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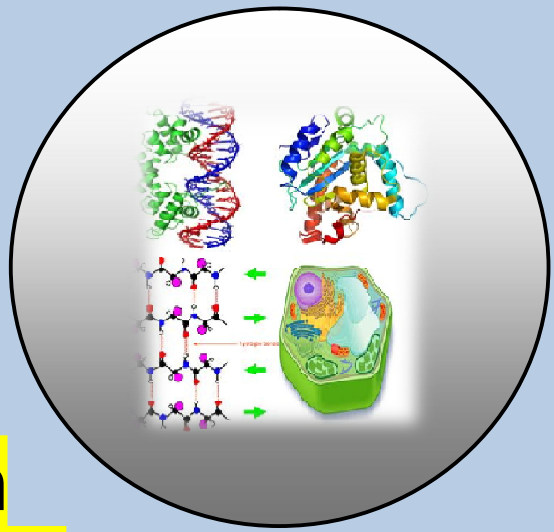
ISSN 0970-4973 (Print)
ISSN 2319-3077 (Online/Electronic)

Index Copernicus International Value
IC Value of Journal 4.21 (Poland, Europe) (2012)
Global Impact factor of Journal: 0.587 (2012)

J. Biol. Chem. Research
Volume 31 (1) 2014 Pages No. 482-494



Journal of Biological and Chemical Research
(An International Journal of Life Sciences and Chemistry)

Indexed, Abstracted and Cited: Index Copernicus International (Europe), Universal Impact Factor, Polish Ministry of Science and Higher Education (Poland, Europe) Research Bible (Japan), Directory of Research Journals Indexing (DRJI), Indian Science.in, Database Electronic Journals Library (Germany), CAS, Open J-Gate, Google Scholar, J Gate e-Journal Portal, Info Base Index, International Impact Factor Services (IIFS) (Singapore) and Eye Source.

Published by Society for Advancement of Sciences®

J. Biol. Chem. Research. Vol. 31, No. 1: 482-494 (2014)
(An International Journal of Life Sciences and Chemistry)

ISSN 0970-4973 (Print)
ISSN 2319-3077 (Online/Electronic)

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RESEARCH PAPER

Received: 03/02/2014 Revised: 10/03/2014 Accepted: 15/03/2014

Area Exclosure as a Strategy to Restore Soil Fertility Status in Degraded Land in Southern Ethiopia

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ABSTRACT

Land degradation is revealed in the form of vegetation and soil fertility degradation. It is becoming a major ecological and agricultural problem in Ethiopia. To overcome the problems of land degradation, area exclosure is used as strategy to restore degraded lands in Southern Ethiopia. The overall objective of this study was to investigate the potential contribution of area exclosure to restore soil fertility status. To achieve the objective, Mitija watershed was selected from Southern Nations Nationalities and Peoples Regional State for the study. Soil samples were collected along transects from area exclosure for eight year and adjacent degraded land with similar landscape positions. Soil samples were collected from transects by systematic sampling plot design technique. The result showed that, Exclosed areas had significantly (P<0.05) different for all soil parameters except for bulk density, EC and pH. The high bulk density, sand, EC, and pH were recorded in the degraded site, whereas the rest of soil properties were high in exclosure. The present study indicated that the mean values of degraded and exclosure site of soil of OC, TN and Av.P were 2.21 and 1.61%, 0.19 and 0.14%, and 7.92 and 5.88 ppm, respectively. Generally, area exclosure has a great contribution to restore soil fertility status in the study area.
Keywords: Area Exclosure, Degraded Land, Land Restoration and Soil Fertility.

INTRODUCTION

Land degradation is one of the serious problems of the developing countries with its multifaceted effects. The decreased productivity of land, gradual decline of soil fertility and vegetation cover are the major consequences of land degradation. According to Blay et al (2004) land degradation is one of the biggest problems in Sub-Saharan Africa threatening the lives of millions of people. Chasek et al (2006) reported that the main consequences of land degradation which negatively affect human livelihoods and the environment as shortages of firewood and other wood, shortages of non-timber forest products, increased sediment deposits, floods and landslides, drying up of springs and water bodies, siltation of dams, increased incidence of water-borne diseases, loss of biodiversity, climate change and desertification.

The dominant cause for land degradation is human interference to the environment, which will lead to the natural loss of productivity of soil and natural vegetation. The major causes of land degradation in Ethiopia are the rapid population pressure, soil erosion, poor farming practices, deforestation, low vegetative cover, overgrazing, use of livestock manure and crop residue for fuel as energy resource of the rural households, salinity and alkalinity problems and unbalanced crop and livestock production (Fistum et al., 1999; Girma, 2001; Bezuayehu et al., 2002). These above causes are rooted in population pressure in a sense that population pressure is the root cause that result in the other mentioned causes like deforestation, severe soil fertility loss, low vegetation cover and so forth. The anthropogenic causes needs urgent attention to avert the situation. As a result, there are restoration efforts taking place in the areas where land degradation is severe problem.

In Ethiopia, there are restoration attempts on degraded lands aimed in abating the effects of poverty. The national government of Ethiopia realized the significance of environmental restoration specifically on deforested and degraded land after the 1973 and 1984/85 major famines struck of the country (Aklilu et al., 2007). Farmers were mobilized by government through "food-for-work" arrangements in building terraces and planting trees on degraded areas. After 1991, the economic policy of the country has been framed in Agriculture Development Led Industrialization (ADLI). The intensified use of land has become now the aggravating factor of land degradation and a turning point to start integrated restoration programmers. The implementation of restoration programme and the results expected out of it begins with identifying the problems of land degradation, the interrelated factors determining the process of restoration and the actors involved in the process. The study area Mitija watershed is located in southern Ethiopia, and is one of the severely affected areas by land degradation, and where practicing the restoration program.

In Ethiopia, where sustainable land management is a priority for the overall development, availability of relevant land management information at all levels is very crucial (Million, 2000). However, there are limited studies in the area dealing how the conversion of free grazing lands and degraded lands into exclosures restoring woody vegetation (Emiru, 2002; Mastewal et al., 2006) and increasing biomass accumulation (Kidane, 2002; Ermias et al., 2006).

Mishra et al (2004) reported that systematic and focused research and developmental activities on restoration of degraded land considering still vital. Due to the diverse agro-ecological, soil and topographic condition of Ethiopia, these studies are not sufficient to conclude about the strength of exclosures to restore degraded land. Besides, the impact of restoration practices on soil fertility replenishment is inadequately known particularly in the area. Therefore, this research was initiated to assess the impact of area exclosure on selected soil physico-chemical properties of Mitija watershed.

MATERIAL AND METHODS

Description of the study area

The study was conducted in Worebitishama Kebele Mitija exclosure at Hurbarag Woreda, Siltie Zone, Southern Nation Nationalities and Peoples National Regional State (SNNPRS). Geographyically the area is located at 7°47'N latitude and 38°08'E longitude. The study site is located 182 km from Addis Ababa, capital city of Ethiopia, and 215 km from Hawassa, the regional city of SNNPRS (Figure 1). The altitude range of the study district is between 1891 and 2040 meters above sea level (m.a.s.l). The mean annual rainfall of the study area is ranges between 900-1200mm. The study area has bimodal rainfall distribution. Accordingly, it has two rainy seasons Belg and Kiremt. Mean annual temperature of the area is 17.7^{0}C and mean minimum and maximum temperature of the area are 10.4^{0}C and 23^{0}C respectively.

The land form belongs to the volcanic lacustrine plains of the rift valley. Ash and pumice tuffs also exist in the floor of the valley. Flat to undulating plain areas are associated with hill fault scarp, which dissect steep and rough land terrain, predominantly covered with exposed rock surface (Seifu, 1999). The land form belongs in the study site is flat to undulating plain. The major soil type is Vertisols which covers about 65% of the study site. Other soil types are Nitosols and Cambisols. The land cover is dominated by scattered trees and shrubs which are found around settlements, in farmlands, and shrubs, trees and grasses in the exclosure areas. The vegetation in the area has been categorized under the Semi-humid woodland with a mixture of broad and narrow leaved species (Aalbaek, 1993). According to data obtained from the Agriculture and Rural Development Office, in the village where exclosure and adjacent degraded sites are about 150 households and highly populated area. The people of the area practice various livelihood and income-generating activities mainly crop production and animal husbandry in addition to petty trading and daily labor. Crop production plays a major role in income generation in the area. Cereals such as teff, wheat, maize, barley and sorghum are the major crops grown. Pulses crops, such as, beans and pea are grown to a lesser extent in the area.

Soil sampling

To determine the effects of area exclosure on soil fertility status, soil samples were collected from area exclosed eight years ago and adjacent degraded lands. A systematic sampling plot design was used to collect soil samples. In both site (exclosure and adjacent degraded) six transect lines were laid at equal distances between them.

On each transect line three sampling plots were laid at equal distances from each point and a total of 18 plots were obtained from each of the exclosure and adjacent degraded land, a total of 36 plots were used for this study. Ten surface soil (0-30cm depth) samples were collected by using auger from each of the plots and mixed to make a composite and representative sample for each plot independently. In addition undisturbed soil samples were taken from each plot by core sampler to determine soil bulk density and soil moisture content.

Samples collected from exclosure and degraded site were separately handled in plastic bags to determine soil texture, pH, electric conductivity (EC), soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Av.P), exchangeable cations (potassium K^+, calcium $Ca^{2+,}$ magnesium Mg^{2+} and sodium Na^+) and cation exchange capacity (CEC).

Laboratory analysis of soil samples

Soil parameters were analyzed at the National Soil Laboratory of Ethiopia, using standard procedures. Physical degradation was assessed using texture, moisture content and bulk density. Soil texture was analyzed using Hydrometer method (Day, 1965) after destroying organic matter by adding hydrogen peroxide (H_2O_2) and dispersing the soil through adding sodium hexametaphosphate $(NaPO_3)_6$. Soil moisture was determined by Gravimetric Method as:

$$Percent\ of\ moisture\,(wt\,\%) = \frac{(A-B)x100}{B-C}$$

Where A=air dry + tin weight, B=weight of oven dry soil in gram + tin weight and C=weight of the empty tin. Bulk density of undisturbed soil sample was determined by core method (FAO, 2007) using core sampler and determining the mass of solids and the water content of the core, by weighing the wet core, drying it to constant weight in an oven at 105°C for 24 hours and calculated as:

$$Bulk\ Density\left(\frac{g}{cm^3}\right) = \frac{W2-W1}{V}$$

Where W2 and W1 are weights of moist and oven dry soils, respectively and V is the volume of the cylindrical core.

Soil pH was measured by using a pH meter in a 1:2.5 soil: water ratios whereas electrical conductivity (EC) was measured in soil to water ratio of 1:2.5 (Von Reeuwijk, 1992). The soil organic carbon was measured by the Walkley-Black oxidation method with potassium dichromate ($K_2Cr_2O_7$) in a sulfuric acid medium (Nelson and Sommers , 1982), total nitrogen by semi-micro Kjeldahl (Bremner and Mulvaney, 1982), and phosphorus by sodium bicarbonate ($NaHCO_3$) extraction (Olsen) procedures (Olsen and Sommer, 1982). Exchangeable potassium and sodium extracted by sodium acetate method and measured by flame photometer, exchangeable calcium and magnesium by ammonium acetate extraction and measured by the atomic absorption spectrometry (AAS) method and cation exchange capacity by ammonium acetate (1 N NH_4OAc) extraction(Chapman, 1965).

Data analyses

Independent t-test was used in order to assess the significances in soil parameters between soils at exclosure and adjacent degraded sites using the Statistical Analysis System (SAS, 2006).

Correlation analysis was also performed in order to analysis the relationship between the selected soil parameters. Relative change (RCH) in soil properties was computed as:

$$RCH\ (\%) = \frac{(Pe - Pd)}{Pd} X\ 100$$

Where Pe is the soil property measured on the exclosure site and Pd is the soil property measured on the adjacent degraded site.

RESULT AND DISCUSSION

Effects of exclosure on soil physical properties

Soil bulk density was one of the major parameters used in this study to assess the fertility status of soil in terms of physical property. The mean values of the soil bulk density (Figure, 2) under exclosed and degraded site were 1.20 and 1.53 g/cm^3 respectively. As compared to adjacent degraded site, bulk density at exclosure site was reduced by 23.4%. However, there was not significantly ($P>0.05$) affected by exclosure (Table, 1). The smaller bulk density at exclosure site was due to high amount of organic matter source from restored woody plant species. The correlation matrix (Table, 3) also showed a negative but significant relationship between bulk density and organic carbon (r= -0.31*). Moreover, the high amount of bulk density at degraded site maybe because of trampling effect of livestock during grazing. This result agrees with earlier findings of Descheemaeker et al (2005) who reported that exclosure was prevent physical soil loss.

The mean value of the soil moisture content under exclosed and degraded site were 18.5 and 13.8 respectively (Figure, 2). It was increased at exclosure site by 34.1%. There was significant ($P<0.05$) difference in moisture content between soil at exclosure and adjacent degraded site (Table, 1). Higher moisture percentage in exclosure site was attributed to the higher organic matter accumulation. Besides, the higher clay percentage (Figure, 2) of the soil in the exclosure might have contributed to the higher moisture retention of the soil in the exclosure site than in the adjacent degraded site. The increased in relative change in moisture content regard of large clay content and organic carbon at the exclosure site was because of the presence of woody plant residues and biomass. The amount of moisture content (Table, 1) also showed that a positive and significantly correlated with clay content (r=0.31*) and organic carbon content (r=0.22*). The presence of forest conservation for the different purpose may affect soil physical properties such as soil water retention and aggregate stability, leading to enhanced crop water availability (Brady and Weil, 2002). Nichols et al (2004) reported that aggregation is important for increasing stability against erosion, for maintaining porosity and soil water movement, and for improving fertility.

Based on the percentages of clay, silt and sand compositions, the textural classes of the soils of the exclosure and adjacent degraded site belongs to clay loam. The mean values of the soil texture: sand, silt and clay under exclosed and degraded site were 35.3 and 36.8, 25.2 and 19.6, and 45.1 and 38% respectively (Figure, 2).

The clay and silt fraction of the soils were significantly (P<0.05) affected by exclosure while there was no significant (P>0.05) difference in sand content (Table 1). As compared adjacent degraded lands, sand content was reduced at exclosure site by 4.1%, but the clay and silt fraction were increased 18.7 and 28.6% respectively. The higher clay content in the exclosure means that there could be relatively low soil erosion in the site, while the lower clay in the degraded means there was relatively higher soil erosion (particularly sheet erosion) at the degraded site, which may reflect the low organic matter, the trampling effect of livestock and the sparse vegetation aggravate soil erosion which selectively removes clay from the adjacent degraded land. (Gachene and Kimaru, 2003) reported that clay particles are lighter than sand particles, and once detached by erosion they are easily transported.

Effects of exclosure on chemical properties of the Soil

Soil pH and electrical conductivity (EC)

Soil pH was reduced at exclosure site by 2.2%. However, there was no significant (P>0.05) difference in soil pH between exclosure and adjacent degraded site (Table, 2). This was probably attributed to similarity in climatic conditions, especially rainfall. Rainfall is the most determinant factor for pH in soils. The present study indicated that, the mean values of soil pH under exclosed and degraded site were 7.13 and 7.29 respectively (Figure, 3). Based on the classification by Pandey et al (2000), soil pH in both sites grouped in neutral pH scale. The low pH value of soil in the exclosure site was due to the accumulation and decomposition of leaf litter which release organic acids. The mean value of the electrical conductivity (Figure, 3) under exclosed sites and degraded sites were 0.156 and 0.159 mmhos/cm^3 respectively. It was reduced at exclosure site by 1.9%. There was no significant (P>0.05) difference in EC between exclosure and adjacent degraded site (Table, 2). The lower values of EC at exclosure site could be because of the absence of salinity or/sodacity and the study site is located in high rainfall area. The correlation matrix (Table, 3) also showed positive and significance relationship between pH and EC (r=0.83*). In line with this Noellemeyer et al (2006) reported that no significance in electrical conductivity due to area exclosure.

Organic carbon, total nitrogen and available phosphorus

This study indicated that, the mean values of soil organic carbon, total nitrogen and available phosphorus of the soil under exclosed and degraded sites were 2.21 and 1.61%, 0.19 and 0.14% and, 7.92 and 5.88ppm respectively (Figure, 3). Soil organic carbon, total nitrogen and available phosphorus were significantly (P<0.05) higher at exclosure site than adjacent soil. Similarly Katrien et al (2007) also found that total nitrogen was significantly increase when an area has been closed for 20 years, compare to degrade or recently closed area in North Ethiopia, Tigray. As compared to adjacent soils, organic carbon, total nitrogen and available phosphorous were increased at exclosure site by 37.3, 35.7 and 34.7%, respectively. The relatively large increase in the total soil N and available P storage in the exclosure site due to resulted from the management, establishment and subsequent increased organic matter input derived from herbaceous species biomass and from reduced soil erosion through effective ground cover.

The correlation matrix (Table 3) also showed that organic carbon was directly and significantly associated with total nitrogen (r=0.99*) and available P (r=0.44*). Besides, there was a synergetic and significant associations between on total nitrogen and available P (r=0.47*). This was in harmony with the findings of Bot and Bentites (2005) who reported area exclosure increases the accumulation of soil organic matter and the presence of this organic matter also affects both the chemical and physical properties of the soil and overall health. Furthermore, the increases in canopy cover with the increase in exclosure duration could decrease sediment-associated soil nutrient losses by reducing the erosive impact of raindrops and soil erosion (Girmay et al., 2009; Mekuria et al., 2009).

Effect of exclosure on CEC and exchangeable bases

The mean values of the cation exchange capacity (CEC), Na^+, K^+, Ca^{2+} and Mg^{2+} under exclosed and degraded sites were 29.7 and 24.8, 0.34 and 0.19, 1.22 and 0.72, 28.6 and 19.9 and, 6.66 and 2.65Meq/100g respectively (Figure, 4). CEC was significantly (P<0.05) affected by exclosure (Table 2). As compared to adjacent degraded site, the higher value of CEC was observed at exclosure site and it was increased by 19.8%. This was attributed to the higher soil organic matter and clay percentage of the soil in the exclosure site. Besides, CEC of the soil was positively and significantly correlated with clay (r=0.60*) and organic carbon (r=0.36*) (Table, 3). In line with this Kibret (2008) reported that soil CEC is associated with clay and organic matter colloids, and especially organic matter renders soils a better CEC. Thus, slight difference in CEC can make a big difference in soil organic matter as observed in this study. Similarly, Kibret (2008) and Abiy (2008) also reported that higher mean value of CEC in exclosure than adjacent degraded site.

The exchangeable bases also showed a significance (P<0.05) difference between the soils at exclosure site and adjacent degraded land (Table 2). As compared to adjacent degraded land, exchangeable Na^+, K^+, Ca^{+2} and Mg^{+2} were increased at exclosure site by 78.9, 69.4, 43.7 and 151.3%, respectively. The highest relative change was observed magnesium while the least relative change was observed in calcium. The higher values of exchangeable bases at exclosure site were quite logical. The increase in basic cations at exclosure site was due to the accumulation of woody biomass. Higher values of exchangeable cations could be attributed to the nutrient cycling role of increased biomass in the exclosure site (Bot and Benites, 2005), as well as improved organic matter content (Hodges and Plank, 1988). In fact, the two colloidal substances (clay and organic matter) are essentially the cations' warehouse or reservoir of the soil and are very important because they improve the nutrient and water holding capacity of the soil (Sachs, 1999). This finding was in agreement with work done by several authors (eg. Abiy, 2008; Kibret, 2008).

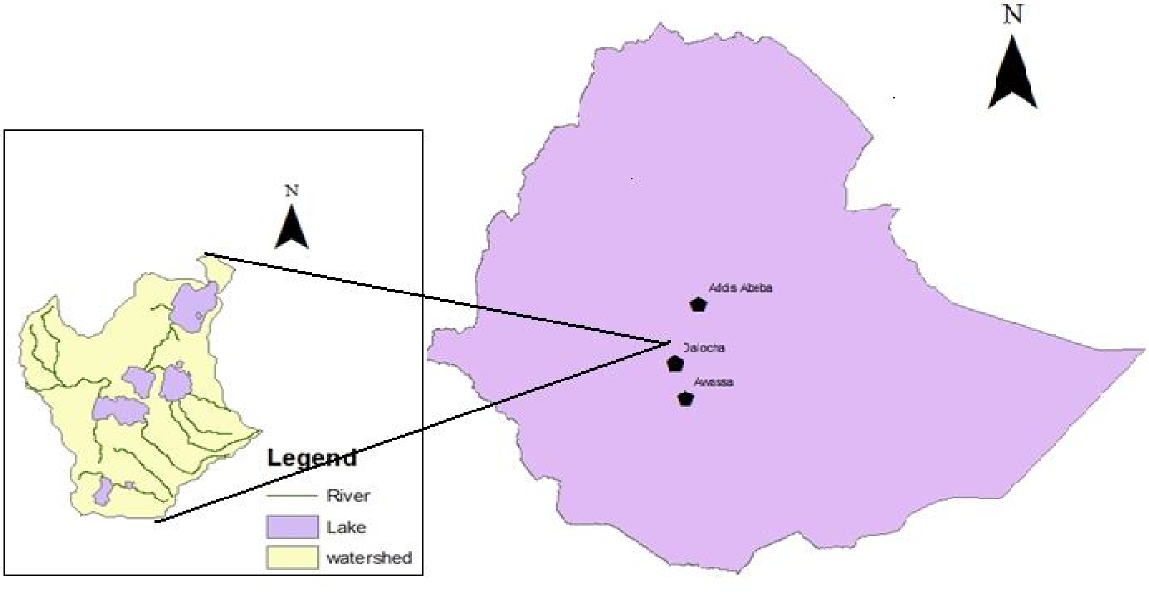

Figure 1 Map of the study area.

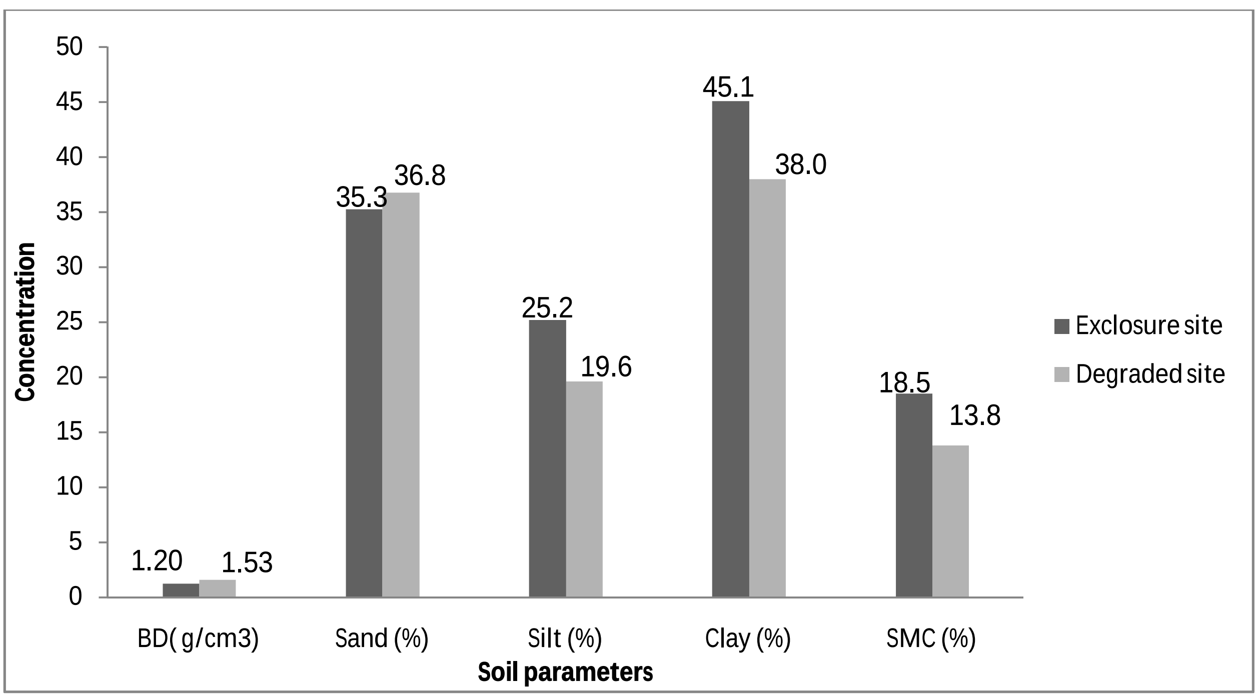

Figure 2. Mean values of bulk density (Bd), sand, silt, clay and soil moisture content (SMC) at degraded and exclosure site.

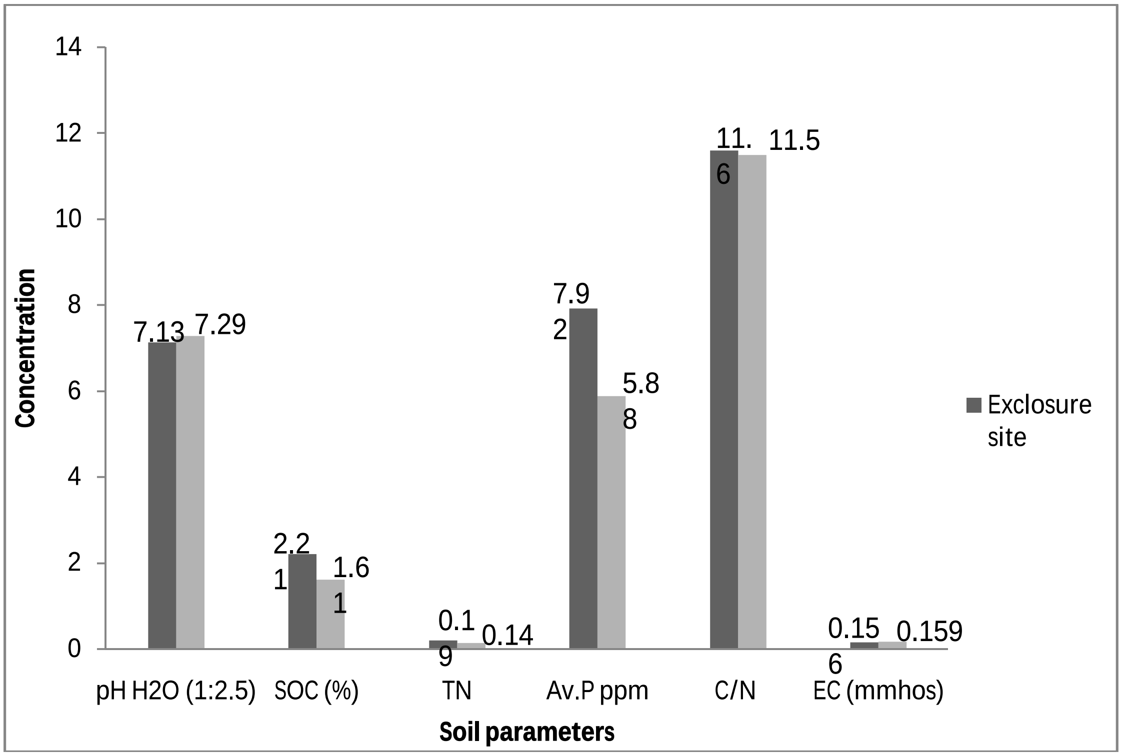

Figure 3. mean values of pH, soil organic carbon (SOC), total nitrogen (TN), available phosphorus (Av.P), carbon nitrogen ratio(C/N) and electric conductivity (EC) at exclosure and degraded sites.

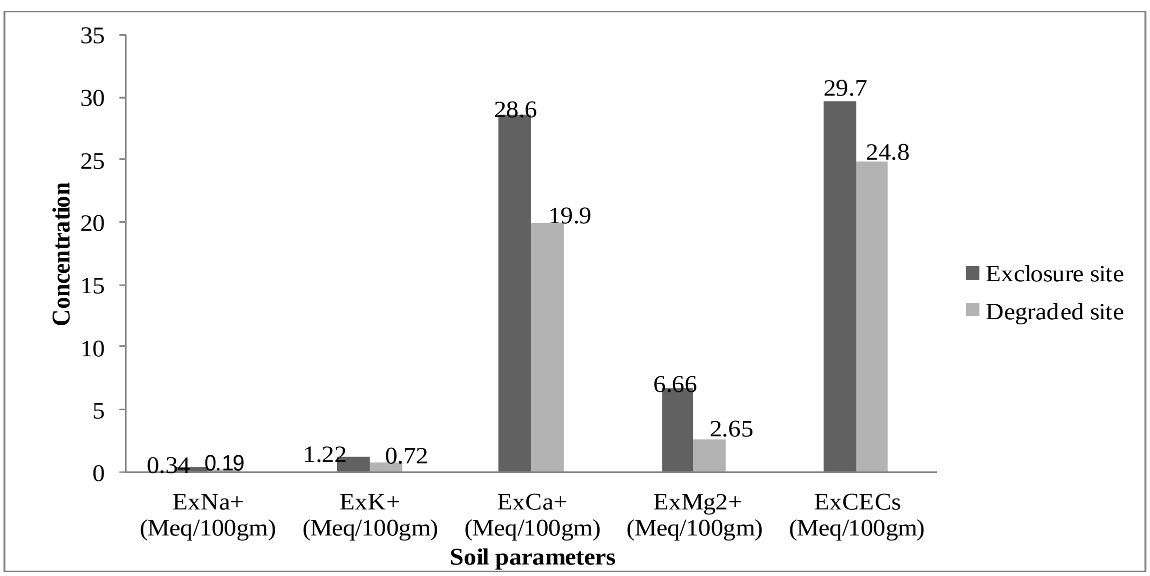

Figure 4. mean value of cation exchange capacity (CEC), exchangeable cations (Na^+, K^+, Ca^{2+} and Mg^{2+} at exclosure and degraded sites.

Table 1. Relative change and statistic test for soil physical parameters.

Soil parameter	T-statistics	P-value	Relative change (%)
Bulk density (g/cm3)	6.90	Ns	-23.4
Sand (%)	-0.55	Ns	-4.1
Silt (%)	2.60	*	28.6
Clay (%)	2.18	*	18.7
Textural class (clay loam)			
Moisture content (%)	2.69	*	34.1

*** = very highly significant P<0.001; **= highly significant at P<0.01; * = significant at P<0.05; ns = not significant at P>0.05

Table 2. Relative change and statistic test for soil chemical parameters

Soil parameter	T-statistics	P-value	Relative change (%)
pH H_2O (1:2.5) Electrical conductivity (EC mmhos/cm^3)	0.97 -0.35	ns ns	-2.2 -1.9
Soil organic carbon (%)	3.85	***	37.3
Total N (%)	2.87	***	35.7
Available P (ppm)	7.58	***	34.7
Exchangeable Na^+ (Meq/100gm)	12.52	***	78.9
Exchangeable K^+ (Meq/100gm)	10.44	***	69.4
Exchangeable Ca^{+2} (Meq/100gm)	3.72	***	43.7
Exchangeable Mg^{2+} (Meq/100gm)	12.89	***	151.3
Soil CECs (Meq/100gm)	11.65	*	19.8

*** = very highly significant P<0.001; **= highly significant at P<0.01; * = significant at P<0.05; ns = not significant at P>0.05

Table 3. Pearson correlation matrix for the selected soil properties.

	MC	BD	Sand	Silt	Clay	K^+	Na^+	Ca^{+2}	Mg^{2+}	Av.P	TN	CEC	EC	pH	OC
MC	1.00*														
BD	0.23*	1.00*													
Sand	-0.22*	0.05^{n}	1.00*												
Silt	-0.17^{n}	0.37*	0.02^{n}	1.00*											
Clay	0.31*	-0.24*	-0.60*	-0.66*	1.00*										
K^+	0.36*	-0.46*	-0.16^{n}	-0.26*	0.22*	1.00*									
Na^+	0.49*	-0.60*	-0.30*	-0.38*	0.35*	0.72*	1.00*								
Ca^{+2}	0.38*	-0.43*	-0.17^{n}	-0.29*	0.74*	0.83*	0.46*	1.00*							
Mg^{2+}	0.47*	-0.44*	-0.38*	-0.35*	0.58*	0.76*	0.80*	0.83*	1.00*						
Av.P	0.30*	-0.47*	0.00	-0.21*	0.17*	0.94*	0.65*	0.35*	0.70*	1.00*					
TN	0.12^{n}	-0.30*	-0.17^{n}	-0.23*	0.32*	0.44*	0.29*	0.60*	0.66*	0.47*	1.00*				
CEC	0.18^{n}	-0.16^{n}	-0.71*	-0.06^{n}	0.60*	-0.05^{n}	-0.16^{n}	-0.06^{n}	-0.03^{n}	0.39*	0.34*	1.00*			
EC	-0.24*	0.01^{n}	0.07^{n}	0.23*	-0.07^{n}	-0.31*	0.93*	-0.16^{n}	-0.13^{n}	-0.19^{n}	-0.56*	-0.14^{n}	1.00*		
pH	-0.33*	-0.04^{n}	0.17^{n}	-0.30*	-0.35*	-0.01^{n}	0.31*	-0.30*	0.37*	-0.04^{n}	-0.41*	-0.05^{n}	0.83*	1.00*	
OC	0.22*	-0.31*	-0.16^{n}	-0.30*	0.37*	0.42*	0.21*	0.05^{n}	0.66*	0.44*	0.99*	0.36*	-0.57*	-0.40*	1.00*

*-refers for significant, n- for no significant, MC=Moisture Content, BD=Bulk Density, K^+=Potassium, Na^+=Sodium, Ca^{+2}=Calcium, Mg^{2+}=Magnesium, Av. P=Available Phosphorous, TN=Total Nitrogen, CEC=Cation Exchange Capacity, EC=Electrical Conductivity, pH=Potential for Hydrogen, OC=Organic Carbon

CONCLUSION

The results of the study showed that a natural resources management strategy like area exclosures basically has shown quite higher improvement in soil fertility at Mitija watershed, southern Ethiopia. Soil fertility indicators like soil chemical and physical property were significantly higher in the exclosure in eight years except, bulk density, electric conductivity and pH. This shows that the vast degraded areas in the study area can quickly and cheaply be restored if the degrading agents such as human and animal disturbances are managed. Therefore, area exclosure could be not only as an alternative but also a compulsory to rehabilitate degraded land and sustainable use of soil resource.

ACKNOWLEDGMENT

We acknowledge Jimma University College of Agriculture and Veterinary Medicine for financing the research and other support..

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