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Grazing land intensification effects on soil C dynamics in aggregate size fractions of a Spodosol

Maria L. Silveira [a,*], Sutie Xu [a], Julius Adewopo [a], Alan J. Franzluebbers [b], Guilherme Buonadio [c]

[a] University of Florida, Range Cattle Research and Education Center, Ona, FL 33865
[b] USDA-ARS, Plant Science Research Unit, Raleigh, NC, 27695
[c] University of Sao Paulo, ESALQ, Piracicaba, SP 13418, Brazil

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ABSTRACT

Impacts of land intensification on soil organic carbon (SOC) responses are important components of sustainable management evaluation. Because of poor aggregation often associated with coarse-textured soils and the limited potential for chemical and physical protection of SOC, we hypothesized that the fine aggregate fraction (<53 μm) represents an important sink for SOC stabilization in sandy soils. We investigated the impacts of converting native rangeland ecosystems into intensively managed pastures on SOC stocks and the distribution and decomposition rates of C associated with aggregate size fractions in a Coastal Plain Spodosol. Experimental sites consisted of three grazing land biomes: native rangelands, pine (Pinus elliottii Engelm)–bahiagrass (*Paspalum notatum* Fluegge) silvopasture, and improved pastures under similar soil and climate conditions, but subjected to different management intensities. As grazing land intensification increased, SOC stock (0- to 20-cm depth) increased. Greater SOC stock was associated with improved pasture and silvopasture (53 Mg C ha^{-1}) as compared to the native rangeland ecosystem (35 Mg C ha^{-1}). This response was due the introduction of more productive plant species (i.e., warm-season C_4 grass) augmented by N fertilization. $\delta^{13}C$ signature of the improved pasture (−14.7‰ to −18.8‰) reflected the influence of introduced C_4 pasture grass, while the native rangeland and silvopasture showed more negative $\delta^{13}C$ values (−20.3‰ to −22.7‰). Grazing land intensification affected C associated with the <53-μm aggregate size fraction, representing clay- and silt-protected SOC. Unlike previous studies that indicated that C associated with fine aggregate size represents a resistant C pool, our data suggested the <53-μm fraction of a Spodooil is dynamic and is susceptible to changes in response to land use intensification.

1. Introduction

Grazing lands, including planted pastures and native rangeland, are among the largest ecosystems in the world, representing approximately 26% of the world land area and 70% of the world agricultural area (FAO, 2008). However, as result of increased demand for food and energy, intensification of grazing lands has increased substantially in the last decades (Follett et al., 2001; Reid et al., 2004; Stewart et al., 2007). This trend is particularly relevant in developed countries where a significant portion of native grazing lands are being replaced by more intensive agriculture and urban development (Follett and Reed, 2010). Because grazing lands provide important ecological services, continuation of this trend is expected to have major impacts on soil quality, regional climate, potential future C sequestration, and greenhouse gas emissions.

Grazing land intensification typically involves the use of highly productive plant species that can support greater grazing pressure, removal of higher proportions of site biomass and nutrients during mechanical harvest or grazing, and increased use of fertilizers, particularly N. Current improved grazing land management strategies are generally aimed at increasing above-ground biomass yield, with less regard for below-ground C dynamics. However, SOC levels in grazing lands are often strongly influenced by management (Conant et al., 2001; Franzluebbers and Stuedemann, 2002; Franzluebbers et al., 2000). Because intensive management affects above- and below-ground biomass (Liu et al., 2011a,b; Schuman et al., 1999), it has important implications on the amount and characteristics of C stored in grazing lands (Conant, 2010; Conant et al., 2001; Dubeux et al., 2006a; Franzluebbers and Stuedemann, 2003, 2009, 2010; Silveira et al., 2013; Wright et al., 2004).

Research has shown that SOC changes in response to conversion from native grazing land ecosystems to intensively managed improved pasture systems are variable. While it has been suggested that many improved pasture management techniques typically increase soil-C stocks (Causarano et al., 2008; Conant and Paustian, 2002; Conant et al., 2001; Follett and Schuman, 2005), overgrazing, for instance, often results in grassland degradation and decrease in SOC pools (Franzluebbers and Stuedemann, 2005; Oldeman, 1994). Guo and Gifford (2002) suggested that well-managed pastures can increase SOC levels by about 8% on

Abbreviations: SOC, soil organic carbon.
* Corresponding author. Tel.: +1 863 7351314; fax: +1 863 7351930.
E-mail address: mlas@ufl.edu (M.L. Silveira).

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average. Based on 115 studies across a wide range of climate and environmental conditions, Conant et al. (2001) concluded that grasslands are very sensitive to management and SOC stocks were significantly increased by eliminating soil disturbances and increasing primary production through improved grazing management, fertilization, sowing improved forage species and legumes, or irrigation.

Soil structure and aggregation are important properties that affect SOC cycling and stabilization (Blanco-Canqui and Lal, 2004; Sollins et al., 1996). Soil texture and management strategies that affect C inputs or disturb the soil can have major impacts on soil stability and SOC dynamics. For instance, while N fertilization results in greater above- and below-ground biomass production (Conant et al., 2001; Dubeux et al., 2006b; Liu et al., 2011a; Stewart et al., 2007), it often also increases SOC decomposition (Mulvaney et al., 2009; Neff et al., 2002; Raich and Schlesinger, 1992). Although grazing land intensification can increase biomass C, this response may not necessarily be synonymous with sequestering more SOC in the long-term. Previous studies in coarse-textured soil (sand, sandy loam, and loam textures) demonstrated that although land use intensification (e.g., greater N inputs) resulted in SOC accretion, the increases in SOC occurred primarily in labile C forms (Franzluebbers and Stuedemann, 2002, 2003; Silveira et al., 2013). Therefore, the form and longevity in which C is stored in the soil are important features when defining long-term SOC sequestration (Billings et al., 2006; Conant et al., 2004; Wang and Hsieh, 2002). In addition, because of the poor aggregation often associated with coarse-textured soils and the limited potential for chemical and physical protection of SOC (Sarkhot et al., 2007b, 2008), the mechanisms by which SOC is stabilized in sandy soils are likely different from those in clay-dominated soils. Although numerous studies demonstrated that SOC turnover decreases from macro- to micro-aggregates, thereby implying that there is a physical protection (Six et al., 1999; Tisdall and Oades, 1982), because of the lack of clay minerals, SOC associated with fine aggregate fraction in sandy soils is weekly protected and can be dynamic (Silveira et al., 2013). Several studies argue that the fine aggregate fraction [either microaggregates (212–53 μm) or occluded light C (100–10 μm)] can be less recalcitrant than has been reported and, therefore, SOC may be susceptible to microbial processes and changes in land use management (Golchin et al., 1994; Jastrow et al., 1996). This hypothesis has been demonstrated by the few previous studies under similar environmental conditions (Dubeux et al., 2006a; Sarkhot et al., 2007b; Silveira et al., 2013). However questions still remain on how management affects SOC protection and stabilization in soil aggregates in coarse-textured soils located in sub-tropical regions. Because of the low clay content of the soils in our experimental sites associated with the warm and humid climate, we expected that the long-term impacts of grazing land intensification on SOC dynamics will be more pronounced in the silt- and clay-protected (<53 μm) aggregate fraction. Although contradicting what it might be expected for clay-dominated soils, the coarse soil texture offers poor aggregation and limited protection against SOC degradation so the fine aggregate fraction, although proportionally small, represents an important sink for SOC stabilization in these soils. Furthermore, we predicted that as grazing land intensification increases SOC susceptibility to degradation will also be favored. To test these hypotheses, this study was designed to: (i) investigate the impacts of converting native rangeland ecosystems into intensively managed systems on SOC stocks; (ii) evaluate how intensification affects SOC distribution among the various soil aggregate size fractions, and (iii) determine rate constants for the decomposition of SOC associated with these soil aggregate size fractions.

2. Materials and methods

2.1. Site description

The experimental sites were located at the University of Florida, Range Cattle Research and Education Center in south–central Florida (27°35′N, 81°55′W). Mean annual precipitation is ~1650 mm. Average maximum/minimum temperatures are 28/17 °C. The soils were classified as a Spodosols [Ona and Smyrna fine sands (sandy, siliceous, hyperthermic Typic and Aeric Alaquods, respectively)]. These soils have sandy A horizons, followed by eluviated E horizon, and spodic (Bh) horizons. The studied soils have a fluctuating water table that often approaches the A horizon during the summer rainy season. The study was conducted on grazing land ecosystens that represent a gradient of management intensities ranging from native rangeland (lowest), silvopasture (intermediate), to improved bahiagrass pasture (highest). Each field replicated site (~6 ha) was adjacent to each other but managed independently. All sites exhibited the same topography, soil series, and climate conditions, and have been established and consistently maintained for over 20 years. A brief description of each grazing land ecosystem is provided below.

2.1.1. Florida's native rangelands

This ecosystem is minimally disturbed and reflects the least managed site in this study. Florida's native rangeland ecosystems consist primarily of pine-palmetto flatwoods and are characterized by an overstory of scattered slash and longleaf (*P. palustris* Mill.) pine and an understory dominated by saw palmetto (*Serenoa repens* Bartr.). When saw palmetto ground cover is relatively sparse, a wide variety of grasses (e.g., *Andropogon*, *Panicum*, and *Paspalum* spp.) can also occur (Kalmbacher et al., 1984). Unlike planted pastures where the vegetation is normally dominated by one to two forage species, ranges often have over 100 species (Kalmbacher et al., 1984). While some plant species occur only at certain times of the season, others are available throughout the year. Long (1974) listed 303 species of plants in the mesic pine flatwoods of South Florida, which according to the author represented the third highest plant diversity of any habitat in South Florida. Pine flatwoods are characterized by seasonal flooding and frequent fires and are frequently interfaced with planted pastures in many ranching operations. They are an important source of winter pastures for beef cattle (Kalmbacher, 1978). Despite its ecological importance, Florida's flatwood ranges are among the least protected habitat, with approximately 36% still remaining (64% loss). Land conversion to urban and suburban development has been the major cause of habitat destruction in South Florida. The native rangelands were never fertilized, but had been subjected to periodic burning (every 3 to 4 years) and occasional grazing activities (<60 days per year). Stocking rates are relatively low (average of 125 animal days ha^{-1} yr^{-1}). Grazing cattle were supplemented with hay and molasses from January to April.

2.1.2. Pine-bahiagrass silvopasture

The silvopasture system consisted of a pine-bahiagrass stand established in 1991. Slash pine seedlings were planted in December 1991 at 1120 trees ha^{-1} in a double-tree row configuration on a 11-year-old Pensacola bahiagrass (Kalmbacher and Ezenwa, 2005). Trees were planted in double rows, 2.4 m apart, with 1.2 m between rows, and 12.2 m alley between double-tree rows. Pine-bahiagrass received annual applications of ~67 kg N ha^{-1} from 1998 to 2002 but has not received any fertilizer since then. Grazing has occurred sporadically (every 2 to 3 years) over the past 10 years but typically cattle were not allowed to graze the pine-bahiagrass silvopastures for more than 30 days each year. Stocking rates were low (average of 207 animal days ha^{-1} yr^{-1}). Management inputs in this ecosystem are considered moderate.

2.1.3. Improved bahiagrass pastures

Grazed pastures consisted of a 31-year-old stand of bahiagrass which has been intensively managed to optimize forage and animal production. Management practices utilized in this area are typical for the region. Bahiagrass pastures were rotationally grazed year-round (7-day grazing period followed by 1 week of resting period). Grazed pastures have been annually fertilized with N (~67 kg N ha^{-1} yr^{-1})