

Research Application Summary

The effect of customary grazing management systems on rangeland carbon stock and sequestration in semiarid pastoral ecosystem system of Eastern Ethiopia

Gebremedhn, H. H.,¹ Kelkay, T. Z.,¹ Tesfay, Y.² & Tufa, S.³

¹African Center of Excellence for Climate-smart Agriculture and Biodiversity Conservation, Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia

²College of Dryland Agriculture, Mekele University, P.O. Box 231 Mekelle Tigray, Ethiopia

³Oromiya Agriculture Research Centre, P. O. Box 81265, Addis Ababa, Ethiopia

Corresponding author: hailuhft418@gmail.com

Abstract

Customary rangeland management practices inherent to pastoralism have shaped rangeland environments for millennia and contributed to the mitigation and adaptation of climate changes. However, without generating estimates from site-specific or small-scale studies, it's impossible to style or to implement sustainable ways of using rangeland resources and therefore the long-term enhancement of carbon sequestration potential. In this study, we have measured carbon stocks and sequestrations in a case study of semi-arid pastoral ecosystems under customary grazing management practices. Data were collected from three customary rangeland management practices of communal open grazing area, private enclosure areas that used for forage reservation in the dry season and communally bush dominated rangelands (Bay in the local name) that used for browser animals. Total carbon stocks including both soil organic carbon and vegetation carbon stocks were significantly ($P < 0.0001$) different among the customary rangeland management practices. The positive conditional variance among the three customary management practices for soil organic carbon, woods and herbs were about 21.24, 1.39, 0.06 and 24.16 t C ha⁻¹ respectively. Moreover, a total of about 349, 349, 177 t CO₂ ha⁻¹ were sequestered from the atmosphere in the open browsing, enclosure and open communal grazing management practices respectively. Carbon stocks have been possibly maintained by pastoralists' grazing management practices, which are characterized by enclosures and bush dominated rangelands.

Key words: Browsing area, climate change mitigations, ecosystem services, open grazing, pastoral ecosystems, rangeland, soil organic carbon

Résumé

Les pratiques habituelles de gestion des pâturages, inhérentes au pastoralisme, façonnent l'environnement des pâturages depuis des millénaires et contribuent à l'atténuation et à l'adaptation aux changements climatiques. Cependant, sans données d'estimations à partir d'études spécifiques à un site ou à petite échelle, il est impossible de concevoir ou de mettre en œuvre des méthodes durables d'utilisation des ressources des parcours et donc d'améliorer à long terme le potentiel de séquestration du carbone. Dans cette étude, nous avons mesuré les stocks et les séquestrations de

carbone dans une étude de cas d'écosystèmes pastoraux semi-arides sous des pratiques de gestion de pâturage coutumier. Les données ont été collectées à partir de trois pratiques coutumières de gestion des pâturages : les zones de pâturage communautaires ouvertes, les zones d'enclos privés utilisées pour la réserve de fourrage pendant la saison sèche et les pâturages dominés par la brousse communautaire utilisés pour les animaux brouteurs. Les stocks de carbone totaux, comprenant à la fois le carbone organique du sol et les stocks de carbone de la végétation, étaient significativement différents ($P < 0,0001$) entre les pratiques de gestion des parcours coutumiers. La variance conditionnelle positive entre les trois pratiques de gestion coutumière pour le carbone organique du sol, des bois et des herbes était d'environ 21,24, 1,39, 0,06 et 24,16 t C ha⁻¹, respectivement. De plus, environ 349, 349, et 177 t CO₂ ha⁻¹ ont été séquestrés de l'atmosphère dans les pratiques de gestion du brouillage ouvert, de l'enclos et du pâturage commun ouvert, respectivement. Les stocks de carbone ont probablement été maintenus par les pratiques pastorales de gestion du pâturage, qui sont caractérisées par des enclos et des parcours dominés par la brousse.

Mots clés: zone de clôture et de navigation, atténuation des changements climatiques, services écosystémiques, pâturage ouvert, écosystèmes pastoraux, parcours, carbone organique du sol

Introduction

Carbon dioxide (CO₂) is the primary greenhouse gas contributing to rapid global climate change, a warming of the earth's surface that is causing significant changes in sea levels, precipitation, wind, and freeze/thaw cycles (Petrokofsky *et al.*, 2012). Sequestering carbon in plants and soil and limiting its release back into the atmosphere will help offset greenhouse gas emissions (e.g., methane [CH₄] and nitrous oxide [N₂O] from livestock production and CO₂ from feedstock and crop production) and slow down climate change (Kane and Vogel, 2009). The potential of rangelands to store carbon in soils and vegetation has been acknowledged in many studies (e.g. IPCC 2007) and lies within the natural state of rangelands or rangelands moderately disturbed by grazing (Yusuf *et al.*, 2015). Rangeland represent a huge stock of carbon and sequestration, not only because of their C content (which is relatively low per unit area) but also because of the vast area they occupy from the landmass of the world (Papagallo, 2018). Likewise customary rangeland management practices inherent to pastoralism have shaped rangeland environments for millennia and contributed to the enhancement of rangeland biodiversity, as well as the mitigation and adaptation of climate changes (Seid *et al.*, 2016). Nevertheless, in pastoral ecosystems characterized by communal grazing, carbon storage potential is poorly understood. Continuous grazing in pastoral ecosystems is often thought to reduce primary productivity or species composition; therefore, no substantial carbon stocks are assumed (He *et al.*, 2011).

In Africa, rangelands constitute about 65% of the total land area and are the major sources of feed for ruminants, which supports 59% of all ruminant livestock (Anafo, 2017). Similarly, rangeland in Ethiopia covers about 62% of the total landmass of the country, located around the periphery, below 1500 m.a.s.l., and supporting about 12-15 million people living in 7 regions involved in pastoral and agro-pastoral livelihoods (Zerga and Gebeyehu, 2016). The Somali Regional State is one of the major pastoral ecosystems in Ethiopia. It has a total land area of about 327,000 km² of which, about 90% is classified as rangeland (Gezahegn, 2006).

However, like other arid and semi-arid rangeland ecosystems in the country, the rangelands in the region have long been exposed to extensive livestock grazing pressures (Haftay *et al.*, 2013). These have gradually caused a reduction in vegetation cover and preferred grass species, depletion of soil nutrients and acceleration of erosion (Gebremeskel, 2018). Although extensive livestock grazing pressure is dominant in the region, it is also common to see the practice of enclosing communal open grazing rangelands (Napier and Desta, 2011). For instance, the pastoralists in the region have been using enclosures in response to declining rangeland productivity (Haftay *et al.*, 2013). Fencing or protecting an area to exclude grazing animals is increasingly being used in Ethiopia as an adaptive strategy to livestock feed shortage (Mussa *et al.*, 2016). These enclosures are generally used for hay production, which is cut and carried to the livestock when there is feed shortage for grazing in the open communal grazing areas. Pastoralists in the Somali region have started setting aside part of their rangelands physically or using social by-laws as fenced grazing reserves since the early periods of the second half of the twentieth century (Beyene, 2010). These long-term enclosures might have impacts on carbon sequestration but yet to be confirmed.

Moreover, the phenomenon of increasing woody species diversity in the rangelands is to be seen as a process of degradation by Somali pastoralists. They perceived that where species such as *Acacia seyal* and *Acacia mellifera* are replacing the other most preferable and valuable species for both human and livestock use, resulting in an imbalance of the grass: bush ratio, with decreasing biodiversity and increasing undesirable woody species. For this response, clearing shrubs and trees to produce grasslands have become a common management strategy by some Somali pastoralists in eastern Ethiopia. For example most of the pastoralists in Harishn district of Somali region do not prefer woody species in their enclosure areas (Hailu, 2017). They frequently clear most of the shrubs and trees from the enclosures by leaving a few species which can be used to shade their animals from the direct hot sun. However, the management strategy of clearing tree/shrub species by Somali pastoralist is not supported by conducting integrated research through universal co-benefits for carbon sequestration. Thus, this study had the following research objectives:

- Assess the effect of customary grazing management systems on vegetation and soil carbon stocks;
- Assess the rangeland carbon stock and sequestration potentials under the customary grazing management systems and;
- Evaluate the rangeland carbon dioxide sequestration conditional variance under three customary grazing management systems in semiarid rangelands

Material and Methods

Description of the study areas. The research was conducted in a pastoral ecosystem found in Somali Regional State (SRS) of Ethiopia (Fig 1.). Somali Region is the eastern-most of the nine ethnic divisions (kililoch) of Ethiopia. It is often called Somalia, though it is not to be confused with the independent country of the same name. The capital of Somali State is Jigjiga. The region borders Kenya to the south-west, the Ethiopian regions of Oromia, Somali and Dire Dawa (Diridhaba) to the west, Djibouti to the north and Somalia to the north, east and south.

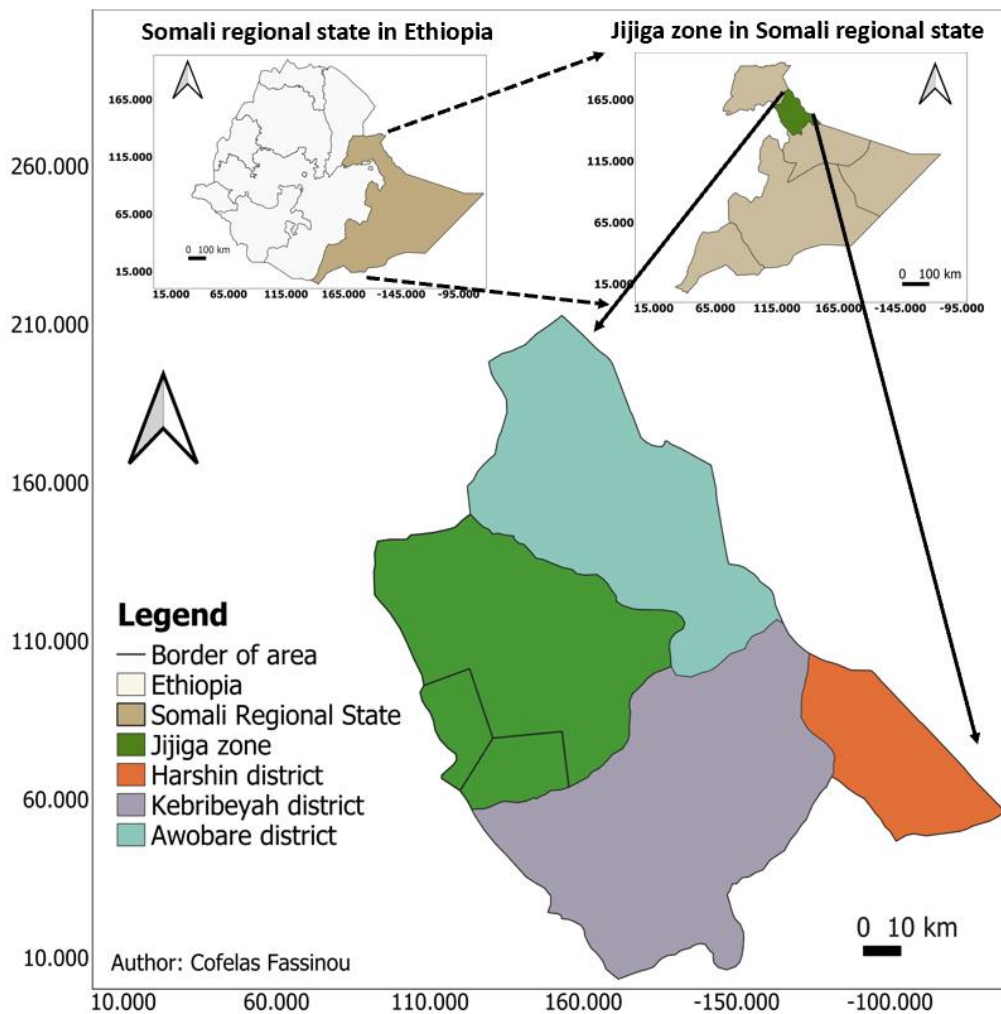


Figure 1. Location of the study area

Project design. Various traditional rangeland management practices (communally grazed area, rangeland areas enclosed (reserved) for dry season grazing and bush encroached rangelands (Bay) for goat and camel browsing were included as sampling sites to determine the carbon sequestration potential of different management practices. A Plot of 20 m x 20 m (400m²) was established and replicated three times in each experimental site. The woody species were recorded within the 20mx20m (400 m²). Four 1m x 1m (1m²) quadrates within the 20 x 20m (400m²) was nested (four at each corner of the plot) to record the herbaceous vegetation and soil attributes. Sample measurements were done at similar times for all the study plots at the end of the rain season.

Woody and Herbaceous Vegetation Sampling. In the 400-m² plots, tree or shrub diameter at breast height (DBH), height, canopy width and canopy length were measured. For those trees with multiple stems, each stem was sampled separately and the average was taken for the sample's stems. In such cases the circumference of the stem at ankle height (5-10 cm) above the ground was used instead of diameter at breast height (DBH). Height measurements, canopy lengths and widths were however conducted for the whole multiple stems by considering it as one tree. A tree with multiple stems at 1.3 m height was treated as a single individual and DBH of the main

stem as indicated by FAO (2004). Shrubs with a basal stem circumference less than 2.5cm was not be sampled but considered under herbs as stated in FAO (2004). To assess herbs dry matter biomass all herbaceous vegetation found within each 1-m² quadrants were harvested at the ground level using hand shears. Then the cut samples were retained for oven drying (105 °C for 24 h) to estimate dry matter biomass.

Sampling of Soil Physical and Chemical parameters. Soil samples at a depth of 30 cm were taken using an auger from each study plot at four nested quadrats per plot. Each set of four soil samples were mixed properly, air dried and passed through 2mm sieve to make ready for analysis. Soil parameters were analyzed for soil texture (%silt, %clay and %sand), bulk density, pH, organic carbon (OC) and organic matter (OM). Soil texture was determined by using the hydrometer method (Day, 1965), while bulk density was determined by the core method (Blake, 1965). A Bulk density was calculated as the ratio of the mass of oven dried soil sample to its core volume.

Data collection and analysis. Other tree/shrub above ground biomass (AGB) were estimated using a non-destructive method by biomass regression equations (allometric equations) developed by previous researchers for estimation of biomass and carbon sequestration potentials of specific trees or shrubs. Root carbon estimates were considered as the 20% of above-ground carbon as a proportion of AGB derived based on predictive relationships established from extensive literature surveys. The total biomass will be calculated by sum the above and below ground biomass. The biomass will be converted to carbon (C) by assuming a 50% biomass to carbon content (IPCC 2003; 2006).

The content of organic carbon in soil estimated in percentage terms was converted to tones per hectare using bulk density, depth of the soil and area (10,000 m²) based on the procedure given by IPCC (2006).

$\text{SOC (t/ha)} = [\text{soil mass in 0 - 30 cm layer} \times \text{SOC concentration (\%)}] / 100$

$\text{Soil mass (t/ha)} = [\text{area (10,000 m}^2 \text{ /ha)} \times \text{depth (0.3 m)} \times \text{bulk density (t/m}^3 \text{)}]$

Data collected from various carbon pools (herbaceous, woody and soil carbon) within each plot were subjected to ANOVA using aov function R Software statistical package to determine the fixed effects of management types. The rangeland carbon dioxide sequestration conditional variance under three customary grazing management types were subjected to maximum likelihood estimator using the lmer function in R statistical Software.

Results

Woody carbon stock. Aboveground and roots woody carbon stocks were significantly ($p < 0.0001$) higher in the Browsing area (Bay) areas than in the rangeland units managed as enclosure areas and open communal grazing areas (Table 1). However, the woody aboveground and root carbon stock were not significantly different ($p > 0.05$) between enclosure areas and open communal grazing areas.

Herbs carbon stock. In the rangeland management types and herbs carbon stocks were significantly ($p < 0.0001$) higher in the enclosure areas than the open browsing and open communal grazing management system (Table 1). However, the Herbs carbon stock were not significantly different ($p > 0.05$) between browsing areas and open communal grazing areas.

Table 1. Effect of customary grazing management systems on woody and herbs aboveground and root carbon stocks (t C ha⁻¹)

Grazing management types	WA	WB	TW	HA	HB	TH	SOC
Enclosure	1.34 ^b	0.267 ^b	1.61 ^b	2.00 ^a	0.40 ^a	2.40 ^a	85.11 ^a
Browsing area(Bay)	8.63 ^a	1.73 ^a	10.36 ^a	1.10 ^b	0.22 ^b	1.32 ^b	84.00 ^a
Open grazing area	3.40 ^b	0.68 ^b	4.08 ^b	0.37 ^b	0.06 ^b	0.45 ^b	54.33 ^b
Mean	4.46	0.89	13.4	0.116	0.23	1.39	74.48
MS error	9.34	0.37	13.46	0.597	0.02	0.86	132.87
P value	0.000	000	000	0.000	0.000	0.000	0.000
Df	24	24	24	24	24	24	24
CV	68.57	68.55	5.34	66.48	66.26	66.52	15.47

Means with the same letter superscripts along columns are not significantly different at $\alpha = 0.05$ level of significance; WA= wood above ground vegetation, WB= wood belowground (root) carbon stock, TW = total wood, HA= herbs above ground, HB = Herbs below ground (root), TH = total herbs, SOC = soil organic carbon; t C ha⁻¹ = ton of carbon per hectare.

Soil Organic Carbon stock. A significantly ($P < 0.0001$) lower soil organic carbon was stored in the communal open grazing areas than in the other two customary rangeland management practices. However, the soil organic between enclosure and open browsing management system were not significantly different in the current study area (Table 1).

Total carbon stocks across the rangeland management practices. Total carbon stocks including both total belowground and aboveground carbon stocks was significantly ($p < 0.01$) lower in open communal grazing areas than in both rangelands managed by enclosures and communal open browsing areas (Fig. 2 and 3). Total rangeland (vegetation and soil) carbon stocks were measured about 88.77, 95.77 and 58.77 in the enclosure, browsing area and communal open grazing areas respectively.

Moreover, a total of about 349, 349, 177 t CO₂ ha⁻¹ were sequestered from the atmosphere in the open browsing, enclosure and open communal grazing management system, respectively. The highest wood carbon sequestration were recorded in the open browsing management systems. However the open communal grazing area had the lowest soil organic and herbs sequestration potential.

Rangeland Carbon sequestration conditional variance across management practices. The SOC, wood, herbs, and total (vegetation and soil) were significantly different ($P < 0.0001$) among the three customary management practices. The positive conditional variance among the three customary management practices for SOC, wood, herbs were about 21.24, 1.39, 0.06 and 24.16 t C ha⁻¹, respectively (Table 3).

Rangeland CO₂ sequestration and emission across management practices. The open browsing management area sequesters (gained) about 48 and 17 t CO₂ ha⁻¹ in the soil and woody carbon storage types, respectively. Moreover the highest soil carbon were gained in the enclosure management system (Fig. 4). The open grazing management systems emits (loses) about 99, 4 and 1 t CO₂ ha⁻¹ from SOC, wood and herbs carbon storage, respectively.

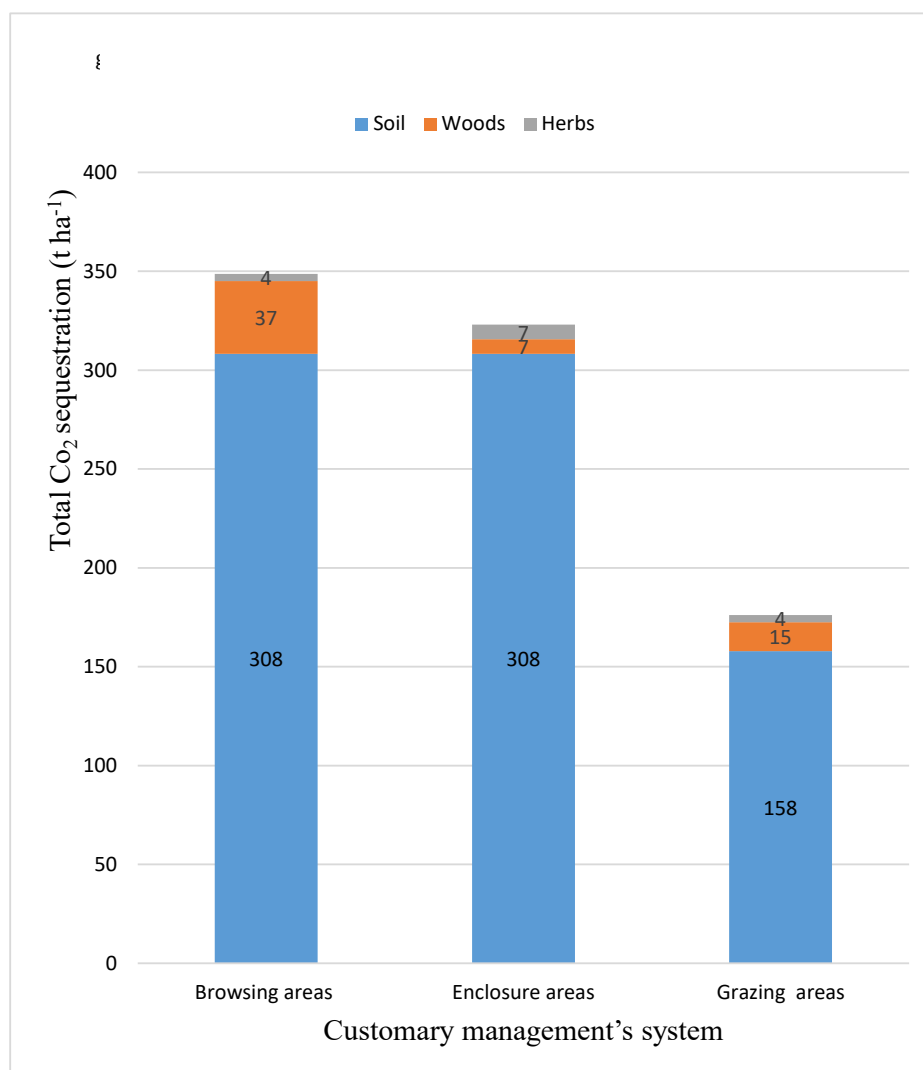


Figure 3. Soil, woody and herbs CO₂ sequestration under three customary grazing management practices in semiarid rangelands of eastern Ethiopia

Conclusion

In this study, we measured carbon stocks and sequestrations in a case study of semi-arid pastoral ecosystems under customary rangeland management practices. The variation of carbon stocks and sequestrations with customary management practices affirms the need to consider asymmetric distribution of range resources in the assessment of rangeland climate change mitigation. In our sample results from varying customary rangeland management practices, we found 349, 349, 177 tons of CO₂ ha⁻¹ in the open browsing, enclosure and open communal grazing areas, respectively. Moreover, the largest proportions of carbon stocks were found in the soils, meaning that any alternative land use to pastoralism that exposes soil carbon would have substantial adverse environmental effects. However the open communal grazing lost 99 tons of soil organic carbon per hectare in the eastern Ethiopia rangelands. Carbon stocks have been possibly maintained by

Table 3. SOC, woody, herbs and total carbon sequestration (t C ha⁻¹) with rangeland management conditional variances in pastoral grazing management systems of eastern Ethiopia

Response categories	Estimate intercept	+SE	Management conditional variance			Positive variance	t value	P Value
			Browsing	Enclosure	Grazing			
SOC	70.44	14.06	+13.15	+13.91	-27.06	21.24	5.01	0.0001
Wood	5.35	2.61	+4.64	-3.47	-1.18	1.39	2.05	0.0001
Herbs	1.22	0.57	-0.67	+1.05	-0.38	0.06	2.16	0.0001
TC	77.01	15.00	+17.28	+11.39	-28.67	24.16	5.14	0.0001

SOC = soil organic carbon; TC = total carbon; + = carbon sequestration gain; - = carbon sequestration loose; t C ha⁻¹ = ton of carbon per hectare

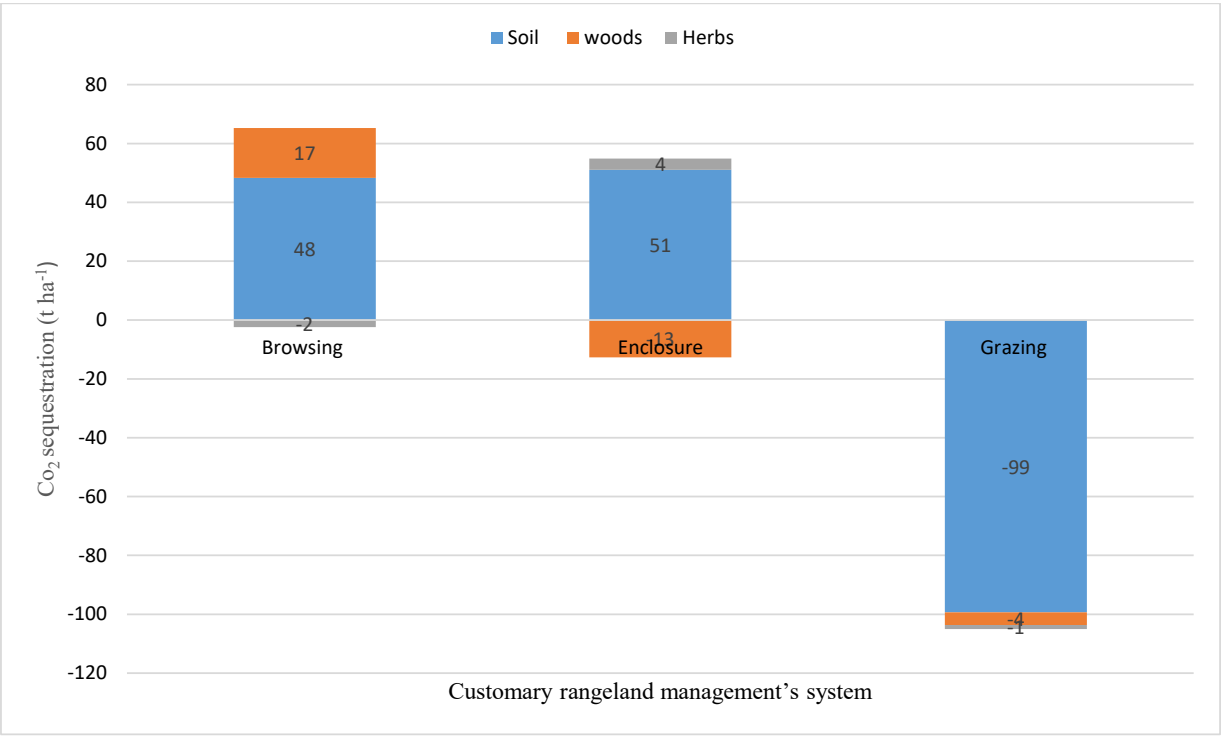


Figure 4. Soil, woody and herbs CO₂ sequestration and emission in three customary grazing managements of eastern Ethiopia

pastoralists' grazing practices, which are characterized by rangeland areas enclosures and bush encroached rangelands (that is called Bay in local name) that is used for browser animals.

Acknowledgement

This work was supported by Africa Center of Excellence for Climate Smart Agriculture and Biodiversity Conservation (ACE Climate SABC) of Haramaya University and Social and Environmental Trade-offs in African Agriculture (SENTINEL) of the Global Challenges Research Fund (GCRF)-UK through the Regional Universities Forum for Capacity Building in Agriculture (RUFORUM) [grant number RU/2019/GTA/DRG/041]. This paper is a contribution December 2021 in Cotonou, Benin.

References

- Anafo, D. 2017. Contested Pastures: State land reform policies, community dynamics and pastoralism in the Nkoranza South Municipality, Ghana. *Sustainable Pastoralism and Rangelands in Africa* 31 (2): 51–55.
- Beyene, F., 2010. Driving forces in the expansion of enclosure among pastoral and agropastoral herders in Ethiopia. *Quarterly Journal of International Agriculture* 49 (2): 127–46.
- Gebremeskel, K. 2018. Impact of grazing pressure around a watering point on natural pasture quality in the rangeland of North-Eastern Ethiopia. *World Journal of Agricultural Sciences* 14 (1): 12–16. doi: 10.5829/idosi.wjas.2018.12.16.
- Gezahegn, A. K. 2006. Characterization of rangeland resources and dynamics of the pastoral production systems in the Somali Region of Eastern Ethiopia. University of the Free State, BLOEMFONTEIN. 250pp.
- Haftay, H., Yayneshet, T., Animut, G. and Treydte, A. C. 2013. Rangeland vegetation responses to traditional enclosure management in eastern Ethiopia. *Rangeland Journal* 35 (1): 29–36.
- Hailu, H. 2017. Analysis of vegetation phytosociological characteristics and soil physico-chemical conditions in Harishin Rangelands of Eastern Ethiopia. *Land* 6 (1):4. doi: 10.3390/land6010004.
- He, N. P., Zhang, Y. H., Yu, Q., Chen, Q. S., Pan, Q. M., Zhang, G. M. and Han, X. G. 2011. Grazing intensity impacts soil carbon and nitrogen storage of Continental Steppe. *Ecosphere* 2 (1):1–10. doi: 10.1890/ES10-00017.1.
- Kane, E. S. and Vogel, J. G. 2009. Patterns of total ecosystem carbon storage with changes in soil temperature in Boreal Black Spruce Forests. *Ecosystems* 12 (2): 322-335. doi: 10.1007/s10021-008-9225-1.
- Mussa, M., Hakim, H., Mukeram, T. 2016. Rangeland degradation: Extent, impacts, and alternative restoration techniques in the rangelands of Ethiopia. *Tropical and Subtropical Agroecosystems* 19 (3): 305–18.
- Petrokofsky, G., Kanamaru, H., Achard, F., Goetz, S.J., Joosten, H., Holmgren, P., Lehtonen, A., Menton, M.C., Pullin, A.S. and Wattenbach, M. 2012. Comparison of methods for measuring and assessing carbon stocks and carbon stock changes in terrestrial carbon pools. how do the accuracy and precision of current methods compare? A systematic review protocol. *Environmental Evidence* 1 (6):1–21.
- Seid, M. A., Kuhn, N. J., and Fikre, T. Z., 2016. The role of pastoralism in regulating ecosystem services. *OIE Revue Scientifique et Technique* 35 (2): 435–44. doi: 10.20506/rst.35.2.2534.

- Yusuf, H.M., Treydte, A.C. and Sauerborn, J. 2015. Managing semi-arid rangelands for carbon storage: grazing and woody encroachment effects on soil carbon and nitrogen. *PLoS ONE* 10 (10): p.e0109063. doi: 10.1371/journal.pone.0109063.
- Zerga, B. and Getaneh G., 2016. Climate Change in ethiopia variability, impact, mitigation, and adaptation. *Journal of Social Science and Humanities Research* 2 (4): 66–84.