THE WIND EROSION PROBLEM IN THE GREAT PLAINS

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Abstract--This is a review paper summarizing briefly current knowledge and philosophies relative to the wind erosion problem in the Great Plains area of the United States. The principal types of wind erosion experienced by the area are identified as "selective erosion" and "mass removal." Present and historical aspects of the problem are outlined. An equation expressing the regimen of soil removed by wind tunnel tests for variations of vegetative cover on soils of different structure and surface roughness is presented. Climatic variation and chance occurrence of adverse combinations of climatic factors are cited as fundamental to the problem. The principles involved and methods used for abatement of the problem are discussed. The needs for climatic, soil, crop, tillage, and erosion control practice research for the development of adequate wind erosion control measures or practices are cited.

The accelerated erosion of soil by wind in the Great Plains is a problem associated with land use. The climax vegetation of the area was predominantly mixed and short grasses. Under grass, the soils were relatively stable and organic matter accumulated throughout the upper portion of the root zone. The equilibrium between vegetation, soils, and climatic environment has been disturbed by use of the lands for annual cultivated crops. Instability of unprotected soil to the forces of wind is the item of major concern with respect to erosion.

Principal types of wind erosion

Little consideration has been given to classifying types of wind erosion although several forms and processes have been identified by FREE [1911], BAGNOLD [1943], and CHEPIL [1943]. There are, however, two distinct types of phenomena in the Plains.

The first of these is "mass removal" of the soil materials from a land surface. It is associated with the finer textured silt and clay soils. In these soils, all of the primary particles may be suspended and removed by wind. They are usually loessial in origin. While the basic soil particles may be aggregated, little sorting of basic materials occurs from wind action. In general, the saltation movement of aggregates causes their breakdown and the soil materials may be transported far from the source area. In the Great Plains these soils are usually dark in color and are known as the "hardlands."

The second type of wind erosion may be termed "selective erosion." It is the sorting of relatively fine materials from an eroding surface. The phenomenon is common to sandy lands containing some basic soil materials too large to be suspended by the wind and removed from the source area. Selective erosion results in the loss of the more fertile portions of the soil from the eroding area. Local products are the accumulation of sand into hummocks or dunes. In some cases extremely coarse material remains in place to form a desert pavement. The soils are usually residual or formed from mountain outwash.

Areal extent

The wind erosion problem in the Great Plains is present in portions of a ten-state region. For convenience the five-state area of Montana, North Dakota, Wyoming, South Dakota, and Nebraska are often called the Northern Plains. Spring wheat is the principal crop of these northern states. Colorado, Kansas, New Mexico, Oklahoma, and Texas form a group called the Southern Plains. Winter wheat, sorghum, and cotton are the principal crops of this area.

Clear cut lines to delineate the areal extent of the problem cannot be drawn. As an estimate, approximately 25 pct of the total ten-state area, or 250,000 sq mi, are subject to the wind-erosion hazard at recurring intervals in a moderate to severe degree. Almost every year the problem will be severe in some more or less localized portion of one or several states. This should be regarded as a condition normal to the area. It is no more unusual than, say, a flood on one of the many secondary streams of the Mississippi River system in a given year. Such conditions are not a harbinger of wide-spread disaster conditions, although they are often misjudged as such.

Upon occasion, climatic conditions may cause severe wind erosion over large areas in several states, although the probability of experiencing such an event is low. This is the condition that prevailed in the 1930's.

Historical aspects of the wind erosion problem

Prairie fires are known to have been common to the ecological development of Plains grasslands. Grazing by buffalo, drought, and the activities of the Indian undoubtedly caused periodic deterioration of the range and it seems reasonable to assume that erosion of soil and plant material by wind existed before white settlement.

White settlement of the Plains west of the Missouri River occurred an even century ago. A report on dust storms during the period 1850-1900 has been given by MILAN [1946]. An excerpt from the newspaper Kansas Free State at Lawrence, Kansas in 1855 is as follows: "The strong south winds that we experience here are our greatest annoyance. They frequently last for several days, and are loaded with the black dust from the burnt prairie, which penetrates every corner of our houses, and makes everyone who is exposed to it as sooty as a collier. This annoyance, however, will not be so great when the surrounding country is brought under cultivation, and the prairies cease to be burned." A century later we have reached the cultivated state that appears to have been the goal a century ago. Today the winds carry little of the residue from prairie fires; their burden is the soil itself.

Much has been written about the folly of breaking the sod of the Plains. The fact of the matter is that cultivation of deep lands in rainfall belts of 16 to 18 inches or more offers no greater an overall erosion hazard than exists in most humid areas. The phenomenon is different in nature, and erosion of soil in the form of a "black blizzard" is simply more spectacular than muddy water.

Toward the western side of the Plains in rainfall belts of 16 inches or less a serious erosion problem exists on shallow soils. The Soil Conservation Service classifies many of these as Class IV lands. These lands are transitional between those suited for cultivation and those that should not be plowed.

During and following World War II a large acreage of sod lands were placed under cultivation. The plow-up for 1948 was in excess of 1.4 million acres. During the same year 0.7 million acres were retired from cultivation. The net increase in cultivated acres from 1944 is shown in Figure 4. This figure is based on compilations of data by the Conditions Committee of the Great Plains Agricultural Council. FINNELL [1949] found that almost one-half of the newly plowed lands in the Southern Plains was Class IV and one-fourth was unsuited entirely for cropland. The retirement of land from cultivation has exceeded new plow-up since 1949. In general, the climatic hazards of drought and high winds have been at a low ebb during the past decade. It will be fortunate in the extreme if further retirement of hazardous lands is made before a climatic situation causes them to go out of control.

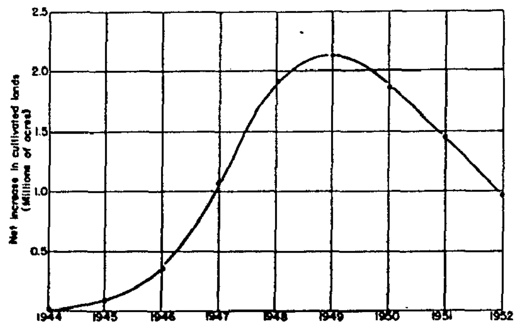

Fig. 4--Net increase in cultivated lands in the Great Plains over those cultivated in 1944

Chief factors involved in erosion

Precipitation, temperature, the level of wind movement, and land use are interrelated to comprise the wind erosion hazard on a given soil. The characteristics of each vary with time and season at a given location.

Land use--Use of land in the Plains seems quite simple in that it may be classified as range or cultivated land. The vicissitudes of weather are such, however, as to require a science of range management on grasslands. The cultivated lands are, in general, cropped to wheat, sorghum, or cotton with fallow periods designed to augment soil moisture. On cultivated lands it is very difficult to follow a routine system of management and cropping due to large variations in climate. The tendency is to employ flexible systems to utilize fully the soil-moisture supply on hand. There is a good deal of danger in this practice, particularly on the poorer soils. For example, one often hears the view expressed that Class IV lands can be cropped for a few years when moisture is plentiful and then retired to grass. Just how these lands can be returned to a protective grass cover before a non-determinable drought period is not known. Again, legumes or grasses are not employed generally in cropping sequences on drylands in the High Plains. A U. S. HOUSE DOCUMENT [1949] gives an estimate that their use is needed on 30-million acres in the Missouri Basin alone.

Farm machinery and its operation is an integral part of land use. The array of different-type plows, sweeps, chisels, subsoilers, disks, and drills all attest to the struggle toward improved crop management and soil and moisture conservation in the Plains area.

Soils and their properties--The Chernozem, Chestnut, Reddish Chestnut, and the Brown soils predominate in the Plains. A lime accumulation layer is characteristic of nearly all soils of these four groups. Because of limited amounts of leaching below the zone of root development, the soils are quite fertile. In general, the soils are formed from Rocky Mountain outwash and many of them have a loessial covering.

Soil texture and structure appear to be the most important soil properties with respect to erodibility of the soil by wind action. Studies by CHEPIL [1953a] have demonstrated that the dry clod structure of soils is related to their texture. The most stable structure is normally found on soils containing 25 to 30 pct clay. Very sandy soils and those containing large amounts of clay are the most erodible basically. The unigranular nature of the sands inhibits the formation of stable dry clods, while excessive amounts of clay tend to cause the formation of a large proportion of water-stable aggregates. The aggregates are, however, normally of a size and apparent density that are moved easily by wind.

In researches on the mechanics of wind erosion, CHEPIL [1953b] found that the per cent by weight of soil material <0.42 or <0.84 mm in diameter in the surface inch of soil bears a relationship to the erodibility of soils by wind. Values of the percentage as determined by the sieving of soils in a dry state afford a convenient index of their erodibility.

Vegetal cover--Vegetal cover tends to vary with precipitation, soil texture, and depth. Thus, as we proceed from east to west across the Plains the amount of vegetal cover produced and the crop residues available for soil protection become less. The close association between wind erodibility, soil texture, the percentage by weight of erodible soil material <0.42 mm in diameter at the surface and the weight of surface residues found in a field study by ZINGG and Others [1953] in eastern New Mexico in the spring of 1952 is demonstrated by the average results shown in Table 3.

Table 3--Data on surface residues and soil removal

Soil textural group	Dry surface soil material <0.42 mm in diameter	Weight of surface residue	Measured soil removal[a]
	pct	lbs/acre	tons/acre
Loamy	69	875	2
Sandy	77	560	9
Very sandy	92	400	67

[a]Weight of soil material removed by a portable wind tunnel at a surface drag level equivalent to 3000 pounds per acre.

Surface roughness--The roughness of a field surface governs to a large extent the distribution of wind force on it. The roughness may be in the form of soil clods, ridges, or residue orientation. Roughness tends to limit the movement of erodible soil material and to concentrate the wind force on relatively stable surface projections or vegetal residues. In the evaluation of field surfaces, a height parameter called the "ridge roughness equivalent" has been developed by ZINGG and WOODRUFF [1951] to gage this factor.

Relationships of soil eroded by wind to surface factors--In considering field surfaces the factors of dry clod structure, weight of surface residue, and surface roughness have been used in combination to account for a portion of measured wind erodibility. For example, an empirical relationship developed from portable wind tunnel tests by ZINGG and Others [1953] of a group of fields in New Mexico is

$$\log x = - 8.96957 + 7.33294 \log A - 1.17067 \log RK$$

where x is the soil material eroded from the test surface in tons per acre, A is the percentage of dry surface soil material <0.42 mm in diameter, R is the weight of surface residue in pounds per acre, and K is the ridge roughness equivalent of the surface in inches. The correlation of the expression is 0.834, which means that approximately 70 pct of the variability of soil eroded is accounted for by the measured variables. The equation was developed for an average surface wind drag equivalent to 3000 lb/ac.

Climatic factors--Wind movement, humidity, precipitation, and temperature must be considered to interpret the wind-erosion problem in the Plains. Normally, the period of most intense wind movement occurs in February, March, and April, prior to the seasonal fall of precipitation in the summer months beginning in May. In the normal course of events, soil structure of a wind-stable type tends to break down over the winter period. A dry, granular surface-soil condition is usually present during the period of high winds which comes in the form of storms with the seasonal change from winter to spring. Unfortunately, a majority of the windstorms occur before the seasonal period for new vegetal growth. Thus, in large measure, the wind-erosion problem is a seasonal one and priority must be given to crop and land management methods and practices which will yield control in the late winter and early spring.

Irregular cyclic variations in wind movement, precipitation, temperature, and resulting crop growth over periods of years are also characteristic of Plains climate and agriculture. High winds and temperatures tend to be inversely related to precipitation and vegetal growth. Hence, during adverse periods of climate all factors combine to produce conditions favorable to soil movement by wind. Studies of these several factors and a speculative approach to the problem have been reported by ZINGG [1953]. Suffice to say that the factors of climate were extremely adverse in the 1930's and have been more favorable than average during the last decade. Further, cyclic fluctuations of this nature are to be expected. Levels of wind movement are also amenable to study on an intensity-frequency basis as shown by ZINGG [1950]. Thus, many of the techniques employed in hydrology may be used in evaluating the wind erosion phenomenon from a climatic standpoint.

Corrective measures for abating wind erosion

Decreasing force of wind on soil--Under climax conditions prairie grasses, wild legumes, forbs, and shrubs possibly afforded the maximum protection of the soil surface from wind. Land-use experience indicates that range use with proper management is the maximum capability of the shallow lands where moisture is the limiting factor in plant growth.

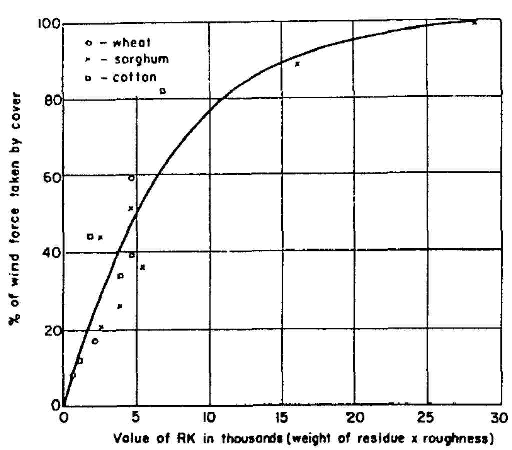

Fig. 5--Per cent of wind force taken by cover in relation to RK

Retaining a maximum cover with crops and their residues approaches conditions for good protection most closely on cultivated lands. The use of the combine where only the grain is removed from the field was a revolutionary step in the harvesting of wheat and grain sorghum. Retaining a portion of crop residue on the surface under both fallow and continuous cropping sequences followed shortly, and management methods to accomplish this end are still in their infancy. The delayed fallow in which wheat stubble is not worked in dry years until after spring winds is a further advance. All these techniques are in the direction of employing methods which approximate the protection afforded by the native vegetation.

The ability of crop residues to remove the direct force of the wind from the soil is illustrated in Figure 5. In this case the product of the weight of surface residue and a parameter of surface roughness are plotted against the percentage of wind force taken by the cover at a height greater than one inch above the average elevation of the soil surface. The values were calculated from dimensionless velocity profiles obtained in field wind tunnel studies by a technique described by ZINGG and Others [1952]. The value of R is the weight of surface residue in pounds per acre and K is the ridge roughness equivalent of the surface in inches.

The planting of crops in a row direction perpendicular to prevailing high intensity winds is a device designed to increase the efficiency of vegetal protection to the soil. The employment of alternate strips provides further mechanical protection through their barrier effect and the elimination of contiguous erodible areas. Unfortunately, in some areas of the Plains almost equal numbers of damaging winds come from east-west and north-south directions. In portions of the Northern Plains benefits are derived from plantings and establishing strips in a north-south direction. In portions of the Southern Plains the east-west directional planting yields benefits.

Field windbreaks afford mechanical protection of the barrier type and are adapted to deep soils having an ample supply of moisture to support them. Their employment to form a part of the land pattern in adapted areas is a development which will come with time. For example, plantings are going forward steadily in portions of southwestern Oklahoma and adjoining areas of Texas. The development is in the form of a network in both north-south and east-west directions.

Enhancing vegetal cover--Management techniques which yield a maximum of soil stability and conserve and utilize moisture efficiently for plant growth are necessary for sustained land use in the Plains area.

Marked developments in higher-yielding and more drought resistant varieties of crops have been and are being made. The introduction of improved varieties of grain sorghum are a boon to the Southern Plains. The average water requirement of sorghum in Colorado was determined by BRIGGS and SHANTZ [1914] to be 322 pounds per pound of above-ground dry matter production. A comparable value for wheat was 481. Not only is the sorghum plant more efficient in the use of moisture but it is a crop which can be planted following winter wheat failure.

The organic carbon and nitrogen content of dryland soils has been decreasing under dryland cultivations. During a 30-year period of cropping at Hays, Kansas, MYERS and Others [1943] found the decrease was approximately one-third from the original level. During the past 30 years the development of improved crops has tended to offset yield declines due to lowering fertility. At the present time many field trials are underway to evaluate the effects of fertilizer on dryland soils. It is reasonable to assume that enchanced crop growth, efficiency of moisture use, and increased soil protection will be forthcoming in years when moisture is not the limiting factor in crop growth. In the higher rainfall areas of the Plains leguminous crops are being employed in increasing amounts with beneficial effects to soil condition and subsequent crop growth.

Maintaining protective cover on the land once it is grown is not the least of the problems of dryland agriculture and wind erosion control. Under drought conditions, pressures to utilize residues by livestock grazing or harvesting for forage are great. Maintaining a supply of forage on hand sufficient to carry livestock through drought years is fundamental to solving the problem. Some progress has been made in storing silage but, in general, the supplies are very inadequate.

Tillage and emergency control methods--In addition to implements designed to leave residues on the soil surface, machines capable of penetrating the soil to considerable depth are being employed. Some of the processes are deep chiseling and plowing, subsoiling, and listing.

The objectives of deep chiseling and subsoiling are to loosen relatively impermeable or consolidated soil materials below the depth cultivated normally to provide more favorable conditions for moisture penetration and root growth. Again, by using the chisel or the lister it is possible to bring consolidated cloddy soil material to the surface to provide relatively wind stable soil conditions for some period of time. An illustration is the employment of the lister in the growing of cotton in the Southern Plains. The soils are blank listed late in the winter months just prior to the season of high winds. After the season of high winds the lands are again listed in the cotton planting operation.

Deep plowing to depths of 12 to 18 inches also has become a common practice on sandy soils on the Southern Plains. Following the sorting action of wind erosion many of the soils have an extremely sandy surface. In general, they are underlain with finer textured material and immediate benefits are associated with burying the erodible surface material and bringing a less erodible soil to the surface. Unless the practice is used as an aid to the establishment of relatively stable land use systems it is exploitative in nature. To date the development is largely of the exploitative variety. The process cannot be repeated many times without accumulating a deep mantle of erodible sand material which will offer a much greater wind erosion problem than exists currently.

Emergency tillage to control erodible land surfaces is more or less a last resort measure to keep land from going out of control or to minimize the abrading action of saltating soil grains on young plants. It is a temporary expedient but under certain conditions is capable of yielding great benefits and saving a crop. The object is to limit soil movement by roughening portions of a field to the point where they are nonerodible or will trap the soil materials moving from intervening areas. Usually from ten to 50 pct of a field is worked at one time in alternate strips. The practice is carried out best with chisels of approximately four-inch width at spacings of two feet. Its success is dependent upon timeliness of the operation and bringing stable clods to the surface. In the state of Kansas the county boards of supervisors have legal authority to enforce the emergency tillage of land to eliminate the hazard to adjoining farm lands.

Moisture conservation practices--The practices of terracing and contour farming are developing well in eastern sections of the Plains where both wind and water erosion occur. Their function is a dual one of moisture conservation and erosion control. Again, deep chiseling and subsoiling has as its partial goal the conservation of moisture although little factual information is available on the subject.

The practice of using rod weeders and packers in seed bed preparation is usually thought to decrease evaporation losses but, again, information of a factual type is meager or non-existent.

Wind-barrier effects obtained from windbreak placement, strip cropping, and row direction practices should be accompanied by modified evaporation phenomenon. In general, however, possible effects have been considerations of a refined nature in relation to the numerous aspects of Plains agriculture.

It has been demonstrated by DULEY and RUSSELL [1939] that stubble-mulch systems of farming cause increased infiltration of water into soils. Studies to evaluate their influence on evaporation and plant growth are underway at a few locations.

In general, it may be stated that less is known concerning soil moisture conditions associated with various practices and land management than any other phase of the dryland problem.

Research needed for development of adequate abatement measures

Climatic, soil, crop, tillage, and erosion control practice research is needed for the development of adequate control methods. Many of the factors comprising the problem are interdependent. Thus, the nature of winds, precipitation, evaporation, soil properties and moisture, plant growth and cultural techniques are involved. One of the greatest needs is for the development of new research techniques employing cooperation of men trained in various fields of physical and biological science.

The characteristics of wind movement need much more study from the erosion standpoint. The motivating force in the problem is wind and the scale and degree of atmospheric turbulence as well as velocity and duration are important. Climatological research should be carried out as an integral part of studies dealing with soil, water, and plant phases of the problem and its control. Again the characteristics of wind as it passes over barriers and land surfaces of different roughness and its force distribution on such surfaces is little understood.

One of the major methods of control on cultivated lands is the maintenance of adequate vegetal cover to protect a given soil from the wind forces anticipated. In most cases this requires the growing of maximum cover. In general, better utilization of precipitation for plant growth is prerequisite. Hence, methods of increasing infiltration, decreasing surface runoff and evaporation, and the adoption of crops and systems of crop culture and tillage that are efficient in the use and conservation of moisture should be the objectives of intensified research.

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DISCUSSION

Louis M. Glymph, Jr., (Agriculture Research Service, Lincoln, Nebraska)--Erosion by wind is shown to be the resultant of numerous variables, many of which are interdependent. Aside from wind itself, vegetative cover seems to be the principal factor in defining the susceptibility of soil to wind erosion. Maintenance of a protective vegetative cover on the soil during the season of most intensive winds would seem to offer the most effective means of control. Vegetative covers are also a very effective means of controlling water erosion. Cropping systems, tillage practices, and moisture conservation measures which encourage vegetative growth therefore contribute to control of both wind and water erosion.

It is perhaps significant to note, however, that periods of protracted drought and high temperatures which limit vegetative growth in the Plains states tend to be periods of intense and frequent winds. In general, therefore, it seems that vegetative measures are less effective in control of wind erosion than in control of water erosion, under extreme conditions. The response of vegetation to greater amounts of precipitation increase its effectiveness as a means for control of erosion by water. But with erosion by wind the opposite is true because of the tendency for winds to occur in the Plains states during precipitation periods unfavorable for the growth of vegetation.