Wheel Traffic Considerations in Erosion Research

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RECENT field experiments in Minnesota showed that wheel traffic from farming operations may compact the soil to a depth of 300 mm or more. This compaction can persist despite tillage, freezing and thawing. Thus, bulk density, aggregate size and stability, random roughness of the soil surface, infiltration rate, and other erosion-related soil properties are changed. This can cause concentrated areas of different soil properties and drastically alter erosion on research plots. Effects of wheel traffic could bias the erosion results of the actual treatment under investigation. This paper describes how wheel-induced compaction may alter erosion results.

INTRODUCTION

The general effects of soil structure on water infiltration rates are included in the Universal Soil Loss Equation (Wischmeier and Smith, 1965). Wind erosion equations also consider soil-structure-related effects (Woodruff and Siddoway, 1965). But the influence of wheel traffic from farming operations on soil structure is generally not considered because its influence is not well recognized. This may be particularly true in much of the Northern United States where earlier compaction studies showed wheel traffic had little, if any, lasting significance (Kucera and Promersberger, 1960; Krumbach and White, 1964; Phillips and Kirkham, 1962; and Wittsell and Hobbs, 1965). Recent field studies in Minnesota, however, showed wheel-induced compaction was more pronounced than previously expected (Blake et al., 1976; and Voorhees et al., 1978).

Under normal farming operations, most wheel traffic is randomly distributed over the field, except for the well defined areas of concentrated wheel traffic from planting, cultivating, and harvesting of row crops. Similar areas of concentrated wheel traffic occur on small research runoff plots. Because of the configuration and relatively narrow width of small research plots, most, if not all, wheel traffic occurs in the same path each year. In spite of the different soil structure induced by wheel traffic on parts of the plot, the entire plot is generally assumed to have one common erodibility factor. This assumption could bias erosion research results.

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The purpose of this paper is to (a) show the magnitude of some soil structural changes caused by wheel traffic; (b) relate these changes to published data showing effects of soil structure on various phases of erosion; and (c) discuss how wheel traffic may influence water and wind erosion research.

PROCEDURES AND RESULTS

Field experiments were conducted on a Nicollet silty clay loam (Aquic Hapludoll) in Southwestern Minnesota. We used the controlled wheel-traffic concept, with all the wheel traffic from all field operations restricted to the same wheel paths for 5 years. Field-sized equipment was used with tractor weight ranging from 3,700 to 7,300 kg. Plot size was 18.3 m wide and 45 m long. Field operations were typical for corn and soybean culture in the Northern Corn Belt and required 5 to 6 tractor passes per season.

Several soil parameters were measured to assess soil compaction in the wheel-tracked and nontracked areas. These parameters were bulk density, penetrometer resistance, clod crushing strength, and aggregate size distribution. Voorhees et at (1978) have reported these measurements along with other experimental procedures. Soil parameter data relevant to erosion are summarized in Table 1.

In addition, clod density and random roughness (micro-variations in height of the soil surface) of the wheel-tracked and nontracked areas in the above plots were measured at various times. Random roughness was calculated from microrelief measurements as described by Allmaras et al. (1966). Microrelief measurements over time were made in the exact same location each time to reduce the number of replications. A total of four measurement sites was randomly selected for each treatment. The density of the individual air-dried clods was determined by water displacement after coating the clods with paraffin. Clods were approximately 50 mm in diameter, and a minimum of 5 clods per treatment was randomly selected from the soil surface. Water retention characteristics were determined from undisturbed soil cores(76 mm diameter and 76 mm long) taken from both wheel-tracked and nontracked areas. These data are in Tables 2-5 and Figs. 1 and 2.

DISCUSSION

Effects on Runoff and Water Erosion

Two soil characteristics — infiltration capacity and structural stability (Wischmeier and Mannering, 1969)— significantly influence soil erodibility (K factor in the Universal Soil Loss Equation). Burwell and Larson (1969) reported that differences in random roughness of the soil surface and total pore volume of the tilled layer accounted for much of the variation in infiltration on a

TABLE 1. EFFECTS OF WHEEL TRAFFIC ON SOME SOIL STRUCTURE CHARACTERISTICS RELATING TO SOIL EROSION (AFTER VOORHEES ET AL., 1978)

Characteristics	Nontracked	Wheel tracked	Significance†
	------------ Mg/m^3 (g/cm^3)------------		
Bulk density			
Before spring tillage, 0-150 mm	1.24	1.32	N.S.
Before spring tillage, 150-300 mm	1.40	1.48	*
After planting, 0-150 mm	1.18	1.53	**
After planting, 150-300 mm	1.16	1.51	**
	------------ KN/m^2 (g/cm^2)------------		
Clod resistance to crushing	13.141 (134)	56.094 (572)	**
	------------ KN/m^2 (kg/cm^2)------------		
Penetrometer resistance‡			
Before spring tillage, 0-150 mm	264.8 (2.7)	539.4 (5.5)	N.S.
Before spring tillage, 150-300 mm	872.8 (8.9)	1127.8 (11.5)	*
After planting, 0-150 mm	284.4 (2.9)	1627.9 (16.6)	**
After planting, 150-300 mm	686.5 (7.0)	1372.9 (14.0)	**

†*, ** wheel-tracked values significantly higher than nontracked values at the 0.05 and 0.01 levels, respectively, as determined by Student "t" test for difference between means.

‡There were no significant differences in the weight fraction of soil water between wheel tracked and nontracked soil, or between the two sampling dates.

Nicollet sandy clay loam prior to initial runoff. Thus, random roughness values (Table 2) suggest a potential benefit from wheel-tracked soil after fall tillage, especially for moldboard plowing. Even though fall and winter generally are not critical runoff-erosion periods for this soil, the greater random roughness of wheel tracked soil can persist over winter (Table 2) and offer potential infiltration benefits in the early part of the critical erosion period.

Total porosity of the tilled layer can be significantly reduced by wheel traffic, especially after spring planting.

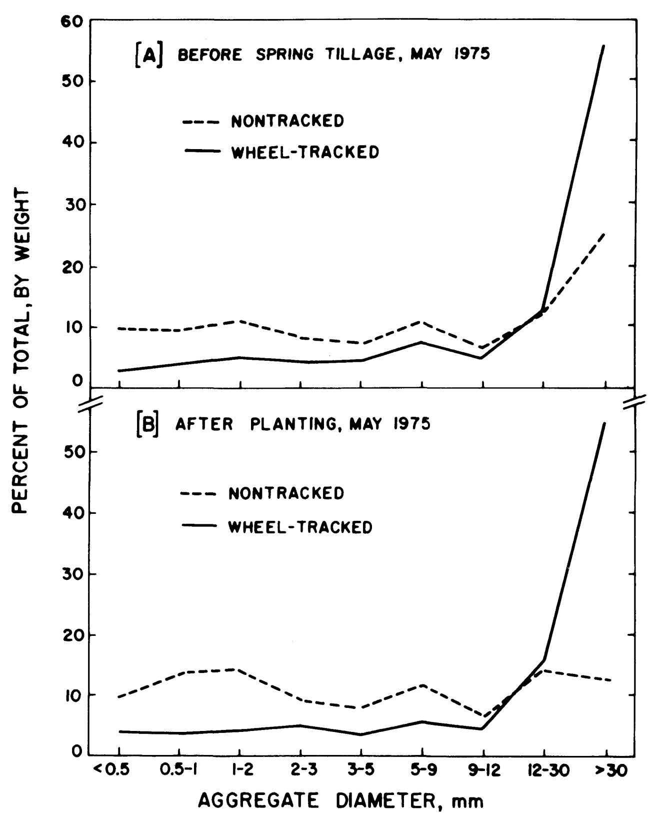

FIG. 1 Aggregate size distribution of a Nicollet silty clay loam as affected by wheel traffic. (A) Measured in May 1975 before spring tillage. (B) Measured in May 1975 after planting.

Then precipitation storage capacity of the tilled layer is reduced. Porosities calculated from bulk density values in Table 1 indicated a reduction of about 40 mm of storage in the upper 300 mm of a Nicollet silty clay loam. In many areas, the most critical erosion period is shortly after planting, the period during which wheel traffic probably most adversely affects infiltration and runoff. Continued packing of the soil by wheel traffic can result in soil water changes in the tilled layer at tillage time

TABLE 2. RANDOM ROUGHNESS OF NICOLLET SILTY CLAY LOAM AS AFFECTED BY WHEEL TRAFFIC, TILLAGE, AND TIME

	Random roughness*			
	Fall plowing		Fall chiseling	
Date of measurement	Non tracked	Wheel tracked	Non tracked	Wheel tracked
	---------- mm ----------			
After planting, May 1975	09.7	12.7	11.2	10.7
After tillage, Oct 1975	24.1	37.3	16.5	18.5
Before secondary tillage, May 1976	20.8	24.6	09.4	09.1
After planting, May 1976	07.6	07.6	11.2	09.1

*Coefficient of variation averaged about 7 percent for all means.

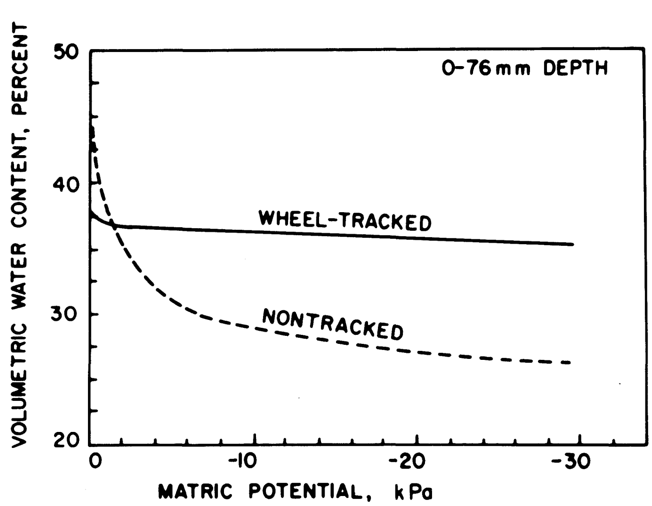

FIG. 2 Water content-potential relationship of Nicollet silty clay loam as affected by wheel traffic.

TABLE 3. CLOD DENSITY AS AFFECTED BY WHEEL TRAFFIC

Date sampled	Clod density		Significance†
	Nontracked	Wheel tracked	
	-------------- Mg/m^3 (g/cm^3) --------------		
After planting, May 1975	1.56	1.72	**
Before fall tillage	1.47	1.73	**
After spring tillage but before planting, May 1976	1.49	1.59	**
Before spring tillage, April 1977	1.38	1.53	**
After planting, May 1977	1.44	1.66	**

†** wheel tracked values significantly higher than nontracked values at the 0.01 level as determined by Student "t" test for difference between means.

which, in turn, can affect how tillage changes random roughness and porosity, in addition to the changes caused directly by the wheel traffic. Allmaras et al. (1967) reported that soil water content at tillage time significantly affected the changes in total porosity and random roughness caused by tillage.

Random roughness is generally associated with a cloddy soil surface. Moldenhauer and Koswara (1968) concluded that if soil clods are large enough (up to 30 mm diameter) or stable enough, runoff can be delayed considerably, allowing more rainfall energy to be adsorbed before runoff begins. The ability of wheel-tracked clods to resist breakdown under the influences of climate and tillage is indicated by higher crushing resistance (Table 1), higher clod density, which can persist overwinter (Table 3), and a relatively large proportion of soil clods larger than 30 mm in diameter (Fig. 1).

Soil resistance to detachment during rainfall is increased by increasing bulk density and matric potential, both of which increase the shearing strength of soil (Cruse and Larson, 1977). Fig. 2 shows the water content-matric potential curves for wheel-tracked and nontracked soil cores for a Nicollet silty clay loam. At a given volumetric water content of less than about 37 percent, the wheel-tracked soil has a higher matric potential than the nontracked soil. This, in addition to higher density, should theoretically allow less soil detachment from raindrop impact. However, at water contents nearer saturation (wetter than about 37 percent) the curves cross, with the nontracked cores having a higher matric potential for a given water content. We do not know if this would offset the effects of lower density with respect to shear strength and soil detachment. The persistence of higher density in wheel-tracked clods (Table 3) suggests that density could be more important than matric potential in resisting soil detachment by raindrop impact.

Soil moisture-potential relationships may also affect erosion by influencing hydraulic conductivity. Blake et al (1976) reported a 65 percent decrease in saturated conductivity due to compaction of a Nicollet clay loam, which resembles the soil reported in Fig. 2, and at similar bulk densities. Near the soil surface (0- to 76-mm depth) wheel traffic caused a 7 percent decrease in volumetric water content at saturation (Fig. 2), and therefore in the total pore volume. This reduction in total pore volume not only reduces the amount of water that can infiltrate soil before runoff begins, but also may reduce hydraulic conductivity at or near saturation causing more runoff. For a matric potential greater than 2 kPa ($\sim$20 cm of water), the wheel-tracked soil has a larger percentage of water-filled pores, which may increase the infiltration rate. Thus, unsaturated conductivity may be increased by wheel traffic. The net result would, of course, depend on degree of compaction, soil water content, and rainfall intensity. The effects on infiltration and water redistribution likely extend throughout the entire depth of the tilled layer and, thus, significantly affect runoff and erosion.

Aggregate-size distribution influences soil erodibility and may be altered by wheel traffic. Young and Mutchler (1977) developed a regression equation that accounted for 93 percent of the variability in the K factor for a wide range of Minnesota soils. Two variables, aggregate index and percent of montmorillonite, explained 75 percent of the variation. Aggregate index was defined as the weight ratio of aggregates 2 to 9 mm in diameter to that of the remaining soil $\leqslant$ 30 mm diameter. But there may be situations where the aggregate index may not be the controlling factor in erosion and runoff. For example, Table 4 shows the aggregate index of a Nicollet silty clay loam as affected by wheel traffic. There was no difference in aggregate index values between wheel-tracked and nontracked soil before spring tillage. Yet land that was wheel tracked prior to fall plowing definitely had a rougher soil surface the following spring and showed evidence of less erosion than the nontracked land (Voorhees, 1977a).

Finally, wheel tracks, even if followed by a secondary tillage operation, often leave a depression in the soil surface which can act as a channel to concentrate the runoff, leading to increased erosion. Fig. 3 shows the range of effects that wheel traffic can have. Standard runoff plots, 6 rows wide, were established on a loam-clay loam site with a 6 to 7 percent slope near Morris, Minnesota. The plots had a history of two spring tillage operations and the planting operation during which all tractor wheel traffic was restricted to the area between certain rows. All operations were done up and

TABLE 4. AGGREGATE INDEX OF NICOLLET SILTY CLAY LOAM AS AFFECTED BY WHEEL TRAFFIC

Date sampled	Aggregate Index*	
	Nontracked	Wheel tracked
Before spring tillage, May 1975	0.54	0.54
After planting, May 1975	0.50	0.45

*Aggregate Index defined as weight of the 2-9 mm aggregates divided by the weight of the remaining $\leqslant$ 30 mm-diameter aggregates (from Young and Mutchler, 1977).

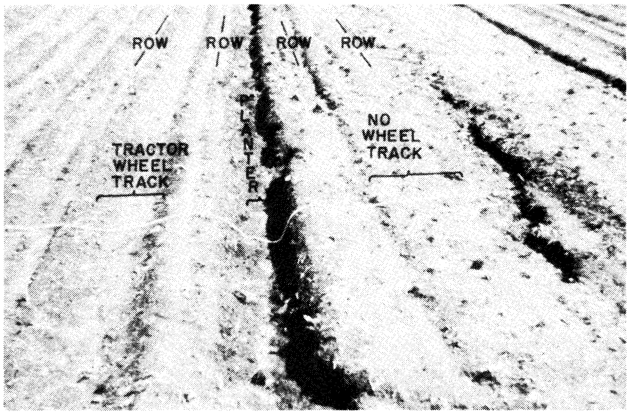

FIG. 3 Runoff and erosion as affected by tractor and planter wheel traffic.

down slope. In addition to the two tractor-wheel traffic lanes on each plot, the wheels on the planter were positioned such so two other interrows on each plot received traffic only from the planter. The two remaining interrows had no wheel traffic at any time. Soybeans were just emerging when about 70 mm of rain fell on the plots within a short period. The noncompacted nontracked interrows absorbed most of the rainfall with minimal runoff and erosion. The interrows compacted by tractor wheel traffic were sufficiently dense and stable to minimize erosion, although runoff was apparently great. The interrows subjected to only planter wheel traffic had high runoff and severe erosion. The single pass of the relatively light-weight planter wheel provided a channel for the concentration of water but it apparently did not compact the soil to the extent of stabilizing it as in the case of the tractor wheel track. Research in progress will quantify these observations of erosion, runoff, and infiltration. These effects may be expected even when wheel tracks are tilled by a subsequent operation, because the compaction by wheel traffic may extend deeper than the tillage depth (Voorhees et al., 1978) and influence infiltration and redistribution of water.

Effects on Wind Erosion

Wheel traffic mainly influences wind erosion by affecting size, density, and stability of individual soil structural units. Lyles and Woodruff (1961) showed that the percentage of clods larger than 6.4 mm in diameter produced by a tillage operation increased as the density of the soil was increased. After planting, the increased bulk density caused by wheel traffic compaction (Table 1) resulted in a 100 percent increase in percentage of clods larger than 5 mm in diameter as compared with areas not subjected to wheel traffic (Fig.1). The wheel tracked clods were also more dense (Table 3) and had a higher mechanical crushing resistance (Table 1). Chepil (1953) reported that resistance of the soil to abrasion by wind-blown sand varied directly with the mechanical stability.

Several criteria are commonly used to specify the cloddiness required to control wind erosion on field soils. One-half to two-thirds of the surface soil by weight should be larger than 0.84 mm in diameter, or 50 percent of the soil surface should be covered with clods larger than 10 mm in diameter (Woodruff et al., 1972). Later data by Lyles et al. (1974) indicated that only 5 percent of the surface area would need to be covered with 10-mm diameter clods if they were uniformly spaced. These criteria are approximate, but soils that meet any of these criteria usually will resist all but the strongest winds. Fig. 1 and Table 5 show that wheel traffic significantly affects both size criteria.

The potential for wind erosion is high when wind speeds are high and there's little vegetative cover (Chepil, 1957). Wheel-induced compaction can reduce plant growth (Voorhees, 1977b). But clods resulting from previously tilled wheel-tracked soil can be beneficial. The **bulk densities of wheel-tracked clods shown in Tables 1 and 3 (visually illustrated by Voorhees, 1977a) reflect** persistance and demonstrate potential effectiveness for reducing wind erosion. Wheel-track effects on soil density and aggregation may be less in the dryer more wind-erosion-susceptible areas in the Great Plains compared to these specific data form Minnesota. In arid regions, the probability of wheel-track soil compaction would be less because mechanical compaction depends strongly on soil water content (Lyles and Woodruff, 1963). Also, the soils most susceptible to wind erosion are coarse textured and are less affected by mechanical compaction forces under dryer conditions.

Soil ridge roughness, the factor K in the wind erosion equation (Woodruff and Siddoway, 1965), influences wind erosion. Soil ridge roughness is roughness from systematic undulations of the soil surface as opposed to roughness caused by soil clods, vegetation, etc. Wheel traffic can cause depressions 50 to 150 mm deeper than adjacent nontracked soil after planting and could help reduce wind erosion 5 to 45 percent, depending on wheel-track depth, spacing, and orientation to the direction of prevailing winds.

Maintaining vegetative cover is the most effective and practical method for controlling wind erosion. Any practice that reduces plant growth or cover increases the wind erosion hazard and requires more careful management.

SUMMARY

The basic erodibility of a soil is related to primary

TABLE 5. FRACTION OF NICOLLET SILTY CLAY LOAM CONSIDERED AS WIND-ERODIBLE (< 1.0 mm DIAMETER)

Date sampled	Percent of soil < 1.0 mm diameter†		
	Nontracked	Wheel tracked	Significance‡
Before spring tillage, May 1975	21.3	14.8	**
After planting, May 1975	26.5	17.5	**

†Total soil sample consisting of ⩽ 30-mm diameter aggregates.
‡** wheel-tracked values significantly higher than nontracked values at the 0.01 level as determined by Student "t" test for differences between means.

particle-size distribution and to stability of the surface structure. These are generally considered as basic soil properties; but wheel traffic can affect their importance, or may even overshadow basic soil properties, and thereby influence water and wind erosion. The researcher must recognize wheel traffic as a factor in erosion research, especially in water erosion research, where a history of wheel traffic is unintentionally, but commonly, imposed in certain areas on small research plots. Soil erosion is influenced since wheel traffic alters those soil structural characteristics related to erodibility. For example, in evaluating a given tillage operation in terms of reducing runoff and erosion, we must recognize that wheel traffic may reduce infiltration but at the same time increase soil structural stability — both of which may differ from that imposed by the tillage operation itself. Thus, an inaccurate evaluation of the tillage method may result. Furthermore, the relative influence of wheel traffic is dynamic with time.

Even though wind erosion research plots, unlike water erosion plots, probably are not subject to a concentration of wheel traffic, the effects of wheel traffic must be recognized. Researchers attempting to produce clods or alter the aggregate-size distribution by certain tillage methods must realize that the wheel traffic can sometimes subtly but significantly, influence their results.

Today's farming practices influence wheel traffic patterns. Irrigators are concerned about runoff from wheel tracks of center pivot systems. The use of herbicides and the trend towards fewer cultivations in row crops extend the influence of wheel tracks from planting operations during the critical spring erosion periods. Therefore, research results must reflect the consideration of wheel traffic.

Wheel traffic can produce both erosion-control benefits and hazards. Because current farming practices require some wheel traffic, we should be aware of its effects and find ways to use the good effects and minimize the bad.

References

1 Allmaras, R. R., R. E. Burwell, W. E. Larson, R. F. Holt and W. W. Nelson. 1966. Total porosity and random roughness of the interrow zone as influenced by tillage. USDA Cons. Res. Rpt. No. 7.

2 Allmaras, R. R., R. E. Burwell and R. F. Holt. 1967. Plow-layer porosity and surface roughness from tillage as affected by initial porosity and soil moisture at tillage time. Soil Sci. Soc. Am. Proc. 31:550-556.

3 Blake, G. R., W. W. Nelson and R. R. Allmaras. 1976. Persistence of subsoil compaction in a Mollisol. Soil Sci. Soc. Am. J. 40:943-948.

4 Burwell, R. E. and W. E. Larson. 1969. Infiltration as influenced by tillage-induced random roughness and pore space. Soil Sci. Soc. Am. Proc. 33:449-452.

5 Chepil, W. S. 1953. Field structure of cultivated soils with special reference to erodibility by wind. Soil Sci. Soc. Am. Proc. 17:185-190.

6 Chepil, W. S. 1957. Erosion of soil by wind. Yearb. of Agr. pp. 308-314.

7 Cruse, R. M. and W. E. Larson. 1977. Effect of soil shear strength on soil detachment due to raindrop impact. Soil Sci. Soc. Am. J. 41:777-781.

8 Krumbach, A. W., Jr. and D. P. White. 1964. Moisture, pore space, and bulk density changes in frozen soil. Soil Sci. Soc. Am. Proc. 28:442-425.

9 Kucera, H. L. and W. J. Promersberger. 1960 Soil compaction . . . A North Dakota problem? North Dakota Bi-monthly Res. Bull. 21:7, Sept.-Oct.

10 Lyles, Leon and N. P. Woodruff. 1961. Surface soil cloddiness in relation to soil density at time of tillage. Soil Science 91(3):178-182.

11 Lyles, Leon and N. P. Woodruff. 1963. Effects of moisture and soil packers on consolidation and cloddimess of soil. TRANSACTIONS of the ASAE 6(4):273-275.

12 Lyles, Leon, R. L. Schrandt and N. F. Schmeidler. 1974. How aerodynamic roughness elements control sand movement. TRANSACTIONS of the ASAE 17(1):134-139.

13 Moldenhauer, W. C. and J. Koswara. 1968. Effect of initial clod size on characteristics of splash and wash erosion. Soil Sci. Soc. Am. Proc. 32:875-879.

14 Phillips, R. E. and D. Kirkham. 1962. Soil compaction in the field and corn growth. Agron. J. 54:29-34.

15 Voorhees, W. B. 1977a. Soil compaction: Our newest natural resource. Crops Soils 29(5):13-15.

16 Voorhees, W. B. 1977b. Soil compaction: How it influences moisture, temperature, yield, root growth. Crops Soils 29(6):7-10.

17 Voorhees, W. B., C. G. Senst and W. W. Nelson. 1978. Compaction and soil structure modification by wheel traffic in the Northern Corn Belt. Soil Sci. Soc. Am. J. 42:344-349.

18 Wischmeier, W. H. and J. V. Mannering. 1969. Relation of soil properties to its erodibility. Soil Sci. Soc. Am. Proc. 33:131-137.

19 Wischmeier, W. H. and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains—A guide for selection of practices for soil and water conservation. Agr. Handb. No. 282, USDA.

20 Wittsell, L. E. and J. A. Hobbs. 1965. Soil compaction effects on field plant growth. Agron. J. 57:534-537.

21 Woodruff, N. P. and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29:602-608.

22 Woodruff, N. P., Leon Lyles, F. H. Siddoway and D. W. Fryrear. 1972. How to control wind erosion. U. S. Dept. of Agr. AIB No. 354, 22 pp.

23 Young, R. A. and C. K. Mutchler. 1977. Erodibility of some Minnesota soils. J. Soil Water Conserv. 32:180-182.