IMPACT OF TILLAGE ON SOIL PROPERTIES

R.P. Wolkowski [1/]

Tillage is defined as the physical manipulation of the soil for the purposes of managing previous crop residues, preparing a seedbed for planting, controlling competing vegetation, and incorporating fertilizers and other crop production inputs. Tillage, when done at the correct soil moisture, allows the soil to fracture along the existing soil structural planes. The soil moisture should be such that soil aggregates will separate easily when worked, without the smearing or destroying the aggregates, which would occur if the soil is too wet. Tillage, and the subsequent residue management effects, will have a profound effect on soil processes and properties that directly impact crop production. Examples of these processes and properties are soil structure, water infiltration and movement in the soil, bulk density, aeration, soil warming, biological activity, and residue and organic matter relationships. Tillage also affects plant nutrient availability. This topic was discussed at the WFCA Conference in 2004 and will not be covered in detail in this paper.

The interest in soil conservation has resulted in increased production under conservation tillage. Researchers have found increased crop yield after several years of conservation tillage (no-till), even though some measured soil physical properties appear unfavorable (Hill, 1990). Some of this effect has been related to increased continuity of pore space, more favorable soil water relationships, and the maintenance of soil organic matter (Karlen et al., 1990). Others have noted a "yield drag" associated with no-till that has been related to cooler soil conditions. This paper will outline some of the effects of tillage on soil physical and biological properties and how they may impact crop production.

Aggregate Stability

Aggregation, or the development of soil structure, is an important property of the soil. Mineral soils are composed of a distribution of sand, silt, and clay size particles that produce a definitive soil texture. In medium- and fine-textured soils these particles are held together by chemical and physical processes, in much larger units known as aggregates. Sands and loamy sands do not form aggregates and are described as single-grained soils. For this reason medium-textured soils have a lower bulk density and higher porosity than sands. Stable aggregates, which are important for maintaining porosity, aeration, and favorable water relationships, are critical for sustaining soil productivity. Typically the strength of structural units is greater in soils having higher clay contents due to greater attraction between particles as they compete for cations. Claims are often made regarding the effect of calcium on soil structure. Most Wisconsin soils have adequate calcium, either natively or from the addition of lime, and there is no conclusive evidence that addition of calcium containing amendments will improve structure.

The decomposition of organic materials such as crop residue, manure, compost, and other organic residuals produce compounds which bind soil particles. Fresh organic materials which have low C:N ratios will have a larger, but shorter-lived influence on aggregate stability, than higher C:N ratio materials that decompose more slowly. For example, researchers demonstrated greater erosion

[1/] Extension Soil Scientist, Department of Soil Science, University of Wisconsin-Madison.

losses following soybean when compared to corn (Laflen and Moldenhauer, 1979). Some are beginning to question the sustainability of the corn/soybean rotation. In addition to the increased erosion that could be attributed to the lower residue level following soybean, Kladivko et al. (1986) found a relationship between rotation and aggregate size (Table 1). Aggregate size was further reduced as the tillage intensity was increased.

Table 1. Water-stable aggregate size in the 0- to 3-inch depth prior to spring tillage.

	Previous two crops			
Tillage system	C-C	C-Sb	Sb-C	Sb-Sb
	--- mm ---			
Fall moldboard	0.9	0.9	0.9	0.6
Fall chisel	1.7	1.2	1.1	0.8
No-till	2.7	1.7	1.7	1.5

Adapted from Kladivko et al. (1986).

Crop residues and other organic amendments serve as the energy source for soil microorganisms, therefore soil aggregation will be the greatest where organic residues are concentrated, such as the surface. Maintaining good aggregation at the surface is important for aeration, infiltration, root growth, and resistance to crusting. This observation suggests that long-term reduced tillage or no-till may enhance soil tilth. Karlen et al. (1994) evaluated a southern Wisconsin soil after 12 yr of either moldboard, chisel, or no-till for several soil quality factors. Average crop yield for the period was 3 bu/acre lower on the no-till when compared to the moldboard. They observed that while the surface of the no-till treatment had a slightly lower porosity, it had greater aggregate stability, total carbon, and earthworm population when compared to either chisel or moldboard. Estimated soil loss was significantly lower on the no-till when compared to moldboard, which could be attributed to both crop residue and improved physical condition.

Most conservation tillage systems will employ some form of secondary tillage to create a seedbed, the most popular being the tandem disk or the field cultivator. Adam and Erbach (1992) compared these two implements over a range of soil moisture content and found that the disk tended to produce larger, stronger aggregates then the C-shanked field cultivator. Their research suggests that the tandem disk will create a more cloddy soil condition, especially as the soil becomes wetter. The tandem disk has also been considered to be a tool that compacts due to the pressure exerted along the edge of each disk.

It should be emphasized that aggregate stability is a complex matter and is likely due to interactions between organic and inorganic components. It is believed that polyvalent cations such as Ca, Mg, Fe, etc. act as bridges between soil particles. Natural events such as freezing/thawing and wetting/drying will promote aggregation as the soil will tend to fracture along planes of weakness. The complexity of aggregation increases when soil management factors such as tillage, crop production, and compaction are introduced. Maintaining the proper soil fertility, especially pH, will maximize crop residue production and optimize conditions for soil microorganisms.

Water Relationships

The type of tillage used may influence both the movement of the water into the soil (infiltration) and the movement of water within the soil (hydraulic conductivity). Water infiltration will be dependent upon the characteristics of the soil surface, including the amount of crop residue, the degree to which the surface of the soil is crusted, and the existence of large pores open to the surface. It is well known that the maintenance of surface crop residue will reduce surface crusting by absorbing energy from raindrop impact. Surface crop residue, because of the greater microbial activity it supports, also helps maintain greater aggregate stability. These factors, which are consistent with reduced tillage, help maintain large, continuous pores at the soil surface which are necessary for infiltration. Earthworm channels, moisture cracks, and root channels represent some of the sources of macropores in soils. Earthworm populations are influenced by tillage and rotation as Kladivko (1993) has shown (Table 2). In addition to enhancing infiltration, earthworms recycle nutrients within their zone of activity in the soil. The earthworm most affected by tillage is the night crawler (*Lumbricus terrestris*) which form large vertical channels and pull residues down into their burrows, forming a midden, or deposit of soil and residue, at the entrance.

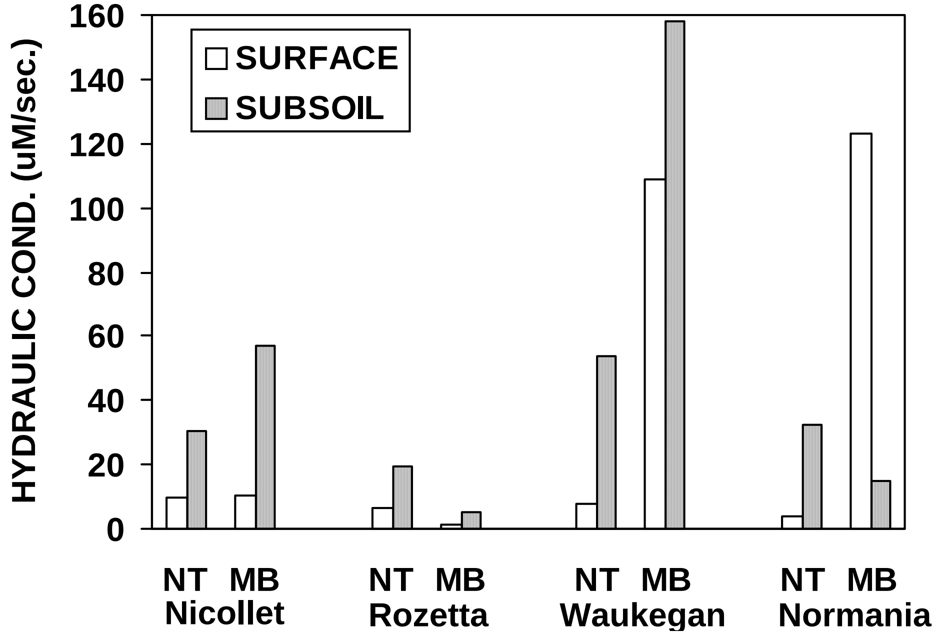
Table 2. Earthworm numbers found in a silty clay loam soil in Indiana following following 10 years of continuous management.

Crop	Management system	Earthworms/m^2
Continuous corn	Plow	10
Continuous corn	No-till	20
Continuous soybean	Plow	60
Continuous soybean	No-till	140
Pasture	Dairy (light manure)	340
Pasture	Dairy (heavy manure)	1300

Adapted from Kladivko (1993).

Unger (1992) concluded that tillage systems that significantly disturb the soil result in lower infiltration rates as the season progresses due to the loss of aggregate stability. Datiri and Lowery, 1991a found that the wetting front moved fastest following large natural storm events in no-till and chisel, when compared to moldboard or ridge-till suggesting more favorable porosity in the no-till and chisel systems. Similarly, Ankeny et al. (1990) found that early season infiltration was greater in chisel plow, when compared to no-till in the un-trafficked portion of the field, but that this relationship reversed where trafficked. Because of the temporal effect, it is critical to identify the

Figure 1. Saturated hydraulic conductivity from two depths of four Midwestern soils under



moldboard plow and no-till cropping systems (adapted from Logsdon et al., 1990).

antecedent conditions when infiltration is measured. Logsdon et al. (1993) found that infiltration rate will also be affected by seasonal effects, not just residue management, making a one-time measurement risky. They found greater variation in infiltration rates between measurement times than they did between tillage systems. They concluded that infiltration was dependent upon the formation of a crust, which they found to be affected by storms with high rainfall intensity, and partially ameliorated drying periods which induced cracking.

Macroporosity is also an important property relative to the movement of water through the soil profile. Evaluations of saturated hydraulic conductivity in soils under different tillage regimes have shown mixed results. Usually no-till soils are found to have a higher bulk density in the surface layer when compared to plowed soils, leading to lower porosity in this system. However, because no-till soils are relatively undisturbed more macropore channels have been found to be continuous with depth in no-till (Heard et al., 1988). Logsdon et al. (1990) measured the saturated hydraulic conductivity in undisturbed cores taken from four upper Midwest soils and found mixed results (Figure 1). These data show considerable variation between sites. For example, the Rozetta soil (Lancaster, WI) had greater flow in the no-till soil at both depths, while the plowed soil had much greater conductivity at both depths in the Waukegan soil (Rosemount, MN).

Conservation tilled (chiseled or disked) soils are often found to have a higher soil moisture content when compared to moldboard plowed soils, because of a greater proportion of smaller pores (Hill et al., 1985) and the shading/mulching effect of the residue. Conservation tilled soils generally had more plant available water, which could be important to a crop in times of moisture stress (Datiri and Lowery, 1991b).

Soil Temperature

Cooler soil temperatures are usually associated with high residue cropping systems. Crop residue will have two major impacts on heat energy. The first is the reflection of incoming solar energy from a relatively lighter colored material, and the second is the insulating effect the residue provides. Several years ago much of southern Wisconsin experienced a frost on Father's Day when most corn was about knee high. Damage from the frost was more severe where there was significant surface crop residue. This residue reduced the diffusion of heat stored in the soil into the crop canopy. Recently cultivated ground suffered a similar fate, because the tilled layer dried out and reduced the heat conductivity from the soil.

Several investigators have measured soil temperatures and the movement of heat energy in the soil. Potter et al. (1985) noted that thermal conductivity was about 20% greater in a no-till soil because of a more continuous arrangement of the soil matrix when compared to the plowed system. They also measured soil temperature shortly after planting at 1, 2, and 6 inches at two sites comparing moldboard, chisel, and no-till systems throughout a 24-hr period. The no-till system at one site was ridge-tilled. They found temperatures at each depth to be similar in the middle of the night across all tillage systems. However, during the mid-day they found more than 10 ^{o}F greater in moldboard than no-till at one site at the 1-inch depth, with chisel intermediate. In contrast, soil temperature in the row in ridge-till was warmer at mid-day than those in chisel. The authors noted that in ridge-till most of the residue was in the inter-row, with the ridge nearly devoid of residue, whereas in the chisel as much as 35% cover was equally distributed over the surface. Overall, temperature differences between tillage became less apparent as the depth in the soil increased. Hatfield (1996) noted that no-till fields have a smaller difference between their daily minimum and maximum temperature, because of the insulating effect of the residue. No-till fields also cool more slowly in the fall. He suggests that the fall temperatures be measured in no-till fields to insure that soil temperature is below 50^{o}F where the fall application of anhydrous ammonia is planned.

Like other researchers, Johnson and Lowery, 1985 found that seed zone soil temperature changes greatly over time in the early season. Figure 2 shows the diurnal fluctuation of soil temperature taken in early June at the two inch depth for four tillage systems at Arlington, WI. The moldboard plow treatment varied by as much as 28^{o}F over a 12-hr period, whereas no-till varied by 21^{o}F.

If soil temperatures differ greatly between tillage systems, there may be differences in the distribution of corn roots in the soil. Kovar et al. (1992) examined corn root growth in a long-term tillage study in a moldboard and ridge-till system in first-year corn following soybean. They found more roots in the inter-row zone under ridge-till. They suggested that this finding may warrant the need for a broader distribution of fertilizer (e.g., banding both in the row and inter-row) in ridge-till.

One method of counter-acting the effect of crop residue on soil warming is to use some form of residue clearing in the row. Today most "no-till" cropping systems include some type of residue clearing usually conducted by disks mounted ahead of the planting units. This practice will be

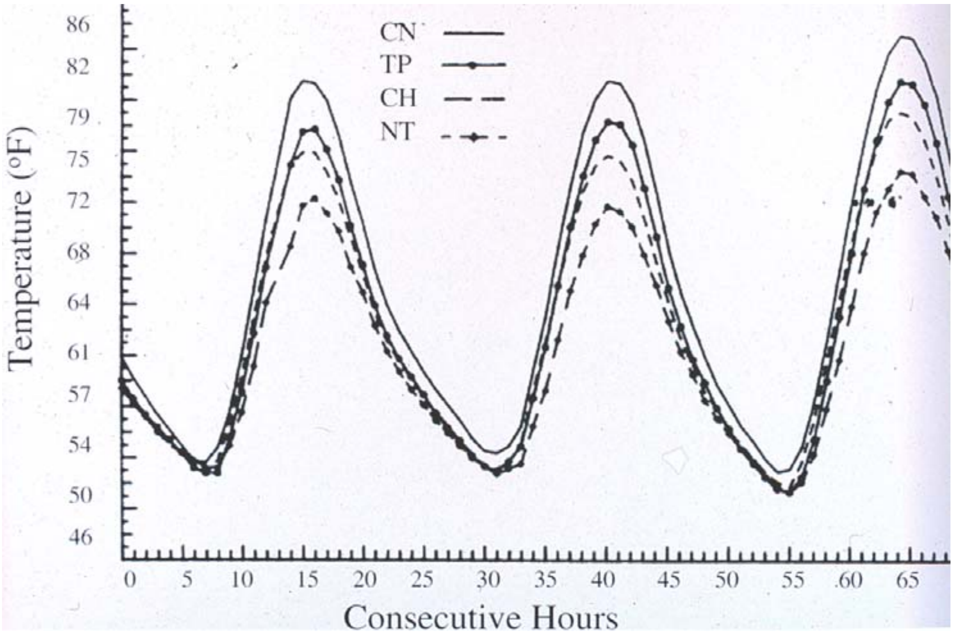


Figure 2. Soil temperature at 5 cm (2 inches) for a 3-day period starting at midnight on June 2, 1982 for four tillage systems (from Johnson and Lowery, 1985).

especially important on erosive soils, where it is vital to maintain crop residue to protect the soil. Research in Iowa demonstrated that a band of six to twelve inches reduced the yield drag associated with no-till (Cruse, 1985). Similarly, work reported by Wolkowski et al. (1996) at Arlington, WI. has shown that residue clearing significantly increases the early growth of corn over that observed with no-till (Table 3).

Table 3. Effect of row clearing on the mean maximum soil temperature for the 3 weeks after planting and the early growth of corn, 1994-1995 (2-yr average).

Tillage	Temperature	Emergence	V6 wt.	V12 wt.	Silked
	^{o} F	plts/ft	---------- g/plt ----------		%
Fall zone	62	1.6	1.1	28	62
Spring zone	N/A	1.5	1.0	26	51
Chisel/disk	63	1.8	1.1	29	80
No-till	54	0.7	0.7	18	36

Adapted from Wolkowski (1996).

Soil Strength

High soil strength, as measured by increased penetration resistance, is indicative of compacted conditions that have been shown to limit root growth. As mentioned earlier, no-till soils often have a greater soil bulk density, resulting in the recommendation that fields should be plowed occasionally. This would disrupt established root channels that researchers have suggested to be beneficial for crop growth in no-till systems.

Larney and Kladivko (1989) evaluated the effect of tillage on soil strength at three Indiana locations following several years in each system. They found that row position has a substantial effect on penetration resistance. Their data showed that the penetration resistance in the row was relatively similar to that found in the moldboard plow. The authors conclude that controlling traffic will be critical in the no-till and ridge till systems to maximize the volume of uncompacted soil for crop growth. Likewise, Voorhees and Lindstrom (1984) found that in the long-term, the negative effect of compaction on the soil porosity can be alleviated. Their southern Minnesota study showed improved aggregation and increased porosity after 4 to 5 yr when wheel traffic was controlled. Unfortunately, the authors did not include yield data in this report, but it can be assumed that the soil tilth was more favorable in the untracked treatment.

Among the methods of controlling compaction in reduced tillage systems is the use of tractors running on tracks instead of tires. Theoretically, a tracked vehicle will have more surface area contact with the soil. Brown et al. (1992) compared a steel-tracked and rubber-tracked implement with both 2- and 4-wheel drive tractors on a silty clay loam soil that had been moldboard plowed and disked. The mass of the tracked vehicles and the 4-wheel drive tractor was similar. However, the 2-wheel drive tractor weight about 50% of the other vehicles. Their study showed, as expected, that the tracked vehicles had less of a compacting effect than the wheeled tractors at the 2- to 5-inch depth (Table 4). The wheeled tractors had a similar effect, despite their weight differences. No difference between vehicle types was observed in the 5- to 8-inch depth.

Some producers have resorted to subsoiling when it appears that crop production has resulted in the formation of a compacted layer. The procedure is energy intensive and has been shown to produce mixed results. Soane et al. (1986) found that the soil bearing capacity after subsoiling was reduced in that sinkage of subsequent traffic was increase 150%. Soane et al. (1987) after evaluating subsoiling at 16 locations concluded that: (1) soils with higher bulk densities would benefit the most from subsoiling; (2) subsoiled fields re-compact with time; (3) controlled or reduced traffic increased the longevity of subsoiling effects; (4) subsoiling was most effective if it alleviated moisture stress; and (5) subsoiling silty soils created negative effects in wet years because of the breakdown of aggregates. Tilled soils may become more compacted compared to a similarly trafficked no-till soil. The tilled soil has much less bearing strength than the no-till soil and if future traffic is not managed the soil may become more resistant to penetration.

Table 4. Effect of tracked and wheeled vehicle on the bulk density, saturated hydraulic

conductivity, and air-filled pore space at the 2- to 5-inch depth and 4-yr average yield.

Vehicle type	Bulk density	Hydraulic conductivity	Air-filled pore space	Yield*
	g/cc	Fm/sec	%	bu/acre
Untracked	1.28	26.0	17.8	166
Steel tracked	1.38	13.0	9.7	148
Rubber tracked	1.46	7.8	7.7	--
Wheeled	1.50	2.7	4.7	139

*Yield for tracked treatments averaged among vehicle type.

One final consideration that is sometimes given to what is considered to be unfavorable conditions associated with reduced tillage is the use of occasional plowing. Pierce et al. (1994) followed the effects of plowing or not plowing on a site that had been in no-till for the previous six seasons. They found that plowing decreased bulk density and increased macroporosity in the year after tillage. The year following tillage these properties were intermediate to the tillage systems, but after a few years they were similar to the continuous no-till treatment. They also noted that plowing redistributed nutrients and stimulated N mineralization.

Summary

One of the purposes of tillage is to improve the soil condition for crop production. Environmental and economic concerns have encouraged a reduction in the intensity of tillage to maintain surface crop residue for soil conservation. The reduced soil disturbance, along with the greater surface residue will have a profound effect on soil properties and crop growth. In the northern grain production region, lower soil temperature in high residue systems often reduce growth and yield. This negative effect can be offset by improved soil water properties such as increased infiltration and plant available water. Controlling wheel traffic is important in conservation tillage. Procedures to remove compacted layers have shown mixed results. Innovative approaches to residue management, such as zone-tillage, offer the potential to balance conservation needs with production and profitability.

References

Adam, K.M., and D.C. Erbach. 1992. Secondary tillage tool effect on soil aggregation. Trans. ASAE 35(6):1771-1776.

Ankeny, M.D., T.C. Kaspar, and R. Horton. 1990. Characterization of tillage and traffic effects on unconfined infiltration measurements. Soil Sci. Soc. Am. J. 54:837-840.

Brown, H.J., R.M. Cruse, D.C. Erbach, and S.W. Melvin. 1992. Tractive device effects on soil physical properties. Soil Tillage Res. 22:41-53.

Cruse, R.M. 1985. Watch soil temperatures. In Crops and Soils Magazine. December 1985. ASA, Madison, WI.

Datiri, B.C., and B. Lowery. 1991a. Tillage effects on rain-generated wetting from migration through a Griswold silt loam soil. Soil Till. Res. 21:243-256.

Datiri, B.C., and B. Lowery. 1991b. Effects of conservation tillage on hydraulic properties of a Griswold silt loam soil. Soil Tillage Res. 21:257-271.

Hatfield, J.L. 1996. Are soil temperatures under no-till really cooler. Proc. No-till. Conf., 11-13 January 1996. St. Louis, MO

Heard, J.R., E.J. Kladivko, and J.V. Mannering. 1988. Soil macroporosity, hydraulic conductivity and air permeability of silty soils under long-term conservation tillage in Indiana. Soil Tillage Res. 11:1-18.

Hill, R.L., R. Horton, and R.M. Cruse. 1985. Tillage effects on soil water retention and pore size distribution of two mollisols. Soil Sci. Soc. Am. J. 49:1264-1270

Hill, R.L. 1990. Long-term conventional and no-tillage effects on selected soil physical properties. Soil Sci. Soc. Am. J. 54:161-166.

Johnson, M.D., and B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Sci. Soc. Am. J. 49:1547-1552.

Karlen, D.L., D.C. Erbach, T.C. Kaspar, T.S. Colvin, E.C. Berry, and D.R. Timmons. 1990. Soil tilth: A review of past perceptions and future needs. Soil Sci. Soc. Am. J. 54:153-161.

Karlen, D.L., N.C. Wollenhaupt, D.C. Erbach, E.C. Berry, J.B. Swan, N.S. Eash, and J.L. Jordahl. 1994. Long-term tillage effects on soil quality. Soil Tillage Res. 32:313-327.

Kladivko, E.J. 1993. Earthworms and crop management. Agr. Guide. AY-279. Purdue Univ. Coop. Ext., West Lafayette, InN.

Kladivko, E.J., D.R. Griffith, and J.R. Mannering. 1986. Conservation tillage effects on soil properties and yield of corn and soya beans in Indiana. Soil Tillage Res. 8:277-287.

Kovar, J.L., S.A. Barber, E.J. Kladivko, and D.R. Griffith. 1992. Characterization of soil temperature, water content, and maize root distribution in two tillage systems. Soil Tillage Res. 24:11-27.

Laflen, J.M., and W.C. Moldenhauer. 1979. Soil and water losses from corn-soybean rotations. Soil Sci. Soc. Am. J. 43:1213-1215.

Larney, F.J., and E.J. Kladivko. 1989. Soil strength properties under four tillage systems at three long-term study sites in Indiana. Soil Sci. Soc. Am. J. 53:1539-1545.

Logsdon, S.D., R.R. Allmaras, L. Wu, J.B. Swan, and G.W. Randall. 1990. Macroporosity and its relation to saturated hydraulic conductivity under different tillage practices. Soil Sci. Soc. Am. J. 54:1096-1101.

Logsdon, S.D., J.L. Jordahl, and D.L. Karlen. 1993. Tillage and crop effects on ponded and tension infiltration rates. Soil Tillage Res. 28:179-189.

Pierce, F.J., M.-C. Fortin, and M.J. Stanton. 1994. Periodic plowing effects on soil properties in a
no-till farming system. Soil Sci. Soc. Am. J. 58:1782-1787.

Potter, K.N., R.M. Cruse, and R. Horton. 1985. Tillage effects on soil thermal properties. Soil Sci. Soc. Am. J. 49:968-973.

Soane, G.C., R.J. Godwin, and G. Spoor. 1986. Influence of deep loosening techniques and subsequent wheel traffic on soil structure. Soil Tillage Res. 231-237.

Soane, G.C., R.J. Godwin, M.J. Marks, and G. Spoor. 1987. Crop and soil response to subsoil loosening, deep incorporation of phosphorus and potassium fertilizer and subsequent soil management on a range of soil types. Part 2: Soil structural conditions. Soil Use Manage. 3:123-130.

Unger, P.W. 1992. Infiltration of simulated rainfall: Tillage system and crop residue effects. Soil Sci. Soc. Am. J. 56:283-289.

Voorhees, W.B., and M.J. Lindstrom. 1984. Long-term effects of tillage method on soil tilth independent of wheel traffic compaction. Soil Sci. Soc. Am. J. 48:152-156.

Wolkowski, R.P. 1996. Evaluation of fluid starter fertilizer for corn grown in zone-tillage systems. 1996 Fluid Forum Proc. Fluid Fert. Found. St. Louis, MO.