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Possible effects of wind erosion on soil productivity

LEON LYLES

ABSTRACT—I propose a procedure for evaluating the effects of wind erosion on soil loss and subsequent crop yields. The procedure uses the wind erosion equation to predict potential annual soil loss, which is converted to the crop yield reduction per inch of erosion for corn, grain sorghum, and wheat. When applied in 13 southwestern Kansas counties, the procedure resulted in estimated annual yield reductions of 339,000 bushels of wheat and 543,000 bushels of grain sorghum on 1.2 million acres of sandy surface soils.

IN nonirrigated agriculture, soil productivity expressed in terms of crop yield per unit area represents an integrated response to numerous soil variables, climatic conditions, management practices, and such hazards as disease, insects, and hail. More specific variables influencing productivity include crop varieties and rotations, planting data, type and dates of tillage, rainfall amounts and distribution, fertilizer rates, slope, rooting depth, soil texture, and erosion.

After studying 41 years of data on grain sorghum yields in 29 counties of western Kansas, Wearden and Orazem (*29*) found that 73 percent of the variance in yield was due to years, about 50 percent of which could be attributed to annual differences in rainfall. Even though crop yields depend on numerous variables, the influence of single variables often concerns individuals, groups, or agencies.

The loss of soil productivity because of wind erosion is included among all those variables mentioned, and concrete data are needed to separate or isolate its influence on crop yields from that of the other variables.

Effects of Wind Erosion on Soils

Qualitative Effects

Wind acts on many soils like a fanning mill on grain, removing the finer fractions and leaving the coarser ones behind (*27, 15, 20, 8, 5*). Silt and clay fractions are removed first, leaving the coarser sand and gravel. This sorting action over many years makes soils progressively coarser until nothing remains but infertile skeletal material forming shifting sand dunes and gravelly pavements.[1]

Soils developed from glacial till, residual material, mountain outwash, and sandy materials of various origins are especially susceptible to sorting. Sometimes wind erosion essentially removes the surface soil. Such nonselective removal by wind is associated with loess soils that were sorted and deposited from the atmosphere during past geologic eras.

Chepil (*4*) reported that a Canadian loamy sand under virgin conditions lost virtually all its silt and clay in less than 60 years. He also noted that sandy loams, which had gained about 15 percent sand in the top 4 inches during the same time, would become sand dunes within 150 years of cultivation (assuming no change in cultural practices).

Loss of plant nutrients and organic matter (*9*) and changes in soil texture resulting from wind erosion (*7, 8*) imply lower productivity but do not provide quantitative information.

Contrasting two studies made in 1936 and 1947 on 2.35 million acres in 7 counties in the heart of the Dust Bowl, Finnell (*14*) concluded that wind erosion was ruining cultivated land (as evidenced by abandonment) as follows: 1 in 40 acres of class II land, 4 in 40 acres of class III land, and 7 in 40 acres of class IV land every 22 years. Extrapolation of such data indicates that all class II, III, and IV land in that area would be abandoned in 880, 293, and 126 years, respectively. Abandonment probably would mean reversion to rangeland.

Other qualitative statements about wind erosion and soil productivity appear in the literature: Finnell (*13*) wrote, "The blowing off of just a few inches has reduced the productivity of even the best Plains soils as much as 40 percent. In some areas where severe wind erosion has occurred, the productivity of the land has been cut down 60 percent or more, and 80 percent of the affected land abandoned." Hopkins and colleagues (*18*) reported that in some regions of the Canadian Prairie Provinces, where 2 or more inches of topsoil had been lost, crop yields for many succeeding years were much lower than before.

Quantitative Effects

Only limited information is available on the rate of decline in soil productivity caused by wind erosion. Stallings (*26*) reported that wind erosion in the Great Plains reduced wheat yields 4.2 bushels per acre in 30 years. From that data, the rate of loss—assuming a linear relationship—would be 0.14 bushel per acre per year. If the wheat yield for 9 Great Plains States (Colorado, Kansas, Montana, Nebraska, North Dakota, Oklahoma, South Dakota, Texas, and Wyoming) is 14.6 bushels per acre (45-year average, 1928-1972), the 0.14 bushel per acre per year loss due to wind erosion represents about 1 percent of the average wheat yield.

The coefficient of variation for long-term wheat yield averages 62 percent for Ford, Finney, and Greeley Counties in western Kansas; 50 percent for Woodward County in Oklahoma; and 37 percent for the Province of Saskatchewan in Canada. The coefficient for grain sorghum is 52 percent for the 3 western Kansas counties and 69 percent for the Dalhart, Texas, region. Apparently it is futile to try to isolate a variable like wind erosion (using long-term yield as the indicator), the effect of which is expected to be less than 10 percent of the mean.

Leon Lyles is an agricultural engineer with the Agricultural Research Service, U. S. Department of Agriculture, Manhattan, Kansas 66506. This article is a contribution from ARS in cooperation with the Kansas Agricultural Experiment Station. Department of Agronomy Contribution No. 1466.

[1] Chepil, W. S. 1962. "Mechanics of wind erosion and significance as a sediment source." Presented at ARS-SCS Sedimentation Workshop, Panguitch, Utah, September 11-14.

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However, one might determine the effects of wind erosion on crop production by relating topsoil thickness or topsoil removed (excluding the effect of fertilizer) to crop yield at several locations in the Great Plains, then computing the potential average annual soil loss using the wind erosion equation [$E = f(I, K, C, L, V)$, where E is the potential annual soil loss rate, I is the soil erodibility, K is the soil ridge roughness factor, C is the climatic factor, L is the unsheltered distance across a field along the prevailing wind erosion direction, and V is the equivalent vegetative cover] (*31*). By converting annual soil loss to inches of soil removed, the corresponding loss in crop yield could be estimated.

Table 1. Effect of topsoil thickness on wheat yields.

Location	*Yield Reduction per Inch of Topsoil*[a] *(bu/a)*	*Yield Reduction per Inch of Topsoil*[a] *(%)*	*Remarks*
Wooster, Ohio	1.7	9.5	virgin soil
Columbus, Ohio	1.3	5.3	cropped soil
Oregon	1.0	2.2	deep soil
Oregon	2.5	5.8	thin soil
Oregon	2.0	6.4	thin soil
Wooster, Ohio	1.5	6.2	
Geary County, Kansas	1.3	6.2	
Palouse Area, Washington	1.6	6.9	loss of top 5 inches
Palouse Area, Washington	1.8	5.3	loss of top 11 inches
Pullman, Washington	1.4	2.9	
Manhattan, Kansas	1.1	4.3	Smolan silty clay loam
Akron, Colorado	0.5	2.0	Weld silt loam
Average	1.5	5.3	
S =	0.5	2.1	

[a] Data sources: (*1, 2, 19, 25, 28*).

Table 2. Effect of topsoil thickness on corn yields.

Location	*Yield Reduction per Inch of Topsoil*[a] *(bu/a)*	*Yield Reduction per Inch of Topsoil*[a] *(%)*	*Remarks*
Geary County, Kansas	3.5	7.5	
Bethany, Missouri	3.0	6.4	Shelby and Grundy silt loams
Bethany, Missouri	4.0	6.0	Shelby and Grundy silt loams
Fowler, Indiana	4.0	4.3	Fowler, Brookston, and Parr silt loams
Fowler, Indiana	3.8	5.5	
Shenandoah, Iowa	6.1	5.1	Marshall silt loam
Greenfield, Iowa	3.2	5.0	Tama silt loam
Greenfield, Iowa	3.1	6.3	Shelby silt loam
Coshocton, Ohio	5.2	8.7	
Clarinda, Iowa	4.0	5.1	Marshall silt loam
Upham, North Dakota	3.4	7.4	
Wooster, Ohio	4.8	8.0	Canfield silt loam
Columbus, Ohio	3.0	6.0	Celina silt loam
East Central, Illinois	3.7	6.5	Swygert silt loam
Average	3.9	6.3	
S =	0.9	1.3	

[a] Data sources: (*1, 3, 12, 21, 25, 28*).

Table 3. Effect of topsoil thickness on grain sorghum yields.

Location	*Yield Reduction per Inch of Topsoil*[a] *(bu/a)*	*Yield Reduction per Inch of Topsoil*[a] *(%)*	*Remarks*
Bushland, Texas (irrigated)	3.0	5.2	Pullman silty clay loam
Bushland, Texas (pre-irrigation only)	2.0	4.1	Pullman silty clay loam
Temple, Texas (non-irrigated)	2.1	5.7	Austin clay
Average	2.4	5.0	

[a] Data sources: (*10, 11, 24*).

I converted published data on soil thickness and crop yields to yield reductions in bushels per acre per inch of topsoil thickness and to percentage reductions in yield per inch of topsoil thickness (Tables 1, 2, 3). These data assume a linear relationship between soil thickness and crop yield, although soil in the top 4 to 6 inches (the plow layer) may be more productive than that at lower depths.

Factors in the wind erosion equation involved various assumptions. Because the equation was solved by computer, I used the percentage of dry aggregates greater than 0.84 millimeter (mm) in diameter in lieu of the I values for each of the wind erodibility groups (Table 4). The soil ridge roughness factor, K, was taken as 0.75 for all soils since this value is midway between 0.5 (rough surface) and 1.0 (smooth surface). For the monthly climatic factor, C (*22*), I averaged March, April, and May (months generally with high erosion susceptibility) data at 20 locations in the Great Plains and 1 location in Iowa. I estimated the unsheltered distance across a field along the prevailing wind erosion direction, L, as 2,640 feet. The preponderance of wind erosion forces in prevailing wind erosion direction was averaged for the same 3 months as the climatic factor (*22*).

Determining the equivalent vegetative cover, V, in March after a fallow season required several estimates. The assumptions for wheat were 40 percent overwinter residue loss (sum of two winters); 50 percent reduction by tillage operations (*30*); 150 pounds per acre of growing wheat, equivalent to 300 pounds per acre of flat, small grain residue (*17*); and 115 pounds of straw for each bushel of wheat. Similar assumptions for grain sorghum were 32 percent of the original stubble after harvest remaining at wheat seeding (*16*), 20 percent overwinter loss, same small grain equivalent for growing wheat, and 1 pound of stubble for each pound of grain yield at harvest. Table 5 presents data on the average grain yield and computed stubble and the amounts of equivalent small grain residue for 9 Great Plains States.

I used these V values in the wind erosion equation for selected sites in various states to compute the annual soil loss rate, E, which was converted to depth of soil loss per year (Tables 6 and 7). Potential wind erosion increases as sand content increases. The potential generally increases also from the Northern to the Southern Great Plains along lines of similar longitude. Of the selected sites, Dalhart, Texas, near the heart of the Dust Bowl, has the highest potential for soil loss by wind. Chepil and his associates (*6*) reported that, based on depth to a lime layer, 9 inches of topsoil were removed in 19 years (1930-1949) from calcareous silt loam soils in Greeley County, Kansas. Such a loss — 0.47 inch per year — seems high compared with estimates of 0.19 to 0.32 inch per year at Dodge City, Kansas (from WEG-4L soil, Tables 6 and 7).

Soil deposition is not considered a renewal process. Chepil noted 0.5 inch of aeolian deposition on grass during a 10-year period (1946-1956) in southwestern Kansas.[2] In contrast, Smith and his colleagues (*23*) measured 0.015 inch per year in dustfall catchers at Tribune, Kansas (1964-1966). If precise data on soil loss and crop yields as a function of soil depth become available, deposition may need to be considered.

Average potential soil loss was about the same for similar soils (wind erodibility groups) in the Northern Plains States (North Dakota, South Dakota, Montana, Wyoming, and Nebraska), western Kansas, and west Texas. Consequently, I averaged soil losses for sites in the three areas, then converted the results to annual reductions in wheat yield (based on data in Table 1) under two kinds of residue management (Table 8). Because of the wind erosion hazard, probably small amounts of the dryland soils in WEG-1 are cultivated in the Great Plains, especially the Southern Plains.

Averaging across residue management and considering WEG-2, annual wheat yield reductions would be 0.24 bushel per acre in the Northern Plains, 0.62 bushel per acre in western Kansas, and 0.96 bushel per acre in west Texas—1.5, 3.8, and 9.4 percent of average yields, respectively. Corresponding values for WEG-6 are 0.06 bushel per acre (0.4 percent), 0.16 bushel per acre (1.0 percent),

Table 4. Descriptions of wind erodibility groups (WEG).[a]

WEG	*Predominant Soil Textural Class*	*Dry Soil Aggregates Greater than 0.84 mm (%)*	*Soil Erodibility "I" (t/a/yr)*
1	Very fine, fine, and medium sands; dune sands	1	310
2	Loamy sands; loamy fine sands	10	134
3	Very fine sandy loams; fine sandy loams; sandy loams	25	86
4	Clays, silty clays; noncalcareous clay loams and silty clay loams with more than 35 percent clay content	25	86
4L	Calcareous loams and silt loams; calcareous clay loams and silty clay loams with less than 35 percent clay content	25	86
5	Noncalcareous loams and silty loams with less than 20 percent clay content; sandy clay loams; sandy clay	40	56
6	Noncalcareous loams and silt loams with more than 20 percent clay content; noncalcareous clay loams with less than 35 percent clay content	45	48
7	Silts; noncalcareous silty clay loams with less than 35 percent clay content	50	38

[a] Data source: (*17*).

Table 5. Average grain and stubble yields (1928-1972) and equivalent small grain residue in March for several Great Plains states.

	Wheat			*Grain Sorghum*		
State	*Grain (bu/a)*	*Straw (lb/a)*	*Equivalent Small Grain in March (lb/a)*	*Grain (bu/a)*	*Stubble (lb/a)*	*Equivalent Small Grain in March (lb/a)*
North Dakota	14.9	1,725	850	—	—	—
South Dakota	12.5	1,450	765	20.8	1,175	425
Nebraska	19.2	2,200	1,005	29.4	1,650	500
Kansas	16.1	1,850	890	24.2	1,350	475
Oklahoma	13.8	1,575	805	19.1	1,075	400
Texas	10.2	1,175	675	27.7	1,550	500
Montana	16.2	1,875	900	—	—	—
Wyoming	15.5	1,775	870	—	—	—
Colorado	13.3	1,525	635	18.8	1,050	400
Average	14.6	1,685	820	23.3	1,310	450

Table 6. Average potential annual soil loss for different wind erodibility groups at 20 locations in the Great Plains: wheat culture.

	Wind Erodibility Groups (WEG)[a]					
Location	*1*	*2*	*3, 4, 4L*	*5*	*6*	*7*
			in/yr			
Bismarck, North Dakota	0.31	0.10	0.05	0.03	0.02	0.02
Minot, North Dakota	0.14	0.05	0.02	0.01	0.01	0.01
Rapid City, South Dakota	0.38	0.13	0.07	0.04	0.03	0.02
North Platte, Nebraska	0.33	0.10	0.05	0.02	0.02	0.01
Scottsbluff, Nebraska	0.31	0.10	0.05	0.02	0.02	0.01
Dodge City, Kansas	1.11	0.36	0.19	0.10	0.08	0.05
Goodland, Kansas	0.73	0.23	0.12	0.07	0.05	0.04
Wichita, Kansas	0.20	0.07	0.03	0.02	0.01	0.01
Oklahoma City, Oklahoma	0.21	0.07	0.04	0.02	0.02	0.01
Amarillo, Texas	1.43	0.51	0.29	0.16	0.13	0.10
Dalhart, Texas	2.09	0.74	0.41	0.23	0.18	0.13
Lubbock, Texas	1.43	0.51	0.29	0.16	0.13	0.10
Midland, Texas	1.35	0.47	0.27	0.15	0.12	0.09
Wichita Falls, Texas	0.40	0.14	0.08	0.04	0.03	0.02
Glasgow, Montana	0.15	0.05	0.02	0.01	0.01	0.01
Lewistown, Montana	0.27	0.08	0.04	0.02	0.02	0.01
Miles City, Montana	0.32	0.10	0.05	0.03	0.02	0.01
Cheyenne, Wyoming	0.39	0.13	0.07	0.04	0.03	0.02
Sheridan, Wyoming	0.19	0.06	0.03	0.02	0.01	0.01
La Junta, Colorado	1.32	0.47	0.27	0.16	0.12	0.10
Des Moines, Iowa[b]	0.11	0.04	0.02	0.01	0.01	0.01

[a] See table 4 for descriptions of wind erodibility groups.
[b] Not in Great Plains; V = 650 pounds per acre of corn stubble.

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[2] Ibid.

and 0.25 bushel per acre (2.5 percent), respectively.

Applying the Procedure in Kansas

As an example of how data in tables 6 and 7 can be used, I applied them to 13 counties in southwestern Kansas (Figure 1). That area has about 1.2 million acres in cultivated sandy soils (sands, loamy sands, and sandy loams).

I assumed the acreage distribution among the three textures to be 6, 27, and 67 percent for sands (WEG-1), loamy sands (WEG-2), and sandy loams (WEG-3), respectively. The corresponding potential soil losses by wind erosion, averaged across residue management, would be 1.28, 0.46, and 0.26 inches per year, giving an estimated wheat yield reduction of 1.92, 0.69, and 0.39 bushels per acre per year for WEG-1, 2, and 3, respectively. Corresponding grain sorghum values would be 3.07, 1.10, and 0.62 bushels per acre per year.

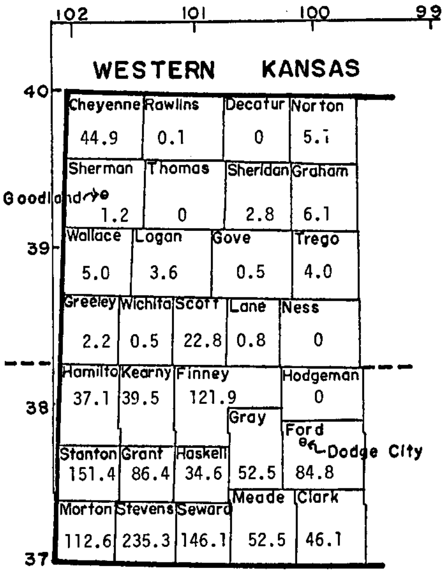

Figure 1. Distribution of sandy surface soils in western Kansas. Numbers are acres in thousands; counties below dashed line are in the southwestern district.

Although about three times more land in southwestern Kansas is in wheat than in grain sorghum, I assumed the crops occupy equal amounts of sandy surface soils. Based on this assumption, the annual yield reduction would be 339,000 bushels for wheat and 543,000 bushels for sorghum—a yearly loss of $1,255,000 in the area if wheat is $1.70 a bushel and grain sorghum is $1.25 a bushel (1972 prices). This economic loss would double under 1973 prices. If data were available on the extent of soils in various textures (WEG) and the crops on those acres by county or land resource area (for areas susceptible to wind erosion), a rough estimate of soil loss, crop yield reduction, and economic loss could be obtained using the approach I have suggested.

Applying the Procedure in Iowa

A final example concerns the effects of wind erosion on corn yields in Iowa, which has about 546,000 acres of sandy surface soils. Assuming the most susceptible erosion condition of clean-tilled fields (Table 7), that 50 percent of the sandy soils are in corn (which is unlikely), and that Iowa has an acreage distribution among wind erodibility groups similar to Kansas, the annual corn yield reduction would be about 85,000 bushels a year, a relatively small economic loss statewide.

The Only Feasible Approach

Relating crop yield to soil thickness or topsoil removed (excluding the effect of fertilizers) and determining potential annual soil loss with the wind erosion equation seems to be the only feasible approach at the moment to measuring the effects of wind erosion on soil productivity. However, the procedure must remain speculative because most of the yield-soil thickness data were from areas outside the Great Plains and for a very limited range of soils (generally fine-textured). Also, many (though plausible) assumptions were made about factors in the wind erosion equation. More research on benchmark soils in the Great Plains should produce the data needed to use the procedure.

Table 7. Average potential annual soil loss for different wind erodibility groups at 13 locations in the Great Plains: grain sorghum culture.

Location	Wind Erodibility Groups (WEG)[a] 1	2	3, 4, 4L	5	6	7
			in/yr			
Rapid City, South Dakota	0.53	0.21	0.12	0.07	0.05	0.04
North Platte, Nebraska	0.58	0.22	0.13	0.07	0.06	0.04
Scottsbluff, Nebraska	0.54	0.21	0.12	0.07	0.05	0.04
Dodge City, Kansas	1.45	0.56	0.32	0.19	0.15	0.11
Goodland, Kansas	1.01	0.39	0.23	0.13	0.11	0.08
Wichita, Kansas	0.34	0.13	0.07	0.04	0.04	0.02
Oklahoma City, Oklahoma	0.34	0.14	0.08	0.05	0.04	0.02
Amarillo, Texas	1.54	0.59	0.35	0.20	0.17	0.13
Dalhart, Texas	2.18	0.83	0.48	0.29	0.23	0.17
Lubbock, Texas	1.54	0.59	0.35	0.20	0.17	0.13
Midland, Texas	1.46	0.56	0.32	0.19	0.16	0.12
Wichita Falls, Texas	0.47	0.18	0.10	0.06	0.05	0.04
La Junta, Colorado	1.45	0.58	0.35	0.21	0.17	0.13
Des Moines, Iowa[b]	0.24	0.10	0.06	0.04	0.03	0.02

[a] See table 4 for descriptions of wind erodibility groups.

[b] Not in Great Plains; no vegetative cover, i.e., V = 0.

Table 8. Estimated annual reduction in wheat yields (bu/a) resulting from wind erosion under two kinds of residue management in the Great Plains.

Location	Wind Erodibility Groups (WEG) 1	2	3, 4, 4L	5	6	7
			Wheat residue management			
Northern Plains[a]	0.45	0.14	0.07	0.04	0.03	0.02
Western Kansas	1.47	0.47	0.25	0.14	0.10	0.07
West Texas	2.52	0.89	0.50	0.28	0.22	0.17
			Grain sorghum residue management			
Northern Plains[a]	0.88	0.34	0.20	0.11	0.09	0.06
Western Kansas	1.97	0.76	0.44	0.26	0.21	0.15
West Texas	2.69	1.03	0.60	0.35	0.29	0.22

[a] North Dakota, South Dakota, Nebraska, Montana, and Wyoming.

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