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Long-term livestock exclosure did not affect soil carbon in southern Ethiopian rangelands

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ABSTRACT

Controlled grazing management is considered as an effective strategy to enhance soil carbon sequestration, but empirical evidences are scarce. Particularly, the role of livestock exclusion related to soil carbon sequestration is not well understood in arid and semiarid savannas of Africa. We investigated the effectiveness of long-term (14–36 years old) exclosures in enhancing soil carbon in the semiarid savanna, southern Ethiopia. We tested for differences in soil carbon content between exclosures and adjacent open-grazed rangelands, while accounting for effects of age of exclosures and soil depths. We collected soil samples at two soil depths (0–20 cm and 20–50 cm depths) from 96 plots from 12 exclosure and adjacent open grazing sites. We found no significant differences ($P > 0.05$) between exclosures and adjacent open-grazed rangelands in soil carbon content in both soil depths. The age chronosequence further suggested a weak non-linear trend in increasing soil carbon content with increasing duration of exclosures. These results thus challenge the opinion that controlled grazing enhances soil carbon sequestration in semiarid savannas. However, we remain cautious in regard to the conclusiveness of these findings given the paucity of information regarding other confounding factors which may disentangle the effects of the exclosure, and most importantly in the absence of soil data prior to exclosures.

1. Introduction

Rangelands constitute the largest global land use with a wide range of potential productivity conditions in every continent (Steiner et al., 2014), and hold great potential for carbon sequestration (Lal, 2004). Some studies lend support to this notion and indicated that rangelands store significant amount of carbon (i.e., 36% globally, and 59% in Africa) (Campbell et al., 2008). The promise that African rangelands hold potential to sequester carbon is partly based on the assumption that they are degraded and under saturated in carbon as a result of overgrazing and frequent use of fire (Neely and de Leeuw, 2008). Consequently grazing management and control of fire are considered interventions with the potential to sequester carbon in rangelands (Conant, 2010; Derner and Schuman, 2007). The potential of these two interventions is further supported by a number of models which predict enhanced carbon stocks under reduced grazing intensity (Conant et al., 2001; Dlamini et al., 2016).

The rate of soil organic carbon (SOC) sequestration with adoption of recommended management technologies depends on soil texture and structure, rainfall, temperature, farming system, and soil management (Parras-Alcántara et al., 2015). Strategies to increase the SOC pool in grazing lands include soil restoration, perennial pasture and woodland regeneration and reduced grazing pressure (Reid et al., 2004). However, studies on the impact of livestock exclusion or reduced grazing on soil carbon stocks are not as conclusive as the above recommendations and model suggest. For example Milchunas and Lauenroth (1993) who reviewed 34 studies comparing soil carbon stocks in grazed and ungrazed sites reported a decrease in 40% and an increase in 60% of the cases. Other studies comparing grazed and un-grazed lands also reported decrease (Reid et al., 2004; Schuman et al., 1999) and increase (Derner et al., 1997; Yong-Zhong et al., 2005) in soil carbon following livestock exclusions. These, together with the inconclusiveness of the evidence indicates that there is a need to study the effect of livestock grazing on soil carbon stocks, before deciding to implement soil carbon

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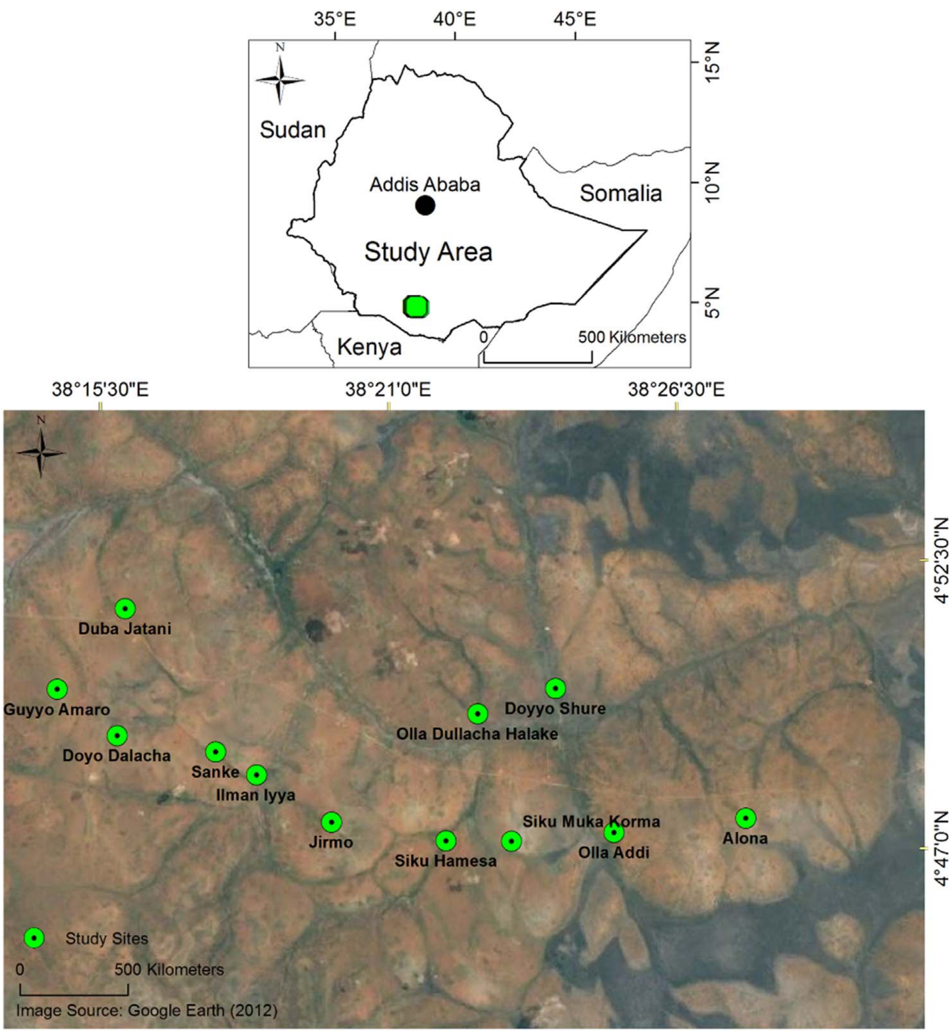

Fig. 1. Map of the study area showing the study sites, a Google earth mage background acquired in 2016.

sequestration programs in African rangelands (Milne et al., 2016).

In East African rangelands, semi-private exclosures are extensively practiced by pastoralists to put aside fodder bank conservation for use during the dry season when grazing resources are in short supply (Bikila et al., 2016). Here, exclosures may be defined as an area of land, which is enclosed by a fence to prevent grazing and/or browsing by livestock and restore vegetation resources (Aerts et al., 2009; Coppock, 1994). Traditionally, exclosures are totally closed to other livestock groups except in drought periods. Rangeland exclosures may play a crucial role in sequestrating atmospheric carbon in the system due to reduced livestock pressure which helps improves soil health and vegetation restoration (Aynekulu et al., 2009; Bikila et al., 2016; Mekuria and Aynekulu, 2013). However, the effectiveness of exclosures in improving SOC exhibits spatial and temporal variation due to differences in land management practices and other biophysical and socio-economic conditions. Thus, understanding the impacts of long-term livestock exclosures on SOC dynamics is essential to improve the management of savanna rangelands.

The Borana rangelands in southern Ethiopia comprise extensive grazing lands with indigenous knowledge on natural resource management (Homann et al., 2008). Since the last four decades, however, the Borana rangelands have undergone substantial reduction in grassland cover due to bush encroachment, expansion of cultivation, and increased settlements (Angassa and Oba, 2008; Dalle et al., 2006; Solomon et al., 2007) with consequences on the livelihood of the local communities. The conversion of the savanna rangelands of Borana into bushland, exclosures and cropland began around 1970s with a peak expansion of bush encroachment and crop cultivation in the 1980s (Angassa and Oba, 2008). During that time, about 40% of the Borana rangelands have directly shifted to bush encroachment (Coppock, 1994), while the communal rangelands were further shrunk by the expansion of cropland, exclosures and ranches (Angassa and Oba, 2008) which led to large declines in valuable perennial grass species and grass biomass (Angassa, 2014). For example, there was a reduction in the carrying capacity of the area for cattle grazing following bush encroachment, while goat and camel populations have increased in the area. Soil erosion is also becoming a problem due to such encroachment and reductions in grass production.

In response to the shifts in patterns of land use, many villages in the Borana area have set aside some of their lands as exclosure where land is degraded by high densities of livestock. Angassa et al. (2010) reported that herbaceous biomass and grass cover were significantly greater in the exclosures than in the open-grazed areas. However, the same authors concluded that the older exclosures had no superior benefits over the younger ones in terms of herbaceous biomass production. Though not quantified so far, changes in land use may greatly affect carbon and greenhouse gas emissions, as grasslands are believed to have the potential to restore carbon and avoid emission (Guo and Gifford, 2002). Hence, we investigated how the local communities' practices of exclosure grazing land management contributed to increase in SOC stock as compared to continuously grazed areas. Such empirical evidence could have implications for livelihood diversification options for pastoralists through facilitating payment for environmental services where livestock is more vulnerable to recurrent drought risk and bush

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