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Cropping system influences on soil chemical properties and soil quality in the Great Plains

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Abstract

Soil management and cropping systems have long-term effects on agronomic and environmental functions. This study examined the influence of contrasting management practices on selected soil chemical properties in eight long-term cropping system studies throughout the Great Plains and the western Corn Belt. For each study, soil organic C (SOC), total N (TN), particulate organic matter (POM), inorganic N, electrical conductivity (EC), and soil pH were evaluated at 0–7.5, 7.5–15, and 15–30 cm within conventional (CON) and alternative (ALT) cropping systems for 4 years (1999–2002). Treatment effects were primarily limited to the surface 7.5 cm of soil. No-tillage (NT) and/or elimination of fallow in ALT cropping systems resulted in significantly ($P < 0.05$) greater SOC and TN at 0–7.5 cm within five of the eight study sites [Akron, Colorado (CO); Bushland, Texas (TX); Fargo, North Dakota (ND); Mandan, ND; and Swift Current, Saskatchewan (SK), Canada]. The same pattern was observed with POM, where POM was significantly ($P < 0.05$) greater at four of the eight study sites [Bushland, TX, Mandan, ND, Sidney, Montana (MT), and Swift Current, SK]. No consistent pattern was observed with soil EC and pH due to management, although soil EC explained almost 60% of the variability in soil NO_3-N at 0–7.5 cm across all locations and sampling times. In general, chemical soil properties measured in this study consistently exhibited values more conducive to crop production and environmental quality in ALT cropping systems relative to CON cropping systems.

Key words: management practices, soil organic matter, electrical conductivity, soil acidity

Introduction

In agricultural systems, soil and crop management decisions will affect soil quality, soil nutrient dynamics, and soil chemical properties. These management decisions include crop rotation, residue management, and the intensity and frequency of tillage. Bowman et al.[1] measured a 20% increase in soil organic C (SOC) in the surface soils of continuously cropped no-till managed dryland systems, which previously were managed under conventionally tilled wheat–fallow. Bowman et al.[1] correlated the increase in SOC to greater annualized crop yield (greater annualized C additions as crop residue). In their analysis, 57% of the variability in SOC at the 0–5 cm depth could be explained by a simple linear relationship with annualized grain yield. Similarly, Pikul et al.[2] measured significantly greater SOC in continuous corn than in a corn–soybean rotation near Brookings, South Dakota (SD). In that study, greater SOC was also thought to be related to the greater C additions in

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continuous corn than in corn–soybean systems. In continuous corn, more total C was fixed over time when compared to a corn–soybean rotation.

Tillage can degrade soil quality by mechanically destroying soil aggregates and exposing protected soil organic matter (SOM) to microbial attack. Tillage also increases residue mixing with the soil, thereby enhancing decomposition of both crop residues and native SOM. Conversely, many studies have linked SOM increases in no-tillage (NT) to an altered surface soil environment that favors slower SOM turnover and increased soil aggregation and aggregate-associated SOM relative to soil managed with conventional (CON) tillage[3,4].

For many years, loss of SOM in the Great Plains has been associated with tillage and summer fallow management[5,6]. Wood et al.[7] observed an increase in SOM at the surface soil (0–10 cm) after 4 years by changing the management practice from tilled wheat–fallow to NT and reducing fallow frequency. In general, management to reduce fallow frequency accompanied with NT and continuous cropping replenishes SOM[8].

Recently, interest has increased in identifying indicators appropriate for describing soil quality changes. Gregorich et al.[9] and Smith and Doran[10] suggested that soil total N (TN), SOC, inorganic N, P, and K, soil pH, and electrical conductivity (EC) are important measurements for assessing chemical aspects of soil quality. Particulate organic matter (POM), defined as a labile fraction of SOM, has also been used as a sensitive indicator of management effects on soil quality[11]. Cambardella and Elliott[11] suggested that decreased POM with increasing disturbance by tillage accounts for much of the SOM lost with cultivation of native sod. These chemical parameters as well as POM and SOC are important measures of soil quality because they provide indicators of soil nutrient supplying capacity (a critical soil function[10,12]), soil structure, SOM dynamics, and C sequestration.

The objective of this research was to assess the value of POM, EC, pH, inorganic N, TN, and SOC as attributes for comparing contrasting management practices over time in established long-term cropping system studies in the Great Plains and western Corn Belt. For each long-term study, a comparison was made between a CON management system that included fallow, tillage, and/or monocropping, and an alternative (ALT) management system that included reduced or conservation tillage, reduced incidence of fallow, and/or extended crop rotations over a period of 4 years.

Materials and Methods

Long-term cropping system studies at eight locations in the Great Plains were used in this study. The locations were near Akron, Colorado (CO); Brookings, SD; Bushland, Texas (TX); Fargo, North Dakota (ND); Mandan, ND; Mead, Nebraska (NE); Sidney, Montana (MT); and Swift Current, Saskatchewan (SK), Canada. At each location, plots representing the traditional CON management practice were compared to an ALT management practice (Table 1). Detailed information about soil characteristics and management practices at each location is provided in Varvel et al.[13].

To assess soil chemical properties, composite soil samples were collected three times a year from three replications of each treatment in CON and ALT systems at each location. Soil samples were collected three times each

Table 1. Contrasting management treatments within eight long-term cropping systems. Treatments selected at each site differed in management intensity as characterized by either type or frequency of tillage, cropping intensity, and/or crop rotation diversity and are termed conventional (CON) or alternative (ALT).

Location/soil series	Treatment	Crop sequence	Tillage	N rate[1]
Akron, CO	CON	WW–F[2]	Sweep (fallow)	Varied
Weld silt loam	ALT	WW–C–M	No tillage	Varied
Brookings, SD	CON	C–C	Chisel plow and disk	High
Barnes sandy clay loam	ALT	C–SB–SW–A	Chisel plow and disk	0
Bushland, TX	CON	WW–SO–F	No tillage	Varied
Pullman silty clay loam	ALT	WW–WW	No tillage	0
Fargo, ND	CON	DW–P	Fall plow	0
Fargo silty clay	ALT	DW–P	No tillage	0
Mandan, ND	CON	SW–F	Chisel plow and disk	Medium
Wilton silt loam	ALT	SW-WW-SU	No tillage	Medium
Mead, NE	CON	C–C	Tandem disk, 2×	High
Sharpsburg silty clay loam	ALT	C–SB–SO–OCL	Tandem disk, 2×	High
Sidney, MT	CON	SW–F	Tandem disk	45 kg ha^{-1}
Vida loam	ALT	SW–SW	No tillage	45 kg ha^{-1}
Swift Current, SK	CON	SW–F	Chisel plow and harrow	Varied
Swinton silt loam	ALT	SW–L	Chisel plow and harrow	Varied

[1] Varied, N fertilizer application rate based on soil test results.
[2] Abbreviations: A, alfalfa; C, corn; DW, durum spring wheat; F, summer fallow; L, lentil; M, proso millet; OCL, oat + clover; P, field pea; SB, soybean; SO, sorghum; SU, sunflower; SW, spring wheat; WW, winter wheat.

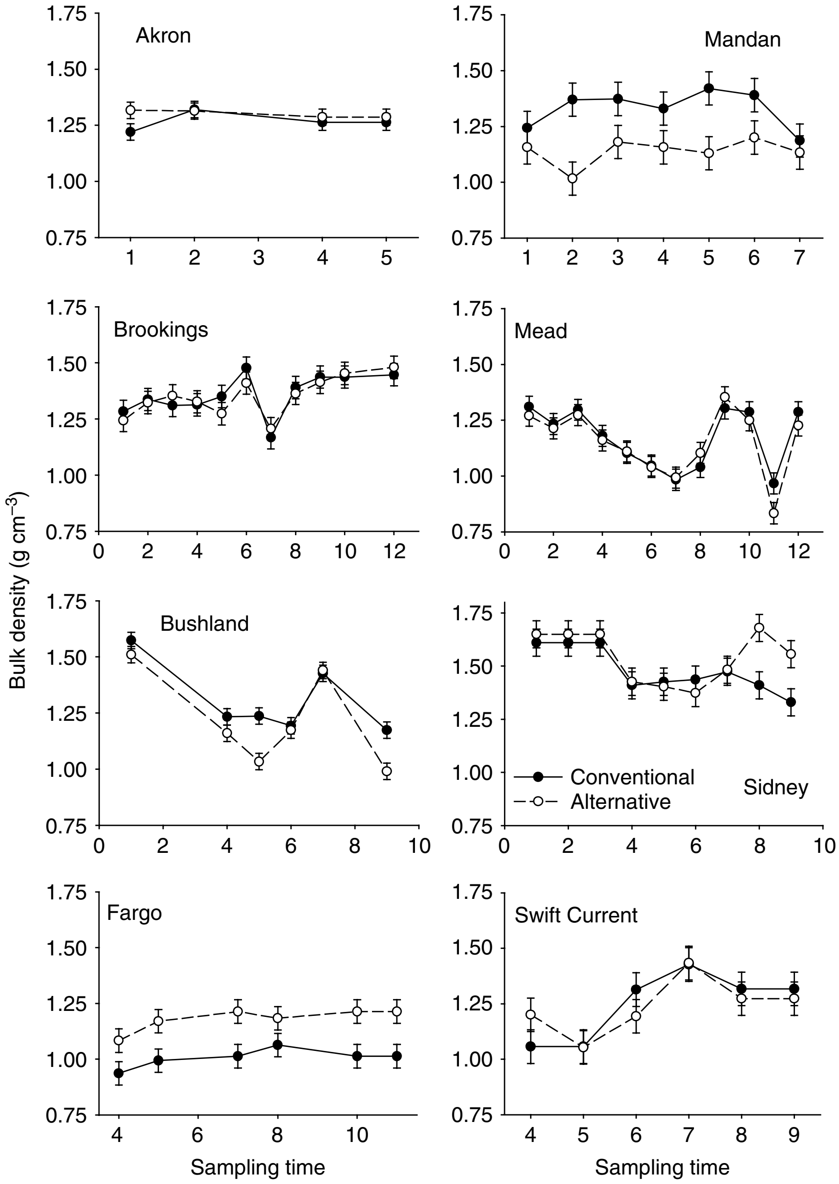

Figure 1. Soil bulk density (g cm^{-3}) in the 0–7.5 cm depth as a function of sampling time (multiple years) under the conventional and alternative management systems at eight locations in the Great Plains. Bars represent 1 SEM. Sampling times correspond to preplant = 1, 4, 7, and 10; peak biomass = 2, 5, 8, and 11; and post-harvest = 3, 6, 9, and 12.

year from each replicate of the treatments (for details of the sampling method, see Varvel et al.[13]). A total of 15–18 cores were collected to provide 500 g of oven-dry soil at each site on each sampling date. The actual mass of oven-dried soil and the volume of soil collected (calculated using the soil probe diameter, number of cores, and depth increment) were used to calculate bulk density. Upon collection, samples were saved in double-lined plastic bags and placed in cold storage (4°C) until processing.

Samples were air-dried and passed through a 2-mm sieve prior to analyses. Each site performed its analysis. Soil total C and TN were determined by dry combustion using a Leco IR C/N analyzer (CHN-2000, St. Joseph, MI, USA, 49085) or a Carlo Erba C/N analyzer (Carlo Erba Instruments, Milan, Italy) on soil ground to pass a 0.106-mm sieve. To determine SOC, inorganic C was subtracted from total C. Inorganic C was measured on soils with a pH$\geqslant$7.2 by quantifying the amount of CO_2 produced after application of dilute HCl stabilized with $FeCl_2$[14]. Inorganic N was determined by extracting 10 g of soil with 100 ml of 2 *M* KCl after shaking for 1 h at 300 rpm on an orbital shaker. The supernatant was filtered through Whatman filter paper No. 2 and stored at 4°C until analyzed colorimetrically for NH_4-N and NO_3-N using the method described by Keeney and Nelson[15]. Soil pH and EC were determined using soil : water in the ratio 1 : 1 (w : w)[10].

POM was determined using the procedure of Cambardella et al.[16]. Briefly, POM was measured by adding 90 ml

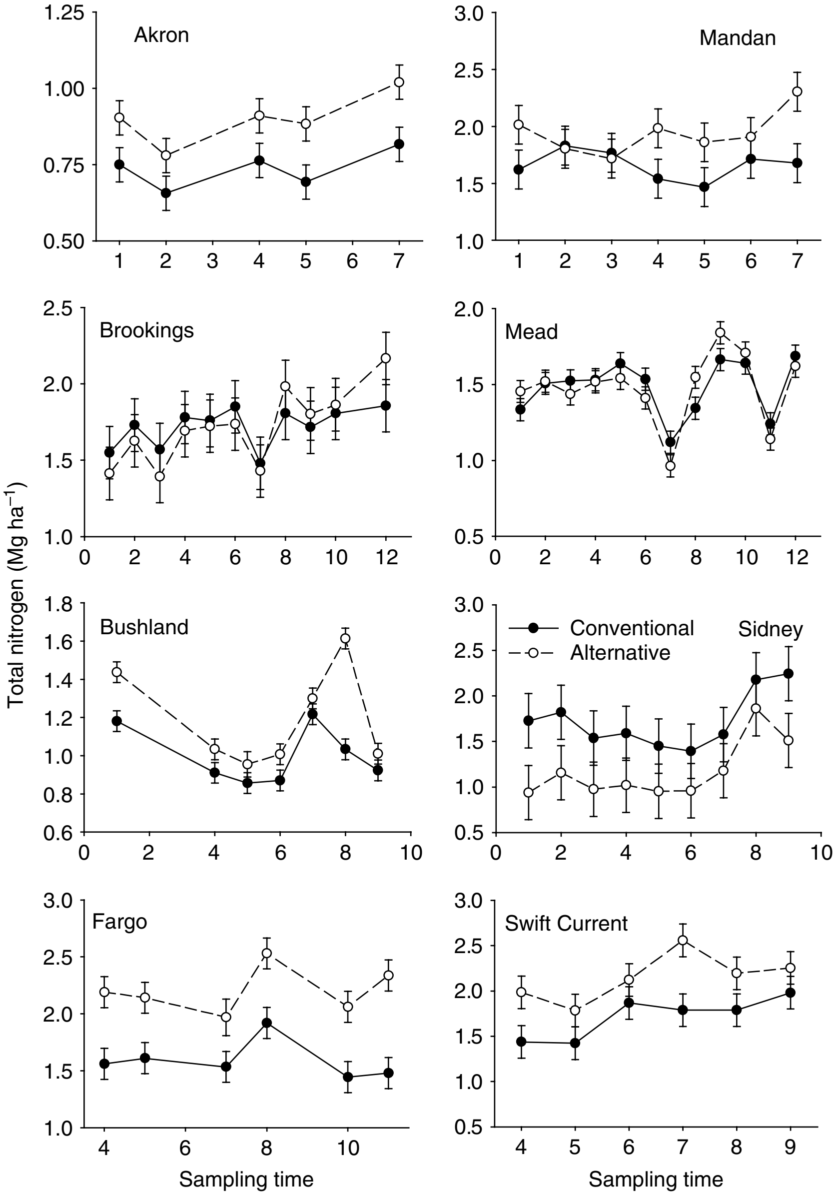

Figure 2. Total soil N (Mg N ha^{-1}) in the 0–7.5 cm depth as a function of sampling time (multiple years) under the conventional and alternative management systems at eight locations in the Great Plains. Bars represent 1 SEM. Sampling times correspond to preplant = 1, 4, 7, and 10; peak biomass = 2, 5, 8, and 11; and post-harvest = 3, 6, 9, and 12.

of 0.5% $Na(PO_3)_x$ to 30 g of air-dried soil in a screw-cap plastic vial. Vials were capped and placed on a reciprocating shaker overnight at 120 rpm. The contents of each vial were then transferred to a set of nested sieves having mesh sizes of 0.5 and 0.053 mm, where the material retained on each sieve was rinsed until all material smaller than the mesh size had been washed through. The material retained on each sieve was transferred into an aluminum weighing pan and dried to a constant weight at 55°C. The dried mass of the 0.5–2.0 and 0.053–0.5 mm fractions was recorded to the nearest milligram. Loss-on-ignition (LOI) for the total soil and POM was determined by mass difference after 4 h in a muffle furnace at 450°C. Air-dried soil (5–10 g) was used for LOI of total soil. POM associated with the two different size fractions was calculated using the equation:

$$\text{mg POM g}^{-1}\text{ soil} = \frac{\begin{matrix}\text{initial mass}\\ \text{of the fraction}\end{matrix} - \begin{matrix}\text{mass of the fraction}\\ \text{after ignition}\end{matrix}}{\text{initial mass of the soil}} \times \frac{1000\text{ mg}}{\text{g}}. \qquad (1)$$

POM as a percentage of SOM was calculated using the equation.

$$\text{POM as \% of SOM} = \frac{\sum \text{mg of the fraction lost on ignition}}{\text{mg of total soil lost on ignition}} \times 100. \qquad (2)$$

Data are reported on a volumetric basis by adjusting data for differences in bulk density. Data were analyzed using a

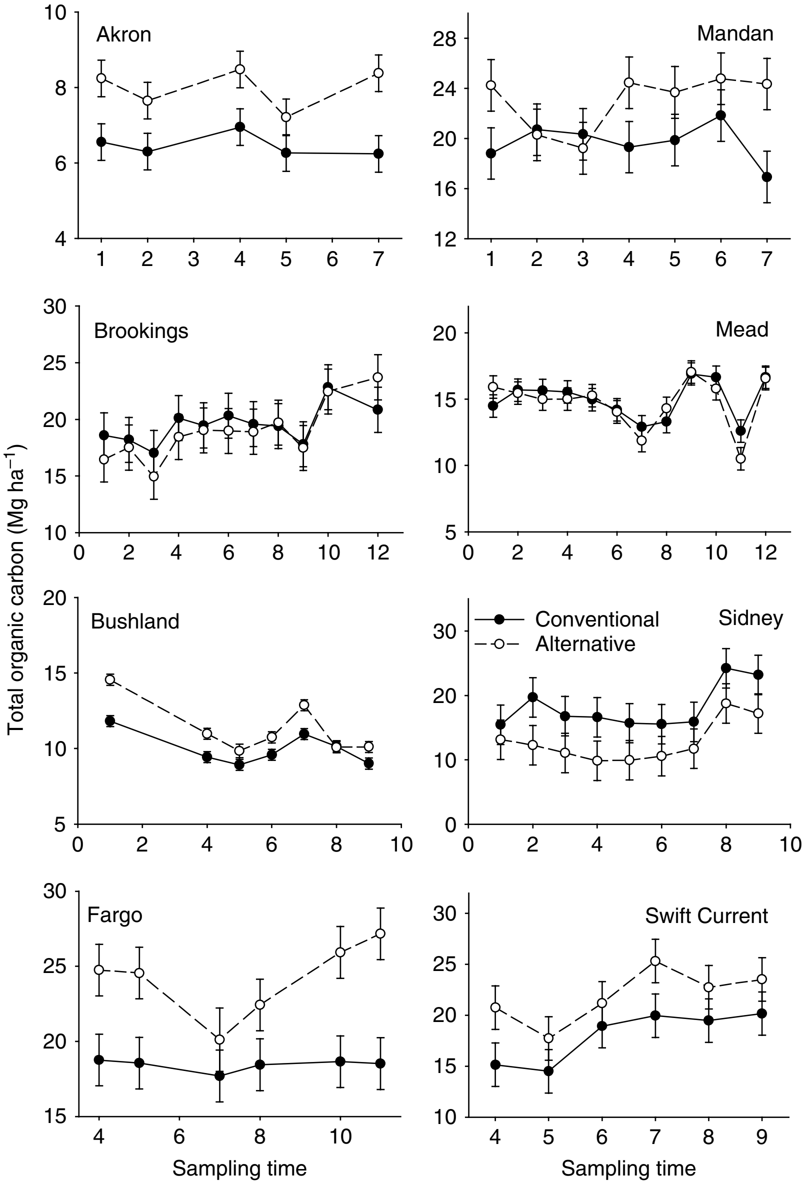

Figure 3. Total soil organic carbon (Mg C ha^{-1}) in the 0–7.5 cm depth as a function of sampling time (multiple years) under the conventional and alternative management systems at eight locations in the Great Plains. Bars represent 1 SEM. Sampling times correspond to preplant = 1, 4, 7, and 10; peak biomass = 2, 5, 8, and 11; and post-harvest = 3, 6, 9, and 12.

completely randomized split plot design with system as the main plot and sampling time as the subplot. The analysis of variance *F*-tests were used to determine treatment differences and *F*-protected *t*-tests were used on pairwise comparisons as a follow-up for any significant finding. The analysis of variance and mean separation difference were conducted for each site using Proc Mixed in SAS[17]. Soil depths were also analyzed independently. All results were considered significantly different at $P < 0.05$ unless noted otherwise.

Results and Discussion

Management treatments affected soil TN, NO_3-N, SOM (both organic C and LOI), POM, EC, and pH in the 0–7.5 cm increment at most study locations. Treatment effects in measured variables in the 7.5–15 and 15–30 cm increments were less commonly observed and when present were usually at locations where the CON and ALT differed in tillage intensity (Brookings, Fargo, Mandan, and Mead). Temporal variation was common for all measured variables in all depth increments and at all locations. A significant treatment by time interaction was infrequently observed. There were no consistent trends for the effect of time, and the observed temporal variation was likely due to changes in bulk density (BD) among growing seasons. BD (0–7.5 cm depth) exhibited temporal variability at Brooking, Bushland, Mead, Sidney, and Swift Current (Fig. 1). The effect of time on BD was significant ($P < 0.05$). In reality, changes in BD developed slowly

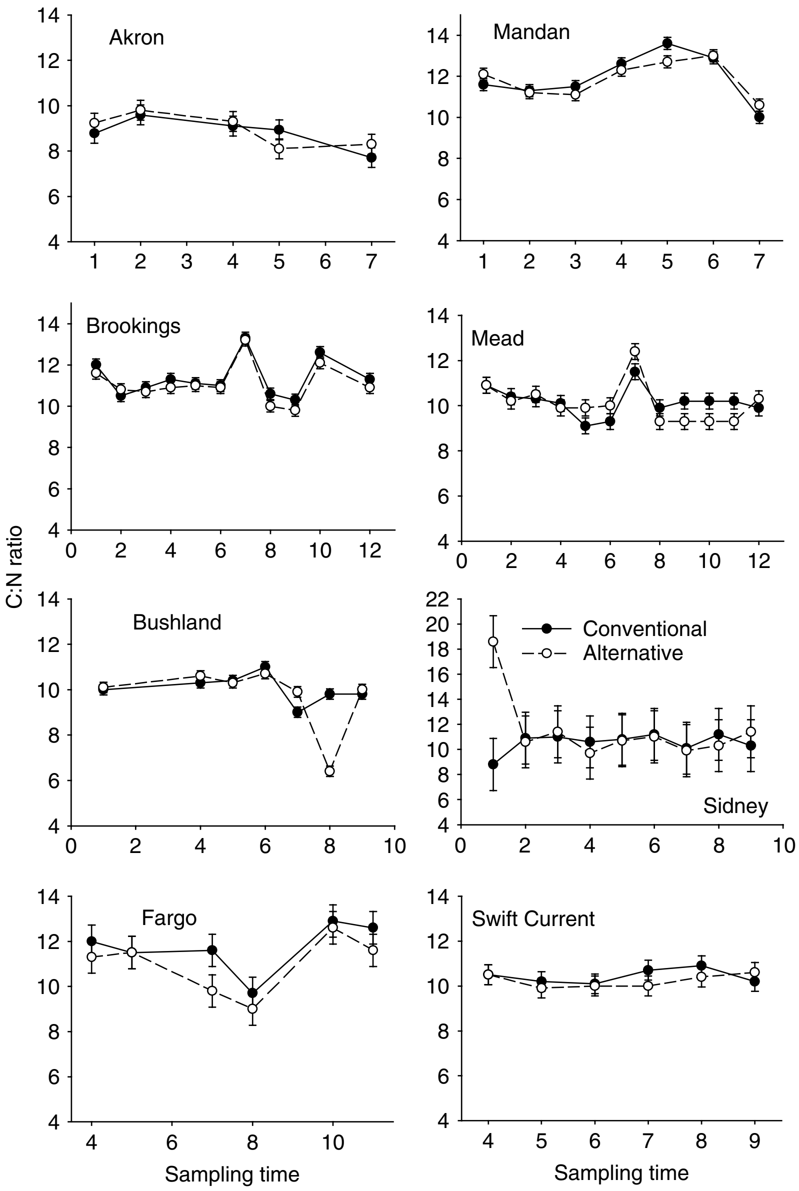

Figure 4. Soil C : N ratio in the 0–7.5 cm depth as a function of sampling time (multiple years) under the conventional and alternative management systems at eight locations in the Great Plains. Bars represent 1 SEM. Sampling times correspond to preplant = 1, 4, 7, and 10; peak biomass = 2, 5, 8, and 11; and post-harvest = 3, 6, 9, and 12.

and without tillage require more than a single growing season to change. Many factors can affect BD measurement. Factors such as soil water content, soil compaction, sampling method, and operator technique need to be considered when sampling for BD. The variations in BD that we observed in this experiment, at individual locations, were probably due to the factors mentioned earlier and, in some cases, were artifacts of soil condition by sampling technique interaction. In general, variation exhibited by the measured variables makes it impossible to recommend a single best time to sample when assessing management impacts on chemical soil properties. Dynamic assessments are essential for separating the effect of management practices on soil properties from variation exhibited by these properties due to weather.

Alternative cropping systems significantly increased TN (0–7.5 cm depth) at Akron, Bushland, Fargo, Mandan, and Swift Current (Fig. 2). TN in the 0–7.5 cm depth exhibited temporal variability at all locations except Mandan. The temporal pattern exhibited by TN in both treatments at each location was similar, suggesting that the temporal variability observed was likely caused by something affecting both treatments. It is conceivable that part of the variability in TN measured is due to variability in BD. TN exhibited temporal variability in the 7.5–15 and 15–30 cm depth increments at all locations. Treatment differences (averaged across all dates) in the lower two depths were observed at Fargo (1.71 Mg N ha^{-1} in the CON treatment versus 2.03 Mg N ha^{-1} in the ALT treatment) and Swift Current (1.72 Mg N ha^{-1} in the CON treatment versus

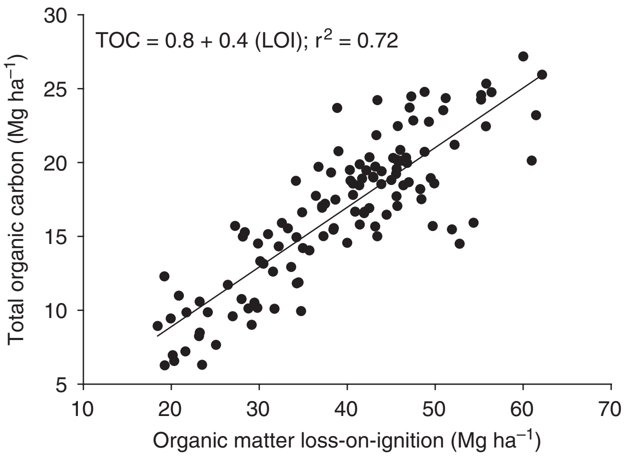

Figure 5. Relationship between two methods of measuring soil organic matter using soils from the 0–7.5 cm depth from contrasting management systems at eight locations in the Great Plains.

1.97 Mg N ha^{-1} in the ALT treatment) for the 7.5–15 cm increment and at Bushland (1.77 Mg N ha^{-1} in the CON treatment versus 2.03 Mg N ha^{-1} in the ALT treatment) for the 15–30 cm increment. Higher TN in the ALT treatment resulted from more intensive cropping accompanied by a decrease in tillage intensity or incidence of fallow.

Soil NO_3-N was highly dynamic throughout the sampled profile with a significant effect of time at all locations. Treatment by time interactions were also significant at all locations except Swift Current. In addition to weather, fertilizer additions of N and crop uptake contributed to the temporal variability observed. Differences in crop rotation and presence of fallow likely contributed to treatment differences (data not shown). Nitrate N is an important crop nutrient and also has potential for contamination of surface and ground water when transported in runoff or leaching. Optimal N management requires that residual NO_3-N be accounted for in making fertilizer recommendations and that realistic yield goals be used for determining appropriate fertilizer rates.

SOC was greater in the 0–7.5 cm depth of the ALT treatment than in the CON treatment at Akron, Bushland, Fargo, and Swift Current. The increase in SOC in the 0–7.5 cm increment was due to reduced tillage intensity at Akron and Fargo, or to a reduction in the incidence of fallow at Akron, Bushland, and Swift Current. The only treatment difference observed in the lower two increments occurred at Fargo (19.5 Mg C ha^{-1} in the CON treatment versus 23.2 Mg C ha^{-1} in the ALT treatment) in the 7.5–15 cm depth. Wood et al. (1991)[7] observed an increase in SOC after imposing NT and intensive cropping in soil previously managed with tillage under wheat–fallow management. Temporal variation in TOC was observed at Brookings, Bushland, Mead, Sidney, and Swift Current. There were similarities between the two treatments in the exhibited temporal pattern, suggesting that the source of the temporal variation was likely affecting both treatments similarly (Fig. 3). Apparently, the variations in TOC for both treatments at various sampling times are an artifact of BD or sampling procedure.

Soil C : N ratio (0–7.5 cm depth) was significantly ($P < 0.05$) affected by time except at Sidney and Swift Current (Fig. 4). Temporal variability of C : N ratio was also observed at all locations except Akron and Swift Current. The temporal pattern exhibited by C : N in both treatments, at each location, was similar (except one sampling time in Bushland, Fargo, and Swift Current), suggesting that the temporal variability observed was likely caused by something affecting both treatments. As with BD, changes in soil C : N ratio are slow to develop and may take years to manifest. Many factors can affect C : N measurement: sampling procedure, grinding method, sample weighing accuracy, instrument sensitivity, and most importantly the presence of plant residues. The reduction in C : N ratio with CON treatment in one sampling date (Fig. 4) at Bushland and Fargo was probably due to instrument sensitivity and/or variability in measurement technique.

When SOM was determined using LOI, treatment differences were less frequently detected than with SOC, with differences in the 0–7.5 cm depth apparent only at Fargo. Treatment differences approached significance at Akron, Bushland, Mandan, and Swift Current. While the LOI method of determining SOM appears less sensitive, there was a strong correlation between total organic carbon (TOC) and organic matter measured using LOI (Fig. 5). Since the LOI method requires less sophisticated equipment, the strong correlation and the trend toward treatment differences suggest that this method has merit for monitoring long-term changes in SOM. In this study, C lost using LOI methods represent 40% of SOC, which is different from the 58% traditionally used, but not unusual.

Treatment differences in SOC and TN were associated with differences in tillage practices between the treatments. This observation agrees with Halvorson et al.[18], where an increase in SOC was observed as tillage intensity decreased within an annual cropping system. Tillage reduces SOC and TN by increasing residue contact with soil microbial populations, which enhances residue oxidation and decomposition[19–21]. Additionally, Blevins and Frye[21] reported that tillage promotes soil erosion and deterioration of soil structure due to destruction of soil aggregates and increased soil compaction. Conversely, NT increases SOC and TN in the surface increment when the soil is not disturbed and residue is not incorporated. With NT, soil water content in near-surface soil tends to be greater, resulting in a proliferation of root growth, which acts to increase SOC and TN. Roots near the soil surface also stabilize soil aggregates by binding them together, thereby reducing the erosion potential of the surface soil and its resident C and N[20,21].

There were no differences in TN (Fig. 2) and SOC (Fig. 3) between the CON and ALT treatments at Brookings and Mead. At these locations, both ALT and CON treatments were tilled (Table 1). The fact that both

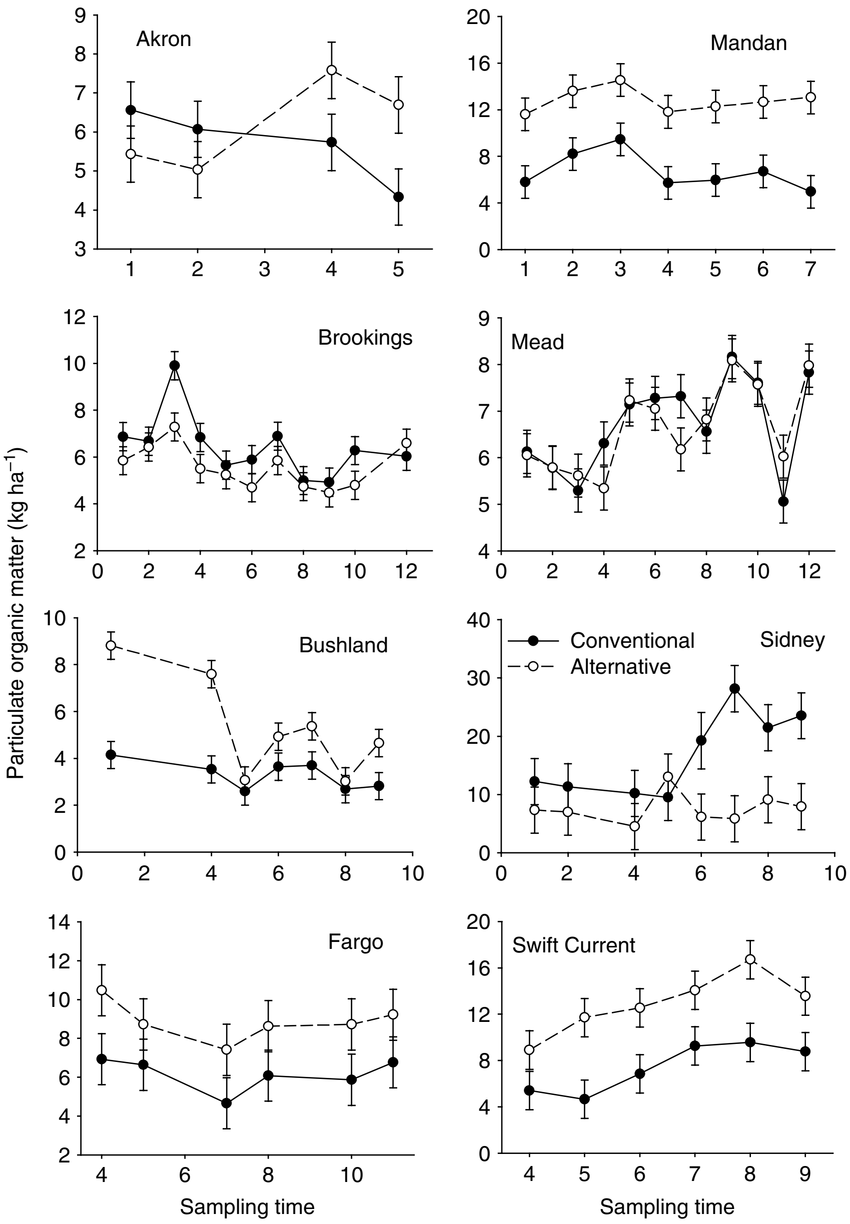

Figure 6. Particulate organic matter (kg ha^{-1}) in the 0–7.5 cm depth as a function of sampling time (multiple years) under the conventional and alternative management systems at eight locations in the Great Plains. Bars represent 1 SEM. Sampling times correspond to preplant = 1, 4, 7, and 10; peak biomass = 2, 5, 8, and 11; and post-harvest = 3, 6, 9, and 12.

CON and ALT treatments were tilled may have masked the cropping sequence differences.

At Swift Current, TN (Fig. 2) and SOC (Fig. 3) were greater in the ALT treatment than in the CON treatment. The increase associated with the ALT treatment is probably due to a reduction in the incidence of fallow, since NT was used in both the CON and ALT treatments (Table 1). In general, summer fallow enhances SOM decomposition, thereby decreasing SOC[8]. Additionally, C additions to the soil are lower in summer fallow systems since a crop is growing every other year[22].

POM was greater in the 0–7.5 cm depth of the ALT treatment than the CON treatment at Bushland, Mandan, Sidney, and Swift Current (Fig. 6). POM was 44% greater in soils from the ALT treatment than in soils from the CON treatment at Fargo ($P = 0.06$). Overall, the increase in POM within the ALT system was associated with a reduction in tillage intensity and fallow frequency. Beare et al.[23] observed 20% greater POM in NT managed soils compared to conventionally tilled soils. Treatment differences in POM in the 7.5–15 cm increment were observed at Mandan (4.0 kg ha^{-1} in the CON treatment versus 6.9 kg ha^{-1} in the ALT treatment) and at Swift Current (5.2 kg ha^{-1} in the CON treatment versus 7.9 kg ha^{-1} in the ALT treatment). Treatment differences in POM in the 15–30-cm depth were observed at Swift Current (4.4 kg ha^{-1} in the CON treatment versus 6.8 kg ha^{-1} in the ALT treatment). Temporal dynamics were exhibited by POM in all soil

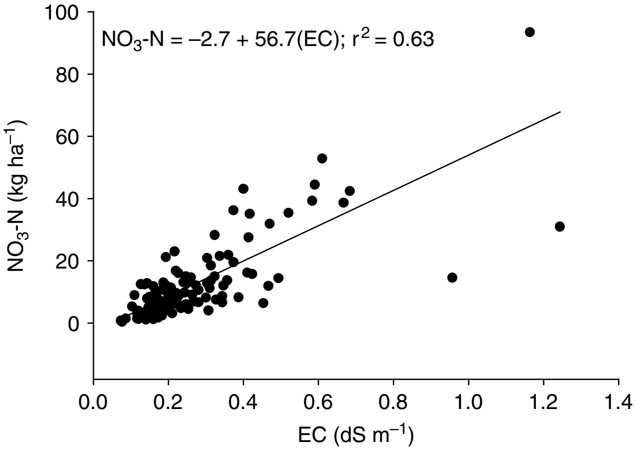

Figure 7. Relationship between soil EC (dS m^{-1}) and NO_3-N content (kg N ha^{-1}) using soil from the 0–7.5 cm depth from contrasting management systems at eight locations in the Great Plains.

depths. In the 0–7.5 cm depth increment, the temporal pattern exhibited by POM was similar between the two treatments, suggesting that a factor such as weather, or BD, was affecting POM similarly in both treatments. In our study, temporal and treatment responses mirrored those of SOM, suggesting that the POM may be a component of SOM that is sensitive to management. The method of determining POM[16] used in this study does not require sophisticated equipment and will be useful for land managers monitoring management influences on SOM.

Soil EC exhibited temporal variability at all locations and in all soil depths. Treatment differences were observed at Brookings, Fargo, and Mead for the 0–7.5 and 7.5–15 cm depths and at Mandan for the 15–30 cm depth. In these non-saline soils, the most likely source of variation in EC is fluctuating NO_3-N content. Soil NO_3-N and EC in the 0–7.5 cm depth were positively correlated (Fig. 7). Smith and Doran[10] also observed a positive correlation between soil EC and NO_3-N ($r = 0.84$ for fall sampling and 0.74 for spring sampling). Since soil EC is extremely easy and inexpensive to measure, these results suggest that EC may serve as a useful tool for land managers to use for estimating NO_3-N content in non-saline soils.

Soil pH exhibited temporal dynamics at all locations in at least one depth increment. Soil pH differed between management practices in the 0–7.5 and 7.5–15 cm depth at Fargo and Mead. Treatment differences in pH were likely due to use of ammoniacal fertilizer. Bowman and Halvorson[24] reported that surface applications of ammoniacal fertilizers tend to decrease soil pH over time. The pH decrease was attributed to nitrification of the ammoniacal N source in excess of nitrate uptake by crops. All of the locations receive annual applications of ammoniacal N to satisfy the N crop requirement. With NT, most of the N fertilizer application is surface applied. Over time, the increase in NO_3-N would be expected to correspond to a decrease in soil surface pH. Liebig et al.[25] found a similar correlation between soil pH and residual NO_3-N.

Conclusions

Chemical soil properties measured in this study (TN, POM, and TOC) were consistently greater in the ALT treatment than in the CON treatment. Improvements in soil chemical properties in the ALT treatment were attributed to a reduction in tillage intensity and incidence of fallow. Differences between the two treatments were usually only detected in the surface 7.5 cm, underscoring the importance of sampling this near-surface soil depth for assessing management effects on soil chemical properties. Many of the attributes measured in this study exhibited temporal variability, with much of the variability being associated with weather and related changes in crop status or soil bulk density estimation during the growing season. There does not appear to be a single sampling time that can be recommended to compare short-term management effects. Instead, dynamic assessments are essential for understanding management impacts on soil quality in the context of specific soil functions.

References

1 Bowman, R.A., Vigil, M.F., Nielsen, D.C., and Anderson, R.L. 1999. Soil organic matter changes in intensively cropped dryland systems. Soil Science Society of America Journal 63:186–191.
2 Pikul, J.L. Jr, Schumacher, T.E., and Vigil, M.F. 2001. Nitrogen use and carbon sequestrated by corn rotations in the northern corn belt, U.S. In Optimizing Nitrogen Management in Food and Energy Production and Environmental Protection: Proceedings of the 2nd International Nitrogen Conference on Science and Policy. The Scientific Word 1(S2):707–713.
3 Beare, M.H., Cabrera, M.L., Hendrix, P.F., and Coleman, D.C. 1994. Aggregate-protected and unprotected organic matter pools in conventional- and no-tillage soils. Soil Science Society of America Journal 58:787–795.
4 Six, J., Elliott, E.T., and Paustian, K. 1999. Aggregate and soil organic matter dynamic under conventional and no-tillage systems. Soil Science Society of America Journal 63: 1350–1358.
5 Hass, H.J., Evans, C.E., and Miles, E.F. 1957. Carbon and nitrogen changes in Great Plains soil as influenced by cropping and soil treatments. USDA Technical Bulletin No. 1164. US Government Printing Office, Washington, DC.
6 Ridley, A.O. and Hedlin, R.A. 1968. Soil organic matter and crop yields influenced by frequency of summer fallowing. Canadian Journal of Soil Science 48:315–322.
7 Wood, C.W., Westfall, D.C., and Peterson, G.A. 1991. Soil carbon and nitrogen changes on initiation of no-till cropping systems. Soil Science Society of America Journal 55:470–476.
8 Campbell, C.A., Zentner, R.P., Liang, B.C., Roloff, G., Gregorich, E.C., and Blomert, B. 2000. Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan-effect of crop rotations and fertilizers. Canadian Journal of Soil Science 80:179–192.

9 Gregorich, E.G., Carter, M.R., Angers, D.A., Monreal, C.M., and Ellert, B.H. 1994. Towards a minimum data set to assess soil organic matter quality in agricultural soils. Canadian Journal of Soil Science 74:367–385.

10 Smith, J.L. and Doran, J.W. 1996. Measurement and use of pH and electrical conductivity for soil quality analysis. In J.W. Doran and A.J. Jones (eds). Methods for Assessing Soil Quality. Soil Science Society of America Special Publication No. 49. Soil Science Society of America, Madison, WI. p. 41–50.

11 Cambardella, C.A. and Elliott, E.T. 1992. Particulate soil organic-matter changes across a grassland cultivation sequence. Soil Science Society of America Journal 56:777–783.

12 Tisdall, J.M. and Oades, J.M. 1982. Organic matter and water stable aggregates in soil. Journal of Soil Science 33:141–161.

13 Varvel, G., Reidell, W., Deibert, E., McConkey, B., Tanaka, D., Vigil, M., and Schwartz, R. 2006. Great Plains cropping system studies for soil quality assessment. Renewable Agriculture and Food Systems 21:3–14.

14 Loeppert, R.H. and Suarez, D.L. 1996. Carbonate and gypsum. In D.L. Sparks (ed.). Methods of Soil Analysis. Part 3. Chemical Methods. Soil Science Society of America Book Series No. 5. Soil Science Society of America and American Society of Agronomy, Madison, WI. p. 437–474.

15 Keeney, D.R. and Nelson, D.W. 1982. Nitrogen-inorganic forms. In A.L. Page, R.H. Miller, and D.R. Keeney (eds). Methods of Soil Analysis. Part 2. 2nd ed. Agronomy Monograph No. 9. Agronomy Society of America and Soil Science Society of America, Madison, WI. p. 643–698.

16 Cambardella, C.A., Gajda, A.M., Doran, J.W., Wienhold, B.J., and Kettler, T.A. 2001. Estimation of particulate and total organic matter by weight loss-on-ignition. In R. Lal, J.M. Kimble, R.F. Follett, and B.A. Stewart (eds). Assessment Methods for Soil Carbon. Lewis Publishers, Boca Raton, FL. p. 349–359.

17 Littell, R.C., Milliken, G.A., Stroup, W.W., and Wolfinger, R.D. 1996. SAS System for Mixed Models. SAS Institute, Inc., Cary, NC.

18 Halvorson, A.D., Wienhold, B.J., and Black, A.L. 2002. Tillage, nitrogen, and cropping system effects on soil carbon sequestration. Soil Science Society of America Journal 66: 906–912.

19 Doran, J.W. 1980. Soil microbial and biochemical changes associated with reduced tillage. Soil Science Society of America Journal 44:765–771.

20 Havlin, J.L., Kissel, D.E., Maddux, L.D., Claassen, M.M., and Long, J.H. 1990. Crop rotation and tillage effects on soil organic carbon and nitrogen. Soil Science Society of America Journal 54:448–452.

21 Blevins, R.L. and Frye, W.W. 1993. Conservation tillage: an ecological approach to soil management. Advances in Agronomy 51:33–78.

22 Metherell, A.K., Camberdella, C.A., Parton, W.J., Peterson, G.A., Harding, L.A., and Cole, C.V. 1995. Simulation of soil organic matter dynamics in dryland wheat–fallow cropping systems. In R. Lal, J. Kimble, E. Levine, and B.A. Stewart (eds). Soil Management and Greenhouse Effect. Lewis Publishers, Boca Raton, FL. p. 259–270.

23 Beare, M.H., Hendrix, P.F., and Coleman, D.C. 1994. Water-stable aggregate and organic matter fractions in conventional- and no-tillage soil. Soil Science Society of America Journal 58:777–786.

24 Bowman, R.A. and Halvorson, A.D. 1998. Soil chemical changes after nine years of differential N fertilization in a no-till dryland wheat–corn–fallow rotation. Soil Science 163: 241–247.

25 Liebig, M.A., Varvel, G.E., Doran, J.W., and Wienhold, B.J. 2002. Crop sequence and nitrogen fertilization effect on soil properties in the western corn belt. Soil Science Society of America Journal 66:596–601.