ASAE Publication 7-81

Crop Production with Conservation in the 80's

Proceedings of the
American Society of Agricultural Engineers
Conference on Crop Production
with Conservation in the 80's

December 1-2, 1980

Palmer House
Chicago, Illinois

Published by
American Society of Agricultural Engineers
P.O. Box 410 • St. Joseph, Michigan 49085

THE U.S. WIND EROSION PROBLEM

Leon Lyles*
Member ASAE

About a half-century ago the severest drought and worst economic depression in U.S. history infinitely accentuated the wind erosion problem. Those twin catastrophes enhanced appreciation of our land resources and awareness of its fundamental importance. The great drought of the 1930's demonstrated the weather's tremendous power to control the lives of individuals and communities.

The "black blizzards" of the dust bowl days inflicted great hardships on people, including the mass exodus so aptly described in John Steinbeck's (1951) "The Grapes of Wrath." The situation was so bad that in 1938 a young farmer, Lawrence Svobida, after enduring 9 years of extreme hardship at Meade, Kansas, closed his book "An Empire of Dust" (1940) with "My own humble opinion is that with the exception of a few favored localities, the whole Great Plains region is already a desert that cannot be reclaimed through the plans and labors of man." Fortunately, the extended drought and economic depression ended about 1940 and to this date neither has returned with the same intensity.

Public perception of soil erosion still remains high, as a recent survey demonstrated when responses from 38 states indicated 75 to 100% of all respondents identified soil erosion as a major concern (USDA 1980).

THE CAUSE

Wind erosion is caused by strong, turbulent winds over erodible soils. Although of greater consequence in semiarid and arid areas, it can be a problem wherever soil, vegetation, and climatic conditions permit it. Such conditions exist when: (1) the soil is loose, dry, and finely granulated; (2) the soil surface is smooth and vegetative cover is sparse or absent; (3) the susceptible area is sufficiently large; and (4) the wind is strong enough to move soil. Those conditions prevail more often in areas where precipitation is inadequate or where fluctuations from season to season or year to year prevent maintenance of vegetation or vegetative residues on the land than in subhumid or humid areas, although here, too, they sometimes occur.

THE PROCESS

The extremely complex wind erosion process involves initiation, transport, sorting, abrasion, avalanching, and finally soil particle deposition. Soil particle movement by wind is generally described in three distinct modes: suspension, saltation, and surface creep. Particles in suspension can range from 2 to 100 μm in diameter, with a mass median diameter of about 50 μm in

*Leon Lyles, Research Leader, AR, SEA, USDA, Manhattan, Kansas. Contribution from U.S. Department of Agriculture, Science and Education Administration, Agricultural Research, in cooperation with the Kansas Agricultural Experiment Station. Dept. of Agronomy Contribution 81-110-A.

an eroding field (Chepil 1957, Gillette and Walker 1977). For example, more than 99% of an ash sample collected near Pullman, Wash., from the Mount St. Helens volcano eruption in May 1980 was less than 100 µm in diameter; about 80% was less than 50 µm. In long distance transport, however, particles less than 20 µm in diameter predominate (Gillette 1977). Some suspension-sized particles are present in soil, but many are created by abrasive breakdown during erosion. Chepil (1945) reported that 3 to 38% of an eroding soil could be carried in suspension, depending on soil texture. Generally, the vertical flux is less than 10% of the horizontal (Gillette 1977, 1978).

The characteristics of saltation (jumping) particles in wind have been described by several scientists (Bagnold 1941, Chepil 1945, Free 1911, White and Schulz 1977). In saltation, individual particles lift off the surface (eject) at a 50 to 90° angle and follow distinctive trajectories under the influence of air resistance and gravity (Chepil 1945, White and Schulz 1977). The particles 100 to 500 µm in diameter (too large to be suspended by the flow), return to the surface at impact angles of 6 to 14° from the horizontal either to rebound or to embed themselves and initiate movement of other particles. Roughly 50 to 80% of total transport is by saltation.

Sand-sized mineral soil particles or aggregates 500 to 1 000 µm in diameter (too large to leave the surface in ordinary erosive winds) are set in motion by the impact of saltating particles. In high winds, the whole sand/soil surface appears to be creeping slowly forward at speeds much less than 2.5 cm/s--pushed and rolled (driven) by the saltation flow. Surface creep reportedly constitutes 7 to 25% of the total transport (Bagnold 1941, Chepil 1945, Horikowa and Shen 1960).

THE EXTENT

In a recent national erosion inventory (USDA, SCS unpublished data 1977), the potential for wind erosion exceeding 11 t/ha·yr exists on 66 million hectares of nonfederal land in the United States--22.5 million hectares of cropland, 43 million hectares of rangeland, and 0.5 million hectares of forest land. Unfortunately, data from areas outside the Great Plains were judged too low in credibility for publication. There are known wind erosion problem areas in the 7 Western States, the Corn Belt and Lake States, and on coarse-textured soils in the Southeast and Atlantic Coast States. Because no published quantitative data are available on wind erosion estimates for those areas, I will confine further discussion of the extent of the problem to the Great Plains Region.

The latest national resource inventory (USDA 1978, 1980) shows 68.2 million hectares of cropland in the "bread basket" of the U.S. (The Great Plains) which contains 71% of the wheat area in this country (Table 1). Cropland occupies 29% of the total nonfederal land in the Great Plains, ranging from 4.5% in New Mexico to more than 50% in Kansas and North Dakota. Seventeen percent of total cropland is irrigated; from less than 1% in North Dakota to more than 50% in Wyoming and New Mexico.

The Great Plains contains 23.5 million hectares where wind erosion is estimated to exceed 11 t/ha·yr, the value commonly accepted as the "tolerable" limit for soils with adequate rooting depths (Table 2). Of the 23.5 million hectares, 15.8 million (67%) is cropland. And that is equal to all the nonfederal cropland in Colorado, Oklahoma, New Mexico, and Wyoming plus one-half of Nebraska's cropland. As expected, the wind erosion hazard area is lower in the Northern than in the Southern Plains where 73% of the erodible cropland and 94% of the erodible rangeland erosion rates exceed 11 t/ha·yr. The greatest hazard for cropland is in Texas, with 6.3 million hectares or 40% of the total; the greatest for rangeland is in New Mexico, with 4 million hectares or 52% of the 7.7 million hectare total.

Table 1. Rural Nonfederal Land in the Great Plains States, 1977 (USDA 1978).

States	Cropland irrigated	Cropland nonirrigated	Pasture and rangeland	Forest land	Other	Total
	1 000 ha					
Northern:						
Montana	915	5 300	16 788	2 567	977	26 548
Nebraska	2 796	5 568	10 075	178	730	19 346
North Dakota	31	10 869	4 902	149	1 189	17 140
South Dakota	192	7 151	9 960	135	988	18 426
Wyoming	669	532	10 888	471	565	13 125
Subtotal	4 603	29 420	52 613	3 500	4 449	94 585
Southern:						
Colorado	1 411	3 076	10 280	1 353	888	17 008
Kansas	1 348	10 310	7 679	318	989	20 645
New Mexico	583	338	17 192	1 386	1 001	20 500
Oklahoma	294	4 483	9 423	1 996	720	16 917
Texas	3 352	8 962	46 206	3 739	2 448	64 708
Subtotal	6 988	27 169	90 780	8 792	6 046	139 778
Grand total	11 591	56 589	143 393	12 292	10 495	234 363

Table 2. Wind Erosion Exceeding the "Tolerable" Limit of 11 t/ha·yr in 1977 on Nonfederal Cropland and Rangeland in the Great Plains States (USDA 1978).

States	Cropland t/ha·yr			Rangeland t/ha·yr			Grand total
	11-22	> 22	Total	11-22	> 22	Total	
	1 000 ha						
Northern:							
Montana	756	626	1 382	---	---	---	1 382
Nebraska	297	261	558	12	45	57	615
North Dakota	931	123	1 054	8	41	49	1 103
South Dakota	858	241	1 099	---	---	---	1 099
Wyoming	155	83	238	72	259	331	569
Subtotal	2 997	1 334	4 331	92	345	437	4 768
Southern:							
Colorado	529	1 275	1 804	21	176	197	2 001
Kansas	1 158	883	2 041	35	124	159	2 200
New Mexico	178	318	496	1 343	2 682	4 025	4 521
Oklahoma	463	414	877	6	---	6	883
Texas	1 425	4 842	6 267	801	2 076	2 877	9 144
Subtotal	3 753	7 732	11 485	2 206	5 058	7 264	18 749
Grand total	6 750	9 066	15 816	2 298	5 403	7 701	23 517

Data on Great Plains land in major crops indicate the wind erosion hazard (based on percentage of land in major crops with erosion exceeding 11 t/ha·yr) follows this sequence, in order of most severe to less severe: cotton, sorghum, wheat, corn, soybeans (Table 3). That sequence should be related to location, soil, amounts of vegetative residues produced, and management. For example, cotton is grown only in the Southern Plains (which has high winds, high temperatures, and low precipitation), much of it on highly erodible sandy soils, and it produces low amounts of residue in clean-tillage systems, all of which contributes to estimated erosion rates exceeding 11 t/ha·yr for 95% of the area planted to cotton.

In contrast, soybeans are generally confined to the eastern subhumid region of the Plains where the climate is less conducive to wind erosion and soils are less erodible, so a low percentage (9%) of planted soybean area has erosion rates more than 11 t/ha·yr. This does not imply that soybeans substituted for cotton would reduce erosion rates in cotton growing areas.

Wind erosion estimates on cropland in the Great Plains are given in Table 4 by major soil limitations. As mentioned earlier, erosion rates are considerably higher in the Southern Plains (with their susceptible, droughty soils in areas subject to periodic drought--capability subclasses e, s, and c) than in the Northern Plains.

THE IMPACT

Wind erosion damages soil, crops, and the environment.

Soil

Soil Conservation Service surveys in the Great Plains States show that wind erosion damages from 0.4 to 6 million hectares annually; on the average, about 2 million hectares is moderately to severely damaged each year.

Wind erosion physically, and often selectively, removes the most fertile portion of the soil, lowering productivity. The effects of erosion on crop production, however, are difficult to generalize because numerous factors influence crop yields. Therefore, the specific relationship between erosion and productivity has not been established for use in management plans. The primary reasons given for reduced yields on eroded soils are reduced plant-available soil water, lowered nutrient content, impaired soil structure, deficient organic matter, and nonuniform soil removal.

Several studies have related crop yields to soil thickness for a limited range of soils (generally fine-textured) (Lyles 1975, 1977 and Pimentel et al. 1976). Rough estimates for yield reductions per millimeter of topsoil loss might be 10 kg/ha for corn and 5 kg/ha each for wheat, soybeans, grain sorghum, and oats. However, the data are too sparse to extend across soils, climates, and kinds of erosion.

A USDA national soil erosion-soil productivity research planning committee is preparing a paper on "The Influence of Soil Erosion on Soil Productivity" that defines the problem, identifies past and current research, and suggests a future approach to better characterize the soil erosion-soil productivity relationship.* The paper will be available for publication consideration soon.

Crops

Agricultural crops are most vulnerable to damage by blowing soil from seeding through early growth (Lyles and Woodruff 1960, Skidmore 1966). Damage may be from "blowouts" before seedlings emerge; seedling survival and growth may be reduced; or seedlings may be totally destroyed by abrasion of wind-driven soil particles. Blowing soil lowers the marketability of such vegetable crops as asparagus, green beans, lettuce, and tomatoes and reduces yields of field crops like wheat and cotton (Armbrust 1968, Woodruff 1956). Sandblast injury affects metabolic processes of young plants before visual damage is apparent (Armbrust 1972). Also, blowing soil may transmit and increase plants' susceptibility to some diseases (Claflin et al. 1973).

*The author is a committee member.

Table 3. Cropland of the Great Plains States by Major Crops With Wind Erosion Rates Exceeding 11 t/ha·yr, 1977 (USDA 1978). Numbers In Parenthesis are Areas Planted to Indicated Crops in 1977 (USDA 1979).

States	Wheat		Sorghum		Corn		Cotton		Soybeans	
	1 000 ha									
Northern:										
Montana	572	(2 185)	2	(0)	3	(36)	0	(0)	0	(0)
Nebraska	135	(1 335)	21	(931)	201	(2 894)	0	(0)	13	(465)
North Dakota	385	(4 031)	0	(0)	24	(251)	0	(0)	21	(73)
South Dakota	350	(1 479)	42	(198)	202	(1 214)	0	(0)	19	(130)
Wyoming	129	(143)	0	(0)	15	(36)	0	(0)	0	(0)
Subtotal	1 571	(9 173)	65	(1 129)	445	(4 431)	0	(0)	53	(668)
Southern:										
Colorado	726	(1 226)	130	(186)	123	(389)	0	(0)	0	(0)
Kansas	957	(5 342)	359	(1 963)	147	(822)	0	(0)	6	(413)
New Mexico	208	(225)	107	(120)	47	(55)	49	(59)	0	(0)
Oklahoma	520	(3 157)	82	(310)	0	(57)	121	(217)	0	(146)
Texas	1 097	(2 550)	1 287	(2 266)	370	(728)	2 656	(2 701)	81	(324)
Subtotal	3 508	(12 500)	1 965	(4 845)	687	(2 051)	2 826	(2 977)	87	(883)
Grand total	5 079	(21 673)	2 030	(5 974)	1 132	(6 482)	2 826	(2 977)	140	(1 551)

Table 4. Wind Erosion on Cropland in the Great Plains States by Major Soil Limitations (USDA 1978).

States	Major limitation*: No major limitation (Class I)	Erosion suscepti- bility (e)	Soil limitation, rooting zone (s)	Excess water (w)	Climatic limita- tion (c)	Avg.
	t/ha·yr					
Northern:						
Montana	---	9.2	5.8	4.5	2.5	5.5
Nebraska	1.3	3.4	2.2	0.4	4.3	2.3
North Dakota	---	4.5	3.1	5.2	2.2	3.8
South Dakota	4.3	6.7	5.2	4.3	4.3	5.0
Wyoming	4.9	6.1	6.1	2.0	5.8	5.0
Sub average	3.5	6.0	4.5	3.3	3.8	4.2
Southern:						
Colorado	5.2	22.6	14.3	2.2	20.8	13.0
Kansas	6.5	6.9	3.8	1.8	8.1	5.4
New Mexico	11.0	31.2	16.6	4.7	0	12.7
Oklahoma	3.4	8.3	2.0	3.4	8.3	5.1
Texas	11.4	44.8	26.4	8.5	22.6	22.7
Sub average	7.5	22.8	12.6	4.1	12.0	11.8
Average	5.5	14.4	8.6	3.7	7.9	8.0

*Symbols in parentheses indicate SCS capability classes or subclasses.

Environment

Environmental quality has been in the forefront of public consciousness for several years. Some soil from damaged lands enters suspension and becomes part of the atmospheric dustload. This atmospheric dust often obscures visibility and pollutes the air, causes traffic accidents, fouls machinery, and imperils animal and human health, and dust deposition causes chemical and sediment pollution. Blowing soil also buries fences and fills road and irrigation ditches, increasing maintenance costs. Approximate calculations suggest that particulate suspension from wind erosion exceeds that from all other sources--both natural and generated by man. Because of the high concentration of coarse particles in duststorms, rural areas often fail to meet EPA Air Quality Standards for total suspended particulates. On the average, eroding lands of the Great Plains were estimated to contribute 221 and 70 million metric tons of dust per year, respectively, in the 1950's and 1960's (Hagen and Woodruff 1973). Annual extremes were 34 million metric tons in 1958 and 318 million metric tons in 1954.

PRINCIPLES AND CONTROL

General principles in control of wind erosion are: reducing wind forces on erodible particles or creating particles resistant to wind forces. From knowledge of erosion processes and mechanics, four specific principles of wind-erosion control have been identified (Woodruff et al. 1977): (1) establish and maintain vegetation or vegetative residues, (2) produce or bring to the soil surface nonerodible aggregates or clods, (3) reduce field width along prevailing wind-erosion direction, and (4) roughen the land surface. Management practices for applying these principles vary from place to place and may change over time, along with cropping and management systems. These four principles plus a factor for climate were used to develop a wind-erosion equation that predicts potential annual erosion rates (Woodruff and Siddoway 1965):

$$E = f(I, K, C, L, V) \quad (1)$$

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 median distance wind travels across a field, and V is the equivalent vegetative cover. Relations among the variables in the equation are complex, and a single equation that expresses E as a function of the dependent variables has not been devised. Initially, the equation was solved in a stepwise procedure involving tables and graphs. Now it can be solved by computer methods (Fisher and Skidmore 1970, Skidmore et al. 1970). Still more recently, procedures were developed for using the equation by periods longer or shorter than 1 year (Bondy et al. 1980), which involves partitioning erosion amounts over time with erosive wind-energy distribution as the criterion.

The equation was developed primarily either to estimate potential erosion from a particular field or to determine the field conditions necessary to reduce potential erosion to tolerable amounts. It has been used extensively in designing and evaluating control systems (practices). It was also used in the 1977 National Resource Inventories (USDA 1978).

The only known way to effectively control wind erosion on dryland sandy soils that blow easily is to establish a permanent vegetative cover. Because a cash crop usually will be more profitable than livestock on such soils, producers are not likely to retire land from cultivation and establish grass unless encouraged by government subsidies or land-use regulations. Almost any kind of land-use control program is certain to be strongly opposed.

Wind erosion usually can be controlled on the less susceptible cultivated soils by residue and tillage management, strip cropping, wind barriers, and emergency tillage. However, droughts intensify the problem. One year of severe drought seldom has any great effect on control strategies, but 2 or more consecutive years can be disastrous because there is little or no crop residue to manage and soil structure will be so degraded that emergency tillage becomes ineffective--all contributing to increased susceptibility to erosion.

Two harbingers on the horizon cause uneasiness about future wind erosion in the U.S. First is the rapid expansion of irrigation (especially center-pivot systems) over the dust bowl region where the Ogallala Acquifer is the water source. Studies indicate that the groundwater supply for irrigation in parts of the Great Plains and the desert Southwest will be largely depleted by 2000 (USDA 1980). When pumping in the area becomes uneconomical, the land will revert to dryland farming, increasing the wind-erosion hazard. Erosion-prone sandy soils under center-pivot systems may be abandoned, leaving conditions ripe for accelerated wind erosion.

Second is the worry of an impending long drought. The sequence and frequency of drought in the Plains States is illustrated by this precipitation data for Dodge City, Kansas:

Period	Years with < 80% of normal precipitation	Consecutive years
	Number	Number
1901-1910	3	0
1911-1920	4	2 (1916-1917)
1921-1930	0	0
1931-1940	6	4 (1934-1937
1941-1950	2	0
1951-1960	4	3 (1952-1954)
1961-1970	3	0
1971-1980	0	0

It shows that in decades since the 1930's not more than 4 years of drought have occurred and no consecutive years since 1954. Through 1979 we had a quarter century without consecutive dry years. Based on such historical data, one might sense an impending long drought in the Central Great Plains, perhaps in the 1980's. The result can be economic disaster to individuals and, in extreme cases, to whole communities. Drought and wind erosion are intimately related.

REFERENCES

1. Armbrust, D. V. 1968. Windblown soil abrasive injury to cotton plants. Agron. J. 60:622-625.

2. Armbrust, D. V. 1972. Recovery and nutrient content of sandblasted soybean seedlings. Agron. J. 64:707-708.

3. Bagnold, R. A. 1941. The Physics of Blown Sand and Desert Dunes. Methuen, London, 265 p.

4. Bondy, E., L. Lyles, and W. A. Hayes. 1980. Computing soil erosion by periods using wind-energy distribution. J. Soil Water Conserv. 35(4): 173-176.

5. Chepil, W. S. 1945. Dynamics of wind erosion: I. Nature of movement of soil by wind. Soil Sci. 60(4):305-320.

6. Chepil, W. S. 1957. Sedimentary characteristics of duststorms: III. Composition of suspended dust. Amer. J. Sci. 255:206-213.

7. Claflin, L. E., D. L. Stuteville, and D. V. Armbrust. 1973. Windblown soil in the epidemiology of bacterial leaf spot of alfalfa and common blight of beans. Phytopathology 63(11):1417-1419.

8. Fisher, P. S., and E. L. Skidmore. 1970. WEROS: a Fortran IV program to solve the wind erosion equation. U.S. Dept. Agr., Agr. Res. Serv. 41-174, 13 p.

9. Free, E. E. 1911. The movement of soil material by wind. U.S. Dept. Agr., Bureau Soils Bull. No. 68.

10. Gillette, D. A. 1977. Fine-particle emissions due to wind erosion. TRANS. of the ASAE 20(5):890-897.

11. Gillette, D. A. 1978. A wind tunnel simulation of the erosion of soil: effect of soil texture, sandblasting, windspeed, and soil consolidation on dust production. Atmos. Environ. 12:1735-1743.

12. Gillette, D. A., and T. R. Walker. 1977. Characteristics of airborne particles produced by wind erosion of sandy soil, high plains of West Texas. Soil Sci. 123:97-110.

13. Hagen, L. J., and N. P. Woodruff. 1973. Air pollution from duststorms in the Great Plains. Atmos. Environ. 7:323-332.

14. Horikowa, K., and H. W. Shen. 1960. Sand movement by wind action. Beach Erosion Bull., Corps Engin. Tech. Memo. No. 119, 51 p.

15. Lyles, L. 1975. Possible effects of wind erosion on soil productivity. J. Soil Water Conserv. 30:279-283.

16. Lyles, L. 1977. Wind erosion: processes and effects on soil productivity. TRANS. of the ASAE 20(5):880-884.

17. Lyles, L., and N. P. Woodruff. 1960. Abrasive action of windblown soil on plant seedlings. Agron. J. 52:533-536.

18. Pimentel, D., E. C. Terhune, R. Dyson-Hudson, S. Rochereau, R. Samis, E. A. Smith, D. Denman, D. Reifschneider, and M. Shepard. 1976. Land degradation: effects on food and energy resources. Science 194:149-155.

19. Skidmore, E. L. 1966. Wind and sandblast injury to seedling green beans. Agron. J. 58:311-315.

20. Skidmore, E. L., P. S. Fisher, and N. P. Woodruff. 1970. Wind erosion equation: computer solution and application. Soil Sci. Soc. Amer. Proc. 34:931-935.

21. Steinbeck, John. 1951. The Grapes of Wrath. Harper, New York, 619 p.

22. Svobida, Lawrence. 1940. An Empire of Dust. The Caxton Printers Ltd., Caldwell, ID., 203 p.

23. U.S. Department of Agriculture. 1978. 1977 National resource inventories. USDA, SCS.

24. U.S. Department of Agriculture. 1979. Agricultural Statistics 1979, 603 p.

25. U.S. Department of Agriculture. 1980. Soil and water conservation act. 1980 Appraisal, Review Draft, Part 1.

26. White, B. R., and J. C. Schulz. 1977. Magnus effect in saltation. J. Fluid Mech. 81(3):497-512.

27. Woodruff, N. P. 1956. Windblown soil abrasive injuries to winter wheat plants. Agron. J. 48:499-504.

28. Woodruff, N. P., and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Amer. Proc. 29:502-608.

29. Woodruff, N. P., L. Lyles, F. H. Siddoway, and D. W. Fryrear. 1977. How to control wind erosion. U.S. Dept. Agr., Agr. Inf. Bull. 354 (revised).