Post-Contract Land Use Effects on Soil Carbon and Nitrogen in Conservation Reserve Grasslands

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ABSTRACT

Carbon and N changes in highly erodible croplands (HELs) under the Conservation Reserve Program (CRP) and the effects of reverting to cultivation in semiarid regions are not well understood. The effects of four transitional production systems [Old World bluestem (*Bothriochloa ischaemum* L.)-unfertilized (OWBUF), Old World bluestem-fertilized (OWBF), conservation-tillage (CT), and no-till (NT) wheat (*Triticum aestivum* L.)] on soil C and N were determined in two CRP fields in western Oklahoma. Soil potentially mineralizable C (PMC) and N (PMN) were determined in cores collected before and after the reinitiation of cultivation in 1994 and in 1997. Compared with soils of the same series from adjoining cultivated fields, Old World bluestem (OWB) cover increased soil PMC, primarily in the 0- to 0.1-m depth of Dalhart (Aridic Haplustalfs) and La Casa-Aspermont (Typic Paleustolls) soils before 1994. Negative PMN required a high level of fertility management to improve stand productivity. Shift from OWB to wheat increased soil PMC and PMN in the short-term. No-till and CT treatments had PMC averaging 8.9 and 9.6 g m^{-3} d^{-1} or 23 to 32% higher than those from OWB treatments in the 0- to 0.3-m depth of Dalhart soil. Soil PMC of the CT treatment averaged 7.2 g m^{-3} d^{-1} or 73% higher than that of the La Casa-Aspermont under OWB. The trend of higher mineralizable C and N suggested that post-CRP conservation practices, in particular NT, contributed to HEL restoration by also controlling the upward movement and loss of CO_3-C, maintaining these lands as C sinks in semiarid regions.

THE CONSERVATION RESERVE was established under Title XII of the Food Security Act of 1985 to control soil erosion and the loss of productivity on over 14 000 000 ha of erosion-prone croplands across the USA. Oklahoma had 485 000 ha enrolled in the CRP after the 12th signup period. Forty percent of this acreage was located in the Oklahoma panhandle, and another 48% was in counties along the Oklahoma–Texas border. Much of this acreage was cropped annually to winter wheat and cotton (*Gossypium hirsutum* L.). Sediments, airborne dust, and particulate-associated nutrient discharges have been significant problems in the production of both crops. Old World bluestem and native grasses were seeded for permanent soil cover of CRP fields. The program has been credited with substantial reduction in wind and water erosion of marginal croplands (Gilley et al., 1997; Lindstrom et al., 1998). The program was reauthorized in 1996, adding environmental benefits to the requirements for contract renewal or new enrollment. Large-scale revegetation efforts to promote soil conservation, increase commodity prices, and support farm income may also have beneficial effects on the global climate. The change in land use may reduce the increase in anthropogenic CO_2 in the atmosphere by sequestering C in the soil (Allmaras et al., 2000). Perennial grass cover increased soil C at an average rate of 1.1 Mg C ha^{-1} yr^{-1} to a 3-m depth at selected CRP sites in Texas, Kansas, and Nebraska (Gebhart et al., 1994). Accumulation and partial incorporation of organic debris into the soil increased organic C (OC) concentrations of the 0- to 0.25-m depth (McConnel and Quinn, 1988). However, others have reported little or no change in soil OC at locations across the Great Plains (Schuman et al., 1999). Minimal differences in total C (TC) and total N (TN) were found between wheat–fallow soils and CRP land seeded to western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love] and brome (*Bromus inermis* Leyss.) stands in southeastern Wyoming (Robles and Burke, 1998). However, the PMC pool increased from 0.37 to 0.99 g m^{-2} d^{-1} in the CRP fields, compared with that under wheat-fallow fields. Similarly, no significant differences between OC and microbial biomass C were observed. Carbon mineralization potentials were higher in CRP soil (784 mg C kg^{-1}) than wheat–fallow soil (518 mg C kg^{-1}) in another study in the state of Washington (Staben et al., 1997). Other studies have shown that biological indicators of soil improvements such as microbial biomass C, dehydrogenase activity, PMC and N, ergosterol, or hyphal length were often more apparent and frequent than physical or chemical changes (Karlen et al., 1999; Gewin et al., 1999).

Returning these HELs to crop production may change them back to being sources of C emission, unless strict CT practices were in place. Tillage and crop residue incorporation were associated with high soil CO_2-C efflux (Kessavalou et al., 1998). Carbon loss to the atmosphere occurred at flux densities averaging 4.2

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Abbreviations: CC, continuously cultivated; CRP, Conservation Reserve Program; CT, conservation tillage; DT, disk-tillage; HEL, highly erodible land; NT, no-till; OC, organic C; OWB, Old World bluestem; OWBF, Old World bluestem-fertilized; OWBUF, Old World bluestem-unfertilized; PMC, potentially mineralizable C; PMN, potentially mineralizable N; ST, sweep-tillage; TC, total C; TN, total N; WEC, water-extractable C.

to 5.8 kg CO_2-C ha^{-1} d^{-1} during a 60-d period following tillage during the noncropped period of winter wheat production (Dao, 1998). Significant long-term losses of C and N increased with cultivation and tillage intensity, averaging up to 530 kg C ha^{-1} yr^{-1} (Bowman et al., 1990; Doran et al., 1998). Reduction in tillage and increase in cropping intensity were needed to slow the decline in soil C (Bowman et al., 1999; Allmaras et al., 2000). Other observed soil degradation included decreased water infiltration and reduced soil macroporosity within 1 yr of converting CRP grassland to croplands (Lindstrom et al., 1998). Sediment loss was appreciably greater under disk-tillage (DT) used to destroy the CRP sod, and averaged between 60 to 150 kg ha^{-1} more than chemically killed sod for NT wheat production (Gilley et al., 1997).

The objectives of this study were to determine the effects of four transitional conservation systems of producing OWB and wheat on the direction and magnitude of soil C and N transformations upon the mechanical destruction or the chemical killing of the CRP sod, and to increase our understanding of the underlying mechanisms of shifts between C fractions as a function of field-scale management practices.

MATERIALS AND METHODS

Field Sites

During a 3-yr period between 1994 and 1997, we evaluated practices of minimum-input and the optimal management of OWB stands and two transitional conservation systems for wheat production on two producers' fields under CRP contracts in western Oklahoma. We measured the changes in soil C and N as induced by CT and NT practices for destroying the CRP grass cover to grow winter wheat. In addition, we estimated the effects of establishing an OWB grass cover on these soils by comparing selected properties of the same soil series under CRP management to those in adjoining cultivated fields that were not in the program. These fields belonged to the same landowner or operators who used identical cultural practices on the acreage enrolled in the CRP. Field preparation and land management treatments were described in previous work (Dao et al., 2000). In summary, one experimental site was in northwest Oklahoma, near the town of Forgan (Beaver County). Annual precipitation averaged 450 mm and mean minimum and maximum temperatures were 5 and 21°C, respectively. The major soil at the Forgan site was Dalhart fine sandy loam (fine-loamy, mixed, superactive, mesic Aridic Haplustalfs) on 1 to 3% slope. The field was planted to 'WW-Spar' OWB in 1988. The second study site was in Jackson County near the town of Duke, OK. The annual precipitation was ≈750 mm. Annual minimum and maximum temperatures averaged 9 and 23°C, respectively. The major soils at the Duke site were La Casa-Aspermont clay loams (fine, mixed, thermic Typic Paleustolls) in a rolling hill landscape with a 1 to 3% slope. The field was planted to 'Caucasian' OWB in 1986.

In 1994, a temporary CRP contract release for the experimental acreage was secured from the USDA Farm Service Agency. The old OWB growth in a 10-ha block of the CRP fields was removed to establish four land management treatments in May 1994 at both locations. At Forgan, four replicated plots measuring 50 by 100 m were established each year in these blocks to evaluate the following post-CRP management options: (i) OWBUF, minimum grass management (no fertilizer added following the removal of the old OWB growth); (ii) OWBF, optimal grass management [fertilizer added following the removal of the old OWB growth; a mixed fertilizer (34-19-0) was used to apply 67 kg N and 16.5 kg P ha^{-1}]; (iii) CT conversion to wheat; and (iv) NT conversion to wheat. At Duke, field plots were established to evaluate the same four management systems, except that DT was used to destroy the sod prior to conversion to conservation wheat production.

For three successive years, the same set of treatments was established in newly prepared 10-ha areas of the CRP fields during 1994 to 1997. In addition, the first-year sweep-tillage (ST), DT, and NT plots were reestablished after wheat harvest for each year of the 3 yr to determine the effects of number of years of recropping. Conservation-tilled plots were sweep-tilled (Forgan) or disked (Duke) in July and September. Weeds and OWB regrowth in NT plots were sprayed with 1.12 kg ha^{-1} of glyphosate in July and September, and plots were planted back to wheat. This schedule resulted in replicated plots with a 1-, 2-, and 3-yr crop history following the initial OWB breakout. The grass management schedule also resulted in replicated OWB plots that were under undisturbed CRP grass management for 7, 8, or 9 yr since the initial OWB seeding.

Soil Sample Collection and Analysis

Soil samples were collected from both locations each year before grass mowing or burning of the old litter and before tillage or NT operations in the cropped treatments, and from conventionally tilled and continuously cultivated (CC) fields that surround the experimental areas after wheat harvest. The adjacent control fields belonged to the same landowner and operator, but were not enrolled in the CRP. These fields were under continuous wheat production for at least 10 yr at both locations. At Forgan, the primary tillage implement used to till Dalhart soil was a 0.9-m-wide V-blade sweep plow; at Duke, the primary tillage implement used to till the La Casa-Aspermont soil was a tandem disk.

Five soil cores were taken to 0.3 m and separated into 0- to 0.05-, 0.05- to 0.1-, 0.1- to 0.2-, and 0.2- to 0.3-m depth samples using a 75-mm inside-diameter soil core sampler. Total sample weights and water content were measured to calculate soil bulk density. Following field collection, the 500-g samples were broken up and uniformly mixed in the plastic bags they were collected in. Equivalent depth increments were mixed, and the composite samples were split in half. A set of soil was kept moist and refrigerated at 4°C for biological measurements. The remainder was air-dried and visible plant debris was removed. The soil was crushed and sieved to pass a sieve with 2-mm openings, and stored at room temperature until chemical analysis.

Water-extractable C was determined in 2.0-g soil samples and 10 mL of deionized water agitated on an end-to-end shaker for 1 h at room temperature. Carbonate and soluble OC were determined in aliquots by persulfate-ultraviolet oxidation using a semiautomated flow-injection ion analyzer (OI Analytical, 1994). Potentially mineralizable C was determined from a 28-d aerobic incubation of triplicate 20-g soil samples at 30°C at 60% water-filled pore space, following the static incubation procedure described by Zibilske (1994). The soil containers were placed in 1-L glass jars along with 20 mL of 1 *M* KOH to trap the released CO_2-C. Aliquots (diluted 1- to 10-mL of deionized water) were used to determine CO_2-C content of the traps by persulfate-ultraviolet oxidation. Cumulative mineralized and fluxes of CO_2-C were determined for the final 21 d of incubation.

Table 1. Mineralizable C and total N pools of the 0- to 0.1- and 0- to 0.3-m depths of the Dalhart and La Casa-Aspermont soils under continuous cultivation and under CRP near Forgan and Duke, OK, respectively, in 1994.

Parameter	Land use	0- to 0.1-m depth: Dalhart	0- to 0.1-m depth: La Casa-Aspermont	0- to 0.3-m depth: Dalhart	0- to 0.3-m depth: La Casa-Aspermont
		g C m^{-3}			
Water-extractable C	OWBUF†	310a‡	501a	633a	1203a
	CC§	174b	296a	441b	832a
		g CO_2-C m^{-3} d^{-1}			
Efflux of mineralizable C	OWBUF	8.3a	6.9a	7.4a	5.2a
	CC	5.2b	4.9b	5.0a	6.4a
		kg N m^{-3}			
Total N	OWBUF	1.2a‡	2.8a	2.3a	5.1a
	CC	1.2a	3.0a	2.5a	5.2a

† OWBUF = Old World bluestem-unfertilized.
‡ Treatment means followed by same letter are not significantly different at the 0.05 level of probability.
§ CC = continuous cultivation.

Potentially mineralizable N was estimated in one of two ways. First, the initial and 28-d extractable NH_4-N and NO_3-N concentrations were measured in the soil samples used to measure mineralizable C (Drinkwater et al., 1996). Potential mineralizable N was calculated as the difference between the initial and the final NH_4 and NO_3-N concentrations. Second, PMN was estimated according to a modification of the procedure of Smith and Stanford (1971), where suspensions of 5 g soil and 25 mL of 0.01 *M* $CaCl_2$ (1:5, w/v) were autoclaved at 0.10 MPa and 120°C in 75-mL culture tubes for 2 h and reautoclaved again, for a total of 4 h. Aliquots were used to measure NH_4 and NO_3-N concentrations in the 0.01 *M* $CaCl_2$ extracts. Potential N mineralization was calculated from the amounts of released inorganic N.

Soil TC, total organic N, and OC were determined before and after acid washing of the soil samples by high-temperature dry combustion (Nelson and Sommers, 1996). One-gram samples were weighed into ceramic boats and oxidized at 1400°C to determine C and N concentrations with a dry combustion C and N analyzer (Model CNS-2000, LECO Corp., St. Joseph, MI)[1]. To remove carbonate-C from another set of all soil samples, a 1 *M* HCl solution was added incrementally to 5 g of soil until effervescence ceased. The sample was equilibrated overnight with an additional 25 mL of a 1 *M* HCl solution. The supernatant was decanted and the soil residue was resuspended in 50-mL aliquots of deionized water until the supernatant pH was near neutral. The soil residue was subsequently dried and TC and N were determined as described above. Final C and N concentrations were adjusted for the weight loss due to carbonate removal.

At each location, the four management treatments were established with four replications based on a randomized complete block design. Triplicate subsamples of soils from each management plot were analyzed as described above for C and N, PMC, and PMN. Significant differences in treatment means were detected following analysis of variance and a multiple range test at the 0.05 level of probability.

RESULTS AND DISCUSSION

Soil Carbon

At the initiation of the experimental study in 1994, the Dalhart soil of adjoining CC fields averaged lower concentrations of water-extractable C (WEC) in the 0- to 0.1- and the 0- to 0.3-m depths than the Dalhart soil under the grass cover of CRP at the same soil depths (Table 1). Maintaining an OWB cover apparently increased the soluble C pool in surface soils by 140 to 210 g C m^{-3} following a 7-yr CRP tenure, compared with uninterrupted annual wheat cultivation. At the Duke location, the La Casa-Aspermont soils also averaged higher WEC in the 0- to 0.1- and 0-to 0.3-m depths under CRP management for 8 yr than the same soil in adjacent CC fields, although the differences were not statistically different (Table 1). The large variability (i.e. CV = 29.6% for the 0- to 0.1-m depth) masked any treatment difference.

In 1997, WEC concentrations in the Dalhart soil under ST management were slightly lower than those of the OWBUF treatment (Table 2). Otherwise, WEC concentrations were not different between NT and the OWB treatments in the 0- to 0.1-m depth, and all four post-CRP land-use options had no detectable effect on WEC in the 0- to 0.3-m depth. Soluble C averaged 394 and 864 g m^{-3} in the 0- to 0.10- and 0- to 0.30-m depths, respectively (Table 2). These levels were about the same as they were in the OWBUF treatment in 1994 (Table 1).

The La Casa-Aspermont soils averaged 494 and 1150 g WEC m^{-3} in the 0- to 0.10- and 0- to 0.30-m depths, respectively (Table 2). Over the period of 3 yr, no significant difference in WEC between all post-CRP treatments was observed. Although the La Casa-Aspermont soil was a fine-textured soil and had a large TC pool, the study was conducted during an abnormally dry period for the region (Dao et al., 2000). Large fluctuations in summer temperature and annual precipitation during 1995 to 1997 may have resulted in the large variability in the water-soluble and microbially labile C pool. Annual precipitation ranged from 1061, 536, and 585 mm at the Duke location and 473, 574, and 465 mm at the Forgan location during 1995, 1996, and 1997, respectively.

Differences in the CO_2-C effluxes during incubation of the Dalhart and La Casa-Aspermont soils paralleled the differences in WEC observed between the CC soils and soils under CRP management (Table 1). Perennial grass cover increased this PMC pool, primarily in the 0- to 0.1-m depth of the soils under CRP management over that of the CC soil, in agreement with other recent

[1] The mention of a trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by the USDA-ARS.

Table 2. Effects of post-contract land use options on selected C pools of the 0- to 0.1-m and 0- to 0.3-m depths of the Dalhart and La Casa-Aspermont soils in 1997, 3 yr after intensive grass and recropping management.

Parameter	Land use	0- to 0.1-m depth		0- to 0.3-m depth	
		Dalhart	La Casa-Aspermont	Dalhart	La Casa-Aspermont
		$g\ C\ m^{-3}$			
Water-extractable C	OWBUF†	442a‡	502a	890a	1140a
	OWBF§	390ab	593a	850a	1240a
	CT¶	369b	493a	842a	1188a
	NT#	397ab	397a	874a	1035a
		$g\ CO_2\text{-}C\ m^{-3}\ d^{-1}$			
Efflux of mineralizable C	OWBUF	7.2b	5.2a	7.0b	3.7b
	OWBF	7.3b	4.6a	7.5b	4.6ab
	CT	9.8a	6.6a	9.6a	7.2a
	NT	8.9a	4.2a	8.9a	4.9ab

† OWBUF = Old World bluestem-unfertilized.
‡ Treatment means followed by same letter are not significantly different at the 0.05 level of probability.
§ OWBF = Old World bluestem-fertilized.
¶ CT = conservation tillage (i.e., sweep-tillage for Dalhart and disk-tillage for La Casa-Aspermont).
# NT = no-till.

work (Staben et al., 1997; Robles and Burke, 1998). A CRP soil was found to have three distinct C pools that were similar in susceptibility to mineralization as those in a wheat-fallow soil, but had larger labile fast-decomposing pools than those of the latter soil (Staben et al., 1997).

The number of years of post-contract land use had no significant effect on PMC of Dalhart and La Casa-Aspermont soils, although an increasing trend in PMC with the number of years of recultivation was apparent (data not shown). By reintroducing mechanical tillage, even limited to shallow in-row tillage during seed placement, the CT and NT treatments had larger PMC fractions (between 23 to 32%) than the OWB treatments in the Dalhart soil (Table 2). The management shift to CT crop production also increased the La Casa-Aspermont PMC pool in the 0- to 0.3-m depth, compared with the OWBUF, OWBF, and NT treatments. It was postulated that the change in management from a OWB grass cover to a more disturbed CT wheat system improved soil aeration and accelerated the microbial decomposition of OWB grass residues and new crop residues into labile mineralizable C forms to account for this increase in the soil PMC. Although the study was not continued for a longer period, it was of great interest to know the new state of equilibrium of C storage and mineralization. A number of questions remained as to whether the increase in PMC in the cropped treatments would be finite, whether this PMC would be incorporated into the passive soil organic matter pool, or that the PMC fluxes may return to a basal rate closer to the one observed in the CC soil of adjoining non-CRP field, given the differences in tillage intensity between the CT and NT production systems (Table 1).

No statistically significant interaction between post-CRP land management systems and number of years of recropping was observed, and main effect means showed that soil TC in the 0- to 0.10-m depth increased with the number of years of recropping the Dalhart soil, by an average 41% over 1994 levels (Fig. 1). However, no change was observed in soil TC in the 0- to 0.3-m depth, and soil OC had remained unchanged (Fig. 1 and Table 3). The TC increase in the 0- to 0.1-m depth suggested an internal translocation of carbonates within the 0- to

Table 3. Total N and C to N ratios of the 0- to 0.1-m and 0- to 0.3-m depths of the Dalhart and La Casa-Aspermont soils, as affected by post-contract land use options in 1997 near Forgan and Duke, OK, respectively.

Parameter	Land use	0- to 0.1-m depth		0- to 0.3-m depth	
		Dalhart	La Casa-Aspermont	Dalhart	La Casa-Aspermont
		$kg\ N\ m^{-3}$			
Total N	OWBUF†	1.14a‡	2.57b	2.41a	4.63b
	OWBF§	1.24a	2.63ab	2.38a	4.63b
	CT¶	1.17a	3.05a	2.45a	5.24a
	NT#	1.20a	2.64ab	2.42a	4.84ab
TC to N ratio††	OWBUF	11.4a	15.1ab	11.2a	18.1a
	OWBF	11.0a	16.0a	10.8a	17.5a
	CT	11.1a	13.4bc	11.2a	16.6ab
	NT	10.6a	12.7c	10.6a	13.7b
OC to N ratio‡‡	OWBUF	10.2a	12.0ab	10.4a	11.8ab
	OWBF	10.9a	12.5a	10.6a	12.4a
	CT	10.6a	10.5c	10.7a	10.9c
	NT	11.4a	11.2bc	10.4a	11.3bc

† OWBUF = Old World bluestem-unfertilized.
‡ Treatment means followed by same letter are not significantly different at the 0.05 level of probability.
§ OWBF = Old World bluestem-fertilized.
¶ CT = conservation tillage (i.e., sweep-tillage for Dalhart and disk-tillage for La Casa-Aspermont).
# NT = no-till.
†† Total C to organic N ratio.
‡‡ Organic C to organic N ratio.

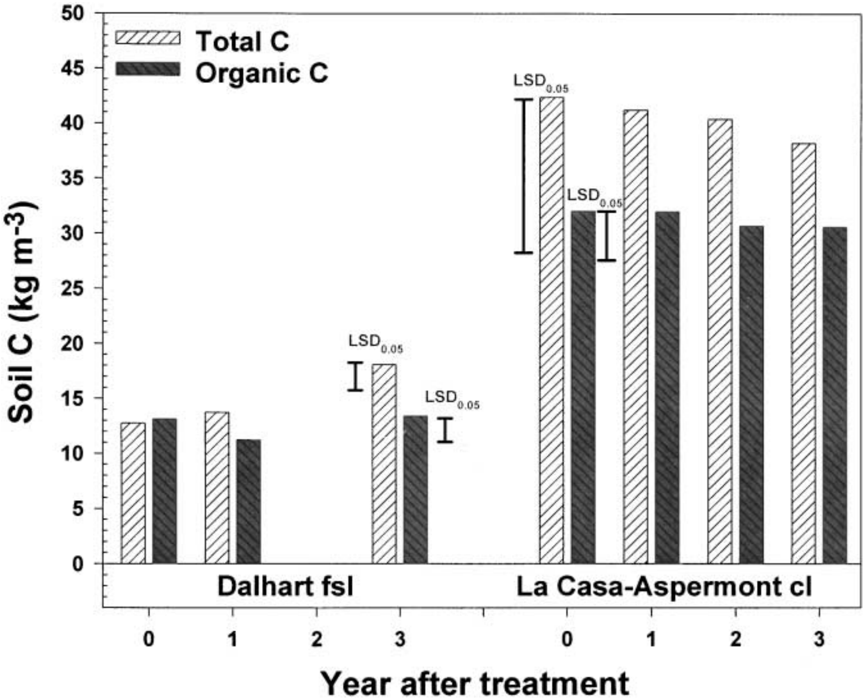

Fig. 1. Effects of number of years of post-contract land use on soil total C and organic C in the 0- to 0.1-m depth of Dalhart fine sandy loam (fsl) and La Casa-Aspermont clay loam (cl) soils near Forgan and Duke, OK, respectively.

0.3-m layer, caused primarily by increases in inorganic C that was brought up to surface layers upon tillage and soil mixing. In the La Casa-Aspermont soils, TC appeared to be declining with time since recropping, but was not statistically different between 1994 and 1997. Soil TC contents averaged 40 kg m^{-3} in 1994 and 38 kg m^{-3} in 1997 for the 0- to 0.1-m depth, and averaged 79 and 76 kg m^{-3} for the 0- to 0.3-m depth in 1994 and 1997, respectively. The period of time since perennial grass establishment was relatively short, and soil TC is a large pool with a slow turnover rate (Schlesinger, 1995). Meanwhile, OC remained essentially unchanged during the study in both soils (Fig. 1 and Table 3). Although visible plant debris and root residues were removed before C analysis, the decomposition and humification of this organic matter eventually contributes to the soil OC pool and C storage because of the large perennial grass aboveground dry matter and the fibrous root mass (Richter et al., 1990).

Overall, the adjacent CC field soil of the same series had the highest concentrations of free carbonates (CO_3-C), particularly in the Dalhart soil (Fig. 2). No significant difference in CO_3-C was observed between post-CRP land management systems. The transitional conservation practices that we used to convert these CRP fields to wheat cropping minimized soil disturbance and C relocation and losses in the short-term. Therefore, minimizing and avoiding soil disturbance with NT practices minimized the movement of CO_3-C up to the surface and the potential alterations in nutrient availability. As the soil-atmosphere interface is under constant flux, C loss occurs with intensive tillage and weathering through the carbon dioxide-bicarbonate-carbonate equilibria controlling the C forms and concentrations.

Soil Nitrogen

In 1994, the Dalhart and the La Casa-Aspermont soils of adjoining CC fields averaged the same or slightly higher concentrations of TN than the CRP field soils (Table 1). No difference was expected, as the soil samples were taken during the fallow period in CC fields and the CRP grass cover had not received any N fertilizer since its establishment.

In 1997, the Dalhart soil under CRP was generally uniform in TN, averaging 1.2 kg N m^{-3} in the 0- to 0.1-m depth and 2.4 kg N m^{-3} in the 0- to 0.3-m depth (Table 3). Although TN in the Dalhart soil was not affected by land-use options, there was a possibility that organic N may be stored with improved fertility management of the ST, NT, or OWBF treatments. This prospect of storage was statistically significant in the La Casa-Aspermont soil after 3 yr of intensive management (Table 3).

Estimates of the PMN pool showed that the Dalhart soil was nutrient-depleted in 1994 and would immobilize any added N (Table 4). The soil incubation results showed that three years of intensive post-contract management increased the PMN pool of the OWBF, ST, and NT treatments, indicating potential increased nutrient availability and possible benefits to forage and crop yields and quality. The NT Dalhart soil showed the greatest improvement and had the highest PMN. During the initial years of NT recropping, the aboveground fixed C in the old grass litter became gradually incorporated into the total soil C pool while slowly lowering the soil OC/N ratio.

At Duke, the PMN of the OWB treatments decreased in 1997, as it appeared that the OWB stand would still

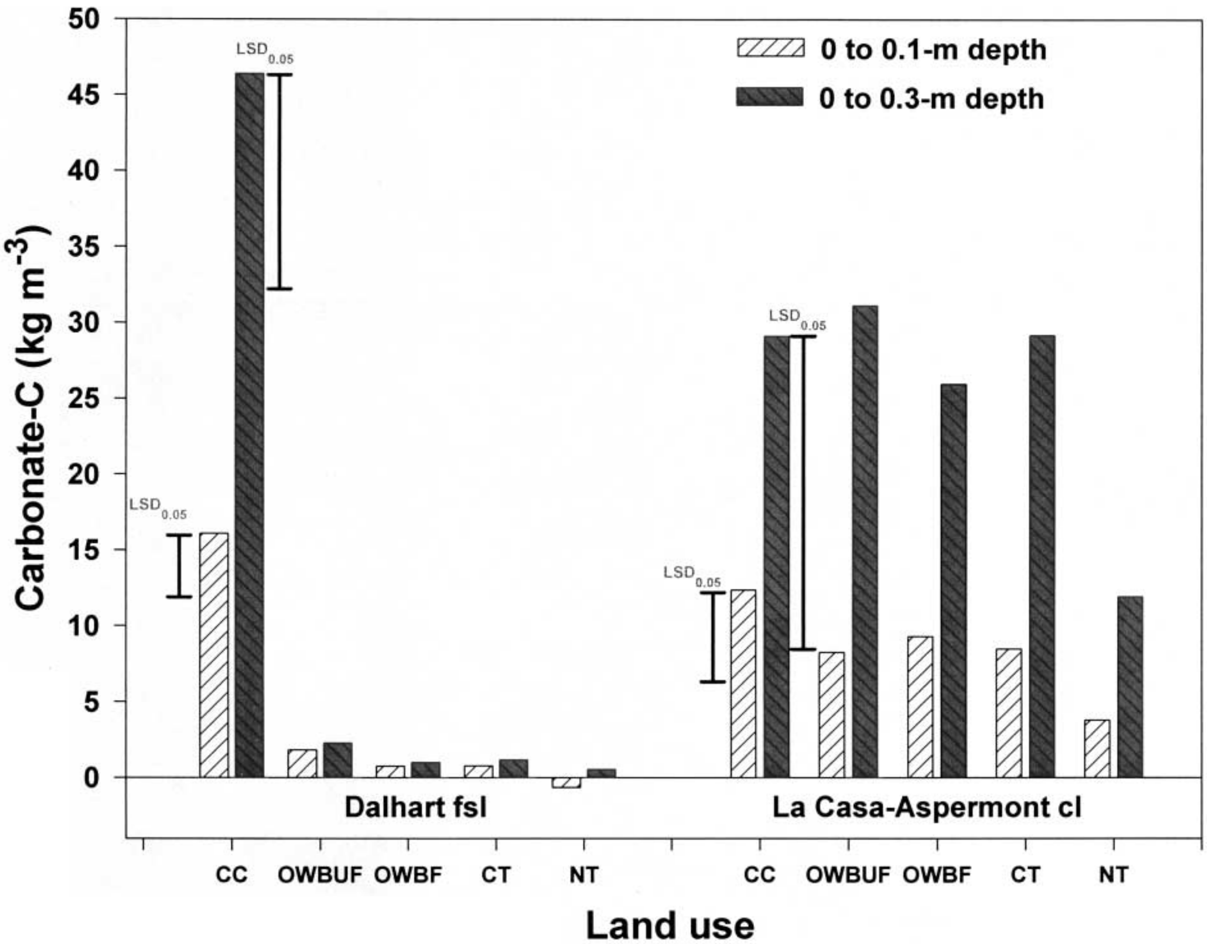

Fig. 2. Carbonate-C contents of the near surface zone of the Dalhart fine sandy loam (fsl) and La Casa-Aspermont clay loam (cl) soils under various post-contract land use options at Forgan and Duke, respectively. CC = continuously cultivated, OWBUF = Old World bluestem-unfertilized, OWBF = Old World bluestem-fertilized, CT = conservation-tillage, and NT = no-till.

require additional N for optimal growth, as PMN averaged −13.1 g N m^{-3} in the 0- to 0.1-m depth and −1.1 g N m^{-3} in the 0- to 0.3-m depth (data not shown) of the La Casa-Aspermont soils, respectively (Table 4). The soil OC/N of these treatments were also higher than the CT and NT cropped treatments (Table 3), as OWB growth was significantly increased as the result of the improved management since 1994 (Dao et al., 2000). The La Casa-Aspermont soil under CT and NT management maintained their potential for net mineralization of N during the study period, considering the large pool of litter C incorporated by tillage or remaining at the soil surface in the NT treatment. The autoclaving technique used to estimate PMN also showed the initial uniformity of the N pool of both soils. This method was less sensitive, and only detected the higher PMN of the NT and fertilized OWBF treatments in the Dalhart soil (Table 4).

CONCLUSIONS

In regions of limited rainfall, the revegetation of an Aridic Haplustalf and a Thermic Paleustoll to perennial warm-season OWB grasses may have reduced the erosion of these fragile soils. Compared with CC soils of the same series from adjoining fields that were not in the CRP, establishing and maintaining the OWB grass cover had increased the PMC pool of Dalhart and La

Table 4. Potentially mineralizable N by soil incubation and autoclaving in the 0- to 0.1-m depth of Dalhart and La Casa-Aspermont soils, as affected by post-contract land use options during 1994 to 1997 near Forgan and Duke, OK, respectively.

	Dalhart		La Casa-Aspermont	
	1994	1997	1994	1997
	g N m^{-3}			
Soil incubation				
OWBUF†	−6.8a‡	7.7b	14.6ab	−13.1b
OWBF§	3.7a	24.9ab	14.0ab	−13.2b
CT¶	−3.6a	13.3b	42.4a	36.0a
NT#	−20.6a	44.6a	21.3ab	19.6ab
Soil autoclaving				
OWBUF	10.1a	9.6c	30.6a	20.7b
OWBF	18.6a	16.8ab	30.4a	17.9b
CT	15.3a	11.1bc	31.9a	25.4ab
NT	15.8a	18.5a	31.7a	30.2a

† OWBUF = Old World bluestem-unfertilized.
‡ Treatment means followed by same letter are not significantly different at the 0.05 level of probability.
§ OWBF = Old World bluestem-fertilized.
¶ CT = conservation tillage (i.e., sweep-tillage for Dalhart and disk-tillage for La Casa-Aspermont).
# NT = no-till.

Casa-Aspermont soils. Upon reverting these soils to annual wheat cultivation, the tendency for storage of PMC existed at both Oklahoma locations, but changes in soil OC were not detected. Although the transitional conservation wheat production systems kept soil disturbance to a minimum, NT more efficiently minimized the movement of CO_3-C to the near-surface zone. After 3 yr of intensive management of the Dalhart and La Casa-Aspermont soils, we were able to maintain or shift the N mineralization-immobilization equilibria toward net mineralization of soil N at both locations with the transitional OWBF and conservation cropping practices.

The change in management from permanent OWB cover to conservation wheat maintained or accelerated the accumulation of PMC and PMN in the short-term. These results suggested that these practices slightly increased C and N availability and the potential benefits to forage and crop quality and yields. The challenge for our land managers will be to maintain and translate this PMC pool into increases in soil OC and to maintain the C-rich environment that existed during the CRP tenure for as long as possible. Every effort made to avoid intensive mechanical tillage to bury the CRP sod minimized the rapid loss of microbially labile C and N pools and prevented shifting of the carbon dioxide-bicarbonate-carbonate equilibrium system toward gaseous C emissions in these semiarid environments.

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REFERENCES

Allmaras, R.R., H.H. Schomberg, C.L. Douglas, and T.H. Dao. 2000. Soil organic carbon sequestration potential of adopting conservation tillage in US croplands. Soil Water Cons. Soc. J. 55:365–373.

Bowman, R.A., J.D. Reeder, and R.W. Lober. 1990. Changes in soil properties in a Central Plains rangeland soil after 3, 20, and 60 years of cultivation. Soil Sci. 150:851–857.

Bowman, R.A., M.F. Vigil, D.C. Nielsen, and R.L. Anderson. 1999. Soil organic matter changes in intensively cropped dryland systems. Soil Sci. Soc. Am. J. 63:186–191.

Dao, T.H. 1998. Effects of tillage system and crop residues on CO_2 evolution and carbon storage in a Paleustoll. Soil Sci. Soc. Am. J. 62:250–256.

Dao, T.H., J.H. Stiegler, J.C. Banks, L. Bogle-Boerngen, and B. Adams. 2000. Post-contract grassland management and winter wheat production on former CRP fields in the Southern Great Plains. Agron. J. 92:1109–1117.

Doran, J.W., E.T. Elliott, and K. Paustian. 1998. Soil microbial activity, N cycling, and long-term changes in organic C pools as related to fallow tillage management. Soil Tillage Res. 49:3–18.

Drinkwater, L.E., C.A. Cambardella, J.D. Reeder, and C.W. Rice. 1996. Potentially mineralizable N as an indicator of biologically active soil N. p. 217–229. *In* J.W. Doran and A.J. Jones (ed.) Methods for assessing soil quality. SSSA Spec. Publ. 49. SSSA, Madison, WI.

Gebhart, D.L., H.B. Johnson, H.S. Mayeux, and H.W. Polley. 1994. The CRP increases soil organic carbon. J. Soil Water Conserv. 49:488–492.

Gewin, V.L., A.C. Kennedy, R. Veseth, and B.C. Miller. 1999. Soil quality changes in eastern Washington with Conservation Reserve Program (CRP) take-out. J. Soil Water Conserv. 54:432–438.

Gilley, J.E., J.W. Doran, and T.H. Dao. 1997. Runoff, erosion, and soil quality characteristics of a former CRP site in SW Oklahoma. Appl. Engineer. Agric. 13:617–622.

Karlen, D.L., M.J. Rosek, J.C. Gardner, D.L. Allan, M.J. Alms, D.F. Bezdicek, M. Flock, D.R. Huggins, B.S. Miller, and M.L. Staben. 1999. CRP effects on soil quality indicators. J. Soil Water Conserv. 54:439–444.

Kessavalou, A., A.R. Mosier, J.W. Doran, R.A. Drijber, D.J. Lyon, and O. Heinemeyer. 1998. Fluxes of carbon dioxide, nitrous oxide, and methane in grass sod and winter wheat-fallow tillage management. J. Environ. Qual. 27:1094–1104.

Lindstrom, M.J., T.E. Schumacher, N.P. Cogo, and M.L. Blecha. 1998. Tillage effects on water runoff and soil erosion after sod. J. Soil Water Conserv. 53:59–63.

McConnel, S.G., and M.L. Quinn. 1988. Soil productivity of four land use systems in southeastern Montana. Soil Sci. Soc. Am. J. 52: 500–506.

Nelson, D.W., and L.E. Sommers. 1996. Total carbon, organic carbon, and organic matter. p. 961–1010. *In* D.L. Sparks et al. (ed.) Methods of soil analysis. Part 3. Chemical Methods. SSSA Book Ser. 5. SSSA, Madison, WI.

OI Analytical. 1994. Flow Solution III. Adv. Technology in flow analysis. Operation manual. Alpkem, Wilsonville, OR.

Richter, D.D., L.I. Babbar, M.A. Hutson, and M. Jaeger. 1990. Effects of annual tillage on OC in a fine-textured Udalf: The importance of root dynamics to soil C storage. Soil Sci. 149:78–83.

Robles, M.D., and I.C. Burke. 1998. Soil organic matter recovery on Conservation Reserve Program fields in southeastern Wyoming. Soil Sci. Soc. Am. J. 62:725–730.

Schlesinger, W.H. 1995. An overview of the carbon cycle. p. 9–25. *In* R. Lal et al. (ed.) Soils and global change. Advances in Soil Science. Lewis Publ., Boca Raton, FL.

Schuman, G.E., J.D. Reeder, J.T. Manley, R.H. Hart, and W.A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecol. Appl. 9:65–71.

Staben, M.L., D.F. Bezdicek, J.L. Smith, and M.F. Fauci. 1997. Assessment of soil quality in Conservation Reserve Program and wheat-fallow soils. Soil Sci. Soc. Am. J. 61:124–130.

Zibilske, L.M. 1994. Carbon mineralization. p. 835–863. *In* R.W. Weaver et al. (ed.) Methods of soil analysis. Part 2. Microbiological and biochemical properties. SSSA Book Series 5. SSSA, Madison, WI.