Soil Carbon Pools and Fluxes Following Land Conversion to Irrigated Agriculture in a Semi-Arid Shrub-Steppe Ecosystem

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Introduction

Worldwide soil carbon (C) losses associated with agricultural expansion and intensification during the past 150 years have contributed significantly to increased atmospheric CO_2 (Houghton et al., 1983; Post et al., 1990; Flach et al., 1997). Soil disturbances resulting from land use changes have been shown to modify the turnover of C and the formation of soil organic matter (SOM) (Huggins et al., 1998; Collins et al., 2000; Dinesh et al., 2003). The conversion of native ecosystems to agricultural use usually results in a loss of SOM. Such losses are well documented for the Great Plains and Corn Belt (Paustian et al., 1997), with few examples in the Pacific Northwest (Rasmussen et al., 1980; Rasmussen and Collins, 1991).

Conversion of the native shrub-steppe in the semi-arid region of the Columbia Basin in Eastern Washington, USA to high input production agriculture has increased with the availability of water. The Columbia Basin Irrigation Project has allowed land conversion on over 271,500 irrigated ha (Bureau of Reclamation, 2005). Land leveling to facilitate irrigation can result in loss of topsoil, exposure of subsoil, reduced organic carbon (OC) and a decrease in microbial activity (Brye et al., 2003). Loss of topsoil from disturbance could have negative impacts on ecosystem function, as native surface soils (0-5cm) in the shrub-steppe were found to have 2-4 times more soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) than subsoil (5-15cm) (Bolton et al., 1993).

While land leveling may reduce and redistribute surface soil organic carbon (SOC), the use of irrigation can increase plant production, increase inputs of plant residues and roots, and therefore increase SOC (Lueking and Schepers, 1985; Entry et al., 2002). Irrigation may also increase the rate of plant residue decomposition because of increased soil moisture (Kumar and Goh, 2000). Native areas in the semi-arid Sandhills of Nebraska with low soil C and N had increased concentrations after 15 yr of irrigation (Lueking and Schepers, 1985), while soils with higher initial C and N decreased slightly. Entry et al. (2002) found that irrigated soils in southern Idaho under pasture and conservation tillage significantly increased in SOC over the native sagebrush ecosystem. The increase in SOC in irrigated agricultural sites is contradictory to the decline in SOC usually observed in rainfed agricultural fields converted from native ecosystems in higher rainfall zones (Paustian et al., 1997; Entry et al., 2002). Semi-arid shrub-steppe ecosystems develop in areas of low annual precipitation that support relatively low plant production, C inputs, and C storage in soil (Bolton et al., 1990; Entry et al., 2002; Smith et al., 2002).

Areas of the Columbia Basin are still experiencing agricultural growth with conversion of the remnant native shrub-steppe to irrigated high value vegetable production, including organic. There is limited knowledge of the effects of soil disturbance on C cycling resulting from land conversion of semi-arid native systems in the Pacific Northwest, especially in the early stages of transition. The objective of this study was to document changes in SOC during the transition of a semi-arid native shrub-steppe to irrigated crop production.

Materials and Methods

The study area was located in Grant County, Washington in a native shrub-steppe ecosystem that had been converted to a series of organic, irrigated agricultural fields. Annual rainfall ranged from 79 mm to 185 mm during the years of this study with most of the precipitation occurring in the winter months, and a mean annual temperature of 10.5° C. The soil was a fine-grain eolian sand classified as a mixed mesic Xerollic Cambothid (Adkins series).

A chronosequence of eight sites in relatively close proximity south of Royal City, Washington (Latitude: 46.9° N; Longitude: 119.6 ° W; elevation: 329 m) were sampled in the spring of 2003 and 2004. The sites included three native sites (NS series) and five cultivated fields; three with one year of cultivation by 2003 (CA series) and two with two years of cultivation by 2003 (CB series) (Table 19.1).

Table 19.1. Site history listing year of conversion from native shrub-steppe, vegetation and crop rotations for native and cultivated sites from 2001 through 2003.

†Site	Yr converted	Hectares	2001 Vegetation 2001 season	2002 Vegetation 2002 season	2003 Vegetation 2003 season
NS-1		---	‡Native veg.	Native veg.	Native veg.
NS-2		---	Native veg.	Native veg.	Native veg.
NS-3		---	Native veg.	Native veg.	Native veg.
C A-1	2002	37.6	Native veg.	Sweet corn	Peas
C A-2	2002	47.8	Native veg.	Sweet corn	Peas
C A-3	2002	44.5	Native veg.	Sweet corn	Peas
C B-1	2001	25.9	Sweet corn	Peas	Sweet corn
C B-2	2001	48.6	Sweet corn	Peas	Sweet corn

†NS = native shrub-steppe sites, CA = 1 and 2 y of cultivation and CB = 2 and 3 y of cultivation at time of sampling. ‡ Native veg. Includes big sagebrush (*Artemisia tridentate* Nutt), antelope bitterbrush (*Purshia tridentate*Pursh DC), rabbit brush (*Chrysothamnus viscidiflorus* (Hook.) Nutt), grasses such as bluebunch wheatgrass (*Pseudoregneria spicata* (Pursh) A Löve), Idaho Fescue (*Festuca idahoensis* Elmer), needlegrass (*Achnatherum nelsonii* (Scribn.) Barkworth and Sandberg's bluegrass (*Poa secunda* J. Presl).

Prior to cultivation, land management consisted of cattle grazing on open rangeland. In 2001, conversion from the shrub-steppe began with the removal of native vegetation by burning and leveling the land to facilitate the installation of center pivot irrigation and the subsequent planting of vegetable crops. The source of irrigation water was the regional aquifer. After clearing, cultivated sites were tilled to incorporate remaining plant residues and organic composted dairy manure. In 2002 and 2003, compost was added prior to planting at a rate of 11.2 and 22.4 Mg ha^{-1}, respectively. Cultivated fields were managed in a three-year rotation of sweet corn – peas – sweet corn. Crop yields were obtained from records kept by the grower/cooperator.

Soil samples were collected in March of 2003 and 2004 before field operations started, which corresponded to the time of year when maximum primary productivity occurs in the shrub-steppe (Rickard, 1988). The interaction of increasing temperatures and soil moisture content during the spring season produces the greatest microbial activity and respiration in semi-arid shrub-steppe soils (Wildung and Garland, 1988). Soil samples were collected at 18 m intervals along two 100 m transects across each field or site, for a total of 90 samples/field. Soil was sampled to a depth of 20 cm with a 2.5-cm diameter soil probe with 15 composite cores taken in a 1 m^2 area around each sampling point. Soils were transported on ice and stored at 4° C until analyzed.

Soil water holding capacity was determined using a volumetric soil-water method (Hook and Burke, 2000). Soil water content at the time of sampling was determined on sub-samples by oven drying at 105º C for 24 hrs (Gardner, 1986). All results are reported on an oven dry soil basis. Soil pH was determined using a 2:1 water method (Robertson et al., 1999). Total soil organic C and N were analyzed by dry combustion on a LECO, CNS-2000 Elemental Analyzer, (St. Joseph, MI). Carbonates were removed by acid treatment. Carbon mineralization was measured using the static-incubation method at 22° C (Zibilske, 1994). Soil organic C has generally been divided into three pools: an active pool (C_a) consisting of labile C (simple sugars, organic acids, microbial biomass and metabolic compounds of incorporated plant residues) with a mean residence time (MRT) of days; an intermediate or slow pool (C_s) consisting of structural plant residues and physically stabilized C with an MRT of 25-50 y; and a resistant fraction (C_r) consisting of lignin and chemically stabilized C with an MRT of 1000-1500 y (Buyanovsky et al., 1994).

The CO_2 evolved was used to determine the size and kinetics of the functional C pools of soil at each treatment (Collins et al., 1997; Paul et al., 1999). We estimated the size and turnover rates of each pool by curve fitting the CO_2 evolved per unit time (C_t) using a three-component first-order model: $C_t = C_a e^{-kat} + C_s e^{-kst} + C_r e^{-krt}$, where the subscripts a, s, and r represent the active, slow and resistant pool respectively. Three parameters C_a, k_a, and k_s were estimated using the non-linear regression model (NonLIN) of Systat (Systat, Inc., Evanston, IL). The slow pool (C_s) is defined as $C_s = C_t - C_a - C_r$. Mean residence time (MRT) is the reciprocal of the decomposition rate constant (k^{-1}) in first order rate reactions. The MRT derived from laboratory incubation at 22° C was scaled to the mean annual temperature (MAT) by assuming a Q10 of 2 ($2^{(25-t)/10}$; where t=MAT). Acid hydrolysis was used to determine the size of the resistant C pool (C_r). The acid resistant organic C fraction was determined by refluxing soil in 6 N HCl for 18 h and remaining C measured by dry combustion on a LECO, CNS-2000 Elemental Analyzer (LECO, Corp., St. Joseph, MI).

Data were analyzed using the General Linear Model Procedure (SAS Institute Inc, Cary, NC, 1995). Analysis of variance was performed on each parameter measured. Means were separated using protected least square difference (LSD). Data were considered significantly different at $p < 0.05$.

Results and Discussion

Soil pH and Soil Water Content

In 2003 soil pH was significantly lower in the native sites than in the cultivated treatments, which were similar (Table 19.2). Soil pH was similar among all treatments in 2004. Many semi-arid soils are naturally alkaline because limited precipitation and reduced leaching cause carbonates to accumulate and remain in the soil profile (Parker, 1983). Calcareous subsoils exposed during land leveling and further mixed with surface soils during cultivation may have contributed to the increase in pH in cultivated fields. Also, the addition of carbonates present in the ground water and applied during irrigation can increase soil pH (Lal et al., 1999). Salts present in subsurface irrigation waters of the Columbia Basin are mostly sodium bicarbonates that can increase the alkalinity of soils (Evans et al., 2000). At the time of sampling, water content was similar among treatments (Table 19.2).

Table 19.2. Soil pH, water content, total organic C and N of surface soil of native shrub-steppe and cultivated soils sampled March 2003 and 2004.

Site	pH		Water content§ %		Total OC g/kg		Total N g/kg		C:N ratio	
	2003	2004	2003	2004	2003	2004	2003	2004	2003	2004
NS	7.5b	7.7a	11	9	4.3a	4.3bc	0.30a	0.31b	14.6	13.8
CA	7.9a	8.3a	12	11	5.0a	6.0ab	0.35a	0.47ab	14.3	12.8
CB	8.1a	8.2a	12	12	4.1a	6.4a	0.28a	0.50a	14.5	12.7

+ NS = native sites, CA = cultivated sites ages 1 and 2 y and CB = cultivated sites ages 2 and 3 y at time of sampling. § Water content at time of sampling. Values within a column, followed by the same letter, are not significantly different at p=0.05.

Soil Organic C and N

Total soil organic C (TOC) and N (TN) averaged 4.3 g C kg^{-1} soil and 0.3 g N kg^{-1} soil, respectively, both years (Table 19.2). Cultivated treatment B had greater TOC than native sites in 2004, the third year after conversion. The increase in TOC in cultivated sites was attributed to C inputs from crop residues and compost additions (Table 19.3).

Table 19.3. Crop yields and C inputs into cultivated soils over three years of cropping since conversion.

Site/Year/Vegetation	Standing Vegetation	Annual Residue Input	Annual Residue C Input	Compost Input	Total C ± Input
Native vegetation†	---- Mg ha^{-1} ----		------------ Mg C ha^{-1} ------------		
Sagebrush	1.3	0.2	0.1	--	--
Grasses	3.6	0.7	0.3	--	--
Roots	8.8	0.4	0.2	--	3.5
Total	13.7	1.2	0.6	--	3.5±
Cultivated sites	Yield	Residue Input	Residue C Input	Compost C Input	Total C Input
Series CA	---- Mg ha^{-1} ----		------------ Mg C ha^{-1} ------------		
2002 (sweet corn)	17.7	4.6	1.8	1.4	3.2
2003 (peas)	7.2	1.9	0.8	2.8	3.6
Series CB					
2001 (sweet corn)	20.2	5.2	2.1	1.4	3.6
2002 (peas)	6.7	1.7	0.7	1.4	2.1
2003 (sweet corn)	11.1	2.9	1.2	2.8	4.0

† Above and below ground biomass for a native sagebrush-bunchgrass site in Eastern WA (Rickard and Vaughan, 1988). Above-ground sweet-corn residue estimates were based upon a sweet corn yield:residue ratio of 1:0.26 (H. Collins personal communication). Plant residues were assumed to be 40 % C on a dry weight basis. ± Total C input of sagebrush and grasses following disturbance, aboveground biomass removed by burning, soil inputs of C from root material.

Agricultural practices such as crop rotation, incorporation of plant residue and the addition of composts, animal or green manures have been shown to increase SOC and improve soil properties (Rasmussen et al., 1980; Collins et al., 1992; Smith et al., 1993; Rasmussen and Collins, 1991). Rotations with high residue producing crops such as corn have been shown to increase soil C (Havlin et al., 1990; Zielke and Christenson, 1986; Paustian et al., 1997).

Total N values followed a similar trend to TOC with cultivated treatment B exhibiting higher N concentrations than native in 2004. This was attributed to the addition of 138 kg N ha^{-1} and 276 kg N ha^{-1} in compost in 2002 and 2003, respectively.

In the semi-arid shrub steppe, moisture limits net primary productivity (NPP) of native plant communities reducing inputs of plant residues and limiting the formation of SOM (Wildung and Garland, 1988; Bolton et al., 1990; Smith et al., 1994). Much of the non-living above-ground C of the semi-arid shrub-steppe is in the form of standing dead plant shoots with only litterfall and a small portion of roots contributing to SOM. Plant residues remain on the soil surface and because of the low annual precipitation and high temperatures are slow to decompose. Therefore, they would contribute only a small amount of C to the SOM. Rickard and Vaughan (1988) reported that the above ground biomass in a relatively undisturbed sagebrush-bunchgrass plant community in Eastern Washington averaged 490 g m^{-2}, with a below ground biomass of 880 g m^{-2} for a total production of 1370 g m^{-2}. The native plant communities assessed in their study was similar to that found in the current study.

For the first year after conversion (Series CA), C inputs from land clearing, compost additions and sweet corn residues were estimated to be 3.5, 1.4, and 1.8 Mg C ha^{-1}, respectively, for a total input of 6.7 Mg C ha^{-1} (Table 19.3). Since the above ground plant biomass of the native vegetation was removed by burning during land clearing, the primary input of C from the native vegetation was from roots (3.5 Mg C ha^{-1}). van der Krift et al. (2001) and others (Puget and Drinkwater, 2001; Allmaras et al., 2004; Zibilske and Materon, 2005) found that root decomposition averaged 70% during field and laboratory studies lasting approximately 1 season, suggesting that under irrigation 2.5 Mg C ha^{-1} of the C added from roots of the native vegetation could be mineralized in the first season. Acid hydrolysis of the compost showed that 73% of compost C comprised the resistant fraction (Table 19.4). This fraction is composed of aromatic humics and lignin which are slow to decompose. During the 130 day laboratory incubation of compost, 4.3% of the total C was mineralized, suggesting that 60 kg C ha^{-1} could be lost though decomposition during the 2002 growing season and 120 kg C ha^{-1} during the 2003 season.

Since corn residues were incorporated late in the fall of 2002 minimal decomposition would have occurred prior to when the fields were sampled the following spring (2003), with little C entering SOM pools until the next growing season. Therefore, net C inputs entering the SOM prior to the first soil sampling in CA would have been 2.34 Mg C ha^{-1} (1.0 Mg C from roots of native vegetation and 1.34 Mg C from compost amendments). Soil C in the top 20 cm of soil profile increased 0.7 g C kg^{-1} compared to the native soil after the first year of cropping. Assuming a bulk density of 1.3 Mg soil m^{-3}, the increase in SOM in the top 20 cm would be 1.8 Mg C ha^{-1}, similar to the 2.34 Mg C ha^{-1} value derived.

In the second year of cropping in CA, 3.6 Mg C ha^{-1} was added as compost and pea vines with an increase in soil C of 2.6 Mg C ha^{-1} in the surface 20 cm. Making similar assumptions for year two, net C inputs after decomposition would be 3.0 Mg C ha^{-1} including C derived from the previous year's remaining corn residue (1.2 Mg C ha^{-1}) additions. In the third year after conversion, C inputs from compost additions and corn residues were 2.8 Mg C ha^{-1} and 1.2 Mg C ha^{-1}, respectively. Residual C from the native vegetation would be minimal, since most of the root C would have been mineralized. Incorporation of two years of compost additions and crop residues resulted in a soil C content of 6.4 g C kg^{-1} soil, a significant 2.1 g C kg^{-1} soil increase above C in soils of the native sites. Differences between C inputs and soil C increases may result from overestimating C inputs derived from native vegetation, that were based on the findings of Rickard and Vaughan (1988), or underestimating rates of decomposition.

C Mineralization

Cumulative CO_2 evolved over 175-day laboratory incubations for soils sampled in 2003 and 2004 showed generally higher cumulative C mineralization in cultivated fields compared to native sites (Figure 19.1). The cumulative CO_2 evolved for CB and CA were similar in both 2003 and 2004. Cumulative CO_2-C for 2003 ranged from an average 562 mg kg^{-1} soil in NS to an average 891 mg CO_2-C kg^{-1} soil in cultivated fields. Cumulative CO_2-C values for 2004 were slightly lower averaging 482 mg and 727 mg kg^{-1} soil for the native and cultivated sites, respectively. The percentage of total C mineralized from the cultivated field samples increased significantly after the first year of cultivation then decreased to below the average native level by the third year after conversion. Soil C resistant to acid hydrolysis was 56% for the native sites decreasing to an average of 53% for the cultivated fields. This decline in relative mineralization and increase in relative acid-resistance is most likely due to the increased additions of compost that had a high percentage (73%) of resistant C and low C mineralization (4.3%) in a 130 day laboratory incubation (Table 19.4).

Table 19.4. Total C, average cumulative C mineralized, and resistant C from native shrub steppe and cultivated soils and from dairy manure compost applied to field sites.

Site/Year/Vegetation	Total C C_T	Average Cumulative C mineralized† CO_2-C	% of C_T	Resistant C §C_r	C_r /C_T
	g kg^{-1}	mg kg^{-1}	%	g kg^{-1}	%
Native	4.3a	522a	12.1	2.4a	56
Series CA					
Year 1 (2002 corn residues)	5.0a	799b	16.0	2.7a	54
Year 2 (2003 pea residues)	6.0b	795b	13.3	3.2b	53
Series CB					
Year 2 (2002 pea residues)	4.1a	891b	21.7	2.3a	56
Year 3 (2003 corn residues)	6.4b	727b	11.4	3.4b	53
Compost	126c	5440c	4.3	92c	73

† Soil incubated for 175 d, compost for 130 d. §Carbon remaining following a 24 h acid hydrolysis (6 N HCl). Values within a column followed by the same letter, are not significantly different at p=0.05. C content of compost based on non-ashed sample.

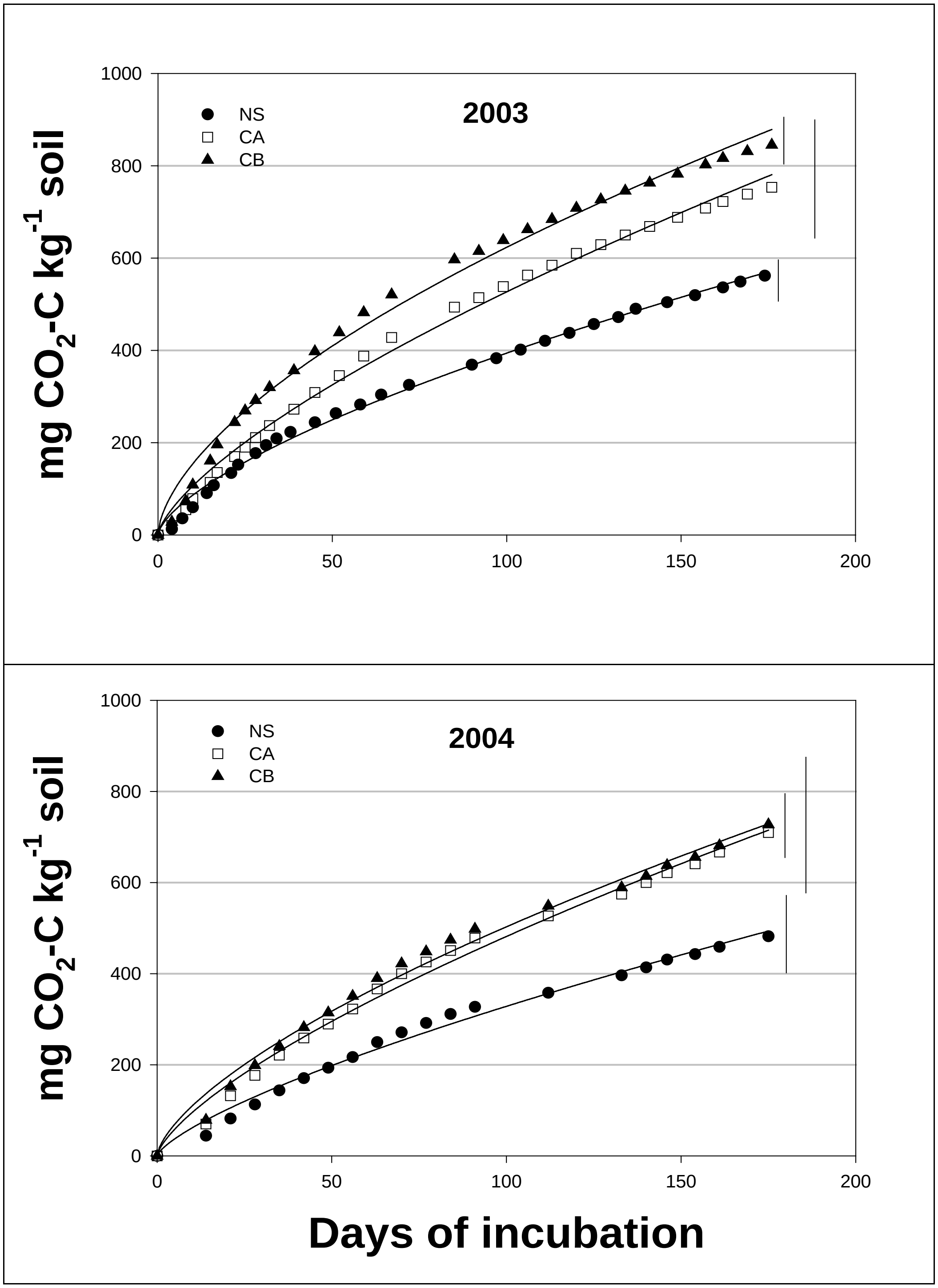

Figure 19.1. Cumulative C mineralization curves during 175 day laboratory incubation for 2003 and 2004 native sites (NS), cultivated fields (CA) and (CB) Bars represent standard error at 0.05 for cumulative value of CO_2-C only.

Acid hydrolysis dissolves the polysaccharide fraction and most of the nitrogenous compounds and leaves behind the aromatic humics (Scharpenseel and Schiffman, 1977) and modern plant lignin residues as defined by Paul et al. (2001a). The residue of hydrolysis has been shown to be comparable to the resistant soil C pool which on average is 1400 years older than the acid hydrolysable OC (Paul et al., 1997) and would not be degraded during the laboratory incubations.

Carbon mineralized in the early stages of incubation for both native and cultivated fields consisted of C from the active (C_a) pool. The rates reflect variable accumulations of labile C from the incorporation of native plant and crop residues and compost. The C_a pool, on average, contained 4.7 % (0.2 g C kg^{-1} soil) and 6.5 % (0.5 g C kg^{-1} soil) of the total C in the native sites and cultivated fields, respectively (Table 19.5). The laboratory MRT of the active pool had significantly shorter turnover times (15-19 d) for cultivated treatments cropped with peas, in the second crop year after conversion for both CA and CB series. For the first and third year after conversion, the incorporation of corn residues increased the MRT of the active pool to 25 and 33 d, respectively, with a doubling of the pool size of the native sites. Wander et al. (1994) found that soils managed with organic amendments such as animal and green manures and organic composts generally increased active soil organic matter pools. A future area for research would be to characterize the chemical composition of the active C pool, as these changes in pool size are likely accompanied by changes in its composition and C:N ratio.

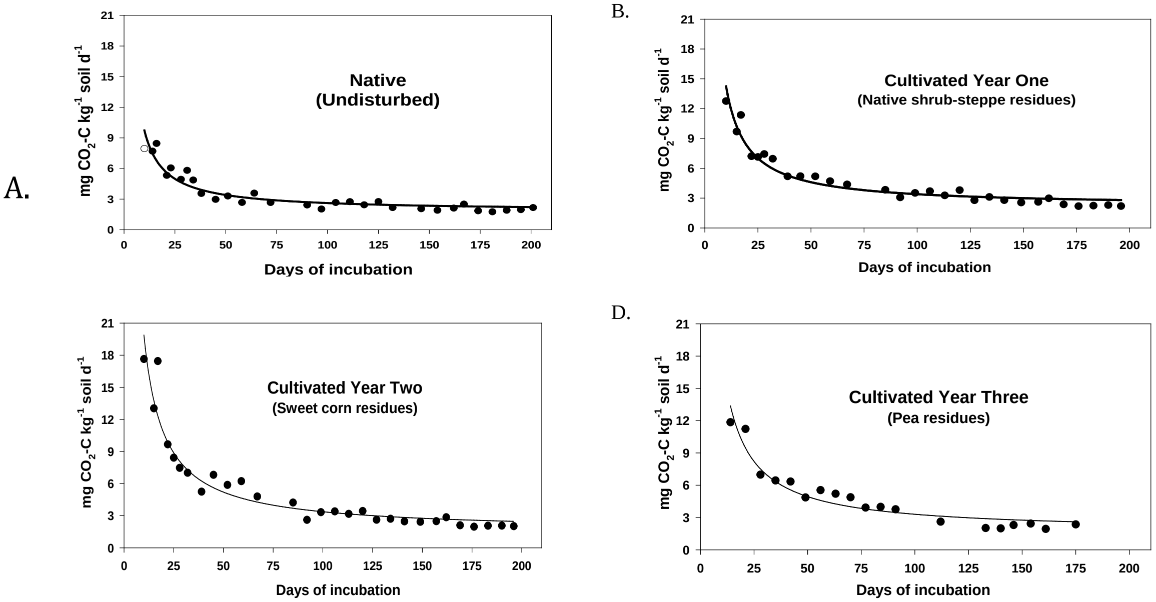

Figure 19.2. C mineralization rates for native sites (A), cultivated fields for one (B), two (C), and three (D) years after conversion from semi-arid shrub steppe to irrigated agriculture.

Table 19.5. Pool sizes and C mineralization kinetics of soil for the active and slow C pools for the native shrub steppe and cultivated sites by years after conversion.

	Active Pool			Slow Pool		
Site/Year/Vegetation	C_a	Lab MRT	Field MRT†	C_s	Lab MRT	Field MRT†
	g kg^{-1}	------ d ------		g kg^{-1}	------ y ------	
Native	0.2a	28a	77ab	1.7a	1.8a	4.9a
Cultivated sites Series CA						
Year 1 (2002 corn residues)	0.3a	25a	68b	2.2ab	1.5a	4.1a
Year 2 (2003 pea residues)	0.4b	15b	41c	2.4b	1.8b	4.9a
Cultivated sites Series CB						
Year 2 (2002 pea residues)	0.5b	19b	52c	2.0b	1.9b	5.2a
Year 3 (2003 corn residues)	0.5b	33a	90a	2.5b	2.6b	7.1b

†MRT-Mean residence times converted to field MRTs using a Q_{10} of 2; ($2^{(25-t)/10}$); where t=Mean annual temperature = 10.5 (Mummy et al., 1994). Values within a column, followed by the same letter, are not significantly different at p=0.05.

The proportion of total C in the slow pool (C_s) averaged 44% for the cultivated fields and 40% for the native (Table 19.5). The increase in the slow pool resulted primarily from the additions of slowly decomposing compost. Curve analysis showed that the slow pool increased with increasing years of cultivation. Laboratory MRT's of the slow pool ranged from 1.8 y for the native with nearly a 50% increase to 2.6 y by the third year after conversion. By correcting for temperature differences between laboratory and field mean annual temperature (MAT), field MRT's showed a greater retention of C in the cultivated sites, becoming significantly greater by the third year after conversion. Total C in both active and slow C pools found in this study were consistently lower than those reported in studies conducted in the Great Plains and Midwest Corn Belt (Collins et al., 2000), where total soil organic C ranged from 1.7 times more (10.7 g C kg^{-1} soil) to 2.8 times more (18 g C kg^{-1} soil) than the TOC found in the third year after conversion in this study. Although Midwestern soils had more TOC, the distribution of C in C_a, C_s and C_r fractions was similar. The resistant and slow fractions comprised on average 46% and 50% of the total C for the Corn Belt soils, respectively. Laboratory MRTs for C_a in Midwestern soils were similar, ranging from 26-52 days, whereas MRTs of the slow pool ranged 7-13 yrs longer in Midwestern soils than those for native and cultivated sites in our study. The greater total concentration of C within the C_s pool was the primary reason for longer MRTs of Midwestern soils.

Conclusion

Conversion from the native shrub steppe to a managed irrigated agricultural system resulted in increases in pH, TOC and TN. Total soil C was greater after 3 years of cultivation than in native soils, indicating that at least in some cases, an increase of C sequestration in soils can result from conversion of native vegetation to cultivation. Soil organic C was divided into three pools: an active pool (C_a) consisting of labile C (simple sugars, organic acids, the microbial biomass and metabolic compounds of incorporated plant residues) with an MRT of days; a slow pool (C_s) consisting of structural plant residues and physically stabilized C and an MRT of years, and a resistant fraction (C_r) consisting of lignin and chemically stabilized C. The use of extended laboratory incubations of soil with measurements of CO_2 have been widely used to differentiate the C_a and C_s functional C pools in residues (Collins et al., 1990) and soil (Motavalli et al., 1994; Paul et al., 1997). This method constitutes a biological fractionation of SOM, where labile fractions are mineralized rapidly by soil biota. Carbon mineralized during the early stages of incubation consisted of C from the C_a pool and reflected variable accumulations of labile C from the incorporation of plant residues. This pool contained 3-5% of the total C and had an average laboratory MRT of approximately 25 days.

The size and turnover rate of the slow pool of C increased with years of cultivation. Positive influences on C storage in this study included crop rotations, addition of organic compost, residue deposition and incorporation, which have been shown to increase SOC over the native shrub steppe vegetation (Rasmussen et al., 1980; Collins et al., 1992; Smith et al., 1993; Rasmussen and Collins, 1991) and water from irrigation that results in increased plant productivity. The system also includes some negative influences on C storage, including harvesting of crops and increased microbial decomposition and volatilization of C as a result of conventional tillage practices and increased moisture. Improved understanding of the impacts of disturbance from ecosystem conversion and continued cultivation practices may help mitigate negative effects of SOM losses from the emerging agro-ecosystem.

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