12-1946

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RAINFALL AND IRRIGATION IN RELATION TO SOIL EROSION

By

WILLARD GARDNER
JOHN HALE GARDNER
C. W. LAURITZEN

BULLETIN 326

Agricultural Experiment Station
Utah State Agricultural College
Logan, Utah

in cooperation with the
Soil Conservation Service
U. S. Department of Agriculture

December 1946
Rainfall and Irrigation in Relation to Soil Erosion

By

Willard Gardner
John Hale Gardner
C. W. Lauritzen

This paper attempts to point out to farmers, agricultural specialists, and others who may be interested, pertinent facts regarding rainfall intensity and other meteorological data that have to do with the wearing down of range and agricultural soils, and to present by means of diagrams illustrations of general relationships between the rate of wearing down of irrigated soils, the size of the irrigation stream and the slope of the eroding surface.

Large streams running down steep slopes, whether from rainfall or from irrigation, constitute a destructive process that cannot be completely controlled. Fortunately, vegetation protects the soil against the destructive effect of rain and irrigation water, and, conversely, water promotes the growth of vegetation. A most constructive step, therefore, would be a carefully considered plan for grazing and for maintaining a vegetative mantle on the soil surface wherever and whenever this can be done without hindering farming operations. Under normal conditions when the surface soil is in good tilth, rain and irrigation water may penetrate better than when it is puddled and compacted. Obviously runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil. The amount of erosion depends upon the size of the stream and the slope of the eroding surface as well as upon the character of the surface soil. Even though the rainfall is comparatively light, if it exceeds the rate at which it may be absorbed by the soil, the size and velocity of the resulting stream must increase as it moves down the slope.

Rainfall in Relation to Erosion

For many years the U. S. Weather Bureau has kept careful records of the precipitation throughout the United States, and since the fall of 1941, special recording rain gauges have been installed at various places, including at the present time about 36 installations in Utah.

Report on project 209—Adams.
Research professor of physics, Utah Agricultural Experiment station, former laboratory helper, and soil technologist, Soil Conservation Service, respectively.
The diagram of figure 1 summarizes data for these 36 stations during the period from July 1944 to December 1945. To illustrate the meaning of this diagram, it may be observed that about 74 percent of the gross precipitation over the areas represented by the 36 stations for the 18-month period has fallen at intensities of less than 0.10 inches per hour, and that approximately 90 percent has fallen at intensities less than 0.22 inches per hour.

The following stations are represented in the diagram:

- Antimony
- Belnap
- Blanding
- Bryce Canyon
- Caineville
- Cedar City
- Coalville
- Cottonwood
- Delta
- Enterprise
- Ephraim
- Fairfield
- Farmington
- Fruitland
- Gooseberry
- Grantsville
- Greenriver
- Knolls
- Locomotive Springs
- Logan
- Lucin
- Milford
- Moab
- Neph
- Ogden
- Plymouth
- Price
- Provo
- Roosevelt
- Richfield
- St. George
- Salt Lake City
- Salt Lake Airport
- Silver Lake
- Soldier Summit
- Wendover

Corresponding diagrams for the individual stations would of course differ somewhat with one another, although the average will not be far from that for a given locality.

Although the records from the ordinary rain gages do not represent rainfall intensities, it is nevertheless instructive to note how the individual records are distributed with respect to the magnitudes. The Yearbook of the U. S. Department of Agriculture for 1941 reports the average annual precipitation for 125 stations in Utah, representing periods of time ranging from 3 to 40 years. These averages were computed from large numbers of individual

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8Except in the cases where rainfall intensities were actually measured, the precipitation records do not represent true "storm sizes" but only the amount of precipitation in a 24-hour period. The term "storm size" as used here denotes the amount of precipitation in a 24-hour period.
measurements, and the diagrams of figures 2 and 3 represent the distribution of these individual records with respect to their magnitudes in precisely the same way as the diagram of figure 1 represents the distribution as to the intensities, except that the data for March only are involved in the one case and for October in the other.

To illustrate the meaning of these diagrams, it may be observed that for the month of March approximately 75 percent of the measurements over the entire state for a twenty-four hour period is less than 0.8 inch, and approximately 50 percent is less than 0.4 inch.

The diagrams of figures 4 and 5 represent the same distribution as those of figures 2 and 3, except that but two stations are represented, Farmington and Greenriver, and the two months represented are February and September. The average annual precipitation for Farmington is 20.21 inches, whereas for Greenriver it is only 6.13 inches. In both cases the percentage that comes in small amounts is much greater in Greenriver than in Farmington. Data not presented here show that this is true for January, March, May, July, August, November, and December. In October and June the percentage in the small amounts is greater in Farmington than in Greenriver, though not appreciably different in
June. There is not much difference in the two localities for the months of March, April, June and August. The number of storms, \( y \), of a given size, \( x \), may be computed from the equation

\[
y = ae^{-k\sqrt{x}} \quad (e=2.72)
\]

by introducing the values of \( k \) and \( a \) given in table 1.

When these diagrams are considered in connection with figure 1, it is noted that only a small part of the precipitation comes in amounts and at rates that should be violently destructive, although there are isolated cases where serious damage has occurred, and of course, the storms of high intensity, even though they are rare, are primarily responsible. In some areas the rainfall from vast stretches accumulates in large streams and silt, sand, gravel, and boulders are carried many miles with the stream. The configuration of the earth is undergoing constant change, the mountains rising on the one hand in response to earthquakes and volcanic eruptions, and on the other hand eroding away and depositing again in the lakes and in the bottom lands and in the ocean, the fine particles being sorted out and carried great distances out into the water. Not only, therefore, is this a destructive process...
but it is at the same time a process that is soil-building—at least for the distant future. Clay, silt, sand, and gravel are thus deposited in heterogeneous proportions.

<table>
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<th>Table 1. Constants $k$ and $a$ for various months of the year for the state as a whole and for the two stations, Farmington and Greenriver</th>
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The gross amount of rainfall throughout the year may have an important bearing on the erosion problem notwithstanding the fact that the intensity has greater immediate significance. At Greenriver, for example, 12.11 inches is the largest amount of precipitation recorded for a calendar year in a period of 38 years, 1905-1943, whereas at Farmington the maximum over the same period was 27.17 inches. The average over this period at Greenriver was 6.15 inches and at Farmington 20.02 inches. Even though the rainfall intensity may have been greater in the Greenriver area, the total erosion for the year might well have been less because of the much smaller total rainfall.

In a brief discussion such as this it would be quite impossible to present all rainfall data that would be significant, but it is believed that the data in table 2 will be of interest. They show the maximum and average monthly and annual precipitation for 77 stations throughout the state, the first part representing the Great Basin area and the second part the Colorado River drainage area. Because of incompleteness of recorded data or because of the brevity of the period of record, data for the remaining 48 stations are not presented.

The numbers representing the maximum annual amount for a given station will in general differ greatly from the sum of the twelve numbers representing the individual months. For example, the number 2.88 for the Alunite station for February does not of necessity represent the same year that the number 1.92 for November does. Except for unavoidable discrepancies in making the com-
putation, the sum of the twelve numbers representing the monthly averages should agree with the corresponding number in the annual column. These discrepancies should of course be small.

**Table 2. Maximum and average monthly and annual precipitation for selected stations in Utah**

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IRRIGATION

The foregoing statements may perhaps serve to give a general picture of the meteorological aspects of the problem of erosion. Erosion resulting from irrigation water is likewise a matter of great concern in the state. On flat lands erosion is perhaps not a serious problem but the farmers are in many places, without fully realizing it, permitting vast quantities of the fertile top soil to be carried down the slope and thus slowly but surely reducing the productivity of vast tracts of fertile land.

At the Utah Agricultural Experiment Station a study of the erosion problem has been pursued jointly for several years by the Irrigation and the Physics Departments in cooperation with the Soil Conservation Service in an effort to develop a general formula giving the rate at which the soil at the up-stream end of the irrigation furrow will be worn down in terms of the size of the stream and the slope of the eroding surface. This study is of technical nature and it will be necessary in this popular discussion to suppress much of the mathematics. It may suffice to say here that the study is based on the equation of continuity (or in other words with the law of conservation of matter). In addition a formula
expressing the silt content of the water in terms of the distance down the irrigation furrow and the time is required. This formula contains numbers which are characteristic of the soil.

In order to eliminate influences that are of erratic nature, it becomes necessary to obtain the significant experimental data in the laboratory. Although certain general features persist from one place to another in the field, variability of topography, of surface soil, of the soil profile, and of many other minor factors tends to mask the invariant features. The irrigator will, however, observe that if the irrigation stream is not excessive in size, the silt content of the water will tend to diminish with time, ultimately becoming clear. The larger the stream and the greater the slope the larger is the size of particles that will be carried, therefore erosion is a kind of sorting process that so modifies the surface as to stabilize it, provided the size of the stream is not excessive. A stream that is excessive continues to carry away the soil without any tendency toward stabilization if the general character of the soil does not change with depth.

As a basis for analyzing the problem it is of vital importance that two important features that characterize erosion when the stream is below the critical size are recognized. The one feature is that as the stream moves down the furrow the rate at which it picks up silt from the bottom will diminish owing to the fact that the stream tends to become loaded to capacity as it moves along the slope. On the other hand, the silt content of the water at a given point will be at a maximum when the water first reaches this point, and will from that time on tend to decrease with time if the stream is below the critical size. In other words, it will begin to clear up at any point just as soon as the water reaches it owing to the fact that the soil that is most readily erodible will have been removed along the course of the stream. This has been observed over and over again with flume tests in the laboratory and no doubt many farmers and others have made the same observation.

These two features: (1) the tendency of the stream to become loaded to capacity the farther down the slope it moves (2) the tendency for the stream to clear up as time goes on constitute the fundamental background upon which the analytical theory has been developed.

Results of flume tests with one soil under carefully controlled conditions in the laboratory are illustrated in figure 6. Each curve represents the relationship between rate of erosion and slope for the specified size of stream. The curve marked CRITICAL STREAM indicates the slope for each size of stream above which the soil will
not stabilize. For example, this critical curve cuts the curve representing the stream of 0.002 cubic feet per second at a point directly above a point at the bottom representing a slope of 5.1 percent. It is apparent that for a larger stream running down a slope of 5.1 percent there would be no tendency for the soil to stabilize, but rather it would go on wearing down indefinitely. On the other hand it would stabilize for any stream of smaller magnitude.

![Rainfall and Irrigation](image)

**Fig. 6** Rate at which the soil wears down, the slope being the independent variable and the size of the stream the parameter. The points along the curve marked "critical stream" correspond to the erosion rates for streams that are critical for the various slopes.

In a technical paper the analytical detail is given to show the basis upon which these curves are founded. It would be desirable but not necessary that the reader consult this article in order to

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develop confidence in the procedure outlined. He should realize
that the experimental data upon which the analysis is founded are
based on flume tests in the laboratory for a particular soil and not
on field trials. Three measurable soil characteristics are discussed
in the article that will in general vary from one soil to another and
therefore the diagram would require some modification for a soil
that differs appreciably in its erosion characteristics from the soil
represented. Furthermore the water running down an irrigation
furrow will not behave as would the water running down a flume
over a soil that has been leveled and smoothed. These curves do,
however, illustrate in general what would happen in the field. Al­
though they will not necessarily determine the exact size of the
stream that the farmer should use on a tract of land with a given
slope, they illustrate the careful consideration which should be
given to the fact that erosion does increase rapidly with slope.

SUMMARY

In this brief discussion of the erosion problem an attempt has been
made to point out various facts regarding precipitation that are
significantly related to the wearing away of agricultural and range
soils. Weather Bureau records indicate that although great dam­
age occurs from time to time and from place to place, a large per­
centage of the precipitation in the state descends in relatively small
daily amounts and at relatively low intensity.

The results of laboratory tests of the rate at which the soil
is worn down by irrigation water have also been presented and
discussed, and it is hoped that they may assist the farmers in their
efforts to conserve the precious agricultural and range soils upon
which the well-being of the people of the state depends. These
lands are choice above all other lands only insofar as they are
properly utilized and conserved.

College series no. 754