Tillage Effects on Microbiological Release of Soil Organic Nitrogen

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Introduction

Soil tillage was an important tool of early farmers in North America to harvest the fertility of forest and prairie soils for production of grain crops. Clean tillage without supplemental fertilization, however, depleted soil organic matter reserves. Within the life span of these early farmers, net mineralization of soil N fell below that needed for sustained grain crop production (Campbell et al., 1976). Severe weather conditions in the 1930s caused accelerated soil erosion losses, economic hardship for farmers, and increased awareness of management-related degradation of soil productivity. Thus, early reduced-tillage management systems were developed to maintain residues on the soil surface to conserve water and organic matter, and reduce soil erosion losses (Unger and McCalla, 1980).

Recent shifts to conservation tillage systems have been stimulated by needs to decrease fuel and labor costs, and to enable production on land too fragile (steep, dry, sandy, etc.) for conventional tillage. Soil organic matter distribution and the cycling and availability of nutrients to crop plants can be altered greatly with reduced tillage (Baeumer and Bakermans, 1973; House et al., 1984). Increased N fertilizer requirements and/or yield reductions with no-tillage management indicate that fertility management may need to vary with tillage practice (Doran and Power, 1983; Thomas and Frye, 1984). Observed responses to management, however, are not always consistent and often vary with differences in climate, soils, cropping, and time.

Management and Soil Organic N Pools

Nitrogen cycling in soil is largely controlled by interactions between the activities of microorganisms and plants in fixation of atmospheric N and C and subsequent release of energy and N during decomposition of plant and animal residues. In this regard, resupply of N to plants depends largely on the opposing effects of mineralization and immobilization, which are closely tied to heterotrophic microbial activity (Jannson and Persson, 1982). Heterotrophic microbial activities in soil and the associated availability of soil N are largely controlled by availability of C substrates and soil environmental conditions.

Up to 99 percent of the total soil N is contained in soil organic matter. Interpretation and prediction of the effects of tillage and residue management on soil N availability to crop plants depends on understanding the unique roles played by living and non-living components of soil organic matter. The majority of soil organic matter is contained in plant and animal debris and soil humus. These non-living components determine the soil physical/chemical environment within which living organisms function. Heterotrophic soil microorganisms and fauna, a relatively small proportion of total organic matter (1 percent to 8 percent), function as important catalysts for transformation and cycling of N and other nutrients. The importance of soil microbial biomass as a significant sink/source for plant-available N has recently been emphasized.

Tillage and crop residue management practices are major determinants of soil temperature, water, and aeration regimes, and the spacial and temporal availability of energy and nutrients to microorganisms. The redistribution of organic matter and soil organisms with reduced tillage is a major factor responsible for slower recycling of N as compared with conventional tillage with the moldboard plow (Fox and Bandel, 1986; House et al., 1984). Surface soil levels of organic matter, microbial populations and biomass levels, and reserves of potentially mineralizable N (PMN) are often significantly higher with no-tillage as compared with moldboard plow tillage (Table 1). These increases in microbial biomass and activity and organic N reserves are associated with conservation of surface residues, greater total soil C and N contents, and a more optimal water status for biological activity in the surface 0 to 10 cm of redud-tillage soils (Ayanaba et al., 1976; Doran, 1987). Increased microbial biomass is also associated with increases in plant rooting activity near the surface of no-tillage soils (Carter and Rennie, 1984; Lynch and Panting, 1980).

The magnitude of management-related changes in surface soil properties and microbial responses can greatly depend on previous management, cropping, and degree of tillage. As illustrated in Table 2, the levels of N, C, and microbial biomass in surface soil of a winter wheat (Triticum aestivum L.) fallow rotation in Nebraska were inversely related to degree of soil tillage during fallow. In the previously cultivated land where initial soil organic matter levels were lower, these differences were much less pronounced than where tillage comparisons were initiated in native grass sod. Also, over an 11-year period, the total soil N content with no-tillage

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TABLE 1. AVERAGE EFFECTS OF TILLAGE ON SOIL WATER CONTENT, CHEMICAL COMPONENTS, AND SOIL MICROBIAL BIOMASS AS A FUNCTION OF SOIL DEPTH AT SIX (FOUR CONTINUOUS CORN, TWO WHEAT/FALLOW) LONG-TERM (6-13 YEAR) TILLAGE EXPERIMENTS IN THE USA.

	Ratio—No Tillage/Plow for four soil depths			
Soil Parameter†	0-7.5 cm	7.5-15 cm	15-30 cm	0-30 cm
Water Content	1.28*	1.08	1.08	1.13
Water Soluble C	1.47*	0.98	1.24	1.23
Total Organic Carbon	1.42*	1.00	0.94*	1.06
Total Kjeldahl N	1.29*	1.01	0.97	1.06
Potentially Mineralizable N	1.37*	0.98	0.93*	1.05
Microbial Biomass	1.54*	0.98	1.00	1.13

†Original data expressed on a volumetric basis

***Level of significance, $P<0.05$**

TABLE **2.** SOIL PHYSICAL CHEMICAL PROPERTIES AND MICROBIAL BIOMASS LEVELS IN THE SURFACE 0 TO 7.5 CM OF SOIL CROPPED TO WINTER WHEAT AS INFLUENCED BY PREVIOUS CROPPING AND FALLOW TILLAGE MANAGEMENT (SIDNEY, NEBRASKA, 1981)

Previous Cropping, Management	Soil Bulk Density	Soil Water Content	Total Organic C†	Total Kjeldahl N†	Microbial Biomass
	------------Mg/m³soil	----------------	-------------------%	---------------------	kg C/ha
Cultivated Wheat/Fallow					
No tillage	1.30a*	0.335a	1.53a	0.156a	440a
Subtillage	1.26b	0.338a	1.34ab	0.141ab	356ab
Plow	1.25b	0.337a	1.21b	0.120b	329b
Native Sod					
Sod control	0.91d	0.303a	2.51a	0.240a	1053a
No tillage	0.99c	0.299a	2.48a	0.233ab	929b
Subtillage	1.05b	0.252b	2.15b	0.229ab	828b
Plow	1.10a	0.221c	1.76c	0.187b	669c

†% volumetric basis (Mg/m^3 soil × 100).

'Treatment means within previous cropping categories followed by different letters differ significantly at $p<0.05$.

management was 9 percent greater than when croplfallow was first initiated. In converting from grassland to wheatlfallow, declines in soil organic C and N levels, regardless of tillage management, reflect decreased inputs of C and N resulting from reduced plant production and surface rooting activity. In either case, however, reduced tillage has conserved surface soil N in the organic form—likely through reducing net mineralization of crop residues and soil organic matter as compared with subtillage or plowing.

Tillage-induced differences in surface soil reserves of potentially mineralizable N and microbial biomass may vary with climate and cropping management practices (Doran, 1987). Differences in mineralizable nitrogen reserves between plow and no-tillage management at six long-term experiments across the United States ranged from 12 to 122 Kg Nlha and were highly correlated with mean annual precipitation (Figure 1). These trends likely result from increased cropping intensity and plant productivity associated with increasing rainfall. Differences between tillage management were least and values for PMN lowest for wheatlfallow production in a low rainfall region. Higher PMN levels and greater differences were observed at four locations in continuous corn *(Zea Mays* L.), especially at the most humid location where a rye cover crop was also planted.

Mineralization/Immobilization

Interactions between microbial activity and mineralization of soil organic N are often controlled by environmental factors. Predicting how changed environmental conditions in reduced-tillage soils will affect net mineralization is difficult because the contrasting effects of increased water and reduced temperatures on net mineralization may vary during the growing season and across climates (Doran and Smith, 1987; Fox and Bandel, 1986). In the early growing season, cooler and wetter soil conditions associated with reduced tillage may result in less microbial activity and mineralization compared with tilled conditions.

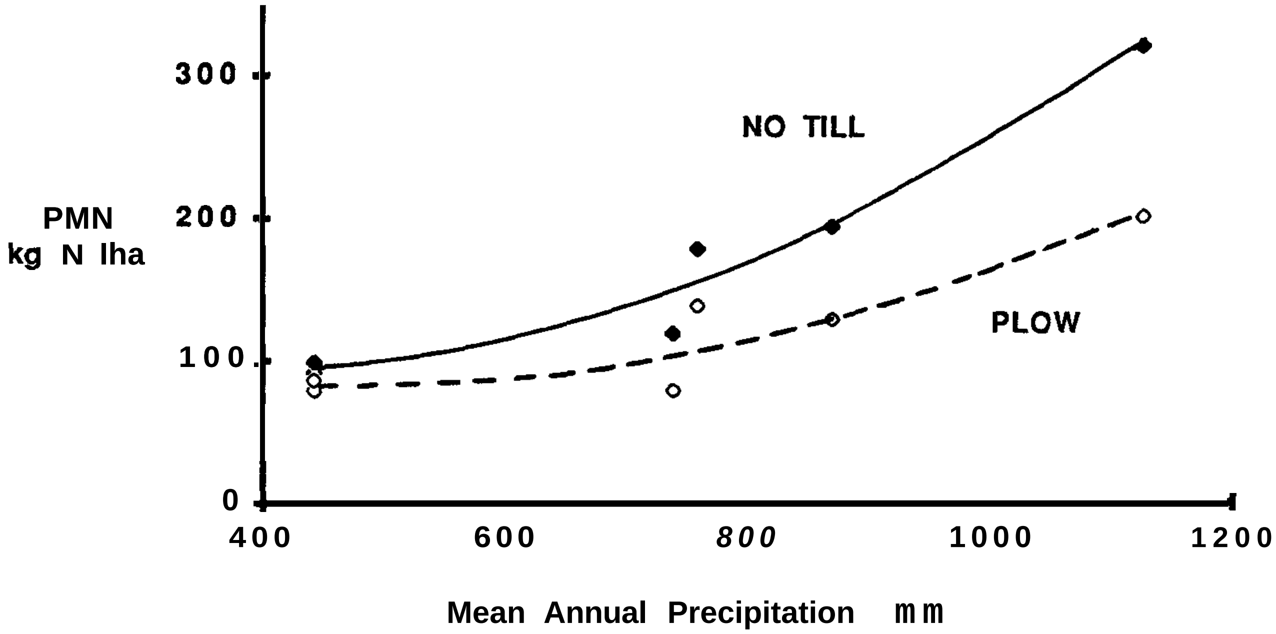

Figure 1. Surface soil (0-7.5cm) potentially mineralizable N versus mean annual precipitation at six USA locations.

Mineralization later in the growing season, when temperatures are more favorable for biological activity, may be higher with reduced tillage as a result of higher and more optimal soil water contents. Also, greater microbial biomass levels in no-tillage surface soils during the growing season can serve as a sink for immobilization of N. Higher soil microbial biomass levels in no-tillage production of wheat and corn have been related to greater immobilization of fertilizer N as compared with plowing or shallow tillage (Carter and Rennie, 1987; Rice et al., 1986).

The effectiveness of tillage in releasing the N contained in soil microbial biomass and organic N reserves is also influenced by soil type and plant rooting density. The productivity of grass pastures is often limited by reduced availability of mineral N as a result of accumulation of root and plant debris with a high C/N ratio and increased immobilization of N in microbial biomass. Periodic cultivation of grass pastures increases mineralization of soil N and stimulates grass production through changes in rooting density and mineralization of microbial and organic N reserves. In clay soils, the N mineralized by cultivation may come largely from stabilized forms of organic N, whereas in coarse-textured soils, microbial biomass may be the predominate source of mineralized N (Table 3). Changes in microbial biomass resulting from cultivation paralleling those for root biomass suggest an association between changes in rooting density and microbial biomass levels in soil.

The increased use of cover crops in reduced tillage management systems may result in pronounced changes in soil N availability. Lower yields and cover crop N

TABLE 3. EFFECT OF SOIL CULTIVATION ON TOTAL N BUDGETS FOR THE 0-30 CM SOIL DEPTH INTERVAL OF GRASS PASTURES AT TWO SITES IN QUEENSLAND, AUSTRALIA (DORAN ET AL., UNPUBLISHED DATA)

Plant or Soil Component	Green Panic, Clay			Buffelgrass, Sandy Clay Loam		
	No Tillage	Chisel Plow	Difference	No Tillage	Plow/ Resown	Difference
	--kg N/ha--					
Plant Nitrogen						
Tops	45	62	+17	28	41	+13
Roots	84	102	+18	116	94	−22
Soil Nitrogen						
NO_3+NH_4	4	10	+ 6	8	7	1
Mineralizable N	945	882	−63	480	459	−21
Microbial biomass N	318	332	+14	153	116	−37
Total organic N	8143			3144		

recovery likely result from competition between plants and heterotrophic microorganisms for inorganic N and increased storage in organic N pools (Table 4). There appears to be a potential for better management of cover crop N and for using some degree of soil tillage to mineralize N for subsequent use by grain crops.

TABLE 4. INFLUENCE OF TILLAGE AND COVER CROP ON CORN GRAIN YIELD AND RECOVERY OF COVER CROP N IN CORN GRAIN AND STOVER (AFTER VARCO ET AL., 1985)

Tillage	Cover Crop	Corn Grain Yield	Cover Crop N Recovered
		Mg/ha	%
No tillage	Vetch	6.4	16
No tillage	Rye	3.3	21
Plow	Vetch	6.9	30
Plow	Rye	5.0	31

Summary

Tillage management systems affect the cycling of soil N through changes in the soil environment and supply of food sources to microorganisms and plants. Interactions between soil physical, chemical, and biological characteristics are greatly influenced by climate, soil, and soil organic matter levels. Development of alternate management strategies for the most efficient use of soil N will be enhanced by a better understanding of these interactions in the soil ecosystem.

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