THESIS

THE RELATION OF RAINFALL TO SOIL MOISTURE

by

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1908.

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The Relation of Rainfall to Soil Moisture.

The need of water, while not self-evident is at least apparent to even the superficial observer. Water is everywhere. It covers three-fourths of the surface of the earth and comprises from 40 to 95 per cent of all forms of live, while on the other hand inanimate things, compounds which are generally regarded as dry, may often contain a high percentage of water. The dry dust of the road may contain about 2 per cent of moisture while some soils contain, when fully saturated, as high as 60 per cent of water. The amount of water held by the earth is sufficient to cover the surface of the earth to a depth of sixteen-hundred feet. Soil water is considered under three heads: Hygroscopic, capillary, and free. It is the capillary and incidentally the free water that concerns this article. It is these three classes of water which, by evaporation and under drainage, consitute the circulating water of streams and seas.

We may assume that rainfall which is more or less evenly distributed over the earth's surface, is the natural source of circulating and consequently of soil water. The precipitation of rain is influenced by many factors, chief among which are; wind currents, mountain chains, and large continental areas, and in consequence of the influence of these factors, the rainfall varies from a mere fraction to an inch in the arid regions, such as in portions of the Andes and of the Great African deserts, to as much as 600 inches or 50 feet in Cherapindigo in eastern India.

Part of this water which falls upon the earth's surface passes immediately as surface runoff into streams where it evaporates or flows to the seas. By far the greater per cent, however, is absorbed by the soil and furnishes moisture for plants or is evaporated from the soil surface, or passes downward by the action of gravity to form the free water of the soil, and eventually it finds its way to the streams as seepage water.

There are several factors which influence the amount of runoff, chief among which are the rate of precipitation and surface slope. The other factors are: the season of the year at which the greatest precipitation occurs, or the distribution of the rainfall throughout the year ; the condition of the soil surface whether frozen, packed or loose; the amount and kinds of crops; the per cent of moisture in the soil; and the type of soil. These conditions may be more clearly stated in the form of a law, first by dividing them into controllable and uncontrollable factors and allowing the uncontrollable factors to remain constant; hence:

If the "rate of precipitation" "surface slope" and "type of soil" remain constant, the amount of rainfall that is absorbed by the soil will vary with the amount and kind of crops, the condition of the surface and the percentage of moisture in the soil.

The influence of these several conditions is shown by many natural occurrences. For instance, the influence of rate of precipitation is shown by the general law that " in going from a region of heavy rainfall to one of light rainfall, the surface runoff diminishes at a greater ratio than does the precipitation." This is illustrated by the stream flow of the main tributaries of the Mississippi, which according to Newell (Irrigation and Drainage) is fifty per cent for the Ohio river, whose drainage area receives a precipitation of from 40 to 60 inches, and 20 per cent for the Missouri, whose precipitation is from 10 to 20 inches per annum, while still farther west where the precipitation is very light the streams when found at all, do not have volume enough to maintain a passage to the sea but end in the sand or salt lakes or marshes.

The influence of the surface slope is illustrated by mountains and prairie regions. In the former we find numerous deep gullies and canyons which have been worn by freshets caused by most of the rainfall rushing immediately from the steep slopes, into the streams which during the storm are raging torrents and in a few hours are quiet streams.

The streams of the prairie region are almost exactly the opposite to this. We find the waterways far apart, sluggish and slow; no rapid fluctuations in volume after heavy rains. The influence of the type of soil may be shown by the washing of clay and sands. In the former the water is absorbed so slowly that it collects in the depressions and finally forms streams which often cut deep gullies. This seldom occurs in sand, unless the slope is considerable and even when the slope is great, clay washes most. Sand allows a more rapid percolation of water, hence there is not so much surface wash. This was further illustrated by a laboratory experiment. Three tubes nine inches long and 1.5 inches in diameter were filled with an inch of the top with sand, clay, and loam respectively, each being firmly packed. The tubes were connected with an overflow pipe so that each was kept under one inch of water. It required seven minutes for the water to reach a constant flow through the sand, 33 hours for the clay, and 27 hours for the loam. Hence, sand will absorb water many times faster than clay or loam.

All kinds of vegetation, herbs, trees, and grasses check the flow of water from the surface, thus allowing water more time to percolate into the soil. The influence of vegetation upon runoff is perhaps shown more clearly upon deforested areas than elsewhere, although the destroying of the natural vegetation by the settlement of the west is responsible, to some extent at least, for the increase in the amount of runoff.

Wherever the drainage basin of a river has been covered with a heavy forest and subsequently removed, there has always followed an increase in runoff. The excessive floods of the lower Ohio and subsequently the lower Mississippi, are due to the removal of the forests from the head waters of those rivers: Notwithstanding the fact that Rafter (Relation of Rainfall to Runoff) says that this is not true with the rivers of New York. The apparent inconsistency of his conclusions may be explained by the fact that his results were obtained by measurements of stream flow. Such measurements of stream flow include not only the runoff proper but also the seepage water due to underflow.

The forests prevent immediate, high discharges of water into streams, but as the accumulation of ground water increases, the seepage increases, until the seepage flow compensates the stream for the lack of runoff.

The writer observed during the Neosho floods of '04, that vegetation exercised great influence upon the flow of water. During that year the river overflowed three times, May 2, June 2, and July 3 respectively. The first overflow covered the whole bottom lands, averaging about two feet deep. The crops were only a few inches in height and consequently they were soon covered. During the period of the flood, we went over about 3000 acres in a boat and marked the height of the water upon the trees and posts. When the second overflow came the wheat and rye was full grown, standing perhaps four feet high. The water covered the old river beds and low places fifteen or twenty feet deep. Here the currents were maintained, but over the higher portions of the fields it did not cover the wheat and rye. Wherever the old river bed and low places occurred in the fields the water rose eighteen inches above the former flood, but amid the wheat an rye it did not rise more than four or five inches higher and in some places failed to reach the marks of the former flood. This flood remained for eight days and so killed all crops. Consequently when the third overflow came there was no vegetation growing and the water rose evenly, perhaps four inches above the first flood, there being no difference in height of water between the low places, where the current flowed, and the adjoining higher portions of the fields.

The influence of a hard surface upon the absorption of rainfall is shown by the comparison of a hard road surface with adjoining, newly plowed fields. In the latter it requires an exceptionally heavy rain before any water escapes as runoff while with the former the most causual shower fills the roadside ditches.

Another laboratory experiment illustrates these characteristics of loose and hard soils. Six tubes were filled with soil. Two of them contained fine sand, one of which was packed and the other loose; two others were filled with clay and were treated the same way; while the remaining two were filled with loam, which were treated the same as the two preceeding sets. The tubes were connected so that an inch of water was maintained over each tube.

The water came through the loose sand in five minutes while it required seven minutes for it to percolate through the same depth of packed sand. The difference in time of percolation between loose and compact clay was thirty hours and forty-five minutes, while that of loam was twenty-four hours and thirty-five minutes. In either case it shows a great advantage in favor of the loose soil.

The first action between dry soil and water is one of repulsion, but as the soil becomes moist, absorption increases until the soil has reached its full capilary capacity. Then the rate of percolation or absorption diminishes until the point of saturation is reached and the entire precipitation passes immediately off, hence the percent of poisture in the soil influences the amount of absorption.

The question is still further complicated by the varying rate of precipitation, also by the tendency of the rainfall to come at different times of the year. Beside, all types of soil are present in any area of considerable extent. Consequently every area will have a different rate of absorption.

From the foregoing it is evident that the rate of runoff and conversely the rate of absorption is very difficult to determine and must of necessity be only approximated. Notwithstanding the indefiniteness of such estimates, it is nevertheless important, especially in the arid and semi-arid regions to know how much of the rainfall becomes available for crops, because agriculture must depend upon rainfall for its moisture, except in a few favored spots where irrigation is possible. Hence, if the amount of soil moisture can be modified by the methods of tillage it becomes important that farmers pursue such methods to the limit of practicability. However, there is another phase of the subject which should be considered here in reference to the amount of rainfall that becomes available for crops. That is, the various physical factors which enable a soil to retain the water which passes into it.

The amount of surface evaporation which reaches above fifty per cent, will be disregarded here, because the discussion belongs to another subject. Also the ability of soils to raise water by capillarity will be disregarded. But the amount of water that passes away by seepage will be discussed, briefly, so as to show the percentage of rainfall that can be relied upon for plant use. This is necessary because the water which passes beyond the limit of evaporation eventually finds its way into the streams and is lost to vegetation just the same as if it had escaped from the surface.

The runoff estimated by the discharge of rivers (Geike Third Edition of Geology, pg 373) shows great variation. He says that the discharge of rivers in general varying from one to one-hundred cubic feet per minute per acre of catchment area, the amount varying with the precipitation varies with the rate of precipitation, i. e. the amount per hour. The amount of discharge also depends upon whether the rain is crowded into a rainy season or extended over the entire year.

The same author gives the discharge of the Thames river in England at 32.40 cu. in. per minute per acre. This amounts in one year to 7.31 inches or a little less than one-third of the total precipitation. This amount did not very much in a record of ten years.

The Miss. River has a discharge of 30 cu. ft. per acre, per minute, or 6.477 inches, which means 24 per cent of the precipitation. The variation of runoff can be further shown by considering the several tributaries of the Mississippi separately. The Ohio river has a runoff of 24 per cent or 10.8 inches per annum. The Upper Mississippi has a runoff of 24 per cent, or 8.4 inches per annum, while some of the small tributaries lose as high as 90%.

Rafter, in his relation of Rainfall to Runoff (Irrigation Papers No. 80) shows that the number of inches discharged by runoff does not depend upon the size of the catchment area. He does show, however, that streams where precipitation ranges from 50 to 60 inches per annum lose more than 50 per cent in runoff, regardless of size of area, while those with a precipitation of from 40 to 50 inches lose much less than 50 per cent.

Again, such streams as the Loupe river of Nebraska, where rainfall for 1894 was 12.84 inches, lost only one inch by runoff; also the South Platt river, with a precipitation of 11.84 inches for the year 1906, lost only .62 inches by runoff, while the Republican river at Junction, Nebraska, lost only .39 of an inch in 1898, when the precipitation was 26 inches.

From the foregoing it is obvious that no general rule can be formulated for computing the amount of runoff or absorption. It must be borne in mind, however, that the runoff as given by stream flow includes both the runoff proper and the seepage due to underdrainage. Nevertheless, the data given bears a direct relation to the amount of rainfall that becomes available for crops.

In order to determine how much of this runoff was seepage water the writer conducted an experiment which lasted from May 1907 to June 8, 1908. For this purpose four plots of sandy loam 4 x 3 feet were portioned off so that the rainfall from each ran into a covered guage. Two of the plots were given a slope of 23 feet per 100; the other two had a slope of two feet per 100. One of the plots with the heavy slope and one of those with a light slope were kept loosened after every rain, so as to show the influence of loose soil. The results are given in the following tables.

Plot No. 1, Slope 23 -- 100; surface loose.

Date	Rainfall, inches.	Runoff, inches	Soil Moisture, inches	Water retained, %.	Time of Precipitation. hrs.
March					
3	T	00	T	100	1
4	.11	00	.11	100	2
5	.25	000	.25	100	2
6	.12	00	.12	100	1
30	.15	00	.15	100	1
April					
4	.1	00	.1	100	1
5	.12	00	.12	100	2
7	1.2	.15	1.08	87.8	6
14	.1	00	.1	100	.5
16	.02	00	.02	100	.5
17	1.21	.20	.94	77.69	6
21	T	00	T	100	1
22	.13	00	.13	100	2
23	T	00	T	100	1
24	.05	00	.05	100	1
26	T	00	T	100	1
27	T	00	T	100	1
May					
4	2.91	.23	2.68	92.76	20
5	113	00	.13	100	2
6	156	00	.56	100	11
10	.61	00	.61	100	7
11	.64	00	.64	100	3
13	.12	00	.12	100	1.75
14	.07	00	.07		2
17	2.05	2.05	1.69		15
21	.35	.00	.35		2
23	.72	.028	.69	96.1	1
24	.25	00	.25	100	1
28	.78	.025	.65	97.8	1.5
31	.13	00	.13	100	1
June					
2	1.32	.27	1.05	79.34	4
4	.02	00	.02	100	.5
5	.40	00	.40	100	2
7	2.53	.37	2.16	83	8
8	.25	00	.25	100	

Average -- 94.5

T = trace, too small to record.

Plot No. 2, Slope 23 -- 100; surface hard.

Date	Rainfall, inches.	Runoff, inches.	Soil moisture, inches.	Water retained,%.	Time of precipitation, hours.
March					
3	T.	00	T.	100	See Plot I.
4	.11	00	.11	"	"
5	.25	00	.25	"	"
6	.12	00	.12	"	"
30	.15	00	.15	"	"
April					
4	.1	00	.1	"	"
5	.12	00	.12	"	"
7	1.2	.12	1.05	90	"
14	.1	00	.1	100	"
16	.12	00	.02	100	"
17	1.21	.16	1.05	86.8	"
21	T.	00	T.	100	"
22	.13	00	.13	"	"
23	T.	00	T.	"	"
24	.15	00	.05	"	"
26	T.	00	T.	"	"
27	T.	00	T.	"	"
May					
4	2.91	.20	2.71	.93	"
5	.13	00	.13	100	"
6	.56	00	.56	"	"
10	.61	00	.61	"	"
11	.64	00	.64	"	"
13	.12	00	.12	"	"
14	.07	00	.07	"	"
17	2.05	.25	1.8	87.9	"
21	.35	00	.35	100	"
23	.72	.03	.69	95.9	"
24	.25	00	.29	100	"
28	.78	.028	.76	96.4	"
31	.13	00	.13	100	"
June					
2	1.32	.16	1.16	87.88	"
4	.02	00	.02	100	"
5	.4	00	.4	100	"
7	2.53	.28	2.25	89.	"
8	.25	00	.25	100	"

Average ------- 97.9

Plot 3, Slope 2 -- 100; surface loose.

Date	Rainfall, inches.	Runoff, inches	Soil moisture, inches.	Water retained, %.	Time of precipitation, hours.
March	See Plot I.				See Plot I.
3	"	00	T.	100	"
4	"	00	.11	100	"
5	"	00	.25	100	"
6	"	00	.12	100	"
30	"	00	.15	100	"
April	"				"
4	"	00	.1	100	"
6	"	00	.12	100	"
7	"	.11	1.09	90.1	"
14	"	00	.1	100	"
16	"	00	.02	100	"
17	"	.11	1.1	90.1	"
21	"	00	T.	100	"
22	"	00	.13	"	"
23	"	00	T.	"	"
24	"	00	.05	"	"
26	"	00	T.	"	"
27	"	00	T.	"	"
May	"	00		"	"
4	"	.19	2.72	93.5	"
5	"	00	.13	100	"
6	"	00	.56	"	"
10	"	00	.61	"	"
11	"	00	.64	"	"
13	"	00	1.12	"	"
14	"	00	.07	"	"
17	"	.20	1.85	90	"
21	"	00	.35	100	"
23	"	.05	.72	93	"
24	"	00	.25	100	"
28	"	.05	.72	93.5	"
31	"	00	.13	100	"
June					"
2	"	.15	1.17	88.87	"
4	"	00	.02	100	"
5	"	00	.9	100	"
7	"	.21	2.32	92.6	"
8	"	00	.25	100	"
					"
					"
			Average ----	98.1	

Plot 4, Slope 2 -- 100; Surface hard.

Date	Rainfall, inches.	Runoff, inches.	Soil Moisture, inches.	Water retained,%.	Time of precipitation, hours.
March	See Plot I.				See Plot I.
3	"	00	T.	100	"
4	"	00	.11	100	"
5	"	00	.25	100	"
6	"	00	.12	100	"
30	"	00	.15	100	"
April	"				
4	"	00	.1	100	"
6	"	.00	.12	100	"
7	"	.13	1.17	89.4	"
14	"	00	.1	100	"
16	"	.00	.02	100	"
17	"	.125	1.17	89.7	"
21	"	00	T.	100	"
22	"	00	.13	100	"
23	"	00	T.	100	"
24	"	00	.05	100	"
26	"	00	T.	100	"
27	"	00	T.	100	"
May	"				
4	"	.20	2.70	.93	"
5	"	00	.13	100	"
6	"	00	.56	100	"
10	"	00	.61	100	"
11	"	00	.64	100	"
13	"	00	.12	100	"
14	"	00	.07	100	"
17	"	.21	1.84	89.6	"
21	"	00	.35	100	"
23	"	.05	.67	93	"
24	"	.00	.25	100	"
28	"	.05	.73	93.6	"
31	"	00	.13	100	"
June	"				
2	"	.16	1.16	87.88	"
4	"	00	.02	100	"
5	"	00	.40	100	"
7	"	.23	2.30	90.1	"
8	"	00	.25	100	"

Average--- 98.

The chief objection to these results is that the experiment was not conducted long enough to make the data good averages. The rainfall for the spring and summer of '07 was very light, only one storm of the year being sufficient to cause a runoff and then only from a closely cropped pasture.

The first rain of sufficient volume to cause runoff occurred on April 7, '08. A precipitation of 1.2 inches gave a runoff of .12 inches or ten per cent. The time of the least runoff was on May 28, with a precipitation of .75 of an inch, the runoff being .025 of an inch, or 3.2 per cent. The maximum runoff occurred on June 7, when .37 or 14.8 per cent escaped, the precipitation being 2.53 inches.

From the above tables it is apparent that the rate of absorption of water by soil is practically constant, or more clearly, a soil will absorb a definite amount of water in a given time. This constat varies with all the above mentioned factors, as given in the law mentioned on page 441.

The idea is advanced by some writers that the amount of runoff in acre inches depends upon the size of the catchment area, the argument being that the water from the higher areas pass successively over the lower areas, thereby giving the soil more time to absorb. This argument, however, is weak in that the water does not pass successively over the lower areas in a sheet but seeks the depressions and forms small streams, thereby lessening the area covered. Beside, this water does not escape from a soil surface until the rate of precipitation exceeds the amount of that particular soil's rate of absorption, hence the lower areas have all they can do to abosrb their own precipitation.

Quoting again from Rafter's Relation of Rainfall to Runoff, he says; "There is no distinct relation between runoff and catchment area," consequently, the time element is active only as long as the precipitation continues.

The influence of rate of precipitation is shown by comparing the results of May 4 with June 7. In the first instance 2.91 inches fell in about twenty hours. The runoff in this case was .23 of an inch. On June 7, 2.53 fell in 8 hours. The runoff in this case was .37 inches. The runoff was .14 of an inch, or 8.26 per cent more when 2.53 inches fell in 8 than it was when 2.91 inches fell in 20 hours. The other conditions remained practically the same. Consequently, the increase of runoff must be due to the greater rate of precipitation.

It must not be inferred from this comparison that the precipitation was constant or uniform in either case, but on the contrary. It was intermittent at times was only adripple. The influence of slope is distinctly shown by comparing the results of plot No. 1 with plot No. 4, where the surfaces were in the same condition. Plot No. 1, whose slope was 23 to 100, lost, on June 7, 14.5 per cent by runoff while plot No. 4, whose slope was 2 feet to 100 feet, lost only 9.9 per cent, or plot No. 1 retained 84.5 per cent of the rainfall while plot No. 4 retained 90.1 per cent, showing a saving of 5.6 per cent in favor of the lighter slope.

The results of plot 1 and 2 whose slopes were the same may be used to show the influence of a loosened surface upon absorption. For instance, plot No. 1, which was hard, lost on April 7, .15 of an inch while Plot No. 2, whose surface was loose, lost .12 of an inch.

The influence of the loose surface is made much more striking when comparing plot No. 2 with plot No. 4. The runoff from plot No. 2 on April 7 was .12 of an inch, while Plot No. 4 lost .13 inches. Again, on June 7, No. 2 lost .28 inches while No. 4 lost .23. In this case the loosened surface nearly compensated the difference in fall.

Drawing conclusions from this limited and thereby questionable data, it would appear that the runoff as given by stream flow is too large, and consequently must contain quite a large per cent of seepage. We must bear in mind the fact that this experiment was conducted upon sandy loam soil and consequently the percent of runoff is below the average.

The general averages of these plots indicate that about 99.4 per cent of the rainfall is absorbed and 23.4 per cent of it is lost by seepage. The loosening of the surface enables the soil to abosrb 1.8 per cent more moisture. Consequently, we may calculate on approximately 76 per cent of the rainfall for crops on sandy loam soils.

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