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POTENTIAL OF AREA EXCLOSURE IN RESTORING SOIL NUTRIENT: CASE STUDY FROM TIGRAY REGION, NORTHERN ETHIOPIA

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ABSTRACT: Area exclosure is a type of land management, implemented on degraded land to address soil and vegetation cover loss, and low water holding capacity of degraded lands for environmental restoration and socio-economic benefit. The present study investigated how exclosure age have an effect on restoration of soil nutrient stocks and properties in Tigray, Ethiopia. Area exclosures of 10, 15, and 20 years old were selected and each exclosure was paired with an adjacent free grazing land. A total of 120 quadrants were sampled using a stratified preferential sampling design technique with flexible systematic model. Pairwise comparisons, Tukey's HSD (Honestly Significant Difference) test, paired t-tests and Pearson correlation tests were conducted to see for significant differences between each category of exclosures duration and the adjacent free grazing lands. Statistical tests were conducted to see the normal distribution of the population and homogeneity of the variance. There was a significant difference ($P<0.05$) for stone cover, grazing, EC, soil organic carbon, and N among the different aged area exclosures and free grazing lands. There was no significant difference ($P>0.05$) between similar aged area exclosures or free grazing areas. However, sand, silt, clay, CEC, pH, BD, K, P, Mg, and Ca did not show significant differences. This study has therefore, demonstrated that area exclosures on degraded free grazing lands is found to be an effective way of land restoration by improving soil nutrient content and soil properties.

Key words/phrases: Area exclosure, Free grazing, Land restoration, Soil nutrient, Tigray.

INTRODUCTION

As a result of its long history of agriculture in the mountains, Ethiopia is faced with high rates of deforestation and land degradation. Major cited causes are: extensive forest clearing for agricultural use; overgrazing on free grazing lands; exploitation of the existing forest for fuel wood, fodder and construction materials (Badege Bishaw, 2001). These have led to reductions in the production of forest products and food, aggravating poverty and malnutrition (Stocking and Murnaghan, 2001).

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Area exclosures hereafter denominated as exclosures are areas closed off or otherwise protected from interference from people and domestic animals, with the goal of promoting natural regeneration of plants and reducing land degradation in formerly degraded communal grazing lands. Natural features such as large gullies and man-made features such as roads usually demarcate the boundaries of exclosures (Yayneshet Tesfay *et al*., 2009). The size of exclosure ranges from as small as 1 hectare to 700 hectares (Betru Nedessa *et al*., 2005).

In the Tigray highlands of northern Ethiopia, the establishment of exclosures has become an important measure to combat land degradation and restore vegetative cover. Because of their sediment trapping capacity, exclosures are efficient soil and water conservation measures. They accelerate fertile soil buildup and prevent important sediment loads from leaving the catchment or silting up water reservoirs (Descheemaeker *et al*., 2006). Because of the wide promotion of exclosure in the northern and central highlands of the country to arrest the land degradation, about 1.3 million ha of area is under exclosure in Tigray (BoANRD, 1997) which have helped to rehabilitate degraded lands and significantly increased the vegetation cover and enhanced regeneration.

It was shown in Eskelimroud basin (Iran), that a five-year exclosure increased vegetation cover, percentages of nitrogen, phosphorus, potassium, organic matter and electrical conductivity in the soil surface over unclosed area (Hosseinzadeh *et al*., 2010). Short time exclosures did not influence soil texture which is a perennial characteristic and it needs a long time to be affected (Hosseinzadeh *et al*., 2010). In some places, local people report that species disappeared in the past to have been restored as a result of the exclosures. For instance, in some parts of eastern Tigray, species that had long disappeared from some areas (e.g. *Olea europaea* subsp. *cuspidata* and *Juniperus procera*) have started to re-appear. In addition, densities and diversities of the flora (particularly grasses) and fauna has increased, the level of soil erosion decreased, and even springs started to flow after exclosures were established (Emiru Birhane *et al*., 2007), and also Betru Nedessa *et al*. (2005) stated that with increase in vegetation cover, wildlife populations (e.g. porcupine and fox) have also increased.

Soil organic matter, soil nutrients as well as soil physical and chemical properties in exclosures were significantly different compared to the adjacent free grazing lands and the improvement in soil properties and nutrients was a key factor for the enhancement of biomass production in exclosures (Mekuria Wolde *et al*., 2009). The major factors affecting the rate of recovery and productivity of the area exclosures are the intensity of past land degradation, soil conditions, moisture, and intervention. Remnants of the former vegetation, mainly trees and shrub species, are the dominant vegetation re-colonizing the niche after the establishment of exclosures.

Though runoff depth is significantly correlated with variables such as rainfall intensity, storm duration and soil water content, total vegetation cover is the most important variable explaining about 80% of the variation in runoff coefficients (Mekuria Wolde *et al*., 2009). Increased vegetation density in exclosures results in increased infiltration and higher transpiration, which in its turn triggers vegetation restoration through increased biomass production. With vegetation restoration, water use for biomass production also becomes more efficient. Vegetation restoration is responsible for the high infiltration capacity of the exclosures, but as transpiration is not increased at the same rate, the surplus infiltration drains beyond the root zone and contributes to ground water recharge. Therefore, this research project was initiated to investigate how exclosure age affects restoration of soil nutrient stocks and properties. Hence, the specific objective of this study was to examine the physical and chemical properties of the soil in area exclosures of different ages and the adjacent grazing lands. In this study, we tested this assumption using variables measured in the exclosures and grazing lands that are less dependent on land use.

MATERIALS AND METHODS

Study area

The study was conducted in three woredas/districts of the exclosures selected based on altitude (ranges between 1400 and 2900), the age of exclosures (vary between 1 and 25 years), size of exclosures (differ from 8 to 125 hectares), proportion of exclosure out of the total area, and distance from residence (vary in the range 0.5 to 9 kilometres). Fair accessibility is also under consideration. However, it is rare to find all the exclosure types in a relatively homogenous environment, mainly, agro-ecological zone.

Soils of the Atsbi Wemberta and Kilte Awelaelo sites were classified into four major groups: Luvisols (Alfisols), Regosols (Entisols), Cambisols (Inceptisols) and Calcisols (Aridisols) (Soil Survey Staff, 1996) and the Fluvisols are mainly confined to the alluvial deposits along the river valley (Gebrekidan Teklu, 2004). In a large part of the area, the vegetation is formed on Enticho sandstone and Crystalline Basement (Asfawossen Asrat, 2002). While in Raya Azebo the dominant soil types are Leptosols, Cambisols, Vertisols, Regosols, and Arenosols (BoANRD, 1997). Most part of the undulating terrains in northern Ethiopia is characterized by shallow soils and frequent rock outcrops, while relatively thick soils are found along valley bottoms (Descheemaeker *et al*., 2006).

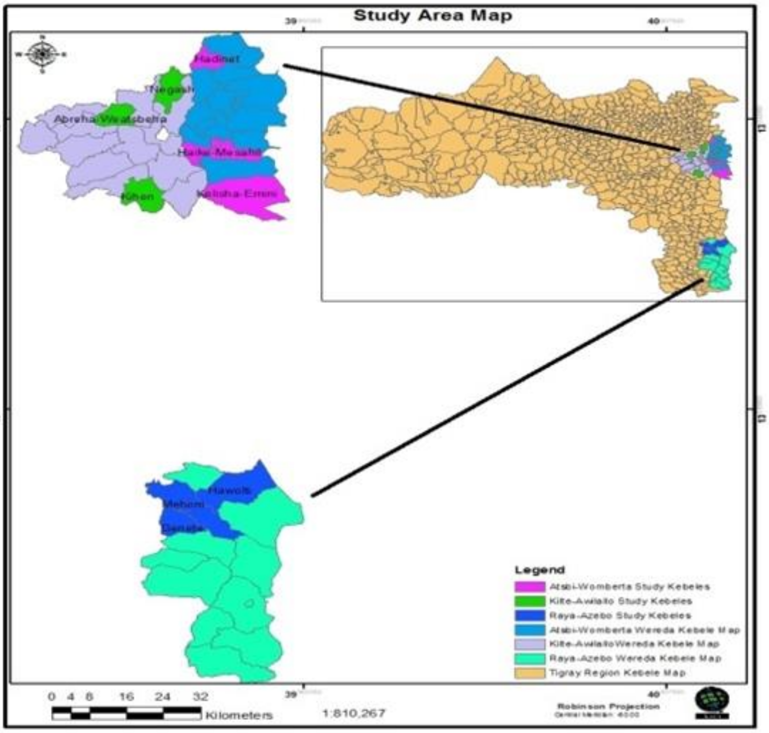


Fig. 1. Map of the study area indicating the selected kebeles in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas/Districts in Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30′ E longitude).

The three main traditional denominations of agro-ecological zones of Ethiopia: the Kolla - lowlands (c. 1400–1800 m.a.s.l.) with relatively low rainfall and high temperatures; the Woinadega - middle highlands (c. 1800–2400 m.a.s.l.) with medium rainfall and medium temperatures; Dega - highlands (c. 2400–3400 m.a.s.l.) with somewhat higher rainfall and cooler temperatures also exist in Tigray and of course in the three study woredas.

The mean annual temperature for Raya Azebo Woreda was 20.8°C and the mean minimum and maximum were 11.8 and 33.5°C, respectively. The hottest months are April and June, while coldest months are from September to December. The mean annual rainfall is 604 mm, which varied greatly from year to year. Generally, the study area has bimodal rainfall pattern, with low rainfall from February to May and the main rainy season (June-

September). Kilite Awelaelo Woreda average daily air temperature of the area ranges between 8°C and 30.1°C with a mean of 19.7°C. The mean annual rainfall of the area is about 610 mm. Kilite Awelaelo Woreda has unimodal rainfall pattern (Fig. 2A and B).

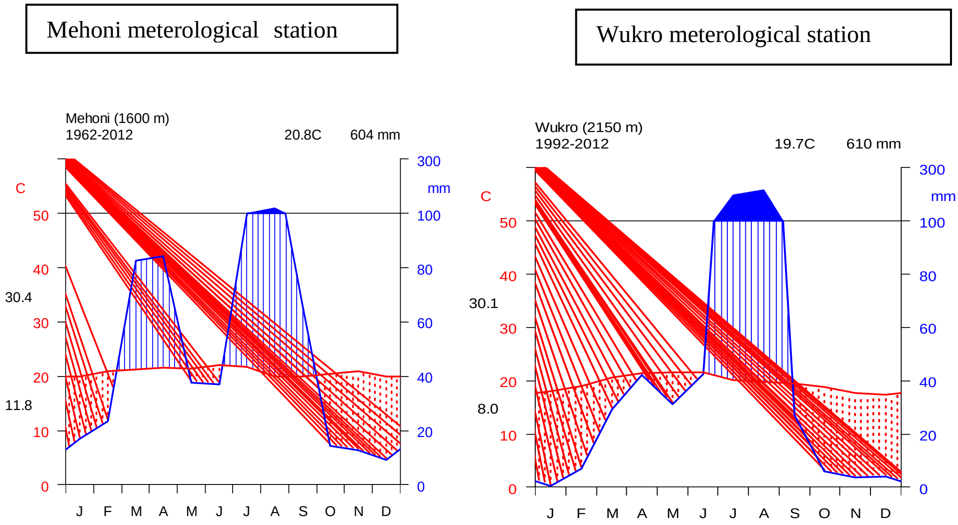


Fig. 2. Climatic diagram of the study area Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30′ E longitude) based on data collected from meteorological stations of Mehoni (A) and Wukro (B) following Walter (1983).

The most common woody vegetation species in the exclosures and in adjacent grazing lands included *Acacia etbaica*, *Acacia seyal*, *Becium grandiflorum*, *Euclea racemosa* subsp. *Schimperi* and *Maytenus senegalensis*. Understory vegetation of exclosures and free grazing lands were dominated by grass species such as *Hyparrhenia hirta* and *Digitaria ternata*.

Soil sampling design and collection

A stratified preferential sampling design technique with the flexible systematic model was used for data collection. Flexible systematic model is a special technique based on the principle of optimum allocation of samples (Smartt, 1978). This method may be viewed as a special form of stratified sampling since samples are allocated on the basis of some predetermined criteria (Kent and Coker, 1992). Local variation of floristic diversity with restoration age was used as a major criterion for sampling. The study area was first divided up into three agro-ecological zones based on altitude before samples were chosen on the basis of size and variation in the landscape. To take representative samples, 30 quadrants were selected from each age class.

Data were gathered from 120 quadrants (90 from restorations or area exclosures of different ages i.e., 10, 15 and 20 years and 30 from adjacent free grazing lands 2–45 ha in size which for soil analysis. Within each site, 3–4 quadrants were taken from the central portions of the restoration and at least 20 m from the edge and covered variations in aspect and slope. From each quadrant, five soil samples (from a depth of 20 cm) were collected from an area of 2 m × 2 m from each corner and center and mixed to produce a composite soil sample, each weighing 0.7–1 kg. One core sample was taken for bulk density analysis. The samples were collected from each position were mixed thoroughly in a large bucket to form a composite soil sample resulting in a total number of the whole samples. The soil samples were air dried by spreading on plastic trays, crushed and sieved with a mesh size of 2 mm. Moreover, surface soil samples from each five subplots were pooled for each main plot and was analyzed for the total Nitrogen (N), available Phosphorus (P), Organic Matter (OM), pH (pH_H_2O), Potassium (K), Calcium (Ca), Magnesium (Mg), Cation Exchange Capacity (CEC) and texture (sand, silt and clay) in addition to soil organic carbon, bulk density and particle size for the soil carbon stock study.

Soil physical and chemical properties

The soil samples were analyzed in the regional soil laboratory of Tigray, following Juo (1978) and Sahlemedhin Sertsu and Taye Bekele (2000). Procedures like pH with potentiometrically in the supernatant suspension of 1:5 soil:liquid mixture; total nitrogen (N) by the Kjeldahl method, Exchangeable calcium (Ca) and magnesium (Mg) was extracted by ammonium acetate (pH 7) using atomic absorption spectrophotometer, and exchangeable potassium (K) and sodium (Na) by leaching with ammonium acetate (pH 7) using flame photometer and available phosphorus (P) was analyzed by Olsen method. Soil organic carbon, bulk density, and particle size were determined using the Walkley-Black method (Walkley and Black, 1934), the core method (Blake and Hartge, 1986) and the hydrometer method (Gee and Bauder, 1982), respectively.

Soil organic carbon and soil nutrient stocks in the 0–0.2 m depth was calculated as follows:

SOC (tC ha^{-1}) = (%C/100) × Bd(Mgm^{-3}) ×depth (m) × 10000 m^2ha^{-1}) or similarly by

SOC (t C ha^{-1}) = WBC (%) × 10 × BD (g cm^{-3}) × 2,

N (tNha^{-1}) = (N(%) × 10^{-2})× Bd(Mgm^{-3}) × depth (m) × 10000 m^2ha^{-1},

Olsen-P (t.P ha^{-1}) = (P (ppm) × 10^{-6}) × Bd (Mgm^{-3}) × depth (m) × 10000 m^2 ha^{-1}

Where SOC, N, Olsen-P, and Bd are soil organic carbon, total soil N, available P, and bulk density, respectively (Veldkamp, 1994).

Organic matter (%) and organic carbon contents (%) were computed using the following equations:

$$OC\ (\%) = \frac{\%OM}{1.724}$$

where OM = organic matter, OC = organic carbon, 1.724 = van Bemmelen factor (i.e. organic matter contains 58% of OC) (Armecin and Gabon, 2008).

Data analysis

Pairwise comparisons of the exclosure age were done for further elaboration using Tukey's HSD (Honestly Significant Difference) test. Paired t-tests was conducted to test for significant differences between each category of exclosures duration and the adjacent free grazing lands. Pearson correlation tests was also undertaken. Four statistical tests were conducted for the normal distribution of the population and homogeneity of the variance. These are Shapiro-Wilk, Bartlett, One Way Analysis of Variance and Kruskal-Wallis tests. The data were analyzed using SPSS ver. 20 and R 3.4.2 software (R Development Core Team, 2017).

RESULTS

Soil nutrient content variability

There was a significant difference ($P<0.05$) for stone cover, grazing, EC, soil organic carbon, and N between the different ages of exclosures and free grazing lands. However, sand, silt clay, slope, CEC, pH, BD, K, P, Mg, and Ca were not significantly different (Table 1 and 2). There was a significant difference ($P<0.05$) for stone cover, EC, soil organic carbon, grazing, and N within the different age groups of exclosures and free grazing lands. However, there was no significant difference ($P>0.05$) within groups or between plots of similarly aged exclosures or free grazing areas. However, sand, silt clay, pH, BD, CEC, K, P, Mg, Na, and Ca were not significantly different both within and between groups (Tables 3–6). These variations are also shown in boxplots in Fig. 3A-L below.

Table 1. Mean values of selected physical and chemical soil properties and site characteristics in area exclosures and free grazing lands studied in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′– 40° 30′ E longitude).

	Stone cover (%)	**pH (1:5 H_2O**	**Bd (gm cm^{-3})**	**Sand (%)**	**Silt (%)**	**Clay (%)**	**EC**	**CEC (Cmol kg^{-1} soil)**	**Exc Na**	**Exc K (Cmol kg^{-1})**	**C %**	**C (ton ha^{-1})**	**N (%)**	**Total N (t ha^{-1})**	**P (PPM)**	**Available P (t ha^{-1})**	**Mg (Cmol kg-1)**	**Ca (Cmol kg^{-1})**
Free G.	60.53	7.33	1.67	41.40	28.73	29.87	0.20	31.61	0.73	4.07	1.04	30.60	0.24	7.38	27.58	0.08	7.81	51.29
10 years	36.87	7.23	1.57	39.13	29.03	31.84	0.24	33.94	0.80	4.56	2.05	39.28	0.25	7.61	28.12	0.10	7.89	54.51
15 years	31.06	7.27	1.52	40.00	29.90	30.10	0.25	37.47	0.96	4.18	2.47	43.91	0.26	9.02	30.24	0.10	7.97	56.91
20 years	28.14	7.12	1.35	41.63	26.00	32.37	0.27	37.52	0.82	3.98	3.56	51.51	0.28	10.31	33.65	0.12	8.61	56.99
Mean	39.15	7.24	1.53	40.29	28.67	31.04	0.23	35.14	0.83	4.20	2.28	41.33	0.26	8.58	29.90	0.10	8.07	54.93
SE	7.35	0.04	0.07	0.64	0.61	0.56	0.02	1.44	0.05	0.13	0.52	4.37	0.01	0.68	1.38	0.01	0.18	1.34
t value	5.32	163.64	22.84	63.07	46.84	55.71	9.65	24.35	17.17	32.90	4.37	9.45	30.16	12.60	21.72	11.66	44.11	40.95
P	0.01	0.07	0.68	0.59	0.86	0.84	0.04	0.06	0.52	0.84	0.01	0.01	0.01	0.01	0.09	0.09	0.15	0.08
Sig.	**						*				**	**	**	**				

Table 1. One way Analysis of Variance for selected physical and chemical soil properties and site characteristics in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′– 40° 30′ E longitude).

		Df	Sum Sq	Mean Sq	F value	Pr(>F)	Sig. codes
as.factor(Exclosure age)-	Altitude	3	208391	69464	0.418	0.741	NS
Residuals		116	19297444	166357			
as.factor(Exclosure age)-	Slope	3	626	208.65	2.578	0.057	.
Residuals		116	9389	80.94			
as.factor(Exclosure age)-	CEC	3	750	250.1	2.453	0.067	.
Residuals		116	11826	102.0			
as.factor(Exclosure age)-	Grazing	3	85.62	28.542	794.6	<2e-16	***
Residuals		116	4.17	0.036			
as.factor(Exclosure age)-	OC	3	6.79	2.263	3.68	0.014	*
Residuals		116	71.34	0.615			
as.factor(Exclosure age)-	Mg	3	11.8	3.942	1.277	0.286	NS
Residuals		116	358.0	3.086			
as.factor(Exclosure age)-	Na	3	0.892	0.2973	1.56	0.203	NS
Residuals		116	22.098	0.1905			
as.factor(Exclosure age)-	EC	3	0.1668	0.05560	4.039	0.009	**
Residuals		116	1.5968	0.01377			
as.factor(Exclosure age)-	N	3	0.0316	0.010528	1.146	0.004	**
Residuals		116	1.0657	0.009			
as.factor(Exclosure age)-	Stone	3	17679	5893.0	77.373	< 2.2e-16	***
Residuals		116	8835	76.2			

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Soil organic carbon, N, EC, grazing and stoniness variation have a significant difference between exclosures and free grazing lands (Table 2). Soil organic carbon and N varied significantly between free grazing lands and 20 years exclosure, while EC varied significantly between free grazing areas vs. exclosures aged 15 and 20 years. Stone cover varied significantly between free grazing and exclosures as well as among exclosures of each age except between exclosures of age 15 vs 20. CEC and slope were also significantly different at P<0.1 only. No difference was observed between free grazing and exclosures on soil pH, BD, sand silt, clay, Ca, K, Mg and available P (Table 2–6).

OC, N, EC, grazing, and stone cover varied significantly (Fig. 3A-L) as exclosure age varied and with some selected parameters that do not have a significant variation with exclosure ages. Results of Shapiro-Wilk normality test, Bartlett test of homogeneity of variances, and of selected variables show significance values for the selected variables and Kruskal-Wallis rank sum test also show that significant values are observed for grazing, EC, stoniness, N and OC.

Table 2. Pairwise comparison of exclosure age based on OC using Tukey HSD in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30′ E longitude).

	Diff	**Lwr**	**Upr**	**p adj**
F-20	-0.43	-0.96	0.1	0.05
F-15	-0.51	-1.04	0.02	0.06
F-10	0	-0.53	0.53	0.56
15-20	0.08	-0.45	0.61	0.98
10-20	-0.43	-0.96	0.1	0.15
10-15	-0.51	-1.04	0.02	0.06

Table 4. Pairwise comparison of exclosure age based on N using Tukey HSD in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30' E longitude).

	Diff	**Lwr**	**Upr**	**p adj**
F-20.	-0.02	-0.08	0.05	0.04
F-15.	0.02	-0.05	0.08	0.08
F-10.	0.02	-0.04	0.09	0.13
15-20.	-0.04	-0.1	0.03	0.42
10-20.	-0.04	-0.1	0.02	0.37
10-15.	0	-0.07	0.06	1

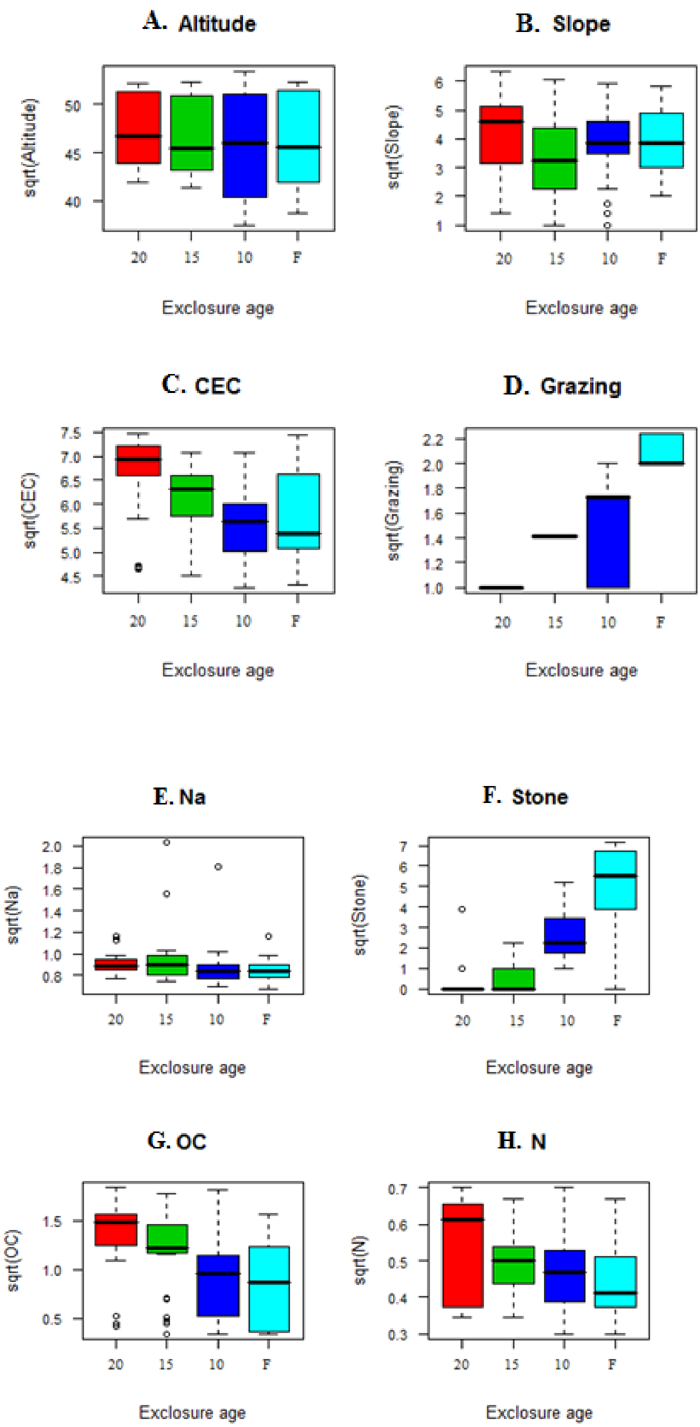
Table 53. Pairwise comparison of exclosure age based on EC using Tukey HSD in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30′ E longitude).

	Diff	**Lwr**	**Upr**	**p adj**
F-20.	0.09	0.01	0.17	0.03
F-15.	0.09	0.01	0.17	0.01
F-10.	-0.01	-0.09	0.07	0.99
15-20.	0.04	-0.04	0.12	0.56
10-20.	0.05	-0.03	0.13	0.41
10-15.	-0.05	-0.13	0.03	0.42

Table 6. Pairwise comparison and exclosure age based on Grazing using Tukey HSD in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30′ E longitude).

	Diff	**Lwr**	**Upr**	**p adj**
F-20.	2	1.87	2.13	0.001
F-15.	2	1.87	2.13	0.001
F-10.	1.83	1.71	1.96	0.01
15-20.	0	-0.13	0.13	1
10-20.	0.17	0.04	0.29	0.02
10-15.	0.17	0.04	0.29	0.01

The environmental data are shown in the soil textural triangles following Lemon (2006), package (plotrix), of the soil samples in Tigray (Fig. 4A and B). Most of the plots are in clay loam category and there is no variation between exclosures and free grazing lands (Fig. 3J, K, and L).


A. Altitude
sqrt(Altitude)
40
45
50
20
15
10
F
Exclosure age
B. Slope
sqrt(Slope)
1
2
3
4
5
6
20
15
10
F
Exclosure age
C. CEC
sqrt(CEC)
4.5
5.0
5.5
6.0
6.5
7.0
7.5
20
15
10
F
Exclosure age
D. Grazing
sqrt(Grazing)
1.0
1.2
1.4
1.6
1.8
2.0
2.2
20
15
10
F
Exclosure age
E. Na
sqrt(Na)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
20
15
10
F
Exclosure age
F. Stone
sqrt(Stone)
0
1
2
3
4
5
6
7
20
15
10
F
Exclosure age
G. OC
sqrt(OC)
0.5
1.0
1.5
20
15
10
F
Exclosure age
H. N
sqrt(N)
0.3
0.4
0.5
0.6
0.7
20
15
10
F
Exclosure age

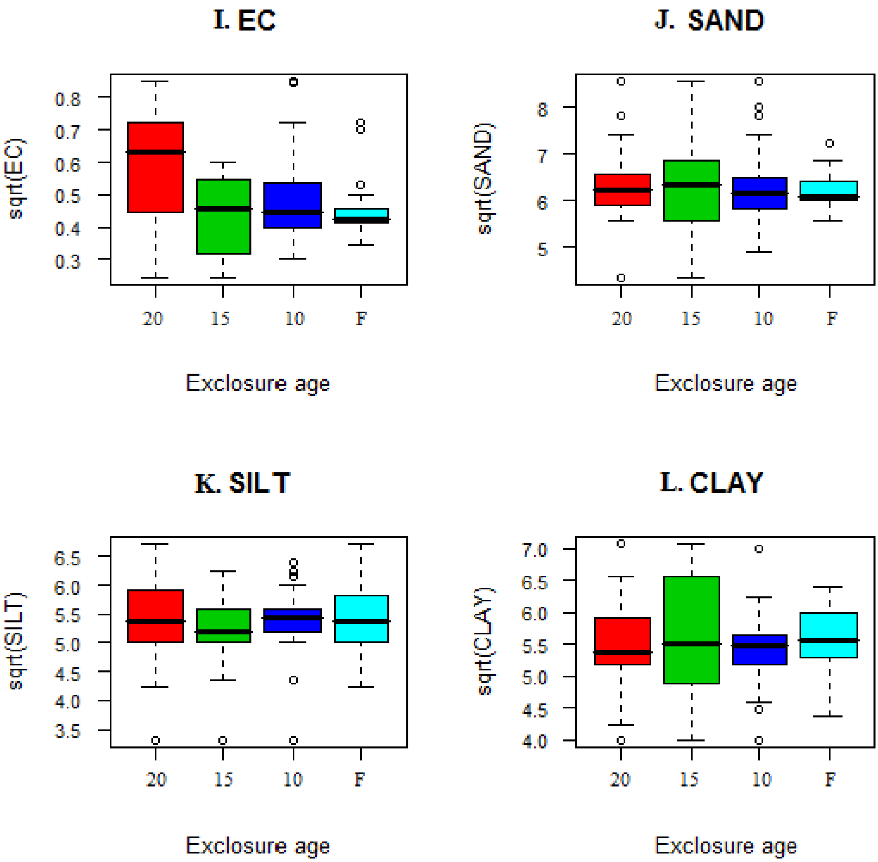


Fig. 3A-L. Comparison of differences among means using boxplot.

Soil nutrient content variables and exclosure ages

The result indicated that exclosure ages were positively correlated with sand, Na, CEC, Ca, Mg, N, and OC, and were inversely correlated with grazing, silt, clay, pH, EC, K, P, BD and stoniness (Table 7). Altitude was positively correlated with sand, pH, Na, CEC, K, N, P and stoniness and was negatively correlated with silt, clay, EC, Mg, Ca and BD. Exclosure ages were significantly correlated with CEC, Na, OC, N, and Mg positively and with stoniness negatively all the other parameters were not statistically significant (Table 7).

Table 74. Pearson correlation between exclosure age and different soil and site characteristics (N = 120) in Atsbi Wemberta, Kilte Awelaelo and Raya Azebo Woredas of Tigray, Ethiopia (12°–15° N latitude and 36° 30′–40° 30′ E longitude).

		Na	**CEC**	**Mg**	**N**	**Stone**	**OC**
Na	Pearson Correlation	1	0.03	0.09	-0.11	-0.10	0.02
	Sig. (2-tailed)		0.72	0.36	0.22	0.27	0.86
CEC	Pearson Correlation		1	-0.03	-0.11	-0.09	0.09
	Sig. (2-tailed)			0.76	0.24	0.29	0.28
Mg	Pearson Correlation			1	0.05	0.018	0.01
	Sig. (2-tailed)				0.57	0.84	0.94
N	Pearson Correlation				1	-0.05	0.92*
	Sig. (2-tailed)					0.56	0.04
Stone	Pearson Correlation					1	-0.06
	Sig. (2-tailed)						0.54
OC	Pearson Correlation						1
	Sig. (2-tailed)						
Exclosure age	Pearson Correlation						
	Sig. (2-tailed)						

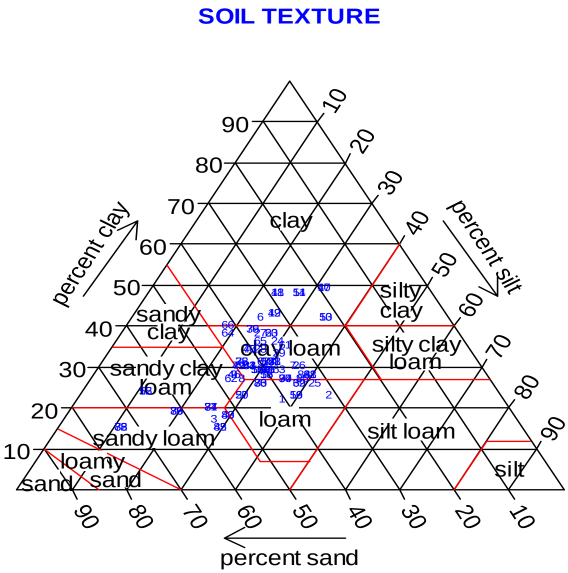
DISCUSSION

Area exclosures and the adjacent grazing lands

The inherent assumption of our space-for-time substitution approach is that exclosures and the adjacent free grazing lands had similar conditions before the area was put under exclosure establishment. In this study, we tested this assumption using variables measured in exclosures and grazing lands that are less dependent on land use (e.g. soil texture) (Fig. 4A and B) and we observed no difference in soil texture between any of the exclosures and free grazing lands (Fig. 3J, K, and L). This indicates that the sites were comparable and were mainly caused by land use change and not by inherent site variability.

The range of precipitation, slope, and soil type included in our study is typical of the highlands of northern Ethiopia. This is due to the fact that more than 80% of the northern highlands of Ethiopia receive annual rainfall between 500 and 800 mm yr^{-1} (Pender and Berhanu Gebremedhin, 2008). Also, the areas which are used for free grazing lands and areas where exclosures are established and have an average slope of greater than 30% and have an abundant stone cover (Descheemaeker *et al*., 2006). Moreover, the majority of the northern highlands in Ethiopia are characterized by degraded soil and vegetation conditions (Betru Nedessa *et al*., 2005).

A. Exclosure



B. Free Grazing Land

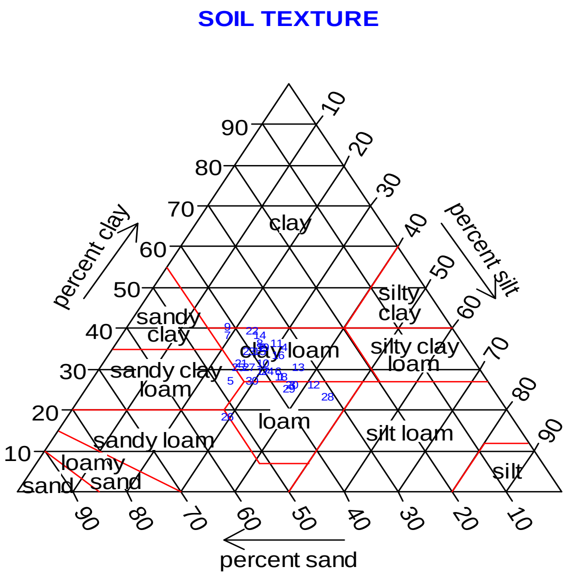


Fig. 41A and B. Soil texture triangle using library plotrix for exclosures and free grazing lands.

Soil chemical properties of an open grazing versus exclosure

The free grazing lands investigated in this study displayed different degrees of land degradation, which is illustrated by the variation in soil nutrient content and properties. The variation in soil degradation among the studied free grazing lands could arise from the difference in the interference of human and domestic grazing animals, which consequently resulted in different degrees of vegetation degradation.

The insignificant correlation of soil nutrient content in free grazing lands indicates that free grazing influenced soil nutrient restoration through reducing organic input to the soil. Other studies also indicated that a direct impact of grazing on rangeland ecosystems is the removal of a major part of the aboveground biomass, consequently the input of the aboveground litter to the soil decreases, which may have important consequences for soil nutrient conservation and cycling (Savadogo *et al*., 2007). Furthermore, livestock grazing could deteriorate hydrological soil properties, mainly structure of the soils, consequently reducing the rate of the microbial process and nutrient retention (Neff *et al*., 2005).

The exclosures and adjacent free grazing lands had similar conditions before exclosure establishment. The higher soil nutrient content in all exclosures indicates that the exclosures have a significant positive effect on the restoration of degraded soils. Similar results were reported from case studies conducted on exclosures established within the last two decades in the Central Highlands of Ethiopia: An increase of 0.67% organic matter, 8.85 mg kg^{-1} increase in available P, and 9.18 cmolc kg^{-1} increases in CEC after 9 years of exclosure was reported by Mamo Kebede *et al*. (2007). Similarly 2.33%, 0.08%, 7.89 cmolc kg^{-1} increases in organic matter, total soil N, and CEC, respectively, were reported after 20 years of exclosure establishment (Abiy Tsetargachew, 2008).

The considerable differences in soil nutrient content and properties between exclosures and free grazing lands can be explained either by increased grazing pressure in the reduced areas of free grazing lands after establishment of exclosures and susceptibility to erosion due to sparse vegetation cover or by increased vegetation cover in the exclosures, which would reduce soil erosion and increase organic matter input into the soil. In contrast to our study, Abiy Tsetargachew (2008) found a higher value of available phosphorous (9.96 mg kg^{-1}) in free grazing land compared with the 20 year-old exclosure (9.33 mg kg^{-1}). This variation could arise from the less dependence of farmers in Central Highlands of Ethiopia on the use of cow dung which emanates from the fact that communities make an extensive use of dung to meet their household energy demand compared with farmers living in the northern highlands of Ethiopia where the natural vegetation has entirely disappeared, which has resulted in increased dependence on the use of cow dung and crop residues for household energy demand (Zenebe Gebreegziabher, 2007). This, in turn, has resulted in the removal of all cow dung from the free grazing lands and reduction of organic inputs and soil nutrients to the soil.

Soil nutrient content, mainly the total soil N, OC and P restoration, was also influenced by exclosure age. This may have resulted from the management rule that restricts grass harvesting after exclosure establishment and subsequently, from increased organic matter input derived from herbaceous species biomass, from reduced soil erosion through effective ground cover, and from relatively slow decomposition under drier and cooler climate condition (Mekuria Wolde *et al*., 2009).

The correlation of soil nutrient content and soil properties in exclosures indicate that exclosures influence soil nutrient content and soil properties through a higher organic matter input into the soil through time. Other studies also reported increasing soil nutrient retention in ecosystem along with the number of plant species and aboveground biomass (Loreau *et al*., 2001). Furthermore, the increase in canopy cover with the increase in exclosure time could decrease sediment-associated soil nutrient losses by reducing the erosive impact of raindrops and soil erosion (Abiy Tsetargachew, 2008; Girmay Gebresamuel *et al*., 2009; Mekuria Wolde *et al*., 2009).

The incorporation of black carbon through the burning of dry vegetation is also practiced on grazing lands like cultivated lands in some parts of the study area. Recent research indicated that incorporation of black carbon significantly increases soil CEC (Liang *et al*., 2006).

What is expected from the land without incorporation of black carbon is lower CEC value, and we found a comparable CEC value for grazing land just like exclosures and in plots of free grazing lands. CEC did not show a significant difference between the exclosures and free grazing lands. This may be attributed to black carbon addition on grazing land as changes in soil management practices influence the amount, quality and turnover of soil organic matter of an area (Glaser *et al*., 2000).

There was a significant difference ($P<0.05$) for stoniness cover, EC, soil organic carbon and total nitrogen among the land use types. However, available phosphorus and exchangeable sodium and potassium were not significantly similar to altitude, slope, CEC, sand, silt, and clay.

There was also insignificant difference between grazing area and exclosure on soil pH value. Both soil organic carbon and total nitrogen significantly varied between the two land use types at $P<0.05$ and are strongly positively correlated. Free grazing lands had the lowest soil organic carbon and total nitrogen. The continuous grazing and associated human impacts in free grazing and less vegetation cover have been suggested to facilitate erosion. Erosion not only affects the level of carbon and nitrogen but also affects other nutrients and soil physical properties.

Foth and Ellis (1997) reported that soils with C:N ratio in the range of 10 to 12 provide nitrogen in excess of the microbial need. Therefore, the result obtained in 20 years exclosure is in the optimum range for active microbial activities such as humification and mineralization of organic residue. Although there was no significant difference in available P between land use types, the current level in the soil is enough to support plant growth. Also, exchangeable K and Na exhibit a similar trend.

CONCLUSION

This study showed that the establishment of exclosures on degraded free grazing lands in the northern highlands of Ethiopia is effective in improving soil nutrient content and properties. It also confirmed that it is possible to generate baseline information and to make a quantitative prediction of the changes in soil nutrient content after the establishment of exclosures using relatively simple field measurements. Such information is critical for evaluating the ecological importance of exclosures and to assist policymakers to consider the value of exclosures in natural resource planning and management. Further studies are needed to investigate the degree to which nutrient enrichment in exclosures is due to soil and nutrient deposition from surrounding areas, as this may affect the sustainability of scaling up the area of exclosures.

There was a significant difference for EC, soil organic carbon and total nitrogen among the land use types. The lowest carbon and nitrogen level of soil was recorded in free grazing lands. Cation exchange capacity, available phosphorus and exchangeable sodium and potassium were statistically insignificant among exclosure and grazing land.

During fieldwork, it was observed that there were efforts to guard the forest land in the study area from encroachment. However, conversion of vegetated land to cultivation land in steeper slopes was also prevalent. Therefore, unless a solution is devised to strongly protect the hillsides covered with vegetation, the process will increase erosion hazard from the catchment. This, in turn, will have an adverse impact on the long-term ecological balance of the area.

Based on the study findings, the following recommendations were drawn. Focusing on environmentally friendly activities - since all economic activities could not affect the natural regeneration, those activities should be carefully studied and encouraged. The activities like beekeeping should be given more attention and conditions should be facilitated in order to maximize the economic return. To fulfill this, the traditional way of beekeeping should be replaced by modern honey production. We assume that if the modern honey production is going to reduce the economic pressure on the population, the degree of impact on the natural forest and in exclosures will be reduced. Therefore, focusing and encouraging such economic activities which are environmentally benign is very important. Considering exclosures as Green Development Mechanism projects and thereby generating financial compensation to support the local communities in their efforts to restore free degraded lands might be a way to increase economic benefits for local communities. However, as carbon market revenues will hardly be sufficient to make exclosures competitive to other land uses, additional (e.g. public) funds could be a means to reward soil restoration services, thereby ensuring future nutrient availability. Special attention should be given to solve the shortage of grazing land due to exclosure so as to encourage community's interest in expanding and managing exclosure practices in their locality. Policy issues such as awareness creation among respective stakeholders would be important in an attempt to implement soil and water conservation practices and community natural resources management in sustainable way, in addition to measures which could enhance the process of restoration measures in area exclosures, such as planting of trees and using assisted natural regeneration methods.

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