Soil Organic Carbon and Total Nitrogen Stock Response to Traditional Enclosure Management in Eastern Ethiopia

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Abstract

Traditional 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 traditional enclosure on soil organic carbon and total nitrogen stock in the Bordade rangelands, eastern Ethiopia. Soil samples were collected from twelve area enclosures and openly grazed areas at a depth of 0-30 cm. The samples were analyzed for soil organic carbon, total nitrogen and bulk density. There were significant differences between enclosure and openly grazed areas in soil organic carbon and total nitrogen stock. Enclosures had significantly more 27.5% soil organic carbon and 27.5% total nitrogen stock compared with the area outside area enclosure. 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.

Introduction

Ethiopia is among the 28 smaller countries (25 in Africa) where grazing land accounts >60% of the total land area (White et al. 2000). In the country, rangelands are major feed resources for livestock. Besides the provision of fodder for livestock as a primary function, rangeland support livelihoods and biodiversity conservation. In addition, grazing lands play a significant role in sequestration of considerable amounts of carbon (Mussa et al. 2017). However, the majority of these grazing lands 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 (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 grazing management practices (Tache 2010). Livestock grazing management practices have effects on the magnitude, distribution and cycling of carbon and nitrogen in the rangeland ecosystems. Improving soil organic carbon storage in the dry land soils through proper management of livestock is one of the techniques advocated for mitigation 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. This study examined the effect of impacts of traditional rangeland enclosure management on soil organic carbon and total nitrogen stock in eastern Ethiopia.

Methods and Study Site

Study Site

The study was conducted in grazing lands of Oromia region, West Hararghe zone, Bordade district, geographically located at 40° 12ˈ31.37ˈˈto 40°32ˈ12.32ˈˈ E and 8° 56ˈ38.75ˈˈN to 9°13ˈ58.35ˈˈ N, ~ 268 km east of Addis Ababa.

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 knowledgeable local community and government representative and visual field observations prior to this study. Heavy grazing sites or open grazing areas are defined as the communal rangeland 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 areas 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 and adjacent open grazing lands were randomly selected to examine the influence of enclosure establishment. Ten sampling sites in each site were selected using a stratified sampling procedure.

Soil sampling and analysis

The study was carried out from September to December 2014. Ten soil samples were taken at a depth of 0 to 30 cm using auger in a 1 m x 1 m quadrant, yielding a total of 240 soil samples (2 sites x 12 sampling sites x 10 soil samples x 1 soil depth). Soil sample at each sites were pooled to form one composite soil sample per sampling site, yielding a total of 24 soil samples (2 sites x 12 sampling sites x soil depth). Samples were mixed thoroughly in a large bucket in order to obtain one composite soil sample per sampling site. The composite soil samples were divided into three equal parts, out of which one was randomly chosen and stored in plastic bags, labeled, sealed and transported, and analyzed at Haramaya University soil laboratory following standard procedures. Soil organic carbon (SOC) was determined following the Walkley and Black method; total nitrogen (STN) by the Kjeldahl method; and bulk density (g cm^{-3}) using the core method. SOC and STN were converted to a mass basis per unit area following the formulae proposed by Wairiu and Lal (2003).

SOC (t ha^{-1}) = ρb (g cm^{-3}) x C (%) x soil depth (cm) x 100 ---------- (1)

STN (t ha^{-1}) = ρb (g cm^{-3}) x N (%) x soil depth (cm) x 100 ---------- (2)

Where ρb = bulk density.

One-way analysis of variance (ANOVA) was applied to examine the effect of grazing intensity on SOC and TNS using R statistical package. The values of the probability lower than 0.05 ($P<0.05$) were regarded as statistically significant.

Results and Discussions

Impact of area enclosure on soil organic carbon stock

Grazing management had a significant ($P < 0.001$) effect on the SOC and SOC stock (Table 1). The result of this study showed higher SOC and SOC stock in the enclosure than the openly grazed areas which agrees with findings by Yusuf et al.(2015). Under heavy grazing, rangelands showed declines in SOC (Bagheri et al. 2009). This can be due to the removal of vegetation by livestock and the deduction of plant cover; and consequently, the decrease of the SOC. Similarly, studies from Kenya, found a significant decrease of SOC and SOC stock due to intensive grazing in semi-arid environments (Stephen et al. 2014). 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 enclosures has altered soil properties and resulted in substantial increases in SOC stock under grazing enclosures. This is in agreement with the observed high SOC due to establishment of area enclosure.

Table 1: Effect of grazing management on soil organic carbon, soil total nitrogen and bulk density

Soil parameters	Grazing management		P value
	Enclosures	Open grazing area	
SOC (%)	2.23±0.6	1.59±0.5	<0.01**
STN (%)	0.21±0.06	0.15±0.05	<0.01**
SOC (t ha^{-1})	43.12±0.72	36.85±0.7	<0.001***
STN(t ha^{-1})	39.63±0.97	33.95±1.04	<0.01*
BD (g cm^{-3})	1.32±0.2	1.57±0.1	< 0.01**

Means within a row with different superscript are significantly different at P ≤ 0.05; *** = very highly significant (P<0.0001 or <0.001); **=highly significant (P<0.01); *=significant (P ≤ 0.05); ns=non-significant (P>0.05)

Impact of area enclosure on soil total nitrogen stock

Both grazing management had significant (P<0.0001) effect on the STN and STN stock (Table 1). The enclosure had 40.4% more STN and 16.7 % more STN stock concentration compared to the openly grazed areas. The observed increase in STN and STN stocks through establishment of area enclosure might be as a result of increase in organic matter content of soil in enclosure. This is due to the fact that most nitrogen forms part of the soil organic matter (Ganuza and Almendros 2003). In addition, this 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,the findings show that STN 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 SOC and SOC stock. Generally, the STN followed the pattern of SOC in all the studied soils.

Conclusions and Implication

The study revealed grazing area enclosure had significant higher soil organic carbon and total nitrogen stocks. 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.

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References

Abebe, M., Oba, G., Angassa, A. and Weladji, R. 2006. The role of area enclosures and fallow age in the restoration of plant diversity in northern Ethiopia. *Afr. J. Ecol.,* 44:507-514.

Abule, E., Smit, G. and Snyman, H. 2005. The influence of woody plants and livestock grazing on grass species composition, yield and soil nutrients in the Middle Awash Valley of Ethiopia. *J. Arid Environ.,* 60:343-358.

Bagheri, R., Mohseni, S. and Chaeichi, M. 2009. Effect of grazing intensity on some soil chemical properties in a semi-arid region Study case: Khabr National Park News and near rangeland. *Rang.,* 3(3):395- 412.

Belay, Z. 2015. Rangeland degradation and restoration: A global perspective. *Point J. Agr. Biotechnology Res.,* 1(2):037-054.

Belsky, AJ., Amundson, RG., Duxbury, JM., Riha, SJ., Ali, AR. And Mwonga, SM. 1989. The effects of trees on their physical, chemical and biological environments in a semi-arid savanna in Kenya. J. Appl. Ecol., 26:1005-1024.

Ganuza, A. and Almendros, G. 2003. Organic carbon storage in soils of the Basque Country (Spain): the effect of climate, vegetation type and edaphic variables. *Biol. Fertil. Soils*, 37:154-162.

Jafari, M., Zare, C., Rahim, Z. and Shafi, Z. 2008. Comparison of litter quantity and its effect on soil of three rangeland spices habitat in Vard abad. *Sci. Res. J. Iranian Range Manag. Soc.,* 1:1-10.

McSherry, M. and Ritchie, E. 2013. Effects of grazing on grassland soil carbon: a global review. *Glob. Change Biol., 19:1347-1357.*

Mekuria, W.2013. Conversion of communal grazing lands into exclosures restored soil properties in the Semi-Arid Lowlands of Northern Ethiopia. *Arid Land Res. Manag.,* 27:153-166.

Mussa, M., Ebro, A. and Nigatu, L. 2017. Soil organic carbon and total nitrogen stock response to traditional enclosure management in eastern Ethiopia. Journal of Soil Science and Environmental Management, 8(2): 37-43.

Napier, A. and Desta, S.2011. PLI Policy Project Review of Pastoral Rangeland Enclosures in Ethiopia. United States Agency for International Development (USAID) city.

Piñeiro, G., Paruelo, JM., Oesterheld, M. and Jobbágy, EG. 2010. Pathways of Grazing Effects on Soil Organic Carbon and Nitrogen. *Rangeland Ecol. Manage.,* 63:109-119.

Pei, S., Fu, H and Wan C. 2008. Changes in soil properties and vegetation following exclosure and grazing in degraded Alxa desert steppe of Inner Mongolia, China. *Agric. Ecosyst. Environ*., 124(1):33-39.

Stephen, M., Ann ,V., Charles, K., Jesse, T., Wasonga, V., Stefaan, D., Elizabeth, M. and Eric, V. 2014. Impact of enclosure management on soil properties and microbial biomass in a restored semi-arid rangeland, Kenya. *J. Arid Land.,* 6(5):561-570.

Su, YZ., Li, YL., Cui, HY. and Zhao, WZ. 2005. Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. *Catena*, 59:267- 278.

Tache, BD. 2011. Range enclosures in Southern Oromia, Ethiopia: an innovative response or erosion in the common property resource tenure? In: 'International Conference on the Future of Pastoralism'. 21–23 March 2011, Addis Ababa, Ethiopia. (Future Agricultures: UK.)

Wairiu, M. and Lal, R.2003. Soil organic carbon in relation to cultivation and topsoil removal on sloping lands of Kolombangara, Solomon Islands. *Soil Tillage Res.,* 70(1):19-27.

White, MA., Thornton, PE., Running, SW. and Nemani, RR. 2000. Parameterization and sensitivity analysis of the BIOME-BGC terrestrial ecosystem model: net primary production controls. *Earth Interactions*, 4:1–85.

Yusuf, H.,Treydte, A., Sauerborn, J. 2015. Managing Semi-Arid Rangelands for Carbon Storage: Grazing and Woody Encroachment Effects on Soil Carbon and Nitrogen. *PLoS ONE.,* 10(10):1-18.