SCIENCE

VOL. LXXIII — FRIDAY, JANUARY 23, 1931 — No. 1882

SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. MCKEEN CATTELL and published every Friday by

THE SCIENCE PRESS
New York City: Grand Central Terminal
Lancaster, Pa. — Garrison, N. Y.
Annual Subscription, $6.00 — Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

EROSION AS A FACTOR IN SOIL DETERMINATION[1]

By M. F. MILLER
UNIVERSITY OF MISSOURI

IT is common knowledge that soils may deteriorate more or less seriously under agriculture. The fundamental changes accompanying this deterioration may include such alterations as a decline in the original store of organic matter, a decrease in the amounts of total and readily available nutrients, an increase in the hydrogen-ion concentration, a modification of the biological activities, and a change in the physical properties of the soil. The extent to which erosion is responsible for such changes has been the subject of much recent speculation. Simple observation warrants the statement that under favorable conditions for erosive action, erosion may be the principal contributing factor responsible for such deterioration, while under less favorable conditions its importance may be of minor significance. There is little doubt, however, that taking the agricultural regions of the United States as a whole far too little consideration has been given to this matter.

Erosion through the action of wind or water is a natural phenomenon with which most people are familiar. The development of the existing topographic relief in any given section of the country is to a large degree the result of erosive action. It, therefore, has a great geological importance in determining the character of land surfaces. But erosion is also of importance in determining the character of both virgin and cultivated soils, and as a consequence it has a great significance to agriculture. Under nature, soil removal through erosion takes place slowly, but under agriculture, particularly a type of agriculture which makes no provision for soil preservation, such losses may be tremendously magnified.

Wind erosion, which is confined largely to semi-arid and arid regions, may under systems of grain farming

[1] Address of the retiring chairman and vice-president of Section O—Agriculture, American Association for the Advancement of Science, Cleveland, Ohio, December, 1930.

bring about great damage to crops and a degree of soil injury which sometimes results in land abandonment. Serious water erosion may also occur in semi-arid regions, although its influence is naturally most wide-spread in the humid and sub-humid sections. The discussion which follows will be confined to water erosion, particularly that of humid and sub-humid regions and largely to that of lands devoted to agriculture.

Water erosion is commonly considered as of two types, sheet erosion and gullying. Sheet erosion is that through which the soil of the immediate surface layers is removed through the flooding of heavy rains. It is this type of erosion which, under agriculture, is responsible for the largest soil losses, particularly where land is plowed and left bare for considerable lengths of time or where it is planted to intertilled crops, such as corn or cotton. Gully erosion, on the other hand, through which the soil is trenched and scarred by the action of run-off water, may occur on grass lands as well as lands under cultivation. The final effect of serious gully erosion is to cut the fields into such small tracts that a profitable agriculture, through the use of ordinary farm implements, becomes practically impossible.

The factors which determine the rate of determination of agricultural lands through erosion are; First, the amount, distribution and the torrential character of the precipitation; second, the number of days of the year when the soil is not frozen; third, the topography; fourth, the character of the soil; and fifth, the system of agriculture. Generally speaking, erosion is most severe where a large percentage of the rains are of torrential character, where the ground is frozen but a small portion of the year, if at all, where the land slopes are steep, where the soil texture is such as to be easily eroded, and where the system of agriculture is one which exposes much of the bare soil surface to surface run-off.

Observations of the losses due to the erosion of agricultural lands show these to be greatest in the soils of the Southern states, particularly those of the southern parts of the Appalachian and Piedmont regions, of the Atlantic coastal plain, of parts of the limestone regions of Kentucky and Tennessee, of the black soil belt of Texas, and of the southern parts of the corn belt. Serious losses are also taking place in parts of the range country of the West, where close pasturing has exposed the soil to the action of the torrential rains of those regions.

Trustworthy estimates of the erosion losses taking place from farm lands are difficult to make. A careful observer traveling through those areas most subject to serious erosion is struck by the tremendous damage that has resulted. Bennett states[2] that in a single county in the Southern Piedmont Region 90,000 acres of land have been permanently ruined by erosion, and 70,000 acres in another, while in many other Southern counties such ruined lands represent areas ranging from 10,000 to 30,000 acres, most of which was once under cultivation. Areas have been examined in these counties where ten or more inches of soil have been removed during 30 years of agriculture. Naturally such losses represent extreme cases rather than the average. There is no doubt, however, that over the southern half of the humid region of the United States and over a part of the northern half, erosion losses are very severe. Moreover, the damage is undoubtedly cumulative, increasing somewhat as the absorptive power of the soil for water decreases, due both to a decrease in the supply of organic matter and to a decrease in the depth of the absorptive surface layer.

Exact measurements of the erosion losses which may take place under agriculture have thus far been made in only a few places. The studies which have been made at the Missouri, North Carolina and Texas experiment stations have furnished the major part of such data. The climate, soils and systems of cropping at these three stations vary widely, as do the amounts of soil eroded under the different crops and cropping systems, yet the data give some idea of what may be expected in widely separated sections of the country.

At the Missouri station the studies have been confined largely to a Shelby loam soil with a grade of 3.68 per cent., a length of slope of 90 feet, and under a rainfall of approximately 37 inches. As an average of twelve years' measurements bare, uncropped and cultivated land has suffered an annual loss of approximately 43 tons of soil per acre. Under exactly the same conditions land cropped continuously to corn has lost approximately 20 tons per acre annually, that in continuous wheat 9 tons, that in a good crop rotation 3 tons, while land left in continuous sod lost soil at the rate of only one third of a ton annually. Under these conditions of the surface 7 inches of soil would be removed from the uncropped, cultivated land in 23 years, from the corn land in 50 years, from the wheat land in approximately 100 years, from the land in a good crop rotation in 350 years, while under sod almost 3,000 years would be required. These figures show the very great influence of the system of agriculture, particularly the cropping system, on erosion losses. Certainly the grade of 3.68 per cent. is not greater than an average for corn

[2] U. S. Department of Agriculture Circular 33.

belt soils and these data give a good idea as to what may be expected under these conditions.

Data similar to those just given are available from these same studies, showing the influence of different grades on erosion losses. As a four-year average and where the same years are compared, land in continuous corn, with a grade of 3.68 per cent., lost soil at the rate of 26 tons per acre annually. With a grade of 6 per cent. the annual acre loss was approximately 85 tons, and with a grade of 8.5 per cent. the loss was approximately 150 tons. Under the 8.5 per cent. grade on this Shelby loam soil, when planted continuously to corn, the surface soil was removed at the rate of one inch per year. The normal depth of the surface soil is approximately 9 inches so that under such conditions the subsoil would be exposed in less than one decade. It is under such conditions that sheet erosion becomes very destructive in removing the fertility which nature has taken thousands of years to accumulate in this humus-bearing layer of surface soil.

Many estimates have been made of the amounts of plant nutrients removed from the land through erosion. Some of these estimates are based on careful determinations of the elements carried in river water. An example of such an estimate is that of McHargue and Peter[3] who analyzed the material carried in solution by the Mississippi River at Baton Rouge, and calculated the annual loss from the Mississippi basin to be approximately 630,000 tons of nitrogen, 62,000 tons of phosphorus, 1,626,000 tons of potassium, and 22,446,000 tons of calcium. This, of course, does not include the nutrients carried to the Gulf in the suspended material or deposited along the course of the Mississippi and its tributaries. On the other hand, much of the mineral nutrients, particularly the lime, was probably derived from rock rather than from the soil. It is, therefore, unlikely that such estimates represent very closely the actual losses from agricultural lands.

The erosion measurements at the Missouri station include some data as to the elements contained in the eroded material. These data show an annual acre loss from the 3.68 per cent. grade under continuous corn of about 65 pounds of nitrogen, 18 pounds of phosphorus and 610 pounds of potassium. Continuous wheat allows a loss of about 30 pounds of nitrogen, 9 pounds of phosphorus and 250 pounds of potassium. Under the corn, wheat, clover rotation, however, the losses are reduced to about 18 pounds of nitrogen, 4 pounds of phosphorus and 140 pounds of potassium, while under continuous sod they reach the extremely small quantities of less than a pound of nitrogen and phosphorus, and only 4 pounds of potassium. These figures represent a single soil under southern corn belt conditions and for a short period of measurement only, yet they give a good comparison of the influences of different crops and a good crop rotation on the losses which may take place.

It will be observed that the losses of nutrient elements through erosion, as compared with the losses through crops in these Missouri studies of a loam soil of 3.68 per cent. grade, depend largely on the cropping system. Under a poor cropping system of continuous grain farming the losses from the two sources, with the exception of the potassium, are about equal, but under a good cropping system the erosion losses are much less than the losses through crops. However, when land with a grade of 8.5 per cent. was studied the erosion losses were multiplied several times. It can be said, therefore, that with a moderate grade and a good cropping system in the southern corn belt, losses of soil nutrients through erosion do not compare with the losses through crops, but with steeper slopes and especially under excessive corn farming, these losses may be several times those through the crops.

The erosion measurements at the North Carolina station have been carried out on a Cecil fine sandy loam soil with a grade of 9 per cent., a length of slope of 75 feet and an average rainfall of 41 inches. A three-year average shows an annual acre loss from cultivated uncropped land of approximately 21 tons, from continuous cotton 20 tons, from continuous corn 13½ tons, and from continuous sod only .42 ton. These losses, even on a grade of 9 per cent., are somewhat less for cultivated uncropped land and for continuous corn land than from the grade of 3.68 per cent. at the Missouri station, thus emphasizing the great differences which may be expected from different soils and different types of rainfall. Both sets of measurements show great losses of soil under the constant production of intertilled crops as compared with sod. The North Carolina measurements show a somewhat less loss of nitrogen, a greater loss of phosphorus and a much greater loss of potassium through the eroded material than through the continuous crops of corn and cotton.

At the erosion experiment farm at Spur, Texas, measurements have been made on the Miles clay loam having a grade of 1 to 3 per cent., a length of slope of 96 feet and an average rainfall of 27 inches. With a grade of 2 per cent. the annual acre loss for three years has been: from cultivated uncropped land 18.6 tons, from continuous cotton 12.6 tons, from continuous Milo maize 5.7 tons, and from continuous Buffalo grass sod 3.8 tons. As compared with those

[3] Kentucky Experiment Station Bulletin 237.

on the 9 per cent. slope in North Carolina these losses on this 2 per cent. slope are remarkably high, showing again the marked variations to be expected under varying conditions of soil and precipitation.

Careful estimates of the soil lost from individual farms have been made in only a few instances. At the erosion experiment farm in northern Missouri, a careful determination of the depth of the soil at 100-foot intervals over the 220-acre tract shows erosion losses, as compared with similar uneroded land, varying from less than an inch to more than 12 inches. Naturally, the 12-inch losses are confined to the steeper grades and the small losses to the more level areas. When these losses are applied to the whole 220 acres, the average loss is almost exactly one inch. Since the average depth of soil is around 10 inches, approximately one tenth of the surface soil has been removed since the land was put into cultivation, or in about 50 years. This land has been handled largely as a livestock farm, and the cropping system has included a good deal of grass so that the erosion has not been excessive. The rate of one inch in 50 years or seven inches in 350 years is identical with that of the corn, wheat, clover rotation on the 3.68 per cent. grade in the Missouri measurements which is probably not far from the average corn belt loss under a good system of cropping. It is, however, from the steeper than average grades and under poor systems of soil preservation that the serious losses occur.

It is quite evident, from the data available, that the erosion factor in soil deterioration is a very significant one, although its importance varies greatly with conditions. Under nature the advancing stages of early erosion may remove good virgin soils which may later be replaced by much poorer ones, yet it is under agriculture that the most rapid changes take place. Under the most favorable conditions for erosion a type of agriculture poorly adapted to soil preservation may allow the entire surface soil to be removed within a generation, or in the case of the very steep grades within a decade.

The relation of climate to the rate of erosion losses is very significant. Generally speaking, erosion losses are low in the cooler climates where the surface is frozen for several months of the year and they are higher in the warm climates. They are high where the precipitation is 20 inches or more and where there are many rains of torrential character. Erosion losses are, therefore, low in the northern part of the United States and in most of northern Europe, since both the temperature and the character of the rainfall are such as to prevent excessive soil removal. These losses are highest where a temperate or subtropical climate leaves the soil unfrozen almost the entire year, and where torrential rains occur during the growing season when the soil is being cultivated. The greatest losses during a given season will occur when a torrential rain falls on bare, cultivated land already filled with the water of a previous rain.

The relation of soil character to erosion losses is not well understood. Middleton[4] has shown that the most important single factor governing the case of erosion of a soil mass is the so-called dispersion ratio, which refers to the proportion of the silt and clay easily dispersed in water. General observations show that as a rule soils having a medium texture of the surface soil (A horizon) such as silt loams, loams and fine sandy loams, suffer most, particularly from sheet erosion, and that such losses decrease as the texture approaches either extreme. If such surface soils are underlaid with a tight clay subsoil (B horizon) the losses from sheet erosion are intensified. While small gullies form readily in soils of medium texture with tight subsoils, deep gullies are developed most rapidly when such surface soils are underlaid by loose silt loam, sandy or sandy loam subsoil. If the deeper soil material is also made up of loose silt or sandy loam, such as is characteristic of some of the loess deposits, uncontrolled gullies may assume frightful proportions. The most marked examples of this in the United States are in the belts of loessial soils lying on the east side of the Mississippi from the Ohio River southward.

In contrast to soils which are very susceptible to erosion there is evidence that some of the lateritic soils of the tropics do not erode seriously even under very excessive amounts of precipitation. It has been suggested that this is associated with the high silica and low sesquioxide content of these soils. Bennett reports that certain lateritic clays of Porto Rico and Cuba remain so porous and friable, even under cultivation, that they absorb great quantities of water and erode very little. Such soils differ greatly from the easily eroded soils of the southern part of the great group of podsolic soils of the United States.

The general relation of the percentage of grade to erosion losses is too well known to need particular comment. However, no exact mathematical expression of this relation with different soil textures is yet available. Because of the influence of such factors as soil granulation, the tightness of the subsoil, and the nature of the rainfall, mathematical relationships are very difficult to establish. Under most conditions land having a grade of over 10 per cent. must be handled with great care to prevent serious loss and under these natural conditions most favorable for

[4] U. S. Department of Agriculture Technical Bulletin 178.

erosion land with a slope of only 2 or 3 per cent. must be given particular attention to avoid excessive damage.

The relation of systems of farming to erosion losses has a very practical significance. When it is considered that bare or cultivated land suffers most and that such losses are largely overcome by the use of sod crops and greatly decreased by the use of small grain crops, the influence of the cropping system is at once apparent. The large acreages of corn in the corn belt and of cotton in the cotton belt are principally responsible for the excessive erosion losses which have taken place in those regions. Coupled with this has been the failure of the average farmer to realize the importance of such losses and as a result he has given little attention to the control measures which lie within his reach. Too often he has allowed sheet washing to proceed and gullies to go uncontrolled until whole farms and groups of farms have reached the stage of abandonment. The farmer should not receive too much blame for this, however, as corn and cotton are the principal money crops in these regions and he is human.

In summation it can be said that in considerable areas of the United States as well as of other countries, where the climate is temperate to subtropical, where other natural conditions are favorable to erosion, and where the systems of agriculture include large acreages of intertilled crops, the erosion factor is by far the most important one in bringing about serious soil deterioration. However, on the great majority of the farms in the corn and wheat belts and on many farms in the cotton belt, the losses are moderate. In some cases, such as very level lands, the losses are negligible. In fact, in the case of very level uplands the erosion losses may be too slow for the good of the land. It must be understood that a limited amount of erosion is beneficial. It is a rejuvenating process. In case of the very level virgin uplands of the humid regions the run-off and erosion are so small that these soils may become badly leached and low in basic material, while at the same time they may develop very tight subsoils with a resulting decrease in natural fertility and in productivity. The most productive virgin upland soils are those which are sufficiently rolling that the surface drainage is ample and from which sufficient erosion takes place that new layers of soil material are constantly, even if very slowly, brought within the action of surface weathering agencies and root penetration. Such soils are not excessively leached and they are not underlaid by excessively tight subsoils. Moreover, if systems of cropping and other means of erosion control are adopted for their proper preservation, these soils remain most productive under agriculture. However, in those regions where natural conditions favor erosion it is rather difficult, even with slight grades, to limit erosion losses to a point that is negligible. If the Missouri figures may be taken to represent southern corn belt conditions, a loss of one inch in 50 years from a moderate grade and under a good cropping system may be expected. Such a loss is not great and it seems quite evident that under proper systems of soil management in this region the average erosion may be reduced to a factor of no great importance. Moreover, in the northern part of the corn belt the conditions for erosion are less favorable, and while no accurate data are available, the losses must be less. It must be remembered, however, that in the corn belt as a whole only a small percentage of the farmers follow a system of farming which is most effective in limiting erosion losses. As a consequence in the rich loose silty soils of the southern and central corn belt, particularly where the topography is rolling to steep, erosion losses are taking place at a rate which allows erosion to rank first among the factors that lessen soil productivity.

Little accurate data are available from which to judge the rate at which weathering agencies will replace the surface layer of soil under erosion losses, but it is generally thought to be very slow. Of course, when the depth of the surface soil has been reduced to 6 or 7 inches the action of the plow in bringing layers of the subsurface soil into the plowed zone and the incorporation of organic matter with it tends to maintain a surface soil layer of plow depth. Moreover, there are experimental data, as well as practical information, which show that through the use of legumes or the incorporation of organic matter, along with the use of lime and fertilizers, raw subsoils may be made to produce good yields of crops. Naturally such a system necessitates considerable expense, particularly in the early years of its use, but where crops of rather high unit value can be produced such systems may be quite profitable. However, such soil rejuvenating systems are never likely to be as profitable as those in which the natural surface soil is preserved. It is highly important, therefore, that the farmers of the corn belt, as well as those of the cotton belt, be encouraged not only to follow systems of farming which minimize erosion losses but to put into practice wherever necessary those mechanical means of erosion control which have been shown to be effective, such as the use of terraces, soil saving dams and contour farming. It is the duty of the federal and state agencies dealing with agriculture to give special consideration to the erosion losses that are taking place and to encourage the general adoption of practical measures of control.