Hindawi
Advances in Agriculture
Volume 2020, Article ID 8866230, 13 pages
https://doi.org/10.1155/2020/8866230

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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Received 13 May 2020; Accepted 20 August 2020; Published 1 September 2020

Academic Editor: Jiban Shrestha

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 237 $t{\cdot}ha^{-1}{\cdot}year^{-1}$ [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 2 $t{\cdot}ha^{-1}$.

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′0″N–6°59′30″N latitude and 37°11′0″E–37°17′0″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.*)*, faba 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.

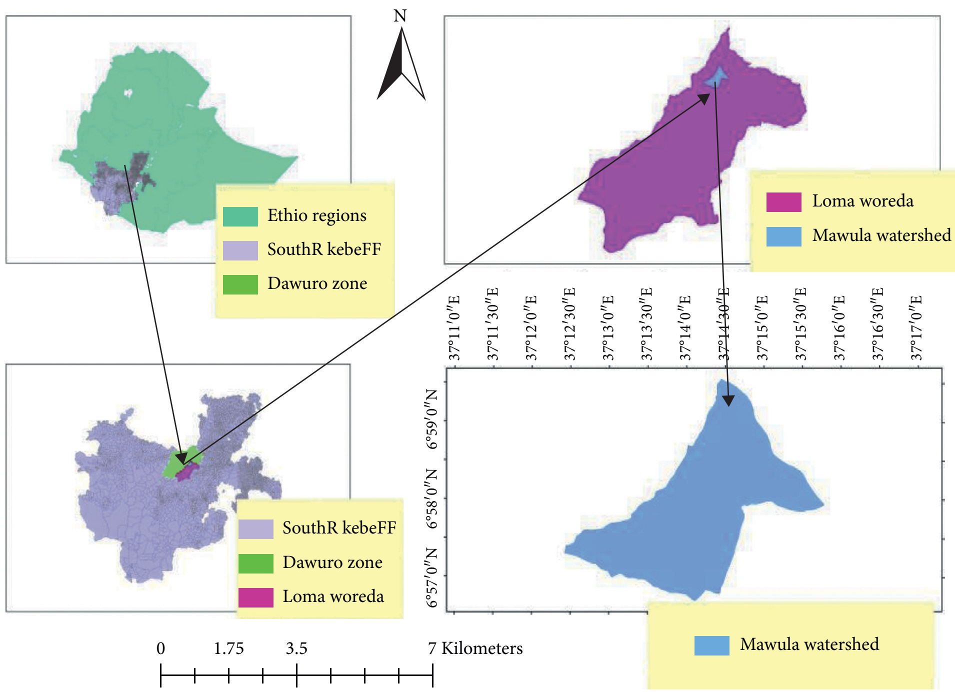

Figure 1: Map of study area.

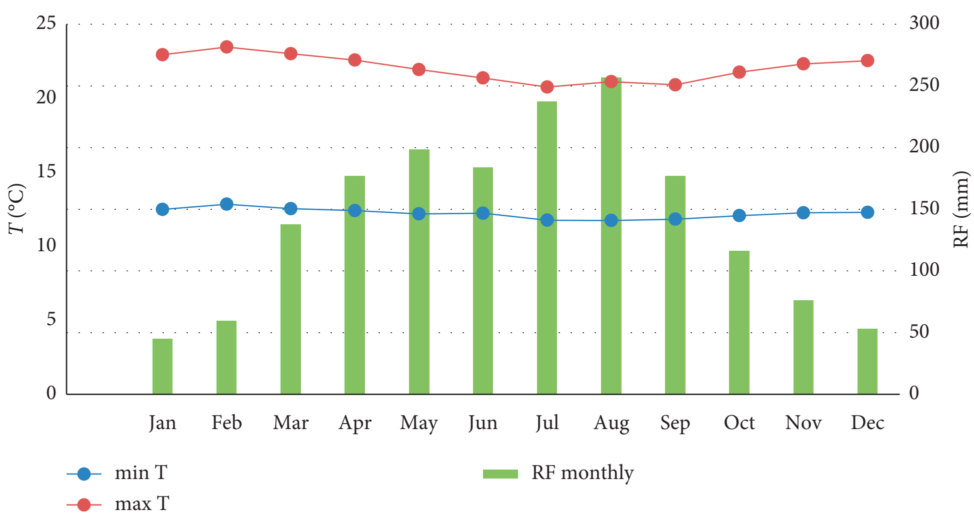

Figure 2: Monthly rainfall and maximum and minimum temperatures of the study area (11 years average).

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. The 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.

Table 1: Sample site characteristics.

Site name	Slope range	Coordinate point	Altitude (masl)	Slope (%)	Aspect
Borthe	Upper	6°58′01″–6°57′21″ 37°14′21″–7°15′38″	2153–2156	20–30	Southern
	Lower	37°15′11″–37°16′31″ 6°58′81″–6°58′82″	1658–1855	2–10	Southern
Fulasa	Upper	6°57′66″–6°57′88″ 37°13′57″–37°14′67″	2153–2156	20–30	Southern
	Lower	6°58′56″–6°58′78″ 37°15′28″–37°16′61″	1658–1952	2–10	Southern
Xossa wora	Upper	6°58′60″–6°58′80″ 37°13′88″–37°14′42″	2153–2156	20–30	Southern
	Lower	6°57′45″–6°57′65″ 37°15′22″–37°16′42″	1658–1952	2–10	Southern

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 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 (M_w). The pH of the soils was measured in soil-water suspension (1 : 2.5 : soil : water) using a glass-calomel electrode [32]. Soil organic carbon content was determined by the Walkley and Black [33] wet digestion method. The Kjeldhal digestion and distillation method was used to measure total nitrogen [34]. Cation exchange capacity (CEC) was determined after extracting the soil samples with 1N NH_4OAc at pH 7.0 and distilling ammonium displaced by leaching with NaCl solution [35]. Available soil P was analysed following procedure of Olsen et al. [36]. Available/exchangeable potassium and sodium were determined by the flame photometry [35]. Calcium, magnesium, and micronutrients (Fe, Zn, Mn, and Cu) were analysed by the atomic absorption spectrophotometer [37].

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]:

$$n = \frac{N}{1 + N(e)^2}, \tag{1}$$

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

Table 2: Effect of soil management practices and slope range on physical properties of soils in Mawula watershed.

SMP	Sand (%)	Silt (%)	Clay (%)	STC	BD ($Mg{\cdot}m^{-3}$)	PD ($Mg{\cdot}m^{-3}$)	MC (%)	TP (%)
NM	50.7^{a}	21.5^{b}	27.7^{d}	SCL	1.165^{a}	2.58^{c}	12.2^{d}	56.2^{c}
SB	47.2^{b}	23^{b}	29.7^{c}	CL	1.08^{b}	2.61^{b}	22.47^{c}	57.4^{cb}
FYM	41.7^{c}	26.5^{a}	31.7^{b}	CL	1.08^{b}	2.62^{b}	27.65^{b}	58.8^{b}
SBFYM	38.5^{d}	27^{a}	34.5^{a}	CL	0.99^{c}	2.64^{a}	32.57^{a}	62.3^{a}
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
Slope range								
US	45.7^{a}	23.92^{b}	30.42^{a}	Loam	1.11^{a}	2.62^{a}	22.67^{a}	57.64^{b}
LS	43.3^{b}	25.25^{a}	31.33^{a}	Loam	1.05^{b}	2.61^{a}	24.78^{a}	59.68^{a}
LSD (0.05)	0.89	1.32	1.18		0.04	0.06	3.11	1.60
SEM (±)	0.89	1.32	1.18		0.045	0.06	3.1058	1.60
CV%	0.36		0.49		0.010	0.003	0.92	0.42

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; 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 with management, such a situation may be warranted on the removal of finer fraction with soil erosion and alteration in the mass proportion of textural separates. The results are corroborated by the findings of Wolka et al. [13] who reported increase in clay and silt contents in soils provided with soil bund and stone bund on cultivated lands in Southern Ethiopia. Also, Dagnachew et al. [24] reported significantly improved silt and clay fractions with soil and water conservation measures (SWC) compared to no SWC on farm lands. Texturally, the performance of soil management practices was in the order of SBFYM > FYM > SB > NM.

The slope range did not show a change in the soil texture 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 $Mg{\cdot}m^{-3}$) compared to soils with soil conservation practices, viz., soil bund (1.08 $Mg{\cdot}m^{-3}$), farm yard manure (1.08 $Mg{\cdot}m^{-3}$), and soil bund combined with farm yard manure (0.99 $Mg{\cdot}m^{-3}$) (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 $Mg{\cdot}m^{-3}$) compared to the lower slope (1.05 $Mg{\cdot}m^{-3}$). 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

Table 3: Interaction effect of soil management practices and slope range on physical properties of the soils in Mawula watershed.

SMP	Sand (%)		Silt (%)		Clay (%)		BD ($Mg \cdot m^{-3}$)		PD ($Mg \cdot m^{-3}$)		MC (%)		TP (%)	
	US	LS	US	LS	US	LS	US	LS	US	LS	US	LS	US	LS
NM	54.7^{a}	52.3^{b}	22.3^{e}	24^{bdec}	22.67^{d}	23.67^{d}	1.21^{a}	1.12^{b}	2.58^{e}	2.59^{de}	14.4^{d}	15.37^{d}	53.2^{d}	56.7^{c}
SB	49^{c}	47^{c}	22.67^{de}	23.3^{dec}	29^{c}	30.3^{cb}	1.12^{b}	1.07^{cb}	2.61^{bc}	2.62^{bc}	21.7^{c}	23.17^{c}	57.1^{c}	59.2^{c}
FYM	44^{d}	41.3^{e}	25.33^{bdac}	27.67^{a}	31.67^{b}	31.67^{b}	1.11^{b}	1.04^{cd}	2.62^{bc}	2.63^{ba}	26.4^{bc}	28.83^{ba}	57.3^{c}	60.2^{ba}
SBFM	40^{fe}	39^{f}	26.33^{ba}	26.2^{bac}	34.3^{a}	35^{a}	1.04^{cd}	1.01^{d}	2.64^{a}	2.65^{a}	31.1^{ba}	34.07^{a}	60.7^{ba}	62.03^{a}
LSD	2.16		2.95		2.45		0.06		0.019		5.582		2.588	
SEM (±)	5.2		6.22		12.3		0.55		2.33		13.5		20.5	

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; 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.

slope positions, 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 (1.21 $Mg \cdot m^{-3}$) and lowest with SBFYM at the lower slope (1.01 $Mg \cdot m^{-3}$). 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 conservation practices could be ascribed to their influence on water storage in soil profile. The practices offering mechanical barriers to the flow of water reduce the runoff velocity and offer more opportunity for water to infiltrate into the soil. Also, the conservation practices reducing loss of fine fractions of soil, including humus, would enhance the water holding capacity of the soils. Similar increase in soil water content with SWC measures over no SWC has been reported by Dagnachew et al. [24]. An increase in water retention as a result of enhanced structure stability in coarse textured soils amended with composted manure and sewage sludge has been reported by Mamedov et al. [43].

The soil moisture percentage was significantly higher under the lower slope (24.8%) than the upper slope (22.7%). The effect was obvious with loss of fine fraction of soil, retaining water, from the upper slopes and its deposition in the lower slopes. The runoff generation and soil erosion become more as degree of slope increases. Dagnachew et al. [24] also found significantly higher volumetric water content at the bottom slope classes than the upper slope due to erosion reduction and the deposition effect of SWC measures.

There was a significant effect of interaction between soil management practices and slope range on soil moisture (Table 3). The highest water content (34.1%) was obtained with SBFYM at the lower slope range and minimum with NM at the upper slope.

3.2. Effect of Soil Management Practices on Soil Chemical Properties

3.2.1. 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.

Similar increases 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

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	5.20^{d}	0.51^{d}	0.09^{d}	5.89^{c}	7.50^{d}
SB	5.91^{c}	2.08^{c}	0.15^{c}	13.59^{a}	13.30^{c}
FYM	6.17^{b}	2.62^{b}	0.21^{b}	12.54^{b}	17.83^{b}
SBFYM	6.52^{a}	2.97^{a}	0.26^{a}	11.6^{b}	21.16^{a}
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	5.80^{b}	1.93^{b}	0.17^{b}	10.76	14.00^{b}
Lower	6.10^{a}	2.17^{a}	0.19^{a}	11.04	15.92^{a}
LSD (0.05)	0.11	0.12	0.01	0.72	0.82
SEM (±)	0.02	0.02	0.001	0.68	0.54

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; 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)	
	US	LS	US	LS	US	LS	US	LS	US	LS
NM	5.1^{f}	5.3^{f}	0.44^{d}	0.59^{d}	0.07^{e}	0.10^{e}	6.0^{d}	5.78^{d}	6.0^{g}	9.0^{f}
SB	5.6^{e}	6.03^{d}	1.75^{c}	2.42^{b}	0.14^{d}	0.16^{d}	12.4^{cd}	14.71^{a}	12.67^{e}	14.0^{e}
FYM	6.2^{dc}	6.36^{c}	2.59^{b}	2.67^{b}	0.21^{c}	0.21^{cb}	12.5^{cb}	12.56^{cb}	17.0^{d}	18.6^{c}
SBFYM	6.4^{ba}	6.6^{a}	2.93^{a}	3.02^{a}	0.24^{b}	0.27^{a}	12.1^{cb}	11.11^{c}	20.3^{b}	22.0^{a}
LSD	0.227		0.249		0.029		1.445		1.650	
SEM (±)	0.075		0.082		0.009		0.476		0.543	

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; SEM, standard error of mean; US, upper slope; LS, lower slope.

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 ($P \leq 0.05$) 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 increases 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].

As for the interaction effect of soil management practices and slope range (Table 5), the practice SBFYM at both upper and lower slopes gave significantly higher content of OC compared to rest of the combinations of practice and slope. The no management recorded significantly lowest OC at both the slope ranges. It was noticed that by employing soil 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 increases 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 ($r = 0.811^{**}$), 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).

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

SMP	Exchangeable cations (cmol kg^{-1}) K	Ca	Mg	Na	CEC (cmol kg^{-1})
NM	0.53^d	4.89^d	3.05^d	0.18^b	22.66^d
SB	0.87^c	7.18^c	4.58^c	0.19b	26.53^c
FYM	1.13^b	9.41^b	5.43^b	0.29^a	30.85^b
SBFYM	1.22^a	11.05^a	6.72^a	0.35^a	34.56^a
LSD (0.05)	0.070	0.359	0.168	0.056	0.925
SEM (±)	0.023	0.118	0.0555	0.0183	0.305
CV (%)	9.3	3.95	4.17	17.9	2.35
Slope range					
US	0.89^b	7.65^b	4.65^b	0.23^b	27.81^b
LS	0.97^a	8.61^a	5.24^a	0.28^a	29.49^a
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 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; 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	K (cmol·kg^{-1})		Ca		Mg		Na		CEC	
	US	LS	US	LS	US	LS	US	LS	US	LS
NM	0.51^d	0.55^d	4.51^g	5.21^f	2.9^f	3.17^f	0.15^d	0.19^{dc}	21.8^h	23.5^g
SB	0.82^c	0.91^c	6.81^e	7.54^d	4.23^e	4.93^d	0.16^d	0.22^{dc}	25.8^f	27.2^e
FYM	1.07^b	1.18^a	8.85^c	9.97^b	5.1^d	5.76^c	0.22^{bc}	0.33^{ba}	29.9^d	31.78^c
SBFYM	1.18^a	1.25^a	10.4^b	11.66^a	6.3^b	7.1^a	0.33^{ba}	0.34^a	33.7^b	35.7^a
LSD	0.099		0.508		0.238		0.078		1.31	
SEM (±)	0.62		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 $P \leq 0.05$; SMP, soil management practices; NM, no management; SB, soil bund; FYM, farm yard manure management; SBFYM, soil bund integrated with farm yard manure; SEM, standard error of mean; US, upper slope; LS, lower slope.

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 ($P \leq 0.05$) 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 ($P \leq 0.05$) 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 less 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 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	5.64^{b}	3.69^{a}	2.95^{a}	5.32^{b}
LS	5.82^{a}	3. 91^{a}	3.26^{a}	5.63^{a}
LSD (0.05)	0.112	0.249	0.382	0.114
SEM (±)	0.037	0.822	0.125	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; SBFYM, soil bund integrated with farm yard manure; 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	
	US	LS	US	LS	US	LS	US	LS
NM	5.1^{e}	5.38^{d}	2.74^{ff}	2.9^{ef}	1.69^{f}	2.43^{ef}	4.45^{g}	4.74^{f}
SB	5.45^{d}	5.6^{cd}	3.26^{cd}	3.49^{cd}	2.74^{ed}	2.87^{edc}	4.98^{e}	5.41^{d}
FYM	5.77^{cb}	5.9^{b}	3.86^{cb}	4.03^{b}	3.34^{bdc}	3.58^{bac}	5.78^{c}	5.93^{cb}
SBFYM	6.23^{a}	6.37^{a}	4.9^{a}	5.19^{a}	4.02^{ba}	4.15^{a}	6.06^{b}	6.45^{a}
LSD	0.226		0.498		0.764		0.228	
SEM (±)	3.2		2.4		3.1		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; SEM, standard error of mean; 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.

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

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).

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.

Acknowledgments

The authors are thankful to Loma Administration and Finances and Economy Development Offices for their financial support.

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