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Soil quality of two Kansas soils as influenced by the Conservation Reserve Program

X. Huang, E.L. Skidmore, and G.L. Tibke

ABSTRACT: Achieving and maintaining a good soil quality is essential for sustaining agricultural production in an economically viable and environmentally safe manner. The transition of land management provides an opportunity to measure soil-quality indicators to quantify the effects of those management practices. This study compared soil chemical and physical properties after 10 years of grass on Conservation Reserve Program (CRP) land with those in continuously cropped land (CCL). The sample sites, located in central Kansas, have two mapping units, Harney silt loam (fine, montmorillonitic, mesic Typic Arigiustolls) and Naron fine sandy loam (fine-loamy, mixed, thermic Udic Argiustolls). Soil samples were collected at two depth increments, 0 to 5 cm and 5 to 10 cm. Soil-quality indicators measured were soil acidity (pH), exchangeable cations, nutrients, total carbon, structure, and aggregation. Soil pH was significantly lower in CCL than in CRP. Soil total C and N in the surface layer (0 to 5 cm) was much greater than in the deeper layer (5 to 10 cm) in the CRP site. The mass of total carbon of Naron soil was significantly higher for 0 to 5 cm and lower for 5 to 10 cm depth in CRP land than in CCL. However, the mass of total carbon of Harney soil was significantly higher in no-tilled CCL than in CRP. Bulk density significantly increased in CCL. Based on dry and wet aggregate stability analysis, the results indicated that CRP land had a greater resistance to erosion by both water and wind than CCL. The improvements in soil quality resulting from CRP included reducing soil acidification, alleviating compaction, and reducing topsoil susceptibility to erosion. However, when CRP was taken out for crop production with conventional tillage, total carbon in the surface layer (0 to 5cm) and aggregate stability gradually decreased. This suggested that appropriate land management practices are needed to extend residual benefit from CRP on soil quality.

Keywords: Aggregate stability, CRP, soil quality, soil total carbon, wind erosion

Continuous cultivation and addition of ammonical fertilizers are generally thought to decrease soil quality by altering soil acidity, depleting soil organic matter, disrupting soil structure, and reducing biological activity (Staben et al. 1997, Hill 1990, Lal et al. 1994). In addition, soil under continuous production is vulnerable to accelerated erosion. To reduce soil erosion and improve soil quality, the U.S. Congress enacted the Conservation Reserve Program (CRP) in 1985. CRP put highly erodible (erodibility index ≥ 8) and environmentally sensitive lands into grass or other perennial plantings. Nationally, 14.8 million hectares were enrolled in CRP in the first 12 signups, with nearly 60% of CRP acreage located in the Great Plains and 1.13 million hectares in Kansas alone (Osborn 1993, Lindstrom et al. 1994).

Many studies were reported that soil erosion has been greatly reduced with permanent vegetative cover in CRP. Airborne dust in the southern High Plains of Texas was significantly reduced because of CRP (Ervin and Lee 1994). Through remote sensing imaging, Wu et al. (1997) found higher soil fertility and lower soil erodibility in CRP land, compared with continuous cropland in Finney County, Kansas. Davie and Lant (1994) studied two watersheds in southern Illinois and reported that CRP land showed decreases in erosion of 24% in one watershed and 37% in another. Less erosion by runoff in the first year of conversion from CRP was reported by Gilley et al. (1997).

In addition to erosion reduction, CRP soil-quality improvement was noted by increasing soil organic matter and soil tilth (Staben et al. 1997). Soil structure improves when continuously cultivated land is put into grass (Lindstrom et al. 1994). Karlen et al. (1999) reported that CRP sites had a higher percentage of water-stable soil aggregates than cropland sites.

Karlen et al. (1999) measured total organic C in paired CRP and cropland sites in Iowa, Minnesota, North Dakota, and Washington. In all states, microbial biomass carbon was 17% to 64% higher at CRP sites than at cropland or fallow sites, while nitrate-N was 18% to 74% higher in cropland than CRP sites. This multistate project showed that several soil-quality indicators were improved by placing highly erodible cropland into perennial grass.

Gebhart et al. (1994) analyzed soil organic matter levels of soils sampled from cropland, native pasture, and five-year-old CRP sites in Texas, Kansas, and Nebraska. They found that soil organic matter levels for cropland, native pasture, and five-year old CRP sites were 59.2, 65.1, and 90.8 metric tons C ha^{-1} in the surface 300 cm, respectively. However, Staben et al. (1997) found no significant differences in total organic carbon between CRP and wheat-fallow soils in eastern Washington on a silt loam. Based on C mineralization, they did, however, suggest that a higher-quality soil organic matter was found on CRP land. Soil-quality benefits derived from CRP may rapidly decline once an area is tilled and then left fallow during the noncropped period (Gilley et al. 1997).

Soil biological properties are sensitive indicators that reflect land-practice change (Huggins et al. 1998, Karlen et al. 1999). Karlen and Parkin (1996) found microbial biomass was significantly higher for CRP than for cultivated areas and suggested soil quality was improved from the biological

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perspective. Staben et al. (1997) investigated microbial aspects of soil quality between CRP and wheat-fallow soils on a silt loam in eastern Washington. They concluded that active bacterial biomass and potential enzyme activities were higher in the CRP soil than in the wheat-fallow soil.

The need is urgent to understand long-term land-management effects on soil quality at various scales—pedon and point, to field and plot, to farm and watershed, and to regional and national levels (Karlen et al. 1998). Expiration of CRP contracts and subsequent return of highly erodible lands to continuous cropping concerns policymakers, conservationists, and farmers (Ervin 1993, Osborn 1993, Lindstrom et al. 1994). Knowledge of changes in soil properties during 10 years of CRP enrollment is important for evaluating the program effectiveness. Also, the return of CRP land to cultivation provides a chance to evaluate changes in chemical and physical properties for soil quality.

The objectives of this study were to compare soil properties between 10 years of grass-planting Conservation Reserve Program land and adjacent continuously cropped land, and to evaluate effects of the Conservation Reserve Program on soil quality during its 10-year enrollment and its transition back into crop production.

Methods and Materials

Field description. Two fields located in central Kansas were selected as study sites. One was near Larned of Pawnee County. The soil was deep, well-drained, Harney silt loam (fine, montmorillonitic, mesic Typic Arigiustolls, 21% sand, 64% silt, and 15% clay at 0 to 10 cm depth). The sampling site for CRP was about 150 m from CCL at this location. The CCL was in nonirrigated, no-till, wheat-corn [*Zea mays* L.] rotation for five years before the beginning of this study. The other site was located near Zenith of Stafford County. The soil was Naron, fine, sandy loam (fine-loamy, mixed, thermic Udic Argiustolls, 75% sand, 15% silt, and 10% clay at 0 to 10 cm depth). In this field, CRP land was adjacent to CCL. The cropping system for this field was dryland continuous winter wheat [*Triticum asetivium* L.] with disk tillage. Initially, native grasses were seeded in CRP fields in 1987. No grazing or burning occurred in CRP fields until the contract expiration in spring 1998. The main grasses in CRP fields were little bluestem [*Andropogen scoparius*], Indiangrass [*Sorghastrum nutans*], and Switchgrass [*Panium virgatum*].

Field and laboratory methods. At Naron soil field, the soil samples were taken from the 400 m long transect spanning 200 m in CRP and 200 m in CCL, respectively. Each treatment accounted for 20 sites in 10 m spacing. At Harney soil field, 19 samples were collected along two diagonal transects with 10 m spacing in the CRP field. Grid sampling was applied in the CCL field. In a 100x100 m field, 35 samples were taken in 20 m spacing. Each sample site for both chemical and physical properties was located using a GPS system to repeat sampling at the same location over time.

In the CRP sites, 10-year grasses were burned in early April 1998. Soils were sampled in late May 1998. CCL samples at Naron soil were taken July 2, 1998, a few days after wheat harvest. CCL samples at Harney soil were taken May 27, 1998, where the field was fallowed with no-tilled corn residue. The CRP fields were moldboard plowed in fall 1998 and cultivated for wheat in Harney site in 1999 and for irrigated corn at Naron site in 1999. The soil samples were again taken at the same location in May 1999 to compare the changes in the properties after return of CRP land to production.

For the soil chemical properties, soil cores were collected to depth of 0 to 5 cm and 5 to 10 cm using a 2 cm diameter hand probe. A total of 20 bore holes and 250 g soils were collected in each sample site. The soil was crushed and placed in a bag, air-dried and taken to the Soil Testing Laboratory at Kansas State University. In the laboratory, a portion of each soil sample was ground to pass through a 2 mm sieve. Soil pH was measured on a 1:1 soil/distilled water paste. Phosphorus was tested by the Bray 1 method. Potassium, Ca, Mg, and Na were extracted by 1*M* NH_4OAc. Exchangeable Ca, Mg, K, and Na were measured by atomic absorption. Cation exchange capacity (CEC) was determined by saturating the soil sample with NH_4^+ and then replacing NH_4^+ by K^+ ions. The replacing NH_4^+ concentration was measured colorimetrically. Total carbon and nitrogen concentrations were determined by dry combustion using a LECO CNS-2000 automatic analyzer (LECO Corp., St. Joseph, MI).

Soil samples were taken from the surface 5 cm of soil using a flat shovel and used for aggregate analysis. Aggregate size distribution was determined by rotary sieving (Lyles et al. 1970). Dry aggregate stability of 6.5 to 19 mm aggregates was measured as described by Skidmore and Powers (1982) with the crushing device built by Boyd et al. (1983). The dry aggregate stability was expressed as the natural logarithm of the aggregate crushing-energy (J/kg). Wet aggregate stability of 1 to 2 mm size fraction was determined by directly immersing 1 to 2 mm fractions into distilled water for 20 minutes. The rest of the procedures described by Kemper and Rosenau (1986) were followed.

A double cylinder, hammer-driven, soil-core sampler (76 x 76 mm) was used to obtain 3 incremental soil-core samples (0 to 10 cm, 10 to 20cm, and 20 to 30 cm depth). The soil cores were trimmed flush with both ends of the retaining cylinder. The soil samples were put into a plastic box with a sponge bottom, kept undisturbed and taken to the lab. These samples were first used to determine low-tension water-release characteristics and then to determine bulk density. Soil-moisture release curves were determined using hanging water column techniques (Klute 1986, Kutilek and Nielsen 1994). The device used for low-tension water-release measurement was composed of a glass funnel with a porous plate and hanging water for pressure head. The water outflow was measured under different potential. The minimum potential was -200 cm H_2O. When the equilibrium was reached at -200 cm pressure head, wet samples were weighed, then oven-dried at 105°C for 24 hours, and dry soil was weighted to determine the soil water content, porosity, and bulk density.

Macroporosity was calculated by soil water content between saturation and potential of -50 cm H_2O head. Mesoporosity was calculated by soil water content between potential of -50 and -200 cm H_2O head (Kutilek and Nielsen 1994, Poulsen et al. 1999). Correspondingly, the pore radius ranges in macropore and mesopore calculated by capillary equation are ≥ 30 µm, and 30 to 7.5 µm, respectively.

Soil saturated hydraulic conductivity (Ks) was estimated using the equation developed by Poulsen et al. (1999). The equation for predicting Ks is based on the water-filled porosity at a soil-water potential of -100 cm H_2O. $\mathrm{Ln(Ks)} = 2.8\mathrm{Ln}(\theta_{100}) + 4.3$, where Ks is in cm d^{-1}, and θ_{100} is air-filled porosity at soil-water potential of -100 cm H_2O in $cm^3\ cm^{-3}$. A portion of soil from the bulk density

Table 1. Comparison of soil acidity and exchangeable cations between CRP and CCL and between two depths on two Kansas soils.

Soil depth (cm), treatment		pH	CEC	K	Ca	Mg	Na
			cmol kg^{-1}	mg kg^{-1}			
Naron fine sandy loam							
Comparison between treatments							
0-5	CRP	5.8±0.02§	7.75±1.24	244±31	667±84	154±15	5.36±0.70
	CCL	5.1±0.06	6.49±0.85	285±42	558±52	99±11	2.66±0.09
	Diff.	0.7***	1.27NS	-41NS	109NS	55**	2.71***
5-10	CRP	5.3±0.02	6.90±0.76	195±15	524±54	127±12	5.18±0.67
	CCL	4.9±0.04	6.62±0.78	221±34	565±50	100±11	2.74±0.21
	Diff.	0.4***	0.27NS	-26NS	-41NS	27NS	2.44***
Comparison between depths within treatment							
CRP	0-5	5.8	7.75	244	667	154	5.36
	5-10	5.3	6.90	195	524	127	5.18
	Diff.	0.47***	0.85NS	49NS	143NS	27NS	0.18NS
CCL	0-5	5.1	6.49	285	558	99	2.66
	5-10	4.9	6.62	221	565	100	2.74
	Diff.	0.1NS	-0.13NS	64NS	-7NS	-1NS	-0.08NS
Harney silt loam							
Comparison between treatments							
0-5	CRP	6.0±0.06	13.8±0.19	580±26	1214±115	242±4	13.6±2.78
	CCL	5.4±0.02	16.5±0.22	494±14	1728±31	275±4	6.89±0.35
	Diff.	0.6***	-2.7***	85.4**	-514***	-33***	6.71*
5-10	CRP	5.7±0.07	14.0±0.42	546±20	1159±73	233±7	16.1±2.73
	CCL	5.4±0.02	16.6±0.25	297±11	1740±27	288±6	11.1±0.64
	Diff.	0.3***	-2.6***	249***	-581***	-55***	5*
Comparison between depths within treatment							
CRP	0-5	6.0	13.8	580	1214	242	13.6
	5-10	5.7	14.0	546	1159	233	16.1
	Diff.	0.3**	-0.2NS	34NS	55NS	9NS	-2.5NS
CCL	0-5	5.4	16.5	494	1728	275	6.89
	5-10	5.4	16.6	297	1740	288	11.1
	Diff.	0.02NS	-0.09NS	197**	-12NS	-13NS	-4.21*

§ Mean value with standard error. Diff. = CRP - CCL, or Diff. = 0-5 - 5-10.*, **, *** Significant at 0.05, 0.01, and 0.001 probability level by 2-tailed t-test, respectively. NS indicates no significant difference.

sample was use for particle-size distribution analysis. Particle-size distribution was determined by sieving the sand fraction and pipetting the clay fraction, according to the method of Gee and Bauder (1986).

Bulk-density data were used to convert soil P, total C and N concentration (mg kg^{-1}) to P, total C, and N mass (kg ha^{-1}). We measured bulk densities at every sample site from 0 to 10 cm depth; those values were used for conversion of mass at 0 to 5 cm and 5 to 10 cm depths.

Statistical analysis. The statistical indices (mean and standard error) for soil chemical and physical properties were performed with the statistic software package for Windows SYSTAT 9.0 (SPSS Inc., Chicago, IL 1999). Means for each soil property between CRP and CCL at two soils and two depths were compared using the 2-tailed two-sample *t*-test with unequal variance assumed with the SYSTAT.

Results and Discussion

Soil pH. Soil pH was significantly lower ($p<0.001$) in CCL than in CRP in both soil types (Table 1). The difference of pH between CRP and CCL was much greater at 0 to 5 cm than at 5 to 10 cm depth. The pH at the upper soil layer after 10 years in grass increased 0.7 and 0.6 in Naron and Harney soil, respectively, compared with continuous cropping. No lime was applied in CCL during that period. Apparently, ammonium fertilizer of the continuously cropped field tended to decrease the pH and acidify soil environment (Darusman et al. 1991).

In addition, pH in the soil profile was significantly greater at the upper soil layer than in the lower layer within CRP, but not within CCL (Table 1). The field operation in CCL, like tillage and fertilization, mixed soil and led to decreased acidity stratification in CCL.

Soil with a lower pH could affect the availability of plant nutrients, the activity of microorganisms, and the solubility of soil minerals (Pierzynski et al. 2000). Continuous cropping noticeably increased soil acidification and reduced soil suitability for plant growth. Other studies similarly have shown that placing land into CRP, however, tended to reverse soil acidification (Staben et al. 1997, Gewin et al. 1999). However, Liebig and Doran (1999) found that differences in soil pH between conventional farming and CRP land were not significant where soil pH

Table 2. Comparison of masses and distribution with depth of soil nutrients between CRP and CCL on two Kansas soils.

Soil depth (cm), treatment		P	Total C May 1998	Total C May 1999	Total N May 1998	Total N May 1999
		kg ha^{-1}	kg ha^{-1}			
Naron fine sandy loam						
Comparison between treatments						
0-5	CRP	27.6±2.5[§]	6519±1068	4980±562	599±67	571±49
	CCL	53.6±4.1	5124±581	5010±521	562±57	594±241
	Diff.	-26***	1395*	-30NS	37*	-23NS
5-10	CRP	24.1±2.1	3341±297	4446±4459	420±23	461±36
	CCL	52.6±4.6	5100±534	4459±434	554±54	478±42
	Diff.	-28.5***	-1759**	-13NS	-134*	-17NS
Comparison between depths within treatment						
CRP	0-5	27.6	6519	4980	599	571
	5-10	24.1	3341	4446	420	461
	Diff.	3.5NS	3178**	534NS	179*	110NS
CCL	0-5	53.6	5124	5010	562	594
	5-10	52.6	5100	4459	554	478
	Diff.	1NS	24NS	551NS	8NS	116NS
Harney silt loam						
Comparison between treatments						
0-5	CRP	30.1±1.2	8915±185	9041±363	839±18	872±44
	CCL	33.8±1.0	11961±252	11997±264	1258±29	1140±25
	Diff.	-3.7*	-3046***	-2956***	-419***	-268***
5-10	CRP	27.2±1.6	7111±122	7974±124	712±15	738±14
	CCL	15.3±0.8	8078±156	9128±312	877±20	871±30
	Diff.	11.9***	-967***	-1154***	-165***	-133*
Comparison between depths within treatment						
CRP	0-5	30.1	8915	9041	839	872
	5-10	27.2	7111	7974	712	738
	Diff.	2.9NS	1804***	1067*	127***	135**
CCL	0-5	33.8	11961	11997	1258	1140
	5-10	15.3	8078	9128	877	871
	Diff.	18.5***	3883***	2869***	381***	269***

[§] Mean value with standard error. Diff. = CRP - CCL, or Diff. = 0-5 - 5-10. *, **, * Significant at 0.05, 0.01, and 0.001 probability level by 2-tailed t-test, respectively. NS indicates no significant difference.**

was greater than 6.0.

CEC. No significant difference in CEC between CRP and CCL was observed in Naron soil (Table 1). For Harney soil, CEC was significantly lower in CRP than in CCL at both depths (p<0.001, Table 1). No significant difference was noted in CEC between the upper and lower soil layers of either Naron or Harney soils. Cation exchange capacity is highly related to clay content and the amount of organic matter. Our data showed that the correlation coefficients between soil total C and CEC were about 0.75 in both soil types. In this study, clay contents for CRP and CCL were the same. The higher CEC in CCL of Harney soil could be attributed to its greater organic C content, which itself was the product of many years of no-till. Hussain et al. (1999) found that soil under no-till had a greater CEC than soil under conventional tillage systems.

Exchangeable Mg and Na in Naron soil were greater in the CRP field than in the CCL field at both depths, whereas no differences in K or Ca between CRP and CCL were found (Table 1). In Harney soil, divalent cations Mg and Ca at both depths were greater (p<0.001) in CCL than in CRP. Conversely, monovalent cations K and Na were lesser in CCL than in CRP. Hussain et al. (1999) suggested that less K, along with greater Ca, could be a result of K fixation caused by Ca in a no-till system.

Soil nutrients. In the Naron soil, available P was significantly higher (p<0.001) in CCL than in CRP at both depths (Table 2). The average P mass was double in CCL relative to CRP. Undoubtedly, the differences resulted from higher amounts of P fertilizer application in crop fields. Similarly, in the Harney soil P at the upper soil layer was significantly lower (p<0.05) in CRP than in CCL, whereas P at the lower layer was greater (p<0.001) in CRP than in CCL (Table 2). Similar results were found by Skidmore et al. (1975) when they studied soil properties of native grass pasture and cultivated field. In the soil profile, the upper layer only in no-tilled CCL Harney soil had significantly higher P than the lower layer did. Higher P accumulated at the upper layer could be caused by surface fertilizer application and no-till practice. Less soil P in Harney soil could be attributed to P fixation by higher Ca concentration. Available P could be easily fixed by colloids and exchangeable Ca (Hussain et al. 1999). Soil with a coarse texture and less colloids, such as

Table 3. Comparison of means for bulk density, soil porosity, and hydraulic conductivity between CRP and CCL in Naron soil.

Soil depth (cm), treatment		Bulk density	Total porosity	Macroporosity	Mesoporosity	Hydraulic conductivity
		Mg m^{-3}	m^3 m^{-3}			cm d^{-1}
Naron fine sandy loam						
0-10	CRP	1.46±0.02§	0.45±0.01	0.20±0.01	0.09±0.01	537±61
	CCL	1.42±0.02	0.46±0.01	0.20±0.02	0.11±0.01	688±85
	Diff.	0.04NS	-0.01NS	0NS	-0.02*	-151*
10-20	CRP	1.60±0.02	0.40±0.01	0.14±0.01	0.06±0.01	197±38
	CCL	1.66±0.02	0.37±0.01	0.13±0.01	0.07±0.01	187±31
	Diff.	-0.06*	0.03**	0.01NS	-0.01NS	10NS
20-30	CRP	1.60±0.02	0.40±0.01	0.12±0.02	0.05±0.01	164±66
	CCL	1.61±0.02	0.39±0.01	0.14±0.01	0.07±0.01	211±36
	Diff.	-0.01NS	0.01NS	-0.02NS	-0.02*	-47NS
Harney silt loam						
0-10	CRP	1.24±0.01§	0.53±0.01	0.15±0.01	0.07±0.01	193±35
	CCL	1.36±0.04	0.49±0.02	0.10±0.10	0.06+0.01	102±21
	Diff.	-0.12***	0.04***	0.05***	0.±1NS	91†
10-20	CRP	1.31±0.02	0.51±0.01	0.10±0.01	0.06±0.01	76±10
	CCL	1.41±0.02	0.47±0.01	0.09±0.01	0.06±0.00	93±31
	Diff.	-0.1***	0.04***	-0.01NS	0NS	-17NS
20-30	CRP	1.34±0.02	0.50±0.01	0.12±0.01	0.05±0.00	96±14
	CCL	1.38±0.01	0.48±0.00	0.11±0.01	0.03±0.00	73±19
	Diff.	-0.04*	0.02*	0.01NS	0.02*	23NS

§ Mean value with standard error. Diff. = CRP - CCL. †, *, **, *** Significant at 0.1, 0.05, 0.01, and 0.001 probability level 2-tailed t-test, respectively. NS indicates no significant difference.

Naron fine sandy loam, would have reduced ability to fix P; as a result, P availability increased.

Total C mass of the Naron soil at 0 to 5 cm depth was significantly higher ($p<0.05$) in CRP than in CCL (Table 2). Conversely, at 5 to 10 cm depth, total C was significantly higher ($p<0.01$) in CCL than in CRP. A large amount of litter accumulated on the surface resulted in a greater increase of total C at 0 to 5 cm depth. In the Harney soil, total C at both depths was lower ($p<0.001$) in CRP than that in CCL. The higher carbon in continuously cultivated Harney soil could be the result of accumulation of residue under the no-till practice.

We do not have baseline data on the sites when the CRP was initiated in 1987, even though the CRP and CCL field are close to each other and have the same soil type. Field investigation showed that soil and landscape condition between CRP and CCL were very similar in the field of Naron soil. In the Harney soil, however, the CRP field was undulated and had poor soil structure. The CCL field was flat and better-managed. The innate difference in C and N might have existed when CRP was initiated in Harney soil. Thus, we could not conclude that greater C and N storage occurred in the no-tilled field than CRP. Huggins et al. (1998) investigated soil properties under CRP and conventional land management during 1993-1994 in Iowa, Minnesota, North Dakota, and Washington. Their results showed that CRP only increased soil organic C in the surface 0 to 7.5 cm. Our result showed that CRP increased total C mass in the surface 0 to 5 cm.

The difference of total C between the two depths in Naron soil under CRP fields was significant, but there was no significant difference in the depth for the CCL field (Table 2). A large amount of litter accumulation on the surface resulted in a greater increase of total carbon content. Apparently, frequent disk tillage in the CCL field resulted in mixing of the soil profile. Total C for both CRP and CCL in Harney soil was higher in the upper soil layer than in the lower layer. There was no soil mixing via tillage at either site.

Total C and total N were highly correlated ($r=0.97$). Trends for total N were similar to those reported for total C (Table 2). Staben et al. (1997) found no significant difference in total C between CRP and wheat-fallow soils after four to seven years in CRP. However, total N was higher ($p=0.01$) in the CRP soil than that in the wheat-fallow soil. A study in the central Great Plains where a wheat-fallow system was returned to grass showed no significant difference in the total C and total N after five years in a clay loam soil, but a significant increase in both C and N was found in a sandy loam soil (Reeder et al. 1998). In our experiment, when cultivation has been discontinued, recovery of surface soil C and N in Harney silt loam has been slower than in the Naron fine sandy loam, in part, because the initial levels of surface C and N in the Naron are low. Bauer and Black (1981) reported that as virgin grassland soils were put under cultivation, organic C and total N concentration declined most rapidly during the first 10 years after cultivation begin, continued to decline at a diminishing rate, and eventually reached an apparent equilibrium level. The apparent equilibrium level attained varied with crop sequences' type and amount of crop residue, as well as tillage practice. Burke et al. (1995) suggested that recovery of total C appeared to be a much slower process and could require about 50 years.

After CRP fields were broken for production by conventional tillage, total C in May 1999 for Naron soil declined from 6529 to 4980 kg ha^{-1} at the upper layer and increased from 3341 to 4446 kg ha^{-1} at the lower layer (Table 2). The stratification of carbon between depths disappeared on the CRP. There was no significant change in total C at

Table 4. Comparison of soil dry and wet aggregate stability between CRP and CCL on two Kansas soils.

Soil	Treatment	Dry aggregate stability		Wet aggregate stability	
		May 1998	May 1999	May 1998	May 1999
		LN (J/kg)		%	
Naron fine sandy loam					
	CRP	2.67±0.15§	3.29±0.14	72±13	57±11
	CCL	2.41±0.12	2.96±0.16	51±7	51±6
	Diff.	0.26†	0.33†	21***	6NS
Harney silt loam					
	CRP	3.28±0.07	3.08±0.10	55±3	40±2
	CCL	3.03±0.05	3.34±0.07	50±2	41±1
	Diff.	0.25*	-0.26*	5†	-1NS

§ Mean value with standard error. Diff. = CRP - CCL. †, *, and *** Significant at 0.1, 0.05, and 0.001 probability level by 2-tailed t-test, respectively. NS indicates no significant difference.

the CRP site in the Harney soil. Mixing of surface and subsurface soil by plowing caused the rapid decline in surface soil C and N for coarse-textured soil, but only slight change for fine-textured soil. Naron soil is more resilient in regenerating carbon with grasses while cultivation is discontinued.

Soil structure. Compacted soils inhibit plant root growth and slow water infiltration. Placing land under CRP could benefit soils by reversing some compaction. At the site with Naron soils, bulk density at a depth of 10 to 20 cm significantly ($p<0.01$) increased in CCL compared with CRP (Table 3). The bulk density between CRP and CCL did not differ in either upper or lower layers. Soil compaction in the upper layer (0 to 10 cm) could be reduced by tillage. However, soil compaction in the root zone (10 to 20 cm) is an important concern. In a sandy loam soil with poor soil structure and low organic matter, bulk density can be reduced by tillage, but when wheel traffic is applied, bulk density will increase (Meek et al. 1992). In Harney soil, although the differences were small, bulk densities at all depths were significantly higher ($p<0.01$) in CCL than in CRP (Table 3). Miller et al. (1999) reported that no-till and conventional tillage had little effect on bulk density for a clay loam soil.

Porosity of soil is a fundamental property affecting many soil water processes. Macropore channel flow through the profile from surface ponding relates to water infiltration rate and water holding capacity. In another aspect, small-scale mesopore (10 to 1000 μm) dominates the flow between aggregates (Luxmoore 1981).

Total porosity was less in CCL fields than CRP fields only at 10 to 20 cm depth in the Naron soil. However, in Harney soil, total porosity in CCL was less than porosity in CRP through all three depths (Table 3).

No differences in macroporosity between CRP and CCL were found at any depth in Naron soil. Mesoporosity was greater at 0 to 10 cm in CCL than in CRP. In Harney soil, macroporosity for CCL was significantly reduced at the 0 to 10 cm depth, compared with CRP. Mesoporosity was not influenced by the treatment. Miller et al. (1999) found greater volumes of smaller pores in conventional tillage and of larger pores in no-till. Different results, however, were reported by Hill (1990). He observed a shift to smaller pore sizes for no-till and to larger pore sizes for conventional tillage.

The results of saturated hydraulic conductivity (Ks) were consistent with soil porosity. The larger the proportion of soil macroporosity, the higher the Ks. A difference in Ks between CRP and CCL only occurred at 0 to 10 cm depth. In Naron soil, Ks at that layer was higher in CCL than that in CRP. Conversely, in Harney soil, Ks was higher in CRP than in CCL. In coarse-textured soil, tillage might create more large pores and increase hydraulic conductivity. The fine-textured soil with no-till should decrease hydraulic conductivity (Hill 1990).

Aggregate stability. Dry aggregate stability is an important measure of soil erosion potential from surface abrasion and was used in wind-erosion prediction models (Hagen 1991). Soils with weak aggregates are generally the most susceptible to wind erosion. Dry aggregate stability in Naron soil was significantly higher ($p<0.1$) in CRP than in CCL (Table 4). For Harney soil, the dry aggregate stability significantly ($p<0.001$) increased in CRP (Table 4). After CRP was plowed for production under conventional tillage in May 1999, the dry aggregate stability for Naron soil was still higher in CRP that that in CCL. But in the Harney soil, increased stable aggregates resulting from CRP were not maintained.

Wet sieving of the soil simulates forces that operate in the field to break down clods and aggregates (Skidmore et al. 1975). When a soil was wet, aggregates from CRP soil were more stable than those from CCL (Table 4). Karlen et al. (1999) also reported that CRP sites had a higher percentage of water-stable soil aggregates than cropland sites. Aggregates from Naron soil had greater stability than those from Harney soil. After CRP was taken out for crop production on conventional tillage, the wet aggregate stability in May 1999 between former CRP and CCL was not significantly different for both soils. Our results, as well as those from Karlen et al. (1999), showed that CRP could reduce soil runoff loss by flooding or heavy rain because the soils contained a higher proportion of stable aggregates.

Summary and Conclusions

Maintaining soil quality is essential for sustained agricultural production and environmental quality. Comparing soil chemical and physical properties between 10 years grass-planting Conservation Reserve Program land and continuously cropped land provided an opportunity to evaluate soil quality during land-management transition. The benefits resulting from CRP included reducing soil acidification, alleviating compaction, and reducing topsoil susceptibility to erosion. Total C mass significantly increased at the surface layer (0 to 5 cm) in CRP compared with continuous cropping. Increasing and maintaining higher soil carbon levels might require more than 10 years in grass status, which is the current standard in CRP contracts. When CRP was taken out to production under a conventional tillage system, total C and aggregate stability gradually decreased. This suggested that appropriate land-management practices are needed to extend residual benefit from CRP on soil quality.

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