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Microbial biomass and mineralizable nitrogen distributions in no-tillage and plowed soils*

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Summary. Distribution of soil microbial biomass and potentially mineralizable nitrogen (PMN) in long-term tillage comparisons at seven sites in the United States varied with tillage management and depth in soil. Microbial biomass and PMN levels of no-tillage soils averaged 54% and 37% higher, respectively, than those in the surface layer of plowed soil. Biomass and PMN levels were greatest in the surface 0 to 7.5-cm layer of no-tillage soil and decreased with depth in soil to 30 cm. Biomass and PMN levels of plowed soil, however, were generally greatest at the 7.5–15 cm depth. Microbial biomass levels were closely associated with soil distributions of total C and N, water content, and water-soluble C as influenced by tillage management. Potentially mineralizable N levels in soil were primarily associated with distributions of microbial biomass and total N. Absolute levels of PMN and microbial biomass and the relative differences with tillage management were dependent on climatic, cropping, and soil conditions across locations. The additional N contained in soil biomass and PMN in the surface 0–7.5 cm of no-tillage compared with plowed soils ranged from 13 to 45 and 12 to 122 kg N/ha, respectively, for 6 of 7 locations. Fertilizer placement below the biologically rich surface soil layer and/or rotational tillage may improve short-term nitrogen use efficiency and crop growth on reduced-tillage soils.

Key words: Microbial biomass – Potentially mineralizable nitrogen – Long-term tillage – No tillage

The continuous use of the moldboard plow to enhance growth of grain crops has resulted in declines of soil organic matter and increase of soil erosion losses. Shifts to agricultural management systems characterized by little or no tillage have been stimulated by needs to reduce soil erosion, decrease fuel and labor inputs for production, and farmland too fragile (steep, dry, sandy, etc.) for production with conventional tillage. Soil organic matter distribution and the cycling and availability of nutrients to crop plants are often influenced by type and degree of soil tillage (Fleige and Baeumer 1974; Dowdell and Cannell 1975; House et al. 1984). Corn and wheat yields with no-tillage are often less at suboptimal rates of surface applied fertilizer N but at higher rates often exceed yields with conventional tillage (Doran and Power 1983; Thomas and Frye 1984; Meisinger et al. 1985). This phenomenon is explained in part by increased immobilization of surface fertilizer N applications due to the concentration of residues and microorganisms near the soil surface with no tillage as compared with plowing (Cochran et al. 1980; Doran 1980; Kitur et al. 1984); it may not exist under situations where crop residues are burned before planting (Dowdell and Crees 1980). Increased N fertilizer requirements and/or yield reductions with no-tillage management have led some to conclude that fertility management should vary with tillage practice (Baeumer and Bakermans 1973; Thomas and Frye 1984).

The ecology of the soil/plant environment under reduced or no-tillage farming can differ from that under conventional tillage with the moldboard plow. Higher soil water contents, organic matter levels, and soil bulk densities at the surface of no-tillage soils often result in changes in microbial populations and N cycling as compared with plowed ecosystems (Doran 1980; Blevins et al. 1984; Linn and Doran 1984a). Levels of microbial biomass and labile organic N reserves in soil are greatest in undisturbed soils and decrease with cultivation and associated cropping of

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grassland and forest soils (Ayanaba et al. 1976; Adams and Laughlin 1981). These effects are largely confined to the surface 5- to 10-cm soil layer and little or no difference may be observed between tillage management when comparing soil conditions averaged to below the depth of plowing (Powlson and Jenkinson 1981; Carter and Rennie 1982).

The objective of this research was to characterize the distributions of microbial biomass and potentially mineralizable N (PMN) at three depth increments in the surface 30 cm of no-tillage and plowed soils at several locations across the United States. The observed differences were compared with various soil physical and chemical properties as influenced by tillage management over a range of soil, climate, and crop management conditions.

Materials and methods

Sites and sampling. Samples from the surface 30 cm of soil from long-term tillage comparisons at 7 locations across the United States were collected for physical, chemical, and biological determinations during the 1980 and 1981 cropping seasons. Soil and site characteristics for each location are given in Table 1. Most comparisons were made between no-tillage management and tillage with a moldboard plow. At Nebraska locations in wheat (*Triticum aestivum* L.), subtillage during fallow with 1.5-m V-shaped sweeps at a depth of 8–10 cm was also compared. A sod control was maintained among tillage comparisons originally initiated in native grassland on the Duroc soil at Sidney, Nebraska. Tillage treatments at all locations were arranged in a randomized, complete block design with four replications (three replications at the Duroc L site in Nebraska). Further details on soil characteristics and management at these sites are given by Mielke et al. (1986) and Linn and Doran (1984a).

Soils were sampled at depth intervals of 0–7.5, 7.5–15, and 15–30 cm 1 to 2 times during the growing season. Samples from each replicate tillage treatment represented a composite within each sampling depth of 12–15 cores of 2.5-cm diameter. For winter wheat (30-cm row spacing) each composite sample consisted of 4 cores from the within-row area (7.5-cm-wide zone centered on the crop row) and 8 from the between row area. For maize (*Zea mays* L.), with a 75-cm row spacing, each composite represented 3 cores from the within-row area (15 cm wide) and 12 cores from the between-row area. Samples were placed in double plastic bags, securely tied, and kept shaded after sampling and before analysis so that soil temperatures remained between 16° and 22 °C.

In 1980 soil samples were transported from each site to the laboratory at Lincoln, NE, for analysis (up to 3 days after sampling). In 1981, all samples were analyzed for biological and chemical components on site within 24 h after collection.

Soil analyses. Prior to analysis the composite soil samples were thoroughly mixed and a subsample removed for gravimetric determination of water content by drying for 24 h at 105 °C. Field moist soil was passed through a 2-mm sieve and divided into three sets: one frozen at −20 °C for microbial biomass analysis (1980 only) and PMN, a second maintained at room temperature for biological analyses (described later), and a third air-dried overnight at room temperature for determination of soil chemical and physical properties. Air-dried samples for determination of total organic C and total Kjeldahl N were ground with a mortar and pestle to pass a 0.5-mm sieve before analysis.

Soil bulk densities were determined using gas sampling cans (Linn and Doran 1984b) and a multidepth sampler (twelve 22.4-mm cores per plot) as described by Doran and Mielke (1984). Total Kjeldahl N, KCl-extractable inorganic N, and water-soluble C were determined as described by Linn and Doran (1984a). Soil organic C was determined using a chromic acid wet digestion technique by the University of Nebraska Soil Testing Service. Methods for mea-

Table 1. Soils, site characteristics, and sampling dates of tillage comparisons at seven United States locations

Cropping, location (soil type)	Soil (0–150 mm)			Mean annual		Years of comparison at sampling	Previous management	N fertilizer[c] rates (kg N/ha)	Sampling date(s)
	C[a]	Sand %	Clay	Precipitation (mm)	Temperature (°C)				
Continuous maize									
Lexington, KY[b] (Maury SiL)	1.8	17	25	1130	13.0	10, 11	Bluegrass sod	0 and 168	4 June 1980 21 July 1981
Elwood, IL (Blount SiL)	1.1	18	25	872	10.3	5, 6	Cultivated maize and soybeans	0 and 179	5 June 1980 7 July 1981
Waseca, MN (Nicollet CL)	2.9	41	26	761	6.9	9	Alfalfa and cultivated maize	196	1 July 1980
Waseca, MN (Webster CL)	3.8	31	36	761	6.9	6	Cultivated maize	190	16 June 1981 16 August 1981
Lincoln, NE (Crete-Butler SiCL)	2.1	17	28	742	10.9	5, 6	Cultivated wheat	0 and 140	9 July 1980 2 June 1981 9 Sept 1981
Wheat/fallow									
Sidney, NE (Alliance SiL)	0.9	37	23	446	9.3	11, 12	Cultivated wheat	0 and 45	13 May 1980 12 May 1981
Sidney, NE (Duroc L)	1.7	40	23	446	9.3	12, 13	Native sod	0	10 June 1980 15 April 1981

[a] Organic carbon content at initiation of tillage experiments expressed as a percentage on a weight/volume basis
[b] Rye (*Secale cereale*) cover crop included at this location
[c] Applied as ammonium nitrate

surement of soil particle size analysis and water retention characteristics are described by Mielke et al. (1986).

Microbial biomass. Soil microbial biomass was determined using the chloroform fumigation-incubation technique (Jenkinson and Powlson 1976). The procedure was modified to use 50-g portions of soil contained in 100-ml glass beakers. Both fumigated and nonfumigated control samples were inoculated with 0.5 g moist nonfumigated soil composited from all treatments at each location. Inoculated soils were adjusted to 55% water-holding capacity, placed in 2 l-glass canning jars, which were sealed with lids fitted with rubber sampling ports. The samples were incubated for 10 days at 25 °C at which time a 1-ml sample was removed from the jar headspace for determination of CO_2 by gas chromatography as described by Linn and Doran (1984b). Incubation jars for the nonfumigated control samples were then flushed with air to remove accumulated CO_2, resealed, and incubated another 10 days at 25 °C, at which time headspace CO_2 was again measured.

Microbial biomass C was calculated by dividing the flush of CO_2-C resulting from chloroform fumigation by a conversion constant (*Kc*) of 0.45 (the fraction of microbial biomass converted to CO_2) as described by Jenkinson and Ladd (1981). The flush of CO_2-C resulting from fumigation was calculated as the CO_2 produced from a fumigated sample during the 0- to 10-day incubation minus that produced from the nonfumigated control over the 10- to 20-day incubation period. Microbial biomass levels in the field were expressed as kg C/ha depth increment of soil (oven-dry basis) using soil bulk densities as determined in the field at sampling. In 1980 soil microbial biomass levels were determined on samples which had been stored at −20 °C before analysis. In 1981 all soil biomass estimates were made on fresh soils within 24 h after sampling.

Potentially mineralizable nitrogen. Potentially mineralizable nitrogen (PMN) was determined using the autoclave method of Stanford and Smith (1976). Twenty grams of soil (stored at −20 °C before analysis) and 25 ml 0.01*M* $CaCl_2$ were autoclaved at 121 °C for 16 h. The soil was washed with another 25 ml 0.01*M* $CaCl_2$ and the extract and washing were combined and adjusted to a final volume of 50 ml. The NH_4^+ content in the extract was determined after steam distillation and boric acid titration. The value for mineralizable N (S) was calculated by subtracting the amount of KCl-extractable NH_4^+-N in fresh soil from the NH_4^+-N released by autoclaving (and freezing). The potentially mineralizable N (N_0) was calculated using the mineralizable N (S) according to the linear relationship: $N_0 = 4.15\,S + 6.6$ (Stanford and Smith 1976).

Statistical analyses. Analysis of variance and Duncans multiple range tests were used to determine the effects of tillage management practices on microbial biomass, PMN levels, and soil properties within sampling depths across locations. Simple correlations were run between biomass and PMN levels and soil physical and chemical properties within sampling depths across locations. Stepwise multiple regression analyses were used to examine relationships between differences in biomass and PMN levels with differences in soil properties resulting from tillage. The employed procedures are reported in the Statistical Analysis System (Helwig and Council 1979).

Results

Soil microbial biomass

Microbial biomass levels in the surface 0- to 7.5-cm soil layer, expressed on a volumetric basis, averaged 34% greater in no-tillage than in plowed soils across locations in 1980 (Table 2). These differences were in part due to higher soil bulk densities in no-tillage surface soils − 11% greater than those of plowed soils at locations cropped to continuous maize. There was lit-

Table 2. Soil water-filled pore space, bulk density, and microbial biomass levels at two sampling depths (cm) as related to tillage management at six locations in 1980

Cropping, location (soil)	Tillage Management[a]	WFPS (%)[b]		Bulk density (mg/m³)		Microbial biomass (kg C/ha)	
		0−7.5	7.5−15	0−7.5	7.5−15	0−7.5	7.5−15
Maize							
Kentucky	NT	66.8*	48.3	1.26*	1.37*	854*	562
(M)	PL	36.0	49.4*	1.19	1.34	442	508
Illinois	NT	83.3*	78.3	1.42*	1.44	287	313
(B)	PL	60.5	83.0	1.30	1.44	252	286
Minnesota	NT	66.7*	53.2	1.30*	1.20	611*	530
(N)	PL	45.3	56.7	1.17	1.25*	456	553
Nebraska	NT	34.6	35.4	1.43	1.38*	605*	380
(C−B)	NT+M	39.9*	36.7	1.41	1.35	747*	475
	PL	29.6	41.1	1.22*	1.35	480*	564*
Wheat							
Nebraska	NT	58.3*	46.0	1.29*	1.30	614	536
(A)	ST	54.6	47.0	1.26	1.31	674*	559
	PL	52.4	42.4*	1.25	1.38*	615	515
Nebraska	SOD	28.2*	34.9*	0.99*	1.35	902*	646
(D)	NT	24.0*	25.9*	1.07	1.35	746	576
	ST	20.9	29.5	1.10	1.34	699	575
	PL	19.3	30.1	1.19*	1.38*	554*	600

[a] Tillage management practices: NT, no tillage; PL, moldboard plow; ST, subtillage; NT+M, no tillage with 32 Mg cattle manure/ha applied on April 15; and SOD, native sod
[b] WFPS (%), Soil volumetric water content/total soil porosity ×100
* Treatment mean within location and sampling depth differs significantly at $P<0.05$

tle or no difference in microbial biomass levels at the 7.5- to 15-cm sampling depth except for the Nebraska site cropped to maize where microbial biomass levels in plowed soil were 48% greater than those of no-tillage soil. Higher surface soil microbial biomass levels with reduced tillage may be due to the accumulation of crop residues near the soil surface. With subtillage, which controls weeds during wheat fallow and also conserves crop residues near the soil surface (also called stubble-mulch fallow), microbial biomass levels in surface soil were greater than those present in plowed soils. The greater soil water contents in no-tillage compared with plowed surface soils was another factor associated with greater microbial biomass levels with no tillage (Table 2). The stimulatory effect of manure application with no tillage on surface soil microbial biomass levels at the Nebraska site cropped to maize probably resulted from both increased availability of substrates and a more optimal water regime.

Soil microbial biomass distributions in no-tillage and plowed soils in 1981 (Fig. 1) were similar to those measured in 1980. Microbial biomass levels in the surface 0- to 7.5-cm layer of no-tillage soils ranged from 313 to 825 kg C/ha and averaged 54% higher, across locations, than those in plowed soils. Surface soil biomass levels for subtillage management with winter wheat were intermediate between those of no tillage and plowing. Microbial biomass levels with no tillage were generally highest in the 0- to 7.5-cm soil layer and decreased with depth. With plowing, however, biomass concentrations were greatest in the 7.5- to 15-cm soil layer.

Potentially mineralizable nitrogen

Tillage management influenced soil PMN levels (Fig. 2) in a manner similar to that observed for microbial biomass. PMN levels in the 0- to 7.5-cm layer of no-tillage soils averaged 37% higher than those of plowed

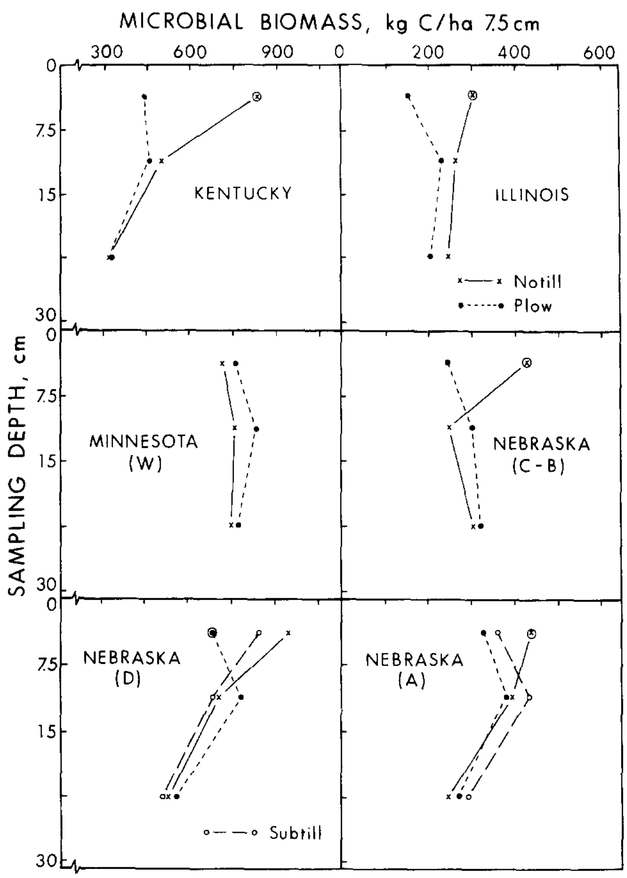

Fig. 1. Soil microbial biomass levels/7.5-cm soil increment at sampling intervals of 0–7.5, 7.5–15, and 15–30 cm for 6 locations sampled in 1981. Graphic plot symbols which are *circled* indicate significant difference between tillage systems ($P < 0.05$) within location and sampling depth

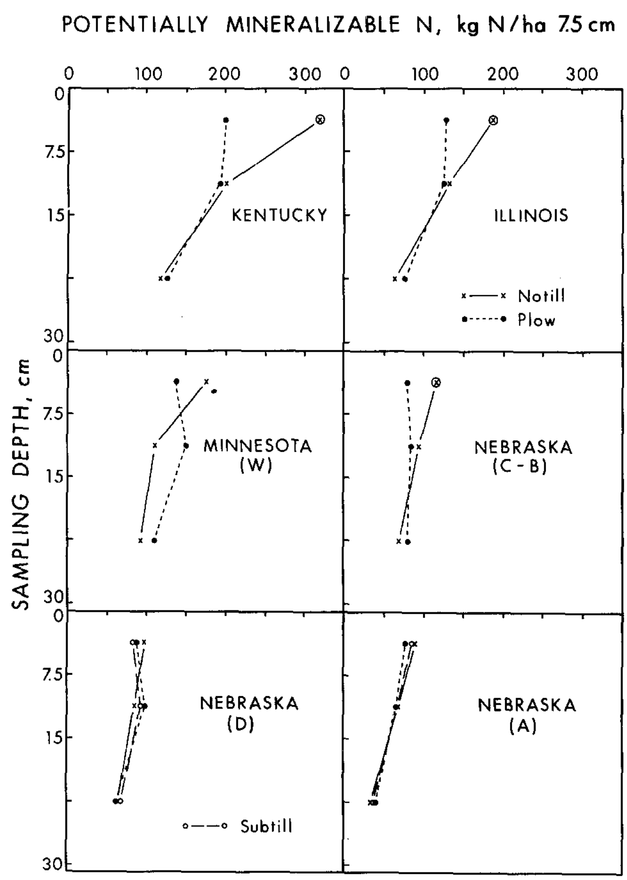

Fig. 2. Soil potentially mineralizable nitrogen levels/7.5-cm soil increment at sampling intervals of 0–7.5, 7.5–15, and 15–30 cm for 6 locations sampled in 1981. Graphic plot symbols which are *circled* indicate significant difference between tillage systems ($P < 0.05$) within location and sampling depth

soils, and ranged from 85 to 322 kg N/ha across locations. As with microbial biomass, PMN concentrations with no tillage decreased with depth in soil whereas those for plowed soils were the same or greater in the 7.5- to 15-cm soil layer.

Aside from differences resulting from tillage management, PMN levels in the surface 0- to 7.5-cm layer of soil were also influenced by climate and N fertilization (Fig. 3). Soil PMN levels were positively correlated with mean annual precipitation across locations ($r = 0.920$, $P < 0.009$) with highest levels under continuous maize in the moistest climates and lowest levels with wheat-fallow in driest climates. The application of surface broadcast ammonium nitrate at several locations also resulted in significant increases in soil PMN levels as compared with nonfertilized controls. The addition of 140–179 kg N/ha to continuous maize and 45 kg N/ha to wheat at one location increased PMN levels in the 0- to 7.5-cm soil layer by 17–34 kg N/ha and 13 kg N/ha, respectively.

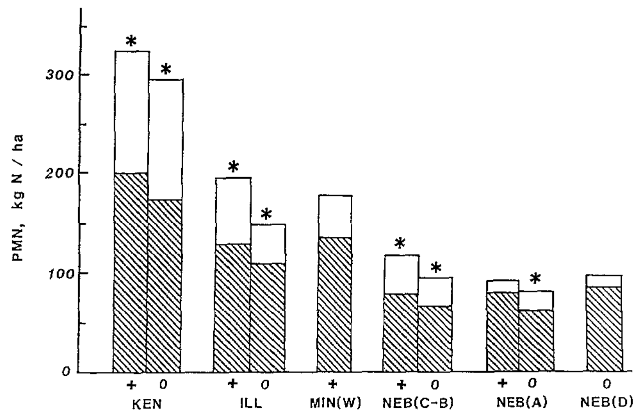

Fig. 3. Potentially mineralizable nitrogen levels in the 0- to 7.5-cm soil layer in 1981 as influenced by tillage management (* indicates significant difference between tillage systems at $P < 0.05$) and N fertilization (+ designates addition of NH_4NO_3, 0 designates no fertilizer N added). □: no tillage; ▧: plow

Soil properties

Differences in soil total C and N contents between tillage practices were largely confined to the 0- to 7.5-cm soil layer; highest values occurred with the no-tillage practice and lowest contents were observed with plowing (Table 3). Soil pH differences between tillage management practices at the Kentucky and Nebraska locations in continuous maize probably resulted from a differential mixing with soil of limestone which was applied at these locations. In general, soil pH values at the sites sampled were not low enough significantly to reduce biological activity. One exception was the naturally acidic, imperfectly drained soil at the Illinois location. As illustrated in Table 3 the water status of no-tillage soils was generally more conducive to greater microbial activity than that of plowed soils, especially in the surface 0–7.5 cm of soil. Other research at these locations, conducted at the same times of sampling, demonstrated that microbial popu-

Table 3. Soil chemical and physical properties at three sampling depths (cm) as influenced by tillage management at six locations in 1981

Cropping, location (soil)	Tillage management[a]	Total organic C (%)[b]			Total Kjeldahl N (%)[b]			Soil pH (0.01 *M* $CaCl_2$)			WFPS (%)		
		0–7.5	7.5–15	15–30	0–7.5	7.5–15	15–30	0–7.5	7.5–15	15–30	0–7.5	7.5–15	15–30
Maize													
Kentucky	NT	2.82*	1.59	0.89	0.289*	0.200	0.140	6.28*	6.06	5.90*	65*	67*	62*
(M)	PL	1.61	1.58	1.08	0.198	0.199	0.144	5.64	6.06	6.20	47	48	54
Illinois	NT	1.84*	1.38	0.72*	0.170	0.164	0.106	4.39	4.91*	4.57	62*	67*	74
(B)	PL	1.23	1.35	0.87	0.147	0.148	0.105	4.50	4.68	4.55	34	49	66
Minnesota	NT	3.92	3.56	2.76	0.346	0.327	0.287	5.96	6.61	6.89	53	52	72
(W)	PL	3.50	4.05	2.83	0.319	0.365	0.325	6.40	6.55	6.90	48	63	74
Nebraska	NT	2.51*	2.34*	1.98	0.231*	0.207	0.179	5.72	5.03*	5.18*	46*	55	69
(C–B)	PL	1.73	2.03	2.06	0.158	0.191	0.193	5.29	5.52	5.58	32	50	70
Wheat													
Nebraska	NT	1.53*	1.28	0.77	0.156*	0.149	0.101	6.32	6.69	7.12	66	74	61
(A)	ST	1.34	1.22	0.80	0.141	0.147	0.103	6.16	6.22	6.99	64	77	64
	PL	1.21	1.22	0.86	0.120	0.141	0.115	6.38	6.41	7.14	64	67	53*
Nebraska	SOD	2.51*	2.00	1.25	0.240*	0.204	0.125	6.49	6.58*	6.46	46*	58	48
(D)	NT	2.48*	1.74	1.29	0.233	0.181	0.139	6.30	6.38	6.49*	50*	59	53
	ST	2.15	1.90	1.22	0.229	0.197	0.131	6.43	6.26	6.39	40	60	44
	PL	1.76*	1.92	1.16	0.187*	0.195	0.122	6.27	6.27	6.30	38	54	45

[a] Tillage management: NT, no tillage; PL, moldboard plow; ST, subtillage; and SOD, native sod
[b] Percentage volumetric basis [equivalent to (Mg C or $N/m^3 \times 100$)]
* Treatment mean within location and depth differs significantly at $P < 0.05$

lations and respiratory activity increase in a linear manner as soil water-filled pore space (WFPS) increases to 60%, which approaches an optimum balance of water and air for maximum aerobic microbial activity (Linn and Doran 1984a, b).

The stratification of organic substrates and soil physical components appears to be a major factor associated with higher levels of microbial biomass and PMN in no tillage as compared with plowed soils. The major differences between tillage management practices occur near the soil surface where soil water contents, total C and N contents, and water-soluble C levels across locations averaged 28%–47% greater than those in plowed soils. These differences were paralleled by microbial biomass and PMN levels which averaged 54% and 37% higher in no-tillage compared with plowed surface soils, respectively. Below the 7.5-cm depth there was little difference in the parameters measured between tillage management systems with the exception that total organic C and PMN levels were 6%–7% higher in the 15- to 30-cm layer of plowed soils. This probably resulted from the burial of crop residues at this depth with plowing.

Correlation analyses of soil microbial biomass and PMN levels and other soil properties across locations and tillage management practices are shown in Table 4. Microbial biomass and PMN were positively correlated at the 0- to 7.5- and 15- to 30-cm sampling depths. Cause and effect relationships are difficult to assess since biomass and PMN were both positively related to total soil N content. In addition soil microbial biomass levels were also positively related to soil factors which influence microbial growth and activity such as total C content, soil water content, and soil pH.

The identification of tillage-imposed changes in soil properties which influence microbial biomass and PMN levels is complicated by differences in soil properties, climate, and previous cropping history across the locations studied. Thus, to normalize these differences, multiple regression analyses were run using ratios for soil parameters between no-tillage and plow (Table 5). Over 70% of the variation in microbial biomass levels between tillage practices was associated with corresponding variations in total organic C, total Kjeldahl N, clay content, and water content. At the surface, variations in microbial biomass were also associated with higher soluble C contents with no tillage.

Discussion

Tillage-induced differences in soil microbial biomass and PMN distributions were remarkably similar across geographical regions and closely associated with changes in soil organic matter and water content with depth in soil. In this study, as in others, soil microbial biomass levels were highly correlated with total organic C and N contents in surface soil, both of which are largely influenced by tillage and cropping management practices (Adams and Laughlin 1981; Ayanaba et al. 1976; Lynch and Panting 1980). A more optimal water status for biological activity, resulting from crop residue accumulation at the soil surface and reduced evaporative losses of water, is another factor associated with greater microbial biomass levels near the surface of no-tillage compared with tilled soils. In concurrent research at the same locations reported here we found tillage-induced variations in populations of several microbial groups and soil respiration activity closely correlated with soil water and aeration status (Linn and Doran 1984a, b).

Responses of soil microbial biomass and organic N mineralization to tillage management vary with climate and cropping and residue management prac-

Table 4. Correlation of soil physical, chemical, and biological properties with soil microbiol biomass and potentially mineralizable N at three sampling depths (cm) across locations in 1981

Parameter Sampling depth (cm)	Significant correlation coefficients ($P < 0.05$)										
	Microbial biomass	PMN	Total organic C	Total N	Water content	WFPS	Clay content	Water-soluble C	pH	Ammonium	Nitrate
Microbial biomass											
0–7.5	–	0.583	0.672	0.728	0.683	NS	NS	NS	0.622	NS	NS
7.5–15	–	NS	0.787	0.851	NS	NS	0.635	NS	0.697	NS	NS
15–30	–	0.523	0.878	0.933	0.817	0.602	NS	0.508	NS	NS	NS
PMN											
0–7.5	0.583	–	NS	0.529	NS	NS	NS	NS	NS	NS	NS
7.5–15	NS	–	NS	NS	NS	NS	NS	–0.658	NS	NS	NS
15–30	0.523	–	NS	0.579	NS	NS	NS	NS	NS	NS	NS

NS, not significant

Table 5. Increase in R^2 for relative changes (no tillage/plow) in microbial biomass and potentially mineralizable N as related to changes in soil properties for three soil depths using stepwise multiple regression analyses across locations in 1981

Dependent variables, depth (cm)	Independent soil factors (NT/PL ratios), R^2 value*		
Relative microbial biomass			
0–7.5	Total organic C	Water	Soluble C
	0.600	0.684	0.737
7.5–15	Water	Clay	
	0.436	0.704	
15–30	Clay	Total N	Water
	0.522	0.674	0.710
Relative PMN			
0–7.5	Clay	Total organic C	Total N
	0.569	0.791	0.791
7.5–15	Total N	Clay	Water
	0.697	0.776	0.837
15–30	–	–	–

* Shown for factors contributing significantly ($P<0.05$) to variations in microbial biomass or PMN

tices. In our study, microbial biomass N (calculated assuming a biomass C/N of 8.5/1) and PMN levels in the surface 0–7.5 cm of no-tillage soils averaged 13–45 and 12–122 kg N/ha respectively, greater than those of plowed soil. Levels of soil microbial biomass and PMN were greatest in humid climates. Differences in levels of biomass and PMN resulting from tillage were generally less at drier sites, especially where a fallow period was included in the cropping sequence. An exception was a semiarid site in western Nebraska, initiated in native grassland, which had the highest surface soil levels of organic matter and microbial biomass and among the greatest differences between tillage management systems. Lack of differences in PMN at this site may reflect inclusion of a fallow period during which high rates of mineralization occur from soil organic N pools associated with soil microbial biomass (E. T. Elliott, personal communication). Microbial biomass levels in soils cropped to wheat are known to vary with plant rooting distributions associated with tillage and seasonal variations in root activity (Carter and Rennie 1984; Lynch and Panting 1980).

Stratification of crop residues, organic matter, and soil organisms within the profile of no-tillage management systems is suggested as a major mechanism for immobilization of N near the soil surface as compared with conventional tillage (Holland and Coleman 1987; House et al. 1984). Microbial biomass and mineralizable organic reserves in no-tillage surface soil, however, may represent either a sink or source for plant-available N depending on climate, cropping, or temporal changes in the soil environment. In the semiarid climate of western Canada, Carter and Rennie (1984) observed no marked differences in N cycling between no-tillage and shallow cultivation but indicated the potential for more rapid remineralization of immobilized fertilizer N with fluctuating soil temperature and moisture conditions associated with tillage. In the humid eastern United States, where crop residues are maintained on the soil surface and maize is planted directly into a chemically killed cover crop, immobilization of surface-applied fertilizer N with no-tillage was twofold higher than that with plowing (Rice et al. 1986). In the same study, lower maize yields at low rates of N fertilization during initial years of establishment with no-tillage, however, were attributed primarily to lower rates of soil N mineralization compared with plowing. After 10 years, soil organic N mineralization rates and maize yields were equal with either tillage management system – apparently the result of accretion of organic matter and greater microbial activity near the soil surface with no-tillage.

The potential for better utilization of microbial biomass and organic nutrient reserves in reduced-tillage soils depends on our understanding of their distribution in soil and associated factors of climate, residue and cropping management, and time which influence their depletion and accretion. In this regard, placement of fertilizer N below the biologically and organic matter rich surface soil or the use of periodic tillage may greatly enhance short-term N-use efficiency and crop production on reduced tillage soils. Long-term stability and nutrient availability, however, may be benefited by concentration of organisms and organic matter at the surface of no-tillage soils. Understanding the synchrony of plants and microorganisms in responding to tillage-related changes in the soil environment and nutrient cycling is important to development of productive and efficient tillage and residue management systems.

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References

Adams T McM, Laughlin RJ (1981) The effects of agronomy on the carbon and nitrogen contained in the soil biomass. J Agric Sci 97:319–327

Ayanaba A, Tuckwell SB, Jenkinson DS (1976) The effects of clearing and cropping on the organic reserves and biomass of tropical forest soils. Soil Biol Biochem 8:519–525

Baeumer K, Bakermans WAP (1973) Zero-tillage. Adv Agron 25:77–123

Blevins RL, Smith MS, Thomas GW (1984) Changes in soil properties under no-tillage. In: Phillips RE, Phillips SH (eds) No-tillage agriculture. Van Nostrand Reinhold, New York, pp 190–230

Carter MR, Rennie DA (1982) Changes in soil quality under zero tillage farming systems: distribution of microbial biomass and mineralizable C and N potentials. Can J Soil Sci 62:587–597

Carter MR, Rennie DA (1984) Dynamics of soil microbial biomass N under zero and shallow tillage for spring wheat, using ^{15}N urea. Plant and Soil 76:157–164

Cochran VL, Elliott LF, Papendick RI (1980) Carbon and nitrogen movement from surface-applied wheat straw. Soil Sci Soc Am J 44:978–982

Doran JW (1980) Soil microbial and biochemical changes associated with reduced tillage. Soil Sci Soc Am J 44:765–771

Doran JW, Mielke LN (1984) A rapid, low-cost method for determination of soil bulk density. Soil Sci Soc Am J 48:717–719

Doran JW, Power JF (1983) The effects of tillage on the nitrogen cycle in corn and wheat production. In: Lowrance R, et al (eds) Nutrient cycling in agricultural ecosystems. Univ Ga Coll Agric Spec Pub No 23. Athens, Ga, pp 441–455

Dowdell RJ, Cannell RQ (1975) Effect of ploughing and direct drilling on soil nitrate content. J Soil Sci 26:53–61

Dowdell RJ, Crees R (1980) The uptake of 15N-labeled fertilizer by winter wheat and its immobilization in a clay soil after direct drilling or plowing. J Sci Food Agric 31:992–996

Fleige H, Baeumer K (1974) Effect of zero-tillage on organic carbon and total nitrogen content, and their distribution in different N-fractions in loessal soils. Agro-ecosyst 1:19–29

Helwig JT, Council KA (1979) A user's guide to SAS. Statistical Analysis System Institute, Raleigh, NC

Holland EA, Coleman DC (1987) Litter placement effects on microbial and organic matter dynamics in an agroecosystem. Ecology 68:425–433

House GJ, Stinner BJ, Crossley DA Jr, Odum EP, Langdale GW (1984) Nitrogen cycling in conventional and no-tillage agroecosystems in the Southern Piedmont. J Soil Water Conser 39:194–200

Jenkinson DS, Powlson DS (1976) The effects of biocidal treatments on metabolism in soil V: A method for measuring soil biomass. Soil Biol Biochem 8:209–213

Jenkinson DS, Ladd JN (1981) Microbial biomass in soil: measurement and turnover. In: Paul EA, Ladd JN (eds) Soil biochemistry, vol 5. Dekker, New York, pp 415–471

Kitur BK, Smith MS, Blevins RL, Frye WW (1984) Fate of 15N-depleted ammonium nitrate applied to no-tillage and conventional tillage corn. Agron J 76:240–242

Linn DM, Doran JW (1984a) Aerobic and anaerobic microbial populations in no-till and plowed soils. Soil Sci Soc Am J 48:794–799

Linn DM, Doran JW (1984b) Effect of water-filled pore space on CO_2 and N_2O production in tilled and non-tilled soils. Soil Sci Soc Am J 48:1167–1172

Lynch JM, Panting LM (1980) Cultivation and the soil biomass. Soil Biol Biochem 12:29–33

Meisinger JJ, Bandel VA, Stanford G, Legg JO (1985) Nitrogen utilization of corn under minimal tillage and moldboard plow tillage. I. Four-year results using labeled N fertilizer on an Atlantic Coastal Plain soil. Agron J 77:602–611

Mielke LN, Doran JW, Richards KA (1986) Physical environment near the surface of plowed and no-tilled surface soils. Soil Tillage Res 5:355–366

Powlson DS, Jenkinson DS (1981) A comparison of the organic matter, adenosine triphosphate, and mineralizable nitrogen contents of ploughed and direct-drilled soils. J Agric Sci 97:713–721

Rice CW, Smith MS, Blevins RL (1986) Soil nitrogen availability after long-term continuous no-tillage and conventional tillage corn production. Soil Sci Soc Am J 50:1206–1210

Stanford G, Smith SJ (1976) Estimating potentially mineralizable soil nitrogen from a chemical index of soil nitrogen availability. Soil Sci 122:71–76

Thomas GW, Frye WW (1984) Fertilization and liming. In: Phillips RE, Phillips SH (eds) No-tillage agriculture. Van Nostrand Reinhold, New York, pp 87–126

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