of nutrient with runoff water from the higher slope and build up at the lower slope position. The soil erosion might have decreased major plant nutrient (TN) at the higher slope and increased at the lower slope.

The C:N ratio was also significantly ($P < 0.05$) higher under soil management practices, viz., SB (13.57), FYM (12.54), and SBFYM (11.6) compared to NM (5.89). However, the difference was nonsignificant between the practices having incorporation of FYM (Table 4). The effect of slope percentage was not significant. The C:N ratio is indication of soil mineralization rate. Generally, the C:N ratio of 10–15 is normal, 15–25 may indicate slowing of decomposition process, and >25 may show organic matter to be raw and unlikely to breakdown quickly. Accordingly, all the soil management practices were having C:N ratios as normal. The interaction effect (Table 5) showed higher ratio for FYM practice than NM.

3.2.4. Soil Available Phosphorus (AP). The soil available phosphorus was significantly ($P < 0.01$) affected by soil management practices, slope range, and the interaction between soil management practices and the slope (Tables 4 and 5). All the soil management practices indicated significantly higher contents of AP than no management. The practice of soil bund integrated with farm yard manure appeared to be significantly superior to the practices of soil bund and farm yard manure alone. Accordingly, AP followed an order SBFYM (21.16 mg/kg) > FYM (17.83 mg/kg) > SB (13.3 mg/kg) > NM (7.5 mg/kg). Generally, variations in available P contents in soils should be related to the level of soil management, i.e., mechanical and cultural practices retaining/adding mineral and organic fractions in soil, besides intensity of soil weathering and P fixation. The practice of soil bund would retain more fertility bearing soil particles as a result of decreased soil erosion. Whereas the soil bund integrated with farm yard manure incorporation would also have addition of phosphorus through manure application besides decreased soil erosion. More buildup of available phosphorus in soil with soil bund and continuous application of farm yard manure has also been indicated by Selassie et al. [23]. Also, Mulugeta and Stahr [26] have reported significantly higher contents of available phosphorus in conserved compared to nonconserved fields. The main effect of slope range also revealed that available P was significantly higher (15.92 mg/kg) in the lower slope than in the upper slope (14.00 mg/kg) because of its removal from the upper slope and deposition in the lower slope.

According to Cottenie [50], the available soil P level of $<5$ mg/kg is rated as very low, 5–9 mg/kg as low, 10–17 mg/kg as medium, 18–25 mg/kg as high, and >25 mg/kg as very high. Thus, the available P of the soils was high under SBFYM and FYM, medium under SB, and low under NM.

The interaction between soil management practices and slope range indicated significantly highest available P content (22 mg/kg) in SBFYM at the lower slope compared to other treatment combinations, followed by the same practice at the upper slope (20.3 mg/kg).
3.2.5. Exchangeable Cations (Macro and Micronutrients) and Cation Exchange Capacity (CEC). The exchangeable cations (K, Ca, Mg, Na, Fe, Zn, Mn, and Cu) were significantly affected by soil management practices, slope range, and interaction between practices and the slope (Tables 6–9). In general, the mean values of all cations were significantly higher under soil management practices of SB, FYM, and SBFYM compared to no management NM (Tables 6 and 8). Among soil management practices, SBFYM was significantly superior to FYM and SB alone. The slope range also affected significantly the contents of macronutrients; the mean values were significantly higher at the lower slope than the upper slope. Such a significant difference for micronutrients was, however, only for Fe and Cu.

Likewise, the CEC values of the soils were significantly affected by soil management practices, slope range, and the interaction between management practices and slope range (Tables 6 and 7). Considering the main effects, the CEC values were significantly higher under soil management practices, viz., SB (26.53 cmol (+) kg⁻¹), FYM (30.85 cmol (+) kg⁻¹), and SBFYM (34.56 cmol (+) kg⁻¹) compared to no management, NM (22.66 cmol (+) kg⁻¹). The practice of soil bund integrated with farm yard manure application was significantly superior to application of farm yard manure alone, which, in turn, was significantly superior to the practice of soil bund alone. The CEC values were in the order of SBFYM > FYM > SB > NM. It is a general fact that both clay and colloidal OM have the ability to adsorb and hold positively charged ions. Thus, soils containing high clay and organic matter contents have high CEC. This is very well corroborated by the highly significant and positive correlations of CEC with clay (r = 0.885**) and OM (0.913**) in this study. An increase in CEC of soils with high organic matter and clay contents has also been reported by Selassie et al. [23] and Selassie and Ayanna [51]. Similarly, Mulugeta and Stahr [26] have supported the idea that high clay soils can hold more exchangeable cations than low clay containing soils. The practice SBFYM was capable of retaining more clay due to lesser erosion besides having addition of OM through FYM application. The practices of FYM and SB alone were not as promising as SBFYM because of absence of either mechanical protection or addition of manure in them.

### Table 6: Effect of soil management practices and slope ranges on exchangeable cations in soils of Mawula watershed.

| SMP     | Exchangeable cations (cmol kg⁻¹) | CEC (cmol kg⁻¹) |
|---------|---------------------------------|-----------------|
|         | K                               | Ca              | Mg   | Na   |                   |
| NM      | 0.53d                           | 4.89d           | 3.05d| 0.18h| 22.66d           |
| SB      | 0.87c                           | 7.18c           | 4.58c| 0.19b| 26.53c           |
| FYM     | 1.13b                           | 9.41b           | 5.43b| 0.29a| 30.85b           |
| SBFYM   | 1.22a                           | 11.05a          | 6.72a| 0.35a| 34.56a           |
| LSD (0.05) | 0.070                             | 0.359           | 0.168| 0.056| 0.925            |
| SEM (±) | 0.023                           | 0.118           | 0.055| 0.0183| 0.305           |
| CV (%)  | 9.3                             | 3.95            | 4.17 | 17.9 | 2.35             |
| Slope range |                                  |                 |      |      |                  |
| US      | 0.89b                           | 7.65b           | 4.65b| 0.23b| 27.81b           |
| LS      | 0.97a                           | 8.61b           | 5.24a| 0.28a| 29.49a           |
| LSD (0.05) | 0.049                             | 0.254           | 0.119| 0.039| 0.6543           |
| SEM (±) | 0.164                           | 0.0838          | 0.0392| 0.0129| 0.2157           |

Means within a column followed by the same letter(s) are not significantly different from each other at P ≤ 0.05; SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure; SBFYM, soil bund integrated with farm yard manure; CEC, cation exchange capacity; US, upper slope; LS, lower slope.

### Table 7: Interaction effect of soil management practices and slope ranges on exchangeable cations in soils of Mawula watershed.

| SMP | Exchangeable cations (cmol kg⁻¹) | CEC (cmol kg⁻¹) |
|-----|---------------------------------|-----------------|
|     | K                               | Ca              | Mg   | Na   |                   |
| NM  | 0.53d                           | 4.51d           | 5.21d| 2.9d | 3.17d            |
| SB  | 0.82c                           | 6.81d           | 7.54d| 4.23c| 4.93c            |
| FYM | 1.07b                           | 8.85c           | 9.97b| 5.1b | 5.76b            |
| SBFYM | 1.18a                           | 10.4a           | 11.66a| 6.3b | 7.1a             |
| LSD | 0.099                           | 0.508           | 0.238| 0.078| 1.31             |
| SEM (±) | 0.062                             | 2.12            | 3.12 | 0.23 | 21.5             |

Means for specific soil parameter followed by the same letter(s) are not significantly different from each other at P ≤ 0.05; SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure; SBFYM, soil bund integrated with farm yard manure; SEM, standard error of mean; US, upper slope; LS, lower slope.
more enrichment of cations was obtained in the soils where there was mechanical protection in the form of soil bund coupled with incorporation of farm yard manure. The favorable effect of soil management practices on soil exchangeable K has been indicated by Selassie et al. [23] in Zikre watershed, northwestern Ethiopia. The higher contents of micronutrients in managed soils could be linked to higher amounts of organic matter in them, as organic matter retards the oxidation and precipitation of micronutrients into unavailable forms and enhances their availability through chelating action. The enhancement of available Zn in soil with the use of farm yard manure and soil conservation measure has been reported by Kumar and Babel [52]. The higher values of CEC at lower slope range (29.49 cmol (+) kg\(^{-1}\)) than the upper slope (27.81 cmol (+) kg\(^{-1}\)) are, obviously, due to more accumulation of clay and organic matter moved from the upper slope.

Considering the interaction effect of land management practices and slope ranges on micronutrient cations in soils of Mawula watershed.

### Table 8: Effect of soil management practices and slope ranges on micronutrient cations in soils of Mawula watershed.

| SMP          | Fe (mg·kg\(^{-1}\)) | Zn (mg·kg\(^{-1}\)) | Mn (mg·kg\(^{-1}\)) | Cu (mg·kg\(^{-1}\)) |
|--------------|----------------------|----------------------|----------------------|----------------------|
| NM           | 5.24\(^{d}\)        | 2.82\(^{d}\)        | 2.06\(^{d}\)        | 4.59\(^{d}\)        |
| SB           | 5.53\(^{c}\)        | 3.38\(^{c}\)        | 2.81\(^{c}\)        | 5.19\(^{c}\)        |
| FYM          | 5.84\(^{b}\)        | 3.95\(^{b}\)        | 3.46\(^{b}\)        | 5.86\(^{b}\)        |
| SBFYM        | 6.30\(^{a}\)        | 5.06\(^{a}\)        | 4.09\(^{a}\)        | 6.26\(^{a}\)        |
| LSD (0.05)   | 0.166                | 0.353                | 0.531                | 0.162                |
| SEM (±)      | 0.056                | 0.116                | 0.178                | 0.053                |
| CV (%)       | 8.46                 | 26.2                 | 13.12                | 58.4                 |

### Slope range

| US  | LS  |
|-----|-----|
| Fe  | 5.64\(^{b}\) | 3.69\(^{a}\) |
| Zn  | 5.82\(^{a}\) | 3.91\(^{a}\) |
| Mn  | 2.95\(^{a}\) | 3.26\(^{a}\) |
| Cu  | 5.32\(^{b}\) | 5.63\(^{a}\) |

### LSD (0.05)

| US  | LS  |
|-----|-----|
| Fe  | 0.112 | 0.249 |
| Zn  | 0.037 | 0.822 |
| Mn  | 0.382 | 0.125 |
| Cu  | 0.114 | 0.037 |

Means within a column followed by the same letter are not significantly different from each other at \(P \leq 0.05\); SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure management; SBFYM, soil bund integrated with farm yard manure management; US, upper slope; LS, lower slope.

### Table 9: The interaction effect of soil management practices and slope ranges on micronutrient cations in soils of Mawula watershed (mg·kg\(^{-1}\)).

| SMP          | Fe | Zn | Mn | Cu |
|--------------|----|----|----|----|
| NM           |    |    |    |    |
| SB           | 5.45\(^{d}\) | 5.69\(^{c}\) | 3.62\(^{a}\) | 2.74\(^{ed}\) |
| FYM          | 5.77\(^{ab}\) | 5.9\(^{b}\) | 3.86\(^{b}\) | 4.03\(^{b}\) |
| SBFYM        | 6.23\(^{a}\) | 6.37\(^{a}\) | 4.9\(^{a}\) | 5.19\(^{a}\) |

### LSD (0.05)

| US  | LS  |
|-----|-----|
| Fe  | 0.226 | 0.498 |
| Zn  | 0.764 | 0.228 |
| Mn  | 3.2   | 3.1   |
| Cu  | SEM (±) | 3.8   |

Means for specific soil parameter followed by the same letter(s) are not significantly different from each other at \(P \leq 0.05\); SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure management; SBFYM, soil bund integrated with farm yard manure management; US, upper slope; LS, lower slope.

### Table 10: Types of soil management practices on Mabula watershed.

| Soil management practices | Frequency | Percentage |
|---------------------------|-----------|------------|
| Soil bund alone           | 16        | 22.2       |
| Farm yard manure          | 24        | 33.3       |
| Soil bund + farm yard manure | 31    | 43.1       |
| Stone bund + farm yard manure | 1     | 1.4        |

### Table 11: Adoption of soil management practices by farmers and their supporters.

| Adoption   | Frequency | Percentage |
|------------|-----------|------------|
| Farmers    |           |            |
| No         | 12        | 16.7       |
| Yes        | 60        | 83.3       |
| Supporters |           |            |
| None       | 10        | 16.7       |
| NGO        | 27        | 45.0       |
| Government | 23        | 38.3       |

Therefore, more enrichment of cations was obtained in the soils where there was mechanical protection in the form of soil bund coupled with incorporation of farm yard manure. The favorable effect of soil management practices on soil exchangeable K has been indicated by Selassie et al. [23] in Zikre watershed, northwestern Ethiopia. The higher contents of micronutrients in managed soils could be linked to higher amounts of organic matter in them, as organic matter retards the oxidation and precipitation of micronutrients into unavailable forms and enhances their availability through chelating action. The enhancement of available Zn in soil with the use of farm yard manure and soil conservation measure has been reported by Kumar and Babel [52]. The higher values of CEC at lower slope range (29.49 cmol (+) kg\(^{-1}\)) than the upper slope (27.81 cmol (+) kg\(^{-1}\)) are, obviously, due to more accumulation of clay and organic matter moved from the upper slope.

Considering the interaction effect of land management practices and slope range, the significantly highest value of CEC (35.4 cmol (+) kg\(^{-1}\)) compared to other treatment combinations was recorded with SBFYM at the lower slope and lowest (21.8 cmol (+) kg\(^{-1}\)) with NM at the upper slope (Table 7). Based on the ratings given by Hazelton and Murphy [53] for CEC, the soils under three soil management practices and no management could be rated as high and medium, respectively. Therefore, proper use of land by providing appropriate soil conservation practices would maintain soil fertility, while keeping it unmanaged would make it poor. The integrated use of soil bund and farm yard manure is the best option for vis-a-vis soil bund or FYM alone.
3.3. Soil Management Practices and Their Adoption. Based on information gathered from sampled households of the watershed, the soil management practices followed for prevention of soil erosion and enhancement of soil fertility were soil bund alone, farm yard manure alone, soil bund + farm yard manure, and stone bund + farm yard manure. The soil bund integrated with farm yard manure was the most preferred (43%) followed by farm yard manure (33%) and soil bund alone (22%) (Table 10). In all, 83.3% of farmers of Mabula watershed perceived well the conservation practices and adopted them (Table 11) for soil fertility gains and productivity enhancement. The conservation practices were supported largely by NGOs (45%) and government (38.3%). The greater role of NGOs in adoption of soil and water conservation technology has been highlighted by Wolka and Negash [54] in Bokole and Toni subwatersheds, Southern Ethiopia. The respondents suggested farmers’ training and experiences sharing (36.1%), technical support (29.2%), and farmers’ sensitization (26.4%) as important determinants of adoption of soil management practices (Table 12).

### Table 12: Farmers’ suggestions on adoption of soil management practices.

| Suggestion                              | Frequency | Percentage |
|-----------------------------------------|-----------|------------|
| Farmers’ sensitization on SMP           | 19        | 26.4       |
| Technical support for SMP               | 21        | 29.2       |
| Farmers’ trainings and experiences sharing | 26    | 36.1       |
| Provision of incentive to the farmers  | 6         | 8.3        |

4. Conclusion

The soil degradation, forcing decline in soil fertility and overall productivity, is one of the factors challenging food security in Ethiopia. To halt the pace of soil degradation, the Government of Ethiopia has launched several initiatives aimed at conservation of soil resources. Little is known yet as to what are the gains of these soil and water conservation measures in respect of improvements in soil fertility and overall productivity under different agroecologies. The present investigation was, therefore, taken up in Mawula watershed, Loma district, Southern Ethiopia, to evaluate the effect of common soil management practices under upper and lower slope conditions on the soil properties indicative of soil fertility.

The soil management practices of raising soil bund (SB), applying farm yard manure (FYM) and soil bund integrated with FYM (SBFYM), had a significant positive effect on improvement of soil fertility as expressed by different soil physical and chemical properties, viz., soil texture, bulk density, total porosity, moisture content, pH, organic carbon, total nitrogen, available phosphorus, exchangeable cations (K, Ca, Mg, and Na), cation exchange capacity, and micronutrients (Fe, Zn, Mn, and Cu). Among three practices, SBFYM proved to be best, as it was significantly superior to FYM and SB. The performance of the practices was in the order of SBFYM > FYM > SB > NM. The lower slope range was better than the upper one in respect of different physical and chemical aspects of soil fertility. The results from farmers’ survey indicated that majority of farmers (83.3%) perceived well and adopted the soil conservation practices.

From the foregoing information on soil and farmers’ adoption of soil management practices, it could be concluded that soil management practices had a positive influence on enhancement of soil fertility of degraded lands. The management practice of soil bund combined with farm yard manure was most promising in improving soil fertility both at upper and lower slopes and could be recommended for wider adoption by the farmers in Mawula watershed.

Data Availability

The data used to support this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding publication of this paper.

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References

[1] T. Gashaw, “Working group on land degradation and desertification of the international union of soil sciences,” in Proceedings of the Second International Conference on Land Degradation and Desertification, Khon Kaen, Thailand, 1999.

[2] A. Hamdy and A. Aly, “Land degradation, agriculture productivity and food security,” in Proceedings of the Fifth International Scientific Agricultural Symposium, Agrosym, pp. 708–717, Sarajevo, Bosnia, 2014.

[3] Project Development Facility, Strategic Investment Programme for Sustainable Land Management in Sub-Saharan Africa: Assessment of the Barriers and Bottle-necks to Scaling-Up Sustainable Land Management Investments throughout Sub-Saharan Africa, Revised Draft, 2007.

[4] L. Mulugeta, “Effects of land use change on soil quality and native flora degradation and restoration in the highlands of Ethiopia. Implication for land management,” Ph.D. thesis, Swedish University of Agricultural Science, Uppsala, Sweden, 2004.

[5] IFPRI, Poverty and Land Degradation in Ethiopia: How to Reverse the Spiral?, International Food Policy Research Institute, Washington, DC, USA, 2005.

[6] T. Gashaw, A. Bantider, and H. Silassie, “Land degradation in Ethiopia: causes, impacts and rehabilitation techniques,” Journal of Environment and Earth Science, vol. 4, no. 9, pp. 98–104, 2014.

[7] D. Paulos, Soil and Water Resources and Degradation Factors Affecting their Productivity in the Ethiopian Highland Agro-Ecosystems, Michigan State University Press, vol. 8, no. 1, East Lansing, MI, USA, 2001.

[8] MoARD (Ministry of Agriculture and Rural Development), "Ethiopia’s agricultural sector policy and investment..."
framework (PIF) 2010–2020,” Draft Final Report, pp. 1–15, MoARD (Ministry of Agriculture and Rural Development), Tirana, Albania, 2010.

[9] L. Berry, "Land degradation in Ethiopia: its impact and extent," in assessing the extent, cost and impact of land degradation at the national level: findings and lessons learned from seven pilot case studies. commissioned by global mechanism with support from the world bank, Technical report, 2003.

[10] A. Tilahun, B. Takele, and G. Endrias, “Reversing the Degradation of Arable Land in the Ethiopian Highlands,” pp. 1–20, International Center for Research in Agro Forestry, Claveria, Philippines, 2001.

[11] J. Nyssen, Land Degradation in Ethiopian Highlands, Royal Museum for Central Africa, Tervuren, Belgium, 2015.

[12] WMO, Climate and Land Degradation, World Meteorological Organization, Geneva, Switzerland, 2005.

[13] K. Wolka, A. Moges, and F. Yimer, “Effects of level soil bunds and stone bunds on soil properties and its implications for crop production: the case of Bokole watershed, Dasowo zone, Southern Ethiopia,” Agricultural Sciences, vol. 2, no. 3, pp. 357–363, 2011.

[14] Ministry of Agriculture and Rural Development & World Bank (MoA & WB) Ethiopia, Thematic Papers on Land Degradation in Ethiopia, Ministry of Agriculture and Rural Development & World Bank (MoA & WB) Ethiopia, Addis Ababa, Ethiopia, 2007.

[15] W. Bewket and E. Tesfier, “Assessment of soil erosion hazard and prioritization for treatment at the watershed level: case study in the Chemoga watershed, Blue Nile basin, Ethiopia,” Land Degradation & Development, vol. 20, no. 6, pp. 609–622, 2009.

[16] K. Hurni, G. Zeleke, M. Kassie et al., “Economics of land degradation Ethiopia. Soil degradation and sustainable land management in the rainfed agricultural areas of Ethiopia: an assessment of the economic implications,” Report for the Economics of Land Degradation Initiative, vol. 94, 2015.

[17] H. S. Gelagay and A. S. Minale, “Soil loss estimation using GIS and Remote sensing techniques: a case of Koga watershed, Northwestern Ethiopia,” International Soil and Water Conservation Research, vol. 4, no. 2, pp. 126–136, 2016.

[18] G. Temeshgen, T. Taffa, and A. Mekuria, “Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile Basin, Ethiopia,” Environmental Systems Research, vol. 6, no. 1, 2017.

[19] H. F. Murphy, "Fertility and other data on some Ethiopian soils," in Proceedings of the Soil Fertility Management Workshop, Addis Ababa, Ethiopia, April 1963.

[20] M. Tekalign, I. Haque, and C. S. Kamara, “Phosphorus status of some Ethiopian highland Vertisols,” in Proceedings of Conference Held at the International Livestock Center for Africa, ILCA, Addis Ababa, Ethiopia, pp. 232–252, 1988.

[21] ATA, Soil Fertility Status and Fertilizer Recommendation Atlas for Tigray Regional State, Ethiopia, Agricultural Transformation Agency, Ministry of Agriculture, Addis Ababa, Ethiopia, 2014.

[22] T. Hawando, “Desertification in Ethiopian highlands,” Rala report no. 200, pp. 75–86, Norwegian Church AID, Addis Ababa, Ethiopia, 1997.

[23] Y. G. Selassie, F. Anemut, and S. Addisiu, “The effects of land use types, management practices and slope classes on selected soil physico-chemical properties in Zikre watershed, North-Western Ethiopia,” Environmental Systems Research, vol. 4, no. 1, p. 7, 2015.

[24] M. Dagnachew, A. Moges, A. Kebede, and A. Abebe, "Effects of soil and water conservation measures on soil quality indicators": the case of Geshy subcatchment, Gojeb river catchment, Ethiopia," Applied and Environmental Soil Science, vol. 2020, Article ID 1868792, 16 pages, 2020.

[25] H. Hurni, W. A. Berhe, P. Chadhokar et al., Soil and Water Conservation in Ethiopia: Guidelines for Development Agents, Centre for Development and Environment, Bern, Switzerland, 2016.

[26] D. Mulugeta and K. Stahr, “Assessment of integrated soil and water conservation measures on key soil properties in South Gonder, North-Western Highlands of Ethiopia,” Journal of Soil Science and Environmental Management, vol. 1, no. 7, pp. 164–176, 2010.

[27] B. Bezabih, A. Aticho, T. Mossisa, and B. Dume, “The effect of land management practices on soil physical and chemical properties in Gojeb Sub-river Basin of Dedo District, Southwest Ethiopia,” Journal of Soil Science and Environmental Management, vol. 7, pp. 154–165, 2016.

[28] LWFNRMO, Annual Report and Socio-Data, Loma Woreda Farming and Natural Resources Management Office, Gessa, Ethiopia, 2017.

[29] Ministry of Agriculture, Ethiosis, Ethiopian Soil Information System, Ministry of Agriculture, Addis Ababa, Ethiopia, 2017.

[30] G. J. Bouyoucos, “Hydrometer method improvement for making particle size analysis of soils,” Agronomy Journal, vol. 54, pp. 179–186, 1962.

[31] C. A. Black, Methods of Soil Analysis Part I, American Society of Agronomy, Madison, WI, USA, 1965.

[32] L. Van Reeuwijk, Procedures for Soil Analysis, International Soil Reference and Information Centre, Wageningen, Netherlands, 1992.

[33] A. Walkley and I. A. Black, “An examination of the digtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method,” Soil Science, vol. 37, no. 1, pp. 29–38, 1934.

[34] J. M. Bremner and C. S. Mulvaney, “Total nitrogen,” in Methods of Soil Analysis. II. Chemical and Microbiological Properties, A. L. Page, R. H. Miller, and D. R. Keeney, Eds., pp. 595–624, American Society of Agronomy, Soil Science Society of America, Madison, WI, USA, 1982.

[35] H. D. Chapman, “Cation exchange capacity,” in Methods of Soil Analysis, Part 2, C. A. Black, Ed., American Society Agronomy, Madison, WI, USA, 1965.

[36] S. R. Olsen, C. V. Cole, F. S. Watanabe, and L. A. Dean, Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate, Allen Institute for AI, Seattle, WA, USA, 1954.

[37] D. L. Rowell, Soil Science: Methods and Applications, Addison Wesley Longman Singapore Publishers (Pty) Ltd., Basingstoke, UK, 1994.

[38] I. Glenn, Sampling and Evidence of Extension Program Impact, Programme Evaluation and Organizational Development, IFAS, University of Florida, Gainesville, FL, USA, 1992.

[39] SAS, The SAS System for Windows. Version 6.12, SAS Institute, Cary, NC, USA, 1996.

[40] S. O. Agele, B. S. Ewulo, and I. K. Oyewusi, “Effects of some soil management systems on soil physical properties, microbial biomass and nutrient distribution under rainfed maize production in a humid rainforest alfisol,” Nutrient Cycling in Agroecosystems, vol. 72, no. 2, pp. 121–134, 2005.
[41] D. Husen, F. Esimo, and F. Getachew, “Effects of soil bund on soil physical and chemical properties in Arsi Negelle woreda, Central Ethiopia,” *African Journal of Environmental Science and Technology*, vol. 11, no. 10, pp. 509–516, 2017.

[42] F. Khan, Z. Hayat, W. Ahmad et al., “Effect of slope position on physico-chemical properties of eroded soil,” *Soil Science Society of Pakistan*, vol. 32, p. 28, 2013.

[43] A. Mamedov, E. Imanverdi, C. Gülser, I. Gümüş, U. Çetin, and G. J. Levy, “Relationship between soil water retention model parameters and structure stability” *Eurasian Journal of Soil Science*, vol. 5, no. 4, pp. 314–321, 2016.

[44] J. Tugizimana, “Effects of soil and water conservation techniques on soil productivity and bean grain yield in Nyamasheke District, Rwanda,” M.sc. thesis, Kenyatta University, Nairobi, Kenya, 2011.

[45] T. Tekalign, *Soil, Plant, Water, Fertilizer, Animal Manure and Compost Analysis* International Livestock Research Center for Africa, Addis Ababa, Ethiopia, 1991.

[46] S. Saggar, A. Parshotam, G. P. Sparling, C. W. Feltham, and P. B. S. Hart, "14C-labelled ryegrass turnover and residence times in soils varying in clay content and mineralogy," *Soil Biology and Biochemistry*, vol. 28, no. 12, pp. 1677–1686, 1996.

[47] S. Saggar, K. Tate, C. Feltham, C. Childs, and A. Parshotam, "Carbon turnover in a range of allophanic soils amended with 14C-labelled glucose," *Soil Biology and Biochemistry*, vol. 26, no. 9, pp. 1263–1271, 1994.

[48] A. Bezu and K. Tezera, "Impacts of soil and water conservation on crop yield, soil properties, water resources and carbon sequestration: a review," *Journal of Soil Science and Environmental Management*, vol. 10, no. 5, pp. 103–113, 2019.

[49] A. Tadele, G. S. Yihenew, H. Mitiku, and C. Yamoh, "Effect of soil and water conservation measures on selected soil physical and chemical properties and Barley (Hordeum spp.) Yield,” *Journal of Environmental Science and Engineering*, vol. 11, pp. 1483–1495, 2011.

[50] A. Cottenie, *Soil and Plant Testing as a Basis of Fertilizer Recommendations* Food and Agriculture Organization of the United Nations, Rome, Italy, 1980.

[51] Y. G. Selassie and G. Ayanna, “Effects of different land use systems on selected physico-chemical properties of soils in north-western Ethiopia,” *Journal of Agricultural Science*, vol. 5, no. 4, pp. 112–120, 2013.

[52] M. Kumar and A. L. Babel, “Available micronutrient status and their relationship with soil properties of Jhunjhununu Tehsil, District Jhunjhunu, Rajasthan, India—a review,” *Journal of Agricultural Science*, vol. 3, pp. 97–106, 2011.

[53] P. Hazelton and B. Murphy, *Interpreting Soil Test Results: What Do All the Numbers Mean*, NSW Department of Natural Resources, CSIRO Publishing, Clayton, Australia, 2nd edition, 2007.

[54] K. Wolka and M. Negash, “Farmers’ adoption of soil and water conservation technology: a case study of Bokole and Toni sub-watersheds, southern Ethiopia,” *Journal of Science & Development*, vol. 2, no. 1, pp. 35–48, 2014.