Soil Organic Carbon and Nutrient Contents are not influenced by Exclosures Established in Communal Grazing Land in Nile Basin, Northern Ethiopia

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Abstract**—**Land degradation through extensification of agriculture and overgrazing is an increasing problem across large expanses of the Ethiopian highlands that give rise to a loss in a range of ecosystem services. Ecological restoration through exclosure establishment has become increasingly important approach to reversing degraded ecosystems in Ethiopia and particularly in the Amhara regional state, northern Ethiopia. The present study was conducted in Nile basin, northern Ethiopia to investigate the changes in soil properties and nutrient contents following establishing exclosures on communal grazing lands. A space-for-time substitution approach to monitor changes in soil properties after conversion of communal grazing lands to exclosures with ages of establishment ranging from 1 to 7-years was used. In the 0- to 20- and 20- to 50-cm depths, significant ($p < 0.05$) differences in soil pH, exchangeable cations, cation exchange capacity, soil moisture content, and bulk density were observed among exclosures and between exclosures and communal grazing land. Communal grazing land displayed significantly higher soil total nitrogen, phosphorus and potassium compared to exclosures. However, differences between exclosures and grazing land in soil organic matter (SOM) content and soil organic carbon (SOC) stock were not significant ($p > 0.05$). The results demonstrated that exclosure age influenced SOM content and SOC stock. The lack of influence in soil nutrient and SOM contents as well as SOC stock after 7-year of exclosure establishment could be attributed to: (a) the favorable environment (e.g., better moisture content and soil pH) in exclosures, which results in increased SOM decomposition, and (b) better vegetation growth in exclosures, which consequently reduce soil nutrient content due to higher nutrient uptake by restored plants. Exclosures alone therefore cannot be regarded as a comprehensive short- or medium-term soil rehabilitation option.

Keywords**—**Belowground carbon, soils, ecosystem services, environmental degradation, exclosure age, restoration.

I. Introduction

LAND degradation resulting from land uses or processes arising from human activities, has a strong impact on ecosystems and the services that they provide [1], [2]. In Ethiopia, land resources are facing intense degradation as a consequence of deforestation, agricultural land expansion and overgrazing [3], [4]. Ecological restoration, which aims to restore disturbed ecosystems, has been an important approach to mitigate human pressures on natural ecosystems [5], and reversing degraded ecosystems [6], [7]. Consequently, restoration of degraded ecosystems through establishing exclosures has become increasingly important in Amhara regional state, northern highland of Ethiopia [8].

Exclosures are areas closed from the interference of human and domestic animals, with the goal of promoting natural regeneration of plants and reducing land degradation of formerly degraded communal grazing lands [9]. The inception of exclosure land management at a watershed level started in 2005 when 25 watersheds were selected and supported within the framework of the Sustainable Utilization of Natural Resources for Improved Food Security (SUN) Program [8]. As part of the SUN program, communities in the Gomit watershed (i.e., the study site), established exclosures on communal grazing lands in 2006 [10]. Detail information on the identification of priority areas, the management and use of the exclosures in the Gomit watershed, and planning and implementation of watershed development activities are discussed in [10].

Few case studies conducted in the highlands of Ethiopia have shown that exclosures can be effective in restoring degraded soils and increase soil carbon (e.g., [9], [11]. However, studies on the impact of exclosures on soil properties and soil carbon are not consistent. For example, [12] reported an increase in soil carbon following the establishment of exclosures on grazing lands, while [13] demonstrated a decrease in soil carbon. In addition, most of these studies were performed outside Africa. This, together with the inconclusiveness of the evidence indicates that there is a need to study the changes in soil properties and soil carbon following the establishment of exclosures.

Such information is critical for evaluation of existing exclosures, designing ways of improving soil properties and soil carbon through exclosure establishment and for deciding whether additional exclosures should be established. Such understanding would help: (1) inform land managers working

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on the restoration of degraded ecosystem to improve ecosystem services, and (2) maximize carbon sequestration and other ecosystem services from existing exclosures established in degraded ecosystems. The present study was conducted in Gomit watershed, northern Ethiopia to: (1) investigate the changes in soil chemical and physical properties following the establishment of exclosures on communal grazing lands over different time periods, and (2) investigate the changes in soil nutrient and soil carbon contents. We hypothesized that exclosures can be effective in restoring degraded ecosystems and improving soil properties.

II. Materials and Methods

A. Study Area

The study was conducted in Gomit watershed located in Libo Kemkem district, South Gondar administrative zone of Amhara region in Northwestern Ethiopia (Fig. 1). Gomit watershed covers an area of 1,483 ha [8]. The total beneficiary population consists of 360 households. As in other parts of the Amhara region, agriculture is the predominant sector of the economy in the Gomit watershed. The agricultural sector is primarily dependent on smallholder farming. The average farm size is 0.82 hectare per household. Smallholders cultivating fragmented micro-holdings produce more than 95% of the annual agricultural output [8]. Mixed crop–livestock farming is the backbone of household livelihoods at the study site.

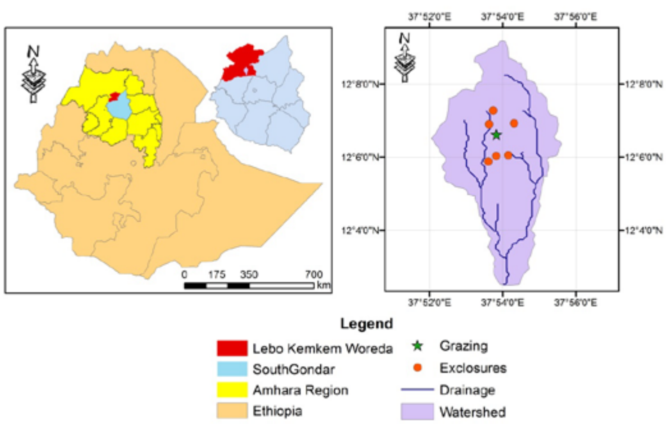

Fig.1 Study area with the location of the study sites indicated in right.

In response to natural resource degradation problems, the communities in Gomit watershed are organized as an association and started land rehabilitation efforts through exclosure establishment and construction soil water conservation (SWC) practices since 2006 [10]. To ensure the sustainable management of exclosures and protection of the SWC structures, the Gomit watershed association together with the community watershed team (CWT) drafted a bylaw based on a model provided by the SUN program. Detail information regarding drafting and approval of the law are provided in [10].

We selected 1-, 2-, 3- 4-, 5-, and 7-year old exclosures as well as a communal grazing land as a control treatment. The area of the exclosures ranged from 2.4 to 14.0 ha while the communal grazing land covers an area of 3.6 ha (Table 1). Existing management activities in exclosures and communal grazing land are described in [10].

TABLE I
BASIC CHARACTERISTIC OF THE EXCLOSURES AND GRAZING LAND.

Study sites	Exclosure age (Years)	Area (ha)	Canopy cover (%)	% coverage of soil types		
				Leptosols	Luvisols	Fluvisols
Grazing land	NA	3.6	3.2 ±4.0)	--	100	--
Atikuwarit	One	2.4	0.5 ±4.0)	--	100	--
Markos	Two	3.2	4.0(±16.0	--	85	15
Kikibe	Three	3.6	5.2 (±5.0)	--	100	--
Enkuro-fej	Four	4.7	0.4 (±9.0)	20	80	--
Tinkish	Five	12.7	7.2 (±4.0)	35	65	--
Deldalit	Seven	14.0	9.2(±18.0	--	--	100

According to the Ethiopian climate classification, Gomit watershed has a "Woina Dega[3]" tropical continental climate. The mean annual rainfall (for the years 1992-2006) was 1148 mm yr^{-1}. The mean minimum temperature was 11.8 °C, while the mean maximum temperature was 27.0 °C. The altitude of the study sites ranges from 1963 to 2056 m a. s. l. The rainy season usually occurs between June and September in which 87 % of the rainfall occurs [10]. Major land uses in the watershed include cultivated lands (23% of the area), degraded secondary forest lands (53%), communal grazing lands (18%) and other uses (6%).

Soils of the study sites were classified into three major groups: Chromic Luvisols, Eutric Fluvisols and Eutric Leptosols (Table 1). The most common indigenous woody vegetation species in exclosures and communal grazing land include *Euclea racemosa subsp. schimperi,(A. Dc.) Dandy, Calpurnia aurea (Alt.) Benth.* and *Dodonaea angustifolia (L.f.).* Understory vegetation of the exclosures and communal grazing land were dominated by grass species such as *Hyparrhenia hirta, (L.) Stapf., Delphinium dasycaulon and Delphinium dasycaulon.* Woody species vegetation cover in exclosures and communal grazing land is provided in Table 1.

B. Experimental Design

We used a space-for-time substitution approach to monitor changes in soil properties and soil carbon stock after conversion of communal grazing lands to exclosures with ages of 1-, 2-, 3-, 4-, 5-and 7 year old. In each exclosure and grazing land, three transects spaced at a minimum distance of 50 m were established (Fig. 2). Along each transect, three landscape positions (upper slope, mid-slope and foot slope) were delineated. At each landscape position, a sampling plot of 20 m × 20 m was established. In each 20 m × 20 m plot,

[3] Woina dega (Subtropical zone) - includes the highlands areas of 1830 - 2440 meters above sea level with an average annual temperature of about 22°C and annual rainfall between 510 and 1530 mm.

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soil samples were collected at four sampling points (Fig. 2). Landscape position was included in our sampling design to characterize the effects of topography-related processes on soil properties and soil carbon. Soil, vegetation and management-related data were collected from September to December 2013.

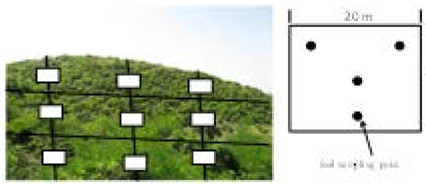


Fig. 2 Experimental design of the soil and vegetation sampling in exclosures

C. Soil Sampling and Laboratory Analysis

In each 20- by 20-m plot, soil samples at the 0- to 0.2- and 0.2- to 0.5-m depths were collected at four sampling points (Fig. 2). One soil sample was also taken from each plot for bulk density determination. The samples collected from each plot (i.e., four sampling points) were mixed thoroughly in a large bucket to form one composite soil sample per plot. During the entire study, we collected a total of 126 composite soil samples (i.e., [7 (sites) × 9 (plots per site) × 2 (sampling depths)] = 126). The soil samples were air dried, sieved through a 2-mm sieve, and ground before analysis. Soil organic C, total soil nitrogen, total phosphorus, and total potassium were analyzed using the modified Walkley–Black method [14], Kjeldahl method [15], Olsen method [16], and sodium acetate method [17] respectively. Exchangeable cations and cation exchange capacity were determined using ammonium acetate method [17]. Bulk density was measured using the core method [18], particle size was determined using the hydrometer method [19], soil pH was determined using a 1:1 soil water suspension. Soil organic C stocks (Mg C ha^{-1}) in the 0- to 0.2-m and 0.2- to 0.5-m depths were calculated as:

$$SOC = \frac{C}{100} \times Bd \times depth\,(m) \times 10{,}000\ m^2\ ha^{-1}$$

Where Bd is the bulk density (Mg m^{-3}) and *C* is the soil carbon concentration (%). The average bulk density of the oldest exclosure was used to calculate the soil organic C stock in all exclosures and grazing land. We used this conservative approach to avoid overestimation of the soil organic C stock due to changes in bulk density [20].

D. Data Analysis

The differences among exclosures and between an exclosure and grazing land in soil properties and soil C stock were assessed using one-way analysis of variance (ANOVA). Significance of differences between treatment means was tested using Turkey Honest Significance Difference test with $p < 0.05$. Pearson correlation test was used to analyze the relationship between inherent soil properties, vegetation parameters and soil organic carbon and nutrient contents.

III. Results

A. Soil Properties in Exclosures and Communal Grazing Land

In the 0- to 0.2-m depth, the relatively oldest exclosures (i.e., 4- to7-year old exclosures) displayed significantly ($p < 0.05$) higher soil pH when compared to the soil pH in communal grazing land and 2-year old exclosure (Table 2). Five year old exclosure displayed significantly higher exchangeable magnesium (Mg^{++}) content compared to the Mg^{++} in communal grazing land and 1-year old exclosure. Communal grazing land showed significantly higher exchangeable potassium (K^{+}) compared to 1- and 7-year old exclosures whereas 3-year old exclosure displayed significantly higher exchangeable sodium (Na^{+}) compared to the Na^{+} in other studied sites (Table 2). Exclosures did not display significantly higher cation exchange capacity (CEC) when compared to the CEC in communal grazing land. However, significant ($p < 0.05$) differences among exclosures in CEC were observed (Table 2). In the 0.2- to 0.5-m depth, similar trends were observed except that 5-year old exclosure displayed significantly ($p < 0.05$) higher exchangeable calcium (Ca^{++}) compared to the Ca^{++} in 1- and 7-year old exclosures (Table 2).

In the 0- to 0.2- and 0.2- to 0.5-m depths, the oldest exclosure (i.e., 7-year old exclosure) displayed significantly ($p < 0.05$) higher soil moisture content when compared to the soil moisture content in youngest exclosures and communal grazing land (Fig. 3). However, bulk density was significantly higher in communal grazing land than the values in exclosures (Fig. 3). Differences in soil texture among sites were not significant ($p > 0.05$) (Table 2).

B. Soil Nutrient Contents and Organic Matter in Exclosures and Communal Grazing Land

In the 0- to 0.2-m depth, the TN content in communal grazing land was significantly ($p < 0.05$) higher than the TN content in 1-, 3-, 4-, and 7-year old exclosures, while the TP content in communal grazing land was significantly higher than the TP content in 1- and 4-year old exclosures (Table 3). In the 0.2- to 0.5-m depth, significant differences between communal grazing land and exclosures in TN and TP; and among exclosures in TN, TP and TK were observed (Table 3).

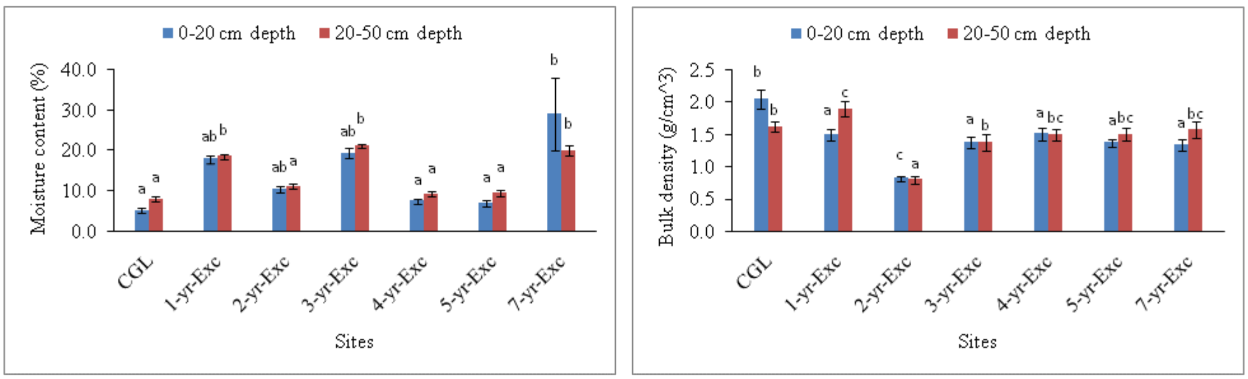
In addition, soil organic matter (SOM) content in the 0- to 0.2-m depth was higher in communal grazing land when compared to the OM content in exclosures (Table 3). However, differences were not significant ($p > 0.05$). In the 0.2- to 0.5-m depth, the highest organic matter content was observed in 2- and 4-year old exclosures (Table 3) though differences between exclosures and communal grazing land were not significant. Differences among exclosure in SOM content were significant (Table 3).

TABLE II

Average (± SE, n = 9) Soil Chemical and Physical Properties in the 0- to 20 and 20- to 50-cm Depths in Exclosures and Communal Grazing Land.

Sites	EC (mS/cm)	Soil pH (H2O)	Ca^{++} (mg/lt)	Mg^{++}	K^{+}	Na^{+}	CEC (meq/100gm)	Sand (%)	Silt	Clay
In the 0- to 0.2-m depth										
CGL	0.2 (±0.0)	6.4 (±0.2)^{a}	18.5(±1.0)	2.8(±0.2)^{a}	4.8(±2.0)^{b}	1.2(±0.2)^{a}	37.3(±1.3)^{bc}	57.6(±2.8)	18.2(±2.5)	24.2(±1.8)
1-yr-Exc	0.3(±0.1)	7.0(±0.2)^{ab}	16.0(±1.1)	3.0(±0.4)^{ac}	0.5(±0.2)^{a}	1.0(±0.2)^{a}	31.8(±2.1)^{ab}	54.6(±2.6)	19.0(±0.8)	26.4(±2.3)
2-yr-Exc	0.1(±0.0)	6.5(±0.1)^{a}	21.2(±1.9)	3.3(±0.2)^{ab}	2.1(±0.4)^{ab}	1.0(±0.2)^{a}	38.3(±2.3)^{bc}	54.7(±2.5)	16.6(±1.6)	28.9(±2.0)
3-yr-Exc	0.2(±0.1)	6.9(±0.2)^{ab}	23.4(±2.2)	4.2(±0.5)^{bc}	1.5(±0.3)^{ab}	2.8(±0.6)^{b}	42.0(±2.6)^{c}	58.2(±3.8)	19.0(±1.6)	22.8(±2.3)
4-yr-Exc	0.1(±0.0)	7.2(±0.1)^{b}	18.6(±1.5)	3.8(±0.3)^{ab}	1.6(±0.6)^{ab}	1.6(±0.7)^{ab}	35.4(±1.5)^{abc}	56.9(±2.6)	19.8(±1.5)	23.3(±1.9)
5-yr-Exc	0.4(±0.1)	7.3(±0.1)^{b}	25.4(±1.6)	4.6(±0.4)^{b}	1.5(±0.2)^{ab}	0.4(±0.1)^{a}	42.5(±3.1)^{c}	56.7(±3.3)	18.1(±1.8)	25.1(±1.7)
7-yr-Exc	0.2(±0.1)	7.2(±0.1)^{b}	30.9(±17.4)	3.2(±0.2)^{ab}	0.5(±0.2)^{a}	1.2(±0.3)^{a}	26.6(±1.6)^{a}	57.3(±3.4)	18.0(±1.1)	24.9(±2.4)
In the 0.2- to 0.5-m depth										
CGL	0.1(±0.0)^{a}	6.1(±0.1)^{a}	19.1(±1.3)^{ab}	2.8(±0.2)^{a}	1.9(±0.4)^{ab}	1.0(±0.1)^{ab}	37.7(±1.4)^{ab}	57.3(±3.4)	18.1(±2.4)	24.6(±2.1)^{a}
1-yr-Exc	0.6(±0.1)^{b}	7.0(±0.2)^{b}	14.1(±2.0)^{a}	3.5(±0.4)^{ab}	0.4(±0.1)^{a}	0.5(±0.1)^{a}	30.2(±1.4)^{a}	59.0(±2.2)	18.9(±0.8)	22.1(±1.6)^{a}
2-yr-Exc	0.1(±0.0)^{a}	6.5(±0.1)^{a}	19.2(±0.3)^{ab}	3.5(±0.2)^{ab}	3.9(±1.5)^{b}	0.9(±0.1)^{ab}	40.0(±2.0)^{b}	48.2(±2.2)	17.3(±1.7)	34.4(±2.1)^{b}
3-yr-Exc	0.1(±0.0)^{a}	6.4(±0.1)^{a}	24.1(±2.8)^{b}	4.1(±0.4)^{bc}	1.7(±0.7)^{ab}	1.9(±0.3)^{b}	40.4(±3.6)^{b}	51.6(±4.0)	23.3(±2.0)	25.1(±2.7)^{ab}
4-yr-Exc	0.1(±0.0)^{a}	7.1(±0.0)^{b}	19.6(±1.4)^{ab}	3.9(±0.3)^{ab}	0.8(±0.3)^{a}	1.2(±0.6)^{ab}	36.2(±1.4)^{ab}	52.8(±3.5)	20.8(±1.5)	26.4(±2.3)^{ab}
5-yr-Exc	0.3(±0.1)^{a}	7.2(±0.1)^{b}	25.6(±1.1)^{b}	4.7(±0.3)^{b}	1.8(±0.4)^{ab}	0.7(±0.1)^{ab}	39.7(±2.1)^{ab}	53.9(±3.5)	18.1(±1.5)	28.0(±2.4)^{ab}
7-yr-Exc	0.3(±0.1)^{a}	7.2(±0.1)^{b}	14.0(±0.6)^{a}	3.2(±0.2)^{ac}	0.5(±0.2)^{a}	1.2(±0.2)^{ab}	31.8(±2.8)^{ab}	56.4(±2.4)	17.6(±0.8)	27.1(±2.0)^{ab}

Note: - Ca++, Mg++, K+, Na+ and CEC refer to exchangeable calcium, magnesium, potassium, sodium; and cation exchange capacity respectively.
-Different letters in the same column indicate significant difference among means after Turky Honest Significance (THS) test with $p < 0.05$.



(a) *(b)*

Fig. 3 Average (± SE, n = 9) soil moisture content (a) and bulk density (b) in the 0- to 0.2- and 0.2- to 0.5-m depths in exclosures and communal grazing land.

TABLE III

AVERAGE (± SE, N = 9) SOIL ORGANIC MATTER AND NUTRIENT CONTENT IN THE 0- TO 20 AND 20- TO 50-CM DEPTH IN EXCLOSURES AND COMMUNAL GRAZING LAND.

Sites	Total N (mg/100g)	Total P (ppm)	Total K (mg/kg)	OM (%)
In the 0- to 0.2-m depth				
CGL	275.5(±33.6)^{b}	97.0(±33.3)^{b}	26.2(±5.0)	4.7(±0.5)
1-yr-Exc	177.5(±17.2)^{a}	17.9(±2.6)^{a}	16.7(±6.0)	3.4(±0.3)
2-yr-Exc	244.2(±20.4)^{ab}	79.8(±15.1)^{b}	37.3(±11.0)	5.1(±0.5)
3-yr-Exc	157.0(±21.7)^{a}	51.7(±6.6)^{ab}	45.7(±10.4)	3.5(±0.5)
4-yr-Exc	177.1(±16.3)^{a}	13.7(±3.1)^{a}	35.2(±13.1)	4.6(±0.3)
5-yr-Exc	249.4(±30.1)^{ab}	41.7(±8.7)^{ab}	47.7(±6.5)	4.6(±0.7)
7-yr-Exc	162.5(±9.0)^{a}	36.7(±9.3)^{ab}	15.5(±4.9)	3.4(±0.1)
In the 0.2- to 0.5-m depth				
CGL	215.2 (±30.4)^{b}	69.3(±13.8)^{bc}	24.8(±6.6)^{ab}	3.6(±0.4)^{abc}
1-yr-Exc	126.2(±18.4)^{ac}	13.0(±1.6)^{a}	12.3(±3.8)^{a}	2.4(±0.3)^{ac}
2-yr-Exc	221.8(±15.3)^{b}	91.2(±17.0)^{b}	41.1(±5.9)^{ab}	4.4(±0.4)^{b}
3-yr-Exc	85.5(±11.6)^{a}	45.1(±9.4)^{ac}	30.2(±9.7)^{ab}	2.2(±0.3)^{a}
4-yr-Exc	176.7(±10.5)^{bc}	10.3(±1.7)^{a}	26.0(±9.4)^{ab}	4.4(±0.3)^{b}
5-yr-Exc	215.6(±23.5)^{b}	42.2(±8.3)^{ac}	55.0(±11.1)^{b}	3.7(±0.4)^{bc}
7-yr-Exc	154.3(±20.5)^{abc}	39.1(±9.7)^{ac}	16.6(±5.0)^{a}	3.1(±0.1)^{abc}

Note: *-Different letters in the same column indicate significant difference among means after Turky Honest Significance (THS) test with $p < 0.05$.*

C. Soil Organic Carbon Stock in Exclosures and Communal Grazing Land

At both depths, we did not observe significant differences between exclosures and communal grazing land in soil C stock. However, in the 0.2- to 0.5-m depth, the 2-, 4- and 5-year old exclosures displayed significantly ($p < 0.05$) higher soil organic carbon (SOC) stock when compared to the SOC stock in the 1- and 3-year old exclosures (Fig. 4). In addition, the 2- and 4-year old exclosures were displayed significantly higher SOC stock in the 0- to 0.5-m depth when compared to the soil C stock in the 1- and 3-year old exclosures (Fig. 4).

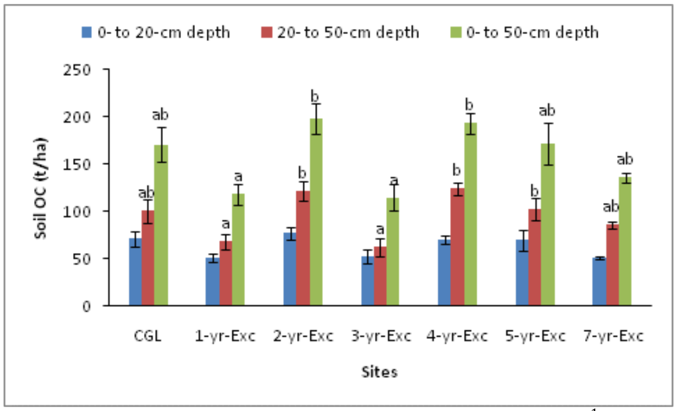


Fig. 4 Average (± SE, n = 9) soil organic carbon stock (t ha^{-1}) in the 0- to 0.2-, 0.2- to 0.5-, and 0- to 0.5-m depths in exclosures and communal grazing land.

IV. Discussion

The inherent assumption of our space-for-time substitution approach is that the exclosures and communal grazing land had similar conditions before exclosure establishment. This argument was supported by the similarities of exclosures and communal grazing land in major soil types (Table 1); and the insignificant differences in soil inherent properties such as soil texture (Table 2). Thus, in general, the exclosures and communal grazing land were comparable and the changes in soil properties, nutrient content and SOC stock following exclosures establishment caused by land use change and not by inherent site variability. References [9] and [21] also tested comparability of sites using soil variables that are less dependent on land use.

The significantly higher soil nutrients content in communal grazing land compared to exclosures (Table 3) could be attributed to better vegetation growth in exclosures [10], increased vegetation cover (Table 1), and favorable soil properties (i.e., higher soil pH, moisture content; Table 2, Fig. 3), which consequently increased microbial activities, nutrient availability and nutrient uptake by plants. Such higher nutrient uptake results in lower soil nutrient content in exclosures. Reference [22] has shown similar results in that exclosures had 50 to 100% more Ca, Mg, K and P in the biomass, but has little effect on soil nutrients or soil carbon. The study also demonstrated that the effect on soils was limited to significantly higher concentrations of total N ($p < 0.05$) and exchangeable Mg ($P < 0.01$) in the 0- to7.5 cm soil depth. The present study also demonstrated that differences between exclosures and communal grazing land in exchangeable Ca and Mg were insignificant, while the communal grazing land displayed significantly higher exchangeable K than exclosures (Table 2). However, a study conducted in the highlands [23] and lowlands [11] of Tigray, northernmost part of Ethiopia demonstrated improvement of soil nutrient content and soil carbon following the establishment of exclosures on communal grazing lands. Such difference in the effectiveness of exclosures to restoring soils could be attributed to the variation in environmental variables (e.g., rainfall) and management [24], and soil properties [25], [26].

The insignificant differences between exclosures and communal grazing land in soil organic matter content (Table 3) could be explained in two ways. On the one hand, favorable environmental conditions such as higher soil pH, CEC and moisture content (Table 2, Fig. 3) in exclosures enhance SOM decomposition and turnover and results in lower SOM in exclosures. On the other hand, the existence of cow dung manure in communal grazing land may improve SOM in communal grazing lands. However, as observed during the field visit, the local communities collect cow dung manure everyday to use as household energy sources, indicating that the higher SOM in communal grazing land is mainly attributed to the favorable environmental condition in exclosure that resulted in increased SOM turnover and lowers SOM content in exclosures. Reference [27] have shown similar results in that C stocks in the soil layers 0–5 and 5–15 cm under grazed grassland were significantly larger than in the ungrazed grassland. However, C stocks below 15 cm were not affected after 7 years without grazing. However, a study conducted in China [28] and Ethiopia [9] indicated that exclosures have the capacity to increase soil C sequestration; however, decades will be required for soil C to recover. Such variation in the changes in soil C following exclosure establishment could arise from the difference in rainfall amount, which control the rate of decomposition of soil organic matter. Reference [29] demonstrated in their review that SOC increased, decreased, or remained unchanged under contrasting conditions across temperature and rainfall gradients. The review further demonstrated that nearly all sites located in the intermediate precipitation range showed decreases or no changes in SOC.

The significant differences among exclosures in soil nutrients and SOM content (Table 3), and SOC stock (Fig. 4) demonstrate the influence of exclosure age in improving soil nutrient content and SOC stock. Reference [28] have shown that soil organic C storage was 1.4, 1.9, and 3.5 times in the 100-cm topsoil after 7, 12, and 25 years of grazing exclusion, respectively, compared to the case in active sand dunes. Studies conducted in Ethiopia (e.g., [9], in Mongolia [30] have also shown increases in SOC with exclosure age. The studies demonstrated that the increases in SOC with exclosure age are mainly attributed to the increase in aboveground carbon input.

V. Conclusion

After 7-year following exclosure establishment in degraded Gomit watershed resulted in improvement of some of the soil physical and chemical properties such as soil moisture, bulk density, CEC and soil pH. However, exclosures had no effect on soil nutrients and soil carbon. Exclosures alone therefore cannot be regarded as a comprehensive short- or medium-term soil rehabilitation option due to enhanced SOM turnover, vegetation restoration and increased nutrient uptake by restored vegetation.

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