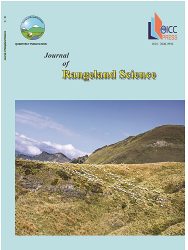

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Indigenous rangeland management systems on carbon sequestration in semi-arid areas of eastern Ethiopia

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Abstract:
The study was conducted in Shinile district of eastern Ethiopia to evaluate soil carbon stock potentials under three indigenous rangeland management practices (communal grazing land, prescribed fire and grazing enclosure) and to address the current pastoralists knowledge on constraints and opportunities for increasing soil organic carbon in the rangelands. Soil samples at different soil depths ($0-20$ cm, $20-40$ cm and $40-60$ cm) from the study district were collected to estimate the below ground soil organic carbon. The soil attributes were analyzed of variance. Priority index was employed to study constraints and opportunities to use rangelands for carbon sequestration. In the study district, enclosure grazing land management had the highest ($p < 0.05$) carbon sequestration potential as compared to the other practices. In addition, the soil organic carbon content decreased with increasing soil depth. The major opportunities to use the rangelands for carbon sequestration were availability of vast rangelands, and rotational grazing. However, there are also constraints, which includes knowledge and experience gap on rangeland resource use for carbon economy and climate variability. Therefore, appropriate land management systems are very important in improving soil organic carbon on rangelands to minimize effects of climate variability on food security in semi-arid areas.

Keywords: Constraints; Pastoralists; Rangeland management; Semi-arid areas; Soil organic carbon

1. Introduction

Plants used carbon dioxide (CO_2) from the atmosphere through photosynthesis to grow and naturally decompose and release Greenhouse Gasses (GHGs) back into the atmosphere to start the whole cycle [**?**, 1]. As long as the amounts of carbon flowing into the atmosphere and out are in balance, the level of carbon in the atmosphere remains constant [1]. However, soil organic carbon (SOC) is greatly influenced by vegetation through organic matter input and therefore, land management is one of the most important factors which influence SOC stock. Rangelands cover about 62% of the total land mass in Ethiopia and contribute as feed sources for livestock and wild animals, in addition to reducing atmospheric CO_2 [2]. The indigenous rangeland management practices can be used for reduction of atmospheric CO_2 as they could store huge amounts of carbon stock. Rangelands have been estimated to store more than 30% of the world's soil carbon [2]. Moreover, a higher carbon stock was reported to be stored in the soils rather than in the aboveground vegetation [3]. Land use changes such as overgrazing can exacerbate the climate change problem as they leave fewer plants to reabsorb the carbon [3]. Though, many studies have been carried out on rangeland productivity; our understanding of indigenous land management effects on the storage of SOC in rangelands remains limited [3, 4]. Therefore, the objective of this study was to assess the soil carbon stocks potential through different indigenous rangeland managements along soil depths and to assess the current knowledge on constraints and opportunities for increasing soil organic carbon in rangelands.

2. Materials and methods

2.1 Description of the study areas

The study was done at Shinile (9°00–10°30′ N and 42°00-42°30′ E) district of eastern Ethiopia. The study district was selected based on accessibility of the rangelands and frequency of drought. The altitude of Shinile ranges between 500 and 1600 m.a.s.l. Based on 35 years of data (1984 – 2018), average annual rainfall for Shinile is 444 mm with coefficient variation 31.5% and the average temperature is 26° C. Under normal condition, Shinile district has bimodal rainfall.

2.2 Site selection and soil sampling method

The three rangeland practices which have been studied were communal grazing areas, prescribed fire and enclosure grazing land management practices. After detailed field observation, we followed random sampling procedure to collect the soil samples. The soil samples were collected immediately after the rainy season (from September to November 2018). Five soil samples per plot at three different depths of 0 – 20 cm, 20 – 40 cm and 40 – 60 cm from the district were taken and analyzed at Haramaya University soil laboratory center. The bulk density was calculated as the mass of oven dried soil sample to core volume ratio. Walkley's and Blacks titration method was used to estimate the soil carbon content [5]. Amount of organic matter was estimated by multiplying the amount of organic carbon by a factor of 1.78 and Rau et al. method was used to calculate the carbon contents in the collected samples [6, 7].

$$\text{Soil C kg/h} = \text{BD}(\text{kg cm}^{-3}) \times (1 - \text{rock}(\text{gravel content}) \times \text{d} \times 10^8 \times \text{C\%}$$

where: d = soil depth (cm), BD = bulk density in kg cm^{-3}, C% = carbon content percent of the sample, and 10^8 = conversion factor. Moreover, to assess the constraints and opportunities for increasing soil organic carbon in rangelands, data were collected using questionnaires. Household sample size during the survey was determined following the formula described by Thrusfield as [8]:

$$n = \frac{\left(\frac{Z_\alpha}{2}\right)^2 P(1-P)}{d^2} = \frac{(1.96)^2(0.5)(1-0.5)}{(0.05)^2}$$

where: n is the required household sample size; $Z_\alpha/2$ is reliability coefficient, which is equal to 1.96 for 95%, P is constraints and opportunities to use rangeland resources for carbon sequestration, and d is the desired level of absolute precision during the survey.
Accordingly, a total of 384 household heads were involved. From the study district, two villages were selected. Data were collected using semi-structured questionnaires. Moreover, the priority index was employed to study constraints and opportunities to use rangelands for carbon sequestration using the following formula:

$$\text{Index} = \frac{\Sigma \begin{bmatrix} (\text{r} \times \text{number of HH in rank first}) + \\ ((\text{r}-1) \times \text{number of HH in rank second}) + \\ ((\text{r}-2) \times \text{number of HH in rank third}) + \ldots \\ (1 \times \text{number of HH in rank last}) \\ \text{for one factor} \end{bmatrix}}{\Sigma \begin{bmatrix} (\text{r} \times \text{number of HH in rank first}) \\ +((\text{r}-1) \times \text{number of HH in rank second}) + \\ ((\text{r}-2) \times \text{number of HH in rank third}) + \ldots \\ (1 \times \text{number of HH in rank last}) \\ \text{for all factors} \end{bmatrix}}$$

Table 1. Soil organic carbon content of different rangeland management practices in Shinile, eastern Ethiopia.
(Means followed by different letter is significantly different at $\alpha = 0.01$ probability level C ha^{-1} = ton of carbon per hectare)

Management practices	Soil organic carbon (t C ha^{-1})
Stock enclosure	198.5 ^{a}
Prescribed fire	138.3 ^{b}
Communal grazing land	98.1 ^{c}
P value	0.001

Index = the sum of (r× no of households ranked first + (r-1)× no of households ranked second + (r-2)× no of households ranked third + (r-3)× no of households ranked forth) for challenges and opportunities divided by the sum of (r× no of household ranked first + (r-1)× no of household ranked second + (r-2)× no of households ranked third + (r-3)× no of households ranked forth) for all of the challenges and opportunities to use rangelands for carbon sequestration.

2.3 Statistical analysis

The soil attributes were analyzed using analysis of variance to test differences in soil carbon stock with soil depths and indigenous rangeland management practices and its interaction by SAS 9.1 software.

3. Result and discussion

3.1 Effects of rangeland management practices on soil carbon

Significant differences ($p < 0.05$) were observed among rangeland management practices related to SOC content in the study district (Table 1). Amongst all the rangeland management practices, enclosure grazing recorded the highest SOC concentration at all soil depths. This might be associated with availability of higher tree and shrub densities and lesser disturbance of soils due to short period of grazing and therefore might have adequate nutrients and

Table 2. Mean soil organic carbon content at different soil depths in Shinile district, eastern Ethiopia.
(Means followed by different letter is significantly different at $\alpha = 0.05$ probability level C ha^{-1} = ton of carbon per hectare)

Soil depth (cm)	Soil organic carbon (t C ha^{-1})
0.0 – 20	158.4 ^{a}
20 – 40	85.6 ^{b}
40 – 60	56.1 ^{c}
P value	0.005

Table 3. Opportunities in promoting carbon sequestration in rangeland ecosystem in Shinile district, eastern Ethiopia.

Activities	Index	Rank
Availability of vast rangelands	0.218	1
Mobility/rotational grazing	0.175	2
Availability of traditional rangeland management practices	0.146	3
Restoration of degraded rangelands	0.127	5
Availability of policy favoring green economy and climate resilience	0.090	7
National commitment towards green economy	0.138	4
International support to enhance carbon sequestration	0.106	6
P value	0.005	

soil microorganisms [9]. Similarly, the highest soil organic carbon in grazing enclosure than the open grazing lands was supported by other studies [9]. Moreover, the lowest soil organic carbon content observed in communal grazing land might be due to lower vegetation covers and subsequently, lower SOC content of grazing lands as they are frequently grazed by animals [3, 10]. The soil carbon content reported in the present study in communal grazed areas (98.1 t ha^{-1}) is less than the findings of Bikila et al. in Borana rangeland (127.8 t ha^{-1}) [3]. This variation might be due to climatic and edaphic differences between the Borana rangeland and eastern Ethiopia rangeland. Moreover, the average soil organic carbon content (144.9 t C ha^{-1}) of the three rangeland management types in the study district was lower than the findings of Bikila et al. in Borana rangelands (179.39 t ha^{-1}), but comparable with sub-Saharan Africa [11]. The replacement of perennial grass species by annuals and reduction species richness are caused by heavy grazing [3].

3.2 Soil carbon stocks at different soil depths

The variations in SOC values under different soil depths in the study district were significant ($p< 0.05$) (Table 2). Soil organic carbon significantly decreased down along the soil depths in the study district. This result is supported by other previous studies [3, 12]. The presence of more SOC content in the lower than upper soil depths is probably due to the accumulation of weathered minerals and organic matter from animal wastes (feaces and urine) and plant litters in the upper part of the soil.

3.3 Opportunities of soil carbon sequestration in the rangelands

Availability of vast rangelands and pastoralist's mobility were good opportunities to sequester carbon in the study areas (Table 3). As plants grow, they sequester carbon into the soil through photosynthesis. This may result in maximizing rangeland production, improve vegetation cover, biomass and increase carbon sequestration [1, 13]. There would also be additional benefits, particularly preserving or restoring biodiversity [13]. Similar result was noted by Bikila et al. in Borana rangelands [3]. Pastoralist's mobility is necessary and practiced to live harmony with the changing climate to restore the rangelands [3, 4].

Most rangeland management activities in the pastoral areas are mandatory for their life used to increase the use of atmospheric CO_2. Restoration of degraded lands and expansion of enclosure grazing lands are also good opportunities to sink CO_2 (Bikila et al., 2016). In addition, availability of international and national efforts to combat climate change and variability problems is also used as an opportunity for

Table 4. Challenges in promoting carbon sequestration in rangeland ecosystem in Shinile district, eastern Ethiopia.

Challenges	Index	Rank
Knowledge and experience gap on rangeland resource use for carbon economy	0.108	2
Climate variability/occurrence of drought with unreliable rainfall	0.109	1
Prevalence of invading species/bush encroachment	0.102	5
Restriction of mobility	0.106	4
Rangeland degradation/overgrazing/desertification	0.108	2
Livestock population pressure and shrinkage of rangelands	0.102	5
Conflict between clans	0.088	9
Limited investment in green economy and carbon sequestration initiatives	0.088	9
Systems for documenting carbon stock changes have not been adopted	0.092	8
Difficulty of developing workable policy and incentives related to green growth	0.097	7
P value	0.005	

reducing atmospheric CO_2.

3.4 Constraints of soil carbon sequestration in the rangelands

Based on the results of constraint ranking, a bigger knowledge gap was observed in rangeland resource use for carbon economy (Table 4). This might be due to the extension services mainly focusing on livestock productivity and less attention to carbon economy. Climate variability is one of the most pervasive constraints limiting the livestock production in pastoral area by reducing the water and food resources. The result of rainfall and temperature trend analysis indicated that at present, the communities in the study area are affected by meaningful impact of inter-annual and seasonal rainfall variability and rise of temperature. The direct effects of climate on pasture growth and water availability in the rangelands are reported to indirectly influence the livelihood of communities [4]. Under increasing trends of environmental changes, rainfall availability is strongly associated with rangeland vegetation cover, species composition and plant diversity.

Total grazing pressure influences carbon and nutrient cycling, as well as vegetation characteristics of rangeland ecosystems. Bationo et al. also noted soil organic carbon is an index of sustainable land management and is declined due to over-grazing of the pastureland and increase of mineralization due to surface disturbance [14]. On the other hand, carbon loss from these systems contributes significantly to atmospheric change.

Bush encroachment/prevalence of invading species has also contributed to rangeland degradation in the study areas. Invasive bush encroachment has fundamentally changed the communal rangelands from open grasslands to bush tickets challenging the sustainability of the pastoral system [15,16]. In recent years, the lifestyle of pastoralists has come under enormous pressure such as mobility restriction, which undermined the ability to maintain the standard of living of a large sector of the pastoralists [4]. Traditionally, pastoralists closed some portions of their grazing lands as standing hay and opened them for grazing when dry season started. Less application of these indigenous strategies might have contributed to woody plant encroachment, which inhibits growth of the understory grasses. The increase in the livestock and human population and the associated expansion cropland in pastoral areas, the pasture land/rangelands allocated to grazing are shrinking from time to time in the pastoral production systems. As a result, the animals are allowed to graze without giving rest period for grazing land to recover, which eventually reduces the ecological benefit of rangelands [4, 13].

4. Conclusion

The results of the study confirmed that soil organic carbon stock is affected by different rangeland management systems, although rates of sequestration values vary between grazing management practices. Soil organic carbon stock was higher on enclosure grazing compared to other land management practices, which implies the need to encourage such practices to mitigate climate variability in the rangelands. The soil organic carbon composition was higher at $0-20$ cm depth and lower as the depth increased. Indigenous rangeland management practices are low cost and environmentally beneficial way of sequestering substantial amount of soil carbon stock for economic and ecological gains. Knowledge and experience gap, climate variability, pastoral mobility restriction, and rangeland degradation were the reported constraints of using the existing vast rangeland resources for carbon economy. The policy should recognize the indigenous way of grazing systems to enhance carbon sequestration potentials. Comprehensive capacity building for pastoral and developmental actors need to be provided on effective rangeland management systems to increase the livelihood of the pastoral community of Ethiopia.

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Conflict of interest statement:
The authors declare that they have no conflict of interest.

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