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Long-term tillage effects on soil quality

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Abstract

Public interest in soil quality is increasing, but assessment is difficult because soil quality evaluations are often purpose- and site-specific. Our objective was to use a systems engineering methodology to evaluate soil quality with data collected following a long-term tillage study on continuous corn (*Zea mays* L.). Aggregate characteristics, penetration resistance, bulk density, volumetric water content, earthworm populations, respiration, microbial biomass, ergosterol concentrations, and several soil-test parameters (pH, P, K, Ca, Mg, Total-N, Total-C, NH_4-N, and NO_3-N) were measured on Orthic Luvisol soil samples collected from Rozetta and Palsgrove silt loam (fine-silty, mixed, mesic Typic Hapludalfs) soils. Plots managed using no-till practices for 12 years before samples were collected for this study had surface soil aggregates that were more stable in water and had higher total carbon, microbial activity, ergosterol concentrations, and earthworm populations than either the chisel or plow treatments. Selected parameters were combined in the proposed soil quality index and gave ratings of 0.48, 0.49, or 0.68 for plow, chisel, or no-till treatments, respectively. This indicated that long-term no-till management had improved soil quality. The prediction was supported by using a sprinkler infiltration study to measure the amount of soil loss from plots that had been managed using no-till or moldboard plow tillage. We conclude that no-till practices on these soils can improve soil quality and that the systems engineering methodology may be useful for developing a more comprehensive soil quality index that includes factors such as pesticide and leaching potentials.

Keywords: Conservation tillage; Tillage system; Soil property; Soil quality index

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1. Introduction

The United States National Academy of Sciences Research Council (1993) recently suggested that the United States should adopt a national policy that seeks to conserve and enhance soil quality as a fundamental first step to environmental improvement. This reflects increasing concern about how various soil and crop management practices are affecting surface water quality, groundwater quality, air quality, soil erosion, off-site sedimentation, and other environmental problems. The concept of soil quality has also been suggested by several authors (Papendick and Parr, 1992; Karlen et al., 1994) as a tool for assessing long-term sustainability of agricultural practices.

This soil quality assessment was conducted on a loess-derived Orthic Luvisol which is classified by the USDA-SCS as Rozetta and Palsgrove silt loam. The soils are representative of those that cover fractured shale, sandstone, and limestone bedrock and extend across the Upper Mississippi Valley of NW Illinois, SW Wisconsin, SE Minnesota and NE Iowa in the United States. Soils in this region are generally highly productive, but erosion is a serious threat to long-term cropland productivity. Forage based cropping systems are among the best for this land resource area, but throughout the 1970s and 1980s, economic forces caused an increase in row crops. These are generally being grown with and without contour farming practices and/or adoption of conservation tillage practices.

Adoption of conservation plans and implementation of practices specified in them are now required for farmers to remain eligible for most US government agricultural support programs. By developing a protocol for assessing soil quality, farmers may be able to periodically assess the effects of their soil and crop management practices. A soil quality index may enable them to more effectively select strategies that will improve environmental quality without reducing crop yields or profitability for their farming operations.

1.1. Potential soil quality indicators

Acton and Padbury (1993) defined a soil quality attribute or indicator as a measurable soil property that influences the capacity of a soil to perform a specified function. Several indicators have been suggested to detect changes over various spatial and temporal scales. Arshad and Coen (1992) selected soil depth, soil organic matter, and electrical conductivity as indicators most affected by soil degradation processes. Selection of indicators that are sensitive to management practices would also be desirable.

Several biological attributes, including microbial biomass, respiration, amino acids, soil enzymes, and earthworm activity have been suggested as soil quality indicators. Physical conditions, such as water-filled pore space which influence biological activity, have also been identified as important indicators (Karlen et al., 1994). Water-filled pore space and many of the biological indicators are much more temporally and perhaps spatially dependent than physical indicators such as bulk density or chemical indicators such as cation exchange capacity (CEC), but they can be very responsive to soil and crop management practices (Doran et al., 1990).

Aggregate stability and size distribution may be useful indicators for evaluating the soil quality effects of practices such as no-tillage because these measurements often reflect resistance of soil to erosion. Soil dispersion in water has also been related to erosion and runoff (Stern et al., 1991). Soil carbon can influence soil quality, because decreases in this parameter can be directly related to decreased water stability of both macro- and micro-aggregates (Tisdall and Oades, 1982; Churchman and Tate, 1987; Pojasok and Kay, 1990). Changes in microbial biomass C and water-extractable carbohydrate fractions (Haynes and Swift, 1990; Haynes et al., 1991) are especially important with regard to aggregate stability following various soil and crop management practices.

Earthworm activity provides an indication of soil quality (Berry and Karlen, 1993) for several reasons. Earthworms can increase the water stability of soils through the production of casts and by excreting materials from their bodies. They can also influence water infiltration, water transport, and plant root development by creating macropores.

Microbial biomass, respiration, and ergosterol, a sterol common to fungal tissue that can be used as an index of fungal biomass (Eash, 1993), are biological indicators that may also be useful for assessing long-term soil and crop management effects on soil quality (Karlen et al., 1994). Periodic assessments of soil-test properties have also been suggested as an important chemical indicator of soil quality (Arshad and Coen, 1992).

1.2. Soil quality assessment

Several approaches for assessing soil quality are currently being evaluated (Larson and Pierce, 1991; Acton and Padbury, 1993; Doran and Parkin, 1994). A common attribute among all these approaches is that soil quality is being assessed with respect to specific soil functions.

Karlen et al. (1994) modified the framework suggested by Karlen and Stott (1994) to evaluate the effects of removing, maintaining, or doubling crop residue for a period of 10 years in a continuous no-till corn production study. The critical soil functions identified in both efforts were the need to: (1) accommodate water entry; (2) facilitate water transfer, adsorption, and delivery; (3) resist degradation; and (4) support plant growth. The objective for this study was to evaluate long-term effects of three tillage systems by measuring several potential biological, chemical, and physical indicators of soil quality and using that information in a proposed soil quality index (Karlen et al., 1994) to evaluate soil quality.

2. Materials and methods

Samples from Rozetta and Palsgrove silt loam soils were collected at a 1.1 ha research site at the University of Wisconsin experimental farm near Lancaster, WI, USA. These Orthic Luvisol soils have approximately 0.6 to 1.5 m of loess over residuum that is derived from limestone and sandstone bedrock. They are found on 10 to 13% slopes which are predominantly north facing. The site had been used for a long-term tillage study. It was planted to continuous corn for 12 years prior to this study and had no-till alfalfa (*Medicago sativa* L.) drilled onto it one week before sampling.

The statistical design was a randomized complete block with four replications. Samples were collected in May 1991 from plots that had received moldboard plowing (plow), chisel-disking (chisel), or no-tillage (no-till) treatments between 1978 and 1990. None of the treatments had received tillage since May 1990. Several sets of samples were collected from within each plot to measure suggested biological, chemical, and physical indicators of soil quality. Data were analyzed by depth increment using a general linear model (SAS Institue Inc., 1985). Tillage treatments and replicates were identified as the main effects. Fisher's protected LSD at $P \leqslant 0.05$ was used to distinguish treatment differences.

2.1. Physical properties

Near-surface soil samples for particle size and water-stable aggregate analysis were collected from a 15-cm by 15-cm by 5-cm volume with a garden trowel. The soil was hand sieved to obtain 1- to 4-mm aggregates which were stored at 4°C until water stability could be measured using a modification of the method described by Kemper and Rosenau (1986). Water stability was also determined using a turbidimetric method (Jordahl, 1991). Particle size analysis of the <2-mm fraction was determined by the pipette method. Porosity was calculated as described by Danielson and Sutherland (1986).

A hand-operated penetrometer that had a 12.83-mm diameter, 30° cone with an area of 130 mm^2 was used to measure penetration resistance to a depth of 500 mm. Data are reported as the maximum force recorded as the cone passed through each 50-mm layer. A tractor-mounted, auger-type powered core sampler was used to collect samples for determining bulk density. Data were collected for each 50-mm layer. Volumetric water content was determined by drying the soil samples at 104°C.

A second soil sample, collected from the surface 80 mm of each plot, was divided into two subsamples. After air drying, one subsample was rotary sieved, while the other was dropped from a height of 2 m as described by Adam and Erbach (1992). Mechanical stability of soil aggregates was calculated by dividing the aggregate mean-weight-diameter after dropping the soil by the aggregate mean-weight-diameter before dropping. After sieving, the maximum force and energy needed to crush randomly selected individual soil aggregates having diameters of 9.5, 19, and 38 mm were determined with a Universal Testing Machine (Instron Model 8501, Instron Corporation, Canton, MA, USA)[1] as described by Karlen et al. (1994).

[1] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the USDA and does not imply its approval to the exclusion of the other products or vendors that may also be suitable.

Three 75 mm wide by 75 mm long, undisturbed surface soil cores were also obtained from each plot. After trimming the surface, saturated hydraulic conductivity was determined on the cores using the constant head method. Water retention was measured using undisturbed soil cores at matric potentials of −0.5 to −40 kPa. Sieved soil from the same plots was used for the −100 to −1500 kPa range.

2.2. Chemical properties

Soil-test samples were collected with a 20-mm diameter hand probe. Eight cores per plot were collected and fractionated into seven depth increments (0 to 25, 25 to 75, 75 to 150, 150 to 250, 250 to 300, 300 to 450, and 450 to 600 mm). Samples were air-dried, crushed to pass a 2-mm sieve, and analyzed for water pH, Bray P1 extractable (0.025 M NH_4F) P, 1 M NH_4OAc exchangeable K, Ca, and Mg. Cation exchange capacity (CEC) was estimated by summation. The NH_4-N and NO_3-N concentrations in 2 M KCl were measured colorimetrically using flow injection analysis technology from the Lachat Corporation (Lachat Instruments, Milwaukee, WI, USA)[1]. Total carbon and nitrogen were measured by dry combustion using a Carlo-Erba NA1500 NCS analyzer (Haake Buchler Instruments, Inc., Patterson, NJ)[1].

2.3. Biological properties

Microbial biomass and respiration were determined by measuring CO_2 evolution at room temperature (25°C) from samples moistened to a soil matric potential of −33 kPa using fumigation and incubation techniques as described by Jenkinson and Powlson (1976). The samples were obtained from the same location and depth as the aggregate stability samples. Bulk soil was forced through a 4-mm sieve, sealed, and kept at 4°C until analysis. Ergosterol, a component of fungal tissue which can be used as an index of fungal biomass (Eash, 1993), was determined by extraction and high pressure liquid chromatography (HPLC) analysis (Grant and West, 1986).

Earthworm activity was evaluated by saturating the soil within a 0.25-m^2 frame for 20 min with a solution containing 6 ml of a 40% formaldehyde solution l^{-1}, as suggested by Edwards and Lofty (1977). Mature and immature earthworms coming to the surface within each frame were counted.

2.4. Soil quality assessment

A soil quality index was computed for each tillage treatment using the framework proposed by Karlen et al. (1994). This procedure is subjective, site-specific, and does not include all the functions that may be needed for a soil quality index. The systems engineering protocol and the use of standard scoring functions to interpret measurements used for a soil quality index, however, are adaptable and transferable to other soils and locations.

2.5. Field validation

Predictions, based on soil quality index values, that no-till practices had created an improved soil quality were evaluated by measuring sediment loss from plow and no-till treatments 10 days before and after this assessment. Sediment loss was measured by collecting the runoff from rainfall simulation studies on each tillage treatment. Steel 30-cm tall frames were driven into the ground to a depth of 20 cm to delimit the test area. Water was applied to the 0.84-m^{-2} plots with a portable, multiple intensity, single-nozzle rainfall simulator (Meyer and Harman, 1979). A Veejet 80150 nozzle (Spraying Systems, Wheaton, IL, USA)[1] was located 3 m above the test area and operated at a pressure of 41 kN m^{-2} to deliver 98% of the kinetic energy of a natural rainstorm at the same intensity. The average application rate and kinetic energy were 72 mm h^{-1} and 0.275 MJ ha^{-1} mm^{-1}, respectively. This represents a rainfall with a return period of approximately 100 years in south-central Wisconsin (Hershfield, 1961). Two rainfall simulations were made on different test areas within each plot that had been plowed or in no-till management from 1978 through 1990. Crop residues from the 1990 corn crop were not removed from either treatment for these 1991 measurements. Surface cover averaged 58% for the long-term moldboard plow treatments and 68% for the no-till treatments with a coefficient of variation of 16%. The difference was not statistically significantly at $P \leqslant 0.05$.

Runoff generated during each 1-h simulated rainfall event was collected by vacuum. Depth of runoff in a tank was viewed through a site glass and converted to volume. A 1-l subsample of the total runoff suspension was retained to determine sediment concentration. Sediment concentration was determined by oven drying the suspension at 105°C. Soil loss was estimated as the product of measured runoff volume and sediment concentration of the total runoff.

3. Results and discussion

Average corn yields during the 12 years of plow, chisel, or no-tillage treatments were 8.8, 8.7, and 8.6 Mg ha^{-1}, respectively. There were yield differences among years, but seasonal (May through August) rainfall, which ranged from 153 to 492 mm, appeared to be a much more significant factor than any of the tillage treatments. Assuming a 1:1 ratio between corn grain and stover yield (Larson et al., 1978), these yield values suggest that the amount of carbon input to each treatment, prior to our sampling, was similar. This is important because many of the potential biological, chemical, and physical indicators of soil quality are influenced by soil organic matter concentrations.

Gravimetric soil water content and volumetric estimates of water-filled pore space in the top 50 mm were significantly higher in no-till plots than in chisel or

Table 1
Gravimetric water content, water-filled pore space, particle size analysis, and pH in the top 50 mm of Rozetta and Palsgrove soils following 12 years of various tillage treatments

Tillage treatment	Water content (%)	Water-filled pore space (%)	Clay (%)	Silt (%)	Sand (%)	pH
No-till	32.4	86.5	15.7	79.5	4.8	5.8
Chisel	25.5	58.6	16.8	77.9	6.2	6.2
Plow	23.1	64.5	17.4	78.2	4.5	6.2
$LSD_{(0.05)}$	5.9	15.3	NS	NS	NS	NS

plow treatments when sampled in May 1991 (Table 1), even though none of the plots had been tilled since the spring of 1990. These soil water differences may have been caused by differences in evaporation prior to sampling. However, residues from the 1990 corn crop had not been removed from any of the treatments, and estimates of surface cover, which were 58% for the plow and 68% for the no-till treatments, respectively, were not significantly different.

Plant available water (PAW) in the top 75 mm, defined as the difference in volumetric water content (θ) between soil matric potentials of -9.8 and -1500 kPa, was not significantly different among tillage treatments (Table 2). The eight values at soil matric potentials of -1.3 and -9.8 kPa were not significantly different, but at a soil matric potential of -0.5 kPa, θ was significantly lower for cores from the no-till treatment than from either chisel or plow treatments. At soil matric potentials of -100 and -1500 kPa, θ was significantly greater for the no-till than for the chisel treatment (Table 2). A visual examination of the cores and field observations found a well-developed platy structure on the no-till plots. This suggests that the increased water retention may have been related to the pore size distribution, and that the no-till treatment had developed a structure consisting of smaller pores. Saturated hydraulic conductivity values were 6.1, 2.9,

Table 2
Tillage effects on porosity, plant available water, and volumetric water content of 75-mm surface soil cores collected following 12 years of various tillage treatments

Tillage treatment	Porosity (%)	Plant available water (PAW)[a] (%)	Volumetric water content (θ) (cm cm^{-3}) at selected matric potentials (kPa)				
			−0.5	−1.3	−9.8	−100	−1500
No-till	44.2	24.5	0.385	0.381	0.370	0.324	0.125
Chisel	47.0	26.3	0.411	0.405	0.382	0.308	0.119
Plow	46.2	25.3	0.411	0.399	0.374	0.313	0.121
$LSD_{(0.05)}$	2.0	NS	0.019	NS	NS	0.012	0.005

[a] Plant available water was calculated as volumetric water content at $\psi = -9.8$ kPa minus volumetric water content at $\psi = -1500$ kPa.

and 2.6 μm s^{-1} for cores from no-till, chisel, and plow treatments, respectively. The differences were not statistically significant, although they suggest that despite the platy structure, the no-till samples may also have had more channels, cracks, or macropores.

Turbidimetric measurements of water stability for the 1- to 4-mm aggregate fraction (Table 3) showed that macroaggregates from the no-till plots were significantly more stable than those from the chisel or plow treatments. Measurements of water stability by wet sieving showed a similar, but statistically nonsignificant trend.

Particle size and pH of soil aggregates from the surface 50 mm showed no significant differences (Table 1). Total carbon concentrations in the aggregates (Table 3) showed significant differences. This presumably reflects the effects of maintaining crop residues on the soil surface in the no-till treatments during the previous 12 years. For 1981 through 1990, measurements of surface crop residue cover after planting averaged 62, 13, and 3% for the no-till, chisel, and plow treatments, respectively. Deeper and more complete incorporation with the chisel and plow treatments presumably hastened decomposition of the crop residues and decreased the amount of carbon available for supporting fungal activity and binding surface soil aggregates.

Microbial biomass, respiration, ergosterol concentration, and earthworm populations were significantly higher following 12 years of no-till continuous corn production than for the chisel and plow treatments (Table 3). Measurements of total carbon in the soil aggregates, however, revealed differences between the chisel and plow treatments, that other potential soil quality indicators were not able to significantly differentiate.

Higher earthworm populations in the no-till treatments (Table 3) suggest that use of primary and secondary tillage operations during the 12 years before this evaluation was made had a significant effect that was consistent with other long-term soil management studies in Iowa (Berry and Karlen, 1993). Tillage, especially during autumn, presumably decreases earthworm populations by destroying crop residues on the soil surface which provide food and habitat protection for the earthworms.

Average soil bulk density (Table 4) for the top 500 mm was 1.46, 1.45, and 1.52 Mg m^{-3} for the chisel, plow, and no-till treatments, respectively. Those values were not significantly different, but differences between depth means, averaged across tillage treatments, were significant at $P \leqslant 0.05$. Penetration resistance, measured in 50-mm increments to a depth of 500 mm ranged from 1390 to 1760 kPa, but showed no significant differences among the three tillage treatments (data not presented). When examined by depth, there were occasional significant differences, but this parameter provided no clear assessment of long-term effects on soil quality.

Volumetric water content in the field showed no significant differences among tillage treatments when averaged for the 500-mm depth or among depth increments when averaged across tillage treatments (data not presented). There were some tillage by depth interactions with θ being significantly greater for the 0- to

Table 3
Tillage effects on selected soil quality indicators in the surface 50 mm following 12 years of continuous no-till corn production

Tillage treatment	Wet Aggregate Stability		Total C in aggregates ($g\ kg^{-1}$)	Biomass[a] ($Mg\ C\ kg^{-1}$ soil)	Respiration[b] ($Mg\ C\ kg^{-1}$ soil)	Ergosterol	Earthworms
	Wet sieve (%)	Turbidity log (%T)[c]					
No-till	45.9	1.36	24	696	352	8.00	78
Chisel	33.9	1.04	16	394	139	3.05	52
Plow	35.9	0.97	11	260	74	2.88	53
$LSD_{(0.05)}$	NS	0.21	4	276	114	3.70	18

[a] Biomass = microbial CO_2 evolved from soil fumigated with chloroform and reinoculated.
[b] Respiration = CO_2 evolved from untreated soil.
[c] $\log T = \log_{10}$ of percent transmittance.

Table 4
Soil bulk density following 12 years of various tillage practices on Rozetta and Palsgrove soils in southwestern Wisconsin, USA

Sample depth (mm)	No-till ($Mg\ m^{-3}$)	Chisel ($Mg\ m^{-3}$)	Plow ($Mg\ m^{-3}$)	Average ($Mg\ m^{-3}$)
0–50	1.33	1.23	1.36	1.30
50–100	1.57	1.36	1.36	1.43
100–150	1.53	1.38	1.41	1.44
150–200	1.52	1.48	1.43	1.48
200–250	1.53	1.58	1.50	1.53
250–300	1.52	1.47	1.54	1.51
300–350	1.52	1.50	1.50	1.51
350–400	1.54	1.48	1.49	1.51
400–450	1.50	1.55	1.49	1.52
450–500	1.63	1.54	1.51	1.56
$LSD_{(0.05)}$		NS		0.08

50-mm depth in the long-term no-till treatment (0.384 $cm^3\ cm^{-3}$) than in chisel (0.310 $cm^3\ cm^{-3}$) or plow (0.322 $cm^3\ cm^{-3}$) treatments. At the 150-, 200-, and 500-mm depths, volumetric water content of soil in the long-term chisel and plow treatments was significantly higher than with no-till (data not presented).

Mechanical stability of soil aggregates from each treatment was determined by dropping soil aggregates from a height of 2 m and comparing mean weight diameters before and after this stress was applied. Mean weight diameter values ranged from 38 to 50 mm before dropping, and from 22 to 36 mm afterwards. Dividing the mean weight diameters before and after sieving showed average stability values of 45, 92, and 96% for long-term no-till, chisel, and plow treatments, respectively. These values were significantly different at $P \leq 0.07$.

Soil aggregates with diameters of 9.5, 19, or 38 mm before dropping were also evaluated by measuring the maximum force and energy required to crush them. Force values ranged from 82 to 106 N and energy values ranged from 0.11 to 0.20 J, respectively, for the three size classes. Long-term tillage treatments had no significant effect on either parameter. The maximum force required to crush the three aggregate sizes, when averaged across tillage treatments, was 49, 80, and 164 N, respectively. These values were significantly different ($LSD_{(0.05)}=31$) indicating that aggregate size influenced both force and energy required to crush them. After dropping the soil aggregates, the average maximum force required to crush the aggregates was 102, 106, and 135 N, and energy values were 0.13, 0.13, and 0.24 J for the chisel, plow, and no-till treatments, respectively. The force measurements were not significantly different, but energy values for aggregates from the different tillage treatments were ($LSD_{(0.05)}=0.08$). When averaged across tillage treatments, the force and energy required to crush soil aggregates with diameters of 9.5, 19, or 38 mm were 53, 108, and 185 N ($LSD_{(0.05)}=35$)

and 0.10, 0.15, and 0.25 J ($LSD_{(0.05)}=0.07$), respectively. There were no significant interactions.

3.1. Soil chemical characteristics

Arshad and Coen (1992) stated that high quality soil must have a readily available supply of plant nutrients. Total C and N measurements in the top 600 mm following 12 years of various tillage treatments were significantly different for the 0- to 25-, 25- to 75-, and 75- to 150-mm depth increments (Fig. 1). Total N concentration in the 0 to 25 mm increment was almost twice as high in the no-till treatment (3.0 mg cm^{-3}) as in the chisel (1.6 mg cm^{-3}) or plow (1.5 mg cm^{-3}) treatments. Significant differences at the 25- to 75-mm depth were due to the lower total N concentration in samples from the plow treatment, while at the 75- to 150-mm depth, the long-term chisel treatment had the significantly higher total N concentration. The same relationships were responsible for significant differences in total C at those three depth increments. Differences at other depths were not statistically significant.

The ammonium nitrogen data (Fig. 2(a)) showed no significant differences among tillage treatments. The nitrate data (Fig. 2(b)) showed significant differ-

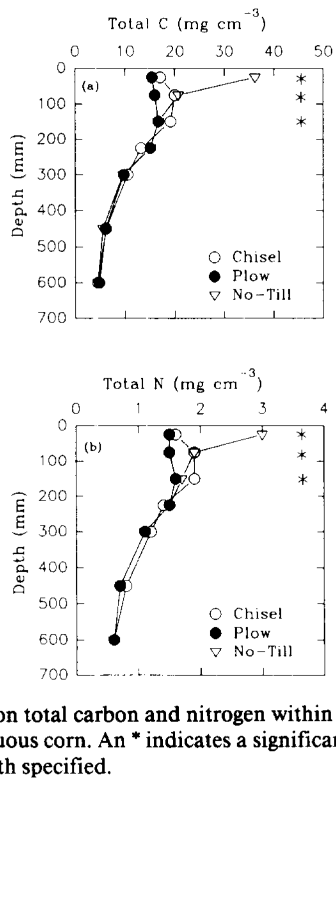

Fig. 1. Tillage treatment effects on total carbon and nitrogen within the upper 600 mm of a silt loam soil following 12 years of continuous corn. An * indicates a significant difference among crop residue treatments at $P\leqslant0.05$ at the depth specified.

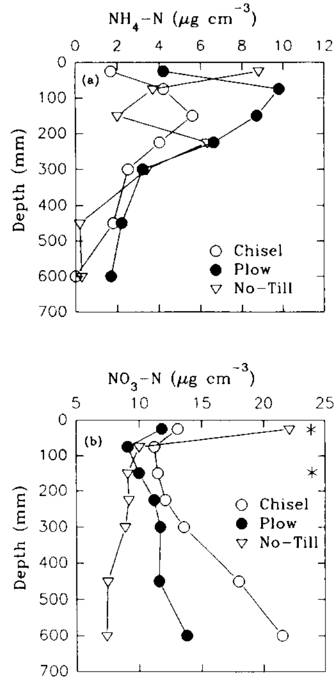

Fig. 2. Tillage treatment effects on NH_4-N and NO_3-N within the upper 600 mm of a silt loam soil following 12 years of continuous corn. An * indicates a significant difference among crop residue treatments at $P \leq 0.05$ at the depth specified.

ences ($P \leq 0.05$) at the 0- to 25- and 75- to 150-mm increments. Differences below 150 mm were not statistically significant, although both the plow and chisel treatments appeared to have substantially higher levels of nitrate nitrogen than were found for the long-term no-till treatment. The total N values in the surface were higher for the no-till, so presumably this reflects more N being incorporated into microbial biomass near the soil surface and less being available for mineralization and possible leaching.

Soil pH, P, K, Ca, and Mg concentrations were also measured, but in general, treatment differences were not statistically significant (data not shown). As expected from previous studies (Karlen et al., 1991) P and K were more stratified in the long-term no-till treatment than for the chisel or plow treatments. Concentrations of both elements were significantly higher in the top 25 mm and lower at the 75- to 150- and 150- to 225-mm depths. Cation exchange capacity (CEC) was fairly uniform to a depth of 225 mm, averaging approximately 10 cmol kg^{-1}. It increased gradually to approximately 16 cmol kg^{-1} at the 450- to 600-mm depth as clay content increased. Long-term tillage treatments caused no significant differences.

Table 5
Runoff, sediment concentration, and calculated soil loss measured from historical plow and no-till treatments, 10 days before and 10 days after soil quality assessments were made

Tillage treatment (date)	Runoff amount (mm)	Sediment concentration ($g\ l^{-1}$)	Estimated soil loss ($Mg\ ha^{-1}$)
Moldboard plow (5/1/91)	33a[a]	3.8a	1.1a
No-till	35a	1.5b	0.5b
Moldboard plow (5/23/91)	42a	5.0a	2.1a
No-till	35a	1.4b	0.5b

[a] Means for each sampling date within a column followed by the same letter are not significantly differnt at $P \leq 0.10$.

3.2. Soil quality assessment

Tillage effects on soil quality in the upper 600 mm of the soil profile were evaluated using the framework proposed by Karlen et al. (1994) for evaluating different crop residue management strategies. Calculations for this study resulted in soil quality ratings within the upper 600 mm of the soil profile of 0.48, 0.49, and 0.68 for the plow, chisel, and no-till treatments, respectively. This suggests that 12 years of no-till management, prior to this sampling and assessment, created a better soil quality in the upper 600 mm of these Rozetta and Palsgrove soils.

3.3. Runoff and sediment loss

To 'field-test' the soil quality index, measurements of runoff and sediment loss from moldboard plow and no-tillage plots were obtained from sprinkler infiltration studies. Those data (Table 5) show that sediment concentrations ($P \leqslant 0.02$) and estimated soil loss ($P \leqslant 0.07$) from the long-term no-till treatment were significantly lower than those from the moldboard plow treatment. Crop residues from the 1990 corn crop were not removed from either treatment before making the measurements, but the percent surface cover (58 and 68%) was not significantly different. The amount of surface cover may have affected simulated raindrop impact energy, but increased water stability for soil aggregates, a predominant factor assumed to affect water entry and resistance to degradation functions within the proposed soil quality index (Karlen et al., 1994), presumably also contributed to less soil loss from the historical no-till treatment.

4. Summary and conclusions

This study demonstrates that adoption of no-till practices can improve several biological, chemical, and physical characteristics of silt loam soils. These improvements presumably enable the soil to resist degradation through water and wind erosion, to accept and retain more water, and to support crop production at levels comparable to those attained by using moldboard plowing or chisel-disking as primary tillage practices. The findings should encourage adoption of soil management practices that decrease tillage intensity on sloping, Orthic Luvisols such as Rozetto and Palsgrove. Adoption of no-till practices would also help maintain or even increase the amount of crop residue that is returned to the soil. This would provide an effective carbon source for improving soil aggregation and structure, presumably leading to additional improvements in soil quality.

We also demonstrated that a proposed soil quality index could detect long-term effects of various tillage treatments. The index, calculated for the upper 600 mm of the soil profile, predicted that no-till soils should have better quality than those which were traditionally plowed. Measurements of soil loss from sprinkler infiltration studies on moldboard and no-till plots supported what the index predicted. We conclude that the systems engineering procedure used to develop this framework can provide a basis for developing an even more dynamic index for evaluating soil quality that includes factors such as pesticide and N leaching potentials.

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