Challenges and Opportunities to Increase Carbon Sequestration in Subtropical Grazing lands

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Abstract
Livestock production has a significant environmental footprint. However, adoption of regenerative grazing land management practices can serve as a means of producing food with lower, or even net positive environmental impacts. Globally, much of the grazing land ecosystems are degraded due to improper management. This is particularly true in the southeastern US, where extensive areas of planted pastures are degraded due to inadequate nutrient and soil management. In this presentation, we will discuss the opportunities and challenges associated with increasing soil and ecosystem C sequestration in subtropical grazing lands through regenerative management practices.
Introduction

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Grazing lands are important sinks of atmospheric CO_2 and play a major role in the overall carbon (C) cycle fluxes. Unlike tropical forests, where most of the C is stored in the vegetation, as much as 90% of the C pools in grazing land ecosystems are located belowground, hence, it can be readily transferred into more permanent storage in the soil. Because soil C is more stable than plant biomass, soil C sequestration in grazing lands provides a long-term alternative to mitigate atmospheric greenhouse gas (GHG) emissions. Estimates suggested that grazing land soils contains approximately 10%–30% of the world's soil carbon reserves (Eswaran et al. 1993), sequestering approximately 0.2 Pg C yr^{-1} (Follett and Schuman, 2005).
Native and cultivated grazing lands encompass an extensive area in the United States (~1/3 of the land area), therefore, even small changes in the amount of C sequestered in grazing land soils have significant consequences in the national and global C cycle. Reports suggested that an increase (or loss) of only 1% of the soil carbon in the top 10 cm of grazing land soils is equivalent to the total C annual emissions from all U.S. cropland agriculture (Follett and Reed, 2001). This trend underscores the importance of grazing lands to mitigate at least part of global atmospheric CO_2 emissions. Increasing soil C sequestrations also offer significant accompanying benefits such as improved soil and water quality, reduced soil erosion and nutrient losses, and greater crop yields. In this presentation, we will discuss challenges and opportunities of increasing soil C sequestration in subtropical grazing lands.

Potential for C Sequestration

Carbon sequestration rates vary by climate, topography, soil type, and past and current management practices. While the majority of rangelands in the United States are located in arid and semiarid regions, most of the cultivated pastures are in eastern regions that receive more rainfall and, consequently, have greater potential to respond to management. For example, because of the warm climate and ability to grow biomass year-round in humid subtropical regions, there is a potential to return great amounts of C to the soil as above-ground (i.e., dead leaves) and below-ground (i.e., roots, root exudates) plant inputs. However, soil C accumulation remains a major challenge because of the fast decomposition rates in warm and moist conditions.

Soil C balance in grazing lands depends on the quantity and quality of plant-derived C inputs from photosynthesis and C losses via respiration. Management practices that increase plant biomass production (e.g., nitrogen fertilization, proper grazing management, use of legumes) often result in greater C inputs to the soil and, consequently, an increase in soil C sequestration (Henderson et al., 2015). However, most of the studies focused on quantifying short- and long-term changes in soil C stocks in response to management were conducted in temperate regions, with much less effort placed on subtropical humid grazing lands. Our current lack of quantitative understanding of the direction and extent of management-induced soil C responses in subtropical and tropical regions hinders adoption of C conservation practices.

A variety of management practices have been proposed to increase soil C sequestration potential. These include fertilization, grazing management, irrigation, sowing legumes, prescribed fire, and species selection. Because most improved management practices can also have benefits for forage and livestock production, they may also provide an incentive for producers to adopt strategies that enhance soil C pools. In a global review, Conant et al. (2017) reported that soil C responses to grazing land management were positive, negative, or remained unchanged. The authors attributed this to the complex interactions among management, temperature, precipitation, and soil characteristics. Similarly, grazing has often be associated with increased soil C sequestration (Schuman et al., 2002; Franzluebbers and Stuedemann, 2010); however, a recent study showed no effect on soil C responses after 74 yr of cattle exclusion (Derner et al., 2019). The apparent discrepancy among studies that evaluated changes in soil C in response to management are likely due to differences in climate, soil type, management intensity, and vegetation composition. For instance, at regional and global scales, climate is considered the key driver of soil C accumulation. Although abundant rainfall and warm temperature in the tropics favor primary productivity, soil C decomposition is also accelerated. Conversely, in cold and wet climates, photosynthesis rates exceed decomposition resulting in high levels of soil C.

While climate generally controls global patterns of soil C, other factors that vary on smaller spatial scales may interact with climate to determine soil C levels. For instance, key soil properties such as mineralogy, aggregation and texture also affect soil C accumulation and protection against degradation. Lack of physical and chemical C protection and stabilization commonly associated with subtropical soils often limits C accumulation, particularly in stable forms. Even when soil C accretion occurs, C is often associated with short-lived, labile fractions with residence times of months to years that can easily be lost via microbial degradation (Silveira et al., 2014; Xu et al, 2018). Accurate characterization of soil C stocks in grazing lands is often problematic due the high spatial variability of soil and vegetation, extensive land area, and heterogeneous distribution of nutrients by grazing animals (Franzluebbers, 2010). Characterization of the spatial variability of soil C and long-term (decadal or older) experimental sites are also critical components to assist modeling efforts as well as quantification of potential C benefits associated with different management practices. However, there are limited studies addressing these concerns. In addition, the time period considered, duration of the study, and previous land use are important factors that may also affect soil C responses. Temporal effects are particularly important in fine-textured soils, that usually respond slower to management than coarse-textured soils. Lastly, the mechanisms underlying changes in soil C are often unclear in most studies, which makes it difficult to generalize soil C patterns, especially across different climatic regions.

Conclusions and/or Implications

Grazing lands provide numerous ecosystem services, including the capacity to store large amounts of soil C; however, our understanding of the complex factors affecting soil C responses to grazing land management is limited, particularly within subtropical and tropical climates. One of the main constrains is the lack of long-term studies to inform management strategies that can potentially increase soil C sequestration in these regions.

From a practical perspective, direct measurement of the rate of C accumulation is often difficult and, in many circumstances, unrealistic. Development of reliable measurement tools and models are critical to design and validate the benefits of adopting conservation practices at different spatial scales and to inform land managers and policy makers. While uncertainties remain, grazing land management has the potential to increase grazing land productivity and resilience while also enhancing C sequestration. There is also a need to consider the potential impacts of management on trace gases (CH_4, N_2O) emissions. The difference between C sequestered and trace gas emissions ultimately define the net GHG balance of grazing lands; however, this balance is affected by a number of site-specific factors, including grazing and fire management (Rowlings et al., 2010). A life cycle analysis approach is required to understand the net benefit of management practices on the C cycle. There is no doubt that this topic of research should and will continue to be relevant in years to come, particularly in subtropical and tropical regions. Furthermore, C trading-related markets and the growing interest in C sequestration as mechanisms for environmental protection are also expected to enhance the economic value of C sequestered in grazing land soils.

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