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Effects of Natural Rehabilitation of Degraded Land by Exclosure on Selected Soil Physicochemical Properties in Eastern Ethiopia

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Abstract: The use of exclosure for ecological restoration has become an increasingly vital approach to reversing degraded lands. Its effectiveness in restoring degraded lands could be varied with differences in climate, vegetation type and soil properties. Thus, the objective of this study was to determine the effect of exclosure on the selected physical and chemical properties of the soil. A six-year-old exclosure and adjacent open land with the same history of land-use types were selected. Soil samples were randomly collected from 0–20 and 20–40 cm depths of each land-use type and measured for texture, soil moisture content (SMC), bulk density (BD), soil organic carbon (SOC), available phosphorus (Av.P), cation exchange capacity (CEC), electrical conductivity (EC) and pH contents. The highest SMC, SOC and Av.P and the lowest BD values were measured from the exclosure. SMC, SOC and Av.P increased by 73, 51 and 55%, respectively, while BD decreased by 31% as compared to the open land. CEC, EC and pH were also influenced positively compared with the adjacent open land. The funding indicates exclosure had a positive effect on the restoration of soil nutrients, which are essential to promote vegetation growth and thereby minimize soil erosion.

Keywords: passive restoration; open land; soil degradation; soil organic carbon; soil moisture content; available phosphorus

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1. Introduction

In Ethiopia, rapidly increasing human populations, increased deforestation, overgrazing and extensive cultivation combined with limited soil and water conservation led to land degradation processes such as fertility reduction, aggravated soil erosion by water and sedimentation on lakes [1,2]. In recent years, interest in the rehabilitation of degraded lands and the adoption of suitable land management practices has grown [3]. The commonly adopted soil and water conservation activities are building stone bunds, gully reclamation using check dams, exclosure and planting trees [4,5]. Natural rehabilitation through exclosure is one of the most implemented methods used for the rehabilitation of highly degraded grasslands and woodlands in northern Ethiopia, Central Rift Valley and eastern Ethiopia [6–8].

Exclosure is a rehabilitation technique, in which lands are closed from the interference of humans and livestock [5]. These activity goals are to promote natural regeneration, conserve genetic diversity and economically productive vegetation and improve soil physicochemical properties [5,9]. It is also a form of land management mechanism established on degraded, generally open access areas, for environmental rehabilitation of degraded lands and the improvement of soil properties [10]. So, it increases the amount of water that enters the soil and decreases the moisture loss through runoff and evaporation, thereby improving the soil physicochemical properties of a given area. Exclosures are mostly implemented in mountain slopes and degraded lands that are intensively affected by overgrazing and other land-use purposes [6].

Different studies revealed that exclosure plays important roles in species richness [6,11], soil nutrient supply [5,9,12], increasing soil organic carbon [7,13] and moisture availability [14] compared to communal grazing lands. It improved soil physicochemical properties and the overall health of the ecosystem by promoting vegetation coverage, which enhanced the amount of accumulated SOM. Soil organic matter is an essential soil component that helps to modify the physical conditions of the soil, improves the water-holding capacity of the soil, reduces soil erosion, provides available nutrients for plants and augments soil cation exchange capacity [15]. Exclosure also improves the structure and moisture content of soil and the diversity and activities of soil organisms [16].

However, different studies indicate contradicting findings on the effect of exclosure at the early stage. For example, the finding of [17] observed significantly lower soil nutrient content in exclosures with ages of 1 to 7 compared with communal grazing land, and Wu et al. [18] observed a reduction in SOM and TN contents under six years exclosure of grazing land in comparison to open grazing lands. Gebregergs et al. [13] revealed a positive effect of five years exclosure on EC, Na, CEC, Ca, OC, Ex.K and TN compared to open grazing lands. The finding of Umer and Sinore [19] revealed that the six-year-old exclosure had significantly higher levels for OM, CEC, TN and pH compared to free grazing land. Similarly, Özcan et al. [20] concluded six years of exclosure is effective in improving most of the topsoil properties. This difference in restoring degraded lands could be varied with differences in climate, vegetation type and soil properties [21,22]. Therefore, soil-, climate- and vegetation-specific assessment is very important to investigate the age effect of area closure on soil physicochemical properties. However, the study on the effects of exclosure on the evolution of selected soil properties in the eastern part of Ethiopia is very limited.

The Lake Haramaya watershed area in Eastern Hararghe Zone of Oromia Region, specifically the Tinike sub-watershed is one of the degraded parts of the watershed due to anthropogenic pressures such as overgrazing of communal land and cultivation of marginal lands [23,24]. To alleviate the problem, local communities established an exclosure as a vital strategy to rehabilitate degraded lands in the watershed. However, the effects of exclosure on the development of soil properties are not investigated. Such information has a tremendous contribution in evaluating the impacts of natural restoration practices in improving soil properties of degraded lands and observing the effect of exclosure at an early stage under different climates. Therefore, this study aimed to assay the effects of exclosure on selected soil physical (texture, bulk density and soil moisture content) and chemical (EC, CEC, pH, Av.P and soil organic carbon) properties compared to adjacent open land.

2. Materials and Methods

2.1. Site Description of the Study Area

The study was conducted in Tinike sub-watershed, Haramaya district, East Hararghe zone, Oromia Regional State (Figure 1). The watershed lies between 9°22′03″–9°27′12″ north latitude and 41°58′14″–42°05′26″ east longitude, at an altitude range of 2010–2433 m above sea level. About 71% of the watershed is characterized by undulating and rolling topography [25]. The slope, landform and the configuration of the hills and peaks surrounding the Watershed have created a drainage network that takes the surface flow towards Lake Tinike from different directions. The mean annual rainfall is 801 mm and the daily temperature ranges from about 10 to 25 °C and the annual mean temperature is 17 °C (Haramaya meteorological station).

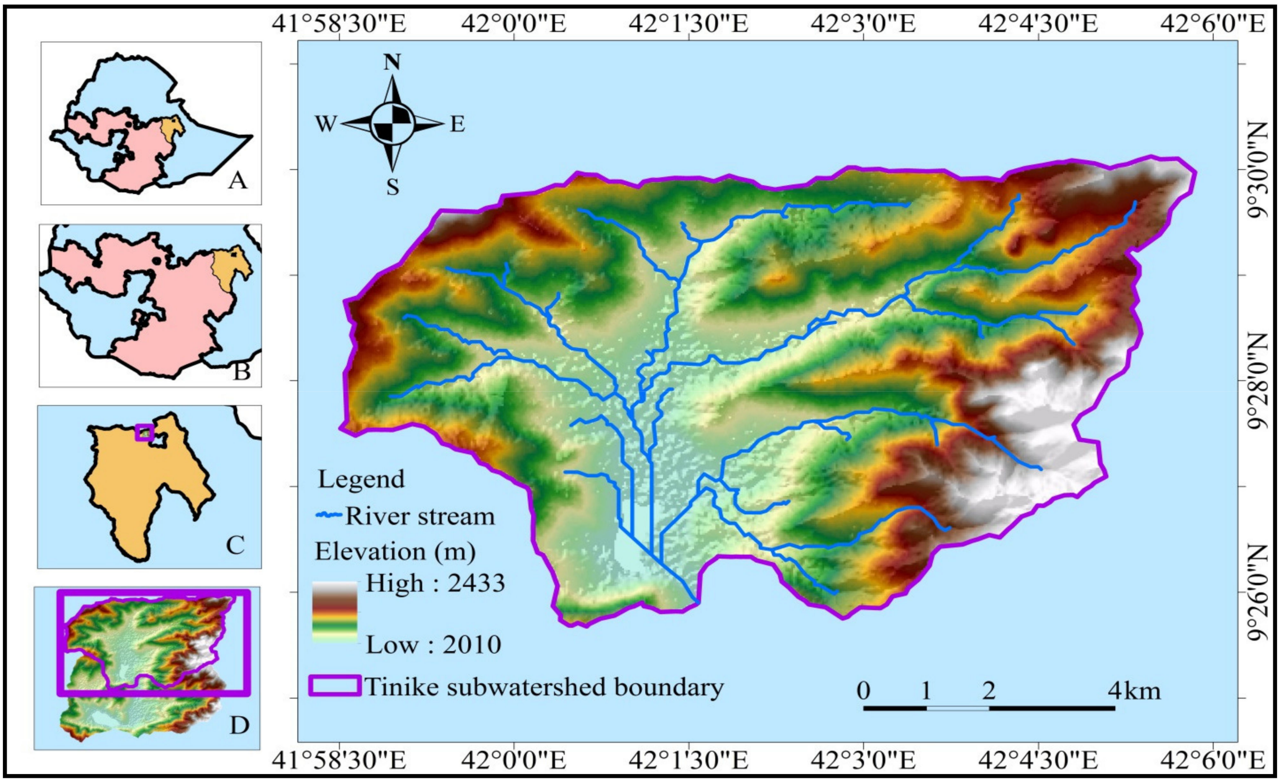

Figure 1. Map of a watershed using satellite image: (**A**) Ethiopia, (**B**) Oromia Region, (**C**) East Hararghe Zone and (**D**) Lake Haramaya Watershed.

The largest portion of the arable land soils is shallow, and most soils of the steeper slopes are unproductive. According to WBR, leptosols, regosols, cambisols, fluvisols and vertisols are the common soil types in the watershed [25]. The watershed has poor vegetation cover. Mountains and hills in the watershed have no vegetation cover. Scattered remnants of indigenous tree and shrub species including *Juniprus procera*, *Olea africana*, *Cordia africana* and *Croton macrostachys* were found [24].

The ever-increasing human population coupled with frequent drought and climate change and mismanagement of the natural resources in the watershed have caused severe degradation of its soils, water resources and vegetation cover. The formation of deep and wide gullies is evidence of the severity of the soil erosion in the watershed [23,25]. This severe soil erosion has affected the production of agricultural land and increased the volume of flood and sedimentation in the lakes in the watershed. To tackle this problem, rehabilitation of degraded lands in the watershed by exclosure was established in 2013.

2.2. Soil Sampling and Laboratory Analysis

A reconnaissance survey was conducted to check the presence of adjacent open land that had the same land-use history. The degraded grazing land has been excluded by social fencing, and binding bylaws among the stakeholders have been formulated to restrict the disturbance by humans and livestock. The exclosure has an elevation of 2210–2241 m above sea level and the area is around 16 ha, and it has been excluded from any domestic animals and humans and supported by additional vegetation (such as *Olea africana*, *Hagenia abysinica*, *Cordia africana*, *Croton macrostachys* and *Acacia species*) and structural conservation since 2013. The exclosure had an almost similar condition with open grazing land before its establishment, because the excluded area was part of the degraded grazing land that was used for domestic animal grazing, which means that the part of degraded open grazing land in the past was naturally rehabilitated using exclosure. Hence, it is assumed that the exclosure and the grazing lands were almost homogenous before the establishment of the exclosure. Then, to minimize the variability in soil properties due to elevation difference, three transect lines were laid across the slope at 100 m intervals on each land-use type (exclosure and open land). Three sampling quadrants (20 m × 20 m) were established randomly along each transect line on both land-use types. Five soil samples (four from the corners and one at the center of each quadrant) were collected at two depths (0–20 and 20–40 cm). These samples were thoroughly mixed and about 1 composite soil sample was prepared. A total of 36 composite soil samples were collected (3 transect lines × 2 land-use types × 3 sampling quadrant × 2 soil depths). Undisturbed samples were also taken using a core sampler (5 cm height and diameter) from the respective soil depth of each land-use type for analysis of bulk density and soil moisture content (SMC).

The composite soil samples were properly packed in a plastic bag, labeled and transported to the laboratory. For the laboratory analysis of selected physicochemical properties of soil except for soil moisture content and bulk density, soil samples were air-dried at room temperature and sieved through 2 mm. Soil texture was determined using hydrometric method [26] after destroying organic matter using hydrogen peroxide (H_2O_2) and dispersing the soils with sodium hexametaphosphate ($NaPO_3$). The core method was used to determine soil bulk density, calculated as the mass of oven-dried soil (105 °C) divided by its volume [27].

$$\rho s\left(\frac{\mathbf{g}}{\mathbf{cm}^3}\right) = \frac{\mathbf{Ms}}{\mathbf{Vb}} \quad (1)$$

where $\boldsymbol{\rho s}$ = soil bulk density (g cm^{-3}), **Ms** = mass of soil after oven drying (g), **Vb** = bulk volume of the soil (cm^{-3})

Cuenca [28] method was used to determine the gravimetric soil moisture content (MC, %). Before the soil was oven dried, the initial weights were measured followed by oven drying for 24 h at 105 °C and weighing the oven-dried soil. The following equation was used to estimate gravimetric soil moisture content.

$$\mathbf{MC}\ (\%) = \frac{\mathbf{Wwet} - \mathbf{Wdry}}{\mathbf{Wdry}} \times \mathbf{100} \quad (2)$$

The soil pH was measured potentiometrically with a digital pH meter in the supernatant suspension of 1:2.5, soil:water suspension [29]. Electrical conductivity (EC) was determined by a conductivity meter in saturated soil paste extracts by applying suction [30]. Walkley and Black [31] method was used to determine soil organic carbon (SOC) content. Olsen's extraction [32] method was used for the available phosphorous (Av.P) determination, and cation exchange capacity (CEC) was determined by extraction with 1M NH4OAc at pH 7 [33].

2.3. Statistical Analysis

Differences between mean values of physical and chemical properties from area exclosure and its corresponding open land were tested by a Student's *t*-test for independent variables (at $p < 0.05$). Pearson correlations among the soil physical and chemical properties for the exclosure and open land were also tested (at $p < 0.01$ and 0.05).

3. Results and Discussion

3.1. Effect of Exclosure on Selected Physical Properties of Soil

The results of physical properties revealed that soil particle size distribution (%) of sand, silt and clay was statistically not significant with land-use types and soil depths whereas the bulk density (BD) and soil moisture content (SMC) were different between the two land-use types at two depths (Table 1). The increase in SMC, silt and clay was observed following the exclosure (Figure 2).

Table 1. Soil physical properties of the exclosure and open land.

Variable	Depth (cm)	Land Use	
		Exclosure	Open Land
Sand	0–20	80.33 ^{a} ± 1.04 *	83.50 ^{a} ± 0.67
	20–40	78.00 ^{a} ± 1.13	85.00 ^{a} ± 0.57
Silt	0–20	9.67 ^{a} ± 0.33	8.50 ^{a} ± 0.53
	20–40	8.93 ^{a} ± 0.39	7.30 ^{a} ± 0.66
Clay	0–20	10.00 ^{a} ± 1.36	8.00 ^{a} ± 0.13
	20–40	13.07 ^{a} ± 1.38	7.70 ^{a} ± 0.41
BD (g/cm^3)	0–20	0.99 ^{b} ± 0.06	1.44 ^{a} ± 0.08
	20–40	1.13 ^{b} ± 0.07	1.61 ^{a} ± 0.05
SMC (%)	0–20	7.69 ^{a} ± 0.76	4.76 ^{b} ± 0.16
	20–40	9.39 ^{a} ± 0.81	5.14 ^{b} ± 0.17

* 80.33 ± 1.04 = mean ± standard deviation; BD = bulk density; SMC = soil moisture content; values with different letter (s) between exclosure and open land are significant at $p < 0.05$ by Student's *t*-test with independence variables.

Figure 2. The increase and decrease in soil physical properties due to natural rehabilitation of degraded land by exclosure within overall (0–40 cm) depth. BD refers to bulk density and SMC refers to soil moisture content.

Exclosure of the degraded grazing land affected the selected physicochemical properties of the soil. Soil moisture was higher in exclosure land use than in open land use throughout the upper 40 cm (Table 1). The possible reason for this is mainly the greater accumulation of organic matter due to the litterfall of grasses, trees and shrubs. This agrees with the study of Kevin et al. [34] that higher organic matter increases soil moisture content through improvements in soil structure. According to Qasim et al. [14], exclosures are important to increase soil moisture content under the tree canopy, and they measured significantly higher soil moisture under exclosure than grazing area. The results showed that there was a difference in bulk density at both depths between exclosure and open land (Table 1). A higher value of bulk density was observed under open land. The higher bulk density of soil in open land is attributed to lower soil organic carbon content (Table 2), soil compaction due to trampling of soil by livestock grazing on the land and direct exposure to raindrops which reduces water infiltration capacity, resulting in higher surface runoff and affecting new grass and tree formation in the soil. In agreement with this finding, Fantaw et al. [8] and Tizita [7] showed higher soil bulk density under open pasture than under exclosure for similar reasons.

Table 2. Soil chemical properties of the area closure and open land.

Variable	Depth (cm)	Land Use	
		Area Closure	Open Land
pH	0–20	7.56 [a] ± 0.02 *	7.67 [a] ± 0.02
	20–40	7.62 [a] ± 0.68	7.73 [a] ± 0.73
EC (mS/cm)	0–20	0.088 [a] ± 0.01	0.093 [a] ± 0.00
	20–40	0.062 [a] ± 0.16	0.077 [a] ± 0.96
SOC (%)	0–20	3.24 [a] ± 0.30	1.97 [b] ± 0.05
	20–40	2.56 [a] ± 0.14	1.85 [a] ± 0.37
Av.P (mg/Kg)	0–20	3.22 [a] ± 0.41	2.28 [b] ± 0.44
	20–40	2.30 [a] ± 0.14	1.28 [a] ± 0.72
CEC (cmol+/Kg)	0–20	33.47 [a] ± 1.46	30.10 [a] ± 0.71
	20–40	30.20 [a] ± 1.24	29.30 [a] ± 0.55

* 7.56 ± 0.02 = mean ± standard deviation; SOC = soil organic carbon; Av.P = available phosphorus; CEC = cation exchange capacity; EC = electrical conductivity; values with different letter (s) between exclosure and open land are significant at $p < 0.05$ by Student's *t*-test with independence variables.

Soil particle size fraction (%) of sand, silt and clay did not vary between the two land-use types with increasing soil depth (Table 1). This is because the exclosure and the open land are on the same geological unit. Similarly, the study by Fantaw et al. [8] and Tizita [7] showed that there was no significant difference in soil particle size distribution between exclosure and open pasture. The absence of vegetation cover in open land facilitates the loss of clay fractions through selective erosion and migration down the soil profile, which ultimately increases the proportion of sand and silt fractions in surface soils [35].

3.2. Effect of Exclosure on Selected Chemical Properties of Soil

Soil organic carbon (SOC) and available phosphorus (Av.P) were significantly different in the uppermost soil layer (0–20 cm) between land uses, whereas cation exchange capacity (CEC), electric conductivity (EC) and soil reaction (pH) did not significantly vary across land-use types with increasing soil depths (Table 2, Figure 3).

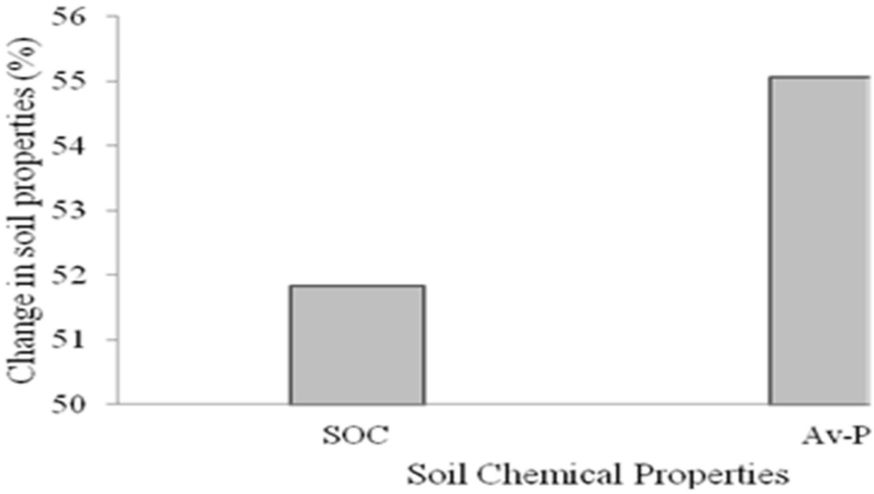

Figure 3. The increase in soil chemical properties due to natural rehabilitation of degraded land by exclosure within overall depth (0–40 cm). SOC refers to soil organic carbon; Av.P refers to available phosphorus.

Soil organic carbon content (SOC) was higher in the set-aside in the topsoil (0–20 cm depth) than in the adjacent open land (Table 2). This is mainly due to the accumulation of organic matter by litterfall from the grasses and trees/shrubs. This was consistent with the findings of Umer and Sinore [19] and Rong et al. [36] who revealed higher SOC under six-year-old and eight-year-old exclosure, respectively. Similarly, Mekuria [12] and Wolde and Edzo [37] reported considerable differences in soil organic matter content between soils of open pasture and exclosure, and, hence, significantly higher ($p < 0.05$) SOM values obtained in soils of exclosure than in open pasture. The study by Fantaw et al. [8] recorded significantly higher SOM contents in soils of exclosure than in open pasture.

The exclosure of the Tinike watershed is dominated by grasses and *Acacia senegal* which produce a higher amount of litter, which has increased the accumulation of organic matter in the soil [24]. By contrast, organic carbon content is lower in the open land compared to the exclosure. This is probably due to the depletion of vegetation by intensive overgrazing and land cover change which limited the accumulation of SOM through litterfall and exposure of topsoil to soil erosion. This is in agreement with the findings of Mikola et al. [38], who reported a reduction in soil organic carbon as a result of lower biomass yield in an open pasture due to very low (lack of) grass cover as a result of intensive grazing.

The value of SOC decreased with increasing soil depth (Table 2). In agreement with this result, Hiederer [39] reported that SOC content decreased with increasing depth in the soil profile. This could be attributed to the presence of lower organic matter accumulation resulting from less root biomass in the subsurface layers. Prior to site abandonment, the site was severely degraded and is currently being rehabilitated primarily with grass and shrubs that have shallow root systems. Similar to SOC, available phosphorus (Av.P) was also higher in the topsoil (0–20 cm depth) of the exclosure than in the adjacent open land (Table 2). The Av.P content also significantly decreased with soil depth under open land-use type (Table 2). This could probably be due to the lower organic matter content in the subsurface layer open land. In agreement with this, correlation analysis showed a strong positive correlation (r = 0.91) of Av.P with SOC (Table 3). This finding supports earlier findings by Worku et al. [40], who stated that the increment in SOC has a great contribution to the increment of Av.P.

Table 3. Pearson correlations among the soil chemical and physical properties of the exclosure and open land.

	pH	SOC	Av.P	EC	CEC	Clay	Silt	Sand	BD	SMC
pH	1									
SOC	−0.96 **	1								
Av.P	−0.97 **	0.91 *	1							
EC	0.11	−0.19	0.13	1						
CEC	−0.89 *	0.93 **	0.91 *	0.08	1					
Clay	−0.70	0.67	0.54	−0.72	0.45	1				
Silt	−0.98 **	0.92 **	0.98 **	−0.03	0.87 *	0.68	1			
Sand	0.84 *	−0.80	−0.71	0.56	−0.61	−0.97 **	−0.83 *	1		
BD	0.91 *	−0.88 *	−0.81	0.43	−0.73	−0.91 *	−0.89 *	0.97 **	1	
SMC	−0.78	0.79	0.61	−0.69	0.58	0.97 **	0.74	−0.98 **	−0.94 **	1

Explanations: * correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.

In contrast, Tizita [7] showed the low Av.P in the exclosure, despite the higher SOM contents of the exclosure, which could be due to the presence of P in its unavailable forms. Relatively, the highest values of cation exchange capacity (CEC) were recorded under the exclosure compared to the degraded area at both sampling depths (Table 2). In agreement with the organic carbon content, the soil CEC values decreased continuously at the shallower depth (Table 2). The lower CEC value on the open land compared to the exclosure could be attributed to the depletion of organic carbon as a result of soil degradation and lack of litterfall. This result is in harmony with the findings of Mekuria [12].

The result also showed that soil reaction (pH) and electrical conductivity (EC) did not vary. However, their values showed a slight difference among land uses and soil depths, where both pH and EC were slightly lower in exclosure than open land (Table 2). This could probably be due to the higher organic matter content in soils under exclosure than open land. This finding is in agreement with the results of Fantaw et al. [8] and Mekuria et al. [5], where exclosure and degraded pastures did not show significant differences in soil pH.

3.3. Relationships among the Soil Chemical and Physical Properties

The soil chemical and physical properties such as SOC and CEC; SOC and silt; Av.P and silt; clay and SMC; and sand and BD significantly ($p < 0.01$) correlated with r = 0.93, r = 0.92, r = 0.98, r = 0.97 and r = 0.97, respectively (Table 3). Similarly, pH and sand; pH and BD; SOC and Av.P; Av.P and CEC; and CEC and silt have also significantly ($p < 0.05$) correlated with r = 0.84, r = 0.91, r = 0.91, r = 0.91 and r = 0.87, respectively (Table 3). However, pH and SOC; pH and Av.P; pH and silt; clay and sand; sand and SMC; and BD and SMC have shown significantly ($p < 0.01$) negative correlation with r = 0.96, r = 0.97, r = 0.98, r= 0.97, r = 0.98 and r = 0.98, respectively. Similarly pH and CEC; SOC and BD; clay and BD; and silt and BD have shown a significant correlation ($p < 0.05$) with r = 0.89, r = 0.91, r = 0.83 and r = 0.89, respectively (Table 3).

The strong relationships of physical and soil chemical properties are indicators of the effects of exclosure on selected soil nutrient conservation in the degraded areas. Most of the improved soil physical and chemical properties in the exclosure were achieved by protecting the area from trampling by animals, implementing structural conservation measures and planting multipurpose tree species. This result implies that despite the young age of the exclosure, the physical and chemical properties of the soil are maintained and improved. Moreover, soil and water conservation practices and planting nitrogen-fixing tree species contribute to increased SOM content. Tadesse et al. [41] also reported the increased soil organic carbon content with the planting of forage tree species and conservation.

In addition, several studies have confirmed that changes in soil physical and chemical properties are strongly related to SOM [42–45]. The results of the correlation analysis (Table 3) are consistent with this conclusion. With the emergence of perennial grasses and woody plants during land development, the interaction between soil and plant roots increased. This trend indicated that improvement in soil physical and chemical properties was related to vegetative restoration.

4. Conclusions

The result of the present study concludes that the establishment of exclosure on the degraded land can improve the selected soil physical and chemical properties. The most affected physical and chemical properties were BD and SMC, and SOC and Av.P, respectively. This study also confirms that it is possible to generate baseline information by taking selected soil physical and chemical properties at the early stage of the exclosure. Such information is critical for evaluating the short duration effectiveness of exclosure rehabilitation of degraded lands and to assist policymakers. It can be concluded that at the age of greater than six years, natural rehabilitation by area closure showed the emergence of perennial grass and woody plants that improved soil fertility. Since the focus of this research was limited to a few soil physical and chemical properties, further studies are needed to evaluate exclosure impacts on the other physical and chemical properties and species diversity for sustainable management of degraded grazing lands.

Author Contributions: A.M.M. and S.F.A. conceived and designed the experiments, performed the experiments and analyzed the data and A.M.M. wrote the paper; S.F.A. and M.P. revised the manuscript. All authors have read and agreed to the published version of the manuscript.

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