International Journal of
Soil Science

ISSN 1816-4978

Academic
Journals Inc.

www.academicjournals.com

OPEN ACCESS International Journal of Soil Science

ISSN 1816-4978
DOI: 10.3923/ijss.2016.1.8

Research Article
Dynamics of Soil Physico-Chemical Properties in Area Closures at Hirna Watershed of West Hararghe Zone of Oromia Region, Ethiopia

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Abstract
The study was conducted at the Kirakufis and Rekatafura in Tulu district of Hirna watershed of West Hararghe zone, Oromiya regional state. The district is among areas highly affected by land degradation and soil nutrient depletion problem. Therefore, aims of the study were to assess the changes in selected soil physicochemical properties of the closure. Surface (0-20 cm) soil samples were collected from the experimental fields using stratified sampling technique. Data analyses were carried out using GLM with 3 replications. Accordingly, clay textures were dominantly observed at the closed areas where as sandy loam was in the open land. The ANOVA test indicated that there was significant different ($p \leq 0.05$) between closed area to open lands for all parameters, except available phosphorous. Based on this, it is possible to conclude that the establishment of area closures in the degraded lands is a viable option of soil physico-chemical properties improvement.

Key words: Area closures, soil properties, open land

Received: August 18, 2015 Accepted: November 09, 2015 Published: December 15, 2015

Citation: Tizita Endale, 2016. Dynamics of Soil Physico-Chemical Properties in Area Closures at Hirna Watershed of West Hararghe Zone of Oromia Region, Ethiopia. Int. J. Soil Sci., 11: 1-8.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Natural resources are the primary source of livelihood support for the poor and efforts to rehabilitate them could become a valuable strategy for livelihood improvement (Shylendra, 2002). However, in many developing countries, the resource base has been deteriorating over time. To combat these severe resource degradation, the practice of establishing area closures has emerged as a promising practice in different parts of Ethiopia (Bendz, 1986), namely in Tigray (Haile and Gebrehiwot, 2001) and Welo and Shewa (Tefera, 2001). According to the reports from case studies conducted on closure in the central and northern highlands of Ethiopia; closed area had twice the plant species richness and diversity value compared with communal grazing lands after 22 years of closure establishment (Tefera *et al*., 2005) and an increase in soil organic matter of 1.1% and total N of 0.1% after 10 years of closure establishment (Mekuria *et al*., 2007). Also, a considerable decrease in soil loss was reported after the establishment of area closure on communal grazing lands (Descheemaeker *et al*., 2006; Girmay *et al*., 2009).

Closers are important to increase water holing capacity of the soil under tree canopy (Kamara *et al*., 1992). They reported that availability of water is 1.5 to 2 times more under closure than the outside of the grazing land at the depth of 0-20 cm. Felker (1989) also reported improved water holding capacity of the soil under closure due to tree canopy. High rates of infiltration and water entry into the soil under tropical forest fallow and the reduction of the rates after two subsequent years of cropping was also reported (Wilkinson and Ania, 1976). Similar studies in India showed high infiltration rate, which is 20 cm h^{-1} under closure and 2 cm h^{-1} under bare farmland (Nair, 1993).

Similarly, Hailu *et al*. (2001) reported that the soil physical properties (soil texture, soil moisture content, soil bulk density and water holding capacity) are shows significant changes under closure than opened land (control) ones. Brady and Weil (2002) reported that the pedologic processes such as erosion, deposition, illuviation and weathering which are shaped by management practices can alter the texture of soils. According to Bewket (2003) under sparser vegetation covers the clay fractions are likely to be lost to processes of erosion and migration down the soil profile. Closures also facilitate aggregation of a soil which provides favorable conditions for development of fine deeper roots and mycorrhizae, so increasing efficiency of nutrient uptake (Young, 1990).

Area closures are areas selected for natural regeneration of the native flora as a means of land reclamation through protection of the areas from human and animal interference (Bendz, 1986). Since the objective of most area closures is for site rehabilitation/reclamation, they were usually established in steep, eroded and degraded areas used for grazing and crop production in the past (Birhane, 2002). Area closures in the Ethiopian context were defined as the degraded land that has been excluded from human and livestock interference for rehabilitation. In principle, human and animal interference is restricted in the area closures to encourage natural re-generation (BoANR) (Forester, 2002).

In terms of ecosystem services, closure contributes to provisioning ecosystem services through generation of animal feed and human food (Haile, 2012) regulating services through below and above ground carbon sequestration (Mekuria and Aynekulu, 2013) and soil erosion control, supporting services through soil formation, nutrient cycling and biomass production and cultural services through generation of aesthetic value and use for educational purposes (Mekuria, 2013). Closures also reduce nutrient loss from a site by controlling runoff (vegetation acting as a physical barrier to soil erosion). This eventually improves the capability of the land to support other vegetation types, including exotic plantations and/or support livestock (Tefera *et al*., 2005).

Most of the communal lands in West Hararghe zone of Oromia region, particularly Hirna in Tulu district are degraded and unproductive due to the deterioration of the physical, chemical and biological properties of the soil, mainly due to accelerated rate of soil erosion and poor management practices. To mitigate the problem, Haramaya University of the School of Natural Resource Management and Environmental Science began to practice area closure, as a viable strategy to rehabilitate degraded lands in Hirna watershed. Although, the restoration ecology and buffering effect of closed areas have been well studied (Aerts *et al*., 2001; Descheemaeker *et al*., 2006), there are relatively few studies in the Ethiopia, which would provide a measure of the success of closed areas as one strategy to help prevent decline of soil physico-chemical properties and improving soil quality thereby increasing agricultural productivity. Furthermore, there are no enough quantitative studies that analyze the change these closures had brought in terms of soil properties in the country, particularly in this study area. This study was therefore designed to assess the changes in selected physicochemical properties of soils in area closure at Hirna watershed of West Hararghe zone of Oromiya regional state.

MATERIALS AND METHODS

The study was conducted at Hirna-Amensis sub watershades (Kirakufis and Rekatafura closed areas). The Hirna watershade is part of the Chercher highlands and it is located in Tulo district, west Hararghe zone of the Oromia National Regional State (Fig. 1). Geographically, Hirna is located in eastern Oromia at about 370 km east of Addis Ababa and 150 km west of Harar city on the Addis Ababa-Harar highway.

The Kirakufis and Rekatafura has three closure areas (area closure I, III and II) which lie 5 km away from Hirna national weather station at latitude of 09°13′03.7″, 09°13′07.5″ to 09°13′47.7″ North and longitude of 041°04′55.6″, 041°04′54.6″ to 041°05′48.8″ East, respectively and has an altitude of 1800 m above sea level (Ethiopian Meteorological Authority in 2013 at the Hirna weather station).

The mountain basement comprises of sandstones of different colors as well as sparsely occurring limestone whereas the mountain top is basaltic, which is fragmented in nature as to allow entrance of water into the deeper portion of the rock inducing intense weathering for soil formation.

The district is situated in the semiarid to sub humid agro-ecological zones of the country. The weather information (2004-2013) recorded at the Hirna weather station according to Ethiopian Meteorological Authority in 2013, reveals that an average annual rainfall of 853.31 mm with mean minimum and maximum air temperatures of 8.4 and 24.9°C, respectively.

According to the FAO (1990) systems of soil classifications, the Amensis sub catchment of Hirna watershed were found the soil development in the topo-sequence followed the order of Entisols>Mollisols>Alfisols>Vertisols (USDA Soil Taxonomy) or Arenosols/Leptisols/Cambisols>Phaeozems>Nitisols> Vertisols/Planosols (FAO/UNESCO System). Maize, sorghum, teff and haricot bean are the major crops grown in the area in order of their importance.

Sampling site selection, soil sampling and analysis: The study was conducted on area closures established in 2001 (Area closures I and II) and 2004 (closure III). Area closures I and III are east-facing in Kirakufis whereas area closure II is west-facing in Rekatafura. The approximate area covered by

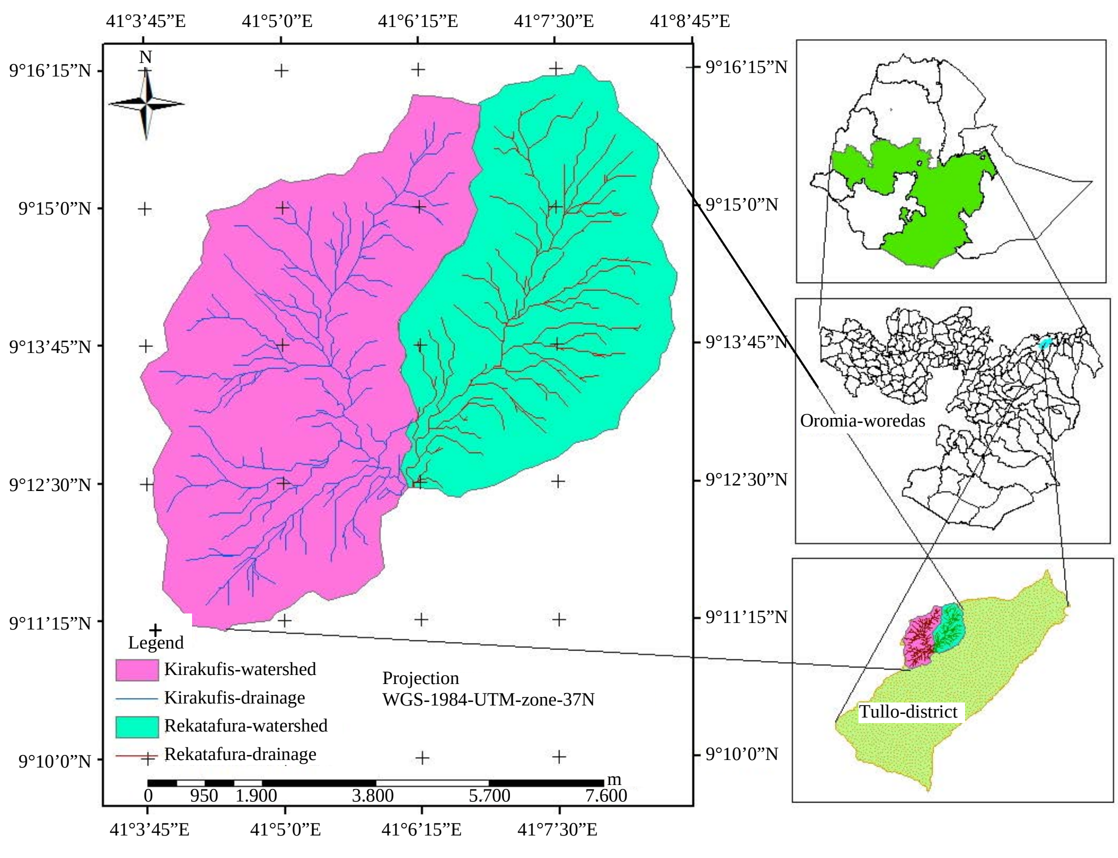

Fig. 1: Location map of the experimental area

each closure is 0.5 ha. Furthermore, area closures I and III adjoin each other. For this study, composite soil samples were taken from each area closure and adjacent open (unprotected) areas of outside of the closures adjoining to each other using stratified sampling technique and were replicated three times.

In order to investigate and assess the changes on the soil physico-chemical properties, composite soil samples were taken from the six sites in which three were from closed area and three were from adjacent open land at a depth of 0-20 cm (surface). Furthermore, 18 soil core samples were also collected for soil bulk density, field capacity and permanent wilting point analysis from each lands. The disturbed samples were collected using auger to determine particle size distribution, soil pH, organic carbon, total nitrogen, available phosphorus, exchangeable bases and cation exchange capacity. Then the collected sample was tagged, mixed well, air dried, ground, sieved with 2 mm sieve and stored for laboratory analysis following standard procedures. The soil samples were further sieved to pass through a 0.5 mm size sieve for the analysis of total nitrogen content of the soil.

The particle size distribution (texture) of the soils was analyzed according to the procedures outlined by FAO (1986) with help of hydrometer method. Soil bulk density was measured using the core method (Blake, 1965). Soil water contents at Permanent Wilting Point (PWP) and Field Capacity (FC) were determined by the pressure plate apparatus procedure. The average soil particle density (rs) value of 2.65 g cm^{-3} for mineral soils was assumed as the rs the soil. Total porosity (f) was estimated from the values of bulk density (r_b) and average particle density of mineral soil as:

$$f\ (\%) = \left(1 - \frac{\rho_b}{\rho_s}\right) \times 100$$

The measurement of soil pH was conducted using pH meter method in the supernatant suspension of 1:2.5 soils to water ratio (Jackson, 1973). Organic carbon of the soils was determined following the wet digestion method as described by Walkley and Black (1947). The OC was calculated from titrat volume. The percentage of organic matter of the soils was calculated by multiplying the percentage organic of carbon value by 1.724 conversion factors (Sahlemedhin and Taye, 2000).

The exchangeable bases (Ca, Mg, K and Na) were extracted by saturating the soil samples with neutral ammonium acetate (1N NH_4O Ac) solution (Blake, 1965). Following their extraction, exchangeable Ca and Mg were measured using atomic absorption spectrophotometer and the exchangeable Na and K were determined by flame photometer. The ammonium acetate method was employed to determine the Cation Exchange Capacity (CEC). Available phosphorus and total nitrogen were tested following Olsen's method and the kjeldahl procedure, respectively (Jackson, 1967; Olsen *et al*., 1954).

Statistical analysis: The data from soil laboratory were subjected to analysis of variance (ANOVA) appropriate to General Linear Model (GLM) using SAS software program (SAS Institute, version 9.1). The analysis results of the soil were interpreted using descriptive statistics. Mean separation was carried out using the Least Significant Difference (LSD) at $p \leq 0.05$ probability levels (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Impact of area closure on soil physico-chemical properties

Soil texture: Although the texture of soil in the field is not readily subject to change, textural differences were observed among various land use types particularly due to the changes in clay and sand fractions. Closed area soils were dominated by clay fractions whereas open land soils were dominated by sand fractions except open land II which was dominated by clay fraction. Sand fraction varied significantly across land uses type ($p \leq 0.05$) (Table 1). Similarly, the clay fraction was strongly

Table 1: Mean value estimates for particle size distribution, bulk density, total porosity and water content of Kirakufis and Rekatafura

	Particle size (%)						Water content (%)	
LUT	Sand	Silt	Clay	Textural class	Bulk density (g cm^{-3})	Total porosity (%)	FC	PWP
CAK I	21.10^{d}	30.50^{a}	48.40^{b}	Clay	1.23^{c}	53.83^{a}	26.73^{a}	17.62^{b}
AOLK I	58.30^{a}	28.33^{b}	13.37^{d}	Sandy loam	1.67^{a}	36.72^{c}	18.18^{c}	15.87^{c}
CAK III	29.00^{c}	28.00^{b}	43.00^{c}	Clay	1.24^{c}	53.12^{a}	25.70^{b}	18.19^{ba}
AOLK III	54.00^{b}	32.00^{a}	14.00^{d}	Sandy loam	1.61^{ab}	38.86^{c}	17.98^{c}	14.79^{c}
CAR II	15.30^{e}	32.50^{a}	52.20^{a}	Clay	1.13^{c}	56.98^{a}	27.76^{a}	19.10^{a}
AOLR II	26.08^{c}	29.42^{b}	44.50^{c}	Clay	1.57^{b}	39.85^{b}	19.19^{c}	14.76^{c}
LSD (0.05)	3.03	2.30	2.12		0.08	2.87	1.30	1.34
CV (%)	5.02	4.50	3.41		3.25	3.29	3.30	4.51

LUT: Land unit type, CAK I: Closed area Kirakufis one, AOLK I: Adjacent open land Kirakufis one, CAK III: Closed area Kirakufis three, AOLK III: Adjacent open land Kirakufis three, CAR II: Closed area Rekatafura two, AOLR II: Adjacent open land Rekatafura two, FC: field capacity, PWP: Permanent wilting point, LSD: Least significant difference, CV: Coefficient of variance, means within a column followed by same letters in superscripts are not significantly different at 0.05 levels influenced by changes in land use types ($p \leq 0.05$) which ultimately led to varying soil management practices. Though it is believed that management practices generally do not alter the textural class of a soil on a field scale, management practices have indirect roles in doing so. Pedologic processes such as erosion, deposition, illuviation and weathering which are shaped by management practices can alter the texture of soils (Brady and Weil, 2002). The presence of good vegetation cover in the area closure reduced erosion through addition of organic matter and surface litter (Skarpe, 1991). Under conditions of low vegetation cover as in the open land case, clay fractions are likely to be lost through processes of selective erosion and migration down the soil profile which ultimately increase the proportion of sand and silt contents in surface soils (Bewket, 2003).

Bulk density: The ANOVA showed that there was statistically significant difference in bulk density at 0.05 levels between closed areas to open land (Table 1). Higher value of bulk density of the open land is due to trampling effect from the livestock population grazing and direct impact of raindrops on the area. Overgrazing led to the degradation of vegetation, soil compaction and wind and water erosion. Higher bulk density on open land led to a decrease in water infiltration capacity, causing in its turn, a higher surface run-off, which may lead to significant soil erosion. The soil erosion problem affects the recruitment of new grass seedlings. There is also soil crusting and sealing in the open land because of lack of vegetation cover which in turn increases bulk density.

The increases in canopy cover with in the closure could decrease soil nutrient losses by reducing the erosive impact of raindrops and soil erosion (Tsetargachew, 2008; Girmay *et al.*, 2009; Mekuria *et al.*, 2009).

Total porosity: The ANOVA revealed that there was statistically significant difference in total porosity ($p \leq 0.05$) between the closed area and open land (Table 1). According to the classification suggested by Landon (1991) sandy soils with a total porosity of less than about 40% and clay soils with less than 50% are liable to restrict root growth due to excessive strength. Thus, the total porosity of the soils as measured from the composite surface soil samples of the experimental sites for closed area were above the limiting value (Table 2) and hence, root growth of crops were not affected while open land were within the range of restrict root growth (Table 2).

Table 2: Mean value estimates for pH, OM, TN and Av.P of Kirakufis and Rekatafura ($p \leq 0.05$) indicate significant differences

LUT	pH-H_2O	OM (%)	TN (%)	Av.P (mg kg^{-1})
CAK I	6.64^{a}	5.04^{a}	0.21^{b}	5.50^{a}
AOLK I	6.67^{a}	1.40^{d}	0.05^{d}	5.61^{a}
CAK III	6.34^{bc}	4.82^{b}	0.19^{b}	4.97^{b}
AOLK III	6.59^{b}	1.70^{c}	0.06^{dc}	5.11^{b}
CAR II	6.20^{c}	5.87^{a}	0.27^{a}	4.65^{d}
AOLR II	6.51^{ba}	1.92^{c}	0.08^{c}	4.81^{d}
LSD	0.16	0.41	0.02	NS
CV (%)	1.43	6.72	10.45	2.24

pH: Power of hydrogen ion, OM: Organic matter, Av.P: Available phosphorus, TN: Total nitrogen, means within a column followed by same letters in superscripts are not significantly different at 0.05 levels, NS: Not significant

Table 3: Mean value estimates for exchangeable bases and cation exchange capacity of the soils Kirakufis and Rekatafura

	Exch.Ca	Exch.Mg	Exch.K	Exch.Na	CEC
LUT	------------------------------(cmol$_c$ kg^{-1} soil)------------------------------				
CAK I	28.01^{b}	13.53^{b}	2.10^{b}	0.49^{b}	42.70^{b}
AOLK I	21.24^{e}	9.94^{e}	1.05^{e}	0.16^{d}	20.35^{f}
CAK III	27.03^{c}	12.94^{c}	1.93^{c}	0.48^{b}	38.98^{c}
AOLK III	22.00^{f}	10.00^{e}	1.16^{e}	0.15^{d}	22.00^{e}
CAR II	28.35^{a}	14.15^{a}	2.58^{a}	0.60^{a}	48.16^{a}
AOLR II	24.38^{d}	10.32^{d}	1.33^{d}	0.22^{c}	22.92^{d}
LSD	0.28	0.31	0.03	0.16	0.79
CV (%)	0.63	1.49	5.34	5.46	1.37

LUT: Land unit type, Exch.Ca: Exchangeable Calcium, Exch.Mg: Exchangeable Magnesium, Exch.Na: Exchangeable sodium, CEC: Cation exchange capacity, means within a column followed by same letters in superscripts are not significantly different at 0.05 levels

Soil-water holding capacity: The study has shown that the soil water retained at field capacity (-33 kPa) did vary significantly ($p \leq 0.05$) with the land use change (Table 1). The largest numerical values were associated with soils under closed area whilst smallest figures were observed in open land soils (Table 2), which is the least in its OM content. It is an established fact that the increasing organic matter increases the water holding capacity of soils (Brady and Weil, 2002). The study has shown, the smallest value of water retained at PWP in soils under open land, which considerably varied from that of soils under closed area. This can be ascribed to its low organic matter content and this relation is viewed as PWP and OM has strong associations (Table 2).

Soil pH: The ANOVA result (Table 3) showed that the mean difference between closed areas to open land was significant ($p \leq 0.05$). The low pH value of soil in the closed area might be due to the accumulation and decomposition of leaf litter and leaching of bases down the soil profile (the vegetation cover of closed area was higher than that of the open land in which infiltration was higher in the former land use which facilitated leaching of bases down the soil profile leaving the top soil acidic). This is probably attributed to similarity in climatic conditions, especially rainfall. Rainfall is the most determinant factor for pH in soil (Smith *et al*., 1995).

Soil Organic Matter (SOM): The SOM content in closed area was the highest and the SOM content in open land was lowest. This finding is in agreement with Mekuria and Veldkamp (2005) reported as the soils of open lands and closed areas differed considerably in content of Soil Organic Matter (SOM), with significantly higher ($p \leq 0.05$) SOM values found in closed areas than in open lands. The higher SOM contents in closed areas compared to that of adjacent open land could be explained by the difference in soil erosion and biomass return. Reduced erosion is expected to occur in well-developed closed areas because the canopy formed by the mature shrubs and under-story vegetation shields the soil from the erosive energy of the falling raindrops and there by protects it from splash erosion and surface or sheet erosion. Rainfall induced erosion can be reduced a hundred fold by maintaining a dense cover of sod, grasses or herbaceous vegetation (Gray and Sotir, 1996). The other reason of increment in organic matter in closed area is the accumulation of litter dominantly from grasses. In addition, less biomass return causes the reduction of SOM and TN in adjacent open lands (Mueller-Harvey *et al*., 1985). The most evident impact of grazing on the ecosystem is removal of a major part of above ground biomass by livestock.

In general, as the litter covers increases, soil loss decreases exponentially (Coppin and Richards, 1990). Also, Bewket and Stroosnijder (2003) claim in their finding that many studies examining the effect of deforestation on soil nutrients concluded that after removal of forest vegetation, soils deteriorate in their chemical properties including organic matter content.

Total Nitrogen (TN): The significant difference in total nitrogen between closed areas to open lands was due to differences in SOM content and intensities of soil erosion. Reduction in organic matter content of a soil is an obvious reason to expect relatively low nitrogen content in the open land. This indirectly suggests that the biological conservation measures on closed area have contributed to the sustainable management of land through replenishing soil nutrients. For instance, Tsetargachew (2008) and Mekuria and Veldkamp (2005) reported that total nitrogen (%) was significantly higher ($p \leq 0.05$) in closed areas than in open lands.

As the grazing intensity increases, higher percentages of mineral soil nitrogen would get more inactive, therefore, less amounts of dynamic exchanging nitrogen would be released (Sanadgol *et al*., 2002). In the other hand, areas which non-grazed by animals had higher soil nitrogen content due to their dense vegetation cover, particularly nitrogen stabilizing plants like legumes and large volumes of plant roots in their soils.

Available Phosphorus (Av.P): There was no significant difference ($p > 0.05$) between closed areas to open land in terms of available phosphorous mg kg^{-1}. However, in relative terms available phosphorous levels in soils of the closed areas were generally lower than the open lands, despite the higher SOM contents of the closed areas. The unusual feature here is that the available P contents of these soils did not necessarily increase with increased soil OM. The low available P in the closed area could be due to the presence of P in its unavailable forms. Generally, the pattern of distribution of available phosphorous among the land use types suggests that the establishment of area closure did not bring a significant change on availability of this vital nutrient. A similar finding that is, insignificant change in available phosphorous following deforestation was reported by a study in tropical India (Saikh *et al*., 1998; Bewket, 2003; Tsetargachew, 2008).

Exchangeable cations (Ca, Mg, K, Na): Generally, in both closed and open lands of composite surface soil, the proportions of the cations were in the order of Ca>Mg>K>Na. This might be related to the parent material from which the soils developed from i.e., basalt rock and their differential attraction to the soil's exchange complex which is approximately in that order. According to Havlin *et al*. (1999), the prevalence of Ca followed by Mg, K and Na in the exchange site of soils is favorable for plant production.

Cation Exchange Capacity (CEC): The ANOVA result showed that there was significant difference ($p \leq 0.05$) in mean CEC $cmol_c$ kg^{-1} between closed areas to open land (Table 3). The CEC $cmol_c$ kg^{-1} under closed area was significantly greater than the open lands. This finding is in agreement, with the work of Mekuria and Veldkamp (2005) who reported that Cation Exchange Capacity (CEC) was significantly higher ($p \leq 0.05$) in closed areas than in open lands. The higher CEC in closed areas compared to the open land could be explained by the difference in organic matter and clay content among the land use types. Most studies showed that there is a direct relationship between organic matter, clay content and CEC.

CONCLUSION

The aims of the study were to assess the changes in selected soil physicochemical properties of the closure. The one way analysis of variance indicated that there was significant different ($p \leq 0.05$) for all parameter comparing closed area to open land, except available phosphorous. Therefore, this study came up with the evidence that establishment of area closure could improve soil physicochemical properties of degraded lands of the study area. Based on the increased vegetation cover and improved soil conditions of the closure, it is possible to conclude that the establishment of area closures in the degraded lands is a viable option for soil physicochemical properties improvement and biodiversity conservation. Furthermore, the establishment of area closures is very advantageous over other methods (watershed management and physical soil and water conservation) since it is a fast, cheap and lenient method for the rehabilitation of degraded lands, and generally one can conclude that, the biological conservation measures of area closure contributed to the improvement of physicochemical properties of soil under the closed area.

ACKNOWLEDGMENTS

First of all I would like to thank the almighty God, for keeping me courageous and inspired to go through all these work. Thanks go to the SIDA project for the financial support of this study. Numerous farmers and experts helped during the data collection and laboratory analysis especially, thanks goes to Dr. Kibebew Kibret, Dr. Muktar Mohammed and Mr. Zerihun Kassa for their support.

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