



Long-term incubations of size and density separated soil fractions to inform soil organic carbon decay dynamics

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ABSTRACT

Soil organic matter in coarse-textured soils is more vulnerable to environmental disturbances due to reduced potential for soil organic carbon (SOC) stabilization in aggregates or organo-mineral complexes. In sandy loam soils from the Rio Grande Plains region of southern Texas, woody encroachment has resulted in the rapid accrual of root and leaf tissues derived from trees and shrubs into poorly physically protected (macroaggregate >250 μm) and non-mineral associated (free light fraction <1.0 g cm^{-3}) soil fractions. To determine the impact of changing plant input chemistry on potential degradability of accumulating SOC fractions, we measured the quantity and isotopic composition of respired CO_2 from year-long incubations of the macroaggregate and free light soil fractions along a grassland to woodland successional chronosequence. During incubation of both fractions, the proportion of SOC respired from older woody stand soils (~40–90 yrs) relative to recently established woody stands (<40 yrs) and remnant grassland soils decreased. We interpreted this decrease with woody stand age to result from a change to plant input chemistry with more lignin and aliphatic structures combined with a progressive shift to more non-hydrolyzable, poorly accessible forms of soil organic nitrogen, resulting in a system with slower short-term decay dynamics. The $\delta^{13}\text{C}$ values of respired CO_2 from all landscape elements indicated a selective release of older grassland-derived SOC in the first month of the macroaggregate incubation, possibly due to the disruption and rapid microbial utilization of grassland SOC after the soil fractionation process. Due to the sensitivity of these rapidly-cycling soil fractions to environmental disturbance and their capacity to influence longer-term SOC dynamics, understanding their decay dynamics is essential for understanding mechanisms of SOC stabilization. This is especially important in coarse-textured soils where large SOC stocks may be present in physical fractions that are relatively unprotected from decomposition.

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1. Introduction

Soil physical fractionation schemes aim to isolate conceptually-defined soil organic carbon (SOC) pools that vary in size, density, and aggregate associations, and therefore differ in turnover times and stabilization potentials. Despite frequent emphasis on long-term SOC pools for C stabilization, the average age of respired CO_2 (Trumbore, 2000) and average turnover time of bulk SOC (Raich and Schlesinger, 1992) is on decadal time scales, which highlights the significance of soil organic matter (SOM) pools with intermediate turnover rates to the global C cycle. Carbon held within shorter- and intermediate-term decadal pools, such as

particulate organic matter (POM) and litter-dominated soil fractions (Krull et al., 2005; Liao et al., 2006b; Bol et al., 2009), are highly sensitive to disturbance and management (Six et al., 1998; Paustian et al., 2000; Haynes, 2005; Leifeld and Fuhrer, 2009) and potentially to future climate change (Trumbore, 1997; Fang et al., 2005; Jones et al., 2005).

In POM and litter, chemical structure dictates short-term decay dynamics so that material with high C:N, lignin:N, and lignin:cellulose ratios, or with high lignin, phenol, and wax contents degrade more slowly (Melillo et al., 1982; Taylor et al., 1989; Heal et al., 1997). Compounds containing aliphatic and aromatic structures have been shown to be more resistant to microbial decay (Marschner and Kalbitz, 2003; Feng et al., 2008), and fire-derived (charcoal) C can persist in soils for hundreds or even thousands of years (Bird et al., 1999; Schmidt et al., 2002; Preston and Schmidt, 2006), suggesting that chemical composition is an important determinant of SOC turnover.

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However, recent reviews have suggested that organic matter chemistry is not particularly important for long-term SOC stabilization (Amelung et al., 2008; Schmidt et al., 2011). Instead, physical protection of SOM on organo-mineral complexes and in soil aggregates plays the dominant role (Marschner et al., 2008; Kleber et al., 2010; Schmidt et al., 2011). The presence of a so-called abiotic “regulatory gate” (Kemmitt et al., 2008) which serves to release previously unavailable SOM into bioavailable forms through processes such as chemical oxidation and desorption from mineral surfaces supports such observations. It stands as a compelling hypothesis that the interaction of soil microbial biota with SOM is not the rate-limiting step in SOM decomposition (Kemmitt et al., 2008), and that it is not the chemical nature but rather the quantity of input to soil that governs SOM accrual (Paterson, 2009; Gentile et al., 2011; Carrington et al., 2012). By examining the decomposition of soil fractions comprised of fresher plant material, fewer mineral surfaces, and lower aggregate protection than whole soil, one might bypass (or greatly minimize) some of the constraints imposed by such abiotic gate controls on SOC decomposition.

Woody plant encroachment into grasslands and savannas is a globally extensive land-cover change (Archer, 1995; Dickie et al., 2011) that can alter the quantity and chemistry of plant inputs, thereby influencing the biogeochemical cycling of SOC and nutrients (Hibbard et al., 2001; Boutton et al., 2009). In the Rio Grande Plains region of southern Texas, encroachment of C₃ woody plants into C₄ dominated grasslands over the last 150 yrs has been accompanied by increases in soil C and N (Boutton et al., 1998; Archer et al., 2001; Boutton and Liao, 2010) predominately in more physically unprotected soil fractions (Liao et al., 2006a; Creamer et al., 2011). The percentage of whole soil carbon held within the more physically unprotected free light fraction (FLF) and macroaggregate-sized fraction increases from 28% in grasslands to 38% in woody clusters <40 yrs of age to 61% in woody clusters >40 yrs of age (Creamer et al., 2012). Due to these large increases in soil C and N in more physically unprotected soil fractions in response to woody encroachment, their decay dynamics are integral to understanding mechanisms of SOC accrual in these soils.

Accumulation of SOC in these more physically unprotected soil fractions is thought to be driven, at least in part, by the changing carbon input chemistry in response to woody encroachment, as the isotopic composition of these soil fractions resembles woody C₃ inputs after about 40 yrs of woody stand development (Liao et al., 2006a, 2006b; Boutton et al., 2009; Creamer et al., 2011). Microbial biomass carbon decreases relative to total soil C and respired CO₂, suggesting SOC in woodland soils is more difficult to degrade (Liao and Boutton, 2008). Higher proportions of cutins, waxes, and more difficult to degrade syringyl and vanillyl lignin in woody plant litter are reflected in the accumulation of these compounds in the FLF and in particulate organic matter (POM) (Fillee et al., 2008). However, incubations of the whole soil revealed that physical accessibility to soil C dictated degradation dynamics more than changes in soil carbon chemistry (Creamer et al., 2011). In addition, recent studies have indicated that progressively accumulating soil N under woody stands is less extractable as amino compounds by wet chemical means than in the grasslands, potentially facilitating soil C accrual (Creamer et al., in press) due to the importance of N in C cycling (e.g. Knicker, 2011). Therefore the actual importance of changing SOC chemistry to the decay dynamics within the soil fractions is unknown.

The purpose of this study was to determine if increases in plant tissues with purportedly slower decay rates facilitate the observed SOC accrual in soil fractions with low physical protection capacity and decadal to sub-decadal mean residence times (the FLF and macroaggregate-sized soil fraction). The low clay content of these

soils (approximately 10%) and absence of dense mineral matter in the FLF prevents any substantial stabilization of SOC on clay particles (Hassink, 1997; Six et al., 2002) and allows for the examination of SOC dynamics and bioavailability without the constraints of abiotic “regulatory gate” controls. We hypothesized that the lower quality of organic matter inputs in older woody plant stands would cause a decrease in the fraction of C mineralized in the rapidly accruing soil fractions. More broadly, this experiment also allowed us to determine differences in C stabilization mechanisms between these soil fractions and the whole soil in order to gain insights into short term SOC dynamics and long-term C stabilization that might be applicable to other ecosystems with coarse-textured soils.

2. Materials and methods

2.1. Site description

The Texas AgriLife La Copita Research Area (La Copita) is in the Rio Grande Plains region of southern Texas (27°40'N; 98°12'W). This area has a mean annual temperature of 22.4 °C and an average annual rainfall of 716 mm. Over the past 150 yrs, fire suppression combined with livestock overgrazing has resulted in progressive encroachment of C₃ woody plants into the native C₄-dominated grasslands (Archer, 1990; Boutton et al., 1998; Archer et al., 2001). The grassland is dominated by grass species such as *Chloris cucullata*, *Panicum hallii*, *Bouteloua rigidisetata*, and *Tridens muticus*. Woody encroachment begins with the establishment of the leguminous *Prosopis glandulosa* (Torr.) var. *glandulosa* (honey mesquite). Other tree/shrub species, such as *Zanthoxylum fagara*, then enter the understory, resulting in the formation of discrete C₃ woody clusters that may coalesce into closed-canopy groves (Archer et al., 1988). The soils under both the remnant grassland and the invading woody clusters are sandy loams (Typic and Pachic Argiustolls). Additional information regarding the study area has been published elsewhere (Scifres and Koerth, 1987; Archer, 1995; Boutton et al., 1998).

2.2. Soil sampling and physical fractionation

Soils were sampled from the site and physically fractionated as described in Creamer et al. (2011). Briefly, soil cores of 5 cm diameter and 30 cm depth were taken in October 2006 from 15 discrete woody clusters and 15 grassland sites. Samples within the discrete woody clusters were taken in the four cardinal directions within 50 cm from the trunk of the largest mesquite tree. The ages of these trees are equal to the ages of the woody clusters (Archer et al., 1988), and were determined by using the basal diameter in site-specific regression equations (Stoker, 1997). The ages (in years) of the fifteen woody clusters sampled were: 14, 16, 23, 34, 37, 41, 41, 52, 56, 63, 65, 70, 73, 82, and 86. For the paired grassland sites, soil cores were taken in the four cardinal directions around a randomly selected C₄ plant located adjacent to, but not within 3 m, of the canopy edge of the sampled woody clusters.

After sampling, the cores were placed on ice and then the 0–10 cm sections from each of the four cores were homogenized into a single sample. After homogenization the field-moist soil was passed through an 8 mm sieve, oven-dried at 50 °C, and then subjected to size and density fractionation following a procedure modified from Cambardella and Elliott (1993) and Six et al. (1998). Briefly, the FLF was first obtained by immersing oven-dried soils in water, then aspirating and drying all floating fragments. The soil was then wet-sieved to isolate the three remaining size fractions (Elliott, 1986): the macroaggregate-sized fraction (>250 μm), the microaggregate-sized fraction (53–250 μm) and the free silt and

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