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Effect of agricultural land management practices on the selected soil quality indictors: empirical evidences from the south Ethiopian highlands

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Abstract

Background Land degradation is a major challenge that adversely affects soil fertility, agricultural production, and environmental sustainability. To curb this, various agricultural land management (ALM) measures have been practiced for the last three decades. This research investigated the effects of ALM practices on selected soil quality indicators in the Ojoje sub-watershed, Southern Ethiopia Highlands. A total of 72 composite soil samples were collected from non-treated and treated plots (i.e., land treated for 5 and 10 years with only physical practices and integrated measures) at a depth of 0–20 cm. A one-way ANOVA was used to demonstrate statistically significant variations on soil quality indicators. Simple regression analysis was used to explain the proportional variance of soil quality indicators due to ALM measures.

Result The findings of the study indicate that integrated ALM practices have positive effects on the soil quality indicators. Most soil quality indicators, such as the soil organic carbon, soil organic matter, total nitrogen, available phosphorous, sulfur, boron and percentage of cation exchange capacity, were significant ($p < 0.01$ and $p < 0.05$) as a result of ALM practices. However, soil bulk density, potassium and percentage of silt contents were higher, but the difference was insignificant. Thus, the mean value of soil quality indicators increased steadily with age of intervention and application of integrated physical and biological conservation measures.

Conclussion ALM practices had stronger effects when land was treated with integrated ALM measures and conserved for an extended period of time. Hence, integrating ALM practices and maintaining them for the long term is crucial for improving soil quality and enhancing agricultural productivity.

Keywords Agricultural land management practices, Soil quality indicators, Intervention years, Treatment type, Watershed

Introduction

Land degradation, especially soil erosion and soil nutrient depletion, is putting massive stress on the rain-fed-based agriculture systems of most developing countries (Kideghesho 2015; MacCormick 2019). Land degradation in the Sub-Saharan region (SSR), including the Ethiopian highlands, is associated with soil erosion, which leads to the decline of soil quality, a decrease in soil fertility, and sediment accumulation (Porter et al. 2014; Debele et al.

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2015; Hishe et al. 2017). This, in turn, leads to a decline in agricultural productivity and poses threats to smallholders' livelihoods (Hurni 1993; Adimassu et al. 2012; Tamrat et al. 2018). Assessment reports related to land degradation show a loss of nearly 5% annual agricultural yield in SSA (Mengistu et al. 2016; Tamrat et al. 2018; Mamush et al 2021). The adverse effects of land degradation are anticipated to reach a 20% annual loss of yield by 2050 (Doukkali et al. 2018; IPBES 2018).

The Ethiopian government designed various land management measures to curb the impeding challenges of land degradation (Wuletaw 2019; Mamush et al. 2021). Hence, various land management approaches, particularly agricultural land management (ALM) practices, have been implemented with collaborative efforts from non-governmental organizations (NGOs), farmers, donors, and local communities' members (Lelago et al. 2016; Meskerem et al. 2018; Mamush et al. 2021). The most widely implemented ALM practices include zero tillage, soil bund, fanya *juu*, crop and livestock diversification, intercropping, mulching, organic manure, agroforestry, crop rotation, and terracing (FAO/OECD 2018; Nigussie et al. 2020).

There have been numerous studies conducted on the effect of ALM practices on the biophysical environment and socio-economic conditions of the communities (Mengistu et al. 2016; Tamrat et al. 2018; Tadesse et al. 2021). Previous studies reported that ALM practices have positive effects on agricultural yields (MacCormick 2019), soil functioning (physical stability, water dynamics, or nutrient recycling) (Webb et al. 2017); soil water retention capacity, and reduce erosion rate (Manns et al. 2016). In addition, it safeguards soil carbon sequestration and food production and improves soil quality (Ran et al. 2018; Tadesse et al. 2021). Nevertheless, the majority of those studies were based on short-term, researcher-managed field experiments. Consequently, drawing a general conclusion on their effects was difficult since several variables affect the effectiveness of ALM practices under natural farm conditions.

In addition, implementations of ALM strategies vary by agro-ecological conditions and type of practices (Haregeweyn and Tsunekawa 2015; Mamush et al. 2021). Thus, the site-specific effects of ALM practices are essential to evaluating the performance of land rehabilitation measures (Land et al. 2017; Tanto and Laekemariam 2019). Although, ALM practices were aggressively implemented in the study area (Alemayehu and Fisseha 2018), to the best of our knowledge, there was no scientific evidence of the effects of these practices on soil quality indicators. Furthermore, although soil boron and sulfur concentrations play critical roles in plant growth and development, including chlorophyll formation, carbohydrate metabolism, yield and crop quality regulation (Brown et al. 2002), and enzyme development (Stewart 2010), much less attention has been given to investigating the effect of ALM practices on their concentrations levels in the soils.

We follow the definition by Schjønning et al. (2004), which states that soil quality is the capacity of soils to function in response to various land management practices and tensions resulting either from natural or human-made factors. Therefore, this study investigated the effects of treatment types and age of ALM interventions on selected physical and chemical soil quality indicators. These include texture, bulk density, pH, soil organic carbon (SOC), soil organic matter (SOM), total nitrogen (TN), available phosphorous (P), sulfur (S), boron (B), cation exchange capacity (CEC), and potassium (K). Obviously, the limitation of our study is that we did not consider the effects of ALM practices on selected biological soil quality indicators.

Materials and methods

Description of study area

The study area, Ojoje sub-watershed, is located in Doyogena district, in the Southern Nations, Nationalities, and People's Regional State (SNNPR), Ethiopia. It is founded between 7°18′ 25″ N and 7° 21′ 49″ N and 37° 45′ 33″ E and 37° 48′ 51″ E (Fig. 1). The watershed covers about 17.9 square kilometres with an elevation ranging from 2354 to 2674 m.a.s.l. It contains six streams: *Shanaya*, *Sana, and Yabela* (permanent), while *Shapa*, *Kashaye*, and *Gondala* (intermittent).

The area was characterized by having one of the most agriculturally productive corners of the country (Lelago et al. 2016). Its topography is widely diversified and has steep, moderate, and gentle slopes. Due to its diversified topography and intensive cultivation, the area is frequently affected by land degradation, mainly soil erosion (Maryo 2020). This in turn leads to a loss of fertile soil, a reduction in crop production, gully formation, and a shortage of fodder (Mariye et al. 2022). During the last three decades, in the study area, various physical and agronomic practices have been implemented to reduce the rate of soil erosion and the depletion of soil nutrients.

Even though sufficient information on soil condition is lacking in the study area, the soils of the catchment are dominated by red and black clay loams (Abonesh et al. 2021). Based on the information obtained from the Hossana branch of national meteorological station, the mean annual rainfall (RF) is 1158 mm, while the maximum and minimum temperatures are 24.6 °C and 15 °C, respectively (Fig. 2). It has a bimodal rainfall distributions pattern. The main rainy season (*Kiremit)* lasts from July to September and the small rainy season (Belg) lasts from

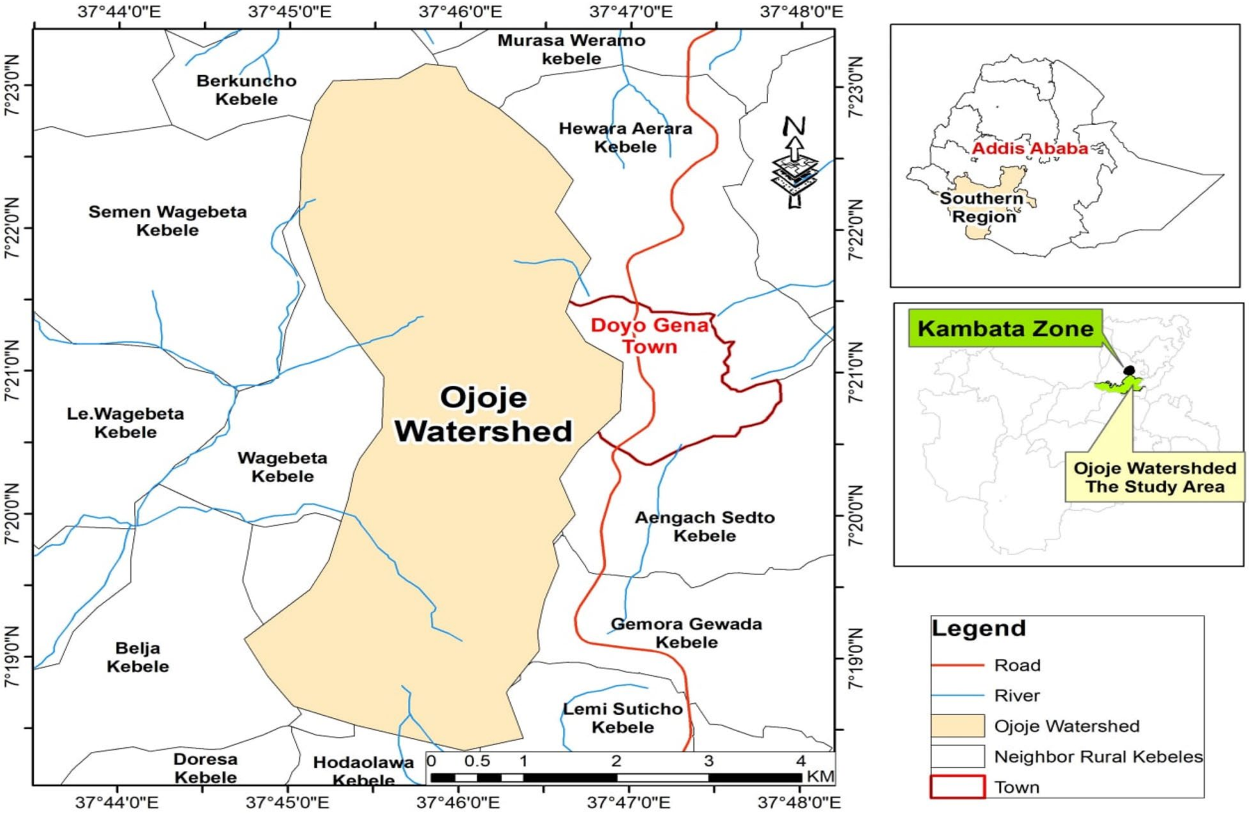

Fig. 1 Map of study area of Ojoje sub-watershed

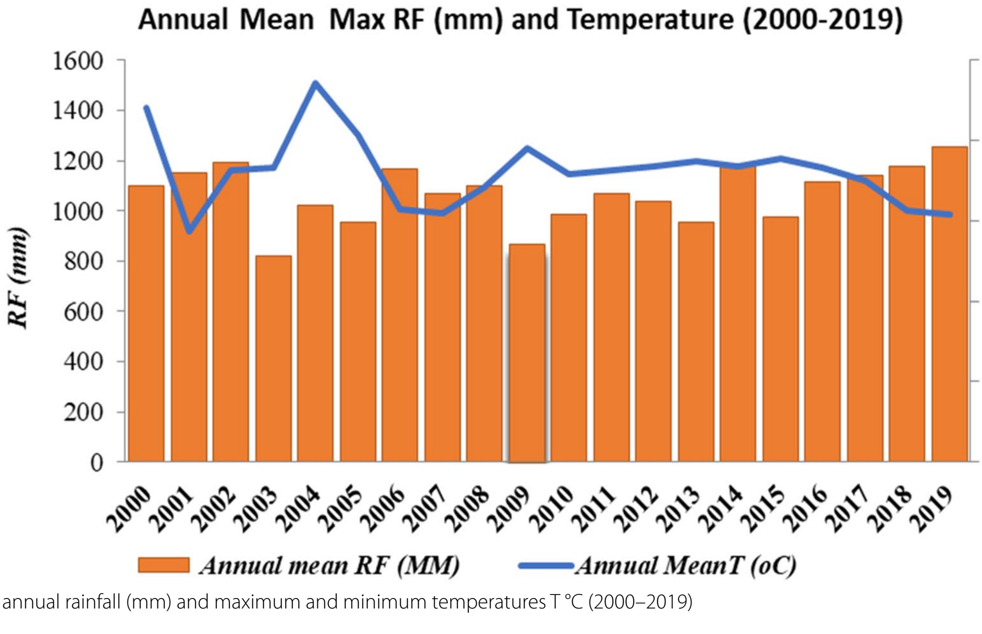

Fig. 2 Mean annual rainfall (mm) and maximum and minimum temperatures T °C (2000–2019)

Fig. 3 Sample site pictures (from right to left): non-treated (NT), land treated with only physical ALM practices for 5 years (ToP5Y), land treated with only physical ALM practices for 10 years (ToP10Y), land treated with integrated ALM measures for 5 years (TIN5Y) and land treated with integrated ALM measures for 10 years (TIN10Y)

March to April. These two seasons contribute more than 80% of the annual rainfall in the study area. The two rainy seasons are interrupted by the dry season (Bega), which lasts from November to February (Fig. 2).

Both remnant and introduced natural vegetation in the area are found in the foothills of mountains and in the surroundings of farms and graves. The dominant tree species are *Cordia africanca*, *Afrocarpus falcatus*, *Croton machrostachys*, *Ficus vasta*, *Ficus sur*, *Vernonia amygdolinica*, *Euphorbia ampliphyla*, *Arundinaria alpina*, *Eucalyptus globules*, *E. camaldulensus*, *Juniperus procera, and Gravilea robusta* (Maryo 2020; DWARO 2021).

The major source of livelihood in the study sub-watershed is subsistence agriculture. Livestock rearing is an integral part of the agricultural system. The primary cereals that grow in the catchment are wheat, barley, pulses, vegetables, teff, beans, potatoes, vegetables, fruits, and Enset (*Ensete ventricosum*).

Based on the Central Statistics Agency's (2013) report, the total population of the study area was 105,265 of which 50.9 percentages were males and 49.1 percentages were females. The sub-watershed has a crude density of 458 people per square kilometer (District Finance and Economic Office report, 2020).

Treatment site selection and soil samples

Treatment selection

We followed Zapata's (2002) suggestions to select soil sample sites based on assumptions of analogous soil types and similar land use histories. Prior to starting fieldwork preliminary assessments were conducted with the help of a topographic map (scale 1:50,000) to identify the boundary and tentative sample site in the study sub-watershed. Similarly, field observation through a transect walk was carried out. Additional information to identify a representative soil sample was collected from the Doyogena woreda agriculture and rural development office, the finance and economic office, development agents (DAs), and experts from the natural resource management sections. First, the exact study sub-watershed boundary was defined. Then, soil sampling sites were identified on farmlands that have identical biophysical conditions but differ with the type and age of ALM interventions.

Accordingly, to evaluate the effects of ALM practices on the selected soil quality indicators, five (5) land sites that were treated with ALM measures were selected based on variations in their treatment type and age. Include: land treated with only physical ALM practices (soil bund and fanya-ju) (Fig 3a and c) and land treated with integrated ALM measures (soil bunds terraced with Pennisetum pedicellatum and elephant grass (Pennisetum purpureum), mulching, zero grazing, agroforestry, manure, intercropping, compost and others), and implemented for 5 and 10 years (Fig 3d and e) were used as treatment groups. On the other hand, adjacent land that was non-treated (NT) (Fig 3a) with ALM practices was identified and selected as a control group.

Soil sampling

Judgmental (purposive) sampling techniques were used to collect representative soil samples from treated and untreated sites with four replications. Samples were collected from an area of 15 m × 10 m through an "X" design of a rectangular plot at a depth of 0–20 cm by using both an auger and a core sampler (undisturbed soil samples) for bulk density measurements, following the 2021 crop harvest season from January to March. A total of 72 soil samples were collected from which, 24 samples were collected from farmlands that were treated with only physical ALM practices for 5 and 10 years. Similarly, other 24 samples were collected from land treated with integrated measures for 5 years and 10 years. The remaining 24 were collected from non-treated (NT) plots in an adjacent area. The collected soil samples were weighted, labelled, and stored to make a composite soil sample of 1 kg, which was packed in a plastic bag for laboratory analysis.

Preparation, laboratory analysis and its procedure

The collected soil samples were air-dried, mixed, weighed, and sieved to 2 mm mesh size before analysis. The laboratory analysis was conducted by Areka Agricultural Research Center, SNNPR. The soil quality indicators considered for analysis include soil texture, bulk density (BD), soil organic carbon (SOC), soil organic matter (SOM), soil reaction (pH), total nitrogen (TN), available phosphorus (P), sulfur (S), boron (B), cation exchange capacity (CEC), and potassium (K).

Each parameter was analyzed through the following standard procedures: the soil particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos 1951; Rowell, 1994). The soil BD was analyzed using the core sample method by drying the soil at 105 °C (Baruah and Barthakur, 1997).

A soil's pH level was determined potentiometrically with a digital pH meter in a 1:2.5 soil-to-water ratio supernatant suspension (Van Reeuwijk 2002). The concentration of soil OC is determined by using the Walkley and Black technique (Sakar and Haldar 2005). Soil organic matter is calculated by multiplying the percentage of organic carbon in the soil by 1.724 (Sakar and Haldar 2005)).

$$\text{Soil organic matter}(\%) = 1.724 \times \text{Organic carbon}(\%). \quad (1)$$

Soil CEC was analyzed using a neutral ammonium acetate extraction technique (Houba et al. 1989). Total nitrogen (TN) was determined through Kjeldahl distillation and digitation techniques (Sakar and Haldar 2005)). The available phosphorus level was determined by the Olsen extraction method (Van Reeuwijk 2002). The soil boron (B) and sulfur (S) were determined by using a hot water extraction colorimetric method in ppm and flame AAS at a wave length of 520 nm. Lastly, soil potassium level (K) was determined by using Morgan solution extraction techniques (Morgan 1941).

Statistical analysis

The data were analyzed using both descriptive and inferential statistical techniques to quantify the effects of independent variables (time since intervention and ALM treatment type) on dependent variables (soil quality indicators). One-way analysis of variance (ANOVA) was carried out to assess significant variation between non-treated and treated farmlands and among treatment types and age of intervention of ALM practices on soil quality indicators.

A Pearson's correlation coefficient (r) was performed to quantify and analyze the degree of interaction between selected soil quality indicators. Simple regression analysis was used to explain the effect of the duration of intervention years (time since intervention) and ALM practices on the selected soil quality indicators. All statistical analysis was performed using the Statistical Package for Social Scientists (SPSS) version 26 (George et al. 2019).

Results and discussion

Effects of ALM practice on selected soil physical quality indicators

Soil texture

The soil textural analysis indicated that the lowest (41.8%) and highest (44.7%) mean values in clay percentage were reported in the non-treated (NT) and land treated with integrated ALM practices for 10 years (TIN10Y) sites, respectively. The ANOVA result also showed a non-significant difference in clay content reported between treated and non-treated plots ($p < 0.05$) (Table 1). Thus, the highest clay fraction in land TIN10Y sites is an indication of soil organic matter (SOM) accumulation (Haileslassie et al. 2009), as well as a reduction in the rate of soil erosion as via of practice of ALM measures (Hailu and Mamo 2015; Hishe et al. 2017).

On the other hand, the distribution of sand fraction was highest in NT sites (25.04%) while the lowest sand fraction (21.9%) was in TIN10Y (Table 1). Result revealed that a statistically significant variation in sand fraction reported among treated and non-treated land sites in the catchment (Table 1). On the other hand, a non-significant difference in silt content was reported among treated and non-treated sites (Table 1). Thus, variation in the intervention year and treatment type of ALM practices can contribute to around 53.5%, 21.4% and 24.2% of the variation in soil clay, sand, and silt percentage, respectively (Table 2). Generally, the share of the soil texture and its class was clay and fine-textured in both treated and non-treated lands. It was dominated by clay fractions.

Bulk density (BD)

Soil bulk density (BD) is a key indicators of soil quality that influences levels of the soil porosity, the rate of aeration, the capacity of soil to hold water, and related aspects of the soil (FAO 2013). Findings of the study indicated that the soil BD was higher in the non-treated farmland than its treated equivalent (Table 1), but the difference was insignificant.

Subsequently, the results of the multiple mean comparisons test indicated that there was a non-significant but noticeable difference in the mean value of soil BD between the non-treated and treated plots ($p<0.05$) (Table 6). Based on the report of the coefficient of determination, differences in the types and duration of ALM practices were responsible for 90.1% of the variation in soil BD (Table 2).

Significantly higher soil BD in NT farmlands could be due to the removal of SOM (by runoff) (Abinet 2011), unprotected grazing (leading to soil compaction) (Tamrat et al. 2018), and high soil erosion and runoff (Descheemaeker et al. 2005). This suggests the soil of NT sample sites was characterized by poor in its structure (aggregation), which ultimately affects soil water retention capacity and results in soil fertility degradation.

Similar findings were reported by Tanto and Laekemariam (2019), who reported that non-treated plots had higher mean values of the soil BD than adjacent land that was treated with physical and biological measures for 2 and 5 years of interventions. Sinore et al. (2018) also found significantly lower BD in plots that was treated with Sesbania, *elephant grass*, and soil bunds for 2 and 5 years, as compared to plots treated only with soil bunds and non-treated plots.

Effect of ALM practices on selected soil chemical quality indicators

Soil reaction (pH)

Soil pH is one of the parameters that determine nutrient solubility, soil microbial activity, plant nutrient availability, and some other soil ecosystem functions (Yadav et al. 2016; Yirgu and Belayneh 2019). Based on Osman's (2013) critical rating of soil pH levels, the soil pH level of the study sub-watershed was found to be moderately and slightly acidic soils for non-treated and treated land, respectively. These could be related to a reduction in soil organic matter, the presence of leaching, the use of excess amounts of inorganic fertilizer, and the loss of essential nutrients (Selassie et al. 2015; Tanto and Laekemariam 2019).

For non-treated and treated land, the average soil pH level was found between 5.31 and 6.60. Here, the differences were significant with respect to treatments type and age of practices ($p<0.05$) (Table 3). As indicated in Table 2, the coefficient of determination (R^2) result revealed that differences in age and treatment type of ALM practices account for 65.7% of the variation in soil pH. Furthermore, the post hoc test result also revealed that a statistically significant difference was reported for soil pH in the NT site as compared with rest of sample sites (Table 5).

Thus, our findings show that treatment types and duration of intervention years of ALM practices exert strong effects on soil pH level. The effect is more evident in sites where treatment spanned a decade, coupled with integrated conservation measures for 10 years. Previous research findings have affirmed the strong effects of long periods of integrated conservation measures on soil pH (Haweni 2015; Neilson et al. 2017; Solomon et al. 2017; Tanto and Laekemariam 2019).

Soil organ carbon (SOC)

The finding showed that significant variation was observed in soil organic carbon (SOC). Its mean value ranges from 2.05% for non-treated (NT) land to 3.32% for land treated with integrated ALM practices for ten years (ToP10Y) sites (Table 3). Furthermore, differences in the types and duration of ALM practices account for 76.6% of the variation in SOC levels (Table 2).

Following to Landon's (2013) ratings of SOC status, the level of SOC in the study area was found to be at a medium (2–10%) level for NT and treated farm lands.

Hence, the result reveals that in the study sub-watershed, ALM practices significantly influenced the SOC content. Its significant impact on SOC was reported on sites that were treated with integrated ALM practices for ten years compared to other sample sites. This could be associated with low soil erosion rates, the existence of agroforestry practices (better for carbon sequestration and enhancing soil fertility), a high biomass return due to biological measures, and a decreasing loss of soil OM (Adugna and Abegaz 2016; Tanto and Laekemariam 2019). Generally, it was shown that ALM practices have a significant effect on the soil OC of farmland when it conserved for longer years and integrated with biological measures.

Table 1 The mean values of sand, silt, clay, and bulk density under ALM treatments and the non-treatment lands

Parameters	Sand (%)	Silt (%)	Clay (%)	Textural class	BD(g/cm^3)
NT	25.04	33	41.8	Clay loam	1.22
ToP5Y	23.77	32.9	42.9	Clay loam	1.13
ToP10Y	21.94	33.9	43.3	Clay loam	1.09
TIN5Y	23.34	33.7	44.1	Clay loam	1.06
TIN10Y	21.91	33.3	44.7	Clay loam	0.97
F	9.38	0.92	7.57		5.61
p	0.000	0.459	0.000		0.065

NT non-treated land, *ToIP5Y* treated with only physical practices for 5 years, *ToIP10Y* treated with only physical practices for 10 years, *TIN10Y* treated with integrate measures for 5 years, *TIN10Y* treated with integrate measures for 10 years

Table 2 Estimation of regression coefficients, p values, F ratios, R, and R^2 change in the study area for selected soil quality indicators

Soil parameter	Coefficient	p	F	(R)	(R^2)
Sand	0.643	0.021*	3.39	0.463	0.214
Silt	1.824	0.031*	4.03	0.492	0.242
Clay (%)	0.768	0.000**	4.79	0.731	0.535
BD	-0.048	0.329	28.32	0.951	0.904
pH H2O (1:2.5)	0.092	0.000**	5.74	0.810	0.657
SOC (%)	0.221	0.001**	9.83	0.875	0.766
SOM (%)	0.119	0.003*	10.54	0.882	0.778
TN (%)	0.011	0.005*	1.49	0.575	0.331
Av. P (ppm)	1.303	0.139*	3.99	0.756	0.571
S (ppm)	1.726	0.021*	4.13	0.523	0.274
B (ppm)	0.151	0.023*	6.57	0.828	0.686
CEC (meq/100gm)	2.656	0.002*	6.7	0.831	0.691
K (ppm)	9.435	0.344	13.67	0.906	0.820

R^2 coefficient of determination

**Significance at $p < 0.01$

*Significant at $p < 0.05$

Our findings were in agreement with those Ademe et al. (2017) and Mamush et al. (2021), who reported high SOC in areas treated with elephant grass and soil bund compared to those only treated with soil bund for 2 and 5 years of intervention and non-treated farmlands. Other scholars, such as Million (2003), Solomon et al. (2017), and Tanto and Laekemariam (2019), reported greater soil OC on land treated with fanyajuu for 5 and 10 years compared to non-treated land.

Soil organ matter (SOM)

The significantly higher (5.71%) SOM occurred in a plot treated with integrated ALM practices for 10 years site, while its lowest (3.53%) was found in the non-treated land (Table 3). The difference was statistically significant ($p < 0.01$). Furthermore, the results of the study indicated that 78% of variations in the soil OM level are explained by differences in the type and duration of ALM practices (Table 2).

The multiple mean compression test indicated that a statistically significant variations were reported in the mean value of SOM between the treated and non-treated land sites ($p < 0.05$) (Table 6). Following Landon (2013) and Ethiosis (2014), the soil OM content of the study area is categorized as low (2.0–3.7) for NT land and moderate (3.7–7.0) for land TIN10Y sites. The deficiency in soil OM content in the NT land site could be related to land degradation, the removal of crop residues, and soil erosion, which resulted in an insufficient accumulation of biomass (Gebrayes et al. 2014; Siraw et al. 2020).

Therefore, our findings indicate that variations in durations of interventions and treatment types of ALM practices play a critical role in improving SOM quality. The average value of soil SOM content steadily increased with time and levels of integration of conservation measures, especially at 10 years of interventions sites, where the highest organic matter content was observed. Previous studies also reported increased SOM quality due to durations of interventions and integration of physical and biological conservation measures (Lelago et al. 2016; Belayneh et al. 2021) (Table 4).

Total nitrogen (TN)

The mean value of total nitrogen and its highest (0.29%) and lowest (0.18%) values were found from plots at TIN10Y and NT sites, respectively (Table 3). The variation in the mean value of TN between treated and non-treated land was significant ($p < 0.001$) (Table 3). By using the critical rating systems of Landon (2013) and Ethiosis (2014) for the TN content, the soil of the study sub-watershed is rated as low for the NT sites and moderate for the TIN10Y land site. The one-way ANOVA result also indicated that soil TN showed a significant difference between sites treated with integrated ALM practices for 5 and 10 years ($F = 7.26$, $p = 0.001$) (Table 5). Similarly, the post hoc Turkey test result revealed that a statistically significant difference was reported between NT and TIN5Y land as well as NT and TIN10Y sites ($p < 0.05$).

Thus, the findings indicated that the study sub-watershed faces a deficiency in soil TN except for land TIN10Y intervention. The deficiency in the soil TN level in the study area was likely due to a shortage of quality SOM, the absence of land management practices (Woolf et al.

Table 3 Mean value of selected soil chemical quality indictors in relation to the type of intervention and age of ALM practices

Parameters	NT		ToP5Y		ToP10Y		TIN5Y		TIN10Y		F	p
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**		
pH-H20 (1:2.5)	5.31	0.45	5.86	0.92	6.44	0.45	6.32	0.46	6.6	0.33	16.9	0.000
SOC (%)	2.05	0.52	2.87	1.18	2.91	1.74	3.2	0.71	3.32	0.73	7.78	0.000
SOM (%)	3.52	0.89	4.93	1.29	5.01	1.22	5.5	1.27	5.71	1.26	10.3	0.000
TN (%)	0.18	0.07	0.24	0.07	0.22	0.06	0.26	0.07	0.29	0.05	5.13	0.001
Av. P (ppm)	11.12	3.95	16.11	18.5	19.06	6.13	22.68	15.5	24.92	5.94	4.45	0.003
S (ppm)	15.7	0.35	21.6	0.18	19.6	0.26	26	0.34	29.9	0.27	3.33	0.015
B (ppm)	0.42	0.04	0.59	0.08	0.65	0.02	0.76	0.06	0.79	0.02	3.44	0.013
CEC(meq/100gm)	24.85	12.2	33.29	8.56	34.97	10.2	36.79	12.2	37.29	16	3.34	0.012
K (ppm)	232.2	87.34	253.1	29.9	261.9	38.5	267.9	44.3	274.9	46.14	1.34	0.265

NT non-treated land, *ToIP5Y* treated with only physical practices for 5 years, *ToIP10Y* treated with only physical practices for 10 years, *TIN10Y* treated with integrate measures for 5 years, *TIN10Y* treated with integrate measures for 10 years, *ppm* parts per million

Table 4 One way ANOVA test results for selected soil quality indicators

Parameters	Treated only with physical measures for:				Treated with integrated practice for:			
	5 years		**10 years**		**5 years**		**10 years**	
	F	**p**	**F**	**p**	**F**	**p**	**F**	**p**
Sand (%)	3.24	0.081 ns	11.6	0.000**	5.21	0.03*	17.9	0.000**
Silt (%)	0.04	0.841 ns	1.53	0.228 ns	1.02	0.32 ns	0.25	0.621 ns
Clay (%)	5.81	0.021	7.79	0.001*	3.21	0.09	26.2	0.000**
BD	2.79	0.247 ns	2.16	0.142 ns	0.13	0.732 ns	0.86	0.000**
pH H_2O (1:2.5)	6.14	0.018	12.1	0.000**	37.3	0.000**	32.6	0.000**
SOC (%)	8.52	0.006	7.01	0.002*	30.9	0.000**	24.1	0.000**
SOM (%)	7.48	0.01	8.63	0.001*	31.9	0.000**	18.2	0.000**
TN (%)	3.77	0.061 ns	2.13	0.131 ns	21.1	0.000**	17.1	0.000**
Av. P (ppm)	1.64	0.209 ns	2.75	0.075 ns	7.86	0.010*	27.6	0.000**
S (ppm)	2.81	0.103 ns	1.23	0.302 ns	4.32	0.051	4.64	0.042
B (ppm)	2.68	0.111 ns	2.61	0.090 ns	5.44	0.03	5.62	0.021
CEC (meq/100gm)	4.55	0.041	4.38	0.018	4.37	0.048	3.47	0.076 ns
K (ppm)	0.65	0.428 ns	0.92	0.408 ns	0.03	0.862 ns	0.26	0.616 ns

ns non-significant, *ALM* agricultural land management

* Significant at $p \leq 0.05$

** Significant at $p \leq 0.01$

2016), the removal of crop residues for fuel and animal feeds (Yirgu and Belayneh 2019); and a deficiency of nitrogen-containing fertilizers such as ammonium nitrate (NH_4NO_3) and urea (Yadav et al. 2016). Similarly, excessive leaching and insufficient application of green manure were factors for low levels of soil TN (Solomon et al. 2002; Tadele et al. 2011; Mengistu et al. 2016; Yimam 2020).

The finding of the study was in line with the research findings of Selassie et al. (2015), Alemayehu (2017), Sinore et al. (2018), and Yirgu and Belayneh (2019), who stated that treated lands with various physical structures and with integrating biological measures significantly influenced the level of the soil TN. In contrast to this, our finding disagrees with the findings of Hishe et al. (2017), who reported a non-significant variation in plots that were treated with physical structures and integrated biological treatment measures.

Available phosphorus (av. P)

The mean values of soil phosphorus (P) levels at treated and non-treated soil sample sites were significant ($p < 0.05$) (Table 3). The highest (24.92 ppm) and lowest (11.12 ppm) average values of soil P were reported from

Table 5 The effect of ALM practices on selected soil quality indicators between intervention types and treatment age

Properties of soil	Treated with integrated measures for 5 and 10 years		Treated with only with physical measures for 5 and 10 years	
	F	p	F	p
Sand (%)	19.09	0.000**	11.63	0.000**
Silt (%)	0.766	0.47^{ns}	1.53	0.228^{ns}
Clay (%)	14.64	0.000**	7.79	0.001*
BD (gm/cm^3)	2.79	0.247^{ns}	2.16	0.142^{ns}
pH H2O (1:2.5)	26.89	0.000**	12.10	0.000*
SOC (%)	14.03	0.000**	7.01	0.002*
SOM (%)	15.36	0.000**	8.63	0.001*
TN (%)	7.26	0.001*	2.13	0.131^{ns}
Av. P (ppm)	6.23	0.000**	2.74	0.075^{ns}
S (ppm)	4.19	0.019*	1.23	0.302^{ns}
B (ppm)	5.49	0.010*	2.61	0.085^{ns}
CEC (meq/100gm)	6.44	0.000**	4.38	0.018*
K (ppm)	2.42	0.097^{ns}	0.92	0.408^{ns}

ns non-significant

[*] Significant at $p \leq 0.05$

[**] Significant at $p \leq 0.01$

land TIN10Y and NT sites, respectively. Moreover, the findings of the study indicated that 57% of the variations in the available P level are explained by the duration and types of treatments used in ALM practices (Table 2).

The one-way ANOVA result revealed that statistically significant variation in soil P levels reported among treatment groups ($p < 0.01$) (Table 4). Based on Landon's (2013), rating of the soil P, except for NT land site, the average P content in the soil of the study sub-watershed is found to be moderate. The moderate content of available soil P in our study sub-watershed could be due to an extended period (e.g., 10 years) of conservation interventions with physical structures and the integration of physical and biological measures. This is clearly evidenced by the progressive increase in available soil P from 11.12 ppm in NT land to 24.92 ppm on land treated with physical and biological ALM measures for ten years (Table 3).Moreover, it could be explained by various interrelated factors, including farmers' excessive use of P-containing inorganic fertilizers like Di-ammonium Phosphate (DAP) (Stroosnijder et al. 2003), the application of organic manure (Adugna and Abegaz 2016), an improvement in soil organic matter (Tolera 2011), and others. On the other hand, a shortage of available P in NT farmland is related to increased crop residue consumption at home and soil compaction caused by overgrazing practices (Biro et al. 2013).

Table 6 Multiple-comparisons for selected soil quality indicators between treatment type and intervention years using the post hoc Turkey HSD test in the study area

Soil parameters	Treatment (I)	Treatment (J)	Mean difference (I–J)	p value
Sand (%)	NT	ToIP10Y	− 3.125	0.000
	NT	TIN5Y	− 3.096	0.000
Clay (%)	NT	TIN10Y	− 2.346	0.002
	NT	ToIP10Y	− 2.931	0.000
BD (gm./cm3)	NT	ToIP5Y	0.089	0.029
	NT	TIN5Y	0.129	0.000
	NT	ToP10Y	0.161	0.000
	NT	TIN10Y	0.246	0.000
	ToP5Y	TIN10Y	0.157	0.000
	TIN5Y	TIN10Y	0.117	0.009
pH-H2O	NT	ToP5Y	− 0.554	0.038
	NT	TIN5Y	− 1.133	0.000
	NT	ToP5Y	− 1.011	0.000
	NT	TIN10Y	− 1.295	0.000
	ToIP5Y	TIN10Y	− 0.741	0.011
	NT	ToP5Y	− 0.82	0.027
	NT	TIN5Y	− 1.27	0.000
SOC (%)	NT	ToP10Y	− 0.86	0.019
	NT	TIN10Y	− 1.12	0.001
	NT	TIN5Y	− 0.13	0.001
SOM	NT	ToP10Y	− 1.473	0.004
	NT	TIN5Y	− 1.899	0.000
	NT	TIN10Y	− 2.175	0.000
TN (%)	NT	TIN10Y	− 0.07	0.026
P (ppm)	NT	TIN5Y	− 13.79	0.004
	NT	TIN10Y	− 11.55	0.025
S (ppm)	NT	TIN5Y	− 9.43	0.003
	NT	TIN10Y	− 14.18	0.012
B (ppm)	NT	TIN5Y	− 0.342	0.044
	NT	TIN10Y	− 0.377	0.021
CEC(meq/100gm)	NT	TIN10Y	12.445	0.039

NT non-treated land, *ToIP5Y* treated with only physical practices for 5 years, *ToIP10Y* treated with only physical practices for 10 years, *TIN10Y* treated with integrate measures for 5 years, *TIN10Y* treated with integrate measures for 10 years, *ppm* parts per million

Thus, the study result was consistent with the findings of Tolera (2011), Hishe et al. (2017), and Yirgu and Belayneh (2019), who confirmed that the level of soil P was highly affected by the years of intervention (2 and 5) and the integration of both physical and biological measures in a single plot. Our findings contrast to those of Selassie et al. (2015) and Mengistu et al. (2016), who observed advanced but non-significant soil phosphorous status in the treated soil. Similarly, it contradicts the findings of Tekalign et al. (2002) and Abebe et al. (2012), who indicated a scarce availability of phosphorus content in most Ethiopian highlands.

Available sulfur (S)

Findings indicated that significant differences were reported in soil the available sulfur between treated and non-treated sites ($p < 0.05$) (Table 3). According to Ethiosis's (2014) critical rating of the level of the available soil S, the soil content of the study area (S) was rated low for NT plots, while for the rest of the soil sample sites, its rating was classified under the moderate classes. The low level of the available soil sulfur in the NT plot was associated with a high rate of soil erosion (land degradation), the removal of crop residues, a deficiency of SOM (Bezabilu et al. 2016), the use of only N and P-containing fertilizers (a deficiency of S-containing fertilizers) and poor land management practices (Motuma and Chimdi 2018), and a lack of effective ALM practice (White et al. 2020).

The results of the multiple mean comparison test revealed that the NT land site has statistically significant variation ($p < 0.05$) when compared to the land TIN5Y and TIN10Y sites. The mean value of the soil S of land TIN10Y (14.18) and TIN5Y (9.43) was higher than that of adjacent NT land. Thus, ALM practices in the study area have shown significant implications for improving soil sulfur levels.

Thus, the results of this study were in line with the findings of Hilette et al. (2015) and Lelago et al. (2016), who reported low amounts of available soil sulfur content in the majority of the Ethiopian watershed.

Boron (B)

The average soil boron level in the research sub-watershed area ranges from 0.42 ppm in NT land sites to 0.79 ppm in land that has experienced integrated ALM measures for ten years (TIN10Y). The one-way ANOVA result, furthermore, indicated a significant difference between NT and TIN5Y ($F = 5.44$), and NT and TIN10Y ($F = 5.62$) ($p < 0.05$.Additionally, there is a statistically significant difference between the sites that used integrated measures and differed solely in the duration of the intervention (Table 5).

The multiple mean comparisons test for soil B content among treatments and duration of intervention in ALM practices indicated that NT sites and land treated with integrated measures for five and ten years showed a significant difference ($p < 0.05$) (Table 6). Based on Landon (1984) and Ethiosis (2014), the classification of soil B in the study sub-watershed is very low for the NT sites, low for treated ToP5Y, and the remaining sites are grouped under "moderate quality".

Therefore, the result implies that soil B level varied not only within the year of intervention but also with treatment types; thus, the mean value of soil B increased with the duration of the intervention and the integration of physical and biological conservation measures. Similar findings have also been reported by Tadesse et al. (2021) in the Tula watershed in south central Ethiopia, where the mean value of soil B increases with an increase in duration of intervention and types of treatment.

Cation exchange capacity (CEC)

The type and duration of the intervention of ALM practices on soil CEC were significant ($p < 0.05$). Accordingly, higher soil CEC was reported in soils under the plots that were TIN10Y as compared to the rest of soil sample sites (Table 3). Similarly, variation in age and treatment type of ALM practices account for 69.1% of the variation in soil CEC (Table 2). This could be due to the effect of a longer period of ALM practices that reduced the removal of sediments and the rate of leaching, leading to a certain degree of improved soil CEC content in the soil TIN10Y.

The ANOVA results also revealed statistically significant variations between ToP5Y and NT ($p = 0.041$), ToP10Y and NT ($p = 0.018$), and TIN5Y and NT ($p = 0.048$) (Table 4). Similarly, the post-hoc turkey test for CEC level shows that a significant mean difference was reported between NT sites and TIN10Y sites. Longer age of interventions coupled with integrated soil and water conservation measures resulted in enhanced capacity of the soils to hold higher CEC (Sinore et al. 2018; Tanto and Laekemariam 2019; Belayneh et al. 2021).

Available potassium (K)

The soil K level in the treated sites with integrated ALM practices for 10 years (267.9 ppm) was higher than that of its non-treated equivalent (232.2 ppm). However, the difference in the mean value among ALM practices was non-significant ($p < 0.05$) (Table 4). In addition, the study's findings showed that changes in the age and treatment type of ALM practices account for roughly 82% of variability in the content of available K (Table 2).

Even though there were no significant differences among treatment types and age of interventions, the soil available K contents were slightly higher for sites treated with integrated measures for a longer duration (10 years) than non-treated sites. According to Landon (2014), the soil available in K is rated as moderate. In general, in most cases, in the study sub-watershed, the content of potassium was sufficient (Table 6).

Interrelationship among selected soil quality indicators

Simple correlation analysis provides information on the strength and direction or magnitude of the linear relationship between two variables (Kwak and Kim 2017;

Table 7 Pearson coefficient of correlation among selected soil quality indictors

Parameters	Clay	BD	PH	SOC	SOM	TN	P	S	B	CEC	K
Clay	1										
BD	− 0.51	1									
PH	0.41	− 0.67	1								
SOC	0.36	− 0.77**	0.78**	1							
SOM	0.38	− 0.71*	0.75**	078**	1						
TN	0.31	− 0.57	0.73*	0.79*	0.77**	1					
P	0.33	− 0.61	0.45	0.46	0.75**	0.73*	1				
S	0.05	− 0.65	0.67	0.65	0.64	0.78**	0.73*	1			
B	0.41	− 0.75**	0.76**	0.77**	0.69*	0.62	0.69*	0.68	1		
CEC	0.39	− 0.76**	0.78**	0.76**	0.76**	0.79*	0.73*	0.52	0.79**	1	
K	0.40	− 0.78**	0.74**	0.72*	0.78**	0.65	0.71*	0.65	0.76**	0.78**	1

*Significant at $p < 0.05$

**Significant at $p < 0.01$

Schober et al. 2018). In this context, it was utilized to show how the parameters of selected soil quality indicators in the study watershed interrelated with each other.

With the exception of bulk density ($r = -0.51$), the clay content had a positive and significant correlation with a variety of soil quality indicators (Table 7). The correlation analysis revealed that soil bulk density was strongly and negatively significant ($p < 0.05$) with SOC (-0.77^{**}), B ($r = 0.75^{**}$), CEC ($r = -0.76^{**}$), and K ($r = -0.78^{**}$) (Table 7). This could be due to the availability of SOM and clay, although there was a relatively low sand fraction in the soil of the study sub-watershed (Belayneh et al. 2019).

On the other hand, available soil phosphorus has a positive and significant correlation with pH ($r = 0.75^{**}$), B ($r = 0.69^{*}$), CEC ($r = 0.76^{**}$), and K ($r = 0.78^{**}$) (Table 7). The study's findings supported the notion that soil with a pH between 6.0 and 6.5 had a higher concentration of available P (Mamush et al. 2021).

Similar findings were found in the studies conducted by Bezabilu et al. (2016), Mengistu et al. (2016), Hishe et al. (2017), and Alemayhu (2017), which showed a strong relationship between SOM and soil pH, TN, CEC, P, B, and K content. In the Ojoje sub-watershed, the majority of soil quality indicators increase concurrently as one indicator's value rises, and vice versa. The study results also supports the findings of Haregeweyn and Tsunekawa (2015) and Hishe et al. (2017), who confirmed that available SOM, CEC, and clay content directly or indirectly influence most soil parameters such as TN and soil BD.

Conclusion

The agricultural land management practices have significant impacts on the improvement of the soil quality indicators in the soil of farmlands. This has been a crucial means to restore the degraded land, and it is a tool for safeguarding the environmental system. This study investigated the effect of ALM practices on the selected soil quality indicators in the Ojoje sub-watershed, southern Ethiopian highlands. The findings of the study indicated that the textural class of soil in the study sub-watershed was clay loamy. The dominant fraction in the particle size distribution was clay. Likewise, most soil quality indicators, such as the percentage of sand and clay, SOC, SOM, TN, P, S, and B, and the percentage of CEC, were significant ($p < 0.01$ and $p < 0.05$) as a result of ALM practices. However, soil BD, K, and percentage of silt contents were higher, but the difference was insignificant.

Thus, applying ALM practices for a longer period (i.e., 10 years) has a strong positive effect on soil quality indicators. Nevertheless, ALM practice suffers from a lack of regular maintenance and the limited use of integrated measures as a complement to physical structures, which are undermining the success of ALM practices in most parts of the study watershed. Therefore, physical ALM measures should be regularly maintenance and integrated with biological conservation measures to enhance soil quality.

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Author contributions

AA conceived the idea, collected data, performed statistical analysis, and led manuscript writing. DW contributed to the development of idea and was involved in manuscript reductions. Both authors critically read and approved the final manuscript.

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Availability of data and materials

Here, as authors we declare that the data and materials presented in this manuscript can be made available from the corresponding author upon request.

Declarations

Ethics approval and consent to participate

Not applicable to this manuscript.

Consent for publication

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Competing interests

The authors declare that they have no competing interests.

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