Soil carbon pools in central Texas: Prairies, restored grasslands, and croplands

K.N. Potter and J.D. Derner

ABSTRACT: Establishment of perennial grasses on degraded soils has been suggested as a means to improve soil quality and sequester carbon in the soil. Particulate organic carbon may be an important component in the increased soil carbon content. We measured particulate organic carbon [defined as organic carbon in the 53 to 2000 µm (0.002 to 0.08 in) size fraction] and mineral associated organic carbon (defined as the less than 53 µm (0.002 in) size fraction) at three locations in central Texas. Each location had a never-tilled native grassland site, a long-term agricultural site and a restored grassland on a previously tilled site. Organic carbon pool sizes varied in the surface 40 cm (16 in) of native grassland, restored grasslands and agricultural soils. The native grasslands contained the largest amounts of total organic carbon, while the restored grasslands and agricultural soils contained similar amounts of total organic carbon. Both particulate organic carbon and mineral associated carbon pools were reduced beyond the depth of tillage in the restored grass and agricultural soils compared to the native grassland soils. The restored grassland soils had a larger particulate organic carbon content than the agricultural soils, but the increase in particulate organic carbon was limited to the surface 5 cm (2 in) of soil. Trends in particulate organic carbon accumulation over time from nine to 30 years were not significant in this study.

Keywords: Particulate organic carbon (POC), native grassland, soil quality, mineral associated carbon (MAC), total organic carbon (TOC)

Soil organic matter is a heterogeneous mixture of organic substances that has an important role in determining soil productivity. For modeling purposes, it has been beneficial to separate soil organic matter into separate pools that have different functions and degradation rates in the soil. However, in practice, it has been difficult to separate soil organic matter into pools similar to the conceptual pools proposed by the modeling community. Techniques developed to isolate soil organic matter pools include chemical, densiometry, and size fractionation methods. Cambardella and Elliott (1992) developed a technique based upon size fractionation that isolates the organic size fraction between 52 to 2000 µm (0.002 to 0.08 in), which they called particulate organic matter. The particulate organic matter pool has been related to nutrient mineralization (N, Parry et al., 2000; and P, Salas et al., 2003), vegetation type (forest, Barrios et al., 1997; and crop, Bremer et al., 1995), soil carbon content under various tillage practices (Needelman et al., 1999; Wander and Bidart, 2000), and soil quality changes (Franzluebbers and Arshad, 1997; Wander et al., 1998; Chan, 1997).

The particulate organic matter fraction, of which the carbon content is referred to as the particulate organic carbon, appears to be more sensitive to changes in management practices than total organic carbon (Cambardella and Elliott, 1992; Needelman et al., 1999; Wander and Bidart, 2000; Bowman et al., 1999). Particulate organic carbon content often changes more rapidly than the total organic carbon content with a change in management. This difference may be a result of differential decomposition rates under various management and climatic conditions

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(Hassink, 1995; Alvarez and Alvarez, 2000), which would agree well with the mechanism proposed in several simulation models. Chan (1997) reported that for an Australian Vertisol, soil organic matter decreased when converting from pasture to cropping, with 70 percent of the loss of organic carbon coming from the particulate organic carbon. Particulate organic carbon may also be an indictor of improving soil quality. Bowman et al. (1999) and Needelman et al. (1999) found in studies where management of conventionally tilled soil was converted to no-tillage, particulate organic carbon content in no-till increased twice as quickly as total organic carbon content increased.

The depth of particulate organic carbon accumulation has been reported as being limited to the surface 5 cm (2 in) in tillage related research (Franzluebbers and Arshad, 1996; Wander et al., 1998; Needelman et al., 1999) and is often related to a decrease in particulate organic matter at depths of 5 to 15 cm (2 to 6 in) (Needelman et al., 1999; Wander et al., 1998). This is similar to reported changes in soil organic matter with depth occurring with the change from conventional tillage practices to no-tillage in Texas (Potter et al., 1998). However, Potter et al. (1999) found that with reestablishment of grass on previously tilled soils, the depth of organic carbon sequestration was as deep as 60 cm (24 in) after 60 years of continuous management. Potter et al. (1999) did not separate the organic carbon into separate pools in this earlier study. Therefore, the purpose of this study was to determine if particulate organic carbon increased in degraded soils with grass reestablishment and, if so, to what depth in the soil profile.

Methods and Materials

We collected soils samples from three areas located in Central and North Texas located near Temple, Riesel, and Commerce, Texas. Each area had a native grassland site, a longterm cultivated site, and at least one site that had previously been tilled for an extensive period of time and then returned to native grasses (restored grass) (Polley et al., 2005). At each site, prairie was restored by applying 'seed-hay' collected from the remnant prairie to a previously cultivated field. Prairies at each site were managed similarly (hayed or burned), but were not grazed by domestic livestock. Sample transects were located on upland areas with about one percent slope as this is where the restored prairies were located. This had the added benefit, when combined with the grass vegetation, of reducing the potential impact of erosion on the soil properties.

The soils at all locations were Vertisols similar to Houston Black (Udic Pellusterts) soil. Mean annual precipitation is 878 mm (35 in) at Temple, 908 mm (36 in) at Riesel, and 1042 mm (41 in) at Commerce. The native grass sites have never been tilled, in contrast with the longterm cultivation sites, which have been in nearly constant agricultural production for 120 years or more. The restored grass sites had been previously in agricultural production for more than 75 years before being restored to native grass at some point in time. The restored grass site at Temple had been in grass for 30 years. At Riesel two sites were sampled, one with nine years of grass and the other with 17 years of grass. The Commerce restored grass site had been in place for 10 years. Size of the restored and native grass sites were 0.5 ha (1 ac; 9-year), 0.8 ha (2 ac; 17-year) and 1.6 ha (4 ac; native) at Riesel, 9.8 and 4.6 ha (24 and 11 ac) at Temple, and 10.8 and 21 ha (27 and 52 ac) at Commerce, respectively. Most of the land surrounding the prairies is cultivated.

Soil cores were taken to a depth greater than 40 cm (16 in) with a hydraulically driven 7.6-cm (3 in) diameter steel coring tube with an acetate liner. Cores were obtained every 20 m (65 ft) along a transect, for a total of six cores per site. The cores were frozen until we could section and process the individual samples. Cores were divided into sections of 0 to 5, 5 to 10, 10 to 15, 15 to 20, 20 to 30, and 30 to 40 cm (0 to 2, 2 to 4, 4 to 6, 6 to 8, 8 to 12, and 12 to 16 in) depth. Individual core segments were measured with a micrometer to determine true length, and total segment wet weight determined. A subsample of the core segment was weighed, oven dried at 105°C (221°F) for 48 hours, and the dry weight determined to calculate the segment water content. The segment water content, segment volume and bulk weight were used to determine the segment bulk density. The remainder of the segment was gently crumbled, passed through a 2 mm (0.08 in) sieve and air-dried. Plant stem and root segments were picked from the soil segment.

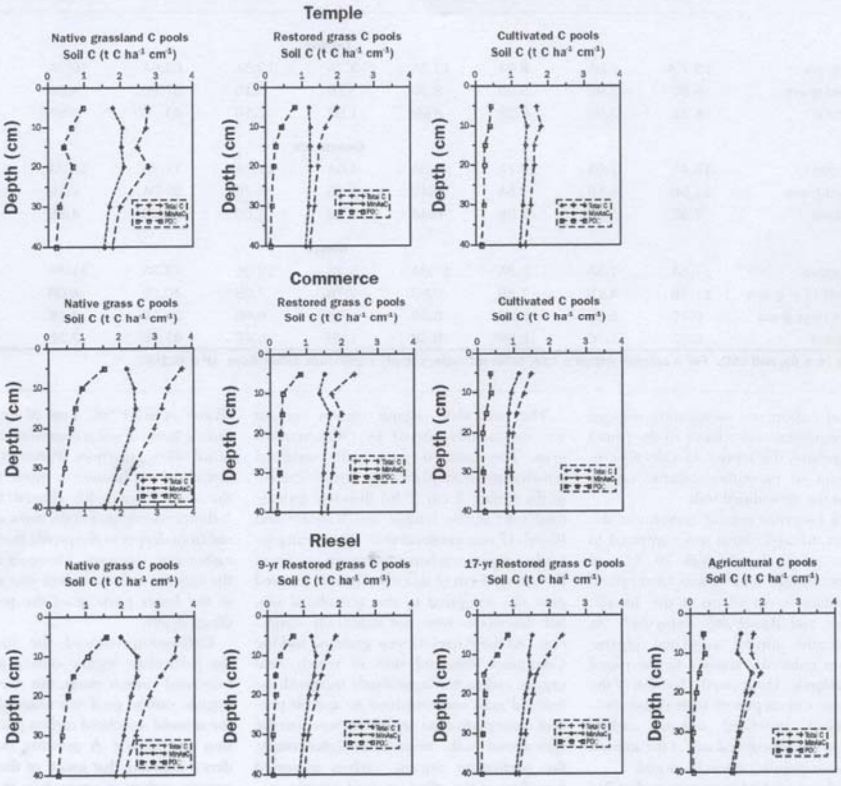
Thirty- and 10-g (0.066 and 0.022 lb) samples were removed from each core segment for particulate organic carbon and soil organic carbon analysis, respectively. The soil for particulate organic carbon analysis was dispersed with 150 ml of 5-g L^{-1} sodium hexametaphosphate and shaken for 18 hours on a reciprocal shaker. The dispersed soil samples were passed through a 500-µm (0.02 in) sieve and then through a 53-µm (0.002 in) sieve and rinsed thoroughly with water until the rinsate was clear. The material retained on the sieves was backwashed into small aluminum pans and dried at 70°C for (158°F) 24 hours. The (silt+clay) material which passed through the 53-µm sieve was dried at 70°C (158°F) for 48 hours. The longer time was needed to evaporate the water accumulated during rinsing. The weight of each dried sample was recorded to three decimal places. The dried whole soil and (silt+clay) fraction samples were ground in a ball mill to pass through a 250-µm (0.01 in) sieve and then stored at room temperature in glass bottles. A sample aliquot (approximately 1 g) was analyzed for organic carbon with a Leco CR412 Carbon Determinator (Leco Corp, Augusta, Georgia) using the combustion method of Chichester and Chaison, (1992). While carbonates were present in the soils, this method of analysis differentiates between organic and inorganic carbon by burning the organic carbon at a temperature that leaves the inorganic carbon relatively intact. Particulate organic carbon was calculated as the difference between total soil organic matter and the (silt+clay)—mineral associated organic carbon (Cambardella and Elliott, 1992). The data were statistically analyzed using a one-way analysis of variance and Least Significant Differences to determine differences between means.

Results and Discussion

Total organic carbon, particulate organic carbon, and mineral associated organic carbon distribution in the surface 40 cm (16 in) of native grassland, agricultural, and restored grassland soils are presented in Figure 1. The native grassland total organic carbon concentration near the surface ranged from 3.97 to 5.63 percent with a decrease in concentration with depth. The agricultural soil in contrast has a nearly constant total organic carbon concentration from the surface to depth of sampling, in this case 40 cm (16 in). Particulate organic carbon distribution was similar to the total organic carbon distribution in the native grassland soils. In the agricultural soils, particulate organic carbon was reduced the most near the surface, although reductions occurred throughout the profile to

Figure 1

Total organic carbon, particulate organic carbon (POC), and mineral associated organic carbon distribution for three native grasslands, restored grasslands, and agricultural soils in Texas.



the 40 cm (16 in) depth. Particulate organic carbon concentration in the restored grasslands had an increase in the surface 5 cm (2 in) of the profile. Below 5 cm (2 in), the particulate organic carbon concentrations were similar to those of the agricultural soils. Mineral associated organic carbon was reduced throughout the soil profile in both the restored grassland and the agricultural soils, and retained the same relative distribution throughout the profile.

At all three sites, significantly different amounts of total organic carbon were found among the soils with different management histories (Table 1). The native grassland soils contained 13.7 to 18.4 t C ha^{-1} (6.1 to 8.2 t C ac^{-1})in the surface 5 cm (2 in), while the agricultural soils ranged from 7.3 to 8.6 t C ha^{-1}(3.3 to 3.6 t C ac^{-1}) in the surface 5 cm (2 in). There was a 40 to 60 percent reduction in total organic carbon in the agricultural soils compared to the native grassland soils. The agricultural 5 to 40 cm (2 to 16 in) soil carbon content was also reduced, containing 40 to 70 percent as much carbon as the native grasslands.

Particulate organic carbon comprised 35 to 44 percent of the total organic carbon in the surface 5 cm (2 in) of the native grassland sites, but only 20 to 24 percent of the total organic carbon content of the cultivated sites (Table 1). Particulate organic carbon content in the native grassland soils, as a fraction of the total organic carbon, decreased rapidly with depth ranging from 24 to 30 percent of the total organic carbon in the 5 to 10 cm (2 to 4 in) depth increment. Particulate organic carbon as a fraction of total organic carbon stayed about the same in the agricultural soils in the 5 to 10 cm (2 to 4 in) depth increment, ranging from 21 to 28 percent. Particulate organic carbon comprised 15 to 18 percent of total organic carbon in the 10 to 40 cm (4 to 16 in) depth increment in the native grassland soils and 7 to 16 percent of total organic carbon found in the agricultural soils. As the

Table 1. Total organic carbon (TOC), particulate organic carbon (POC), and mineral associated organic carbon (MAC) for three depth increments.

	0 - 5 (cm) TOC	0 - 5 (cm) POC	0 - 5 (cm) MAC	5 - 10 (cm) TOC	5 - 10 (cm) POC	5 - 10 (cm) MAC	10 - 40 (cm) TOC	10 - 40 (cm) POC	10 - 40 (cm) MAC
					t C ha^{1}				
					Temple				
Native grass	13.7*A	4.8A	8.9A	13.5A	3.2A	10.3A	63.6A	10.7A	52.9A
Restored grass	9.8B	3.9B	5.9B	8.3B	2.1B	6.1C	37.9B	4.9B	34.8B
Agricultural	8.3B	2.0B	6.3B	8.9B	1.9B	7.1B	44.7B	5.9AB	38.8B
					Commerce				
Native grass	18.4A	7.6A	10.7A	16.3A	4.6A	11.7A	71.4A	13.3A	58.1A
Restored grass	11.6B	4.1B	7.5A	8.4B	1.7B	6.7B	52.0A	7.1B	44.9A
Agricultural	7.3C	1.7C	5.6B	6.4B	1.8B	4.6B	29.0B	4.8B	24.2B
					Riesel				
Native grass	17.6A	7.8A	9.8A	17.3A	5.2A	12.0A	73.3A	11.3A	61.9A
Restored 17-yr grass	11.7B	4.1B	7.5B	9.8B	2.7B	7.0B	40.2B	4.0B	36.2BC
Restored 9-yr grass	9.4C	3.4B	5.9C	8.3B	1.6B	6.6B	35.1B	4.7B	30.5C
Agricultural	8.6C	1.7C	6.5BC	8.4B	1.9B	6.4B	43.5B	3.2B	40.3B

* **Mean (n = 6), and LSD. For a column within a site, different letters imply significant differences (P = 0.10).**

amount of carbon was significantly reduced in the agricultural soils relative to the paired native grassland, this represents a decrease in the amount of particulate organic carbon present in the agricultural soils.

Mineral associated organic carbon was also reduced in the agricultural sites compared to the native grassland soils, with 70, 52, and 66 percent as much mineral associated carbon in the surface 5 cm (2 in) at the Temple, Commerce, and Riesel sites, respectively. At deeper depths mineral associated organic carbon was reduced compared to the paired native grasslands. However, as a fraction of the total organic carbon present with a given profile, mineral associated organic carbon increased in the agricultural soils as the amount of particulate organic carbon decreased.

The soils which had been previously tilled and then seeded to grasses, did not always retain more carbon in the surface 40 cm (16 in) of the profile than the agricultural soils which were under cultivation (Figure 1). The total soil profile carbon contents were similar between the restored grass and agricultural soils at two of the three sites, but the restored grass soil had much higher total organic carbon than the agricultural soil at the Commerce location. In the surface 5 cm (2 in), total organic carbon was similar in the agricultural and restored grass sites at the Temple and Riesel-nine year sites. Total organic carbon was greater in the surface 5 cm (2 in) of the Commerce and Riesel-17 year restored grass sites than in the agricultural sites.

The particulate organic carbon content was significantly altered by conversion to grass. The restored grass soils contained significantly more particulate organic carbon in the surface 5 cm (2 in) than the agricultural soils at the Temple and Riesel-9 and Riesel-17 year grassland sites. The mean particulate organic carbon content was greater in the surface 5 cm (2 in) of the Temple restored grass site compared to the agricultural site, but differences were not statistically significant. At the Riesel-17 year grassland and the Commerce grassland sites in which total organic carbon was significantly increased, the restored grass soil contained 80 and 68 percent more particulate organic carbon than the agricultural soils, respectively. Interestingly, the particulate organic carbon increased regardless of the effect on total organic carbon, although the larger increases in particulate organic carbon did occur in sites that increased in total organic carbon content. Particulate organic carbon content was similar in the restored grass and agricultural sites at the 5 to 10 cm (2 to 4 in) depth increment. The particulate organic carbon content in the 10 to 40 cm (4 to 16 in) depth increment of the restored grass soils ranged from 94 to 143 percent of that occurring in the agricultural soils. Regression analysis relating particulate organic carbon content to length of time in grass was not significant.

The native grassland and agricultural soil total organic carbon profiles are typical of those found in Vertisols in central Texas (Potter et al., 1998). Loss of carbon in the surface layers of soil is common with conventional tillage practices (Potter et al., 1998). Often the explanation is given that mixing the surface layers has diluted the organic carbon concentrated in the surface layers with soil from deeper in the profile that has a lower carbon concentration. However, in this study the organic carbon content was also reduced in the lower portions of the profile below tillage depth.

Cultivation reduced the size of both the particulate organic carbon and mineral associated carbon pools, but the particulate organic carbon pool was reduced more than the mineral associated carbon pool, especially near the surface. A growing body of evidence indicates that much of the particulate organic carbon is retained in the anaerobic portion of larger soil aggregates (Franzluebbers and Arshad, 1996; Aoyama et al., 1999; Wander and Bidart, 2000). With tillage the aggregates are disrupted and the particulate organic carbon exposed to aerobic conditions, leading to oxidation of the organic carbon. As the particulate organic carbon is decomposed, it enters the mineral associated organic carbon pool. This, combined with the slower degradation rate of the mineral associated carbon (Franzluebbers and Arshad, 1997; Alvarez and Alvarez, 2000), may be why the particulate organic carbon was more impacted by tillage than the mineral associated organic carbon pool.

Changes in particulate organic carbon can happen quite rapidly initially after tillage but also may continue at a slower rate for long periods of time. Chan (1997) reported that particulate organic carbon was lost more rapidly than other carbon fractions when pasture was converted to cropping. The fastest change in particulate organic carbon occurred within the first four years with subsequent losses occurring at a slower rate. One of the soils in a study reported by Chan (1997) was a Vertisol with similar clay content as the soils in the current study. After 50 years of conventional tillage and burning of the stubble in the Australian study, the particulate organic carbon (POC) concentration in the soil was 42 percent of the total organic carbon concentration in the surface 10 cm (4 in). This is similar to the Temple agricultural site (49 percent POC) but more than that found in the Riesel and Commerce agricultural sites (28 percent POC). For several other Australian soils, after many years of intensive cultivation, the particulate organic carbon pool ranged from 42 to 74 percent of the total organic carbon in the surface 10 cm (4 in) (Dalal and Chan, 2001). In the current study, particulate organic carbon was also reduced in the 10 to 40 cm (4 to 16 in) depth increment in the agricultural sites with 28 to 55 percent as much particulate organic carbon as was found in the native grassland sites.

The mineral associated organic carbon pool was reduced in the cropland soils and restored grassland soils compared to the native grassland soils. The mineral associated organic carbon pool was also smaller in the restored grasslands compared to the cropland soils. It appears that the mineral associated organic carbon pool was originally depleted by many years of cultivation that disrupted soil aggregates and increased organic carbon oxidation. When the soils were returned to grass, and without the disturbance of tillage, a portion of the added carbon was retained as particulate organic carbon instead of quickly decomposing into mineral associated organic carbon sized material.

The particulate organic carbon pools in restored grasslands were smaller than that of the native grassland soil, even after 30 years without tillage. Particulate organic carbon was greater in the restored grasslands than in the cropland sites. Most of the particulate organic carbon accumulation after restoring grass is in the surface 5 cm (2 in). This is similar to the particulate organic carbon increases reported in other studies (Franzluebbers and Arshad, 1996; Wander et al., 1998; Needelman et al., 1999). The particulate organic carbon accumulation is thought to be derived from recent root and residue additions. Cambardella and Elliott (1992) found particulate organic carbon from a grassland-derived agricultural soil planted to winter wheat rotations was composed mostly of root fragments, with a large portion derived from plant material added within the past 20 years. Chan (1997) found that 75 percent of the soil carbon increase four years after converting from cropping to pasture was in the particulate organic carbon size fraction. The rapid increase in particulate organic carbon and the relatively young age of carbon inputs suggests that particulate organic carbon accumulation in soil may approach a new plateau level relatively quickly. This may explain why regression analysis of particulate organic carbon content relative to time-in-grass was not significant in this study.

Summary and Conclusion

Organic carbon pool sizes varied in the surface 40 cm (16 in) of native grassland, restored grasslands and agricultural soils. The native grasslands contained the largest amounts of total organic carbon, while the restored grasslands and agricultural soils contained similar amounts of total organic carbon. Both particulate organic carbon and mineral associated organic carbon pools were reduced in the restored grass and agricultural soils compared to the native grassland soils, even beyond the depth of tillage. The restored grassland soils had a larger particulate organic carbon content than the agricultural soils, but the increase in particulate organic carbon was limited to the surface 5 cm (2 in) of soil. Trends in particulate organic carbon accumulation over time from nine to 30 years were not significant in this study.

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