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AEROBIC AND ANAEROBIC SOIL MICROBIAL ACTIVITY AS INFLUENCED BY TILLAGE AND SOIL PHYSICAL PROPERTIES

by

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AEROBIC AND ANAEROBIC SOIL MICROBIAL ACTIVITY AS INFLUENCED

BY TILLAGE AND SOIL PHYSICAL PROPERTIES

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LITERATURE REVIEW

Conservation Tillage

The development of conservation tillage practices in the United States arose from a direct need to conserve both the soil and water of agricultural lands. The initial work conducted by Duley and Russell (1939, 1942) on the stubble-mulch (sub-tillage) system to control weed growth during the fallow period with winter wheat production demonstrated that leaving crop residues on the soil surface conserved soil water and effectively reduced soil erosion losses. Furthermore, they demonstrated that a crop could be successfully produced without the use of the moldboard plow or other conventional tillage operations. As a result of these early efforts, by 1959 more than 8 million hectares of cropland were being managed by the stubble-mulch system (McCalla and Army, 1961). Secondary tillage operations, however, were still required to control weed growth, regardless of the tillage system used. In this regard, it was not until the late 1940s and 1950s, when selective herbicides were developed and made available, that conservation tillage systems less dependent on tillage than the stubble-mulch system were developed (Wiese and Staniforth, 1973).

Among the conservation tillage systems evaluated during the late 1950s and early 1960s was the concept of no-till crop production. In 1960 Moody, Shear, and Jones (1961) demonstrated that corn (*Zea mays* L.) could be successfully grown in a herbicide-killed sod mulch without the

need for tillage. Following this initial demonstration, a substantial research effort was initiated in the late 1960s and early 1970s to evaluate the no-till system with respect to its influence on crop productivity and the physical and chemical properties of soil. Much of this research has since been reviewed, and the conclusion drawn that, despite some problems, the no-till system represents a practical alternative to the use of conventional tillage practices (Baeumer and Bakermans, 1973; Phillips et al., 1980; Unger and McCalla, 1980).

Estimates of the total acreage of U.S. cropland currently managed by conservation tillage systems, including no-till, indicate the widespread acceptance of these systems. In 1981 nearly 33 million hectares of cropland were managed using some form of conservation tillage (Berg, 1982). Furthermore, the United States Department of Agriculture (USDA, 1975) has estimated that nearly 45 percent of U.S. cropland (62 million hectares) will be managed with the no-till system by the year 2000.

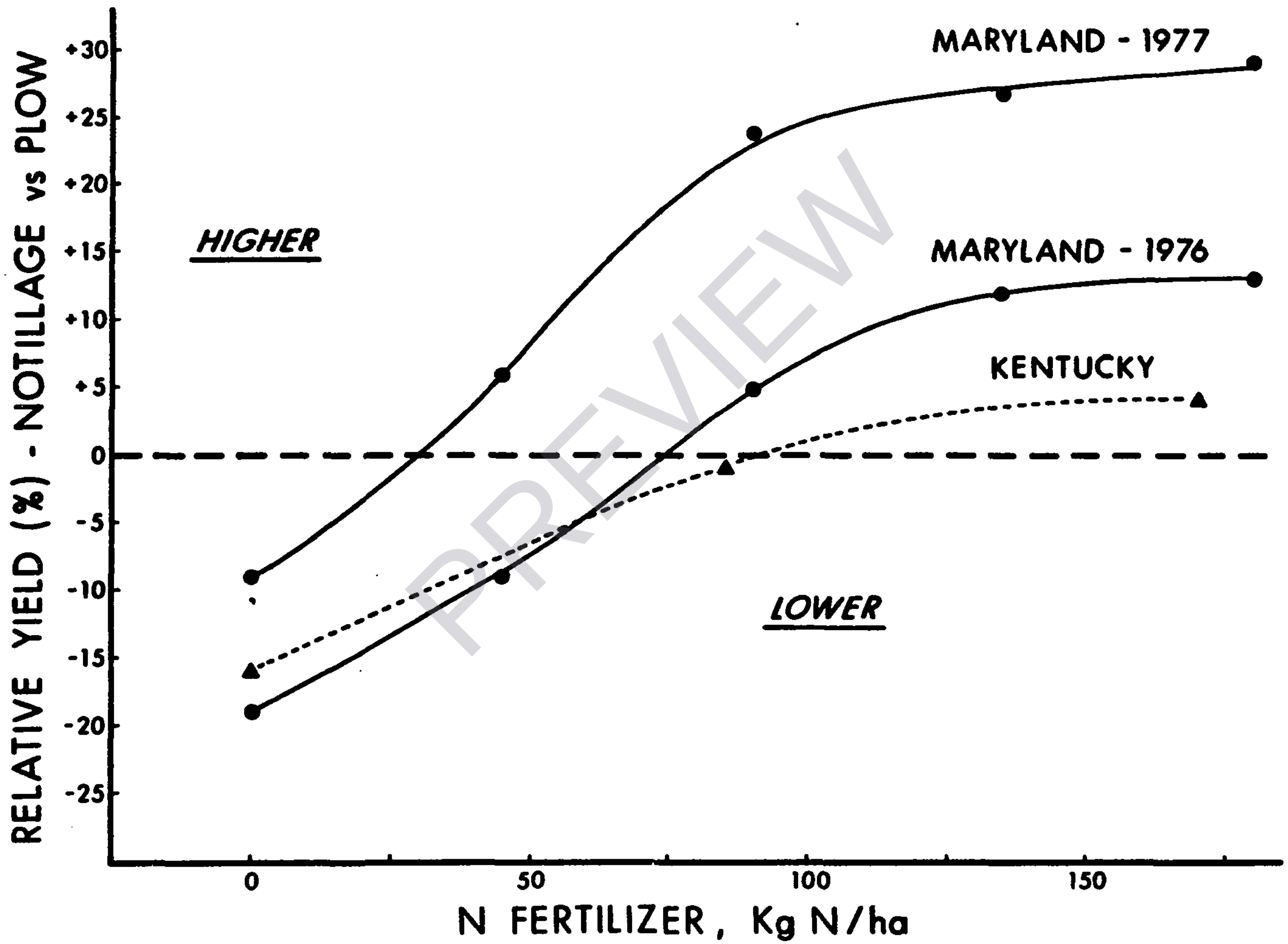
The acceptance of no-till practices among crop producers has come about primarily because of the advantages this system has to offer over conventional tillage practices. Among these advantages, reduced soil erosion losses, conservation of soil moisture, and lower equipment and fuel costs are of particular importance (Phillips et al., 1980). Many of the problems encountered with the no-till system are regional in nature and, to a great extent, can be corrected by good management techniques. These problems include, an increased susceptibility to insect

damage and crop disease, cooler early season soil temperatures (Phillips et al., 1980; Unger and McCalla, 1980), a greater potential for soil compaction (Gantzer and Blake, 1978; Voorhees, 1977a; 1977b; Cannell et al., 1978), a greater difficulty in weed control (Wiese and Staniforth, 1973), and a tendency for surface no-till soils to become acidic in the absence of adequate liming practices (Blevins et al., 1978).

Another problem of importance is that, with low levels of applied nitrogen, yields from crops grown with no tillage are often lower than those from conventionally tilled crops. In contrast, when greater amounts of nitrogen fertilizer are applied, no-till crops have generally responded with higher yields than conventionally tilled crops. The relationship between continuous corn yields, nitrogen fertilizer rate, and tillage at several locations in Kentucky and Maryland is depicted in Figure 1. An application of 30-90 Kg N/ha was required before yields were comparable between no-till and conventional tillage practices at these locations.

The requirement for greater amounts of nitrogen by no-till crops often results from lower soil NO_3^--N levels with reduced tillage soils as compared with those under conventional tillage (Dowdell and Cannell, 1975; Moody et al., 1952; Thomas et al., 1973). Several factors appear to be involved, including losses of soil NO_3^--N from increased rates of leaching (Thomas et al., 1973), lower rates of mineralization

Figure 1. Comparison of relative grain yields from continuous corn between no-till and conventional tillage practices in relation to nitrogen fertilizer rate. (After Doran and Power, 1982).



and nitrification (Broder, 1981[1]; Dowdell and Cannell, 1975), increased denitrification (Doran, 1980b; Smith et al., 1980), and increased microbial immobilization of soil nitrogen (Doran, 1980b; Doran and Power, 1982).

It becomes apparent from the research sited above that the influence of soil microorganisms in regulating the availability of nitrogen to a crop under reduced tillage conditions is of considerable importance. Other research indicates that the extent to which microorganisms are capable of influencing the levels of soil nitrogen and carbon is directly related to the degree of tillage. Some of the factors involved in the relationship between tillage and the activity of soil microorganisms are presented below.

Effects of Tillage on Soil Microorganisms

The physical and chemical properties of soil play an important role in regulating the composition and activity of the soil microbial community. Soil water content, aeration, temperature, pH, and the availability of organic and inorganic substrates are all of particular importance in this regard (Stozky, 1972). Tillage practices bring about marked changes in these soil parameters. As a result, tillage induced changes in the soil microenvironment can substantially alter the micro-

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[1]Broder, M. W. 1981. Changes in nitrogen metabolizing microorganisms under different tillage systems in western Nebraska. Masters Thesis, University of Nebraska-Lincoln.

bial nature of soil.

In general, conventionally tilled soils support greater numbers of microorganisms, within the tillage zone shortly after tillage, than do uncultivated soils (Sommers and Biederbeck, 1973). The increased microbial activity from tillage results in the oxidation and loss of substantial amounts of organic carbon and nitrogen after several years of cultivation (Allison, 1973; Brady, 1974; Russell, 1973). This loss of soil organic matter is in large part attributed to the mechanical disruption of soil aggregates by tillage which exposes previously inaccessible organic matter to microbial degradation (Rovira and Greacen, 1957). Moreover, tillage results in the mixing of crop residues with the surface soil which effectively increases the exposure of the residue to microbial degradation which further accelerates the oxidative process.

In comparison with conventional tillage, the no-till system results in a slowing of soil organic matter oxidation (Blevins et al., 1977; Fleige and Baeumer, 1974; Juo and Lal, 1979; Moschler et al., 1972). One mechanism by which this occurs is the development of less-oxidative conditions within the soil microenvironment as tillage is reduced. This concept is supported by the findings that soils subject to reduced tillage practices generally support greater numbers of facultative anaerobes and denitrifying bacteria than do conventionally tilled soils (Doran, 1980b; Suzuki et al., 1969). The populations of aerobic microorganisms are also influenced by the degree of tillage. Moreover,

the soil conditions imposed by tillage can alter both the predominance of one group of microorganisms over another (e.g., bacterial vs. fungal populations) and the distribution of microorganisms within the soil profile (Doran, 1980b; Sommers and Biederbeck, 1973).

A summary of the differences in the numbers and types of microorganisms in soils under conventional and reduced-tillage practices, as observed by several researchers is given in Table 1. Dawson et al. (1948) examined the effects of plowing, stubble-mulching, and the amount of surface-applied crop residue on the distribution of microorganisms in the soil and found that greater numbers of microorganisms were frequently present in the surface 2.5 cm of soil where crop residues were maintained on the surface by stubble-mulch tillage. Moreover, they noted that the numbers of microorganisms in the surface 2.5 cm of stubble-mulched soil increased with increasing rates of surface-applied crop residues. Conventionally tilled soil, however, was noted to support greater numbers of microorganisms at the 2.5 to 15.0 cm soil depth. Although not determined, the authors conjectured that variations in soil water content and nutrient availability were responsible for the observed differences in microbial populations between these tillage treatments.

The effects of subsurface tillage and surface-applied crop residues on the populations and distribution of soil microorganisms that Dawson et al. observed were later substantiated by Gamble et al. (1952) and Schaller and Evans (1954). Gamble et al. observed an increase in the

Table 1. Relative differences in microbial populations between tillage treatments at several locations and with different crops.

Microbial group	Ratio (RT/CT)[a] for microbial populations with depth in soil		Sampling times	Crops grown; tillage treatment (depth of tillage)	Reference and location
	0-5.0 cm	18-23 cm		Spring barley;	Barber & Standell 1977
Aerobic bacteria	1.06	0.60	1	RT = Direct drill CT = Moldboard plow	Oxfordshire,
Fungi	1.48	0.50	1	(20 cm)	England
	0-2.5 cm	2.5-15 cm		Corn/Oats/Wheat and Sweetclover /Corn or Wheat or Sorghum rotations; RT = Subtill (7.5-10 cm);	Dawson et al., 1948 Nebraska, U.S.
Aerobic bacteria + Actinomycetes	1.75	1.02	12	CT = moldboard plow (15-20 cm)	
Fungi	1.41	1.00	12		
	0-7.5 cm	7.5-15 cm		Corn or Wheat-Fallow	Doran, 1980b
Total Aerobic Organisms	1.35	0.71	7	RT = No-till	Kentucky,
Fungi	1.57	0.76	7	CT = Moldboard plow	Minnesota,
Actinomycetes	1.14	0.98	7	(10-25 cm)	Nebraska (3 sites)
Bacteria	1.41	0.68	7	+ disk, mulch	Oregon,
NH_4^+ oxidizers	1.25	0.55	7	harrow, or rod	W. Virginia, U.S.
NO_2^- oxidizers	1.58	0.75	7	weeder	
Facultative Anaerobes	1.57	1.23	7		
Denitrifiers	7.31	1.77	7		

Table 1 (continued).

Microbial group	Ratio (RT/CT)[a] for microbial populations with depth in soil			Sampling times	Crops grown; tillage treatment (depth of tillage)	Reference and location
	0-15 cm				Corn; RT = Doublecut plow, inverts 0-7.5 cm & subtills 7.5-18 cm + Harrow 7.5 cm; CT = Moldboard plow (15-20 cm) + double disk	Gamble et al., 1952 Virginia, U.S.
Aerobic bacteria	0.99			6		
Fungi	1.33			6		
	0-7.6 cm				Corn and wheat; RT = Subtill (7.5-12.5 cm); CT = Moldboard plow (10-20 cm) + rod weeding	Norstadt and McCalla, 1969 Nebraska, U.S.
Aerobic bacteria + Actinomycetes	1.73			7		
Fungi	1.46			7		
	0-7.5 cm	10-17.5 cm			Corn; RT = Subtill (7.5-15 cm); CT = Moldboard plow	Schaller and Evans, 1954 Iowa, U.S.
Aerobic bacteria + Actinomycetes	1.17	0.92		5		
	2-7 cm	12-17 cm	22-27 cm		Corn or Barley; RT = Disk, harrow (7 cm) CT = Moldboard plow (15-20 cm), double disk	Suzuki et al. 1969 Saitama, Japan
Aerobic bacteria	1.85	0.71	0.53	2		
Actinomycetes	1.35	0.73	0.45	2		
Bacillus (Spore-formers)	1.36	0.81	0.47	3		
Cellulose decomposers	1.08	0.74	0.65	2		
Nitrosomonas sp.	1.16	1.03	0.55	1		
Anaerobic bacteria	1.57	0.50	0.20	1		

[a]Ratio of microbial populations, reduced tillage over conventional tillage values.

number of fungi in the surface 15 cm of soil with mulch-tillage, however, a significant difference between mulch- and conventional tillage with regard to bacterial populations was not observed. This latter observation was, with little doubt, an artifact of sampling the surface 15 cm of soil *in toto*. Dawson et al. (1948) stated that "When the 0-6 inch (0-15 cm) depth was considered as a whole the significance due to tillage, so pronounced in the surface inch (2.5 cm) was lost". Schaller and Evans (1954) observed that greater numbers of microorganisms frequently extended to a depth of 7.5 cm in subsurface tilled soil, confirming the earlier observations of Dawson et al.

The presence of greater numbers of microorganisms in the surface 5.0 to 7.5 cm of reduced and no-till soils has since been demonstrated by several researchers using a variety of techniques including microbial plate counts (Barber and Standell, 1977; Doran, 1980a; 1980b), soil dehydrogenase activity (Doran, 1980a; 1980b), soil respiration rates (Barber and Standell, 1977), and microbial biomass determinations (Lynch and Panting, 1980). The work of Doran (1980b) and Barber and Standell (1977) confirmed the earlier observations by Dawson et al. (1948) that within the surface 15 cm of conventionally tilled soils microbial populations tend to increase with soil depth, while in reduced and no-till soils microbial populations decreased with depth. In addition, while these trends adequately characterized the changes among aerobic microbial populations, Doran (1980b) noted that the populations of facultative

anaerobes and denitrifying bacteria in no-till soils remained greater than those of conventionally tilled soils throughout the surface 15 cm.

These observations, particularly those concerning the distribution and number of anaerobic microorganisms, support the concept noted earlier that a reduction in tillage leads to the development of a less oxidative soil microenvironment. The abundance and type of microorganisms within a soil, however, are generally considered reflections of physical and chemical properties of soil (Alexander, 1977). In no-till and reduced-tillage soils, substrate availability and soil water content, both of which are strongly influenced by the presence of crop residues on the soil surface, have been sited most often as influential in regulating the numbers and activities of the indigenous microbial populations (Barber and Standell, 1977; Dawson et al., 1948; Gamble et al., 1952; Kruglov et al., 1979; Schaller and Evans, 1954; Suzuki et al., 1969). Soil water content, however, was sited by Doran (1980b; 1981) as a primary factor influencing the differences in numbers of microorganisms between no-till and conventionally tilled soils. Furthermore, the greater soil water contents and bulk densities that are often associated with no-till soils can result in the establishment of lower soil air-filled porosity. Hence, as Doran and Power (1982) have noted, soil aeration may well be an important factor regulating the nature of the microbial community in no-till soils.