Carbon and Nitrogen Pools of Southern High Plains Cropland and Grassland Soils

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ABSTRACT

Soil C and N have long been recognized as important indicators of soil productivity. The current low levels of soil C and N of cropland soils have led to interest in sequestering C with reduced tillage cropping systems and the Conservation Reserve Program (CRP). Our objective was to assess agroecosystem effects on soil C and N pools in the Southern High Plains. The agroecosystems included three cotton (*Gossypium hirsutum* L.) cropping systems, CRP land, and native rangeland (NR). We sampled 0- to 5-, 5- to 10-, 10- to 15-, and 15- to 30-cm soil depths at 12 farm sites in five counties in West Texas. Total soil C and N, particulate organic matter (POM) C and N, natural abundance of carbon-13 isotope (δ^{13}C) of POM and of whole soil, potentially mineralizable C and N, water-extractable carbon (WEC), and extractable ammonium (NH_4^+) and nitrate (NO_3^-) were determined. Total C and N in the 0- to 30-cm soil profile were 34 Mg C ha^{-1} and 2.5 Mg N ha^{-1} for NR, and 23 Mg C ha^{-1} and 1.9 Mg N ha^{-1} for cropland systems, respectively. Total soil C and N in CRP land were greater in cropland soils only in the 0- to 5-cm layer, and were 24 Mg C ha^{-1} and 2.1 Mg N ha^{-1} in 0 to 30 cm. Labile C and N pools were positively correlated with each other and with total soil C and N. Low soil test P may have limited C and N sequestration in CRP land and NR. Improved management practices are needed to sequester C and N in CRP and conservation-tillage cotton systems in the Southern High Plains.

INTEREST IN sequestering C in cropland soils with reduced tillage (Bauer and Black, 1981; Lamb et al., 1985; Salinas-Garcia et al., 1997; Halvorson et al., 2002; Zibilske et al., 2002), by increasing cropping intensity (Bowman et al., 1999; Halvorson et al., 2002; Ortega et al., 2002), and/or use of N inputs (Potter et al., 1997; Salinas-Garcia et al., 1997; Halvorson et al., 2002) has been increasing in North America and worldwide. The Food Security Act of 1985 authorized the voluntary CRP to provide cover to sensitive lands to control soil erosion, protect water quality, and to provide wildlife habitat (Council for Agricultural Science and Technology, 1990). The CRP land and native rangelands have likewise been subjects of C sequestration research in the last decade (Woods and Schuman, 1988; DeLuca and Keeney, 1994; Gebhart et al., 1994; Zobeck et al., 1995; Huggins et al., 1997; Staben et al., 1997; Reeder et al., 1998; Follett et al., 2001). Many of these C sequestration studies also examined total soil N (Bauer and Black, 1981; Lamb et al., 1985; Follett and Schimel, 1989; Unger, 1991; Staben et al., 1997; Reeder et al., 1998; Ortega et al., 2002; Zibilske et al., 2002), labile soil C pools (Follett and Schimel, 1989; Huggins et al., 1997; Reeder et al., 1998; Zibilske et al., 2002), or labile N pools (Follett and Schimel, 1989; Doran et al., 1998; Reeder et al., 1998).

Nitrogen has been recognized as playing an important role in C sequestration in CRP land (Robles and Burke, 1997; Reeder et al., 1998) because legumes or N fertilizer additions can minimize N limitations, resulting in faster recovery of soil C levels. Nitrogen mineralization has been reported to be positively related to soil C levels in grassland and cropland soils (Follett and Schimel, 1989; Salinas-Garcia et al., 1997; Doran et al., 1998). Franzluebbers et al. (1996) and Haney et al. (2001) have recently suggested that potential C mineralization measured by 24-h incubation at −0.03 MPa can estimate potential N mineralization, and possibly serve as a N soil test. Doran et al. (1998) stated that most of the differences in microbial biomass and potential N mineralization between no-till and tilled soils were in the 0- to 7.5-cm surface soil. However, the stratification of soil C in the upper layer of no-till systems can also result in enhanced immobilization of N (Doran et al., 1998; Zibilske et al., 2002). Bronson et al. (2001) reported that greater N fertilizer requirement in terminated-wheat conservation tillage compared with conventional tillage was likely due to immobilization of N in wheat residue. Other researchers have reported net immobilization of N in soils in the year CRP land is converted to other uses (Dao et al., 2002).

Carbon and N pools or fractions in soil are important to study to understand the processes of soil C sequestration. Particulate organic matter is plant material in various stages of decomposition that represents active C and N fractions of soil (Cambardella and Elliott, 1992; Cambardella, 1998; Wander and Bidhart, 2000). Native prairie and CRP land have significant fractions of total soil C as POM-C and total soil N as POM-N (Cambardella and Elliott, 1992; Huggins et al., 1997). The POM-C can be greater in the 0- to 5-cm layer of no-tillage soils than in plowed soils (Hussain et al., 1999; Wander and Bidhart, 2000). Below 5 cm, POM-C levels are often similar. The role of POM in N cycling in soils is notable, as potentially mineralizable N has been correlated with POM-N (Wander and Bidhart, 2000) or POM-C (Chan et al., 2002). Laboratory studies have shown that macroorganic matter or POM additions to soil can result in

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Abbreviations: δ^{13}C, natural abundance of carbon-13 isotope; CRP, Conservation Reserve Program; NR, native rangeland; NRCS, Natural Resource Conservation Service; POM, particulate organic matter; WEC, water-extractable carbon.

N immobilization (Whalen et al., 2000) or in slight increases in N mineralization (Yakovchenko et al., 1998). The sources of plant C (C_3 or C_4 photosynthetic pathway) that make up POM-C can be determined with ^{13}C natural abundance techniques (Cambardella and Elliott, 1992; Six et al., 1998; Garten and Wullschleger, 2000). Warm-season grasses of the Southern High Plains are dominated by C_4 photosynthetic pathways, while the dominant row crop of the region is cotton, which is C_3 (Kelly et al., 1991; Follett et al., 1997; Boutton et al., 1998). Therefore, it should be possible to quantify the amount of soil C derived from cotton cropping in Southern High Plains soils that have soil C derived mostly from C_4 native grasses.

Data on soil C and N pools are lacking for the common agroecosystems of Southern High Plains. The CRP land and rangeland occupy 0.84 and 3.8 million ha, respectively in the Southern High Plains of New Mexico and Texas (USDA Economic Research Service, 1996). The economically most important cropping systems in the Southern High Plains are dryland and irrigated cotton systems, which are planted to about 1.3 million annually (USDA Economic Research Service, 1996). Conservation tillage cotton with a chemically terminated winter wheat (*Triticum aestivum* L.) cover crop is a growing practice that allows producers to meet conservation compliance. Both conservation tillage systems and CRP lands have potential to sequester soil C in West Texas. The objective of this study was to determine the effect of cotton, CRP, and native range (NR) agroecosystems on soil C and N pools in the Southern High Plains of West Texas.

MATERIALS AND METHODS

Soil Sampling and Site Descriptions

Soil cores were collected in fall of 2000 and spring 2001 from Crosby, Cochran, Hockley, Howard, and Lubbock counties in the Southern High Plains of West Texas. Five agroecosystems were sampled: conventional tillage irrigated cotton (noted as "irrigated cotton" from here on), conventional tillage dryland cotton (noted as "dryland cotton" from here on), conservation tillage irrigated cotton, CRP, and NR.

In irrigated, conservation-tilled sites, cotton was planted into rye (*Secale cereale* L.) or wheat winter cover crops that were terminated chemically with glyphosate [isoprophylamine salt of N-(phosphomonomethyl) glycine] application. We shall refer to the conservation tillage cotton sites as "terminated-wheat cotton." The CRP sites were in place from 1985 to 1991, with the average inception date being 1989.

The main species in CRP sites were Blue grama (*Bouteloua gracilis,* C_4), Old World Bluestem, [*Bothriochloa ischaemum* (L.) Keng, C_4], sand dropseed [*Sporobolus cryptandrus* (Torr.) A. Gray, C_4], sideoats grama [*Bouteloua curtipendula* (Michx.) Torr., C_4], silverleaf nightshade (*Solanum elaeagnifolium* Cav., C_3), and weeping lovegrass [*Eragrostis curvula* (Schrad.) Nees, C_4]. Native rangeland was dominated by blue grama, sand dropseed, sideoats grama, silverleaf nightshade, yucca (*Yucca* spp.), and honey mesquite (*Prosopis glandulosa* Torr., C_3).

Farm sites were selected, with the help of USDA-Natural Resource Conservation Service (USDA-NRCS) personnel, that had two, three, or four of the systems of interest within the same soil series as mapped by the USDA-NRCS. The soil series sampled included Amarillo sandy loam (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) at six sites, Acuff sandy clay loam (fine-loamy, mixed, superactive, thermic Aridic Paleustolls) at two sites, Olton clay loam (fine, mixed, superactive, thermic Aridic Paleustolls) at three sites, and Patricia loamy sand (fine-loamy, mixed, superactive, thermic Aridic Paleustalfs) at one site. Two, five, two, one, and two sites were chosen in Cochran, Crosby, Hockley, Howard, and Lubbock counties, respectively (Fig. 1). Twenty-eight system-site combinations were sampled. Sites with surface soil layers that tested positive for calcium carbonate ($CaCO_3$) in the presence of 1 *M* HCl were avoided to restrict soil C analysis to organic C only.

The number of sites (replicates) sampled within each system ranged from four to six. Within each system–site combination, three sets of five 30-cm-deep, 4.5-cm-diam. cores were sampled with a Giddings soil sampling machine (Giddings Machine Co., Fort Collins, Co). The sets, or subsamples, of three were separated by <100 m, and the sets of five were all within 1 m of each other. Mean distance between systems within sites was <500 m. The cores were sectioned into 0- to 5-, 5- to 10-, 10- to 15-, and 15- to 30-cm depths. Subsamples from the sets of five were then composited by depth. Samples were air-dried and then passed through a 2-mm sieve before all analyses detailed below. Soil bulk density was calculated using dry weights and the volumes of soil sampled. Some compaction did occur when soil sampling, but the known volumes sampled were used in the calculations. Bulk density values were used to calculate soil content (mass per area) of C and N pools from concentrations.

Particle Size and Chemical Analysis

Clay, sand, and silt concentrations were determined by the hydrometer method (Gee and Bauder, 1986). Olsen-extractable-P (Olsen et al., 1954) and ammonium acetate-extractable K^+ (Knudson et al., 1982) were determined by colorimetry and atomic absorption, respectively. Soil and water mixtures of 1:1 (McLean, 1982) were used for pH determinations with a pH electrode (Table 1).

Total Carbon, $\delta^{13}C$, and Total Nitrogen

Samples were analyzed for total C, $\delta^{13}C$, and total N using an automated Carlo-Erba CN analyzer (CE Instruments, Milan, Italy) that was interfaced to a VG Isomass mass spectrometer (VG Isogas, Middlewich, UK). Soil was first ground to 0.25 mm in an ultracentrifugal mill (ZM 100, Retsch GmbH & Co., Haan, Germany) and 35-mg subsamples of milled soil were weighed into Sn capsules for analysis.

Potentially Mineralizable Carbon

Potentially mineralizable C was determined as CO_2 production during a 24-hr aerobic incubation (Haney et al., 2001). Two grams of soil were weighed and spread on the bottom of a 50-mL beaker. Water potential was adjusted to −0.03 MPa for each soil by depth and by system. The beakers and soils were placed in 1-L canning jars and immediately covered with the gasket-lined lid. Laboratory air in the jar was flushed out with medical breathing air (360 $\mu L\ CO_2\ L^{-1}$) for 5 min at 1000 mL min^{-1} through inlet and outlet fittings installed on the jar lids. The 24-h incubation was conducted in the dark at 25°C in a controlled temperature room. Carbon dioxide was analyzed in the headspace of the canning jar with an infrared gas analyzer (model 6200, LI-COR Inc., Lincoln, NE) after 24 h. Triplicate empty jars were similarly flushed with breathing air, capped, incubated for 24 h, and then analyzed

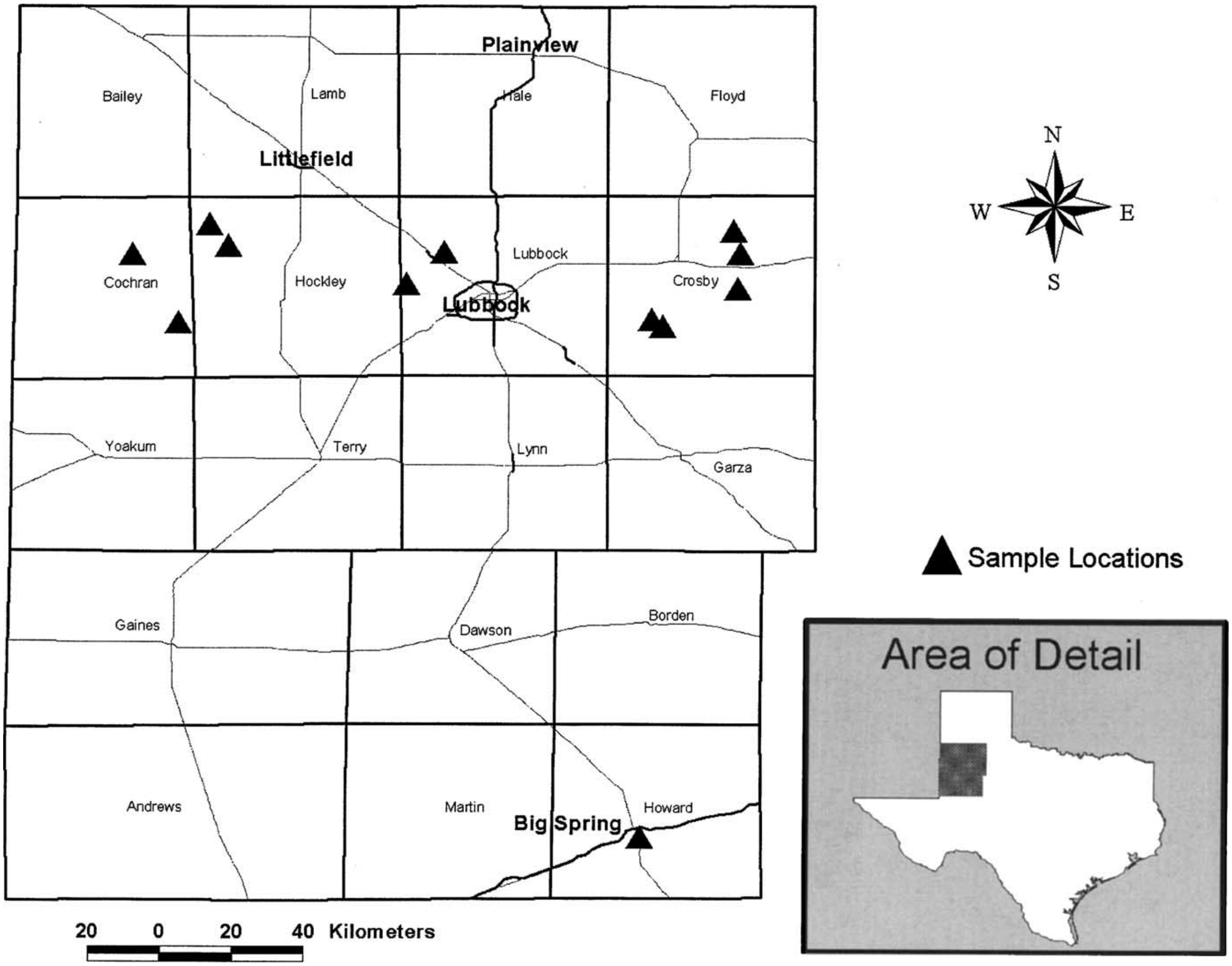

Fig. 1. Locations of farm sites sampled in the Southern High Plains of West Texas.

for background CO_2. Net CO_2–C production was calculated as the difference in the amount of CO_2–C in the sample jars and the background CO_2–C, and expressed as mg CO_2–C kg soil^{-1} d^{-1}.

Potentially Mineralizable Nitrogen

Potentially mineralizable N was determined on the same soil units that were subjected to the potentially mineralizable C assay. After the 24-h CO_2–C production incubation and analysis, the soil and beaker units were removed from the canning jars and covered with plastic wrap, sealed with a rubber band, and placed in styrofoam coolers. Before closing the coolers, several additional 50-mL beakers filled with water were placed in the cooler to further help prevent evaporation of water from the soil units. The coolers were placed in a controlled temperature room at 25°C. After 27 d, soil units were equilibrated with 2 *M* KCl using a 1:10 soil-to-extractant ratio for 1 hr. The supernatant was filtered through a Whatman no. 2 filter paper that was previously washed with deionized water. Soil extracts were analyzed for NH_4^+–N and NO_3^-–N (Adamsen et al., 1985) on a Technicon Autoanalyzer 2 (Technicon Industrial Systems, Tarrytown, NY). Net N mineralization was calculated as the difference of the [NO_3^- + NH_4^+–N] before and after incubation. Gaseous losses of N such as NH_3 were not accounted for.

Particulate Organic Matter Carbon and Nitrogen

Twenty five grams of soil were weighed into 125-mL polyethylene bottles, and 100 mL of sodium hexametaphosphate solution (5 g L^{-1}) was added (Gregorich and Ellert, 1993). The soil-solution mixture was shaken for 1 h at high speed on an end-to-end shaker. With several deionized water rinses and gentle strokes with a rubber spatula, the mixture was poured over a 53-μm sieve. Sand and POM remaining on the sieve were gently backwashed into a preweighed aluminum dish that was later dried at 60°C for 24 h. Sand plus POM was ground to 0.25 mm in an ultracentrifugal mill. Thirty-five milligrams of milled soil were weighed into Sn capsules and analyzed for total C, $\delta^{13}C$, and total N using an automated Carlo-Erba CN analyzer interfaced to a VG Isomass mass spectrometer. Values of $\delta^{13}C$ of soil C and POM-C are reported as per thousand and were in reference to Pee Dee Belemnite (PDB) limestone as

$$\delta^{13}C = [(R_{sample}/R_{PDB}) - 1]\ 1000‰, \qquad [1]$$

where R = $^{13}C/^{12}C$. Additionally, the proportion of C derived from C_4 or C_3 plants was estimated as suggested by Boutton et al. (1998):

$$\delta^{13}C = (\delta^{13}C_{C4})(x) + (\delta^{13}C_{C3})(1 - x), \qquad [2]$$

where $\delta^{13}C$ is the $\delta^{13}C$ value of the POM (and sand) or whole

Table 1. Physical and chemical characteristics of cropland and grassland soils, West Texas.

System	Bulk density	Clay	Silt	Sand	pH	P†	K‡
	g cm^{-3}	g kg^{-1}				mg kg^{-1}	
			0–5 cm				
Dryland cotton	1.29 (0.03)§	148 (24)	151 (25)	698 (38)	7.1 (0.2)	13.1 (2.8)	397 (47)
Irrigated cotton	1.27 (0.03)	136 (25)	169 (26)	698 (41)	7.8 (0.2)	8.5 (3.6)	343 (61)
Terminated-wheat cotton	1.29 (0.03)	163 (24)	158 (25)	677 (39)	7.6 (0.2)	23.1 (2.6)	474 (44)
CRP¶	1.33 (0.03)	225 (23)	205 (24)	573 (37)	7.4 (0.2)	2.7 (2.7)	362 (45)
NR#	1.17 (0.04)	189 (28)	231 (28)	577 (44)	7.1 (0.2)	8.6 (3.1)	439 (52)
LSD ($P < 0.05$)	0.09	57	ns††	85	ns	9.0	ns
CRP vs. cropland	ns	**	*	**	ns	*	ns
NR vs. cropland	ns	ns	*	*	ns	ns	ns
			5–10 cm				
Dryland cotton	1.34 (0.03)	159 (24)	125 (25)	715 (40)	6.9 (0.2)	11.5 (3.5)	359 (29)
Irrigated cotton	1.39 (0.03)	145 (25)	145 (27)	711 (42)	7.9 (0.2)	7.7 (4.7)	308 (38)
Terminated-wheat cotton	1.38 (0.03)	187 (25)	128 (25)	686 (40)	7.5 (0.2)	23.1 (3.3)	351 (28)
CRP	1.46 (0.03)	218 (24)	191 (24)	590 (38)	7.6 (0.2)	3.0 (3.4)	349 (28)
NR	1.42 (0.04)	180 (26)	221 (29)	600 (45)	7.3 (0.2)	4.2 (4.0)	331 (33)
LSD ($P < 0.05$)	ns	39	63	87	0.6	11.7	ns
CRP vs. cropland	**	**	*	**	ns	*	ns
NR vs. cropland	ns	ns	**	*	ns	*	ns
			10–15 cm				
Dryland cotton	1.51 (0.03)	170 (24)	155 (28)	676 (42)	6.9 (0.2)	9.7 (2.6)	304 (28)
Irrigated cotton	1.51 (0.04)	174 (25)	122 (30)	702 (45)	7.9 (0.3)	4.6 (3.6)	241 (39)
Terminated-wheat cotton	1.50 (0.03)	183 (25)	145 (28)	673 (43)	7.5 (0.2)	14.4 (2.5)	277 (28)
CRP	1.52 (0.03)	194 (24)	217 (27)	587 (40)	7.6 (0.2)	3.5 (2.6)	326 (29)
NR	1.43 (0.04)	164 (27)	163 (32)	675 (48)	7.3 (0.2)	3.1 (3.1)	323 (34)
LSD ($P < 0.05$)	ns		63	ns	ns	8.9	ns
CRP vs. cropland	ns	ns	**	*	ns	ns	ns
NR vs. cropland	ns	ns	ns	ns	ns	ns	ns
			15–30 cm				
Dryland cotton	1.60 (0.04)	219 (30)	161 (24)	630 (47)	7.3 (0.2)	5.7 (1.4)	256 (21)
Irrigated cotton	1.53 (0.05)	213 (32)	129 (24)	647 (50)	7.7 (0.2)	3.6 (2.0)	235 (30)
Terminated-wheat cotton	1.57 (0.04)	208 (31)	151 (24)	50 (48)	7.5 (0.2)	6.4 (1.4)	232 (21)
CRP	1.52 (0.04)	225 (30)	188 (23)	575 (45)	7.5 (0.2)	3.1 (1.3)	276 (21)
NR	1.29 (0.05)	207 (33)	168 (25)	634 (54)	7.5 (0.2)	1.7 (1.7)	308 (25)
LSD ($P < 0.05$)	0.13	ns	40	ns	ns	ns	ns
CRP vs. cropland	ns	ns	**	ns	ns	ns	ns
NR vs. cropland	**	ns	ns	ns	ns	ns	*

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
† Olsen extract.
‡ 1 *M* NH_4OAc extract.
§ Standard errors are in parentheses.
¶ CRP, conservation reserve program land.
# NR, native rangeland.
†† ns, not significant at $P = 0.05$.

soil sample, $\delta^{13}C_{C4}$ is the $\delta^{13}C$ value of the C_4 parts of the sample (−12.0‰, Smith and Epstein, 1971), x is the fraction of C from C_4 plant sources, $\delta^{13}C_{C3}$ is the $\delta^{13}C$ value of the C_3 plant parts (−26.0‰, Smith and Epstein, 1971) and $1 - x$ is the fraction of C from C_3 plants.

Water-Extractable Carbon

Soil samples were analyzed for WEC by weighing 6 g into 50-mL polyethylene centrifuge tubes and 30 mL deionized water (25°C) was added to each tube. The soil-water mixture was equilibrated for 1 h using an end-to-end shaker set at high speed. After shaking, tubes were centrifuged at 17 000 rpm for 15 min using an eight-place fixed angle rotor centrifuge (Sorvall SL-50T, Kendro Laboratory Products, Newtown, CT). The supernatant was filtered through a Whatman no. 42 filter paper (previously leached with deionized water) and the resulting filtrate was stored at 4°C until analysis 3 to 7 d later. Water-extractable C in the filtrate was analyzed with a total organic carbon/N analyzer (Model TOC-V CPH/CPN, Shimadzu Corporation, Japan).

Statistical Analysis

The experimental design employed in this study was an unbalanced incomplete block design. The lack of balance is because of unequal numbers of replicates within each management system (four to six) and the unequal block (farm sites) sizes (two to four). Analysis of variance by soil depth was performed for all C and N pools measured with PROC MIXED (SAS Institute, 1999) with the five management systems as a fixed effect. Block and block × system were considered random. Sand concentration was included in the ANOVA models as a covariate because sand concentration had a strong negative correlation with most of the soil C and N pools. Least square means were estimated and LSDs ($P = 0.05$) were calculated if the system effect in the ANOVA was significant at $P < 0.05$. Single degree of freedom contrasts CRP vs. cropland soils, and NR vs. cropland soils were determined as well. Additionally, simple correlation analysis (PROC CORR, SAS Institute, 1999) was performed among all C and N pools with and without separation of depths.

RESULTS

Particle Size and Chemical Analysis

Bulk density was similar among the systems except at 15 to 30 cm, where NR soils had lower bulk density (Table 1). Sand concentration in the upper 10 cm (and

Table 2. Carbon pools of cropland and grassland soils, West Texas.

	Whole soil					†POM	
System	Total C	Total C	δ^{13}C‡	Potentially mineralizable C	WEC§	Total C	δ^{13}C
	g kg^{-1}	Mg ha^{-1}	‰	mg CO$_2$–C kg^{-1} d^{-1}	mg kg^{-1}	Mg ha^{-1}	‰
			0–5 cm				
Dryland cotton	6.0 (0.7)¶	3.8 (0.4)	−18.2 (0.9)	44 (7)	68 (7)	0.9 (0.3)	−19.9 (0.8)
Irrigated cotton	5.3 (0.7)	3.3 (0.5)	−18.4 (1.0)	29 (7)	53 (7)	0.6 (0.3)	−20.8 (0.8)
Terminated-wheat cotton	6.9 (0.7)	4.4 (0.3)	−19.6 (0.9)	44 (6)	72 (7)	0.9 (0.3)	−22.6 (0.8)
CRP#	7.8 (0.7)	5.3 (0.4)	−19.2 (0.9)	49 (7)	72 (7)	1.5 (0.3)	−18.4 (0.8)
NR††	12.2 (0.8)	7.0 (0.5)	−19.8 (1.0)	69 (7)	104 (8)	3.3 (0.4)	−18.3 (0.9)
LSD ($P < 0.05$)	2.1	1.3	ns‡‡	17	20	0.9	2.3
CRP vs. cropland	*	*	ns	ns	ns	ns	*
NR vs. cropland	**	**	ns	**	**	**	*
			5–10 cm				
Dryland cotton	5.4 (0.6)	3.6 (0.4)	−17.5 (0.7)	32 (4)	64 (11)	0.7 (0.1)	−19.5 (0.8)
Irrigated cotton	5.0 (0.6)	3.4 (0.4)	−18.2 (0.7)	27 (4)	54 (11)	0.5 (0.1)	−21.3 (0.8)
Terminated-wheat cotton	5.7 (0.6)	4.0 (0.4)	−19.4 (0.7)	30 (4)	70 (10)	0.5 (0.1)	−21.5 (0.7)
CRP	5.3 (0.6)	3.9 (0.4)	−19.4 (0.7)	31 (4)	80 (10)	0.8 (0.1)	−18.3 (0.7)
NR	5.3 (0.7)	7.3 (0.5)	−17.6 (0.8)	32 (5)	71 (12)	1.6 (0.1)	−17.5 (0.9)
LSD ($P < 0.05$)	1.9	1.3	1.7	ns	ns	0.4	2.3
CRP vs. cropland	ns	ns	ns	ns	ns	ns	*
NR vs. cropland	**	**	ns	ns	ns	**	**
			10–15 cm				
Dryland cotton	4.7 (0.5)	3.4 (0.6)	−17.0 (0.6)	23 (4)	72 (7)	0.4 (0.1)	−21.3 (1.1)
Irrigated cotton	5.3 (0.5)	4.1 (0.7)	−18.4 (0.7)	20 (4)	58 (7)	0.6 (0.1)	−20.0 (1.2)
Terminated-wheat cotton	5.3 (0.5)	3.9 (0.6)	−18.5 (0.7)	23 (4)	61 (7)	0.4 (0.1)	−21.5 (1.1)
CRP	4.7 (0.5)	4.6 (0.6)	−18.7 (0.7)	32 (4)	75 (7)	0.6 (0.1)	−18.2 (1.1)
NR	7.3 (0.6)	5.4 (0.7)	−15.1 (0.7)	27 (5)	78 (8)	0.9 (0.1)	−15.3 (1.3)
LSD ($P < 0.05$)	1.5	ns	1.7	ns	ns	0.2	2.9
CRP vs. cropland	ns	ns	ns	ns	ns	ns	*
NR vs. cropland	**	ns	**	ns	ns	*	**
			15–30 cm				
Dryland cotton	4.9 (0.5)	11.5 (1.2)	−15.6 (0.8)	18 (4)	80 (8)	0.7 (0.2)	−21.4 (1.1)
Irrigated cotton	5.1 (0.5)	11.6 (1.3)	−16.6 (0.9)	28 (4)	68 (8)	0.8 (0.2)	−20.7 (1.2)
Terminated-wheat cotton	5.4 (0.5)	12.6 (1.2)	−17.4 (0.9)	20 (4)	63 (7)	1.0 (0.2)	−19.5 (1.1)
CRP	5.1 (0.5)	11.8 (1.2)	−15.8 (0.9)	29 (4)	85 (7)	1.2 (0.2)	−17.7 (1.1)
NR	6.9 (0.5)	13.7 (1.5)	−14.7 (1.0)	23 (5)	101 (9)	1.7 (0.2)	−16.3 (1.3)
LSD ($P < 0.05$)	ns	ns	ns	ns	23	0.6	2.8
CRP vs. cropland	ns	ns	ns	ns	ns	ns	*
NR vs. cropland	*	ns	ns	ns	**	**	**

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
† POM, particulate organic matter.
‡ δ^{13}C, stable carbon-13 composition.
§ WEC, water-extractable carbon.
¶ Standard errors are in parentheses.
# CRP, conservation reserve program land.
†† NR, native rangeland.
‡‡ ns, not significant at $P = 0.05$.

upper 15 cm for CRP land) in CRP and NR soils was less than in cropland soils (Table 1). This was probably because of greater wind erosion on the cropland soils, and wind deposition of clay and silt into CRP and NR soils (Nichols, 1984; Parton et al., 1987). Terminated-wheat cotton had the highest Olsen-extractable P, probably because of greater P fertilization than the other cotton cropping systems. Soil pH was similar among systems, except at 5 to 10 cm, where dryland cotton soils had lower pH than the other systems. Olsen-extractable-P was <5 mg kg^{-1} in the 0 to 10 cm of CRP soils and in the 5- to 10-cm layer of NR. Levels of Olsen-P <5 mg kg^{-1} are considered low and having a high probability of a crop response if P fertilizer is applied (Thomas and Peaslee, 1973; Havlin et al., 1999). All soils at all depths had an alkaline pH (i.e., 6.9–7.9). Exchangeable K$^+$ was similar among the systems except at 15 to 30 cm, where NR soils had higher soil exchangeable K$^+$.

Soil Carbon Pools

Total C concentration was greater in NR soils than in CRP and cropland soils at all depths to 15 cm (Table 2). However, total C concentration and content were greater in CRP soils than in cropped soils in the 0- to 5-cm surface layer only. Total soil C content in the 0- to 30-cm profile was 22, 22, 25, 24, and 34 Mg C ha^{-1} for dryland cotton, irrigated cotton, terminated-wheat cotton, CRP, and NR, respectively. Total soil C content was significantly greater in NR than in the other systems (LSD = 5.9 Mg C ha^{-1}). Water-extractable C, while sensitive to management, only averaged about 1% of total C. Native rangeland soils had greater WEC than cropland soils in the 0- to 5- and 15- to 30-cm layers. The CRP soils had similar WEC compared with cropped soils.

Delta ^{13}C of whole soil was generally not affected by cropping system, but did increase with depth (Table 2). Native rangeland had the greatest δ^{13}C of soil in the 10-

Table 3. Nitrogen pools of cropland and grassland soils, West Texas.

System	Total N	Total N	POM-N†	NH_4^+–N + NO_3^-–N	Potentially mineralizable N
	g kg $^{-1}$	kg ha^{-1}			kg ha^{-1} 28 d^{-1}
			0–5 cm		
Dryland cotton	0.6 (0.07)‡	392 (41)	51 (25)	9.6 (1.6)	8.8 (2.0)
Irrigated cotton	0.3 (0.08)	207 (43)	33 (25)	8.4 (1.7)	6.0 (1.9)
Terminated-wheat cotton	0.6 (0.07)	364 (40)	73 (24)	7.8 (1.6)	12 (1.8)
CRP§	0.7 (0.07)	463 (41)	101 (25)	5.2 (1.6)	5.6 (1.8)
NR¶	1.0 (0.09)	579 (48)	197 (28)	7.2 (1.9)	11 (2.1)
LSD ($P < 0.05$)	0.2	110	74	ns#	ns
CRP vs. cropland	ns	**	ns	ns	ns
NR vs. cropland	**	**	**	ns	ns
			5–10 cm		
Dryland cotton	0.5 (0.04)	333 (31)	35 (19)	10 (1.9)	4.9 (0.8)
Irrigated cotton	0.4 (0.04)	272 (32)	32 (20)	9.4 (2.0)	5.2 (0.7)
Terminated-wheat cotton	0.5 (0.04)	377 (30)	46 (19)	7.1 (1.8)	6.0 (0.7)
CRP	0.4 (0.04)	336 (36)	43 (19)	4.1 (1.9)	3.6 (0.7)
NR	0.6 (0.04)	428 (36)	161 (22)	5.2 (2.2)	6.6 (0.8)
LSD ($P < 0.05$)	0.1	83	57	ns	ns
CRP vs. cropland	ns	ns	ns	*	*
NR vs. cropland	*	*	**	ns	ns
			10–15 cm		
Dryland cotton	0.4 (0.04)	323 (39)	30 (10)	11 (2.1)	5.4 (0.8)
Irrigated cotton	0.3 (0.05)	238 (41)	36 (11)	7.4 (2.2)	6.7 (0.8)
Terminated-wheat cotton	0.5 (0.04)	354 (38)	38 (10)	8.5 (2.0)	6.7 (0.8)
CRP	0.4 (0.04)	368 (39)	44 (10)	4.7 (2.1)	3.6 (0.8)
NR	0.5 (0.05)	404 (47)	62 (12)	5.2 (2.5)	6.2 (0.9)
LSD ($P < 0.05$)	0.1	ns	ns	ns	ns
CRP vs. cropland	ns	ns	ns	ns	*
NR vs. cropland	*	ns	*	ns	ns
			15–30 cm		
Dryland cotton	0.5 (0.03)	1087 (87)	52 (16)	22 (4.8)	26 (2.9)
Irrigated cotton	0.5 (0.03)	1014 (94)	78 (17)	28 (5.1)	20 (2.8)
Terminated-wheat cotton	0.5 (0.03)	1002 (88)	58 (16)	25 (4.7)	22 (2.6)
CRP	0.4 (0.03)	964 (86)	83 (15)	12 (4.7)	12 (2.6)
NR	0.6 (0.04)	1110 (103)	107 (19)	12 (5.8)	22 (3.3)
LSD ($P < 0.05$)	ns	ns	ns	ns	8.3
CRP vs. cropland	ns	ns	ns	*	**
NR vs. cropland	*	ns	*	*	ns

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
† POM, particulate organic matter.
‡ Standard errors are in parentheses.
§ CRP, conservation reserve program land.
¶ NR, native rangeland.
# ns, not significant at $P = 0.05$.

to 15-cm layer only. Potentially mineralizable C was greater in NR than cropped soils and CRP in the 0- to 5-cm layer only.

Particulate organic matter C was greater in NR than in cropped soils in the entire 0- to 30-cm profile (Table 2). The CRP soils had similar POM-C levels compared with the cropped soils. Delta ^{13}C of POM was greater in CRP and NR soils than in cropped soils in the entire 30-cm profile sampled. The fraction of POM-C to total soil C in the 0- to 5-cm layer was 0.45 for NR soils and 0.20 for cropped soils (data not shown). These proportions agree well with Cambardella and Elliott (1992) who reported that 39, 19, and 25% of total organic C was POM-C in the 0 to 20 cm soil of native grassland of the Nebraska panhandle, stubble-mulch wheat, and no-tillage wheat, respectively. Below 5 cm, there was no difference in the POM-C/total soil C fractions among systems in our study, and this proportion declined to 0.10 in the 15- to 30-cm soil layer. Fifty-four percent of whole soil C in all systems was derived from C_4 plants in the 0- to 5-cm soil, and this increased to 69% in the 15- to 30-cm layer (data not shown). The percentage of POM-C that was derived from C_4 plants did not differ with soil depth and averaged 59% in CRP and NR and 35% in cropland soils.

Soil Nitrogen Pools

Total soil N concentration was greater in NR than in cropped soils in the entire 30-cm profile (Table 3). Total soil N content was greater in NR than cropland to 10 cm. Total soil N content was greater in CRP soils than in cropped soils in the top 5 cm only. In the 0- to 30-cm profile, total soil N was 2.1, 1.7, 2.2, 2.1, and 2.5 Mg N ha^{-1} for dryland cotton, irrigated cotton, terminated-wheat cotton, CRP, and NR, respectively. Total soil N was significantly greater in the NR than in cropped soils, except for conservation-tillage cotton (LSD = 0.45 Mg N ha^{-1}). Total soil N was less in irrigated cotton than dryland cotton or terminated-wheat cotton. Particulate organic matter-N was greater in NR soils than in cropped soils in all layers sampled, except the 10- to 15-cm layer (Table 3). The C:N ratio of POM averaged 17 and was not affected by system or soil depth. Extractable

Table 4. Correlation among carbon and nitrogen pools (units are all concentration in soil) of cropland and grassland soils, West Texas ($n = 112$).

	POM-N†	C mineral.‡	N mineral.	WEC§	Total C	Total N	Sand	Silt	Clay
POM-C	0.74**	0.64**	0.59**	0.39**	0.69**	0.69**	−0.23*	0.34**	ns#
POM-N		0.52**	0.43**	0.30**	0.62**	0.56**	ns	0.33**	ns
C mineral.			0.56**	0.54**	0.70**	0.75**	−0.57**	0.58**	0.46**
N mineral.				0.32**	0.58**	0.73**	−0.38**	0.56**	0.59**
WEC					0.54**	0.55**	−0.55**	0.52**	0.47**
Total C						0.86**	−0.74**	0.74**	0.60**
Total N							−0.69**	0.68**	0.57**
Sand								−0.91**	−0.91**
Silt									0.66**

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
† POM, particulate organic matter.
‡ mineral., mineralization.
¶ WEC, water-extractable carbon.
# ns, not significant at $P < 0.05$.

NH_4^+ plus NO_3^- (>90% NO_3^-) was significantly less in CRP and NR soils than in the cropped systems in the 15- to 30-cm layer (and in the 5–10 cm layer for CRP). In the 0- to 30-cm profile, total extractable N was 55, 52, 48, 27, and 30 kg N ha^{-1} (LSD = 26 kg N ha^{-1}, data not shown) for dryland cotton, irrigated cotton, terminated-wheat cotton, CRP, and NR, respectively. Potentially mineralizable N was the lowest in CRP soils in the 5- to 30-cm depths.

Correlations between Carbon and Nitrogen Pools

Correlations between soil C and N pools were similar between soil depths, therefore only the correlations with depths pooled will be presented. Total soil C and N concentrations were highly correlated among all treatments ($r = 0.86$, Table 4). Correlations of total or POM-C and -N with each of the other C and N pools were greater when expressed as concentrations than as contents. This may have been because of variation in bulk density. Correlations between soil C concentration and sand, silt, and clay were −0.74, 0.74, and 0.60, respectively. Water-extractable C, potentially mineralizable C, and POM-C were correlated with total soil C concentration with $r = 0.54$, 0.70, and 0.69, respectively. Correlations of total soil N concentration with sand, silt, clay, WEC, and POM-C were similar to the correlations with total soil C concentration. Potentially mineralizable N concentration was correlated with total soil N concentration ($r = 0.73$) to a similar degree as potentially mineralizable C was correlated with total soil C concentration ($r = 0.70$). Potentially mineralizable N concentration was moderately correlated with potentially mineralizable C ($r = 0.56$).

Particulate organic matter C concentration was correlated with potentially mineralizable C ($r = 0.64$), but POM-N concentration was only weakly correlated with potentially mineralizable N ($r = 0.43$). Correlation of POM-C concentration with potentially mineralizable N was 0.59. The C:N ratio of POM was only weakly related to potentially mineralizable C and N ($r = 0.20$ and 0.23, respectively, significant at $P < 0.05$, data not shown).

DISCUSSION

The lower total soil C and N observed in cultivated cropland soils compared with NR soils have been well documented (Haas et al., 1957; Bauer and Black, 1981; Lamb et al., 1985; Woods and Schuman, 1988). In our study, however, the 0 to 30 cm total soil C in CRP land was not as high as in the NR system. Additionally, total soil C and N in 0- to 30-cm CRP soils were not greater than in cropland systems. Reeder et al. (1998) reported that soil C and N in CRP soils were statistically similar to that of an adjacent native prairie after 5 yr in a sandy loam, but not in a clay loam. Huggins et al. (1997) reported after 7 yr in the CRP, soil C and N in a loam were still less than that of a tall grass native prairie. Potter et al. (1999) reported that soil C and N on 60-yr restored grassland on a clay were still less than on native prairie, but greater than in adjacent cropland. In our study in the Southern High Plains, the relatively short time of 9 to 15 yr that the CRP was in place may have limited C and N sequestration. The warm climate of the Southern High Plains, and its associated rapid organic matter oxidation rates, may also explain lack of C sequestration in CRP soils compared with other studies in cooler sites.

Absence of P fertilization apparently resulted in low soil test P levels in CRP and NR soils, which may have limited plant biomass production and C sequestration. Although soil test P in the 0- to 5-cm layer of NR soils was greater than the critical level of 5 mg P kg^{-1} (Thomas and Peaslee, 1973; Havlin et al., 1999), this topsoil layer is usually dry and therefore not as important in nutrient acquisition. The 5- to 10-cm layer of NR, however, had only 4 mg P kg^{-1}, and was therefore P deficient. The high soil test P levels observed in the terminated-wheat cotton may have been because wheat is one of the most P-sensitive crops (Fixen and Grove, 1990). Visual P deficiency in wheat such as stunting may have led producers to apply additional P fertilizer.

In contrast to our findings, Brejda et al. (2000) reported similar soil test P (Mehlich 3) among cropland, CRP, and NR sites. The lack of grazing in the CRP sites is probably also an important factor in C sequestration, but recent studies report that grazing can result in either increases or decreases in soil C (Milchunas and Lauenroth, 1993; Schuman et al., 2001). Cattle grazing in NR, however, would have added some N and P into the system from supplemental feeds.

Low extractable-N and mineralizable-N suggests that N may have limited C sequestration in CRP and NR soils. However, low [NO_3^- + NH_4^+–N] in grassland soils may also be because of rapid N cycling. Legumes play an important role in N soil fertility and soil C levels (Robles and Burke, 1997). Although not exceedingly abundant, there were N_2–fixing legumes observed in both CRP and NR sites. The most common N_2–fixing legumes in NR were honey mesquite and catclaw acacia (*Acacia greggii* A. Gray). Purple prairie clover (*Dalea purpurea* Vent.) and yellow blossom sweetclover [*Melilotus officinalis* (L.) Lam.] were observed in many CRP sites. However, it is not clear how much N_2 was fixed in the grassland systems in this study. The levels of extractable inorganic N in the cotton systems were relatively high and similar to that reported for farmers' fields in the Southern High Plains (Bronson, 2003). Since soil sampling was conducted after cotton harvest, high levels of residual NO_3^- are probably the result of overfertilization and/or not achieving yield goals.

None of the soil C pools measured differed between terminated-wheat cotton and irrigated or dryland cotton. Conservation tillage systems are usually associated with high amounts of crop residue. However, the amounts of small grain residue in the terminated-wheat cotton system are usually $<$1200 kg ha^{-1}, because the winter cover crop is not irrigated and the winters in West Texas are dry (Bronson et al., 2001). The low amounts of small grain residue therefore were apparently not enough to impact any of the soil C pools measured in this study. There was more tillage in conventional irrigated and dryland cotton than in terminated-wheat cotton, but apparently this did not result in additional soil organic C loss.

The magnitude of the total C and N concentrations and contents of the grassland and cropland soils in our study are not unexpected considering the warm, dry climate where the average annual temperature of Lubbock, TX, is 16°C, the average annual rainfall is 47 cm, and the relatively high sand concentration of our Southern High Plains sample sites. Decreasing soil organic C from the Northern to Southern High Plains is well documented (Burke et al., 1989; Follett et al., 1997; Brejda et al., 2000). Potter et al. (1999) reported greater C and N contents of cropland, restored grassland, and prairie in clay soils in the higher-rainfall area of Central Texas. Soil C and N contents in native shortgrass prairie and adjacent cropland in a loam soil in the Northern Plains of Western Nebraska were much greater than we report (Cambardella and Elliott, 1992). On the other hand, soil C and N in NR in our study sites were similar to a sandy loam native shortgrass prairie site in Wyoming (Reeder et al., 1998), and greater than NR sites of sandy loam to sandy clay texture in Colorado (Burke et al., 1995). However, in our study, soil C and N were less than in cropland sites in the Wyoming study, and greater than cropland sites in the Colorado study. The soil C and N concentrations reported for cropland, CRP, and NR sites in the Southern High Plains of Texas, New Mexico, and Oklahoma by Brejda et al. (2000) were all less than the concentrations we report for these systems. This may be because the soils in that study had on average, less clay and silt, and greater sand concentrations than the soils in our study.

Clay and silt concentrations were positively correlated with total soil C and N, and sand was negatively correlated with the same. This relationship has been reported previously (Nichols, 1984; Parton et al., 1987; Burke et al., 1989). Sand concentration was a significant covariate in nearly all of the ANOVAs at all depths that were performed on soil C and N pools.

The POM fractions of soil C or N have been reported to be active fractions or labile pools of C and N (Cambardella and Elliott, 1992). Correlation between potential C mineralization and total soil C concentration minus POM-C was 0.56 (data not shown), and the correlation improved to 0.69 when POM was not subtracted (Table 4). This suggests that a significant amount of POM-C was mineralized in the potential C mineralization assay. Correlation between potential N mineralization and total soil N concentration minus POM-N was 0.67 (data not shown), and only improved to 0.73 when POM was not subtracted. This suggests that POM-N makes a contribution to potential N mineralization, but that its relative importance may not be as great as POM-C is to C mineralization. Our results are similar to Janzen et al. (1992), who reported that macroorganic matter (C:N of 16) N content did not relate to potential N mineralization as well as macroorganic matter C content related to respiration. Curtin and Wen (1999), however, reported that macroorganic matter N was highly correlated (R^2 = 0.83) with potential N mineralization. The C:N ratios we reported for POM are similar to other studies (Cambardella and Elliott, 1992; Wander and Bidhart, 2000). Although C:N ratios $<$20 to 25 are well known to result in net N mineralization (Parr and Papendick, 1978; Paul and Clark, 1989), our results suggest a marginal role of POM-N in N mineralization.

In our study, WEC correlated moderately with potential C mineralization (r = 0.54), but WEC was only about 1% of total soil C. Similar to our results, Dao et al. (2002) reported that mineralizable C and WEC were greater in grasslands than cultivated soil in a Southern High Plains site in Oklahoma.

Potential C mineralization measured by 24-h incubation at $-$0.03 MPa has been suggested as an estimator of potential N mineralization (Franzluebbers et al., 1996; Haney et al., 2001). Our results, however, showed only a moderate correlation (r = 0.59) between these two measures. Total soil N estimated potentially mineralizable N to a greater degree (r = 0.73) than any of the soil C or N pools. However, the top soil layers, where total soil N was highest in CRP and NR, did not show greater potential N mineralization than cropland soils (Table 3). In fact, in the 5- to 30-cm layers, where total soil N was similar among systems, CRP soils had less potential N mineralization than the cropped soils. This may have implications for N fertilization practices when CRP contracts end, when CRP soils need N fertilization to be productive.

Carbon-13 levels in the whole soil were generally not affected by system at any depth, indicating that C_3 cotton cropping was not impacting total soil C. The decrease with depth that we observed in C_4 percentage of total soil C (or increase of $\delta^{13}C$ in soil with depth) has been previously reported (Boutton et al., 1998; Follett et al., 1997). This trend has been attributed to greater rooting depths of C_4 plants compared with C_3 plants (Kelly et al., 1991; Follett et al., 1997), and is most apparent in the 10- to 15-cm layer of NR. Also contributing to the $\delta^{13}C$ trend with soil depth is the discrimination that heterotrophic bacteria exhibit against ^{13}C as organic matter decomposes, and this effect is more apparent in the older soil C at depth (Blair et al., 1985; Agren et al., 1996).

Carbon-13 in POM was in approximate equilibrium (i.e., within 1.1‰) with ^{13}C in whole soil from 0 to 15 cm in CRP and NR soils only. Carbon-13 was significantly affected by system in the POM-C fraction, which was not unexpected, since POM is made up of recent C additions. The majority of POM-C in cropped soils apparently came from cotton roots and residues. It is possible that the 35% of POM-C from C_4 plants is from the occasional sorghum (*Sorghum bicolor* L.) catch crops that are grown in the Southern High Plains when cotton is destroyed by hail. However, the overall levels of POM-C had declined drastically since the cropped sites were in native prairie. The 60% of POM-C in CRP and NR soils that was derived from C_4 plants was consistent with our observations of the plant species at these sites. The ^{13}C levels observed in whole soil were similar to the levels for Southern Plains soils reported by Follett et al. (1997).

In general, soil N pools reflected soil C pools across systems. One exception to the strong soil C and N correlation was the observation of lower total N in the 0- to 15-cm soil of irrigated cotton than in the other cropped systems. The reason for this is not clear, as in the 15- to 30-cm layer, total soil N in irrigated cotton was similar to the other cotton croplands.

CONCLUSIONS

Total soil C and N concentration was greater in NR than for cropped soils from 0 to 30 cm. Native rangeland also had greater total C and N content than cropland soils for the entire 30-cm soil profile studied. The CRP soils had greater total soil C and N concentration and content than cropland soils in the top 5 cm only. Potentially mineralizable C was greatest in NR in the 0- to 5-cm layer. Potentially mineralizable N was less in CRP soils than in cropland in the 5- to 30-cm depths, and may have implications for N fertilization following CRP contracts. Particulate organic matter C was greater in NR soils than cropland soils in 0 to 30 cm, and POM-N had this trend in all depths to 30 cm except the 10- to 15-cm layer. Low soil test P may have been a limitation to plant biomass production and C sequestration in CRP and NR soils. It is less clear how limiting N was in these soils, as N_2–fixing legumes were present in both CRP and NR soils. In general, all C and N pools were positively correlated, regardless of system or soil depth. Improved management is needed to sequester C and N in conservation-tillage cotton in the Southern High Plains. One possibility is to irrigate the winter cover crop to increase rye or winter wheat aboveground biomass before termination with herbicides. The economic benefit, however, of cover crop irrigations needs to be examined before producers would adopt this practice. Research is needed to identify management practices that result in C and N sequestration in CRP and conservation-tillage terminated-wheat cotton soils in the Southern High Plains.

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