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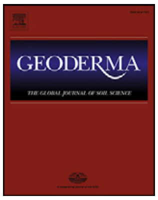

Soil carbon sequestration potential in semi-arid grasslands in the Conservation Reserve Program☆

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ABSTRACT

The Conservation Reserve Program (CRP) in the USA plays a major role in carbon (C) sequestration to help mitigate rising CO_2 levels and climate change. The Southern High Plains (SHP) region contains >900.000 ha enrolled in CRP, but a regionally specific C sequestration rate has not been studied, and identification of the C pools and processes important in controlling C sequestration rates remain unresolved. We aimed to address these gaps by utilizing a CRP chronosequence with historical rangeland as a reference ecosystem. Soil samples (0–10 and 10–30 cm) were collected in 2012 and 2014 from a total of 26 fields across seven counties within the SHP and included seven croplands (0 y in CRP), 16 CRP fields that ranged from 6 to 26 y (as of 2012), plus three rangelands. Multiple regression analysis was conducted to gauge the rate of C sequestration under CRP within C pools: soil organic C (SOC), particulate organic matter C (POM-C), and microbial biomass C (MBC), with two additional predictors (soil clay + silt content and precipitation). Despite attempts to control for soil texture by targeting a dominant soil series (Amarillo fine sandy loam), the percent of clay + silt (15.2–48.7%) significantly influenced C accrual. The C sources (C_3 from previous cropping systems or C_4 from CRP grasses) in SOC and POM-C were assessed using stable C isotope signatures. Additionally, the role of soil microbes in C sequestration was evaluated by investigating the relationship between MBC and CO_2 flux and C sequestration. SOC increased at a rate of 69.82 and 132.87 kg C ha^{-1} y^{-1} and would take approximately 74 and 77 y to reach the rangeland C stocks at 0–10 and 0–30 cm, respectively. The C_4-C primarily from the introduced grasses was the main source of C sequestration. SOC gains were essentially due to increases in POM-C and MBC, accounting for 50.04 and 15.64% of SOC sequestration at 0–30 cm, respectively. The highest semi-partial correlation coefficients between the increasing years under CRP restoration and MBC indicated CRP had the strongest effect on MBC compared to other C pools. In addition, increasing soil CO_2 flux and MBC:SOC ratio with years of CRP restoration indicated MBC played a critical role in the C sequestration process. Conservation of CRP lands and efforts to sustain perennial systems in this highly erodible landscape should be a high priority of conservation programs. In doing so, significant offsets to increasing atmospheric CO_2 levels may be achieved in addition to erosion control and improved wildlife habitat.

1. Introduction

In 1985, the United States Department of Agriculture (USDA) initiated the Conservation Reserve Program (CRP), which is a cost-share and rental program that pays landowners to convert environmentally sensitive land from agricultural production and planting species that reduces soil erosion and improve wildlife habitat and water quality. Through the establishment of grasslands, forests, or wetlands on marginal lands, CRP

Abbreviations: CRP, conservation reserve program; SOM, soil organic matter; SOC, soil organic carbon; POM, particulate organic matter; SHP, Southern High Plains.

☆ Mention of trade names or company names in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the Texas Tech University and U.S. Department of Agriculture.

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enrollment increased surface cover and by 2009 reduced soil erosion nationwide by 215 and 230 teragrams due to water and wind erosion, respectively (USDA-FSA, 2009). In May 2016, Texas led the USA in hectares (ha) enrolled in CRP (1.21 million or 12.5% of total ha), with the majority of this land (0.92 million ha) located on sandy, highly erodible soils within the semi-arid Southern High Plains (SHP) (USDA-FSA, 2016). Additionally, these perennial grasses also play a critical role in sequestering atmospheric CO_2 linked to global climate change (Piñeiro et al., 2009) and because of the vast areas enrolled in CRP, these lands may sequester large amounts of C (Gebhart et al., 1994). Programs that have set aside agricultural lands such as CRP have shown a quick increase in soil labile C and total long-term C sequestration over an average time span of 10 y (Piñeiro et al., 2009). Following conversion of cropland to grassland or pastures, C sequestration rates have been shown to vary from 0 to 1224 kg C ha^{-1} y^{-1} at 0–10 cm and 100 to 2220 kg C ha^{-1} y^{-1} at 0–30 cm soil depth in cool temperate steppe ecosystems (Follett et al., 2001; Gebhart et al., 1994; Post and Kwon, 2000) to 4731 kg C ha^{-1} y^{-1} at 0–20 cm in frigid temperature and udic/aquic moisture regime in Minnesota (Follett et al., 2001). In addition, negative C sequestration rates also have been found in mesic temperature regimes with arid/ustic or udic/aquic moisture regimes (Follett et al., 2001), or tropical yet dry regions (Trumbore et al., 1995). The potential of soils to sequester C varies depending on regional differences due to climate and plant species composition, age of ecosystem, and inherent soil properties such as texture, (Conant et al., 2001; Kucharik, 2007; Lal and Kimble, 1997; Post and Kwon, 2000; Six et al., 2002), and is determined by a balance of plant C inputs and C outputs through decomposition (Jenny, 1994; Schlesinger, 1977). In general, total SOC increased with more precipitation (Lal and Kimble, 1997) and decreased with increasing temperature (Jobbágy and Jackson, 2000). Under similar climate conditions, soil texture was the dominant factor controlling SOC decomposition (Schimel et al., 1994). SOC mineralization rate decreased with soil clay + silt content (Bai et al., 2012; Bosatta and Agren, 1997) and SOC increased with clay + silt content (Bai et al., 2012).

Despite numerous conservation successes provided by CRP lands and the increasing public demand to participate, the CRP program is threatened by a decline in acreage allowed to enroll as well as market demands on land that is scheduled for contract expiration (Stubbs, 2014). Recognizing the specific contribution of CRP on additional ecosystem services, such as C sequestration to offset rising CO_2 levels and mitigate climate change may provide policy makers with enhanced justification to continue support and increase allowable acreage and cost-shares. A key step in this process is to develop accurate estimates for C sequestration that are regionally specific and can account or adjust for key factors that influence rates (e.g., soil texture, site age, etc.). Numerous studies have attempted to calculate C sequestration rates across diverse soil types and spatial regions (local areas to states) (Derner and Schuman, 2007; Kucharik, 2007; Paustian et al., 1997; Post and Kwon, 2000) but these estimates are subjected to over- or under-estimating rates when scaling to larger regional or national levels if key properties, such as particle-size distribution, are not accounted for. For instance, Gebhart et al. (1994) reported a C sequestration rate of 800 kg C ha^{-1} y^{-1} for a depth of 0–40 cm during the first 5 y of CRP management (significance at $p < 0.1$), which was an average across three soil types (Patricia fine sandy loam, Ulysses silt loam, and Valentine fine sand) and three states (Texas, Kansas, and Nebraska). The soils varied greatly in their C sequestration rate and was mainly associated with textural differences: silt loam soil sequestered an average of 1590 kg C ha^{-1} y^{-1} (2380 and 800 kg C ha^{-1} y^{-1} in Colby and Atwood, Kansas, respectively) in the top 40 cm; whereas the sandy loam soil sequestered an average of 240 kg C ha^{-1} y^{-1} (420 and 60 kg C ha^{-1} y^{-1} in Big Spring and Seminole, Texas, respectively). Moreover, C sequestration rates differed widely within the same soil textural class, indicating a need to adjust for specific soil particle distribution (i.e. clay %, silt %, and sand %) in the C sequestration rate estimations. To address this variability and improve the accuracy and robustness of these estimates, a significant number of local-scale (e.g. county level) studies that normalize C sequestration based on soil texture and environment factors are needed (Lal and Kimble, 1997; Post and Kwon, 2000).

Evaluation of the relative proportions of the different C pools (Bell and Lawrence, 2009) as well as tracking of C using stable C isotopes holds great promise in enhancing our understanding of how soil will respond to management shifts or a changing climate. Labile fractions of SOC including particulate organic matter C (POM-C) (Cambardella and Elliott, 1992; Cambardella and Elliott, 1993) and microbial biomass C (MBC), reflect the active C fractions of SOC and serve as early indicators of SOC changes (Mao et al., 2012). During CRP establishment, agricultural fields are converted from the dominant crop species (typically cotton in the SHP, a C_3 plant species), to C_4 grasses. Therefore, sources of C in CRP lands include the C_3-C from the previous crop as well as natural C_3 species including forbs and perennial shrubs such as yucca (*Yucca glauca*) and fresh C_4-C from C_4 grasses seeded during CRP establishment as well as volunteer species. By tracking the fate of different C sources (previous C_3 and current C_4 inputs) into SOC and POM-C using specific $\delta^{13}C$ values for C_4 vegetation (range from -10 to -15‰ with an average of -14‰) and C_3 vegetation (range from -21 to -30‰ with an average of -27‰), we can better understand the rate, magnitude and processes of C sequestration in CRP lands (Bernoux et al., 1998; Boutton, 1991; Ehleringer et al., 2000; Henderson et al., 2004; O'Leary, 1988).

The understanding of SOM formation and C sequestration continues to evolve. Organic matter exists as an on-site continuum of organic fragments which are continuously processed by the decomposer community (mainly microbes) towards smaller molecular size (Grandy and Neff, 2008; Lehmann and Kleber, 2015). C sequestration is mediated by soil microbes as they are involved in the majority of processes in C storage and decomposition (Agnelli et al., 2014; Trivedi et al., 2013). Most studies that investigate soil microbes in CRP restoration have focused on using MBC as an indicator of soil health restoration (Acosta-Martinez et al., 2003; Bach et al., 2012; Karlen et al., 1999) and less on the role they play in C sequestration and SOM formation. Recent studies by Kallenbach et al. (2016) challenge traditional views of SOM dynamics by providing direct evidence that soil microbes are responsible for the formation of chemically diverse, stable SOM. It is critical to understand how microbes influence C sequestration in long-term CRP restoration, ultimately to help predict how soil will respond to management practices and shifts in climate.

Hence, the goals of this study were to: 1) utilize the cumulative temporal effect of lands under CRP to develop more accurate soil C sequestration estimates in different C pools (SOC, POM-C, and MBC); 2) investigate processes of C sequestration by assessing sources of sequestered C using natural abundance ^{13}C isotope tracking; and 3) explore influences of CRP restoration on soil microbes and the role of microbial biomass in C sequestration. We hypothesized that: 1) C stocks in the SHP under semi-arid climate with fine sandy loam soil would increase with increasing years under CRP attributed to the continued organic inputs and no disturbance but will remain lower than undisturbed rangeland soils; 2) C sequestration rate estimates would be improved by adjusting for soil particle size distribution (soil clay + silt %); and, 3) that MBC and POM-C would be sensitive indicators for C sequestration potential in SHP CRP lands. By exploring the rate and magnitude of C sequestration, we aim to gain increased knowledge regarding how long CRP restoration (i.e. 10, 20, 50, or 100 y) was needed to reach concentrations/content of C stock similar to that found in undisturbed rangeland soils. Identification of the dominant processes (e.g., CRP C inputs and environmental constraints) and the relationships between C sequestration and soil microbes will provide critical insights for establishing regional C sequestration estimates in these and similar semi-arid ecosystems.