Changes in Soil Microbial and Chemical Properties under Long-term Crop Rotation and Fertilization

A. B. Omay, C. W. Rice,* L. D. Maddux, and W. B. Gordon

ABSTRACT

With renewed interest in maintaining our soil resources, it is important to establish criteria that can describe and quantify the effect of different crop management practices on soil organic matter (SOM). We conducted this study to assess changes in SOM and other soil properties after long-term (>10 yr) continuous corn (*Zea mays* L.; CC) and corn–soybean rotation [*Glycine max* (L.) Merr.; C/SB] with and without fertilizer. Soil samples were collected from two furrow-irrigated CC and C/SB rotations on a Crete silt loam (fine, montmorillonitic, mesic Pachic Argiustoll) and a Eudora loam (coarse-silty, mixed, mesic Fluventic Hapludoll). Long-term (350-d) laboratory incubation at optimum moisture and temperature conditions measured potentially mineralizable C (PMC) and N (PMN) as a measure of the active fraction of soil organic C and N. Microbial biomass C (MBC) and N (MBN), organic C and N, pH, and texture also were determined. Crop rotations that included high-residue-producing crops such as corn and addition of fertilizer increased soil organic C and N. Crop rotation did not affect PMC in the Crete soil, but addition of fertilizer significantly increased PMC by 32%. The PMN in both soils was not affected by crop rotation or fertilizer addition. Inclusion of soybean in the rotation decreased the stable and active fractions of organic C and N. Changes in soil organic C and N in response to crop rotation and fertilizer addition were related to the estimated amount of crop residues returned to the soil and to soil texture.

With the increasing emphasis on sustainable agriculture and soil quality, it is important to determine the effect of different crop management practices on SOM. Although SOM in soil changes slowly, some fractions may be more sensitive to change. The SOM fractions that are considered important include microbial biomass, PMC and PMN, and organic C and N. Potentially mineralizable C and N may be good indicators of changes in soil organic C and N induced by crop rotation, fertilization, or tillage practices since they represent the more active fraction of SOM (Carter and Rennie, 1982; Campbell et al., 1989). At present, PMC and PMN from long-term incubations are rarely estimated in crop rotation studies. Simultaneous determination of PMC and PMN provides a better understanding of soil organic C and N turnover, because mineralization of organic N is related closely to that of organic C (McGill et al., 1981). Microbial biomass is more responsive to cultural treatments than total SOM (Powlson and Jenkinson, 1981; McGill et al., 1986). Long-term cropping practices would be expected to affect these fractions of SOM.

Long-term studies have shown positive effects of crop rotations, especially with legumes, and of various cultural management practices in maintaining SOM levels (Voss and Shader, 1979; Balbock et al., 1981; Odell et al., 1984; McGill et al., 1986; Janzen, 1987; Campbell et al., 1991). Tillage methods influence crop N utilization from soil and fertilizer sources and impact the physical, chemical, and biological properties (Papendick and Miller, 1977; Doran, 1980). Research demonstrated that N mineralization potentials in the surface 15-cm layer were higher for corn with no-tillage than with conventional tillage (Bandel et al., 1975; Bennett et al., 1975).

Stanford and Smith (1972) proposed the concept of PMN, as determined by the incubation–leaching method and a mineralizable rate constant, k_o, to characterize potentially available N. Since then, this incubation technique has been used to characterize the size of the potentially mineralizable N pool in soils and to determine the effect of different cultural practices on soil fertility (Carter and Rennie, 1982; El-Harris et al., 1983; Campbell et al., 1984; Hadas et al., 1986; Bonde et al., 1988; Rice and Garcia, 1994) and organic waste amended soils (Lindenman and Cardenas, 1984; Boyle and Paul, 1989).

The objectives of this study were to assess changes in SOM and other soil properties after long-term (>10 yr) CC and C/SB with and without fertilizer. Changes in SOM were assessed by measuring soil organic C (SOC) and soil organic N (SON), PMC and PMN, and MBC and MBN.

MATERIALS AND METHODS

Soil

Surface soil samples (0–15 cm) were collected in early September 1991 from two existing furrow-irrigated C/SB rotation experiments in Kansas. Some of the physical and chemical properties of the soils are reported in Table 1. Treatments at these sites included three crop rotations and four N rates replicated four times. At the first site, where the plots were conventionally tilled, CC and C/SB rotations had been in existence for the previous 11 yr on a Eudora loam at the Kansas River Valley Experiment Field near Silver Lake, KS. The clay and sand contents are 112 and 395 g kg^{-1}, respectively. Soil samples were collected from the four replications of the 0 and 252 kg N ha^{-1} yr^{-1} treatments. Fifteen samples were collected from each replication using an Oakfield hand sampler (2.26-

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Abbreviations: SOM, soil organic matter; CC, continuous corn; C/SB, corn–soybean rotation; PMC, potentially mineralizable carbon; PMN, potentially mineralizable nitrogen; MBC, microbial biomass carbon; MBN, microbial biomass nitrogen; SOC, soil organic carbon; SON, soil organic nitrogen; PVC, polyvinyl chloride.

cm diam.) and bulked. The samples were transported to the laboratory in a cooler and stored at 4°C at field moisture. Subsamples were taken from the bulked soil from each replicate for the different chemical and microbiological analyses. Fertilizer N was applied as NH_4NO_3, and no N was applied to soybean following corn.

At the second site, the North Central Kansas Experiment Field, Scandia, KS, CC and C/SB rotations had been in place for 10 yr on a Crete silt loam. The clay and sand contents are 202 and 101 g kg^{-1}, respectively. Soil samples were collected from all four replications, as described above, from the 0 and 224 kg N ha^{-1} yr^{-1} treatments. Ammonium nitrate was applied in a ridge-till system; no N was applied to soybean.

Nitrogen Mineralization

Potentially mineralizable N and the mineralization rate constant, k, were determined by laboratory incubations. This procedure was based on the leaching method proposed by Cabrera and Kissel (1988a) as modified by Garcia (1992). Field samples were sieved to pass a 6-mm mesh and subsampled for soil water content. Based on soil water content and assuming a bulk density of 1.1 g cm^{-3}, 105 g of moist soil were packed into PVC cores (5.08-cm diam., 10-cm length) to a depth of 4 cm. Fine acid-washed sand (3 g) was added to the soil surface in each core to prevent disintegration of the soil during leaching. After packing, the cores were weighed and stored at 4°C up to 30 d until initiation of the incubation period. For leaching of N mineralized during incubation, the cores were placed on plastic Buchner funnels (7-cm diam.), which were attached to a side-arm 500-mL Erlenmeyer flask connected to a vacuum pump. Cellulose filters (Millipore Corp., Bedford, MA) with a bubble-point pressure of 0.0685 MPa were glued to the bottom of the funnels. The bubble-point pressure of the filter allowed soil equilibration to a water potential of 0.033 MPa. Plastic mesh was placed on top of the filters in order to protect them during leaching. A 3- to 4-mm-thick layer of glass beads (solid glass spheres, 29-μm mean particle size, Potters Industries Inc., Parsipanny, NJ) was added to the top of the plastic mesh before leaching for maximum contact with the soil. The cores were leached by allowing 250 mL of 0.01 M $CaCl_2$ to percolate through the soil (in 50-mL increments), while a constant vacuum of 0.005 MPa was applied. The leachate was transferred to a 250-mL volumetric flask and made up to volume with 0.01 M $CaCl_2$. The NH_4^+–N and NO_3^-–N concentrations were determined on an Alpkem Autoanalyzer (Alpkem Corp, Clackamas, OR). After each leaching, N-free solution (50 mL) was added to each core and a vacuum of 0.033 MPa was applied for 6 h. The N-free solution, prepared with KH_2PO_4, K_2SO_4, $MgSO_4$, and $CaSO_4$, contained 100, 24, 113, 0.5, and 4 mg L^{-1} of Ca, Mg, S, P, and K, respectively. Solution pH was approximately 7 (Cabrera and Kissel, 1988a). Subsequent leachings were performed in a similar manner after 7, 14, 28, 56, 77, 105, 140, 189, 231, 280, and 350 d. Between leaching events, the cores were placed in 940-mL mason jars to measure CO_2. Approximately 20 mL of water was at the bottom of the jar to maintain a humidified environment and prevent water loss. The jars were incubated at 32°C for 350 d.

Carbon Mineralization

Every 2 to 4 d during the first month and on a weekly basis thereafter, the CO_2–C evolved from the soil cores was determined. This was done by taking a 1-mL gas sample of the mason jar headspace through a rubber septum fitted in the lid of the jar. The concentration of the CO_2–C was measured on a Shimadzu Gas Chromatograph-8A (Shimadzu Inc., Kyoto, Japan). The gas chromatograph was equipped with a thermal conductivity detector and a 2-m Porapak column. The column temperature was 70°C and the carrier gas was He at a flow rate of 14 mL min^{-1}. After the headspace gas was sampled, the jars were opened for ≈15 min to allow equilibration with the atmosphere. The concentration of CO_2 in the laboratory air was measured and subtracted from the CO_2 in the mason jar.

Table 1. Some chemical properties of the soils used.

Treatment	Crete silt loam			Eudora loam		
	pH†	SON‡	SOC‡	pH	SON	SOC
		—— g kg^{-1} ——			—— g kg^{-1} ——	
Rotation						
CC	6.1 a§	1.78 a	16.71 a	6.2 b	1.19 a	8.72 a
C¶/SB	6.1 a	1.73 ab	15.91 ab	6.8 a	1.14 a	8.19 ab
SB¶/C	6.0 a	1.70 b	15.21 b	6.9 a	1.06 b	7.16 b
N rate, kg N ha^{-1}						
0	6.2 a	1.71 a	16.03 a	7.2 a	1.10 b	8.04 a
224#/252	5.9 b	1.76 a	15.85 a	6.1 a	1.15 a	8.01 a

† Measured by glass electrode in a 1:1 soil/water (w/v) solution.
‡ Determined by direct combustion on a Carlo Erba C/N Analyzer; SON = soil organic N; SOC = soil organic C.
§ Values within a column followed by the same letter do not differ significantly (LSD = 0.05).
¶ Current-year crop when samples were collected in early September 1991.
# First value for Crete silt loam and the second value for the Eudora loam.

Microbial Biomass Carbon and Nitrogen

Soil microbial biomass was determined using the chloroform fumigation–incubation technique (Jenkinson and Powlson, 1976). Twenty-five grams of each sample were added to two 125-mL Erlenmeyer flasks. When the gravimetric soil water content was <0.25 kg kg^{-1}, water was added to attain this level. Both samples were preincubated at 25°C for 5 d. After the preincubation period, one of the samples was fumigated with chloroform in a vacuum dessicator with a wet paper towel at the bottom and a beaker containing approximately 50 mL of ethanol-free chloroform and nonvolatile granules for distillation (Boilezeers, Fisher Scientific, Fair Lawn, NJ). Vacuum was applied three times for approximately 30 s to allow the chloroform to boil. Immediately after the third evacuation, the dessicator was closed tightly to allow chloroform to diffuse into the soil. After 18 to 24 h, the beaker and paper towel were removed, and the dessicator was evacuated eight times for 3 min each time. The flasks were then placed in 940-mL mason jars containing enough water at the bottom to maintain a highly humidified environment. Jars were closed tightly and incubated for 10 d at 25°C. Oxygen concentration inside the jar was >20% after 10 d. At the end of the incubation period, CO_2–C concentrations in the headspace were determined following the procedure mentioned above for C mineralization. After measuring CO_2–C, 100 mL of 1 M KCl were added to each flask and the contents were shaken for 1 h on an orbital shaker at 300 rpm. The suspensions were transferred to 250-mL centrifuge bottles and centrifuged at 16 000 × g for 10 min, filtered through a nylon mesh (10 μm), and stored in the freezer until analyzed for NH_4^+–N and NO_3^-–N. The MBC and MBN were calculated as suggested by Voroney and Paul (1984):

$$\text{Microbial biomass C} = F_C - UF_C/K_C$$
$$\text{Microbial biomass N} = F_N - UF_N/K_N$$

where

F_C = CO_2 flush from the fumigated sample,
UF_C = CO_2 produced by the control,
K_C = fraction of biomass C mineralized to CO_2, which is 0.41,

F_N = flush of NH_4^+ due to fumigation,
UF_N = NH_4^+ mineralized during 0 to 10 d from a control, and
K_N = proportion of microbial N mineralized to NH_4^+ during the 10-d incubation period = $-0.014(F_C/F_N) + 0.39$.

Total Carbon and Nitrogen

Soil subsamples were finely ground, passed through a 100-mesh sieve, and analyzed by direct combustion for total C and N using a Carlo Erba Model 1500 CNS Analyzer (Carlo Erba Strumentazione, Milan, Italy).

Kinetics of Carbon and Nitrogen Mineralization

The Marquardt option in NLIN, a nonlinear curve-fitting procedure (SAS Institute, 1988), was used to fit one-pool, two-pool, and mixed-order models (Stanford and Smith, 1972; Molina et al., 1980; Brunner and Focht, 1984) to cumulative N mineralized (NH_4^+ and NO_3^-) and CO_2–C evolved with time. The last two models failed to converge or resulted in higher root mean square error, so the calculations generated are not presented. The one-pool model fit the data with a range of r^2 from 0.9877 to 0.9990. The one-pool model is of the form:

$$C_m \text{ or } N_m = C_o \text{ or } N_o(1 - e^{-kt})$$

where

C_m = mineralized C in g CO_2–C kg^{-1},
N_m = mineralized N in mg N kg^{-1},
C_o = potentially mineralizable C in g CO_2–C kg^{-1},
N_o = potentially mineralizable N in mg N kg^{-1},
k = rate constant of mineralization d^{-1}, and
t = time in d.

Data Analyses

Data were analyzed using a split-plot design. Analysis of variance and separation of means by least significant differences were performed using SAS procedures (SAS Institute, 1988).

RESULTS

Soil Organic Carbon and Nitrogen

Bulk density values in the Crete soil were 1.05, 1.04, and 1.01 Mg m^{-3} for the CC, C/SB, and SB/C treatments, respectively. In the Eudora soil, the bulk density in the CC treatment was 1.06 Mg m^{-3}, 1.11 Mg m^{-3} for the C/SB, and 1.06 Mg m^{-3} in the SB/C rotation. Because crop rotation and N fertilizer addition had no significant effect on bulk density, organic C and N are expressed in concentration units, assuming that these values are directly proportional to units of mass per unit area. After >10 yr of crop rotation, SOC in the Crete soil was significantly higher under CC and was lowest when soybean was the current crop (Table 1). The amount of total C after corn in the C/SB rotation was intermediate. Fertilizer addition did not significantly affect total C content when averaged across rotations. The trend for total N was similar. Total N was 5% greater under CC than in the treatment where soybean was the current crop.

Although the Eudora soil had lower total C and N contents than the Crete soil, the same pattern was observed for the effects of crop rotation (Table 1). Total C and N were significantly higher in CC and lowest in the treatment where soybean was the current crop.

Table 2. Pool sizes (potentially mineralizable C [PMC]) and rate constants (k) for the one-pool model used to describe C mineralization for the Crete and Eudora soils.

Treatment	Crete silt loam		Eudora loam	
	PMC	k	PMC	k
	mg kg^{-1}	d^{-1}	mg kg^{-1}	d^{-1}
Rotation				
CC	2855	0.00629 a†	2384 a	0.00508
C‡/SB	3187	0.00459 b	2196 a	0.00423
SB‡/C	3026	0.00459 b	1646 b	0.00474
N rate, kg N ha^{-1}				
0	2604 a	0.00535	1707 a	0.00468
224/252	3442 b	0.00496	2444 b	0.00467
LSD (0.05)				
Rotation (R)	NS§	0.0005	213	NS
N rate (N)	568	NS	169	NS
R × N	NS	NS	NS	NS

† Values within a column followed by the same letter do not differ significantly (LSD = 0.05).
‡ Current crop when samples were collected in early September 1991. C = corn; SB = soybean.
§ NS = not significant at $P = 0.05$.

Nitrogen addition did not significantly affect total C but significantly increased total N compared with the control.

Potentially Mineralizable Carbon and Nitrogen

In the Crete soil, rotation had no significant effect on PMC (Table 2). Fertilizer addition significantly increased the pool of PMC by 32%. The rate constant k was significantly higher under CC than in the rotation. No significant differences were observed in the rate constants with N fertilizer addition.

In the Eudora soil, crop rotation and fertilizer addition significantly affected PMC. Potentially mineralizable C was highest in the CC treatment and lowest when soybean was the current crop (Table 2). Fertilizer N increased PMC by 43% but did not significantly affect the rate constant. The pools of PMC and their rate constants were lower than those of the Crete soil.

Nitrogen mineralization potential and their corresponding rate constants were not affected significantly by rotation at either site (data not presented). Potentially mineralizable N ranged from 140 to 153 mg kg^{-1} in the Crete soil and 149 to 210 mg kg^{-1} in the Eudora soil.

Table 3. Microbial biomass C and N in the 0- to 15-cm depth as influenced by crop rotation and N addition.

Treatment	Microbial biomass C		Microbial biomass N	
	Crete	Eudora	Crete	Eudora
	mg kg^{-1}			
Rotation				
CC	108	115 a†	27	23
C‡/SB	128	106 ab	24	26
SB‡/C	124	80 b	21	19
N rate, kg N ha^{-1}				
0	135 a	99	28 a	26
224/252	105 b	101	20 b	24
LSD (0.05)				
Rotation (R)	NS§	32	NS	NS
N rate (N)	24	NS	6.0	NS
R × N	NS	NS	NS	NS

† Values within a column followed by the same letter do not differ significantly (LSD = 0.05).
‡ Current crop when samples were collected in early September 1991. C = corn; SB = soybean.
§ NS = not significant at $P = 0.05$.

Table 4. Relationship among potentially mineralizable C (PMC), potentially mineralizable N (PMN), soil organic C (SOC), soil organic N (SON), microbial biomass C (MBC), and microbial biomass N (MBN) for the Crete soil.

Treatment	PMC/PMN	PMC/SOC	PMN/SON	MBC/PMC	MBN/PMN
Rotation					
CC	19.76	0.178 b†	0.109	0.0393	0.181
C‡/SB	21.95	0.218 a	0.107	0.0424	0.190
SB‡/C	19.13	0.191 ab	0.109	0.0401	0.148
N rate, kg N ha^{-1}					
0	19.10	0.166 a	0.104	0.0508	0.210 a
224	21.46	0.224 b	0.112	0.0303	0.135 a
LSD (0.05)					
Rotation	NS§	0.0298	NS	NS	NS
N rate (N)	NS	0.0412	NS	NS	0.0426
R × N	NS	0.0471	NS	NS	NS

† Values within a column followed by the same letter do not differ significantly (LSD = 0.05).
‡ Current crop when samples were collected in early September 1991. C = corn; SB = soybean.
§ NS = not significant at $P = 0.05$.

Microbial Biomass Carbon and Nitrogen

Microbial biomass C was not influenced by crop rotation in the Crete soil but the addition of fertilizer significantly reduced MBC in the N treatment (Table 3). Microbial biomass C was affected significantly by rotation in the Eudora soil. Higher MBC was observed in the CC than the treatment where soybean was the present crop. The MBC was intermediate in the treatment where corn was planted after soybean. Microbial biomass N was not influenced by crop rotation at either site. The addition of fertilizer resulted in a significantly lower microbial biomass N in the Crete soil but had no significant impact in the Eudora soil (Table 3).

Microbial Quotient

The ratio of MBC to organic C is potentially a sensitive index of cropping system impacts on SOM. Crop rotation had no effect on the C_{mic}/C_{org} ratio in either soil (data not presented). Addition of fertilizer decreased C_{min}/C_{org} ratio in the Crete soil (0.85 vs. 0.66) but had no effect in the Eudora soil.

Relationships among Potentially Mineralizable Carbon, Nitrogen, and Other Parameters

Potentially mineralizable C and PMN were correlated highly for both soils ($r = 0.64$ for Crete soil and $r = 0.67$ for the Eudora soil at $P = 0.05$), indicating the close relationship between the two pools (Tables 4 and 5). In the Crete soil, no significant differences were observed with rotation. Fertilizer addition did not affect the PMC/PMN ratios. In the Eudora soil, crop rotation and fertilizer addition did not significantly affect the PMC/PMN ratios. Crop rotation and fertilizer addition significantly affected the PMC/SOC ratios in both soils. The ratio PMN/total N was significantly affected by crop rotation and fertilizer addition in the Eudora loam but not in the Crete silt loam soil.

The contribution of MBC and MBN to the PMC and PMN pools revealed a smaller labile fraction of the organic matter compared with the nonbiomass active fractions for the two sites. Microbial biomass C and N averaged 4 and 17% of the PMC and PMN for the Crete soil and 5 and 16% of the PMC and PMN for the Eudora soil.

DISCUSSION

Crop management practices such as crop rotation, N addition, and tillage can greatly affect the SOM content (Tiessen et al., 1982; Dalal and Mayer, 1986; Havlin et al., 1990). The type and amount of residue added to the soil also would affect the organic matter equilibrium level. After >10 yr, soil organic C and N in the two soils were significantly higher in the monoculture than in the rotation with soybean as the present crop. This difference could have been due to the greater residue input from corn. Estimates of the residue returned to soil for one cropping season in the Crete soil averaged 14.5 Mg ha^{-1} for corn. In the Eudora soil, the amount of residue returned to the soil averaged 13.5 Mg ha^{-1} for corn. The amount of soybean residue returned to

Table 5. Relationship among potentially mineralizable C (PMC), potentially mineralizable N (PMN), soil organic C (SOC), soil organic N (SON), microbial biomass C (MBC), and microbial biomass N (MBN) for the Eudora loam.

Treatment	PMC/PMN	PMC/SOC	PMN/SON	MBC/PMC	MBN/PMN
Rotation					
CC	13.69	0.250 ab†	0.195 b	0.0501	0.183 a
C‡/SB	10.69	0.299 a	0.262 a	0.0480	0.160 ab
SB‡/C	11.09	0.241 b	0.198 ab	0.0474	0.132 b
N rate, kg N ha^{-1}					
0	11.38	0.228 a	0.198 a	0.0559 a	0.160
224	12.27	0.298 b	0.238 b	0.0410 b	0.157
LSD (0.05)					
Rotation	NS	0.0297	0.0042	NS	0.0438
N rate (N)	NS	0.0326	0.0149	0.0191	NS
R × N	NS	NS	NS	NS	NS

† Values within a column followed by the same letter do not differ significantly (LSD = 0.05).
‡ Current crop when samples were collected in early September 1991. C = corn; SB = soybean.
§ NS = not significant at $P = 0.05$.

the soil averaged 5.0 and 7.0 Mg ha^{-1} for the Crete and Eudora soils, respectively. Havlin et al. (1990) and Varvel (1994) found that cropping systems that included high-residue-producing crops resulted in greater soil organic C and N, whereas inclusion of soybean in the rotation decreased organic C and N.

The mineralizable and microbial biomass fractions of organic matter may be more sensitive to cropping systems than total SOM. In this study, crop rotation significantly decreased PMC only in the Eudora soil. Fertilizer addition significantly increased PMC in both soils. No significant difference occurred in PMN with rotation or N fertilization. A 16% increase occurred in PMN with N fertilizer in the Eudora soil. Averaged across rotation and N addition, PMC accounted for 20 and 26% of soil organic C for the Crete and Eudora soils, respectively. These values are lower than the 67% measured by Boyle and Paul (1989) in soils cropped to barley (*Hordeum vulgare* L.) for 11 yr without sludge amendment but are within the range obtained by Garcia (1992) for tallgrass prairie. For both soils, the amounts of SON accounted for in PMN were within the range of 5 to 18% previously reported (Campbell and Souster, 1982; Bonde et al., 1988; Cabrera and Kissel, 1988b). The greater proportion of the active pools of C and N for SOC and SON for the rotation (C/SB) suggests faster SOC and SON turnover compared with the corn monoculture. This is supported by the higher rate constants for the rotation. Faster turnover of SOC and SON could mean greater N availability. The apparent differences in the potentially mineralizable fraction of organic C and N in the Eudora soil indicates greater sensitivity to changes in cultural management practices compared with the Crete soil. Thus, the Crete soil appears to have greater resilience to management practices. Differences in the response of the two soils to management practices could be attributed to organic matter content and texture.

Potentially mineralizable C and N have been found to vary seasonally (Bonde and Rosswall, 1987; El-Harris et al., 1983) and also within the growing season (Franzluebbers et al., 1995). These changes could be related to rhizodeposition (i.e., exudates, mucilage, and sloughed cells) and organic inputs from crop roots and residues. In this study, soil samples were only collected once, after harvest. Because both crops, corn and soybean, were represented during the same growing season, the index of the fractions of organic C and N sensitive to current crop and crop rotation and N addition could be examined. Within a rotation, current crop significantly affected PMC. To assess seasonal variations in PMC and PMN of the two soils, several soil samples would need to be collected throughout the year.

Texture is known to influence the organic matter content in soils. Campbell and Souster (1982) found that fine- and medium-textured soils contained higher organic matter levels, whereas losses of organic matter, PMN, and the active N fraction were greater in coarse-textured soils. Adsorption of organics to surfaces of clay particles (Tisdall and Oades, 1982) and entrapment of organics in small pores in aggregates inaccessible to microbes are some of the suggested mechanisms to explain the phenomenon of physical protection. The percentage of PMN was greater in the Eudora loam than in the Crete silt loam. This agrees with the findings of Catroux et al. (1987) and Hassink et al. (1993) that a higher percentage of PMN occurred in coarse-textured soils than in fine-textured soils. Also, studies conducted elsewhere revealed similar findings (Van Veen et al., 1985; Hassink, 1994). A greater percentage of organic C and N in the active fraction would make the SOM more susceptible to cropping systems.

Microbial biomass is linked primarily to the availability of substrates derived from crop residue. It was affected greatly by crop rotation, cultivation, residue management, and fertilizer addition (Biederbeck et al., 1984). Also, microbial biomass may respond more quickly to a change in cultural management practices than total SOM. Under the conditions of the study, crop rotation did not significantly affect the size of the biomass at either site at the time the soils were sampled. The effects of the current crop in the rotation were more pronounced than the overall rotation effect. Microbial biomass was higher in the control or where no N fertilizer was added. Similar results were obtained in studies conducted elsewhere (Biederbeck et al., 1984, 1986, 1994). Those researchers speculated that severe N deficiency resulted in a microbial population with a comparatively high proportion of dormant cells. Also, the higher MBN in the nonfertilized treatment might indicate that the N was sequestered by microbes to degrade the poorer quality plant residue (higher C/N ratio).

Microbial biomass C constituted 1 to 4% of the total soil C (Jenkinson and Ladd, 1981), whereas MBN constituted 2 to 6% of the total soil N (Brookes et al., 1985). The ratio of MBC to total C has been reported to be a useful indicator of soil processes (Ross et al., 1982; Anderson and Domsch, 1989; Sparling, 1992). Because of differences in soils and crop management practices, as well as variations in sampling time and analytical methods, a wide range of MBC/total C ratios from 0.27 to >7% are reported in the literature (Anderson and Domsch, 1980; Jenkinson and Ladd, 1981; Brookes et al., 1984; McGill et al., 1986; Insam et al., 1989). The proportion of MBC/total C in both soils in this study were within the range of reported values. Because microbial C changes more rapidly than total C, the ratio of MBC/total C reflects organic matter input, the efficiency of conversion to microbial C, losses of C from the soil, and stabilization of organic C by the soil mineral fractions (Sparling, 1992). At both sites, cropping treatment had no effect on the microbial quotient. The MBC/total C ratio was affected significantly with N addition in the Crete soil but not in the Eudora soil. Thus, the MBC/total C ratio proposed by Sparling (1992) was not particularly sensitive under the conditions of this study.

Soil texture may also influence the ratio. The coarse-textured soil, Eudora loam, had a higher ratio than the fine-textured soil, Crete silt loam. Sparling (1992) obtained similar results comparing six soils in New Zealand. These observations suggest that a proportionally larger amount of nonmicrobial C was contained in the organic C fraction of the clay soils. This agrees with the findings of Blakemore and Miller (1968) and Nowak and Nowak (1990), who found decreased decomposition and greater stabilization of SOC in soils with higher clay contents.

Microbial biomass C and MBN contribute a variable but significant portion of the active pools of C and N. The results from this study showed lower contributions compared with that of a prairie soil (Rice and Garcia, 1994), to 50% as MBC in sludge-amended soils (Boyle and Paul, 1989), and to 35% for soils that had been cropped to N-fertilized cereals (Robertson et al., 1988).

In both soils, the values obtained for C mineralization rate constants were lower than the 0.007 d^{-1} for prairie soils (Garcia, 1992) and N mineralization rate constants were lower than the 0.0077 d^{-1} reported for many U.S. soils (Stanford and Smith, 1972), the 0.0058 d^{-1} for Australian soils (Campbell et al., 1981), and the 0.006 d^{-1} for prairie soils (Garcia, 1992). However, the values obtained were much higher than those obtained by Harris (1993). The value of k has been reported to vary depending on incubation length and temperature (Addiscott, 1983; Campbell et al., 1984, 1991). Long periods of incubation produced lower and less variable k values (Paustian and Bonde, 1987).

In summary, changes in SOC and SON in response to crop rotation and fertilizer addition were related to the estimated amount of crop residues returned to the soil and the texture of the soil. The increase in residue input could be attributed to the positive effect of fertilization. Inclusion of soybean in the rotation reduced SOC and SON. Further decreases in SOC and SON could be expected with time as this study continues. Texture (clay and sand content) is an important factor in how soils respond to management. High clay and low sand contents may increase resilience to management. Our results confirm the usefulness of PMC and PMN as an index of SOM dynamics.

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