ANNEX 2

(not to be quoted)

Soil quality case studies in central Michigan: comparing rotations with high or low diversity of crops and manure

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Abstract

Differences in soil quality indices associated with increased diversity in residues returned to the soil were assessed in nine pairs of farm fields on corn rotations in central Michigan. Matching sites that mapped to the same soil series and having contrasting high and low diversity in main crops, cover crops and manure were selected. Methods proposed for on-farm measurement of soil quality indices were used. Two-way ANOVA revealed that total nitrogen and soil respiration after irrigation were significantly higher and surface soil penetrability was lower ($P < 0.05$), on the fields receiving a higher diversity of residues. These results suggest that a higher diversity of residues returned to the soil can lead to improved soil quality after a single rotation cycle.

Introduction

Management strategies to sustain or improve soil quality usually call for increasing the diversity of cropping by using cover crops and intercropping in rotations (Karlen et al. 1992). Increasing the diversity of cropping may help improve soil quality by increasing the amount, quality and diversity of residues returned to the soil, and by lengthening the time that roots are active in the soil during the growing season. Increasing the diversity of residues returned by cover crops, intercrops, and manure can protect the soil and increase organic matter; thus reducing soil erosion, and increasing the efficiency of nitrogen utilization and retention of water in the soil (Karlen et al. 1992). However, while it is thought that the robustness of agricultural systems can be improved by imitating the variety of natural ecosystems, little information is available about how cropping diversity, and thus the mix of residues returned to the soil, affects soil quality. The aim of this research was to utilize methods proposed for estimating soil quality to test whether diversity in residues returned to the soil in corn-based rotations is associated with improvements in physical, chemical, or biological properties of soils in south-central Michigan.

Materials and Methods

In selecting matched sites for comparison, we attempted to minimize differences in soil forming factors except management. The candidate sites' histories of main and cover cropping and manuring were recorded for the years 1989-93 by interviewing farmers and extension agents. To verify that the potential paired sites were on the same soil series and had similar aspect and topographic position, we consulted soil maps and made observations in the field. Paired sites were selected as physically close together as possible, although distances between them varied from 0.1 to 2 km (Table 1).

Diversity in residues returned to the soil was estimated by considering each crop and cover crop species, and manure applied, as one source of diversity. Thus continuous corn for five years without cover crops or manure counted as one, while a rotation that included corn, wheat, and soybeans, with clover as cover crop, and manure every other year counted as five. To be selected for comparison, field pairs were required to have a minimum difference of two points in residue diversity. Although cropping histories were usually reconstructed from farm records, a few were based mostly on recollection. Sometimes cropping histories were hazy, or recollections differed among family members. This led to selections being made in the field on the basis of information which was later judged erroneous (e.g. Table 1, comparisons 3 and 5). In at least three comparisons, one field was later found to have received manure much more frequently than its neighbor (comparisons 2,4, and 5).

The selection process was often made more difficult by the presence of extensive inclusions of other soil series in the mapped unit, the inability to match aspect and topographic position, the presence of features such as poorly drained spots in one field and not the other, etc. Moreover, the size of the areas of matching conditions was surprisingly small due to restrictions placed by the geometry of cropped fields, the patchiness of the soil series, or the need to work in the corn phase of the rotation.

Once a farm pair was selected for study, the process of installing the three pairs of sampling stations per plot began. Stations were separated 6.8 m along the inter-row space, and the three station pairs were installed 12 corn rows (approx. 10 m) apart; study plots were thus ~0.01 ha. Sampling stations consisted of a single-ring aluminum respirometer/infiltrometer (18 cm diameter X 15 cm height) installed ~ 7.5 cm deep in the center of the inter-row space. Sampling stations were located in the center of the inter-row because differences in the geometry of ridges, on which corn was generally planted, made matching the placement of the infiltrometer/respirometer difficult otherwise. Another reason for selecting the inter-row space was our interest in testing for the legacy of residues returned during the last five growing seasons, and it was felt that this effect would be less noticeable within the corn row. Inter-rows were selected only after considerable trial-and-error, and were generally non-wheel track rows, free from obvious disturbances such as fertilizer bands, etc.

Measurements taken in a trial run conducted in a corn field adjacent to the Living Field Laboratory (Kellogg Biological Station, MI), were used as controls for the nine comparisons. Methods were as in Doran (1993); but in addition, we measured surface penetration resistance, and installed two additional double-ring infiltrometers (data not shown). Soil samples (0-20 cm), as well as other measurements, were taken from the inter-row area 30-50 cm from the respirometer/infiltrometer (e.g. sampling station). Samples were stored over ice in the field until transported to the laboratory, where portions to be used for measuring biological properties were kept at ~ 4 °C. Although some measurements were also made in soil samples in the field, only laboratory results are reported here. Soil properties were analyzed as follows: bulk density by pushing a small, bottomless aerosol can approximately 7.5 cm into the soil, and removing the soil quantitatively after measuring the length of head space; percent gravel by sieving (2 mm); texture by the hygrometer method; water-holding capacity by using pressure plates to determine water content in undisturbed soil cores at 30 kPa and in packed samples bulked from the six soil samples at each plot at 1.5 MPa; penetration resistance by using a Soiltest CL-700A pocket penetrometer (n = 6) at each station; A-horizon depth and rooting depth by digging (n = 2) at each station; infiltration rate by measuring the time required for 2.5 cm of water added at once to enter the soil in the (single-ring) infiltrometer; inorganic N ($NO_3^+ + NO_2^- + NH_4^-$) by extracting with 2 M KCl and using automated colorimetry, mineralizable N by anaerobic incubation; total C by high temperature combustion (Dohrmann DC 190); total N by the Kjeldahl procedure; extractable P by the Bray procedure; soil respiration by taking samples in the infiltrometer headspace after 1 h incubation and measuring CO_2 by gas chromatography; microbial biomass by measuring CO_2 evolved by 20 g subsamples of moist soil during 10 d following fumigation with chloroform; CO_2 evolved by unfumigated subsamples during the same period was used as a measure of respiration rate of the soil microbial biomass. The soil infiltration and respiration rate measurements were made in the early morning and repeated in the early afternoon 4-6 h after the first irrigation. Corn yield was measured by hand harvesting 6.8 m of row (n = 4) from the area within the study site.

The paired comparison t-test procedure was used to test for differences in soil properties at study plots within each site (n = 6), and for differences across the nine pairs by using the site means. Differences in soil properties between rotations with high or low residue diversity were tested by two-way ANOVA in a 6 X 2 block design, using a procedure that treated subsamples (e.g.

individual sampling-station measurements) as replicates. Three pairs of farms that differed greatly in the number of years manure was applied during 1989-93 were not considered (5 d.f.). Infiltration data were transformed to the $\log_{10}$, and microbial biomass carbon to the square-root form in order to obtain a normal distribution for analysis.

Results and Discussion

Soils were generally of medium texture and density, non-saline (EC $\leq$ 0.1 dSm^{-1}, data not shown) slightly acid to neutral, and fertile (Tables 2-4). Except for low pH, the means of the controls were similar to the average soil properties (Table 5). Paired comparisons of soil properties across the nine sites showed no significant differences and few trends (not shown). Moreover, little pattern could be discerned from the within-site comparisons (Tables 2-4). Nevertheless, inspection of t-test results between individual high and low diversity plots showed that significant differences occurred in the majority of the nine comparisons for chemical, but for only a few comparisons in the physical and biological properties. Of those cases in which significant differences occurred, the majority tended to be in the direction of higher soil quality for the higher diversity side, and lower soil quality for the lower diversity side. For example, mineralizable N differed significantly in five of the nine comparisons, but was higher in the high diversity side in three of those five cases. The controls also exhibited significant differences in several soil properties, likely mirroring strong differences in texture and bulk density across the 40 m distance between study plots.

The high and variable concentrations of extractable N recorded at some plots may have been due to sampling "hot-spots" near fertilizer bands. But the high concentrations of extractable P were likely due to long-term manuring. Further interviews with farmers clarified cropping histories and confirmed three cases in which the low diversity rotations had received yearly applications of manure four or more years during the five-year period under study. The rates of water infiltration and soil respiration (adjusted to 25 °C and 60% water-filled porosity) were lower after irrigation. These second measurements of infiltration, which should occur in soil at field capacity, are meant to measure the soil's response to near-optimal conditions of moisture and aeration. Water-filled porosity measured in undisturbed cores at 30 kPa was 46 ± 11 % (n = 114), but that measured 2-3 h after the second infiltration/respiration measurement was 55 ± 13 % (n = 117). Diffusion rates of CO_2 are markedly reduced when water filled porosity exceeds 60% (Doran 1993). Waiting 4-6 h after the first irrigation before initiating the second was probably insufficient time to reach field capacity. Better results would doubtless have been obtained by making the first measurement in the afternoon, and returning in the morning for the second. Although the second measurements likely are not good estimators of infiltration and respiration rates in soil at field capacity, they are still useful for purposes of comparison. In comparison number 5, soil respiration rates were anomalously low in the high diversity plot; but inspection of the data did not reveal errors, and no explanation could be found for the low readings.

Two-way ANOVA, using subsamples as replicates and not considering the three comparisons that differed in manure application, showed that total soil nitrogen and soil respiration after irrigation were significantly higher and surface penetrability lower ($P \leq 0.05$); and corn rooting was deeper, and infiltration after irrigation faster ($P \leq 0.10$), on the fields receiving a high diversity of residues (Table 5). These results indicate that increased diversity of residues returned to the soil was associated with an improvement in soil quality, which was expressed as improved soil tilth, nutritional status, and biological activity. The increase in total, but not extractable or mineralizable, nitrogen suggests that the improvement in nutritional status resulted from an increase in the pool of organic nitrogen in the soil. Results presented here are consistent with those of Reganold et al. (1993) in that improved soil quality was associated with improvement in soil tilth, nutritional status, and biological activity. The use of subsamples as replicates, which in a strict sense constitutes false replication in a statistical analysis of this type, has been criticized and defended (Wardle and Reganold 1994). In this study, because of the impossibility of replicating farm management, it permitted detecting soil quality differences across sites.

Indices of cropping diversity and manuring frequency were devised that correlated moderately well with soil properties (e.g. microbial biomass carbon, $r = 0.57$). These correlation analyses revealed that improvements in soil quality could not be associated simply with diversity in rotations, cover crops or manure applied, but rather with diversity and frequency in all three sources of residues. Although factors such as quantity and quality of residues could not be controlled, and their effects cannot be discounted, the cropping histories do not suggest that these factors biased the results. It is likely that replacing corn with either wheat or soybeans would result in lower quantities, and equal or slightly higher quality, of residues returned to the soil. Thus, results reported here indicate that a higher diversity of carbon inputs from crop residues can lead to improved soil quality after a single rotation cycle.

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Table 1. Landscape and soil characteristics, and 1989-1993 history of cropping and manuring of study sites in south central Michigan.

Comparison	Landscape	Distance between study sites (~ m)	Soil series (% slope)	Cropping	Cover crops	Manure ~ Mg ha^{-1}	Residue diversity
Control	Nearly level	40	Kalamazoo sl 0-2%	A A A A C	— — — — —	— — — — —	2
1 high	S shoulder, small knoll	200	Spinks ls 0-6%	Tr S C S C	— — — — —	— 25 — 25 —	4
1 low	S shoulder, small knoll		Spinks ls 0-6%	C C C C C	— — — — —	25 25 — — —	2
2 high*	Nearly level bottom	200	Capac l 0-3%	C C S W C	cl — — cl cl	— — — — —	4
2 low*	Nearly level bottom		Capac l 0-3%	C C C C C	— — — — —	25 25 25 25 25	2
3 high	Nearly level	100	Capac l 0-3%	C C S W C	cl — — cl cl	— — — — —	4
3 low	Nearly level		Capac l 0-3%	C S W C C	— — — — —	— — — — —	3
4 high*	Rolling, midslope	100	Marlette fsl 2-6%	C S C S C	cl — — — —	— — 25 — —	4
4 low*	Rolling, midslope		Marlette fsl 2-6%	C C C C C	— — — — —	25 25 25 25 25	2
5 high*	Nearly level	1000	Capac l 0-3%	C S W C C	— — cl cl cl	— — — — —	4
5 low*	Nearly level		Capac l 0-3%	A A A C C	— — — — —	25 25 25 25 —	3
6 high	Small undulations	150	Ithaca l 0-3%	Cu W C S C	— — — — —	— — — 25 —	5
6 low	Small undulations		Ithaca l 0-3%	C C S C C	— — — — —	— — — — —	2
7 high	Nearly level	2000	Kalamazoo sl 0-2%	C C W C C	— — cl — —	25 — 25— —	4
7 low	Small undulations		Kalamazoo sl 2-6%	C C C C C	— — — — —	— — — — —	1
8 high	Small undulations	1000	Capac l 0-3%	C B Cu W C	— — — cl —	25 25 25 — —	6
8 low	Small undulations		Capac l 0-3%	C C C C C	— — — — —	25 25 25 — —	2
9 high	S shoulder, small knoll	400	Marlette fsl 2-6%	A W C S C	og v — — v	— 12.5— — —	7
9 low	S shoulder, small knoll		Marlette fsl 2-6%	W F C S C	— — cl — —	— — — — —	4

C= Corn, S = Soybeans, A= Alfalfa, W =Wheat, Tr = Triticale, Cu = cucumbers, F = Fallow, cl = clover, og = orchard grass, v = vetch. * Not considered in ANOVA because of difference in the number of years manure was applied.

Table 2. Comparisons of soil physical properties in corn fields with high or low cropping diversity of residues returned to the soil during 1989-93. Values are means (std. error of the mean) n = 6.

Soil property	Control[a]		Comparison 1		2		3		4		5		6		7		8		9	
			High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Texture [b] (%clay-gravel)	cl (30-1)	l (25-14)	ls (7-2)	ls (6-2)	cl (35-1)	scl (29-1)	scl (29-15)	scl (26-4)	sl (10-10)	sl (11-6)	scl (28-2)	scl (22-3)	scl (31-8)	scl (27-1)	sl (17-1)	sl (18-5)	cl (29-6)	sl (18-6)	sl (16-17)	sl (19-10)
Bulk density[c]	1.05 (0.02)	1.25** (0.04)	1.38 (0.01)	1.43# (0.02)	1.01 (0.04)	1.03 (0.04)	1.06 (0.01)	1.29* (0.06)	1.26 (0.01)	1.25 (0.02)	1.15 (0.04)	1.29 (0.07)	1.25 (0.03)	1.23 (0.04)	1.44 (0.04)	1.40 (0.03)	1.29** (0.03)	1.15 (0.02)	1.27 (0.04)	1.20 (0.03)
Water holding capacity[d]	1.90# (0.06)	1.25 (0.18)	0.98 (0.13)	1.02 (0.08)	2.29 (0.39)	1.69 (0.19)	1.20 (0.28)	1.34 (0.19)	2.48 (0.26)	2.20 (0.29)	1.52 (0.12)	1.51 (0.15)	1.10 (0.22)	1.49* (0.22)	1.99* (0.33)	1.38 (0.30)	1.72 (0.17)	2.36# (0.17)	2.18* (0.21)	1.00 (0.17)
Penetration resistance[e]	0.9 (0.2)	1.0 (0.2)	wet ~0	wet ~0	0.9 (0.3)	0.5 (0.1)	0.7 (0.1)	2.4* (0.5)	1.9 (0.2)	1.1 (0.4)	1.9 (0.1)	1.8 (0.3)	0.4 (0.1)	0.8** (0.1)	0.9 (0.2)	1.5 (0.3)	1.1* (0.2)	0.6 (0.1)	1.0 (0.2)	0.7 (0.1)
A horizon depth[f]	nd[i]	nd[i]	25.9 (0.5)	28.5# (0.8)	26.3 (0.9)	31.4* (1.4)	30.0 (1.1)	29.8 (0.8)	25.1 (0.3)	22.8 (1.0)	28.6 (0.3)	28.1 (0.6)	25.3 (0.7)	23.8 (1.7)	29.8* (0.6)	26.7 (0.7)	26.1 (1.0)	24.4 (0.7)	21.6 (0.4)	23.9*** (0.5)
Corn rooting depth [f]	24.8 (2.0)	25.8 (1.5)	23.3 (0.5)	23.3 (0.5)	21.8 (0.7)	22.0 (1.8)	24.8 (2.1)	22.6 (1.2)	19.7 (0.5)	22.8# (1.0)	23.2 (0.9)	25.4** (0.9)	25.1 (0.7)	23.8 (1.7)	27.8** (0.8)	21.8 (1.1)	22.6 (0.9)	20.9 (0.9)	20.1 (0.5)	23.3** (0.4)
Infiltration rate[g]	3.67*** (0.45)	0.17 (0.04)	0.40** (0.05)	0.10 (0.01)	23.2 (6.01)	11.4 (3.04)	17.5* (3.10)	0.60 (0.38)	1.74 (0.65)	3.65 (1.92)	7.82 (1.78)	12.2 (5.56)	0.99 (0.36)	1.29 (0.60)	0.33 (0.15)	0.32 (0.11)	0.94 (0.40)	3.33 (0.88)	1.84 (0.32)	1.22 (0.31)
Infilt. rate after irrigation[h]	0.43 (0.19)	0.88 (0.31)	0.37 (0.04)	0.28 (0.19)	9.41 (4.26)	7.24 (2.54)	3.42* (1.19)	0.08 (0.05)	0.91 (0.44)	1.66 (0.92)	2.95 (1.01)	7.39 (3.26)	0.29 (0.12)	0.34 (0.15)	0.10 (0.03)	0.14 (0.07)	0.13 (0.06)	0.19 (0.10)	0.26 (0.07)	0.44 (0.16)

[a]Trial comparison at Living Field Laboratory, Kellogg Biological Station, MI., on "uniform" soil with same cropping history during previous five years; [b] bulk sample n = 1; [c] 0-7.5 cm depth; [d] cm in upper 20 cm soil; [e] surface, kg cm^{-2}; [f] cm; [g] cm min^{-1}, 2.5 cm H_2O (falling head); [h] cm min^{-1}, 2.5 cm H_2O 4-6 h after first irrigation (falling head); [i] not determined; #, *,**,*** significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively.

Table 3. Comparisons of soil chemical properties in corn fields with high or low diversity of residues returned to the soil during 1989-93. Values are means (std. error of the mean) n = 6.

Soil property	Comparison																			
	Control[a]		1		2		3		4		5		6		7		8		9	
			High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
pH[b]	5.2	5.4	6.5#	5.8	6.9	7.1*	6.3	6.5	5.9	5.7	6.4	6.3	6.1	5.8	5.6	6.1	5.8	6.8	5.8	5.9
Total C[c]	43.7** (1.27)	34.6 (1.50)	29.0 (1.33)	33.8# (2.38)	80.1 (3.55)	74.1 (4.20)	52.0 (1.96)	56.5 (2.33)	51.8 (6.17)	42.5 (1.88)	42.9 (1.44)	58.2** (3.10)	49.8# (3.10)	46.6 (2.61)	50.5** (2.85)	32.9 (2.05)	61.9 (2.42)	55.8 (1.75)	30.6 (1.46)	34.7# (2.27)
Extractable N[d]	70.3 (8.5)	59.5 (7.0)	43.5 (2.9)	292* (65)	83.5* (5.2)	59.4 (6.3)	369# (155)	23.2 (1.7)	37.1 (7.2)	45.0 (2.0)	54.0 (12.3)	335 (190)	98.1 (21)	73.1 (25)	42.9 (2.4)	35.7 (9.6)	131# (35)	51.3 (4.7)	42.0 (4.9)	153* (30)
Mineralizable N[d]	51.2 (2.1)	44.2 (3.6)	31.0 (2.0)	186* (56)	61.7# (6.4)	52.9 (5.0)	102 (33)	47.2 (2.9)	67.4 (10)	79.1 (11)	33.1 (1.2)	159# (59)	41.7 (2.0)	33.9 (4.0)	77.8* (6.8)	50.7 (3.5)	46.9 (5.1)	49.3 (3.4)	45.5* (2.8)	34.6 (1.2)
Total N[c]	4.27*** (0.11)	3.28 (0.14)	1.99 (0.11)	2.69* (0.11)	9.81# (1.0)	7.52 (0.51)	5.57 (0.14)	5.47 (0.17)	4.31 (0.36)	3.94 (0.12)	4.00 (0.17)	5.91*** (0.24)	5.51# (0.40)	4.34 (0.17)	4.82* (0.17)	3.29 (0.16)	5.65 (0.14)	5.24 (0.25)	3.02 (0.12)	3.43** (0.08)
C:N ratio	10.3 (0.3)	10.6 (0.3)	14.7 (1.0)	12.6 (0.8)	8.4 (0.6)	9.9* (0.3)	9.4 (0.3)	10.3* (0.2)	11.9 (0.7)	10.8 (0.3)	10.8 (0.4)	9.9 (0.5)	9.1 (0.2)	10.7*** (0.2)	10.5 (0.5)	10.0 (0.4)	10.9 (0.2)	10.7 (0.5)	10.1 (0.2)	10.2 (0.6)
Extractable P[de]	163 (11)	157 (10)	758* (46)	675 (28)	260 (27)	192 (30)	140# (11)	124 (11)	380 (33)	1510*** (132)	163 (5)	188 (15)	267* (11)	172 (19)	806* (143)	208 (21)	277 (46)	578** (61)	84.9 (14)	278*** (17)

[a]Trial comparison at Living Field Laboratory, Kellogg Biological Station, MI, on "uniform" soil, same cropping history during previous five years; [b]1:1 soil:H_2O; [c]Mg ha^{-1}; [d]kg ha^{-1}; [e]Bray 1; #, *,**,*** significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively.

Table 4. Comparisons of soil biological properties and yield in corn fields with high or low diversity of residues returned to the soil during 1989-93. Values are means (std. error of the mean) n = 6.

Soil property	Control[a]		Comparison 1		2		3		4		5		6		7		8		9	
			High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High	Low
Soil respiration[b]	40.8 (3.5)	33.4 (6.2)	17.2 (2.6)	13.9 (7.8)	23.8 (3.0)	30.4 (4.4)	42.4 (9.2)	29.7 (5.5)	32.8 (6.1)	27.8 (7.2)	1.98 (6.5)	34.8# (11)	39.9 (6.8)	60.3# (11)	27.7 (3.8)	31.1 (3.1)	37.1 (6.6)	27.1 (4.8)	64.2 (7.9)	45.7 (3.1)
Soil resp. after irrigation[b]	24.7 (4.0)	18.6 (4.5)	10.8 (2.5)	8.83 (3.3)	10.6 (1.9)	15.7# (2.0)	17.9 (3.3)	13.9 (4.6)	8.58 (3.2)	6.68 (1.6)	3.08 (1.0)	32.4** (5.3)	6.21 (0.3)	6.86 (1.2)	29.6* (5.3)	15.0 (1.2)	15.4 (3.5)	11.4 (2.3)	12.5 (0.9)	11.0 (2.8)
Microbial biomass C[c]	1.40 (0.10)	1.27 (0.14)	1.07 (0.15)	1.27 (0.20)	2.20# (0.09)	1.88 (0.10)	1.61 (0.25)	1.55 (0.15)	1.13 (0.10)	1.33 (0.16)	1.46 (0.05)	1.81# (0.15)	1.01# (0.09)	0.84 (0.04)	1.30*** (0.08)	0.88 (0.07)	1.38 (0.13)	1.62 (0.07)	1.06 (0.07)	0.95 (0.06)
Microbial respiration[b]	25.7 (5.5)	30.2 (5.6)	35.8 (7.9)	51.2 (9.1)	36.5* (6.9)	14.3 (1.0)	17.5 (4.2)	16.7 (2.4)	8.86 (1.9)	14.8 (2.2)	17.8 (5.0)	21.2 (0.8)	14.3 (5.8)	12.6 (4.1)	32.1 (8.5)	15.7 (3.9)	21.9 (5.3)	26.6 (4.9)	11.6 (4.7)	8.69 (1.7)
Specific respiratory activity[e]	0.75 (0.13)	1.03# (0.21)	1.50 (0.34)	2.09 (0.65)	0.70# (0.14)	0.32 (0.03)	0.44 (0.05)	0.44 (0.04)	0.31 (0.06)	0.45# (0.03)	0.49 (0.12)	0.50 (0.03)	0.75 (0.41)	0.64 (0.23)	1.03 (0.28)	0.79 (0.24)	0.67 (0.13)	0.70 (0.14)	0.44 (0.17)	0.40 (0.09)
Cmic/Ctotal[f]	3.22 (0.26)	3.72 (0.43)	3.77 (0.57)	3.81 (0.65)	2.77 (0.16)	2.58 (0.21)	3.17 (0.58)	2.79 (0.33)	2.37 (0.45)	3.15 (0.44)	3.42 (0.08)	3.16 (0.35)	2.02 (0.15)	1.85 (0.19)	2.58 (0.04)	2.69 (0.18)	2.23 (0.19)	2.93# (0.15)	3.51 (0.27)	2.74 (0.37)
Mineralizable N/ Total C[g]	1.17 (0.04)	1.30 (0.13)	1.07 (0.06)	6.84 (2.87)	0.77 (0.07)	0.72 (0.07)	1.41 (0.42)	0.84 (0.04)	1.39 (0.29)	1.83 (0.21)	0.77 (0.02)	2.84 (1.16)	0.85# (0.06)	0.73 (0.09)	1.57 (0.15)	1.55 (0.08)	0.75 (0.07)	0.89 (0.07)	1.51* (0.13)	1.01 (0.05)
Corn yield[ch]	–8.53–		5.56 (0.02)	7.35# (0.46)	10.8* (0.46)	8.90 (0.65)	11.1** (0.10)	5.84 (0.70)	10.7 (0.58)	10.1 (0.39)	11.1* (0.36)	6.48 (1.10)	10.3 (1.37)	9.74 (0.79)	8.23 (0.46)	7.15 (0.53)	10.3 (0.16)	10.7 (0.33)	5.48 (0.50)	8.22* (0.49)

[a] Trial comparison at Living Field Laboratory, Kellogg Biological Station, MI., on "uniform" soil, same cropping history during previous five years; [b] kg CO_2-C ha^{-1} day^{-1}; [c] Mg ha^{-1}; [e] (soil microbial respiration/soil microbial biomass) X1000; [f] %; [g] X1000; [h] (n = 4); #, *,**,*** significant at the 0.10, 0.05, 0.01, and 0.001 levels, respectively.

Table 5. Comparison of soil properties in corn-based rotations with high or low diversity of residues returned to the soil, analyzed in a 6 X 2 block design by two-way ANOVA procedures using subsamples as replicates. Three pairs of farms that differed greatly in the number of years manure was applied during 1989-93 were not considered.

Soil property	Diversity High	Diversity Low	P value	Ratio High:Low
Bulk density 0-7.5 cm depth, g cm^{-3}	1.28	1.28	0.98	1.00
Penetrability, kg cm^{-2}	0.68	1.00	0.04*	0.68
Corn rooting depth, cm	23.9	22.6	0.05#	1.06
A horizon depth, cm	26.4	26.2	0.61	1.01
Water holding capacity, cm H_2O in 20 cm soil	1.53	1.41	0.40	1.08
Infiltration rate, cm min^{-1}	1.18	0.78	0.31	1.51
Infiltration rate 4-6 h after irrigation, cm min^{-1}	0.34	0.16	0.07#	2.12
Extractable N, kg ha^{-1}	121	105	0.65	1.15
Mineralizable N, kg ha^{-1}	57.4	66.9	0.49	0.86
Total C, Mg ha^{-1}	45.6	43.4	0.16	1.05
Total N, Mg ha^{-1}	4.43	4.08	0.02*	1.08
C:N ratio	10.8	10.8	0.92	1.00
Extractable P, kg ha^{-1}	389	339	0.28	1.15
Soil respiration, kg C ha^{-1} day^{-1}	37.1	32.4	0.25	1.14
Soil respiration 4-6 h after irrigation, kg C ha^{-1} day^{-1}	15.5	11.0	0.02*	1.41
Microbial biomass C, Mg ha^{-1}	1.24	1.18	0.49	1.05
Microbial respiration, kg C ha^{-1} day^{-1}	22.2	21.9	0.93	1.01
Specific microbial respiration [qCO_2] (X1000)	0.81	0.85	0.80	0.95
$C_{microbial}/C_{total}$, %	2.88	2.81	0.75	1.02
Mineralizable N/C_{total} (X1000)	1.17	1.81	0.13	0.65
Corn yield, Mg ha^{-1}	8.51	8.17	0.51	1.04

#, * significant at the 0.1 and 0.05 levels, respectively.