Soil Wind Erodibility Index in Seven North Central States

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ABSTRACT

MULTIPLE regression equations were developed to estimate the wind erodibility index — percent dry aggregates > 0.84 mm in diameter — in Iowa, Kansas, Michigan, Minnesota, North Dakota, Ohio, and South Dakota following fall tillage and again before spring tillage. Significant variables affecting the fall index were soil texture (sand, silt, clay), organic matter, exchangeable calcium, location, and kind of tillage management. Most of these variables plus cumulative precipitation (between fall and spring) and the fall index affected the spring index. The kind of crop did not influence either index. With noted exceptions, the derived soil erodibility factors (I), which appear in the wind erosion equation, were within about 25% of those assigned by the Soil Conservation Service to the soils studied. The fall regression equation may be useful for estimating aggregate size distribution following tillage, a parameter needed for the new wind erosion prediction system (WEPS), now under development by the Agricultural Research Service.

INTRODUCTION

The percentage of aggregates (clods) > 0.84 mm in diameter is the simplest criterion for estimating erodibility of soil by wind (Chepil, 1958). On bare unprotected soil, about 80% aggregates > 0.84 mm are needed for erosion to approach zero in standard wind tunnel tests, where the friction velocity (a common measure of the winds capability to erode soil) is about 61 cm/s (Chepil, 1958).

Surface soil aggregation is transient and depends on numerous soil, climatic, and mechanical factors (Lyles et al., 1969). Important soil factors are texture, organic matter, density, water content, exchangeable calcium, and cementing agents. Climatic factors are rainfall intensity and duration, freezing (especially freeze drying), and thawing. Mechanical factors include type of tillage implement, depth, and speed of tillage (Woodruff et al., 1957; Lyles and Woodruff, 1962). Also, kind of crop or cropping sequence influences surface aggregation (Armbrust et al., 1982; Skidmore et al., 1986).

We determined the wind erodibility index (% aggregates > 0.84 mm) in the fall and spring and attempted to relate it to soil properties, climate, crop, and tillage for seven north central states.

METHODS

State Agronomists for the USDA, Soil Conservation Service (SCS) in Iowa, Kansas, Michigan, Minnesota, North Dakota, Ohio, and South Dakota selected the soils, crop sequences, and tillage managements of special interest to them. Field sites were established in several counties where data were collected by the local SCS District Conservationist (Table 1).

Fall tillage managements included chisels, tandem or offset disks, moldboard plows, sweeps, and no tillage.

Air dry (with some exceptions) surface soil samples were taken with a square-cornered spade from the 0 to 2.5 cm depth within a 10 m designated circle following fall tillage (if any) and again before spring tillage. Each sample was about 0.9 kg. The percent of aggregates > 0.84 mm was determined by hand sieving these samples using a single 20 cm flat sieve shaken about 50 times.

TABLE 1. LOCATION OF SOIL SIEVING SITES AND OTHER SITE INFORMATION IN SEVEN NORTH CENTRAL STATES

Location State	County	Sampling period years	Test sites number	Soil series number	Crop sequence*
IA	Humboldt	1978-84	8	1	C-SB
	Monona	1978-83	8	1	C-SB
	O'Brien	1979-85	8	1	C-SB
	Pocahontas	1978-83	8	1	C-SB
KS	Finney	1980-85	5	5	C-S-W; C-C-C; W-W-W
	Grant	1980-85	4	4	C-C-C; S-S-S
	Haskell	1980-85	5	5	C-C-C
	Kearny	1980-85	4	4	C-C-C; W-W-W
	Stevens	1980-85	6	5	C-S-W-F (combinations)
MI	Bay	1980-84	8	4	C-DB; P-SB-C
	Lapeer	1980-82	5	3	Carrots; Celery
	Tuscola	1980-85	4	2	W-C-DB-B
MN	Pennington	1979-81	4	1	W-SF
	Polk	1979-82	21	2	W-W-B; W-W-SF
ND	McHenry	1979-82	2	1	W-F
	Ramsey	1979-82	6	3	W-W-F
	Renville	1979-81	8	2	W-W-F
OH	Allen	1981-85	3	1	C-SB-W
	Auglaize	1980-84	4	1	C-SB
	Hancock	1980-84	4	1	C-SB-W
	Lucas	1980-84	2	1	C-SB
	Paulding	1980-84	3	1	C-SB-W
SD	Beadle	1979-82	4	1	C-W
	Bennett	1979-82	4	1	W-F
	Lyman	1980-82	6	1	W-F
	Spink	1979-82	4	1	C-O
			148	54	

* C (corn), SB (soybeans), S (grain sorghum), W (wheat), F (fallow), DB (dry beans), P (potatoes), B (sugar beets), SF (sunflowers), O (oats)

Article was submitted for publication in October, 1987; reviewed and approved for publication by the Soil and Water Div. of ASAE in June, 1988.

Contribution from the USDA-ARS, in cooperation with the Department of Agronomy. Kansas Agricultural Experiment Station contribution number 88-98-J.

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Samples collected at the no-tillage sites were sieved at about the same time. Six separate sievings were performed at each site for the two sampling dates (generally from mid October to early December in the fall and from late March through May in the spring).

Additional (one-time) reference soil samples (0 to 2.5 cm and 2.5 to 15 cm depth increments) were collected from each test site within the same 10 m circle during the spring of the first sampling season (fall to spring). The samples were air dried and sieved through a 2 mm sieve. Organic matter and exchangeable calcium were determined from these samples by the Kansas State University Soil Testing Laboratory. Soil texture (sand, silt, and clay) was determined using dispersal by a sonicator, then separating sand sizes by washing through a 50 μm sieve. Centrifugation was used to remove clays, and clay content was determined by subtracting the sand and silt percentage from 100%.

Precipitation and air temperature data were taken from the weather station nearest each test site. Longitude and latitude were determined near the center of each county.

Organic matter (%), exchangeable calcium (cmol/kg), sand (%), silt (%), clay (%), longitude (°), latitude (°), adjustments for tillage and crop, interactions, and other selected variables were correlated with fall aggregates (A_f) > 0.84 mm (average of six sievings), using stepwise multiple regression techniques, in which the variables were entered according to their contribution to the variance. Those variables plus cumulative precipitation (cm) and average air temperature (°C) during the fall-spring period were correlated with spring aggregates (A_s) > 0.84 mm, using the same regression procedures. For the spring aggregate correlations, fall aggregates were both included and omitted as an independent variable.

To account for possible differences in the erodibility index (A_f or A_s) because of tillage implement and crop, we determined adjustments for each by subtracting the overall mean from the individual tillage or crop mean for both fall and spring aggregates (Table 2). These were used as independent variables in the regression analyses. Because the crop adjustment was never selected in the best six variables (as will be discussed later), it was not included in Table 2.

RESULTS AND DISCUSSION

Fall Aggregates

The best six-variable regression equation for estimating fall aggregates (A_f) > 0.84 mm with the terms appearing according to their contribution to the variance was:

$$A_f = 0.4329(Si) + 0.0089(TF)(Si) + 2.24 \times 10^{-3}(S)(C)(CA) - 3.69 \times 10^{-5}(LT)(LG)(OM) - 4.920(CA/OM) + 11.1329(C)^{0.5} - 3{,}0037; \qquad R^2 = 0.756 \quad \ldots\ldots [1]$$

where Si is silt content (%), TF is fall tillage adjustment (percentage points), S is sand content (%), C is clay content (%), CA is exchangeable calcium (cmol/kg), LT is latitude (°), LG is longitude (°), and OM is organic matter (%).

All the independent variables, except the fall adjustment for crop, appear in equation [1]. Because about 25% of the variance in A_f is unexplained and most variables appear in "interaction" terms, it is best not to speculate about causes or effects of individual variables. About the only unambiguous statements concerning individual variables in equation [1] involve clay content and the fall adjustment for tillage. Increasing amounts of clay increase A_f. Except for the moldboard plow, the fall adjustment for tillage is negative (Table 2). Therefore, fall tillage with other implements will reduce the estimate for A_f (holding silt constant). The effects of other variables on A_f are not clear. For example, it appears that increasing sand content will result in increasing A_f in equation [1], an unlikely effect. However, sandier soils must be lower in clay or silt and are commonly associated with lower organic matter. Consequently, increasing sand content usually gives decreasing values for A_f, as expected.

Of course, we would prefer a higher R^2 for estimating fall aggregates > 0.84 mm. At many sites, there was variation in A_f between years. The only variables measured (identified) to account for these year-to-year differences were kind of crop and kind of tillage (in a few cases). Soil variables were assumed constant at each site over the test period. The crop adjustment was not selected among the six best variable terms; so other variables not measured must account for the between-year variation. Probably the two most important variables not measured were soil water content and soil bulk density at time of tillage (Lyles and Woodruff, 1961; Lyles and Woodruff, 1962).

We studied the residuals (differences between the measured and predicted values) for each county and

TABLE 2. ADJUSTMENTS FOR VARIOUS TILLAGE MANAGEMENTS, USED AS INDEPENDENT VARIABLES IN THE REGRESSION ANALYSES

Tillage	$\bar{A}_f$ %>0.84	n	$\bar{A}_f-\bar{\bar{A}}_f$* Percentage points	$\bar{A}_s$ %>0.84	n	$\bar{A}_s-\bar{\bar{A}}_s$† Percentage points
Chisel	54.6	54	− 0.8	36.3	54	− 3.7
Disk	53.8	71	− 1.6	34.5	71	− 5.5
Mold, Plow	87.4	47	+32.0	64.2	47	+24.2
No-Till	47.1	96	− 8.3	37.4	74	− 2.6
Sweep	26.6	19	−28.8	21.2	19	−18.8
$\bar{\bar{A}}_f$=	55.4		$\bar{\bar{A}}_s$=	40.0		

* Fall adjustment
† Spring adjustment

TABLE 3. SOIL ERODIBILITY FACTORS DERIVED IN THIS STUDY (I_1) COMPARED TO THOSE ASSIGNED BY THE SOIL CONSERVATION SERVICE (I_2) ACCORDING TO WIND ERODIBILITY GROUP (WEG)

	Iowa			Kansas			Michigan			Minnesota		
WEG	I_1	I_2	I_1/I_2	I_1	I_2	I_1/I_2	I_1	I_2	I_1/I_2	I_1	I_2	I_1/I_2
	t/(ha·year)		—	t/(ha·year)		—	t/(ha·year)		—	t/(ha·year)		—
1							511	695	0.74			
2				388	300	1.29	336	300	1.12			
3				217	193	1.12						
4	148	193	0.77							191	193	0.99
4L				157	193	0.81						
5							179	126	1.42			
6	83	108	0.77	130	108	1.20				164	108	1.52
7	69	85	0.81									

	N. Dakota			Ohio			S. Dakota			Weighted average		
WEG	I_1	I_2	I_1/I_2	I_1	I_2	I_1/I_2	I_1	I_2	I_1/I_2	I_1	I_2	I_1/I_2
	t/(ha·year)		—	t/(ha·year)		—	t/(ha·year)		—			
1	634	695	0.91							547	695	0.79
2										363	300	1.21
3							296	193	1.53	235	193	1.22
4				0	193	0	273	193	1.41	157	193	0.81
4L	226	193	1.17							202	193	1.05
5										179	126	1.42
6				13	108	0.12	244	108	2.26	123	108	1.14
7				0	85	0				58	85	0.68

state, but no strong patterns of deviation appeared, except that equation [1] always under-predicted A_f in Auglaize County, OH, and significantly over-predicted A_f in Kearny County, KS, and Spink County, SD.

Equation [1] could be used for generating fall soil erodibility factors (I) for use in the wind erosion equation by crop stage periods (Woodruff and Siddoway, 1965; Bondy et al., 1980). Also, equation [1] may be useful in estimating aggregate size distribution following tillage for the new wind erosion prediction system (WEPS), now under development by the Agricultural Research Service.

Spring Aggregates

The best six-variable regression equation for estimating spring aggregates (A_s) > 0.84 mm and including A_f as an independent variable (again arranged according to contribution to the variance) was:

$$A_s = 2.8074\,A_f - 0.0516(A_f)(LT) + 0.0031(Si)(OM)(P)$$

$$+ 0.0014(Si)(CA)(P) - 6.02 \times 10^{-4}(S)(C)(P)$$

$$- 4.680(CA/S) + 0.9071; \qquad R^2 = 0.783 \;\ldots\ldots [2]$$

where the new variable is cumulative precipitation, P (cm), between the fall and spring sampling. A corresponding equation excluding fall aggregates is:

$$A_s = 0.0399(Si)(P) - 0.0266(P)(1.8T + 32)$$

$$+ 0.0148(TS)(Si) + 0.0383(C)(1.8T + 32)$$

$$- 8.67 \times 10^{-4}(TS)(S)(P) - 2.1972(C/S) + 8.1236;$$

$$R^2 = 0.713 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots [3]$$

where the new variables are average air temperature, T (°C), between fall and spring sampling and spring tillage adjustment, TS (percentage points).

Again, it is best not to speculate about effects of individual variables on A_s, especially those in interaction terms. The first two terms in equation [2] indicate that sites with larger amounts of fall aggregates > 0.84 mm are expected to have larger amounts of spring aggregates > 0.84 mm. Those first two terms account for about 72% of the variance in A_s. The second term in equation [2] shows that the importance of fall aggregates on the expected amounts of spring aggregates diminishes at more northerly latitudes. The effect of cumulative precipitation on A_s in equation [2] may be positive or negative, depending on soil texture, organic matter, and exchangeable calcium. Note that neither tillage nor crop adjustment was among the variables in equation [2].

If no data on fall aggregates are available, then equation [3] would be used to estimate spring aggregates. About 53% of the variance in A_s is accounted for by the silt x cumulative precipitation interaction—the first term in equation [3]. Organic matter, exchangeable calcium, and the crop adjustment were not selected among the best six variables in equation [3]. Thus, the crop adjustment does not appear in any of the equations. Apparently in this study, the kind of crop or crop sequence had little consistent effect on the fall or spring aggregates > 0.84 mm, i.e. the wind erodibility index.

Equations [2] or [3] could be used for generating I-factors in the wind erosion equation (Woodruff and Siddoway, 1965) on the basis of tillage tool for sites that have not been tilled before spring, following tillage or no-tillage in the fall. They may have limited value for estimating aggregate size distribution in the spring for

TABLE 4. WIND ERODIBILITY GROUPS (WEG) AS RELATED TO SOIL TEXTURAL CLASS AND CALCIUM STATUS

WEG	Predominant soil texture class of surface layer	Dry soil aggregates > 0.84 mm	Soil erodibility factor (I)
		%	t/(ha·year)
1	Very fine sand, fine sand, sand, or coarse sand.	1	695
2	Loamy very fine sand, loamy fine sand, loamy sand, loamy coarse sand, or sapric organic soil materials.	10	300
3	Very fine sandy loam, fine sandy loam, sandy loam, or coarse sandy loam.	25	193
4	Clay, silty clay, noncalcareous clay loam, or silty clay loam with more than 35% clay.	25	193
4L	Calcareous loam and silt loam, or calcareous clay loam and silty clay loam.	25	193
5	Noncalcareous loam and silt loam with less than 20% clay; or sandy clay loam, sandy clay, and hemic organic soil materials.	40	126
6	Noncalcareous loam and silt loam with more than 20% clay or noncalcareous clay loam with less than 35% clay.	45	108
7	Silt, noncalcareous silty clay loam with less than 35% clay and fibric organic soil material.	50	85
8	Soils not susceptible to wind erosion because of coarse fragments or wetness.	–	–

use in the WEPS model, which will be available in the near future.

Soil Erodibility

The soil erodibility factor (I), a major factor in the wind erosion equation, is defined as the potential soil loss in tons per hectare per annum from a wide, unsheltered, isolated field with a bare, smooth, noncrusted surface based on long-term climatic conditions near Garden City, KS (Woodruff and Siddoway, 1965). Although data on aggregates > 0.84 mm during the "critical" erosion period are needed for many years to estimate I-factors, we obtained an I-factor for each spring aggregate observation from a table (Table 1) given by Woodruff and Siddoway (1965), then averaged them across wind erodibility groups (WEG's) by states (Table 3). Soils were assigned to WEG's according to soil texture and calcium status (Table 4).

The fine-textured soils in Ohio appear much less erodible than the WEG assigned to them. An I-factor of zero indicates that the soil contains so many nonerodible aggregates in the spring that no wind erosion is expected. The opposite applies to the South Dakota soils, in which more erodible-size aggregates were present than indicated by the assigned WEG. Except for the WEG-5 soils in Michigan and the WEG-6 soils in Minnesota, soils in the other states were within about 25% of the assigned I-factors for the WEG's. These data illustrate the marked variability in spring aggregates > 0.84 mm across fall tillage managements, soils, and space. They suggest possible adjustments to assigned WEG's may be needed if factors other than texture and calcium status are considered.

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