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Effects of enclosure management on carbon sequestration, soil properties and vegetation attributes in East African rangelands

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ABSTRACT

The use of enclosures has globally gained popularity as an effective strategy to enhance soil carbon sequestration, but empirical evidence is lacking particularly in arid and semi-arid rangelands of Africa. This study addressed the effectiveness of long-term (15–37 years old) enclosures in enhancing soil carbon sequestration in a semi-arid rangeland of Southern Ethiopia. We tested for differences in soil properties and vegetation characteristics between enclosures and adjacent open-grazed areas, while accounting for effects of age of enclosures and soil depths. Three enclosures age categories (< 20, 20–30 and > 30 years) each paired with adjacent open-grazed areas were selected. We collected soil samples at three soil depths (0–5 cm, 5–15 cm and 15–30 cm), and vegetation attributes from 90 plots within 9 enclosures and adjacent open grazing sites. The results showed that soil properties did not differ significantly ($P > 0.05$) between the two management systems across the three soil depths. However, relatively higher soil organic carbon content and stock was recorded in the enclosures than open-grazed lands. We recorded an overall mean of soil organic carbon stock of 39.6 ± 3.5 Mg ha^{-1} in enclosures of < 20 years old, 40.8 ± 3.4 Mg ha^{-1} in enclosures of 20–30 years old and 51.0 ± 4.4 Mg ha^{-1} in enclosures of > 30 years old. The soil organic carbon stock for the adjacent open-grazed areas ranged from 34.4 ± 2.5 to 47.9 ± 5.1 Mg ha^{-1}. The age of enclosures did not show any significant effect on soil organic carbon stocks. However, enclosure management had a significant ($P \leq 0.05$) effect on vegetation attributes. We concluded that enclosure had a significant role in terms of soil carbon sequestration and adaptation to climate change.

1. Introduction

Rangelands constitute the largest and most diverse land resources in the world (Reeder and Schuman, 2002), and hold great potential for carbon sequestration (Lal, 2004). According to Campbell et al. (2008), rangelands can store enormous amount of terrestrial carbon stocks both globally (36%) and in Africa (59%), and help to mitigate the impact of climate change (Neely et al., 2009). Sequestration of carbon in the soil system is essential for the improvement of soil quality, nutrient retention and water holding capacity to increase the net primary productivity for more carbon assimilation (Lal, 2015).

Despite the potential of rangelands for carbon sequestration, heavy grazing pressure has contributed to the rapid losses of soil carbon (C) and nitrogen (N) (Reid et al., 2004). The degradation of rangeland resources is a major problem in arid and semi-arid ecosystems with significant impact on the environment and livelihoods of the pastoral communities (Angassa, 2014; Oba et al., 2000). Previous studies (Bikila et al., 2016; Tessema et al., 2011) have shown that increased grazing pressure has resulted in the losses of soil carbon (C) and nitrogen (N). According to Piñeiro et al. (2010), the effect of grazing modifies the structure and function of ecosystems, affecting biomass and soil organic storage.

Management practices such as community enclosures and rotational grazing can help to restore rangeland ecosystems (Nosetto et al., 2006). Similarly, others (Howden et al., 1991; Glenn et al., 1993; Walker and Steffen, 1993) have also indicated that rehabilitation of degraded rangelands by means of grazing exclusion is a key strategy in reducing the loss of carbon (C) from terrestrial ecosystem. Although several studies

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(Mekuria et al., 2007; Pei et al., 2008; Steffens et al., 2008; Su et al., 2005) have documented an increase in soil C accumulation in exclusions, others (Nosetto et al., 2006; Reeder and Schuman, 2002; Shrestha and Stahl, 2008) have reported no improvement in soil carbon. On the other hand, earlier studies (Mekuria et al., 2011; Mureithi et al., 2014; Verdoodt et al., 2009) have confirmed that soil properties and vegetation characteristics have improved following grazing exclusion.

Generally, differences among various studies and regions are apparent because of variations in climate, soil properties and soil depth, landscape position, plant community composition and management practices (Derner and Schuman, 2007; McSherry and Ritchie, 2013). Similarly, the complexity of vegetation dynamics, land use practices and soil characteristics are additional inadequacies to fully understand the driving factors (Angassa et al., 2012). This suggests the need to investigate the effect of grazing management on soil carbon stocks.

In East Africa, community enclosures are extensively practiced by pastoralists to conserve standing pasture for dry season grazing (Angassa and Oba, 2010; Oba et al., 2001; Verdoodt et al., 2010). Enclosures are defined as area of rangeland, which is enclosed by a fence with branches of thorny *Acacia* trees as well as traditional rules to protect vegetation from grazing and/or browsing with the exception of calves and sick animals (Coppock, 1994; Oba, 1998). In some cultures, such enclosed areas may be called "exclosures" (Aerts et al., 2009). According to Angassa and Oba (2010), calves are allowed grazing inside enclosures for 3 to 4 months depending on the length of the dry season.

The use of communities' enclosures that are over 30 years old in Southern Ethiopia may improve restoration of rangeland vegetation with significant implication on the potential of carbon sequestration. However, this potential has rarely been investigated. Thus, understanding the potential of rangeland restoration for carbon sequestration may help to inform policies for diversification of local livelihood options through carbon finance. Previous studies (Angassa and Oba, 2010; Dalle et al., 2006; Oba et al., 2000) that have so far conducted in the rangelands of Borana in Souther Ethiopia only focused on the effects of grazing on vegetation ecology and range condition assessment. On the other hand, few studies (Belay and Kebede, 2010; Bikila et al., 2016; Yusuf et al., 2015) have reported the influence of land use and vegetation types on carbon stocks and these studies are limited and sites specific. Furthermore, these studies did not show the effects of enclosures management along age chronosequence on soil carbon stock. We expected that age of enclosures may reflect the spatial separation of carbon sequestration in terms of time of restoration of vegetation states.

Therefore, the objectives of the study were: (i) to investigate the effects of management systems on soil properties, SOC, TN stocks and vegetation characteristics; (ii) to investigate how the age of enclosures influence SOC, TN dynamics, and vegetation characteristics. We hypothesized that (1) There is no difference in soil C and N, and herbaceous biomass between enclosure management and the adjacent open-grazed areas; (2) enclosure management would favor more accumulation of soil C and N, and herbaceous biomass than the adjacent open-grazed areas; (3) there is no difference between the older and younger ages of enclosures in soil nutrients and herbaceous biomass accumulation; (4) The older age of enclosures would accumulate more soil nutrients and herbaceous biomass than the younger enclosures.

2. Materials and methods

2.1. Study area

The study was carried out in Dida-Hara area (04°47.318′N and 038°20.017′E), which is located at about 30 km North-East of Yabello town in Borana rangelands, Southern Ethiopia. Dida-Hara covers an area of about 985 km^2 (Fig. 1). The altitude of the Borana Plateau ranges from 1000 to 1500 m above sea level (m.a.s.l.) with a few peaks up to 2000 m (Coppock, 1994). Dida-Hara is located between an altitude range of 1200 and 1600 m.a.s.l. (Angassa and Oba, 2010).

The Borana rangelands are characterized by arid to semi-arid climate with most areas receiving between 238 mm and 896 mm annual precipitation, with a high coefficient of variability (18% to 69%) (Angassa and Oba, 2007). The rainfall in Borana is bimodal with the long rainy season occurs between March and May, while the short rainy season occurs between October and November. The major dry season is from December to February. The mean daily temperature in the Borana rangelands is 24 °C, with a mean maximum and minimum daily temperatures of 28 °C and 17 °C, respectively (Coppock, 1994).

Soils in the Borana rangelands are developed from granitic and volcanic parent materials and their mixtures (Coppock, 1994). The upland soil is mainly red in color, while the bottom land soils are dominated by dark vertisols (Oba et al., 2000). Upland soils elsewhere in the Borana rangelands are well drained and usually have equitable proportion of sand (53%), clay (30%) and silts (17%) (Coppock, 1994).

Vegetation of the study area is dominated by tropical savannah with varying proportions of perennial grasses and woody vegetation (Angassa and Oba, 2010). In the enclosures management, disturbance due to grazing and browsing was minimal. The vegetation within enclosures was dominated by tall grasses (*Cenchrus ciliaris*, *Chrysopogon aucheri*, *Cynodon dactylon*, *Sporobolus*, *Digitaria milanjiana* and *Panicum repens*) with moderately closed canopy of the upper storey trees (*Acacia tortilis*, *Acacia seyal* and *Balanites aegyptiaca*). On the other hand, the open-grazed areas adjacent to enclosures were unfenced and the impact of grazing was severe due to increased grazing pressure (Homann et al., 2008).

In the past, the Borana pastoralists used the communal rangelands for seasonal grazing that involved livestock movements between the wet and dry seasons grazing (Coppock, 1994). Before the 1970s, Dida-Hara was an open perennial grassland, which was used for grazing during the rainy season. After the 1980s, range enclosures were established by the community following the development of perennial ponds that attracted permanent settlements. The creation of settlements had substantially affected the patterns of seasonal grazing to a year-round grazing (Angassa and Oba, 2010).

The pastoral population in Dida-Hara area is settled in semi-permanent settlements locally known as *Olla*. The mean livestock holding of household was estimated at 12.63 cattle, 11.13 small ruminants (goat and sheep) and 2.38 camels (Solomon et al., 2007). Most of the communal rangelands are degraded due to the high stocking rate, which was estimated at 0.235 Tropical Livestock Units ha^{-1}(1 TLU ~ 250 kg) (Homann et al., 2008). Although the stocking density of enclosures was not regulated, overgrazing is not a threat as enclosures are seasonally grazed by calves only during the dry season and rested during the growth season (Angassa and Oba, 2010).

2.2. Experimental design

Before starting the actual field sampling, field survey and mapping of enclosures were carried out in Did-Hara between May and June 2012 with technical support from the International Livestock Research Institute (ILRI, Kenya). In the identification and mapping processes, knowledgeable community members, especially those managing the enclosures and experts working in the area were participated. A high resolution satellite from Google earth® and Geographic Position System (GPS) were used to delineate the boundary of enclosures following line features (fence). Hence, a total of 16 semi-private enclosures were identified and mapped (Fig. 2). Information collected during the preliminary field survey was used as a guide in selecting the study sites for the final data collection.

Following the initial step, we selected 9 semi-private enclosures associated with settlements (*Olla*) using a systematic random sampling method. The selected enclosures ranged from 60 to 620 ha in size, while ages of the enclosures were between 15 and 37 years old at the time of data collection (May–June 2013). We grouped the enclosures into three age chronosequence: [< 20 years old (younger), 20–30 years old