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ORIGINAL ARTICLE

Contrasting grain crop and grassland management effects on soil quality properties for a north-central Missouri claypan soil landscape

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Abstract

Crop management has the potential to either enhance or degrade soil quality, which in turn impacts on crop production and the environment. Few studies have investigated how crop management affects soil quality over different landscape positions. The objective of the present study was to investigate how 12 years of annual cropping system (ACS) and conservation reserve program (CRP) practices impacted soil quality indicators at summit, backslope and footslope landscape positions of a claypan soil in north-central Missouri. Claypan soils are particularly poorly drained because of a restrictive high-clay subsoil layer and are vulnerable to high water erosion. Three replicates of four management systems were established in 1991 in a randomized complete block design, with landscape position as a split-block treatment. The management systems were investigated: (1) annual cropping system 1 (ACS1) was a mulch tillage (typically ≥ 30% of soil covered with residue after tillage operations) corn (*Zea mays* L.)–soybean (*Glycine max* (L.) Merr.) rotation system, (2) annual cropping system 2 (ACS2) was a no-till corn–soybean rotation system, (3) annual cropping system 3 (ACS3) was a no-till corn–soybean–wheat (*Triticum aestivum* L.) rotation system, with a cover crop following wheat, (4) CRP was a continuous cool-season grass and legume system. In 2002, soil cores (at depths of 0–7.5, 7.5–15 and 15–30 cm) were collected by landscape position and analyzed for physical, chemical and biological soil quality properties. No interactions were observed between landscape and crop management. Relative to management effects, soil organic carbon (SOC) significantly increased with 12 years of CRP management, but not with the other management systems. At the 0–7.5-cm soil depth in the CRP system, SOC increased over this period by 33% and soil total nitrogen storage increased by 34%. Soil aggregate stability was approximately 40% higher in the no-till management systems (ACS2 and ACS3) than in the tilled system (ACS1). Soil aggregation under CRP management was more than double that of the three grain-cropping systems. Soil bulk density at the shallow sampling depth was greater in ACS3 than in ACS1 and ACS2. In contrast to studies on other soil types, these results indicate only minor changes to claypan soil quality after 12 years of no-till management. The landscape had minor effects on the soil properties. Of note, SOC was significantly lower in the 7.5–15-cm soil depth at the footslope compared with the other landscape positions. We attribute this to wetter and more humid conditions at this position and extended periods of high microbial activity and SOC mineralization. We conclude that claypan soils degraded by historical cropping practices will benefit most from the adoption of CRP or CRP-like management.

Key words: claypan soils, conservation reserve program, cropping system, landscape, soil quality.

INTRODUCTION

For several decades, reduced-tillage or no-tillage and crop rotation practices have been promoted in the US and other countries to improve the quality of soil properties that are indicators of crop productivity and environmental function. Understanding management impact on soil quality is vital for identifying sustainable cropping

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practices. Many soil quality studies have focused on temporal changes in soil quality properties caused by tillage and crop rotation practices. Only a few studies have investigated management impact on soil quality properties over different landscapes. In the present study, both management and landscape, along with the potential interactions of these two factors, were examined.

Tillage practice is viewed by many as the predominant component of crop management systems affecting soil properties. In fact, many tillage studies focus on identifying practices that improve soil quality properties. Soil organic carbon (SOC) is frequently studied in relation to management. Reducing tillage intensity often increases surface residues and SOC in the surface soil (Baker *et al.* 2007) and improves the retention of water in the soil profile. The implementation of no-till management after years of conventional tillage increased SOC in a wide range of soils and climates across the Great Plains (Peterson and Varvel 1989; Potter *et al.* 1997, 1998; Wood *et al.* 1991; and Bowman *et al.* 1999). Campbell *et al.* (1996) reported a positive relationship between clay content and SOC increases in association with no-till practices. Jung and Han (2007) documented that reducing tillage intensity helped sequester carbon in a Korean rice paddy surface soil. Halvorson *et al.* (2002) found that as tillage intensity decreased, SOC sequestration in the surface soil increased in annual crop rotation systems, but few differences for stored carbon were detected over the whole profile among tillage systems (Baker *et al.* 2007). Cultivation can reduce SOC by increasing wind and water erosion and soil organic matter decomposition rates by breaking soil aggregates (Chaney and Swift 1984; Chepil 1956; Oades 1984). Soil organic matter degradation is attributed to the negative effects of cultivation on soil productivity (Bauer and Black 1981). Soil organic carbon and total nitrogen (TN) have declined dramatically over the 50–100 years of cultivation in semiarid regions of the Great Plains, with estimated losses of up to 50% of the original SOC (Campbell and Souster 1982; Mann 1985).

The effect of tillage has also been explored relative to other properties. Rhoton (2000) reported that no-till practices improved soil fertility in an 8-year tillage study with cotton (*Gossypium hirsutum* L.)–grain sorghum (*Sorghum bicolor* L.)–corn and soybean–wheat cropping systems. The beneficial changes in soil properties from the adoption of no-till practices are most rapid in the first 10 years (Dick *et al.* 1991). Dao (1996) found that tillage initially decreased bulk density (D_b), but no-till soil had a lower D_b by the end of the growing season. In contrast, Hammel (1989) found that no-till soil had a higher soil D_b in the surface 0.3 m relative to other tillage systems. Edwards *et al.* (1992) reported that conventional tillage increased surface runoff in a watershed by approximately 20 times compared with no tillage. Conversely, no-till on claypan soils increased runoff (Ghidey and Alberts 1998). On poorly drained claypan soils, only minor changes in some soil properties (e.g. D_b, saturated hydraulic conductivity and soil water retention) were found after 13 years of no-till management (Blanco-Canqui *et al.* 2004) and these researchers concluded that tillage played a minor role in improving claypan soil quality.

Crop type and intensity also play a role in altering soil quality. The effects of cropping choices on soil physical properties are also often related to increases in SOC (Ghidey and Alberts 1997; Haynes 2000). Soil organic carbon and TN increased 20% in the top 10 cm of soil over time in a continuous cropping system compared with a wheat–fallow system (Sherrod *et al.* 2003). However, even with increased cropping intensity, SOC and TN levels at a site with high potential evapotranspiration were 50% less than at sites with low and medium potential evapotranspiration. The stability of soil aggregates often decreased in soils under annual crops, such as wheat or corn (Angers 1998). Crop type also impacts on surface runoff from no-till practices (Alberts and Wendt 1985; Gantzer and Blake 1978; Scott *et al.* 1994).

The Conservation Reserve Program (CRP) is a USDA soil conservation management system that provides farmers economic return on marginal land removed from grain crop production and set aside into some type of non-harvested forage (Dicks 1994). Interest has been particularly high with regard to the impacts of CRP management on soil quality. The SOC levels in the top 0.4 m of CRP-managed soil increased by an average of 4.0 Mg ha^{-1} after only 5 years (Gebhart *et al.* 1994). Rainfall simulations have shown that undisturbed CRP land tends to have greater initial water runoff rates, but after 64 mm of rainfall, undisturbed CRP land has less water runoff and soil erosion than some tilled systems (Gilley and Doran 1997). Nitrate leaching decreased when tile-drained soils were managed in CRP, in large part because the drainage was approximately fivefold greater for row crops than for CRP land in years of excess precipitation (Randall *et al.* 1997). The flow-weighted average NO_3-N concentration was 32 mg L^{-1} for continuous corn compared with 2 mg L^{-1} for CRP land. Converting CRP into a hay or pasture system reduced erosion and runoff compared with grain cropping systems (Gilley *et al.* 1996). Conversely, the tillage and planting operations used to re-initiate row crop production on CRP acres generally increased erosion and runoff. Similar to CRP, continuous cropping of timothy (*Phleum pratense* L.) hay for a claypan soil resulted in over 300% greater aggregate stability, 21–27% greater soil strength and 55–67% less soil splash compared with continuous wheat or continuous corn (Rachman *et al.* 2003).

Only a few studies have simultaneously evaluated both the effects of different crop management systems and landscape positions when assessing soil quality properties. For dry-land conditions, SOC, TN and aggregate stability have been shown to be greatly influenced by cropping system and landscape position (Bowman *et al.* 1999; Campbell *et al.* 2000). Cropping intensity that increased total residue production, regardless of landscape position, was the major management factor that increased porosity, aggregation, SOC and TN for dry-land environments (Shaver *et al.* 2002; Sherrod *et al.* 2003). For claypan soils in a humid environment, saturated hydraulic conductivity was > 10-fold higher with CRP than with grain crop systems; however, this difference was only observed on the backslope position and not on footslope and summit landscape positions (Jiang *et al.* 2007).

A better understanding is needed for how management practices interact with soil landscapes to change soil quality properties. The purpose of the present study was to assess the impact of different management systems and landscape position on soil quality properties for a US Midwest claypan soil.

MATERIALS AND METHODS

Study site

The research site was located 3 km north of Centralia, Missouri (39°13′48″N, 92°07′00″W). The predominant soils are Adco (fine, smectitic, mesic Vertic Albaqualfs) and Mexico (fine, smectitic, mesic Aerie Vertic Epiaqualfs) series. The soils are deep, somewhat poorly drained and very slowly permeable, formed in loess or loess and pedisediment. They occur on uplands and have slopes of 0–3%. Surface soil texture ranges from silt loam to silty clay loam. The subsoil claypan horizons are silty clay loam, silty clay or clay and commonly contain as much as 50–65% clay. These soils are poorly drained because of this restrictive high-clay subsoil layer. Severe erosion can result in the claypan horizon being exposed at the soil surface. The mean annual temperature is 12°C and the mean annual precipitation is 1004 mm (US Department of Agriculture-Natural Resource Conservation Service 1995). This research site was initiated in 1991 as a part of the Missouri Management Systems Evaluation Area (MSEA; Ward *et al.* 1994). Historic farming practices prior to 1990 at this site are given in Lerch *et al.* (2005).

Experimental design and soil sampling

Five different crop management systems were established in the spring of 1991 on long (190 m), narrow (20 m) plots (0.35 ha each). For the present study, four of the five management systems were selected. The experiment was conducted as a four cropping system × three landscape position × three replicate study, in a randomized complete block design with landscape position as a split-block treatment. Three of the management systems were grain cropping systems and one was CRP. Details of each management system are given in Table 1. During the first few years of CRP, the growth of all plant species was observed. However, by 1995 tall fescue predominated and few other species were found. The CRP system had

Table 1 Description of the four management systems selected for the study

Management system	Description	Fertilizer input	Yield goal
Annual cropping system 1 (ACS1)	Mulch tillage[†] with a corn (*Zea mays* L.)–soybean (*Glycine max* [L.] Merr.) rotation	N: 190 kg ha^{-1} for corn. Lime, P and K: by soil test	10.1 Mg ha^{-1} for corn and 2.5 Mg ha^{-1} for soybean
Annual cropping system 2 (ACS2)	No-till with a corn (*Zea mays* L.)–soybean (*Glycine max* [L.] Merr.) rotation	N: 151 kg ha^{-1} for corn. Lime, P and K: by soil test	7.5 Mg ha^{-1} for corn and 2.5 Mg ha^{-1} for soybean
Annual cropping system 3 (ACS3)	Mulch tillage (1991–1995) then no-till (1996–2002) with a corn–soybean–wheat (*Triticum aestivum*) rotation, with either hairy vetch (*Vicia villosa*) (1994–1995) or red clover (*Trifolium pretense*) (1996–2002) cover crop following wheat	N: 150 kg ha^{-1} for corn. 101 kg ha^{-1} for wheat. Lime, P and K: by soil test	8.7 Mg ha^{-1} for corn, 2.5 Mg ha^{-1} for soybean and 4.0 Mg ha^{-1} for wheat
Conservation reserve program (CRP)	Initiated as a mixture of grasses (i.e. orchard [*Dactylis glomerata* L.], smooth brome [*Bromus inermis* Leyss.], timothy [*Phleum pratense* L.] and tall fescue [*Festuca arundinacea*]) and a legume (i.e. alfalfa [*Medicago sativa*]) drilled in the spring of 1991. In March 1992 additional legumes (i.e. hairy vetch, red clover, lespedeza [*Lespedeza striata*] and birdsfoot trefoil [*Lotus corniculatus*]) were over-seeded	None	None

[†]Tillage system that targets maximum retention of crop residues (30% or more) on the soil surface.

no agrichemicals and the weeds were controlled by mowing every other year, with plant residues allowed to remain on the field.

Three landscape position locations were chosen in each plot, representing the footslope (0–1% slope), backslope (1–3% slope) and summit (1–2% slope). In November 2002, soil samples from each management system and landscape position were collected at depths of 0–7.5, 7.5–15 and 15–30 cm using a Giddings Machine Company (Fort Collins, CO, USA) hydraulic soil core sampler. These sample depths were chosen because they matched previous similar investigations (Brejda *et al*. 2000; Johnson *et al*. 2001; Kettler *et al*. 2000; Wander and Bollero 1999). Three 5.5-cm diameter cores within 1 m of each other were taken at each sampling site within a landscape position. From one core, a 5.1-cm long section of core (120 cm^3) from each of the three depths was sub-sampled and oven-dried at 105°C for 3 days for soil water content and D_b determination. The other two cores were mixed by depth increment. From this, approximately 170 cm^3 of soil was sub-sampled and refrigerated at 4°C for microbial biomass determination. The remainder of the sample was air-dried and ground to pass through a 2-mm sieve for other analyses. For the grain cropping systems, plots that had been cropped in soybean in 2002 were sampled.

To understand the change in soil properties over the 12-year period, the 2002 soil property results were compared to baseline soil samples taken just prior to initiation of the management systems in 1991. The exact locations of the 1991 sampling did not exactly coincide with the 2002 sampling locations. Results from 1991 were matched as closely as possible to the 2002 locations and in all cases were within 20 m. For the 1991 sampling data, 1.2-m soil sample cores were collected and sub-sampled by soil horizon increment for laboratory analysis. As the 1991 sample was taken by horizon and the 2002 sampling was by set increments, comparison was done between Ap horizon (average depth of 15 cm) data for 1991 and the average of the 0–7.5 cm and 7.5–15 cm soil depths for 2002.

Soil analysis

The soil physical properties measured included soil particle size distribution using the pipette method as outlined by the National Soil Survey Center Staff (1996). The D_b was calculated using the oven-dried mass of the sample divided by the sample volume (Blake and Hartge 1986). Chemical properties consisted of cation exchange capacity (CEC) (1 mol L^{-1} ammonium acetate extractable at pH 7.0), SOC (dry combustion; Leco, St Joseph, MI, USA; insignificant or no carbonate C was assumed because nearly all samples had a pH < 7.0), TN (dry combustion; Leco) and P using the Bray 1 extraction method (Olsen and Sommers 1982). Microbiological properties included substrate-induced respiration and water-stable soil aggregation (Kremer and Li 2003). Substrate-induced respiration was measured to provide an indication of potential soil microbial respiration (Horwath and Paul 1994). Soil samples (5 g) adjusted to 0.25 g g^{-1} water content and amended with 1 mL of 25% glucose were analyzed for CO_2 evolution after 1, 2, 3 and 7 days incubation at 25°C using a gas chromatograph fitted with a thermal conductivity detector (Zibilske 1994). For water-stable aggregate determination (on the surface sample only), air-dried samples were gently crumbled by hand and sieved to retain the 1–2-mm aggregates. These aggregates were stored at 4°C until tested for stability using a wet-sieving technique (Kemper and Rosenau 1986).

Statistical analysis

Descriptive statistics were calculated by soil quality property. ANOVAs were carried out using SAS PROC GLM (SAS Institute 1989) to assess the impact of management system, landscape position and their interactions on soil physical, chemical and microbiological properties. Two separate ANOVA procedures were conducted. The first included the merged 1991 and 2002 soil sample results and their difference (1991 values subtracted from 2002 values) to assess whether significant changes had take place over the 12-year period. Orthogonal contrasts within the ANOVA were used when significant differences ($P < 0.05$) were found. The second analysis was with the 2002 data only and was done by the three soil sample depths. Soil depth was not a factor in the analysis because it was not an objective of the present study. When an *F*-value was found to be significant ($P < 0.05$), least significant difference (LSD) was calculated to show the differences.

RESULTS

Descriptive statistics of the soil quality properties by soil sampling depth are summarized in Table 2. Depth was statistically evaluated and nearly all properties showed differences with depth. Average D_b was slightly higher at the middle sampling depth of 7.5–15 cm. Clay content increased and silt and sand decreased with soil depth as expected because deeper sampling penetrated the B_t horizon. The CEC differences by depth were parallel to clay content. Soil aggregate stability in the surface soil was highly variable (coefficient of variation [CV] = 54%). Soil pH was highest at the shallowest sample depth and decreased with depth. Common to typical stratification in a soil profile, SOC, TN, Brayl-P and microbial respiration decreased with sampling depth. Brayl-P showed the highest variation with sample depth (CVs ranged

Table 2 Descriptive statistics of soil properties by soil depth

Soil properties	Depth†	Mean	Min.	Max.	Median	Range	SD
D_b (Mg m^{-3})	1	1.26_b‡	0.97	1.53	1.27	0.56	0.13
	2	1.43_a	1.2	1.68	1.44	0.49	0.15
	3	1.32_b	1.08	1.61	1.29	0.52	0.15
Clay (g kg^{-1})	1	242_c	151	524	219	373	80
	2	348_b	173	637	295	464	149
	3	527_a	232	701	531	469	115
Silt (g kg^{-1})	1	671_a	436	771	692	335	75
	2	594_b	346	748	644	402	127
	3	451_c	291	702	450	411	100
Sand (g kg^{-1})	1	87_a	40	130	87	90	18
	2	58_b	10	102	60	92	25
	3	22_c	5	74	14	69	19
Aggregate stability (g kg^{-1})	1	303	106	739	268	633	164
K extractable (cmol kg^{-1})	1	0.4_a	0.2	0.9	0.3	0.7	0.2
	2	0.3_b	0.1	0.6	0.3	0.5	0.2
	3	0.5_a	0.2	0.6	0.5	0.4	0.1
CEC (cmol kg^{-1})	1	20_c	13	35	18	22	5
	2	24_b	14	39	21	25	9
	3	35_a	15	45	36	30	7
SOC (g kg^{-1})	1	12.7_a	7	19	12	12	2.6
	2	9.3_b	6	12	9	6	1.3
	3	8.9_b	3	12	9	9	1.9
pH	1	6.8_a	6	7.5	6.9	1.5	0.4
	2	5.6_b	4.8	6.8	5.7	2	0.5
	3	5.0_c	4.7	5.8	5	1.1	0.2
TN (g kg^{-1})	1	1.2_a	0.8	1.8	1.1	1	0.3
	2	0.9_b	0.3	1.8	0.9	1.5	0.3
	3	0.9_b	0.3	1.6	0.9	1.4	0.3
Bray1-P (mg kg^{-1})	1	26_a	9	90	24	81	15
	2	5_b	1	11	5	9	2
	3	3_b	1	31	2	30	5
Soil respiration (mg CO_2-C kg^{-1} per 3 days)	1	260_a	99	366	266	266	61
	2	153_b	83	261	146	178	46
	3	130_b	43	238	129	195	46

†1, 0–7.5-cm soil depth; 2, 7.5–15-cm soil depth; 3, 15–30-cm soil depth. ‡Least significant difference ($P = 0.05$). Samples were taken in November 2002 ($n = 36$). D_b, bulk density; CEC, cation exchange capacity; SD, standard deviation; SOC, soil organic carbon; TN, total nitrogen.

from 47 to 163%), while pH showed the least variation (CVs ranged from 4 to 9%).

Effect of 12 years of cropping systems

When examined by management system and by landscape position, all but one of the soil properties were unchanged when comparing the 1991 and 2002 sampling dates. The exception was SOC, which significantly increased (23%) under CRP management, averaging 490 kg ha^{-1} $year^{-1}$ in the top 15 cm of soil (Table 3), and remained approximately the same under ACS. Although the average change in ACS SOC was positive (95 kg ha^{-1} $year^{-1}$), the change was not statistically significant over the 12-year period. When comparing landscape position, SOC increased approximately 15% at the summit and backslope positions, but showed little change at the footslope (Table 3).

Impact of crop management and landscape on soil quality properties

The effects of the management systems and landscape position on soil properties were independent (i.e. no significant interactions were observed) and therefore they are presented separately. Management system effects on soil quality properties are plotted in Fig. 1. The SOC was significantly higher in CRP than in the other crop management systems at the shallow soil sampling depth (0–7.5 cm), and had a similar pattern at the second depth. Total N behaved similarly. Soil D_b was greater for the surface soil with ACS3 than the other cropping systems. No differences were observed among management systems with regard to soil pH, soil texture, Brayl-P and CEC. Surface K was higher in CRP than ACS.

Table 3 Net change in soil organic carbon (1991 values subtracted from 2002 values) and associated ANOVA results from the top 15 cm of soil after 12 years of crop management practices

		SOC		
		1991	2002	Change (2002–1991)
Management system	Treatment	($g\ kg^{-1}$)		
Cropping system (CS)†				
Annual cropping system (ACS)	ACS1	9.4 ± 0.4	10.3 ± 0.4	0.9 ± 0.6
ACS	ACS2	10.0 ± 0.3	10.1 ± 0.4	0.1 ± 0.4
ACS	ACS3	9.8 ± 0.7	10.5 ± 0.4	0.7 ± 0.7
Conservation reserve program	CRP	10.4 ± 0.5	12.9 ± 0.6	2.4 ± 0.6
Landscape position (LP)				
	Footslope (FS)	9.8 ± 1.5	9.9 ± 1.7	0.1 ± 2.2
	Backslope (BS)	10.3 ± 1.2	11.7 ± 1.4	1.5 ± 1.4
	Summit (SS)	9.7 ± 1.6	11.2 ± 1.7	1.5 ± 1.9
		ANOVA		
Source of variation	d.f.	*P*		
		1991	2002	Change (2002–1991)
Block	2	0.15	0.01	0.60
CS	3	0.90	< 0.01	0.11
CS contrast				
ACS *vs* CRP	1	0.69	< 0.01	0.04
ACS1 *vs* (ACS2 and ACS3)	1	0.59	0.12	0.23
ACS2 *vs* ACS3	1	0.81	0.16	0.76
LP	2	0.43	0.96	0.02
LP contrast				
FS *vs* BS	1	0.22	0.90	0.01
FS *vs* SS	1	0.51	0.79	0.17
CS × LP	6	0.66	0.10	0.80

†The management systems are described in detail in Table 1. Values are mean ± standard error. SOC, soil organic carbon.

Soil aggregate stability assessed in the surface soil decreased as tillage intensity increased (26 ± 3.2% for no-till [ACS2 and ACS3] and 19 ± 1.5% for minimum tillage [ACS1]) (Fig. 2a). The soil aggregate stability of CRP (50 ± 5.4%) was significantly greater than that recorded for any grain crop management system. No significant differences were observed by landscape position (Fig. 2b).

Soil respiration is representative of microbial biomass and is a more sensitive indicator of changes in soil processes because the turnover rate is greater than just measuring changes in SOC. Soil microbial biomass as measured by CO_2-C emission tended to decrease with soil depth (Fig. 3), although the effect of soil depth was not tested. Differences over time and by management system were greatest at the shallowest soil depth, where fresh decaying crop residues and shallow roots were most prevalent. As previously noted, SOC and TN were generally higher at this depth. By day 2 or 3 into the incubation, an effect of management system was apparent for all three sampling depths. In the top two soil layers, ACS3 had some of the highest measurements of microbial biomass. The microbial biomass of CRP was similar to ACS3 after 7 days of incubation in the surface soil.

Landscape position affected soil quality properties as shown in Fig. 4. In general, SOC decreased with soil depth (not statistically tested). Significantly lower SOC was found in the 7.5–15-cm soil depth at the footslope when compared with the other landscape positions. Again TN followed a similar trend as SOC, but the differences were not statistically significant. Soil D_b and silt content were significantly less and clay content was greater in the 7.5–15-cm soil depth at the backslope landscape position. Small differences were found in pH, with slightly lower values at the sideslope landscape position in the top two sample depths. As expected, CEC tracked clay content. No noteable differences were found with landscape position for Brayl-P and microbial biomass (data not shown).

DISCUSSION

Root growth from perennial grass/legume forages in CRP was sufficient to enhance SOC compared with ACS (Fig. 1). When comparing this finding to other studies that assessed the same soil depths, the average SOC sequestration on this CRP was slightly higher than that reviewed by Lai *et al.* (1999) (240–400 $kg\ ha^{-1}\ year^{-1}$),

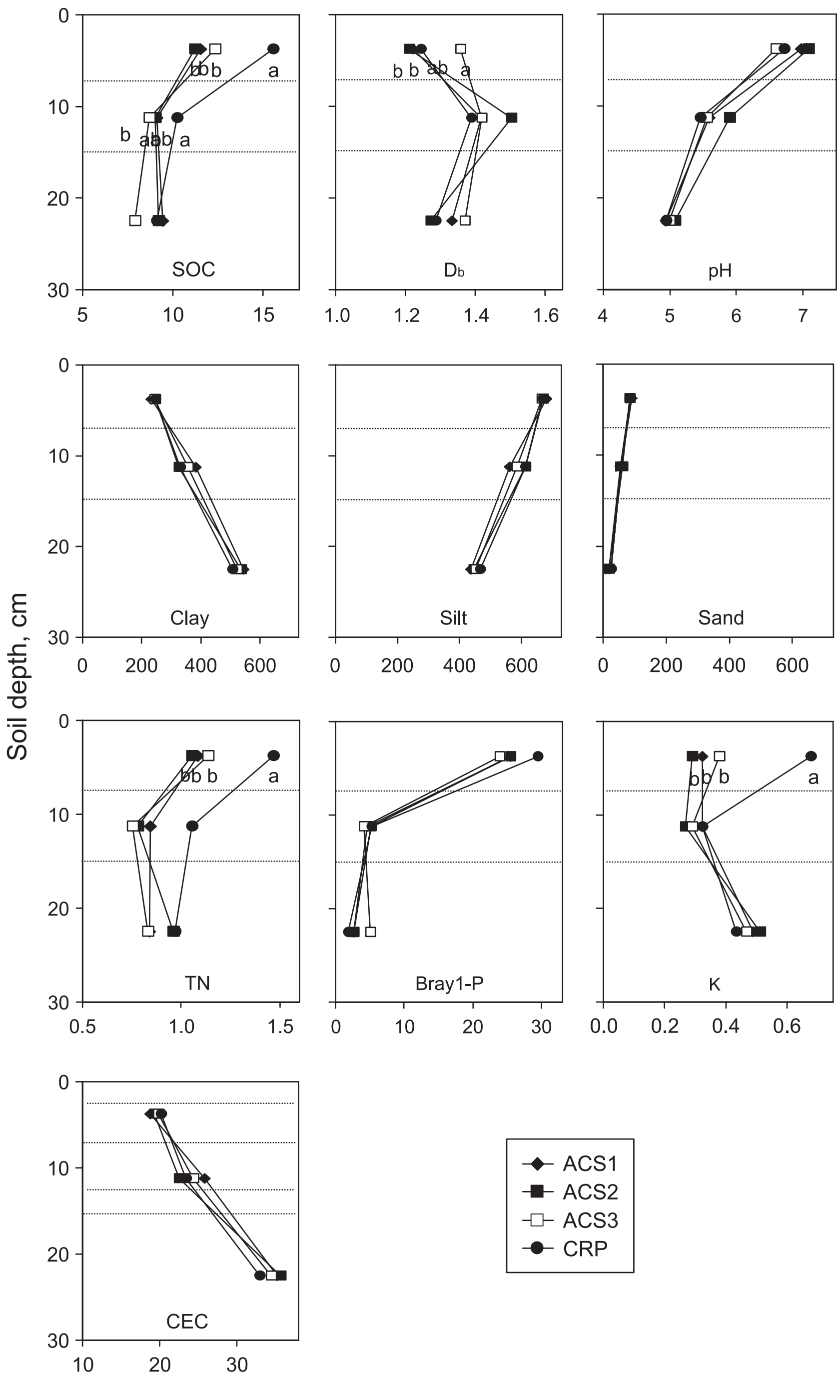

Figure 1 Soil quality properties by management systems and soil depth. The units of each property are presented in Table 2. The management systems are described in Table 1. Different letters indicate a significant difference between the management systems within a soil depth based on least significant difference ($P = 0.05$). D_b, bulk density; CEC, cation exchange capacity; SOC, soil organic carbon; TN, total nitrogen.

but within the range reported by Follett (2001) (100–600 kg ha^{-1} year^{-1}). The positive, but not significant, increases in SOC for the ACS were less than those reported for similar grain cropping systems on other soil types (200 kg ha^{-1} year^{-1}; Lai *et al.* 1999).

Increased SOC and TN with CRP are notable (Fig. 1). Nitrogen plays an important role in carbon sequestration for CRP land (Bronson *et al.* 2004). As no fertilizer N was added to this system and most of the legumes were crowded out by grasses only 4 years after establishment, increases in SOC and TN in the surface soil are likely to have resulted from decreased mineralization without tillage and storage of C in the roots of perennials.

In general, SOC and TN decreased with soil depth because of decaying plant matter, either in the form of shallow roots or surface plant residues, occurring near the soil surface (Figs 1,4). Little change in SOC at the footslope position over the 12-year period was unexpected.

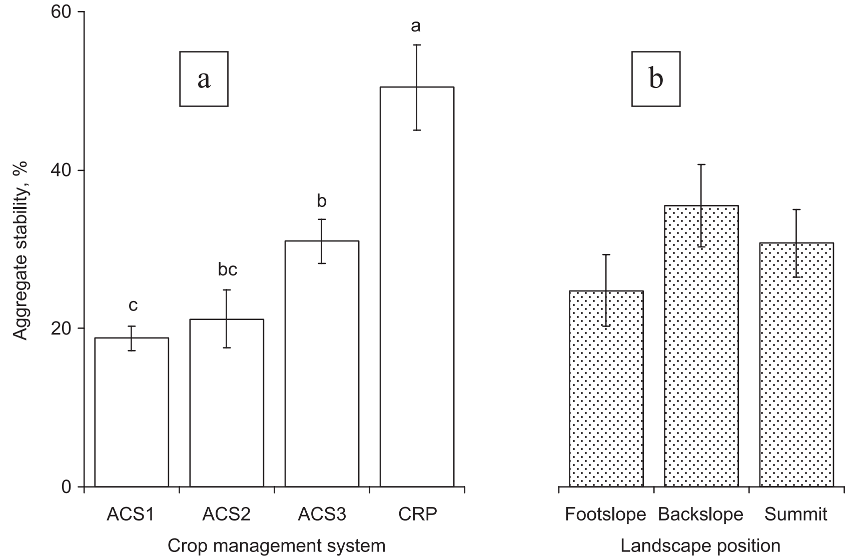

Figure 2 Aggregate stability by (a) crop management system and (b) landscape position. The management systems are described in Table 1. A different letter represents significant management systems and landscape position differences based on least significant difference (P = 0.05). Bars represent standard error of the mean.

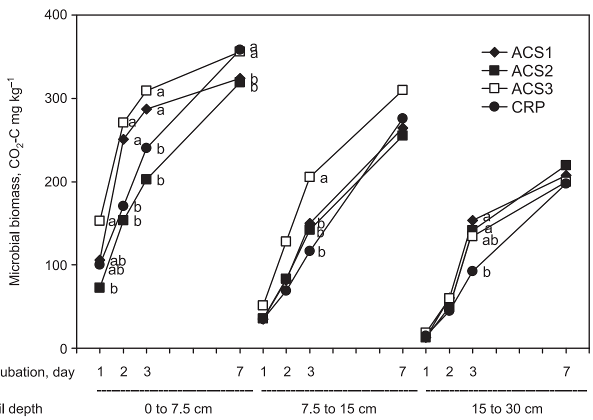

Figure 3 Microbial biomass after the 7-day incubation by management system. The management systems are described in Table 1. Different letters indicate a significant difference between the management systems within a soil depth based on least significant difference (P = 0.05).

Grain yield and biomass production were often greatest at the footslope position (N. R. Kitchen, unpubl. data, 2003), possibly because of the greater potential plant-available water capacity within the soil profile at the claypan footslope positions (Jiang *et al.* 2007). Greater grain production, but less SOC accumulation, at the footslope contrasts with the results of Sherrod *et al.* (2003) for a dryland agroecosystem. The difference in these findings on claypan soils has several plausible explanations. First, the claypan soils of the present study are in a humid environment with approximately three-fold the annual precipitation of the Sherrod *et al.* (2003) investigation. Under wetter and more humid conditions, root and above-ground plant residues on the footslope of a claypan landscape would be subjected to extended periods of high microbial activity and SOC mineralization. The net result was less SOC stored in this landscape position. Second, SOC changes at the footslope position might have been more pronounced below the 15 cm maximum sampling depth of the present study. Average SOC content from 1991 for the 15–90 cm depth was 5.7, 4.2 and 7. 7 g kg^{-1} for the summit, backslope and footslope, respectively, suggesting that more C was stored deeper in the profile at the footslope position. Although SOC is a critical component driving surface soil quality, this assessment is inconclusive for SOC storage changes without a more comprehensive profile sampling. This very point was highlighted by Baker *et al.* (2007) in a review of SOC distribution and storage as affected by tillage practices.

Our findings of increased D_b at the middle sampling depth (Table 2) supported a previous investigation on claypan soils (Blanco-Canqui *et al.* 2004). We presume that compaction at this depth resulted from operations such as cultivation and tractor wheel traffic. Greater soil D_b for the surface soil with ACS3 (Fig. 1) is a problematic feature of claypan soil management. The cover crop in this system, killed by herbicides 2–3 weeks before crop planting, provided a heavy mat of plant residue and extended wet soil conditions into the spring when planting operations were to occur. In a few cases, planting on this system had to be delayed by up to several weeks compared with the other cropping systems. Whether delayed or not, it was common that ACS3 planting was done on “wetter” soils as described by the field technician (M. R. Volkmann, pers. comm., 2003). Soils with heavy-textured sub-soils and thin topsoil, like these claypan soils, are prone to higher D_b when mechanical operations are conducted under moist conditions (Anderson and Cassel 1984).

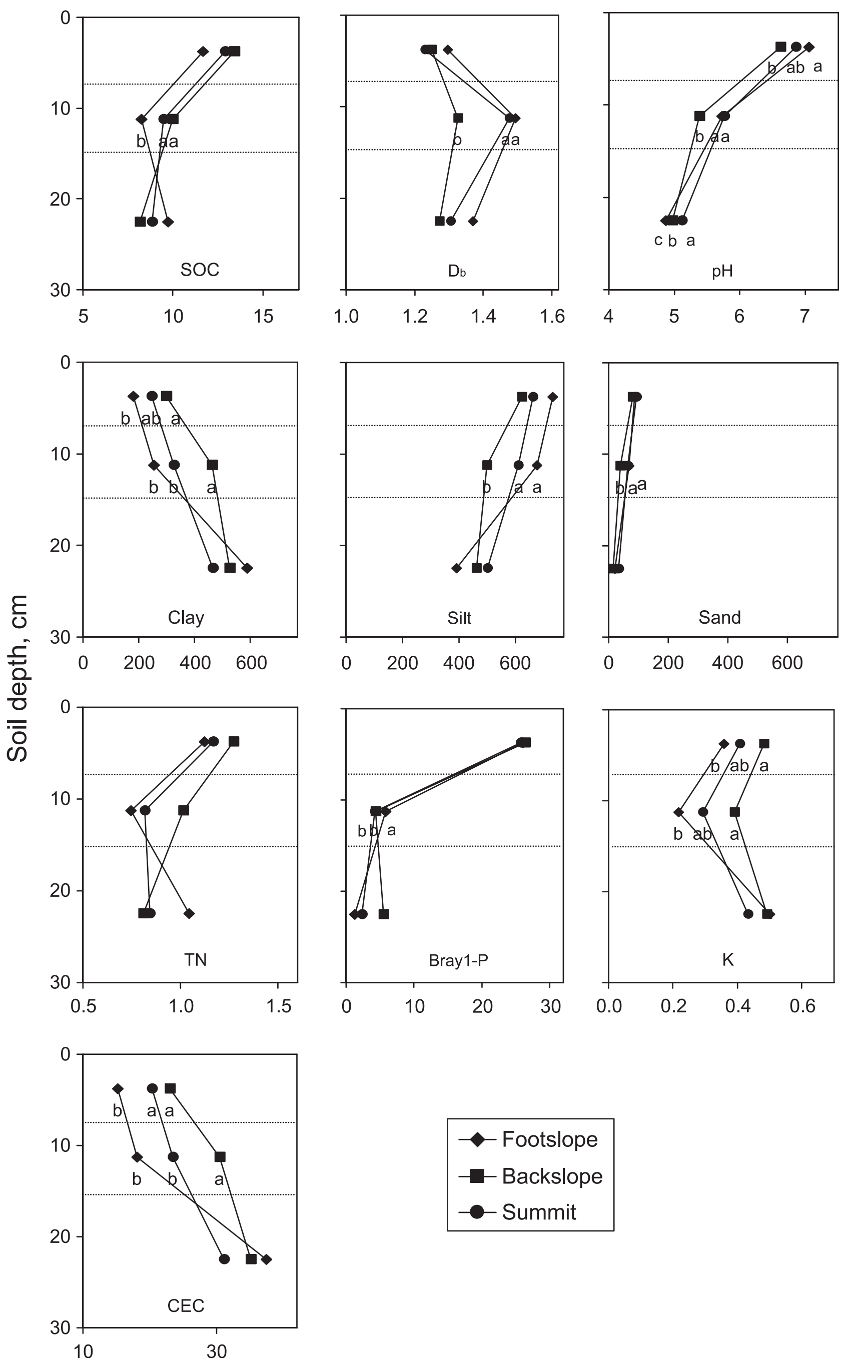

Figure 4 Distribution of soil quality properties by landscape position and soil depth. Units of each property as presented in Table 2. Different letters indicate a significant difference between the landscape postions within a soil depth based on least significant difference ($P = 0.05$). D_b, bulk density; CEC, cation exchange capacity; SOC, soil organic carbon; TN, total nitrogen.

Higher surface K in CRP than in ACS is a function of several factors (Fig. 1). Potassium was removed with harvested grain in the ACS systems, but these systems were also fertilized with K every 2 years; CRP was neither fertilized nor harvested. Therefore, we attribute K enhancement in the surface of CRP to bioaccumulation of K in the upper root-zone provided by perennial plant systems.

Increased aggregate stability in CRP (Fig. 2) is likely to result from continuous plant biomass covering the soil, which limits degradation of soil structure from rainfall energy. In addition, perennial root growth and belowground C portioning favored enhanced soil aggregation and porosity in this system. Finally, microbial activity under high SOC and TN also enhanced soil aggregate stability. Franzluebbers (2004) reported that the water-stable aggregate fraction is greater in soil under no-till and permanent vegetation because high soil organic matter favors microbial activity and the production of substances necessary for aggregate formation.

High microbial biomass in the top two soil layers of ACS3 can be attributed to the enhancement of plant and root residues with the cover crop in this system (Fig. 3). At all three soil depths, the rate of CO_2-C emissions between day 3 and day 7 was greatest with CRP, suggesting a more active microbial biomass associated with high enzyme production compared with ACS. Previous studies have demonstrated higher microbial enzyme activity in soils of CRP and long-term pasture sites relative to cultivated fields (Acosta-Martinez *et al.* 2008; Kremer and Li 2003). Soils under perennial vegetation also develop highly functionally diverse microbial communities (McKinley *et al.* 2005) that actively metabolize a wide array of C substrates (SOC components), resulting in higher soil respiration (Rutigliano *et al.* 2004). Recent molecular studies of soil DNA extracted from CRP and ACS1 at this study site show distinct differences in microbial genetic diversity of the soil bacterial communities (R. J. Kremer, unpubl. data, 2007). The higher rate of CO_2 efflux from the ACS3 and CRP systems suggests that an active and diverse microbial community involved in SOM decomposition and nutrient cycling contributed to the improved soil quality (Sparling 1997).

Higher clay content and lower D_b at the backslope position is the result of a greater portion of the argillic horizon sampled than at the other landscape positions. Average depth to the Bt horizon was approximately 20, 10 and 40 cm for the summit, backslope and footslope positions, respectively. Because of inter-lattice space between clay particles (i.e. small air spaces), D_b decreases as clay content increases in these soils (Jamison *et al.* 1968). In addition, with little slope to shed rain on the footslope and summit landscape positions, these soils would stay wet longer and would be more vulnerable to compaction when trafficked. Similar D_b results were found when landscape position was contrasted in a study on claypan soils by Jiang *et al.* (2007).

In summary, while CRP caused notable soil quality enhancements, these findings suggest that grain crop management had only a minor impact on these claypan soil properties after a 12-year period. Furthermore, these results suggest small effects on soil properties with landscape position. As noted before in the SOC discussion, the sampling strategy of the present study looked only at properties in the surface 30 cm of soil, as opposed to soil profile differences that would encompass the whole root zone. In the case of SOC, whole profile measurements are preferred when both grain and CRP management systems are being compared because perennial crops tend to store C below ground at deeper depths than annual crops. Profile measurements are critical when the capacity of the soils to store atmospheric C is being assessed (Baker *et al.* 2007). In contrast, other studies evaluating management effects on soil quality have suggested much smaller depth increments are needed near the surface (Sherrod *et al.* 2003; Wood *et al.* 1991), when the essence of the quality of that property is a function of the soil–atmosphere interface (e.g. aggregate stability and detachment with rain).

Conclusions

The impact of crop management systems and CRP on claypan soil quality properties was examined over different landscape positions. No interactions were observed between these two factors. The impact of ACS on soil quality properties varied little after 12 years, even when comparing tilled to no-tilled systems. More differences were found when comparing grain cropping systems with the CRP system. Several properties stood out, including SOC, TN and aggregate stability. Soil organic carbon was significantly improved after 12 years of CRP management. We theorize that the primary reason for this difference comes from growing perennial plants that partition more C below ground than annual grain crops. This finding showed that claypan soil quality could be enhanced by applying a CRP management system. Differences between ACS were subtle and support a previous claypan study (Blanco-Canqui *et al.* 2004). The benefits of no-till on soil quality as documented by others (Kettler *et al.* 2000; Sherrod *et al.* 2003) were not found with this investigation. In general, when the cropping system did affect soil properties, it was in the top 15 cm of soil. In conclusion, claypan soils degraded by historical cropping practices will benefit most from the adoption of CRP or CRP-like management.

DISCLAIMER

Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the US Department of Agriculture or the University of Missouri.

REFERENCES

Acosta-Martinez V, Acosta-Mercado D, Sotomayor-Ramirez D, Cruz-Rodriguez L 2008: Microbial communities and enzymatic activities under different management in semiarid soils. *Appl. Soil Ecol.*, **38**, 249–260.

Alberts EE, Wendt RC 1985: Influence of soybean and corn cropping on soil aggregate size and stability. *Soil Sci. Soc. Am. J.*, **49**, 1534–1537.

Anderson SH, Cassel DK 1984: Effect of soil variability on response to tillage of an Atlantic costal plan ultisol. *Soil Sci. Soc. Am. J.*, **48**, 1411–1416.

Angers DA 1998: Water-stable aggregation of Quebec silty clay soils: some factors controlling its dynamics. *Soil Tillage Res.*, **47**, 91–96.

Baker JM, Ochsner TE, Ventera RT, Griffis TJ 2007: Tillage and soil carbon sequestration – what do we really know? *Agric. Ecosystems Environ.*, **118**, 1–5.

Bauer A, Black AL 1981: Soil carbon, nitrogen, and bulk density comparisons in two cropland tillage systems after 25 years and in virgin grassland. *Soil Sci. Soc. Am. J.*, **45**, 1166–1170.

Blake GR, Hartge KH 1986: Bulk Density. *In* Methods of Soil Analysis: Part 1 – Physical and Mineralogical Methods. SSSA Book Ser. No. 5. Ed. A. Klute, pp. 363–375. Soil Science Society of America and American Society of Agronomy, Madison.

Blanco-Canqui H, Gantzer CJ, Anderson SH, Alberts EE 2004: Tillage and crop influences on physical properties for an Epiaqualf. *Soil Sci. Soc. Am. J.*, **68**, 567–576.

Bowman RA, Vigil MF, Nielsen DC, Anderson RL 1999: Soil organic matter changes in intensively cropped dryland systems. *Soil Sci. Soc. Am. J.*, **63**, 186–191.

Brejda JJ, Karlen DL, Smith JL, Allan DL 2000: Identification of regional soil quality factors and indicators: II. Northern Mississippi loess hills and Palouse prairie. *Soil Sci. Soc. Am. J.*, **64**, 2125–2135.

Bronson KF, Zobeck TM, Chua TT, Acosta-Martinez V, van Pelt RS, Booker JD 2004: Carbon and nitrogen pools of southern high plains cropland and grassland soils. *Soil Sci. Soc. Am. J.*, **68**, 1695–1704.

Campbell CA, McConkey BG, Zentner RP, Selles F, Curtin D 1996: Long-term effects of tillage and crop rotations on soil organic C and total N in a clay soil in southwestern Saskatchewan. *Can. J. Soil Sci.*, **76**, 395–401.

Campbell CA, Souster W 1982: Loss of organic matter and potentially mineralizable nitrogen from Saskatchewan soils due to cropping. *Can. J. Soil Sci.*, **62**, 651–656.

Campbell CA, Zentner RP, Liang BC, Roloff G, Gregorich EC, Blomert B 2000: Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan – Effect of crop rotations and fertilizers. *Can. J. Soil Sci.*, **80**, 179–192.

Chaney K, Swift RS 1984: The influence of organic matter and aggregate stability in some British soils. *J. Soil Sci.*, **35**, 223–230.

Chepil WS 1956: Factors that influence clod structure and erodibility of soil by wind: V. Organic matter at various stages of decomposition. *Soil Sci.*, **78**, 413–421.

Dao TH 1996: Tillage system and crop residue effects on surface compaction of a Paleustoll. *Agron. J.*, **88**, 141–148.

Dick WA, McCoy EL, Edwards WM, Lai R 1991: Continuous application of no-tillage to Ohio soils. *Agron. J.*, **83**, 65–73.

Dicks MR 1994: Costs and benefits of the CRP. *In* When the CRP Contracts Expire: The Policy Options. Proc. of the Soil and Water Conservation Society. 10–11 February 1994, Ankeny, IA, USA, pp. 39–45.

Edwards JH, Wood CW, Thurlow DL, Ruf ME 1992: Tillage and crop rotation effects on fertility status of a Hapludalf soil. *Soil Sci. Soc. Am. J.*, **56**, 1577–1582.

Follett RF 2001: Soil management concepts and carbon sequestration in cropland soils. *Soil Tillage Res.*, **61**, 77–92.

Franzluebbers AJ 2004: Tillage and residue management effects on soil organic matter. *In* Soil Organic Matter in Sustainable Agriculture. Eds F Magdoff and RR Weil, pp. 227–268. CRC Press, Boca Raton.

Gantzer CJ, Blake GR 1978: Physical characteristics of Le Sueur clay loam soil following no-till and conventional tillage. *Agron. J.*, **70**, 853–857.

Gebhart DL, Johnson HB, Mayeux HS, Polley HW 1994: The CRP increases soil organic carbon. *J. Soil Water Conserv.*, **49**, 488–492.

Ghidey F, Alberts EE 1997: Plant root effects on soil erodibility, splash detachment, soil strength, and aggregate stability. *Trans. ASAE*, **40**, 129–135.

Ghidey F, Alberts EE 1998: Runoff and soil losses as affected by corn and soybean tillage systems. *J. Soil Water Conserv.*, **53**, 64–70.

Gilley JE, Doran JW 1997: Tillage effects on soil erosion potential and soil quality of a former conservation reserve program site. *J. Soil Water Conserv.*, **52**, 184–188.

Gilley JE, Patton BD, Nyren PE, Simanton JR 1996: Grazing and haying effects on runoff and erosion from a former conservation reserve program site. *Appl. Eng. Agric.*, **12**, 681–684.

Halvorson AD, Wienhold BJ, Black AL 2002: Tillage, nitrogen, and cropping system effects on soil carbon sequestration. *Soil Sci Soc. Am. J.*, **66**, 906–912.

Hammel JE 1989: Long term tillage and crop rotation effects on bulk density and soil impedance in northern Idaho. *Soil Sci Soc. Am. J.*, **53**, 1515–1519.

Haynes RJ 2000: Interactions between soil organic matter status, cropping history, method of quantification and sample pretreatment and their effects on measured aggregate stability. *Biol. Fertil. Soils*, **30**, 270–275.

Horwath WR, Paul KS 1994: Soil respiration. *In* Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties. Eds RW Weaver, JS Angle and P Bottomley, pp. 653–724. Soil Science Society of America, Madison.

Jamison VC, Smith DD, Thornton JF 1968. Soil and Water Research on a Claypan soil. USDA-ARS Tech. Bull. 1379. US Government Printing Office, Washington.

Jiang P, Anderson SH, Kitchen NR, Sadler EJ, Sudduth KA 2007: Landscape and conservation management effects on hydraulic properties of claypan-soil toposequence. *Soil Sci Soc. Am. J.*, **71**, 803–811.

Johnson CK, Doran JW, Duke HR, Wienhold BJ, Eskridge KM, Shanahan JF 2001: Field-scale electrical conductivity mapping for delineating soil condition. *Soil Sci Soc. Am. J.*, **65**, 1829–1837.

Jung WK, Han HS 2007: Paddy soil tillage impacts on SOC fractions. *Korean J. Soil Sci Fert.*, **40**, 326–329.

Kemper WR, Rosenau RC 1986: Aggregate stability and size distribution. *In* Methods of Soil Analysis, Part I, 2nd edn. Ed. A Klute, pp. 425–442. American Society of Agronomy, Madison.

Kettler TA, Lyon DJ, Doran JW, Powers WL, Stroup WW 2000: Soil quality assessment after weed-control tillage in a no-till wheat fallow cropping system. *Soil Sci. Soc. Am. J.*, **64**, 339–346.

Kremer RJ, Li J 2003: Developing weed-suppressive soils through improved soil quality measurement. *Soil Tillage Res.*, **72**, 193–202.

Lai R, Follett RF, Kimble J, Cole CV 1999: Managing US cropland to sequester carbon in soil. *J. Soil Water Conserv.*, **54**, 374–381.

Lerch RN, Kitchen NR, Kremer RJ *et al.* 2005: Development of a conservation-oriented precision agriculture system: I. Water and soil quality assessment. *J. Soil Water Conserv.*, **60**, 411–421.

Mann LK 1985: Changes in soil carbon storage after cultivation. *Soil Sci.*, **142**, 279–288.

McKinley VL, Peacock AD, White DC 2005: Microbial community PLFA and PHB responses to ecosystem restoration in tallgrass prairie soils. *Soil Biol. Biochem.*, **37**, 1946–1958.

National Soil Survey Center Staff 1996: Soil Survey Laboratory Methods Manual. Soil Survey Investigations Rep. 42. Version 3.0. United States Department of Agriculture-Natural Resource Conservation Service, Lincoln.

Oades JM 1984: Organic matter and water-stable aggregate in soils. *J. Soil Sci.*, **33**, 141–163.

Olsen SR, Sommers LE 1982: Phosphorus. *In* Methods of Soil Analysis. Part 2. 2nd edn. Agron. Monogr. 9. Ed. A. L. Page, pp. 403–430. Soil Science Society of America and American Society of Agronomy, Madison.

Peterson TA, Varvel GE 1989: Crop yield as affected by rotation and nitrogen rate: III. *Com. Agron. J.*, **81**, 735–738.

Potter KN, Jones OR, Torbert HA, Unger PW 1997: Crop rotation and tillage effects on organic carbon sequestration in the semiarid southern high plains. *Soil Sci.*, **162**, 140–147.

Potter KN, Torbert HA, Jones OR, Matocha JE, Morrison Jr JE, Unger PW 1998: Distribution and amount of soil organic C in long-term management systems in Texas. *Soil Tillage Res.*, **14**, 39–52.

Rachman A, Anderson SH, Gantzer CJ, Thompson AL 2003: Influence of long-term cropping systems on soil physical properties related to soil erodibility. *Soil Sci. Soc. Am. J.*, **67**, 637–644.

Randall GW, Huggins DR, Russelle MP, Fuchs DJ, Nelson WW, Anderson JL 1997: Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. *J. Environ. Qual.*, **26**, 1240–1247.

Rhoton FE 2000: Influence of time on soil response to no-till practices. *Soil Sci. Soc. Am. J.*, **64**, 700–709.

Rutigliano FA, D'Ascoli R, Virzo De Santo A 2004: Soil microbial metabolism and nutrient status in a Mediterranean area as affected by plant cover. *Soil Biol. Biochem.*, **36**, 1719–1729.

SAS Institute 1989: SAS/STAT User's Guide. Ver. 6. 4th edn. SAS Institute, Cary.

Scott HD, Mauromoustakos A, Handayani IP, Miller DM 1994: Temporal variability of selected properties of loessial soil as affected by cropping. *Soil Sci. Soc. Am. J.*, **58**, 1531–1538.

Shaver TM, Peterson GA, Ahuja LR, Westfall DG, Sherrod LA, Dunn G 2002: Surface soil physical properties after 12 years of dryland no-till management. *Soil Sci. Soc. Am. J.*, **66**, 1296–1303.

Sherrod LA, Peterson GA, Westfall DG, Ahuja LR 2003: Cropping intensity enhances soil organic carbon and nitrogen in a no-till agroecosystem. *Soil Sci. Soc. Am. J.*, **67**, 1533–1543.

Sparling GP 1997: Soil microbial biomass, activity and nutrient cycling as indicators of soil health. *In* Biological Indicators of Soil Health. Eds CE Pankhuist, BM Doube and VVSR Gupta, pp. 97–119. CAB International, Oxon.

United States Department of Agriculture-Natural Resource Conservation Service 1995: Soil Survey of Audrain County, Missouri (1995-387-974/00537/SCS). US Government Printing Office, Washington.

Wander MM, Bollero GA 1999: Soil quality assessment of tillage impacts in Illinois. *Soil Sci Soc. Am. J.*, **63**, 961–971.

Ward AD, Hatfield JL, Lamb JA, Alberts EE, Logan JJ, Anderson JL 1994: The management systems evaluation areas programs: tillage and water quality research. *Soil Tillage Res.*, **30**, 49–74.

Wood CW, Westfall DG, Peterson GA 1991: Soil carbon and nitrogen changes on initiation of no-till cropping systems. *Soil Sci. Soc. Am. J.*, **55**, 470–476.

Zibilske LM 1994: Carbon mineralization. *In* Methods of Soil Analysis, Part 2. Microbiological and Biochemical Properties. Eds RW Weaver, JS Angle and P Bottomley, pp. 653–724. Soil Science Society of America, Madison.