

Full Length Research Paper

Soil organic carbon and total nitrogen stock response to traditional enclosure management in eastern Ethiopia

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Traditional area enclosures are widely used by pastoralists in East Africa. However, the response of basic soil properties to the establishment of traditional enclosure management remains poorly understood. The aim of this study was to investigate the impacts of area enclosure on soil organic carbon and total nitrogen stock in the Bordade rangelands, eastern Ethiopia. The soil samples were collected from twelve area enclosures and openly grazed areas at a depth of 0 to 15 and 15 to 30 cm. The samples were analyzed for soil organic carbon, total nitrogen and bulk density. Establishment of area enclosure had significantly more 27.5% soil organic carbon and 27.5% total nitrogen stock compared with the area outside area enclosure. Soil organic carbon and total nitrogen stock were significantly higher in the top 0 to 15 cm soil layer compared with 15 to 30 cm subsoil. Overall, the study showed that establishment of rangeland enclosures and the short-term resting period followed by dry season grazing at light stocking rate has the potential to improve soil organic carbon and total nitrogen stock, which is an option for realizing positive vegetation changes that support the local pastoral economy in the semiarid rangelands of eastern Ethiopia.

Key words: Carbon sequestration, enclosures, sequestration, total nitrogen stock.

INTRODUCTION

The rangeland biomes of Ethiopia are major feed resources for livestock and wild animals. In the arid to semi-arid environments of the Country, more than 62% of the land is used for livestock grazing (EARO, 2003). However, the majority of these biomes have been subjected to loss of nutrients and biodiversity changes,

soil organic matter and land deterioration due to vegetation removal by livestock and/or burning, and climate variability (Du Preez et al., 2011a; Belay, 2015).

In response to different kinds of land deterioration and the scarcity of feed for vulnerable herd classes, pastoralists conducted land restoration through livestock

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grazing management practices (Tache, 2010; Teshome, 2016). Livestock grazing management practices have effects on the magnitude, distribution and cycling of carbon and nitrogen in the rangeland ecosystems (Tessema et al., 2011; Ayana et al., 2012). Improving soil organic carbon storage in the dry land soils through proper management of livestock is one of the techniques advocated to mitigate against and/or adapt to greenhouse gas emission (McSherry and Ritchie, 2013). Despite this fact, the knowledge of the interaction between soil carbon dynamics and livestock grazing in dry lands remains limited, particularly in sub Saharan Africa, where extensive livestock grazing is one of the most common and widespread forms of land uses.

The impacts of livestock grazing management are highly variable and, despite many studies (eg. Reeder, et al., 2004; Li et al., 2011; Tessema et al., 2011), the impact of livestock grazing management on soil organic carbon and total nitrogen stock in rangelands is still unclear. Increasing livestock grazing intensities increases soil carbon (Tessema et al., 2011; Ayana et al., 2012) and nitrogen concentrations (Liu et al., 2011), have no effects (Jafari et al., 2008) or decreases soil carbon (Gill, 2007) and nitrogen levels (Steffens et al., 2008). This variation in carbon and nitrogen stock is a reflection of variation in climate, soil type, landscape position, plant community type and management practices (Reeder and Schuman, 2002; Li et al., 2011; McShery and Ritchie, 2013).

The availability of nitrogen can control both carbon and nitrogen accumulation because it constrains both inputs and outputs of carbon and nitrogen (Piniero et al., 2010). It increases primary productivity, increasing carbon inputs to the soil, and may also decrease soil respiration, decreasing carbon outputs from the soil (Piniero et al., 2010; Cheng et al., 2011). Grazers can alter nitrogen stocks by increasing or decreasing nitrogen inputs and outputs. They may decrease N inputs by decreasing legume biomass or cover as most grasslands experience some level of nitrogen limitation (Lal, 2004). Heavy grazing can negatively influence vegetation by destroying and/or disrupting the soil structure, enhancing organic matter oxidation (Frank and Evans, 1997; Evans et al., 2012), and resulting in the changes of soil organic carbon and total nitrogen storage. Grazing induced change in carbon and nitrogen balance modifies the concentration of other plant nutrients in the soil (Evans et al., 2012; Marriott et al., 2010) and soil compaction (Evans et al., 2012).

Previous studies intensively evaluated the impact of grazing on vegetation in arid and semiarid rangelands of Ethiopia. Only a few studies documented the effects of land management systems on soil properties in the rangelands of Ethiopia. However, the impacts of grazing on carbon and nitrogen stocks and other soil properties have not been studied in rangelands of eastern Ethiopia. In drier and arid ecological regions, there might be trade-

offs between managing lands for soil carbon and nitrogen, and animal production. Context-specific information is essential to advocate land management practices that increase carbon sequestration (Derner and Schuman, 2007). Therefore, this study was to assess impacts of traditional rangeland enclosure management on soil organic carbon and total nitrogen stock in eastern Ethiopia.

MATERIALS AND METHODS

Study area

The study was carried out in the Bordade Rangelands of the Oromia Regional State, eastern Ethiopia (40° 12' 31.37'' to 40° 32' 12.32'' E and 8° 56' 38.75'' N to 9° 13' 58.35'' N), ~ 268 km east of Addis Ababa (Figure 1). The rainfall in the study areas is bimodal with a short rainy season from March to April, and the main rainy season from July to September. The mean minimum rainfall is ~400 mm and means maximum rainfall ~900 mm. The mean annual temperature is 21°C. The natural vegetation of the study area is characterized as Acacia-wooded grasslands (Le Houérou and Corra, 1980). This study was carried out from September to December 2014, immediately after the main rainy season.

Sampling design

The study was conducted along the livestock grazing gradients representing two sites that were subjected to different grazing intensities (light and heavy) based on the history and intensity of livestock grazing and discussion with local pastoralists and districts pastoral development offices staff, who have extensive knowledge of study areas and visual field observations prior to this study. Heavy grazing sites or open grazing land represents the most common land use system in the Bordade Rangelands and is defined as the communal rangelands that are not privately owned, yet belonging to the communities whose members have equal access rights to the communal resources. Light grazing sites or enclosures in this study means a shrub fenced area of < 1 ha grazing land which is protected from grazing during the wet season, while the adjacent openly grazed rangelands are utilized, although some grazing may occur in the enclosure in the late dry season and in drought years when the forage is extremely scarce (Napier and Desta, 2011).

Twelve replicate of enclosures within the same age group (10 yrs) and 1-2 km apart (aerial distance, measured using Garmin GPS 72 (Garmin International Inc., USA) and adjacent open grazing lands were randomly selected to examine the influence of enclosure establishment across the gradients of woody encroachment. Ten sampling sites in each light and heavy grazing site were selected, using a stratified sampling procedure. The replicates were located on similar lithology, soils, topography and slope.

Soil sampling and analysis

Ten soil samples were taken at a depth of 0 to 15 cm and 16 to 30 using auger in a 1 m x 1 m quadrant, yielding a total of 480 soil samples (2 sites x 12 sampling sites x 2 soil depth x 10 soil samples). The soil samples at each site were pooled to form one composite soil sample per sampling site, yielding a total of 48 soil samples (2 sites x 12 sampling sites x 2 soil depth). Samples of the same depth were mixed thoroughly in a large bucket in order to

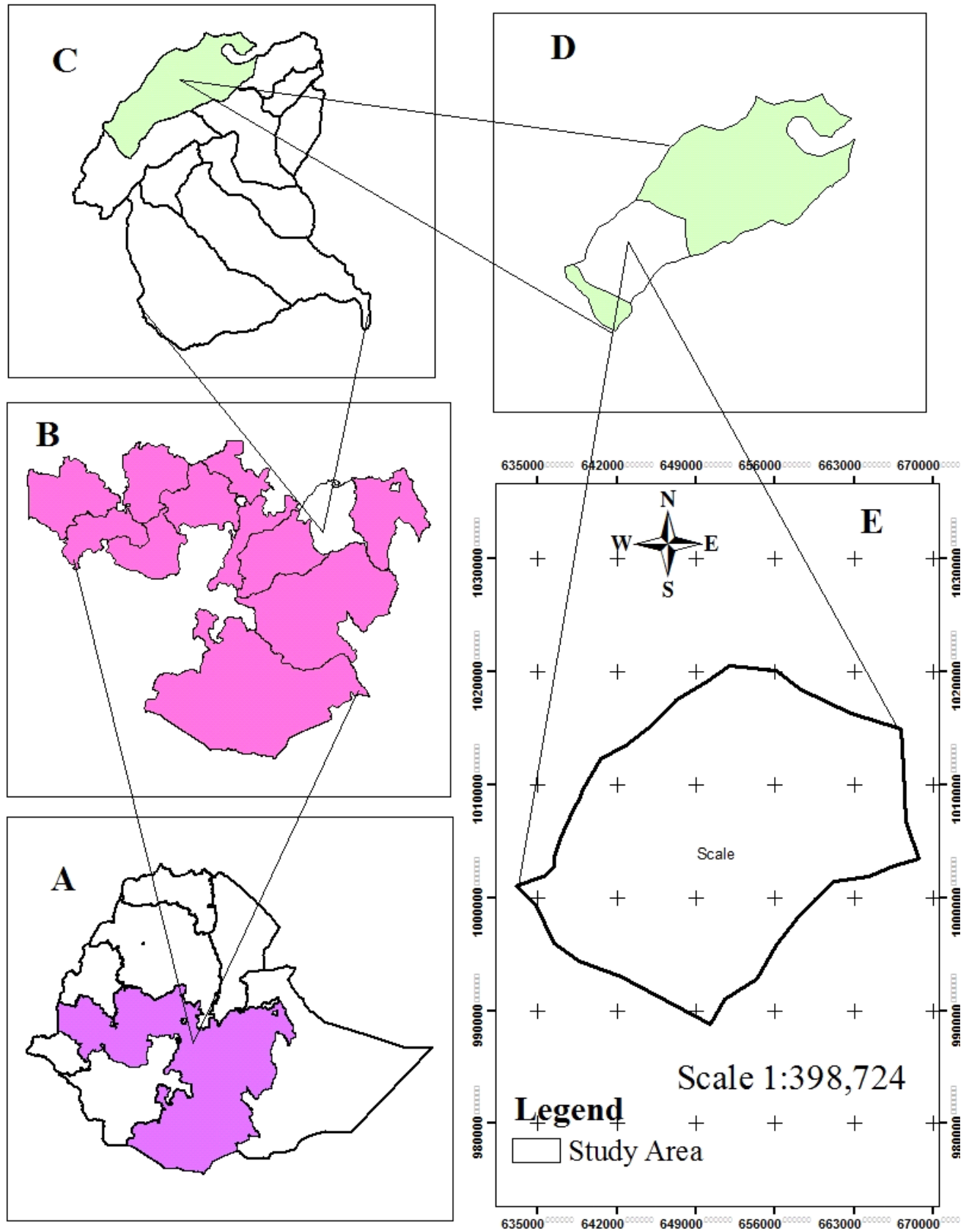


Figure 1. Oromia Region in Ethiopia(A), West Hararghe Zone in Oromia Region (B), Mieso District in West Hararghe Zone (C) Map of study area (D).

Table 1. Partial ANOVA table showing degrees of freedom (d.f.) and P-values (at $\alpha = 0.05$) for soil organic carbon (SOC), soil total nitrogen (STN), and bulk density (BD) across grazing management (GM) and soil depth (Sd) in the semiarid rangeland, eastern Ethiopia.

Grazing management	d.f.	SOC (%)	STN (%)	SOC (t ha ⁻¹)	STN(t ha ⁻¹)	BD (g cm ⁻³)
GM	1	<0.001***	<0.001***	<0.001**	<0.01*	< 0.001***
Sd	1	<0.001***	<0.001***	<0.001***	<0.001***	< 0.001***
GM x Sd	1	0.05NS	<0.01*	0.05NS	0.05NS	0.05NS

NS, $P \geq 0.05$, * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

Table 2. Percent soil organic carbon (SOC), soil total nitrogen (STN), and bulk density (BD) as affected by grazing management and soil depth (mean \pm Sd) in the semi arid rangelands, eastern Ethiopia.

Fixed effect	Soil parameter				
	SOC (%)	STN (%)	SOC (t ha ⁻¹)	STN(t ha ⁻¹)	BD (g cm ⁻³)
Grazing management					
Area enclosure	2.23 \pm 0.6	0.21 \pm 0.06	43.12 \pm 0.72	39.63 \pm 0.97	1.32 \pm 0.2
Grazed area	1.59 \pm 0.5	0.15 \pm 0.05	36.85 \pm 0.7	33.95 \pm 1.04	1.57 \pm 0.1
Soil depth(cm)					
0-15	2.41 \pm 0.42	0.23 \pm 0.04	48.49 \pm 0.67	45.3 \pm 0.53	1.36 \pm 0.2
15-30	1.4 \pm 0.37	0.13 \pm 0.03	31.47 \pm 0.37	28.28 \pm 0.59	1.52 \pm 0.14

Means followed by different superscript letters in the rows are significantly different at $P = 0.05$ level, $n = 48$.

obtain one composite soil sample per depth increment per sampling site (Yusuf et al., 2015). The composite soil samples were divided into three equal parts, out of which one was randomly chosen and stored in plastic bags, labelled, sealed and transported to the Haramaya University (HU) soil laboratory.

Soil samples were analyzed for organic carbon, total nitrogen and bulk density following standard procedures at HU. Prior to analysis, samples were air-dried at room temperature and passed through a 2 mm sieve to remove the coarse mineral fractions, plant leaves, visible roots and other debris. Soil organic carbon was determined following the Walkley and Black (1934) method; total nitrogen by the Kjeldahl method (Bremner and Mulvaney, 1982); and bulk density (g cm⁻³) using the core method (Blake and Hartage, 1986). SOC and STN were converted to a mass basis per unit area following the formulae proposed by Wairiu and Lal (2003).

$$\text{SOC (t ha}^{-1}\text{)} = \rho_b \text{ (g cm}^{-3}\text{)} \times \text{C (\%)} \times \text{soil depth (cm)} \times 100 \quad (1)$$

$$\text{STN (t ha}^{-1}\text{)} = \rho_b \text{ (g cm}^{-3}\text{)} \times \text{N (\%)} \times \text{soil depth (cm)} \times 100 \quad (2)$$

Where ρ_b = bulk density

Data analysis

The data were statistically analyzed by two-way analysis of variance (ANOVA), using the R statistical package (R Development Core Team, 2005) to determine the effect of grazing intensity, soil depth and their interaction on soil carbon sequestration and total nitrogen stock. The values of the probability lower than 0.05 ($P < 0.05$) were regarded as statistically significant. Averages were calculated per sampling site to avoid pseudo-replication, as sampling sites were assumed to be independent. Data were transformed to meet the assumption of normality and homogeneous

variances.

RESULTS

Soil organic carbon stock

The results of this study showed that both grazing management and soil depth influenced both the percent of soil organic carbon and soil organic carbon stock (Table 1). The percentage of soil organic carbon was significantly lower for openly grazed areas compared with enclosure ($P < 0.001$). As a result, the traditional rangeland enclosure areas attained higher soil organic carbon stock ($P < 0.01$) in comparison to the openly grazed areas. The enclosure had 40.4% more percentage of soil organic carbon and 17% more soil organic carbon stock concentration compared to the openly grazed areas. With regard to soil layers, the soil organic carbon and soil organic carbon stock content varied considerably (Table 2). The uppermost soil layer treatment showed higher ($P < 0.05$) percentage of soil organic carbon and soil organic carbon stock concentration compared to the sub-soil layer.

Soil total nitrogen stock

The results of this study showed that the percentage of

soil total nitrogen was significantly influenced by both grazing management and soil depth (Table 1). The percentage of soil total nitrogen was lower for openly grazed areas compared with area enclosures ($P < 0.001$). As a result, the traditional rangeland enclosure significantly attained higher soil total nitrogen stock ($P < 0.01$) in comparison to the openly grazed areas. The enclosure had 40.4% more soil total nitrogen and 16.7 % more soil total nitrogen stock concentration compared to the openly grazed areas. With regard to soil layers, the total soil nitrogen and soil total nitrogen stock content varied considerably (Table 2). The uppermost soil layers treatment showed higher ($P < 0.05$) percentage soil total soil nitrogen and soil total nitrogen stock concentration compared to the sub-soil layer.

Bulk density

Both grazing management and soil depth influenced bulk density (Table 2). The bulk density of soil at the time of sampling was significantly higher ($P < 0.01$) in the open rangeland than that of area enclosures. The mean values of bulk density 1.57 ± 0.1 and $1.32 \pm 0.2 \text{ g/cm}^3$ were recorded for open grazed and enclosure areas respectively. There was also a significant ($P < 0.05$) difference in bulk density of soil between uppermost surface soil and sub surface soil, while other grazing management-by-depth combinations had insignificant ($P > 0.05$) effects on bulk density (Table 1).

DISCUSSION

Impact of area enclosure on soil organic carbon stock

The results of this study show higher soil organic carbon and soil organic carbon stock in the area enclosures than in the openly grazed areas. The observed higher soil organic carbon and soil organic carbon stocks in area enclosure agrees with findings by Yusuf et al. (2015). The higher soil organic carbon and soil organic carbon stocks could be attributed to the increased vegetation production, litter quality and nutrient cycling (Austin and Vivanko, 2006), and decrease of nitrogen losses via volatilization of ammonia and nitrate through animal urine and dung patches (Pinerio et al., 2010). Higher nitrogen concentration in our enclosures soils might be resulted in enhanced nitrogen availability for soil organic matter formation and storage (Pineiro et al., 2010; Mekuria, 2013).

Heavy grazing outside area enclosure leads to a decrease in soil organic carbon and nitrogen by direct removal of above ground biomass, that is, reduction of potential CO_2 fixation in photosynthetic tissue and reduction in belowground carbon inputs through lower root production and higher root litter turnover (Reeder et al., 2004). Young et al. (2005) in their research evaluated

the effect of area enclosure and grazing on soil characteristics in north of China, showed that grazing leads to decrease in plant cover and soil organic carbon. Under heavy grazing, rangelands showed declines in soil organic carbon (Bagheri et al., 2009; He et al., 2011). This can be due to the removal of vegetation by livestock and the deduction of plant cover; and consequently, the decrease of the soil organic carbon. The result of this study is in agreement with Yusuf et al. (2015) who reported lower soil organic carbon and soil organic carbon stock from the areas outside area enclosure in southern Ethiopia. Similarly, studies from Kenya, found a significant decrease of soil organic carbon and soil organic carbon stock due to intensive grazing in semi-arid environments (Stephen et al., 2014).

The finding of this study together with those from previous study in Borana rangeland by Yusuf et al. (2015) and Tigray lowlands by Mekuria (2013) indicated that establishment of area enclosures has altered soil chemical and physical properties and resulted in substantial increases in soil organic carbon stock under area enclosures. This is in agreement with the observed high soil organic carbon due to establishment of area enclosure of this study.

The result of these studies also showed a significant difference in soil organic carbon and soil organic carbon storage between two depths in the study rangelands. The soil organic carbon and soil organic carbon storage were significantly higher in uppermost surface soil than sub soil. Because the aerial organs fall above ground and biological activities are increased. Then, carbon transfers to the root and finally goes to the soil. Yousoufin et al. (2011) and Jafari et al. (2008) in line with the result of this study, they reported decreasing soil organic carbon stock with increasing the depth of the soil. The percentage of soil organic carbon in the first 0 to 15 cm were higher than 15 to 30 cm, therefore the carbon stock in the first depth was greater than the second depth.

The decreasing trend of soil organic carbon with an increase in soil depth was also reported by Abebe et al. (2006) in Borana rangeland and Abule et al. (2005) in the Middle Awash Valley of Ethiopia. Moreover, because most organic residues are incorporated in, or deposited on the surface, organic matter tends to accumulate in the upper layers (Brady and Weil, 1996). Soil organic carbon contents are therefore generally much lower in subsurface horizons than those of the surface soils (Brady and Weil, 1996). According to Yousoufin et al. (2011) and Jafari et al. (2008), soil organic carbon and soil organic carbon stock has indirect relationship with soil depth. This implies that more carbon is sequestered in the top 15 cm of soil.

Impact of area enclosure on soil total nitrogen stock

There was an appreciable increase in soil total nitrogen through establishment of area enclosures (Table 2). The

observed increase in soil total nitrogen through establishment of area enclosure might be as a result of increase in organic matter content of soil in area enclosure. Similarly, the higher percentage of nitrogen concentration and total soil nitrogen stocks in enclosures soils might be a result of lower nitrogen losses via volatilization of ammonia and nitrate through animal urine and dung patches (Pineiro et al., 2010). On the other hand, our findings showed that total soil nitrogen was lower the openly grazed rangelands. The possible explanation might be attributed to low nitrate content which are easily lost through soil erosion (Belsky et al., 1989) and higher N losses via volatilization of ammonia and nitrate through animal urine and dung patches (Mekuria, 2013).

Study results by Su et al. (2005) and Pei et al. (2008) from semi-arid environments of Central Asia and Yusuf et al. (2015) from Borana rangelands of southern Ethiopia indicate that establishment of area enclosure have the capacity to improve the percentage of soil organic carbon and soil organic carbon stock. Generally, the soil total nitrogen followed the pattern of soil organic carbon distribution in all the studied soils. This is due to the fact that most nitrogen forms part of the soil organic matter (Ganuza and Almendros, 2003).

Higher soil total nitrogen and soil total nitrogen stock was held in the top soil layer than the lower layers in this experiment, which was consistent with data on arid rangelands of Kenya (Verdoodt et al., 2009). According to Abebe et al. (2006) in Borana rangeland and Abule et al. (2005) in the Middle Awash Valley of Ethiopia, soil depth indirectly related to soil total nitrogen and soil total nitrogen stock and Yousoufin et al. (2011) confirmed this opinion. This may imply the effect of livestock grazing management on soil total nitrogen is more pronounced in the top soil layer.

Conclusions

This study has demonstrated that soil organic carbon and total nitrogen stocks were responded positively to the establishment of area enclosures. There were significantly higher soil organic carbon and total nitrogen stocks inside the area enclosures than in the openly grazed areas. There were also higher soil organic carbon and total nitrogen inside the area enclosures than in the open access grazing areas. The results suggest that establishment of area enclosures in formerly degraded communal grazing lands of semi arid regions is a feasible (conservation-oriented) management option for carbon sequestration and land rehabilitation through an improved plant soil system. However, from perspectives of resource utilization, wet season resting period followed by grazing during dry season at light stocking rate would improve soil organic carbon and total nitrogen, and optimize returns in terms of livestock products, ecosystem services and functions. Further studies are, however,

required to investigate the ecological, economic, and social impacts of enclosures before expanding area enclosure for land management as further expansion of enclosures could increase grazing pressure on the remaining communal grazing lands and aggravate degradation in the lowlands of eastern Ethiopia.

Conflict of Interests

The authors have not declared any conflict of interests.

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