ferent years as much as 0.16 inch per day for corn, 0.13 inch per day for small grain and alfalfa, and 0.10 inch per day for potatoes. These differences are primarily the result of a relatively wet, cool growing season compared to a hot, dry season. It is noteworthy that the peak use rate for small grain was as high as that for alfalfa.

Peak use rates for most crops occur during the stage of most rapid vegetative growth and usually include the fruiting period. This period of plant development also corresponds to the time when, during June, July, and August, the climate reaches its maximum evaporative potential. Jensen and Sletten, 1957, found that the maximum water use rate for grain sorghum at Bushland, Texas, occurred in August, 1954, during the fruiting period. Erie and Dimick (1954) reported peak use rates for flax about 10 days after blossom; sugar beets in the middle of growing season; potatoes at the time tubers set; corn shortly after the silking stage; dry beans at blossom; and wheat during the early boot stage.

### G. Research Problems

Expansion of irrigation in the Great Plains has created special research problems in addition to those common to arid regions. Some of the more important ones include the following:

1. Water inventories of both surface and underground supplies, the interrelationships of each, and the rate of natural recharge of underground reservoirs.
2. Basic long-term yield data for both irrigated and dryland production including studies on drought probabilities, particularly in the subhumid areas, for computing cost-benefit ratios as a result of irrigation.
3. Efficient use of water including methods of irrigation, choice of crop, and how to use limited amounts of water, either extensively or intensively.
4. Methods for recharging underground aquifiers, particularly in areas where surface runoff accumulates in wet-weather lakes.

## VII. Wind Erosion Problems

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The wind erosion problem, just as most agricultural problems in many parts of the world, developed after man began to interfere unduly with the natural equilibrium between vegetation, soil, and climatic environment. Overcultivation, burning, and overgrazing have been his chief means of disturbing this equilibrium. The problem, therefore, is associated with the way the farmer uses his land.

### A. Present Situation and Practices

The driest sections of the Great Plains generally are most seriously affected by wind erosion. Crops often have been destroyed by abrasive action of windblown soil particles. These losses, though serious, are less important than loss of silt, clay, and organic matter gradually sorted from the surface soil and carried to distant areas where they may be of little or no use to agriculture (Daniel, 1936; Chepil, 1957a). Crop yields in some areas have been much lower after than before serious erosion by wind occurred (Finnell, 1949). In some cases, the land appears to have been injured permanently.

The primary causes of wind erosion are few and can be stated simply. Wherever (1) the soil is loose, finely divided, and dry, (2) the soil surface is smooth and bare, and (3) the wind is strong, erosion may be expected.

By the same token, wherever (a) the soil is compacted, kept moist, or made up of stable aggregates or clods large enough to resist the force of wind, (b) the soil surface is roughened or covered by vegetation or vegetative residue, or (c) the wind velocity near the ground is somehow reduced, erosion may be curtailed or eliminated. These general conditions form the basis for effective wind erosion control.

The most important of the major causes of wind erosion appears to be the depletion or destruction of vegetation or vegetative residue on the land. Drought at times has reduced or stopped the vegetative growth, but drought alone has not been the cause of serious wind erosion. Little erosion occurred when the land was protected by natural vegetation. Vegetative cover is nature's way of protecting the earth's surface from erosion. Man has not been able to devise a more effective practical way to control erosion. Adequate protection of the land by vegetation or vegetative residue still remains the key to both wind and water erosion control.

Extended periods of drought and high wind velocity have contributed to the severity of wind erosion. Great variations in precipitation, temperature, and wind velocity exist on the Plains. These variations are governed by certain probability laws. Therefore, the general frequency of occurrence of periods of high wind and precipitation are predictable from past records for any location (Zingg, 1949). Unfortunately the time when these periods will occur cannot be predicted. It is essential, therefore, to establish permanent soil conservation practices that will be effective against wind erosion whenever adverse climatic conditions occur.

The growing of cultivated crops incapable of providing sufficient vegetative cover on the land has contributed greatly to land denudation and erosion by wind. Cotton, sugar beets, peas, beans, and potatoes, leave little cover on the land and contribute greatly to erosion of soil by both wind and water. Some land classes require less cover than others for protection against erosion and are therefore more suited to those erosion-susceptible crops, especially if special farming systems such as strip cropping and rotation with erosion-resistant crops are adopted. Some land classes, on the other hand, require the adoption only of erosion-resistant crops and some permit no cultivated crops if erosion is to be controlled. In this country, large areas of land suited only for permanent grass or forest cover are still devoted to cultivated crops. In the Great Plains alone about 14 million acres not suited for permanent cultivation were cultivated in 1955.[1] Much of this land offers meager returns and is subject to severe wind erosion even in average years.

Another cause of depletion of a vegetative cover and consequent erosion by wind has been the improper choice and use of tillage implements. In the early period of agricultural history in this country, the plow and the disk and drag harrows developed in and adapted to more humid areas were the principal tillage implements in dry regions. Vegetative residues were buried and the soil was often left smooth, loose, and fine and thus highly erodible by wind. Later, when the importance of vegetative cover began to be recognized, the plow in many cases was discarded and the one-way disk which leaves some residue on the surface, was adopted. With careful use, the implement served and is still serving a good purpose. However, improper or excessive use of this implement has often resulted in the soil surface becoming loose and fine with much of the residue buried.

The practice of fallowing, essential for storage of soil moisture in dry regions, often has created large areas of bare or partially denuded land. In the northern sections, the fallowed land is seeded in spring about 20 months after harvesting a previous crop. During all this period the ground must be kept free from weed growth if moisture is to be conserved. Tillage so far has been the only practical means of killing the weeds. This tillage tends to break up and bury the vegetative residue needed for protection of the surface against erosion by wind and water. Consequently, great care is required if weeds are to be killed, moisture conserved, and erosion curtailed. Due to lack of better methods, a farmer often has to compromise by curtailing tillage and losing some soil moisture to gain a possible decrease in erosion, or vice versa.

In the southern sections fallow is sown, usually to wheat, in the fall. If germination and growth are favorable, a good protective cover against next spring's winds is almost assured. If the surface soil is dry, however,

[1] *U.S. Dept. Agr. Leaflet* SCS 394, 1955.

and wheat fails to germinate or make sufficient growth, the danger of wind erosion becomes acute. Some lands have been so highly susceptible to wind erosion that fallowing had to be abandoned in preference to a continuous system of cropping. Continuous cropping increases the hazard of crop failure but on the other hand assures a more continuous vegetative cover and reduced erosion. Where fallowing was attempted and wind erosion resulted, drastic emergency tillage measures had to be utilized to check the spread of erosion to other lands.

Another conflict often is encountered in the date of seeding winter wheat. Better protective cover against erosion may be expected with an earlier date of seeding. However, too early seeding induces the development of certain insects and diseases and uses valuable stored water which often reduces yields. Some insects may be controlled by burying the crop residue, but this practice undoubtedly induces erosion. Also, some weeds can be controlled best by plowing the weed seeds under, but such a practice also increases the hazard from erosion.

The wind erosion problem is complicated because it is dependent on many conditions and because it is interrelated with many other technical and economic problems. Each condition can be modified considerably by human action. A thorough understanding of the physics of the wind erosion process and the principles of soil stabilization are prerequisites for its solution.

### B. Recent Developments

Probably one of the greatest advances in wind erosion control in recent years has been the retention of crop residues (stubble mulch) at the surface of the ground. Although the beneficial value of stubble mulch as a preventive measure against wind erosion was recognized in some areas more than thirty years ago, little basic information was available and its general adoption has been slow. Gradually, its value for wind erosion control was recognized from many investigations, some examples of which are cited in this article (Bennett, 1939; Duley and Russel, 1948; Hopkins *et al.*, 1946).

Maintenance of crop residues on cultivated land has been facilitated by considerable progress made in development, improvement, and application of tillage implements that tend to leave the crop residues on the surface of the ground (Chase, 1942; Duley and Russel, 1942; Johnson, 1950). During wind erosion conditions of the 1950's, farmers in many parts of the Plains have been able to control wind erosion by resorting to emergency tillage. Success of emergency tillage appears to be largely due to recent improvements in emergency tillage machinery and more adequate power for proper adjustment of speed and depth of cultivation.

Intermediate to moderately high speeds of 3.5 to 5 m.p.h. have produced the greatest degree of cloddiness and surface roughness and reduced the erodibility more than slower speeds if tillage was performed at a depth sufficient to bring up clods (Woodruff and Chepil, 1956).

Measurements have indicated that rate of soil movement by wind is zero on the windward edge of an eroding field, but increases with distance to leeward in some cases for more than a mile (Chepil and Milne, 1941). This increase in rate of soil flow with distance downwind across an unsheltered wind-eroding area is known as avalanching. The rate of soil avalanching has an important bearing on how wide erosion-susceptible strips in a strip cropping system should be to give a certain degree of erosion control. The more erodible the soil, the narrower the strips must be for equal effectiveness. Soil erodibility was found to be associated closely with soil textural class (Chepil, 1953). Recent work indicates how wide erosion-susceptible strips should be for any soil textural class, height of wind barrier in the erosion-resistant strips, wind velocity, and wind direction, to hold soil loss to a tolerable rate on the leeward sides of strips (Chepil, 1957b). Suitable width of strips is based on the tolerable rate of erosion. This width assumes the quantity of crop residue, degree of surface roughness and/or soil cloddiness that can be expected with proper farming practices in years of limited precipitation, high wind velocity, and low crop yields. The system, even then, will fail on rare occasions.

Researches have shown that strip cropping alone is not sufficient as a wind erosion control measure under most circumstances. It must be supplemented with other practices. Strip cropping can be expected to reduce the intensity of erosion and to limit the erosion to the area of origin. Without strip farming, once erosion starts it generally gets out of control. With strip farming, on the other hand, erosion is much more easily held in check, provided an effective set of erosion resistant strips is maintained.

A method of estimating wind erodibility of farm fields and of determining land surface conditions required to reduce wind erodibility to any degree was developed by Chepil and Woodruff (1954). The method is based on three major factors that influence wind erodibility of a field surface. They are surface roughness, vegetative cover, and degree of soil cloddiness. The method indicates how these factors can be measured, how erodibility of a field surface can be determined, and what degree of surface roughness, vegetative cover, and soil cloddiness would be needed to reduce erodibility to any degree.

Considerable fundamental information has been obtained recently on the value of shelterbelts, hedges, snow fences, and other barriers for wind erosion control (Woodruff, 1954). The work indicated that complete protection from wind erosion of dune sand occurs within a net distance of 9 barrier heights from a single row belt for a velocity of 40 m.p.h. at 50-foot height. This information gives some idea of barrier spacing required for full protection of highly erodible soil.

Some information on probabilities of occurrence of various levels of wind velocity, temperature, and precipitation associated with dust storms have been reported by Zingg (1949). This study points the way to determining how often certain degrees of drought and wind erosion conditions will occur at any given geographic location on the Great Plains.

Results obtained primarily with wind tunnels have indicated that the most erodible soil fractions are about 0.1 millimeter and the least erodible seldom exceed 1 millimeter in equivalent diameter (Chepil, 1951). These particles or grains are moved along the surface of the ground in jumps known as saltation. Saltation is the cause of two other types of movement —rolling and sliding along the surface (surface creep), and lifting of fine dust in the air (suspension). Saltation is a predominant type of movement on arable soils. Because of this movement, it is evident that erosion is dependent primarily on the velocity and force of the wind. Therefore one of the principles of wind erosion control should be based on preventing soil from becoming finely granulated, a condition most inducive to movement by saltation.

### C. Research Problems

It is known at present what soil structure approaches an ideal condition for resisting wind. Attempts to achieve such a condition have met with little success. Creation of soil structure that would resist erosion, absorb water freely, and maintain a good medium for crop growth is urgently needed at the present time.

Although considerable information on the value of crop residues has been obtained, little is known of the influence of kind, manner of placement, and degree of anchorage of various types of crop residue on wind erodibility of different soils under various wind velocities. So far, only the influence of amount of crop residue has been investigated in detail.

A study of the effects of soil compaction, texture, and moisture on different types of tillage action is needed for development of more effective wind erosion control by tillage methods. An implement that leaves the soil surface in a cloddy condition without burying the crop residue is required.

Analyses of air flow, temperature, and evaporation patterns over and around shelterbelts and other types of surface barriers such as snow-fences, hedges, crop strips, ridges, and soil aggregates are being continued. Part of this study is to be applied to a classification standard for shelterbelts presently in existence on the Plains. Ultimately it is hoped that some clarification may be made of the principles governing air flow patterns and soil erodibility in the vicinity of all barriers ranging from the size of clods to field shelterbelts.

Measurements of aerodynamic forces on soil particles on the ground and at different heights in a fluid boundary are being continued. These measurements include determination of the magnitude of fluctuation in aerodynamic forces at various heights above surfaces of various degrees of roughness. The measurements also include determination of the equilibrium conditions between the transported soil particles and the moving fluid. These studies are basic to an understanding of the physics of soil movement by wind and of the principles of wind erosion control.

Study of climatic factors influencing wind erosion on the Great Plains has been initiated but little information is available at present on the probabilities of occurrence of various intensities of wind erosion conditions for different soils and geographic locations. Many wind erosion control practices stand or fall depending largely on whether or not they can survive certain intensities of wind erosion. A study is needed for different soils and geographic locations on the quantity of crop residues and degree of surface roughness and soil cloddiness required to withstand wind erosion for certain percentages of time.

### D. Conclusions

The solution of the wind erosion problem is dependent on overall progress in basic research, field testing, and extension. It is believed that substantial overall progress has been made towards the solution of the problem. The severity of dust storms in some parts of the Great Plains under similar conditions of drought, temperature, and wind velocity were generally much greater in the 1930's than the 1950's. These differences are believed to be due to better techniques, more favorable financial resources, and more earnest desire on the part of everyone to control erosion by wind.

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