Conservation Reserve Program: Effects on soil organic carbon and preservation when converting back to cropland in northeastern Colorado

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ABSTRACT: Information on the potential for carbon sequestration from the Conservation Reserve Program (CRP) and knowledge concerning the fate of accrued carbon on sod takeout and recropping to a wheat-based rotation are essential. We conducted two separate field studies in northeastern Colorado to quantify the soil organic carbon (SOC) changes after various amounts of time in the CRP program, and to assess problems associated with converting CRP grass to cropland and the potential for loss of accrued SOC with different tillage systems. For our first objective, we assessed six CRP sites, with three sites showing increased SOC content over the adjacent winter wheat/summer fallow sites, and three sites showing no differences. In the conversion study, systems with little or no tillage yielded more winter wheat (*Triticum aestivum L.*) grain than systems with tillage because of more available soil water at planting time. Furthermore, SOC loss was less with no-till and reduced-till (herbicides plus one tillage) systems than by conventional tillage with numerous sweep plow operations. Thus, NT and reduced-till systems designed to control perennial CRP grasses will enable producers to maintain some of the gains in SOC when CRP land is converted to cropland.

Keywords: Carbon sequestration, crop biomass, native sod, soil organic matter, wheat/fallow

The Conservation Reserve Program (CRP) was originally designed to reduce soil erosion and commodity surpluses by paying farmers to remove highly erodible lands (HEL) from crop production for 10 years (Osborn 1993). Farmers were required to stabilize the land by planting perennial grasses or other protective vegetation. Secondary benefits from the program included additional wildlife habitat and improved water quality because of less runoff of water containing agricultural chemicals. In 1998, total national CRP enrollment stood at 375,000 farmers, with some 16 million ha (40 million ac) taken out of production at a cost of about $400 billion. About 55% of this set-aside is in the Great Plains states.

In Colorado, more than 1 million ha (2.5 million ac) are in the program, encompassing 6,200 contract holders. It is estimated that the state's farm sector receives $81 million in annual rental payments. With contract expiration looming, some producers are considering converting some CRP lands back to cropland. In a Colorado State University survey (Colorado Rancher and Farmer, 1994), producers responded that post-contract decisions would be based on: 1) market prices for crops, 2) loss of cropland base for farm program participation, 3) government price support for crops, 4) expected cost of crop production, 5) market prices for livestock, and 6) cost of required conservation practices. By 2000, some of these concerns had changed. Farmers no longer have to worry about cropland base and government price controls. The federal emphasis today is more on environmental improvement (use of an environmental benefit index) and water quality. However, a federal program was kept in place for the most fragile lands, such as those with an erodibility index greater than 15, and those within 31 m (100 ft) of a body of water.

Some of the more academic post-CRP questions for the nation and Colorado are: 1) which lands can be returned to farming, and what is the most effective sod take-out procedure for these lands, 2) is there a critical soil organic carbon (SOC) level below which land should not be farmed, and 3) how do producers maintain SOC or soil quality improvements acquired over the CRP period when returned to cropland. A corollary to this last question is whether a no-till operation is necessary upon sod take out to maintain SOC and soil quality without sacrificing yields.

Producers may convert CRP fields to cropland if grain prices appear high, or if the CRP is discontinued (Lindstrom et al. 1994; Unger 1999; Halvorson et al. 2000). To prepare for such an action, a strategy has to be developed to preserve improved soil conditions achieved with CRP. Taking out CRP perennial grasses with herbicides and no tillage appears to be the logical choice for minimal loss of soil quality benefits if such a system can generate profit. However, systems relying solely on herbicides have been ineffective in controlling perennial grasses, especially under semiarid conditions (Kleven and Wyse 1984; Anderson 1996; Halvorson et al. 2000). Our goal, therefore, was to evaluate systems where reduced-tillage was combined with a systemic herbicide to improve perennial grass kill, yet preserve favorable soil changes accrued during the CRP period.

We conducted two studies in Colorado to evaluate SOC levels in CRP farmer fields and to assess the potential for SOC loss during CRP grass conversion to cropland. In the first study, our main objective was to quantify and compare SOC levels in the CRP sites, in adjacent continual winter wheat/summer fallow (W/F) sites, and native or rangeland sod sites. Secondarily, we wanted to know the potential for mineral N contribution from the CRP grasses. In the second study, on a site distinct from the first study, our primary objective was to assess changes in soil properties after CRP smooth bromegrass (*Bromus inermis Leyss*) sod from CRP was controlled.

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After sod take out, a cereal-based rotation (winter wheat/fallow) with different tillage systems was imposed to evaluate these different management practices as they affect seed bed, weeds, plant cover, crop growth, grain yields, and SOC changes.

Methods and Materials

Comparison of SOC changes in CRP, W/F, and native sod sites (Study 1). Six CRP sites from producers' fields were selected in northeastern Colorado (Table 1): two established in 1986, two in 1988, and two in 1990. These sites were sampled in the spring of 1996. At all sites, soil samples were taken from the 0-5 and 5-15 cm (0-2 and 2-6 in) depths in the CRP, adjacent native sod, and continuous W/F sites. Profile depth to lime was determined as a surrogate for the depth of the A and B horizons (solum), where the bulk of the rooting volume is generally found.

Generally, these sites receive about 420 mm (16.5 in) of precipitation annually, with about 80% occurring in April through September. Frost-free season is about 139 days, with average frost-free dates of May 11 to September 28.

We sampled all three management site types (CRP, W/F, sod) in areas of comparable soil type, slope, and aspect. Soil samples were taken from five different areas (within each management site replication). The sampling area consisted of a central point with four others around it in the form of an "X" with 90-degree angles. Soil samples were taken about 50 m (165 ft) from the central sampling point. There were three composited samples [within 5 m (16 ft) of one another] for each field sampling point.

Introduced CRP grasses at each site were intermediate wheatgrass (*Thinopyrum intermedium*), smooth bromegrass, switchgrass (*Panicum virgatum* L.), little bluestem (*Schizachyrum scoparium*), and sideoats grama (*Bouteloua curtipendula*). Vegetation biomass was sampled randomly on all sites in the CRP on a 1 m^2 (1.2 yd^2) grid replicated three times. Percentage surface cover was not assessed. No surface cover data were collected at the native sod or at the W/F sites. Dominant grass species at the sod treatment were blue grama (*Bouteloa gracilis*), buffalo grass (*Bucloe dactiloides*), and western wheatgrass (*Pascopyrum smithii*). Data from the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS) (Soil Survey of Washington County1982) showed that these native range areas generally produced from 800 to 1200 kg of biomass per hectare (715 to 1070 lb ac^{-1}) depending on texture, slope, and rainfall patterns.

Table 1. Selected physical and chemical properties for the six native sod sites (0-15 cm).

Site soil Series	pH 1:2	CEC†	D$_b$†	Sand	Silt	Clay	Depth to Lime
		Cmol/kg	Mg/m^3	g/g			cm
Platner l	7.0	15.3	1.35	0.45	0.37	0.18	>40
Norka-Colby l	7.8	16.5	1.27	0.33	0.49	0.18	20
Colby l	7.5	12.8	1.35	0.37	0.40	0.23	20
Keith-Kuma sl	6.4	13.4	1.27	0.38	0.40	0.22	>30
Ascalon sl	6.3	14.0	1.40	0.70	0.18	0.12	>40
Ascalon sl	6.3	14.0	1.40	0.62	0.33	0.12	>40

†Cation exchange capacity

†Soil bulk density.

Conversion of grassland to cropland and its effect on SOC (Study 2). From 1994 to1998, in a separate study, we compared the effect on SOC content of four tillage systems for controlling grasses at a site planted to smooth bromegrass. The CRP was established in the spring of 1987, but a waiver was given to the Agricultural Research Service by the USDA NRCS to conduct the research before the mandatory 10-year minimum expiration time. Tillage systems were comprised of various combinations of glyphosate [N-(phosphonomethyl)glycine] applications and tillage with a sweep plow ranging from no-till to conventional-till systems (Table 2). The sweep plow consisted of V-shaped blades 75 cm (30 in) wide that sever weed roots with minimum soil disturbance and till to a depth of 5-8 cm (2-3 in). No-till plots were mowed in August to minimize interception of spray solution by dead plant material and to stimulate fall growth of smooth bromegrass.

Table 2. Cultural components of tillage systems for converting grassland to cropland study.

	Timing of cultural operation					
Tillage System	August	October	May	June	August	September
No-till	Mowing	G: 1.2	G: 1.2	G: 0.8	G: 0.6	G: 0.6
Reduced-till - I		X	G: 1.2	G: 0.8	G: 0.6	G: 0.6
Reduced-till - II		X	X	G: 0.8	G: 0.6	G: 0.6
Conventional-till		X	X	X	X	X

G: represents variable amounts of glyphosate applied (kg active ingredient/ha)

X represents tillage with a sweep plow.

Experimental design was a randomized complete block with four replications. Plot size was 10 by 16 m (30 by 50 ft). Soil was a Platner fine sandy loam (Aridic Paleustolls). The study was repeated in 1995.

Winter wheat, TAM 107, was planted at 65 kg ha^{-1} (60 lb ac^{-1}) in late September 1995 with a no-till disk drill. Ammonium nitrate (NH_4NO_3) was applied broadcast at 65 kg ha^{-1} (73 lb ac^{-1}) before the winter wheat was planted. Grain yield was determined by harvesting a 1.5 m by 16 m (5 ft by 50 ft) area of each plot.

Soil water content was determined gravimetrically (Gardner 1986) for all treatments before planting winter wheat. Two samples were collected per plot and divided into 25 cm (10 in) increments. Sampling depth was 1.5 m (5 ft). Volumetric water content was converted to available water by using a lower limit of water extraction (wilting point) of 8% (Nielsen et al. 1999).

Grass residue levels on the surface were measured after winter wheat planting by the line transect method (Laflen et al. 1981). Within each plot, four 16 m (50 ft) transects were laid out diagonally, with residue counted at 50 predetermined points along each transect.

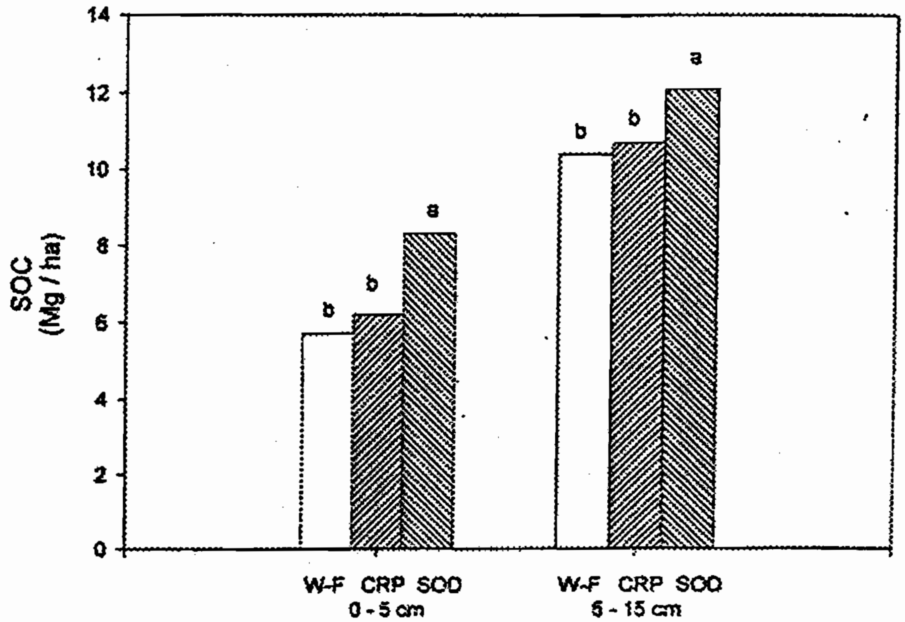
A visual estimate of land area infested and number of smoothbrome grass plants were recorded in early May and 18 (in winter wheat) and 30 months after initiation of treatments. Three 1 m^2 (10.5 ft^2) sites were randomly located in each plot for plant counts, whereas the whole plot was evaluated for grass infestation.

For SOC evaluation among tillage treatments, soil samples were taken in the spring of 1997 at the 0-5 and 5-15 cm (0-2 and 2-6 in) depths. Four composite samples were taken from each treatment for all four replicates. The sod soil samples were taken from a site of the same soil series and general slope characteristics across the road from the tillage study. Soil samples were air dried and passed through a 2 mm (0.1 in) screen before analysis.

Analyses. For comparisons among W/F, sod, and CRP sites, the following analyses were determined: total SOC and total N by C-N gas analyzer and chromic acid digestion (Nelson and Sommers 1982), total soil P (TP) (Bowman 1988), soil texture (hydrometer method), soil pH (1:1 in water), and bulk density (core method).

Statistics. For Study 1, analysis of variance was conducted for differences in SOC content for the three management site types for all six sites at the two depths. Sites were assessed collectively and singly. For Study 2 (recropping study), the effects of tillage systems on SOC content were determined. Mean separation by Duncan's Multiple Range Test ($P = 0.05$) was used to evaluate significant differences for both studies. For the six CRP farmer field sites (Study 1), comparisons were made for all six sites and within each site by treatments (CRP, W/F, sod). For the conversion study (Study 2), comparisons were made for SOC content at the 15 cm (6 in) depth two years after the various tillage systems were imposed.

Figure 1.
Average soil organic carbon (SOC) at the 0–5 cm and the 5–15 cm depths averaged over the six sites.



Results and Discussion

Changes in SOC, N and TP for CRP, W/F, and native sod (Study 1). Changes in SOC content can be evaluated directly by quantifying the amount of SOC in a management treatment initially (time zero) and then again at some future time. Thus, given sufficient time, increases in SOC from a CRP treatment and losses in SOC content from a conventionally-tilled W/F treatment can be assessed directly. However, when producers initiated the CRP, establishment of ground cover to prevent erosion was the primary concern, and no data were gathered on SOC content or other soil parameters. Later, as researchers and action agencies evaluated the benefits of CRP in terms of soil quality and SOC changes, direct comparisons were made on the three management treatments (sod, CRP, W/F) with the assumption that, because of spatial proximity, changes were essentially to the result of management treatments and not differences in initial soil conditions. Thus, at time zero before cultivation started, we assumed all three sod sites were in sod and contained essentially the same amount of SOC. We also assumed that the CRP site, which was in a W/F rotation for decades before conversion to grass, contained the same amount of SOC as the adjacent continuous W/F treatment (Gebhart et al. 1994; Staben et al. 1997). Obviously, such assumptions can be readily confounded by slope conditions, textural variations, soil profile depths, and management practices. For this reason, adequate replications and composite sampling are necessary if significant changes are to be found (Bowman 1991). However, since there are no time zero measures, it is not certain that significant differences resulted from treatment effects rather than inherent differences within treatments, even though statistical differences were found. A resampling in 2006 (1996 used as time zero) for sites that remained in the program would give a direct comparison to assess changes.

Since soil texture was not the same at all sites (Table 1), the time factor (farmer sites placed in the CRP in 1986, 1988, and 1990) was not used in the analysis of variance. While the two sites put into the CRP in 1986 had the same amount of time to sequester new carbon, rate of SOC accrual would differ because of different soil properties (Nichols 1984). The sites varied in pH from near neutral to calcareous (pH=7.8). The calcareous soils were more sloping in nature, with a shallow solum [depth to lime <30 cm (12 in)] and no developed B horizon. Bulk density in the sod was generally 10-15% less than in W/F and CRP sites.

When all six sites were assessed together (Figure 1), the SOC content at the 0-5 cm (0-2 in) depth for the W/F (5.84 Mg ha^{-1}; 6,500 lb ac^{-1}) and the CRP (6.33 Mg ha^{-1}; 5,620 lb ac^{-1}) sites showed no differences. The SOC content was significantly higher (8.66 Mg ha^{-1}; 7,730 lb ac^{-1}) in the sod than in the CRP and W/F treatment plots. However, when each site was assessed separately (Figure 2), three sites showed differences in SOC content among all three management systems, one showed no difference among all three, and two showed no difference between W/F and CRP. Thus, only half the sites showed a significant accrual of SOC in the CRP treatment versus the W/F areas.

Soil organic carbon was strongly associated with TP (Figure 3), presumably because both are highly correlated with the clay fraction. From the regression, 71% of the SOC content can be explained by the total P content. Both parameters are equally affected by

Figure 2

Soil organic carbon (SOC) content at the 0–5 cm depth for CRP, W/F and sod treatments at six different sites in northeastern Colorado. (N-C = Norka-Colby; K-K = Keith-Kuma; Asc = Ascalon).

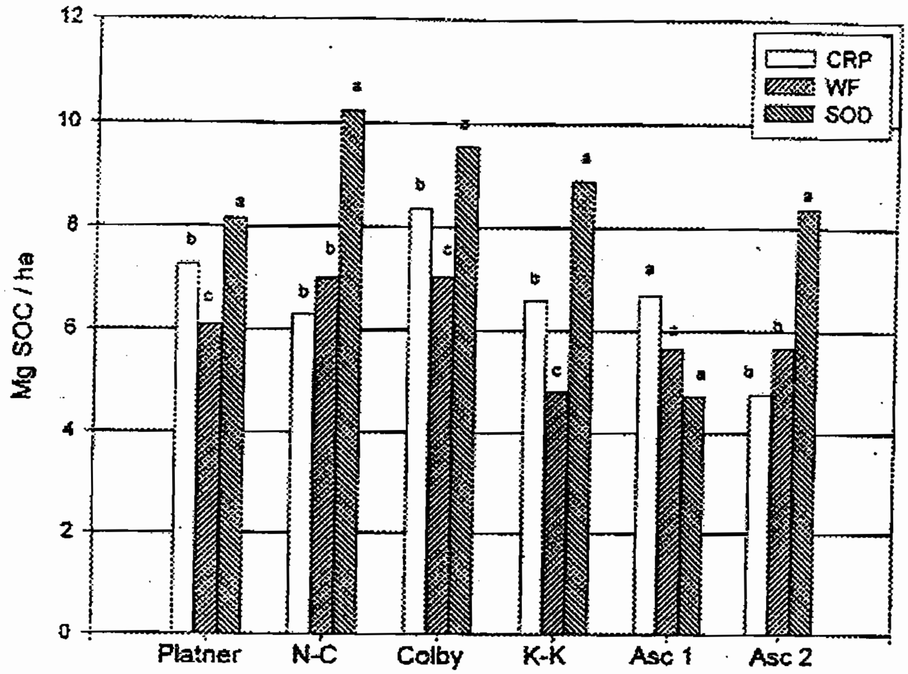
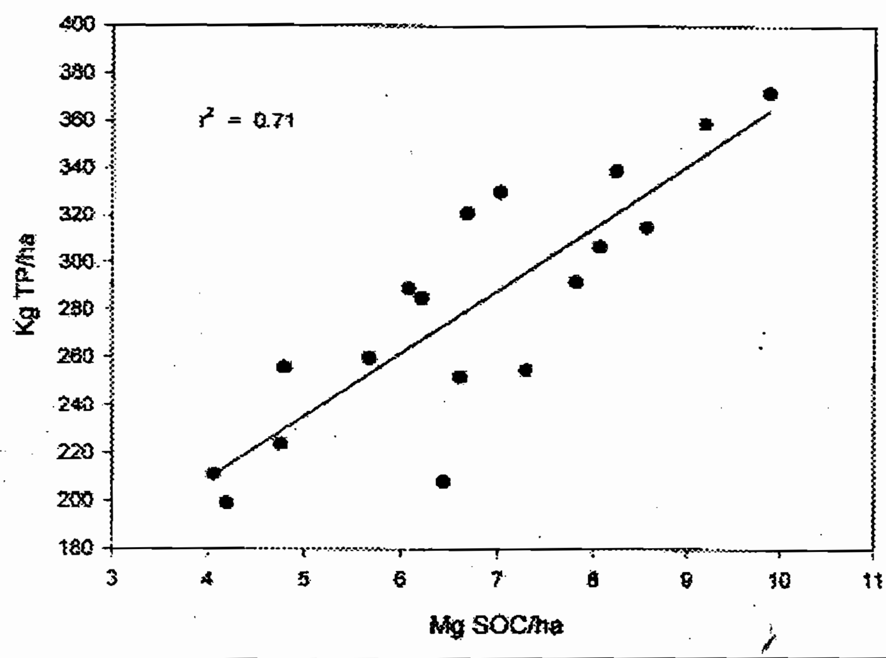


Figure 3

Relationship between soil organic carbon (SOC) content and total soil P (TP) content.



erosion when soil sediment moves and by decomposition of soil organic matter.

Potential N contribution from CRP plots was estimated from N in the plant residue and N in the soil organic matter (Table 3). Both surface residue and SOC amounts are a function of previous biomass, which is a function of rainfall amounts and timing, slope, soil texture, and grass mixture. The sandy soils (sites with Ascalon sandy loams) showed the least potential for N contribution from grass biomass. Generally, the available N content in these soils as measured by nitrates is very low (Westfall and Peterson 1996), and addition of supplemental N is advised before going into a cereal-based rotation.

While a definitive or critical value for SOC content or concentration cannot be easily given for a site, changes in certain physical and chemical soil traits can aid in the decision to keep the site in the CRP program. For example, the SOC loss compared to the original sod, or the SOC accrued relative to the continuous W/F, will reflect the soil improvement made over time in the CRP. In addition, climatic factors, slope, soil texture, and depth of the solum greatly influence carbon changes for a specific site. If soil erosion is severe, the potential to sequester carbon is decreased because water infiltration is decreased and, therefore, the potential to produce biomass is decreased. Thus, sloping sandy sites with lime at a relatively shallow depth (< 30 cm; < 12 in) may not be suitable for crop reintroduction. The NRCS suggests that sites with an erodibility index greater than 15 should remain in the program. Also, if the percentage of carbon loss after rehabilitation with the CRP program is still high (>50%) relative to a native site, the site may require a longer period in the CRP. Retention and stabilization of carbon is a function of soil texture (stabilization potential) and climate (accrual and decomposition), and the 50% carbon loss is an arbitrary guideline that can be modified accordingly.

Cropping of Converted CRP land and SOC changes (Study 2). Winter wheat grain yield was greatest in the no-till and reduced-till-I systems (Table 4). Yield loss with the reduced-till-II and conventional-till treatments was attributed partly to less available water at planting and higher smooth bromegrass density compared to the reduced-till-I system. Plant residue on the soil surface was greatest in the reduced-till systems. The no-till system had less surface residue than the reduced-till systems because it was mowed 13 months before winter wheat was planted (Table 4), there was increased residue decomposition, and there was probably loss due to wind.

In winter wheat 18 months after initial treatments, the land area infested with smooth bromegrass was less than 5% for all treatments (data not shown). However, 30 months after initiation of treatments, smooth bromegrass

Table 3. Potentially available N from Conservation Reserve Program residue cover, soil organic matter (SOM), and total N.

Site	Residue biomass N†	SOM- N	Total N
	kg/ha		
Platner	41	20	61
Norka Colby	30	22	52
Colby	55	20	75
Keith-Kuma	31	19	50
Ascalon 1	15	10	25
Ascalon 2	15	10	25

†Calculated from N concentration and residue biomass, assuming all N from plant residue available and 30 kg N/ha available from 0.6% soil organic carbon (1% SOM to a 15 cm depth).

Table 4. Effect of tillage system on smooth bromegrass density, residue cover, and available soil water, and winter wheat grain yield.

Tillage System	Bromegrass density*	Residue cover**	Available soil water**	Grain yield
	plants/m2	%	cm	kg/ha
No-till	3.0	55	14.0	2890
Reduced-till - I	1.5	64	17.8	2890
Reduced-till - II	3.4	63	11.4	2490
Conventional-till	6.5	45	12.5	2560
LSD (0.05)	3.9	6	3.2	270

*** 30 months after initiation of treatments**

****at planting**

density was greater in the conventional-till than in the reduced-till-I system (Table 4). Land area infested with smooth bromegrass, however, was less than 10% for all treatments (data not shown). Our results with no-till and conventional-till contrast with previous studies at Akron, Colorado, where a no-till system was 20% less effective than sweep plowing in controlling perennial grasses (Halvorson et al. 2000; Anderson 1996). In our current study, late summer precipitation stimulated fall growth of smooth bromegrass; thus, we were able to apply glyphosate in the fall to improve control (Davis et al. 1978; Ivany 1981). In the previous studies (Anderson 1996; Halvorson et al. 2000), perennial grass did not grow in the fall because of dry conditions; herbicide applications were delayed until the spring, which reduced glyphosate's effectiveness.

SOC content (0-5 cm; 0-2 in) for different tillage systems relative to the native sod and the CRP control plot in smooth bromegrass showed a greater decline on the reduced-till-II and conventional-till treatments than the no-till and reduced-till-I treatments (Table 5). For SOC at the 5-15 cm (2-6 in) depth, only the reduced-till-II and conventional-till treatments were lower than the native sod (Table 5). While there was a 10% decline with the reduced-till-I treatment relative to the CRP control, that percentage increased to 20% for the conventional-till and reduced-till-II treatments.

Since grass weeds (residual or new) have to be controlled for successful seeding and economical grain yields, the reduced-till-I treatment may be necessary to control grass weeds before planting winter wheat. Tillage with non-inversion implements like the sweep plow minimizes residue burial (Good and Smika 1978) yet stimulates the rhizome buds of perennial grasses to germinate (Harker and O'Sullivan 1993). If buds remain dormant, herbicide performance is reduced (Harker 1995). A further difficulty for semiarid producers is limited precipitation; if August and September prior to winter wheat planting are dry, perennial grasses remain dormant, thus eliminating the herbicide option for grass kill in the fall (Ivany 1981). Reduced-till systems will aid producers in maintaining surface residue as well as provide an alternative option to control perennial grasses during dry years. This agrees with the results reported by Halvorson et al. (2000).

Table 5. Soil organic carbon contents of the different tillage practices at the 0-5 and 5-15 cm depths.

Management	Soil organic carbon levels (Mg/ha)	
	0-5 cm	5-15 cm
Native sod	6.9	10.7
CRP control (Brome)	6.6	9.5
No-till	6.2	9.3
Reduced-till-I	6.1	9.3
Reduced-till-II	5.6	9.1
Conventional-till	5.6	9.1
LSD (0.05)	0.4	0.7

Summary and Conclusion

In general it appears that some CRP sites in northeastern Colorado were accruing more SOC in the surface 15 cm (6 in) depth than existing W/F sites. However, because of possible inherent initial differences among treatment sites, it can only be speculated that the CRP sites contained similar amounts or even less SOC content than the W/F sites upon initiation of the program and that, therefore, 1996 comparisons were inferred as valid.

Recropping with no-till or minimum tillage should help to conserve the gains made during the CRP rest period.

Producers can further enhance soil protection after CRP conversion to cropland by using alternative rotations or crop sequences that minimize the frequency of fallow. Since many of these soils were once prone to excessive erosion, maintenance of surface cover and frequent cropping with proper management will be paramount to minimize degradation.

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