A STUDY OF THE ABSORPTION AND
LOSS OF SOIL MOISTURE

by

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INTRODUCTION.

The importance of soil moisture is realized by the common observer as his attention is attracted to the suffering vegetation in time of drought. Its greater importance is realized by the few, who have investigated the problem and have discovered how intimately the supply of soil moisture is connected with plant life. The attempts to determine the relations existing between soil and plant have shown that the influencing factors are many and that the problem of controlling the soil moisture supply is a very complicated one.

It is generally accepted that the soil may retain it's moisture in three different states, namely: hygroscopic, capillary, and free or gravitational. These forms differ, not in their composition, but in the position which they occupy in relation to the soil particles. The hygroscopic and capillary water exist as film forms. They surround the soil particle, and are held partly by the attraction of the particle, and partly by the molecular attraction of the liquid. The hygroscopic film of water is spoken of as the water of condensation or adsorption; the capillary water as that portion of the film in which molecular movement, except for the influence of viscosity, is perfectly free and unimpeded. The free or gravitational water is termed that portion of soil moisture which moves thru the soil unimpeded and percolates away. It is the moisture which is in the capillary state that concerns us most, inasmuch as it is as capillary water that the plant is able to secure most of its supply.

When rain or irrigation water enters the soil it is absorbed principally as capillary moisture. If more water falls than can at once penetrate, it runs off the surface and is known as 'runoff'. If an over supply enters the soil, it percolates away as free or gravitational water. What becomes of the amount retained by the soil, as capillary or film water, is the important matter from the standpoint of the plant. That the plant uses large quantities of this capillary or film water has long been known, and that considerable quantities escape from the soil thru evaporation is also known. Evidently during seasons of deficient rainfall the amount of water escaping by evaporation is of great importance, and it has been the attempted elimination of this loss thru the use of soil mulches that has formed the most important feature of the plan of moisture control.

It has been commonly believed that the evaporation of moisture from the soil surface was greatly facilitated by the rise of moisture thru capillary action impelled by the laws of surface tension and capillarity. It has been thot that this rise could be rather readily controlled by the use of a soil mulch, and that where proper tillage was given to cultivated crops, this surface evaporation could quite largely be prevented. Recent investigations have created some doubt as to the importance of rapid capillary rise, as well as to the importance of the soil mulch. Leather of India for instance, denounces the use of the word 'capillary' in relation to soil moisture. He says, "it is true that surface tension is the

cause of the retention of water in soils, but the term 'capillary' should be restricted to the case of a liquid completely filling a narrow space. In the upper soil, i.e., the aerated soil in which our crops develop, this condition does not exist and hence the impropriety of the term 'capillary'." Rotmistrov of Russia says, "the less said about the capillary rise of water the better." Shantz's of the U. S. D. A., and Burr of the Nebraska Experiment Station have shown that under arid and semi-arid conditions water does not move upwards with any degree of rapidity, unless the water-table is close to the surface. The view these men take is almost contradictory to the old idea of capillary movement of moisture from the lower to the upper soil layers. It is contrary to the theory upon which the use of the dry-mulch was based.

The object in carrying out the investigation here reported has been to determine certain facts which would help to formulate the correct idea of moisture movements. The investigation not only includes a laboratory study of certain physical forces at work in the soil, but also a careful investigation of the more important question of soil moisture movements in the field. The investigation is only the initiation of a continued study which is to be made on this question at Missouri University.

PREVIOUS INVESTIGATIONS

Investigations concerned with Percolation and Evaporation Losses

Dalton, as far back as 1796, constructed a percolation gauge, consisting of a cylinder three feet deep, filled with soil, and sunk in the ground to the level of its upper edge, arrangements being made for collecting and measuring the water which passed thru. His investigation extended over a period of three years and from the results he drew the deduction that 25% of the rain percolated away and that 75% was lost by evaporation.

It is necessary to note here that this mode of experimenting, which was later adopted by many observers, such as, Maurice, Gasparin, Dickinson and Evans, Greaves, Ebermayer*, and others, required that the soil forming the drain-gauge should be more loose and open in structure than the natural consolidated soil of a field, thus admitting a freer percolation. Care has seldom been taken to include the natural subsoil in the percolation-cylinder which has generally been filled entirely with a surface soil. The surface of the gauge has again not been interfered with, and has sometimes become covered by a mass of grass and weeds. The evaporation is of course greatly increased by the presence of this vegetation.

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* A brief notice of the results of Maurice, Gasparin, Ebermayer, and others with a summary of results obtained at Rothamsted up to date, will be found in the Minutes of the Proceedings of Civil Engineers, Session, 1876.

During 1796 and 1797, Maurice of Geneva carried on investigations concerning the amount of percolation and evaporation losses of soil moisture. The procedure he followed was similar to Dalton's method. Cylindrical iron vessels filled with earth were used. The rainfall averaged for the two years about 26 inches per annum, 39% of which was lost thru percolation and 61% by evaporation.

During 1821 and 1822, Gasparin of Orange, South of France, carried on experiments somewhat similar to those of Maurice, and with an average rainfall of 28 inches per annum found that only 20% was lost thru percolation and 80% by evaporation.

Of the results obtained by the Dalton gauges by far the most extensive were those by Dickinson, Nash Mills, Hemel Hempstead, Herts, commencing in 1836*, later continued by Evans; and those commenced by Greaves at Lee Bridge in 1851, and carried on to the present time. Greaves' works will be discussed later.

Dickinson and Evans employed two drain-gauges consisting of cast-iron cylinders 3 feet in depth, and 18 inches in diameter. One was filled with the surface soil of the neighborhood, the other with fragments of chalk; both bore a growth of grass. During the first eight years of the experiment which was conducted by Dickinson, he found that 42.5% was lost

* Results for the first eight years are recorded in the Journal of the Royal Agricultural Society, 1845, p. 150.

thru percolation and 57.5% by evaporation which included that due to vegetative growth. The average rainfall during the 8 years was 26.61 inches.

Evans, 1860 to 1873, continuing the work of Dickinson found even more striking example of the disturbing action of vegetation than those of Greaves (note Greaves works below). The average rainfall during fifteen years was 25.55 inches. The summer drainage from the turfed soil averaged 0.35 inches, the evaporation 12.12 inches. The winter drainage was 5.23 inches, the evaporation 7.85 inches. In the whole drainage-year the average drainage was 5.58 inches, the evaporation 19.97 inches. The summer evaporation, however, actually ranges from 7.59 to 16.09 inches, and that of the whole year from 13.20 to 26.55 inches.

Lawes, Gilbert, and Warrington* say, "that this wide range in the amount of evaporation was in part due to the insufficient supply of rain. The full evaporation power of the turf has perhaps not yet been shown, the whole of the rainfall having been evaporated even in the wettest summer of the fifteen years. In these experiments the distribution of the rain has a marked effect on the amount of drainage. Rainfalls not sufficiently heavy to penetrate the turf are probably evaporated while those passing the turf appear, more or less, as drainage."

In the percolator filled with chalk, the average annual drainage was 8.79 inches, and the evaporation 16.76 inches.

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* Journal Royal Agricultural Society, Ser. II, 17, p. 55.

The soil no doubt being less compact in this case and the growth of grass being more vigorous than in the percolator filled with arable soil, the drainage was therefore naturally larger and the evaporation less.

During 1867 and 1868, Risler of Caleves, near Nyon, Switzerland, by using gauging drains 1.2 meters (about 4 feet) deep, filled with compact and impervious subsoil, the land being cropped as usual during experiment, found that 30% was lost thru percolation and 70% by evaporation. The evaporation included that due to plant growth on the surface. The average rainfall was 41 inches per annum.

Greaves'* drain-gauges consisted of two square boxes made of slate, 3 feet in depth and 3 feet square; one of these was filled with sand (such as is employed for filter-beds, passing thru a screen of 33 #10 wires in 6 inches) to within 2 inches of the top, the other with a mixture of soft loam, gravel and sand, trodden in and turfed. He had also a gauge for measuring the evaporation from a water-surface, consisting of a tank one foot in depth, and having an area of one square yard; this tank was kept afloat in a flowing stream. The tank contained a few inches of water, the rise or fall of which was ascertained from time to time. It is to be noted that Greaves' investigations were undertaken from an engineering rather than from an agricultural viewpoint and are interpreted as such.

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* Minutes of the Proceedings of the Institute of Civil Engineers, session 1876, p. 53.

Greaves' results respecting, Drain-
age and Evaporation

Average of 14 years, 1860 - 1873.

Month	Rainfall	Drainage		Evaporation		
		Sand	Turfed soil	Sand	Turfed soil	Water
	inches	inches	inches	inches	inches	inches
Jan.	2.870	2.734	2.029	0.136	0.841	0.761
Feb.	1.596	1.524	1.085	0.072	0.511	0.603
March	1.936	1.605	0.879	0.334	1.060	1.065
April	1.428	1.117	0.275	0.311	1.153	2.098
May	2.056	1.656	0.105	0.400	1.951	2.753
June	2.205	1.572	0.156	0.633	2.049	3.142
July	1.774	1.212	0.013	0.562	1.761	3.443
Aug.	2.332	1.783	0.113	0.549	2.219	2.850
Sept.	2.347	1.737	0.071	0.610	2.276	1.606
Oct.	2.730	2.402	0.515	0.328	2.215	1.056
Nov.	2.021	1.963	0.833	0.058	1.188	0.707
Dec.	2.422	2.173	1.508	0.249	0.914	0.574
Whole Year	25.720	21.478	7.582	4.242	18.138	20.658

The mass of sand which fills one of the percolators supplies an extreme example of a soil of the lowest water-holding and capillary power. The rain passes thru it without hindrance, and but little water is evaporated from the surface even in the height of summer. In the whole year the quantity calculated as evaporated amounts to but 4.242 inches. The true amount of evaporation is probably greater than this, however, as it is not very uncommon for the drainage from this gauge to exceed the rainfall, owing, as Greaves supposes, to condensation of water directly from the atmosphere. This excess of drainage over rainfall occurs most frequently in January and February.

On the turfed soil the amount of evaporation from January to March is very similar to that observed on the bare soil at Rothamsted (note later data in regard to Rothamsted results); but from April to September - the growing season of the grass - practically no drainage takes place, nearly the whole of the rainfall being evaporated. Drainage-water was indeed collected in July and August only on two, in June on three, and in May and September on four occasions during the fourteen years. The average amounts of water evaporated from the turf during summer, winter, and the whole year, namely, 11.409, 6.731, and 18.123 inches, are very similar to those of Rothamsted, probably because of the very moderate amount of rainfall supplied to the soil. In the wet summer of 1860, 15.608 inches were evaporated by the turf in six months; and the wet season of 1872, the evaporation during twelve months reached 25.141 inches. There is thus but little constancy in the amount of evaporation, which depends largely on the amount of rainfall, and on the activity of the vegetation. With a heavier rainfall we should doubtless obtain more constant figures.

The figures representing the evaporation from a water surface are full of interest. The average summer evaporation is 15.892 inches; that for winter, 4.766 inches; the total for the year 20.658 inches. The amount of variation is considerable. In 1862 the annual evaporation was only 17.332 inches; in the hot season of 1868 it reached 26.933 inches. There are some obvious reasons why the evaporation

from a water surface should be more variable than that from a bare soil. On a water surface sunshine and wind must always produce their full effect, while on soil, evaporation receives a check as soon as the surface is dried. Another disturbing cause in Greaves' determinations has been variable condensation from the atmosphere, making the winter evaporations appear lower than they really are.

Greaves found that in the gauge containing a mixture of soft loam, gravel and sand, trodden in and turfed, for a period of 22 years, with an average rainfall of 25.8 inches that 29.8% was lost by percolation and 70.3% by evaporation. That for the similar gauge containing sand, during a period of 14 years and with an average rainfall of 25.7 inches, 83.6% was lost by percolation and 16.4 by evaporation.

Ebermayer of Bavaria ran a series of experiments during the 12 months, March 1868 to February 1869. His gauges consisted of zinc cylinders, with an area of one square foot, and 1, 2, and 4 feet (Fr.) deep, filled with adjacent soil and exposed to air and rain for sometime to acquire normal physical characters. He found the following results:

Percentage of Percolation to Rainfall

	1 foot deep (Fr.)	2 feet deep (Fr.)	3 feet deep (Fr.)
Open ground, bare.....	54	50	53
Forest, without litter....	67	-	-
Forest, with litter.....	74	77	60

It might be noted in regard to Ebermayer's work in order to show how difficult it is to imitate soil in its natural condition, that he attempted to fill, by calculation, a number

of tubes, 5 feet deep and 2 feet in diameter, with the soil of the immediately adjoining field in its exact natural condition. After putting in 3 feet of soil, pouring a great deal of water thru, and applying a weight of more than one ton for many months, the soil had not sunk down to the 3 feet by about 6 inches. It is almost impossible by artificial means to compact a soil like a natural one.

Ebermayer quotes Woldrich as having determined the amount of percolation (2 feet deep) thru turf, and thru bare ground, at Salzburg and in the neighborhood of Vienna. At Salzburg the percolation was

In May	25.2%	less	thru	turf,
In June	53.1%	"	"	" ,
In July	23.4%	"	"	" ,
In Aug.	29.3%	"	"	" ,
In Sept	12.7%	"	"	" .

The difference was the least in January. In May, both at Salzburg and at Vienna, more than twice as much percolated thru bare earth as thru turf. From June 16th to 30th there percolated at Salzburg

2.13 inches	thru bare earth,
0.02 inches	thru turf.

The maximum difference was in June and July, and less in autumn and winter. Ebermayer concluded that in the summer half-year forest soil was the moistest, bare, open ground less moist, and turf the driest.

The Rothamsted gauges offer a marked step in advance in studying the percolation and evaporation question of soil moisture. They differ from those of Dalton, as well as all previous observers, in containing undisturbed soil, and as Mil-

ler* says in commenting on them, "soil which has been put into cylinders and subjected to the action of rain, will no doubt, as time goes on, acquire a more and more natural condition of consolidation, but we cannot know when this desirable condition is completed and can only take it for granted after a considerable time. The Barnfield gauges are free from this disadvantage, and as a means of measuring drainage which is what they were mainly intended for, leave very little to be desired. As regards, however, the relation of the constituents of the drainage to those of the soil, our knowledge must always be somewhat imperfect, since it is obviously impossible to obtain exact estimates of what the soil originally contained."

In the summer of 1870, the three drain-gauges were established at Rothamsted. Each gauge consisted of an area of 1/1,000th of an acre. The soil was undermined at the desired depths (20, 40, and 60 inches, respectively) and perforated iron plates were inserted beneath the soil to support it as the undermining proceeded. When this was completed, trenches were then made on the other three sides of the blocks of soil, and these were then isolated by means of 4½ inch brick walls.

Miller reports that the average yearly amounts of water percolating thru 20, 40, and 60 inches of soil are very similar and amount to about 14 inches, or approximately 50% of the rainfall. The results obtained with the 20- and 60-inch gauges were nearly identical; while the 40-inch gauge yields on

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 * Rothamsted Memoirs, Vol. VIII, 1902-1912, p. 377.

the average nearly one inch more drainage than the others.

At Grignon, near Paris, experiments similar to Greaves' were conducted between the years 1892 and 1897 by Deherain* in a number of gauges (20), which consisted of cement tanks into which the excavated soil of the site had been refilled; the surface and sub-soil being placed in the tanks in their natural relative positions. The soil of several of these gauges was maintained fallow, whilst on the majority various crops were cultivated. The effect of these crops on the amount of drainage varied, but in the year 1896-7, of which the quoted records are the most complete, the amount of drainage water was from about three-fourths down to one-half of that from the fallow gauges. Thus at Grignon the effect of the crop was very much less marked than in Greaves' experiment.

Wollny** in 1894 found, in experimenting with soil from 5 centimeters to 30 centimeters deep, that the amount of drainage diminished with the depth of the soil up to a certain point (15 centimeters of soil) and then increased. The percentage increasing considerably with the depth of the soil up to 20 centimeters and then remaining fairly constant.

Four gauges for the measurement of the amount of water which percolates thru agricultural land, were constructed by Leather*** of India at the Cawnpore Agricultural Experiment Station in 1903, and four similar gauges at the Agricultural Research Institute, Pusa, in 1906. All of these gauges were similar to those at Rothamsted, and consisted of blocks of or-

* Reported by Leather, Memoir of the Dept. Agric. Chem. Series 2, p.79

** From Wollny's Forschungen, 16, 1-14.

*** Memoirs, Dept. of Agric. of India, Chem. Series, 1, No. 5.

dinary agricultural land measuring 1/1,000th of an acre superficially. They were isolated and walled in, and "false bottoms" inserted beneath them; at each station two gauges are 3 feet deep and two are 6 feet deep. Apparatus below the gauges was constructed to collect and measure the drainage water coming thru. It is noted, that in addition, the gauges at Pusa have overflow pipes connected to subsidiary tanks to take off "surface" drainage, which is thus measured separately.

Up to 1911, Leather* reports, that, (a) the amount of drainage and evaporation in India exhibit the same characteristics that have been met with at Rothamsted, namely, the quantity evaporating is nearly independent of the season, whilst the drainage varies with the rainfall; (b) one effect of a crop is to reduce the amount of water evaporating from the surface soil, and the Indian records have provided an estimate of this protective effect. A good crop, whilst itself transpires large amounts of water, will reduce loss of moisture in this manner to two-thirds or one-half of what it would be from fallow land; (c) the evidence of the Indian records goes to show that the water descending during wet weather passes very uniformly thru the soil and not chiefly by means of "larger channels" as has been commonly supposed.

At Cawnpore, India, for a five-year period, 1904-8, and with a rainfall of 31.4 inches, Leather found 38% of the rainfall percolated away, whilst 62% evaporated, from the 6-foot gauges. In the case of the 3-foot gauges for the same period, 42.9% was percolation loss and 57.1% evaporation loss.

* Memoirs, Dept. of Agri. of India, Chem. Series, Vol. II, #2.

At Pusa, India, for four years, 1906 to 1910, with an average rainfall of 42.41 inches, the mean percolation was 24.61% of the rainfall and the mean evaporation 68.12% for the 6-foot fallow gauge. For the 3-foot fallow gauge the mean percolation was 29.50% and the mean evaporation 67.28%.

At Cornell University*, Ithaca, N.Y., a system of cement tanks has been constructed. Each tank is about four and a half feet square and four feet deep. The tanks are sunk in the ground and a sloping bottom is provided, with a drainage channel opening into a tunnel beneath and at one side. As the tanks are arranged in two parallel rows, one tunnel suffices for both. The sides of the tanks are treated with asphaltum in order to prevent solution. Owing to this method of construction the soil was placed in the tanks. This caused a disturbance of its structural condition which of course will make the rate of flow and composition of the drainage water out of accord with field conditions for a number of years. Such an experiment must necessarily be one of long duration. The results obtained have not been reported, except for a few analysis made upon the drainage water.

* Science, N.Ser., Vol. 29, No. 746, pp. 621-623. 1909.

Investigations concerned with the Action of Capillarity

Numerous determinations of the capillary rise of water in dry soils have been made by various investigators in the United States, as well as in foreign countries (England, Germany, India, and others). Loughridge's* studies on the California soils are among the best of those made in the United States. In his investigations which included adobe and silty soils, he found that the capillary rise in no case exceeded 50 inches, even at the expiration of 200 days.

King** in 1889 in investigating the capillary movement of water in a moist sand resembling quicksand, which underlies the Wisconsin Experimental Farm, found a very appreciable capillary movement of water upwards. The columns of soil were placed in water, the water-level being regulated at 1, 2, 3, and 4 feet from the surface. King found water to pass upwards at rates varying from 2.37 pounds to 0.9 pounds per square-foot per day.

King*** in results from later experiments discusses the data of certain investigations in which soil columns 10 feet long and with a cross section of 0.04611 square feet made of water-tight galvanized iron tubes, were exposed to drying influences for 314 days, at the conclusion of which time the loss of water appeared to be felt slightly at 10 feet from the surface. He says, "it is certain that a drying of these soils had taken place thru a depth of 10 feet and hence the moisture

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* California Agri. Exp. Sta. Report, 1892-3-4, p. 91.

** Wisconsin Agri. Exp. Sta., Sixteenth Annual Report, p. 203.

*** Ibid., p. 219.

10 feet below the surface of the ground may become available for vegetation purposes at or near the surface! Briggs and Lapham in commenting on the results, say, "King's results do not show the capillary limit of the soil that he had under investigation, but show only that the capillary limit exceeded the length of the soil column used." King, also, remarks in the discussion of his results, "that it does not follow necessarily from the experiments recorded that the upward movement here found was due to capillarity alone as it may be found that internal evaporation takes place in soils allowing water to pass up thru the soil pores of drier soils by gaseous diffusion and condenses on the colder soil grains higher up."

King* in 1905 determined the evaporation in the open from soils supplied from below with a constant water-supply, by means of large cylinders four feet in diameter and two feet deep. A shelter was constructed within the cylinders containing a device which automatically recorded the rate of evaporation. He obtained the following results:

Soil	Total for season Inches	Mean per day Inches	Mean per day lbs. per sq.ft.
-----	-----	-----	-----
Goldsboro, N.C. Norfolk Sandy Soil	23.920	0.212	1.100
Upper Marlboro, Md., Norfolk Sand ..	27.270	0.192	0.980
Lancaster, Pa., Hagers- town Sand	21.740	0.153	0.796
Janesville, Wis., Janes- ville Loam	25.260	0.180	0.938
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* U.S.D.A., Bur. Soils, Bul. 26.

Stewart* in investigating the capillary limits as to the height of rise in dry and moist Michigan soils, found this limit to be much greater where the soil was damp.

Briggs and Lapham** found in comparing the evaporation from tubes of different lengths (85 and 165 centimeters, respectively) of Sea Island soil, that the shorter column showed over 5 times as much evaporation as the longer column in a period of 42 days.

Wollny*** has shown sand with 9.5% of moisture to raise moisture from a water-table one-half higher in six days than did the same sand dry.

Buckingham**** in his studies on the movement of soil moisture, says, "when a moist soil dries by contact with the air above it, the loss of water is by evaporation close to the surface, the amount lost by direct evaporation from points several inches below the surface being, in general negligible. As the surface soil dries out, a moisture gradient is established, and the dry surface soils draws up water from the moister below by capillary action. If this capillary flow of water be prevented or lessened, as by the use of a mulch, the escape of water is decreased, because the evaporation has on the whole, to take place from farther below the surface, so that it encounters greater resistance and is slower."

Leather***** after making a number of measurements showing the amount of water evaporated from the soil at Pusa

* Reported by Briggs & Lapham, U.S.D.A., Bur. Soils, Bul. 19, p.26.

** Ibid., pp. 24-25.

*** Reported by Lön, Fippin, Buckman, Soils, Their properties and Management, p. 226.

**** U.S.D.A., Bur. Soils, Bul. 38, p. 18.

***** Memoirs, Dept. Agri. of India, Vol. 1, #6.

in Bengal, India, during a dry season, concludes in substance,

1. Showers effect surface only.
2. Rate of loss decreases as the depth increases, but the want of unifromity of the soil makes it impossible to get an expression showing the rate of loss.
3. Water moves upward from a limited depth only, none coming from the seventh foot.

Alway and Clark*recently^{have} done some work regarding the movement of water in soils, at North Platte, Nebraska. Their work consisted of five experiments to determine,

1. The upward movement of water from moist soil into drier soil.
2. The downward movement from moist soil into drier soil.
3. The loss from saturated soil in contact with the natural subsoil in situ.
4. The upward movement in a column of soil protected from loss below and at the sides, but fully exposed to evaporation at the surface.
5. The downward movement of water applied to the surface of an air-dried soil.

From the results of their work they conclude that when the water content was below 10%, the capillary movement of moisture in any direction was slight; but when some of the soil with a moisture content above 10% was placed in contact with the same soil containing only the maximum hygroscopic moisture, there was practically uniform movement of water from all parts of the former into the latter, - except that immediately adjoining the drier soil the change was much the greatest. The higher the water content the greater was the movement of water. When soil with a moisture content of approximately 12% was freely exposed to evaporation from the surface no loss by capillary movement occurred to a depth of 30 inches until after the third week, but by the end of 11 weeks the loss from this depth

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* Nebraska Exp. Sta., 25th Annual Report, pp. 246-286. 1912.

amounted to 1%.

Rotmistrov* according to evidences from the Odessa Experiment Field, Russia, states, "that a wrong impression exists regarding the circulation of water in an upward direction - the impression that water can rise to the surface from the deep layers of the soil by capillary action (deep layers meaning those the water of which is inaccessible to the roots of plants unless it is raised)." He contends, "that the limit from which water can make its way upward by capillary action lies much higher than the limit accessible to roots. Experiments at the Odessa Field showed that upward movement by capillarity in a dried soil proceeded very slowly and was observed only when the bottom of the pile of soil was sunk in water. It is difficult to say how the upward transference of water is carried on in the soil under conditions of a non-saturated soil and in the absence of an available source of water in the vicinity, but there is one thing that tells in favor of the movement taking place in a state of vapor and not in the state of liquid drops, and that is, the fact that, in a strict sense capillaries do not exist in the soil. When the soil is not fully saturated with water a certain proportion of the interstices between the particles are filled with air, and the other with water, - in consequence of which water is found in the form of separate drops cut off from one another by air. If an upward movement appeared in a significant thickness of soil, that movement could only contain the more mobile parts, e.g., the air; and the drops of water would re-

* Nature of Drought, p. 16 f.

main where they are, or because of their weight sink downward. all these considerations, and absence of facts to the contrary lead to the conclusion that an upward movement of water only goes on in soils saturated with water; whereas, those in a non-saturated condition suffer a loss of water wherever a drop lies, by evaporation into the air surrounding that drop. For this reason the loss of water in the superficial soil layer goes on very slowly even when the layer is in a compact condition."

Alway* after careful study in regard to the circulation of non-available water^{in valation} to the hygroscopic coefficient concludes, "that the loss of water from the subsoil of dry lands under crop seems to take place almost entirely thru transpiration. In the absence of plants the loss from the subsoil is small. The stored moisture of the different depths of subsoil in the field becomes available to plants by the roots being developed into these depths, but little moisture being elevated to the roots by capillarity The amount of water retained by a soil saturated in pots or cylinders is far in excess of the amount retained by a similar soil saturated in a field where the water-table is at a considerable depth below the surface as in ordinary dry-land."

Burr** of the Nebraska Agricultural Experiment Station after making a study of the problems relating to a greater use of the water that falls upon the land in Western Nebraska, concludes along with other conclusions, the following:

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* Neb. Agri. Exp. Sta., Research Bul. 3, p. 121.
 ** Ibid., Research Bul. 5, pp. 9-10.

1. That capillarity is an effectual agent within certain limits, when operating close to a supply of free water. It may be an important factor in crop production where sheet water is close to the lower limits of the soil zone occupied by the roots of the crop.
2. Away from a source of free water and in a soil partially dry, capillary movement has not been detected.
3. Water supply by capillarity is not an important factor in crop production on Nebraska upland soils.

He, also, states, "that the movement of water thru the soil by capillarity is so slow that it is practically useless in bringing water from a lower soil area for the use of a growing crop. The rapid use of water by crops, especially during seasons of drouth and increased transpiration, requires more water than can be supplied by capillarity. Plants will suffer and die under extreme conditions after having used the available water within reach of the roots, even tho there is additional water in the soil immediately below"

Shantz of the U.S.D.A., Bur. of Plant Industry, stated in a lecture during the Summer School Session of Missouri University, 1915, "that soil moisture in these soils - referring to the soils of the dry land regions - does not move upward, as we have hitherto supposed unless the water-table is very close." Dr. Shantz found in his investigations, that wheat had utilized the soil moisture to a depth of four and one-half feet and that at the time observations were made, the soil moisture below this depth was higher than that in soil in which the roots had been feeding. He said, "if there is anything in the old ideas we have fondled regarding capillary tubes, the moisture in the soil at depths

of five and six feet would have moved upwards to give equal distribution, but this was not the case."

Investigations concerned with Run-off Loss

Of all the problems that have to do with a study of the relation between water and soil, probably the question of surface drainage is the most variable and the most difficult to determine. The factors that go to control it are of such a character, that it is impossible to find the exact amount. However, this is no reason for entirely neglecting the possibility of measuring its magnitude, especially when such an estimate is made under well controlled conditions.

Up to the present time, it is not known that any experiments have been attempted by which the actual percentage of run-off from land under definite treatment has been determined. Many rough estimates have been made of the percentage of surface drainage and the amount of surface erosion it may thereby cause. Geologists for a number of years have estimated the percentage of run-off from large drainage areas, and have calculated how long it will take the mountains, plateaus, and plains of the earth to be worn down to sea level.

The per cent of rainfall leaving the land as run-off and discharged by rivers varies with the amount and rapidity of the rainfall, the slope of the drainage area, the texture of the soil and mantle rock, the vegetative growth present, and other factors. Norton* of Cornell University says, "with an annual rainfall of fifty inches in an open country, about 50% is discharged; while with a rainfall of twenty inches only 15% is discharged, part of the remainder being evaporated, and part

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* Elements of Geology, p. 55.

passing underground beyond the drainage area. Thus the Ohio discharges 30% of the rainfall of its basin, while the Missouri carries away but 15%. A number of the streams of the semi-arid lands of the West do not discharge more than 5% of the rainfall."

The late Dr. Hilgard* of the University of California, says, "this portion (the run-off) of the disposal of rain may range all the way from nothing to almost totality, according to the nature of the soil and the condition of its surface....."

Toumey** states that, "in the San Bernardino mountains in southern California, the first rainfall (in December) was absorbed to the extent of 95% in forested areas, against only 60% in the non-forested; but that later, after the soil had been partially saturated, 60% only was absorbed in the forested land, against 5% in the non-forested. While it is generally admitted that forests diminish the run-off, Rafter*** contends that in New York state the reverse is true."

Leather**** in his evaporation and drainage studies has tried to make a study of the surface drainage from his gauges. During 1909 with a rainfall of 46.23 inches, he obtained the following results:

No. of Gauge	Condition	Amount of Surface drainage	Percent of Rainfall
I (6 ft.)	Fallow	8.32"	18.0
II (6 ft.)	Maize	1.24"	2.7
III (3 ft.)	Fallow	5.35"	11.6
IV (3 ft.)	Maize	4.21"	9.1

* Soils, p. 216.

** Ibid., p. 216. Also, U.S.D.A., Yrbk., pp. 279 f. 1903.

*** U.S.D.A., Yrbk., p. 287. 1903.

**** Memoirs of Dept. Agri. of India, Chem. Series, Vol. II, #2.

Leather emphasizes the point that the surface drainage from land is not nearly as large as the usual practical agriculturist estimates. However, it will be observed from the results obtained in this investigation that Leather has no doubt underestimated this loss, and that the loss due to surface run-off is a very important factor, at least when the matter of erosion of the valuable humus layer is considered.

Rodhouse* in his preliminary studies on the water resources of Missouri, has obtained some very interesting results on drainage areas of considerable size. He found that Grindstone creek near Columbia, Missouri, with a watershed of 14.7 square miles during 1910, with a rainfall of 42.22 inches, had a total run-off of 15.74 inches, or a ratio of run-off to rainfall of 37.3 per cent. Also, during the first six months of 1911, with a rainfall of 13.05 inches, a run-off of 3.33 inches resulted, or a ratio of run-off to rainfall of only 25.5 per cent. In studying the monthly discharge of Current river at Van Buren, Missouri, from August 25, 1912, to November 30, 1914, with a drainage area of 1812 square miles, he found that the ratio of run-off to rainfall during this period was 21.48 per cent.

* Mo. Engr. Exp. Sta., Series 15, No. 33, pp. 11 and 27.

PLAN AND SCOPE OF INVESTIGATION.

The plan of the investigation here reported includes a study of the per cent of water penetration, runoff, evaporation, percolation, and amount of erosion, taking place under field conditions, with cultivated and uncultivated land. Also, a study of the capillary movement in ~~soil~~^{water} evaporation, as well as how soil moisture is effected by the force of gravity.

A part of the investigation was carried out under laboratory and greenhouse conditions, while the major part was carried out under actual field conditions and surroundings.

The laboratory experiments consisted of a study of the depth of the water-table as effecting evaporation loss and capillary rise of moisture in a soil, and the gravitational effects on capillary movements of soil moisture.

The field experiment consisted of a study of the per cent of water penetration, run-off, evaporation, percolation, and amount of erosion, taking place upon four definite areas of ground (two of which were enclosed) under field conditions and subject to cultivated and uncultivated treatments. A study was made of the moisture movements from the time the water reached the soil as rain, until it left the soil as an unabsorbed excess - run-off, or as gravitational water - percolation, and as water vapor - evaporation.

In addition accurate records were kept of the amount of rainfall, the wind velocity, and water-free-surface evaporation at this location during the period of the experiment.

LABORATORY EXPERIMENTS.

Experiment I.

Depth of water-table as effecting capillary
rise of moisture in the soil and evaporation
losses.

A study of the capillary rise of soil moisture was made under as ideal conditions as possible in the laboratory. A constant water-table was maintained at the base of the soil columns and a moist soil was used to begin with, both of which should be in favor of the action of capillarity. The loss from the water-table up into the soil columns was determined accurately, as well as the loss thru evaporation from the soil surface.

It is realized in undertaking a study of this kind that many things must be taken into consideration, and that where only one type of soil is under investigation, it is only possible to draw conclusions in a general way as to soils of different types with varying textures. However, where a careful study is made of the principles underlying and the factors controlling moisture movements in one type of soil with a definite texture, the same principles must be more or less true in other types.

R. W. McClure of Missouri University initiated this investigation thru the advice of Professor M. F. Miller, and is to be given credit for collecting the data reported in Experiment A.

Experiment A.

Plan of Experiment -

The method of carrying out this experiment was to place a soil in cylinders of various heights, so constructed that a permanent water-table could be provided at the base - thereby furnishing the maximum and ideal conditions under which capillarity may act. The soil was put in the cylinders so as to represent field conditions as nearly as possible; and by weighing at intervals and measuring the amount of water taken up from the water-table below, the amount of water being lost thru evaporation could be compared with the amount taken into the soil by capillarity from the water-table below.

Accordingly, six galvanized iron cylinders of the design shown in Plate I, and 6 inches in diameter, were constructed, these being arranged in three series 2, 4, and 6 feet in height respectively. The lower ends were encircled by a cylindrical tank, 4 inches high and 10 inches in diameter, soldered onto the inner cylinder in such a way that the floor of the tank supported the inner cylinder. A screw-cap opening placed at "C" allowed for the addition or measurement of water. The lower portion of the cylinder "A", which was to be filled with soil was perforated with sixteen one-fourth inch holes arranged in two rows of eight each, the rows being one-half inch and two inches from the bottom. This allowed for free passage of water from the water-tank "B" into the soil column, thus providing a permanent water-table. To the top of each cylinder were riveted two iron hooks by which they could

PLATE-I.

FIG. 1 - SOIL CYLINDER.

FIG. 2- SIPHON.

be lifted in weighing.

Since the experiment was started in the late winter and the subsoil in the fields was not in a fit condition to handle, it was not possible to put soil into the cylinders in the actual field condition. It was thot best to use a surface soil thruout the whole depth of the cylinders for this first experiment, and if striking results were secured, to attempt to secure the soil in its actual field condition later.

The soil used was the surface foct from the plowed land just South of the Agricultural Building; it was a silt loam containing considerable organic matter. As the ground was covered with snow at this time it was necessary to dry the soil in the greenhouse. About 50 pounds was taken to the laboratory to determine the proper amount of water it should contain and the amount of tamping necessary to obtain a field condition as near as possible in regard to compactness. Experiment showed that 17% was about the proper moisture content, so the remaining soil was dried to that per cent, sifted thru a 4-mesh seive and thoroly mixed. It was covered securely with oil-clth to insure its remaining at this moisture content until all cylinders were filled.

Because of the possibility of the compact soil clogging up the perforations in the lower part of the cylinders, a small amount of gravel was placed in the bottom of each, - enuf to extend above the top of the second row of holes. This allowed for free percolation of water from the outside water tank into the interior cylinder containing the soil.

The cylinders were weighed empty and with the gravel

in them. The plan used in putting in the soil was to put two small scoopfuls into the cylinder, put in the tamp and turn it lightly several times to level the soil then tamp 20 times, using a plunge of approximately two inches, and with as nearly as possible the same amount of force each time, so as to secure uniform compactness.

As the first cylinder in each series was filled it was weighed and the amount of soil in it recorded so that an equal or nearly equal amount could be weighed out for the duplicate in the series. The cylinders were filled level full, weighed, and cloth covered temporarily to prevent escape of moisture.

To each water-tank was immediately added 3,000 cubic-centimeters of water, and the total weight of cylinder, soil, and water secured. Daily observations were made of the height of water in the cylinders to determine the amount passing up into the soil column. It was thought that by allowing the cylinders to stand thus for about three weeks, the water would tend to become^{better} equalized thruout the duplicates than would be the case if the experiment was started at once. The height of water in the tanks was measured by means of a metal rod and a meter-stick.

After a week the cylinders were weighed to determine if any loss of moisture had taken place. Practically no loss had occurred, and the height of water in the tanks was not noticeably changed. More water was added to each cylinder till it stood at a height of 3 5/16 inches. The cylinders were again weighed and tightly covered with paraffined paper.

Daily observations continued to be made regarding the height of water, weighings being made at intervals of eight days. It was found that the soil column was taking up but little more water from below, so the paraffined papers were removed and the weighings to determine the moisture loss were begun.

Experimental Methods -

The cylinders were weighed on a platform balance, the method of lifting them being by means of a chain and pulley supported on a trestle. They were weighed accurately to within a quarter of an ounce every two or three days. After the experiment had been running a couple of days the soil at the surface seemed to shrink in, leaving a slight crack between the soil columns and the cylinders; cracks also appeared on the surface. All of these openings were shallow and were filled in by scraping soil from the surface into them and compacting with a stick, so that the water would necessarily need to pass thru surface soil instead of escaping thru soil fissures.

When the water in the tanks appeared to be getting close to the two-inch mark the cylinders were refilled, the old and new weights being recorded together with the new height of water.

Experimental data -

The results secured from April 10th, to May 19th, 1915, are as follows:

Table 1. - Inches of Water absorbed by Soil Columns.

Date	No. of days	Series A 2-foot Cyls.		Series B 4-foot Cyls.		Series C 6-foot Cyls.	
		A-1	A-2	B-1	B-2	C-1	C-2
4/10-4/18	8	9/16	18/32	3/32	3/32	1/32	2/32
4/18-4/26	8	6/16	11/32	4/32	7/32	2/32	2/32
4/26-5/3	7	11/32	11/32	1/32	0	0	0
5/3 -5/10	7	3/16	8/32	6/32	4/32	1/32	1/32
5/10-5/19	9	6/16	12/32	2/32	6/32	1/32	0
Total	39	1-27/32	1-7/8	1/2	5/8	5/32	5/32
No. of cuin.		93.04	94.63	25.24	31.54	7.89	7.89
No. of ounces		53.84	54.76	14.60	18.20	4.56	4.56
Ave. cuin. per series		93.84		28.40		7.89	
Ave. ounces per series		54.30		16.40		4.56	

Table 2. - Ounces of Water lost from Soil Columns.

Date	No. of days	Series A 2-foot Cyls.		Series B 4-foot Cyls.		Series C 6-foot Cyls.	
		A-1	A-2	B-1	B-2	C-1	C-2
4/10-4/18	8	19.75	19.75	12.00	12.50	11.75	11.25
4/18-4/26	8	7.75	7.50	4.00	5.25	2.25	3.50
4/26-5/3	7	5.00	5.75	5.25	4.00	2.50	1.50
5/3 -5/10	7	8.50	8.00	1.75	2.75	3.00	5.50
5/10-5/19	9	10.50	11.00	4.25	4.00	2.75	2.75
Total	39	51.50	52.00	27.25	28.50	22.25	24.50
Ave. ounces per series		51.75		27.88		23.38	

Table 3. - Ounces of water lost
compared with ounces of water absorbed.

Series	Ounces lost	Ounces taken up	Difference
A (2-ft. Cyls)	51.75	54.30	plus 2.55
B (4-ft. Cyls)	27.88	16.40	minus 11.48
C (6-ft. Cyls)	23.38	4.56	minus 18.85

PLATE-II

EVAPORATION LOSS
COMPARED WITH
WATER-TABLE LOSS.

Table 4. - Loss of Water per Acre per Series for 39 Days.

Series	Depth of Water-table	Loss of Water in 39 days

A {2-ft. Cyls}	2 feet	718,750 lbs.
B {4-ft. Cyls}	4 feet	387,222 lbs.
C {6-ft. Cyls}	6 feet	324,722 lbs.

General Observations -

Table 1 shows the actual amount of water that has passed up into the soil columns, calculated both in terms of cubic-inches and of ounces. It is shown that the greatest amount has been taken up by Series A, the 2-foot columns; the amount has dropped considerably in Series B, the 4-foot columns; and, is still less in Series C, the 6-foot columns. In Series A, while water appears to have been taken up most rapidly during the first week, still a more or less uniform amount was taken up in subsequent weeks. In Series B the rate was not nearly so rapid nor so regular. In Series C practically no water was taken up after the first two weeks.

Table 2 shows the actual amount of water lost from the columns by surface evaporation. The loss occurs in the same order in which water was taken up, tho not in the same proportion. By far the greatest amount of evaporation has taken place in Series A. In all series the greatest amount of evaporation took place during the first week, a sharp demarcation being noted between the loss the first week and those thereafter, showing that the surface soil was drying rapidly during that time.

Table 3 shows a comparison of the amount of water lost by evaporation from the surface and the amount taken up from the water-table. It will be noted that in Series A the amount of water taken up by the soil column in five weeks was 2.34 ounces in excess of the amount lost by evaporation, so this soil must have been in a slightly more moist condition at the end than at the beginning of the experiment, at least near the bottom of the column. In both B and C series, however, considerably more had been lost by evaporation than had been taken up, - the difference being 11.5 ounces in Series B, and 18.9 ounces in Series C. In Series B the soil had taken up slightly more than half as much as it had lost. In Series C it had taken up only about one-fifth as much as it had lost, most of this being taken up during the first two weeks of the experiment which shows that the lower soil was not capillarily saturated when the water was added in the jacket, and that it took up enuf to reach capillary equilibrium in the lower layers, but that very little if any passed upward in the entire length of the column.

Experiment B.

After the above readings were obtained by McClure, the cylinders were allowed to remain in the greenhouse during the summer of 1915. Water was kept in the tanks at the bottoms of the columns to prevent undue evaporation, as well as to prevent the soil columns from becoming dry and hard.

Experimentals Methods -

A little moss was found growing upon the surface of each of the cylinders on September 25th which was killed by a few drops of a dilute solution of copper sulphate. It was then removed by scraping the surface and removing approximately one-eighth of an inch of the soil surface.

In order to insure that the soil columns would be in ideal condition for water movement to take place, each column was saturated with water. This was brought about by maintaining a constant dripping of water onto the columns for several days or until it was observed that all the columns were losing water thru the opening "C" (see Plate I, fig. 1), the covering of which had previously been removed. As soon as the columns were saturated approximately one inch of water was removed by siphon from each tank. This brought the water to the same level in all the tanks, after which, initial weighings were made and this second experiment started.

A different method was used in determining the water loss from the water-table and in the maintenance of a constant water-level, than was used in Experiment A. Siphon as shown in Plate I, fig. 2, was used. It was marked at "X" showing the height of the water-tables in all the cylinders at the beginning. At each weighing by using a 100 cubic-centimeter graduated cylinder the proper number of cubic-centimeters of water was added to bring the water up to the mark "X" - the initial water-table level. This amount was recorded as the amount that had been lost from the water-table thru capillarity. In order to compare this loss to the evaporation loss

it was converted into ounces by using 28.35 cubic-centimeters equal to one ounce. In the weighing of the cylinders, the same platform balance (Fairbank's) was used as in Experiment A, which was accurate to a quarter of an ounce. After the experiment was well underway, readings were made once a week, on the same day and hour.

All thru Experiment B evaporation readings from a free-water-surface were taken. A porcelain jar, ten inches in depth and with approximately the same surface area as the soil columns was used. A pointed steel rod, mounted on a square galvanized iron base, was used to indicate the exact height of water surface. The number of cubic-centimeters necessary to bring the water-level up until the point just broke the surface film was recorded as the evaporation loss for the previous period. All readings were made at the time of weighing the cylinders. The jar was situated on a table near the soil columns, in order that the factors affecting it would be the same as for the soil.

The cylinders occupied the same position in the greenhouse during the entire period. On May 15th, 1916, the greenhouse was whitewashed and the sun's rays excluded to some extent. The effect is seen in the lessened evaporation loss from the free-water surface on the week ending May 20th, in comparison with that for the week ending May 13th.

Almost immediately after the experiment was started the same difficulty was experienced as in Experiment A, in that the soil at the upper surface of the cylinders seemed to shrink away from the sides, leaving a slight crack between the soil and the cylinder wall. Cracks appeared, also, in the surface

of some of the cylinders. All these openings were shallow and were filled in by scraping soil from the surface into them and compacting with a stick, so that the entire loss of water should take place thru the soil. This had to be done several times during the course of the experiment.

On April 15th, 1916, the surfaces of all the columns were scraped and a small amount of soil removed from each. For sometime previous to this it was noticed that a white layer of salts was collecting on the surface of all the columns, particularly on those of the 2- and 4-foot lengths.

Experimental data -

The following pages contain tables of results obtained.

Table 7. - Ounces of Water lost in Quarter Periods.

Quarter	Series A 2-foot Cyls.		Series B 4-foot Cyls.		Series C 6-foot Cyls.	
	A-1	A-2	A-1	A-2	A-1	A-2
1	52.50	63.32	32.15	37.71	38.01	25.30
2	42.46	49.93	19.64	21.54	10.00	17.90
3	43.98	44.32	14.76	19.22	17.46	12.38
4	27.88	29.46	11.41	14.08	7.15	8.92
Total	166.82	187.03	77.96	92.55	72.62	64.50

Table 8. - Water lost compared with Water absorbed.

Series	Ounces lost	Ounces absorbed	Difference
A (2-ft. Cyls.)	176.92	176.00	0.92
B (4-ft. Cyls.)	85.25	56.90	28.35
C (6-ft. Cyls.)	68.56	9.88	58.68

PLATE-III

EVAPORATION LOSS
COMPARED WITH
WATER-TABLE LOSS.

Table 9. - Evaporation from Free-Water-Surface.

Date	Amount in ounces
Oct. 30, 1915	2.50
" 31	2.75
Nov. 1	2.57
" 2	2.29
" 3	2.31
" 4	1.34
" 5	2.14
" 6	2.00
" 7	2.80
" 8	-
" 9	5.60
" 10	1.60
" 11	2.20
" 13	3.60
" 20	7.60
" 29	9.00
Dec. 4	4.90
" 11	6.30
" 17	4.10
" 24	7.60
Jan. 8, 1916	20.00
" 15	5.70
" 22	5.18
" 29	9.50
Feb. 5	11.10
" 12	12.30
" 19	16.00
" 26	17.00
Mar. 4	11.40
" 11	22.10
" 18	21.00
" 25	23.00
Apr. 1	9.70
" 8	10.00
" 15	11.00
" 22	9.20
" 29	12.50
May 6	13.50
" 13	23.00
" 20	10.10
" 27	9.80
June 3	8.80
" 10	7.05
" 17	8.50
" 24	8.60
Total	289.33

PLATE - IV

Comparison of Evaporation and Water-Table Losses.

General Observations -

The effect that the position of the water-table has upon capillary movement of water thru soils is strikingly shown in Table 5. The rapidity with which evaporation is taking place as influenced by the force of capillarity is also plainly seen. It will be seen later in examining Table 8 that practically the entire evaporation loss from the 2-foot columns has been from the water-table. The average total loss in ounces for the 220 days from Series A, the 2-foot columns, was 176.00; from Series B, the 4-foot columns, 56.90; and, from Series C, the 6-foot columns, only 9.88. It has taken a marked quantity of water to maintain the water-level in A-1 and A-2. It has taken only about one-third as much to maintain the water-level in B-1 and B-2. While in C-1 and C-2, the quantity has been almost negligible.

In Series A, there was a constant and steady loss of soil moisture. The amount necessary, outside of the initial amount added on November 13th to restore the proper level, varied from 1.98 ounces to 7.58 ounces for a 7-day period. At all the different observation periods A-2 was more moist on the surface than A-1. The different readings, as well as the total, showed that A-2 was losing the most water of this series. This was probably due to a slight difference in compaction of the soil when placed in the cylinders, a more perfect soil column for the movement of water having been made in the case of A-1.

In Series B, a much lower evaporation loss occurred. The losses for a period of seven days varied from zero to 4.34 ounces. The initial amount added to B-2 on November 13th is no

doubt too high to be due entirely to capillary movement within the soil column. Probably the reason for this is partly due to the fact that soon after the commencement of the experiment, a crack occurred in the seam at the base of this cylinder where it was soldered onto the cylindrical tank. Before it could be repaired a few ounces of water splashed out thru it during the different weighings, and a small amount must have evaporated. The major portion of the evaporation loss from this series has been due to the capillary movement of water from the water-table, altho a large portion of the initial water in the soil column has been lost.

In examining Series C, it is noticed on the first day, November 13th, that water was added to bring the water-levels up to the proper heights, that 4.51 ounces was added to C-1. This is accounted for by an error in resetting this column after the weighing had occurred. At the next reading when the cylinder was placed in its proper position, the water-level was above the mark on the siphon which was no doubt due to the amount added the previous reading. A new mark was made on the siphon for C-1 which coincided with the water-level on November and was used thereafter. Not including this initial amount, the total loss for C-1 was 7.25 ounces and for C-2 7.99 ounces, which shows that only a very slight movement due to capillarity, if any at all, was taking place in these columns; but that the principal loss has been due to the evaporation taking place from the upper part of the soil column.

Table 6 gives the number of ounces of water lost from the soil columns thru evaporation. The duplicate readings of the different series compare closely considering

the number of factors that control or influence the water movement. The total average loss for Series A was 176.92 ounces; for Series B, 85.25 ounces; and for Series C, 68.56 ounces. Outside of the first seven days, in which all the cylinders lost approximately the same amount, the cylinders of Series A lost more steadily than those of B and C, the average range being from two and one-half ounces to six ounces for a 7-day period. Series B also, lost rather steadily, but the average loss for a 7-day period is considerably lower than in the case of Series A, the total average loss being practically one-half as much as in the 2-foot columns. In Series C the loss has taken place irregularly, varying from three ounces to zero. This is a striking difference from the more or less steady loss in the case of Series A and B. The total loss for Series C (68.56 ounces) was only 17.69 ounces less than in the case of Series B. It will be noted, however, that the loss has occurred almost entirely from the soil columns.

Table 7 giving the loss by quarters shows that the greatest loss was during the early part of the experiment when the upper parts of the columns were drying out most rapidly. After they had dried materially the loss decreased both because of the less water in the surface layers and because this lessened water content decreased the rate of capillary movement to the surface. The more favorable conditions during the latter part of the period have not been able to maintain the rate of loss from the soil columns.

Table 8 shows a comparison of the amount of water lost by evaporation from the surface and the amount absorbed from the water-table. It will be noted that in Series A the amount of

water absorbed by the soil columns during the entire 220 days was only 0.92 of an ounce less than the amount lost by evaporation. So that as far as the total moisture content of the entire column is concerned it must contain practically the same amount as it did at the beginning. In both B and C series, however, considerably more had been lost by evaporation than had been taken up from the water-table, the difference being 28.35 ounces in Series B, and 58.67 ounces in Series C. In Series B the soil columns have taken up from the water-table two-thirds as much as they lost, while in the C series only about one-seventh of the evaporation loss is equal to the water-table loss.

Table 9 gives the weekly evaporation in ounces from the free-water-surface.

Discussion of Results -

These results indicate that depth of water-table has a marked effect on capillary rise of moisture in soils. Apparently when the water-table is very close to the surface, considerable quantities of water move upward by capillarity, but as its depth is increased the capillary rise becomes less. In this experiment capillary movement was in full sway where the water-table was but two feet deep, and it moved rather uniformly thruout the period of the experiment. In the 4-foot series the rate of capillary rise had decreased greatly, the water-table loss being considerable less than the evaporation loss, altho, both were more or less uniform in showing that capillarity was at work. The evaporation loss being the greatest caused the soil column to lose moisture faster than it could be supplied

from below by capillary action, which was also shown by its surface which was harder and drier. This same condition of the surface was noticed on the cylinders of Series C, except to a greater extent. In Series C an almost negligible quantity of water was taken up from the water-table, while the principal amount was lost thru evaporation from the upper soil layers, almost as much as in Series B. Consequently Series C contained much less water at least in the upper layers of soil than it did at the beginning of the experiment.

The results show that depth of water-table is of primary importance when discussing capillary rise of moisture in soils; and also, they tend to combat the old theory which holds that capillary moisture can be brought rapidly to the surface from considerable depths in the soil.

It is realized that in this single experiment only one kind of soil is under study, a soil of uniform texture thruout its whole depth - a condition which would rarely be found under actual field conditions. Then too, the soil was tamped in the cylinders which again is but an approximation of the natural soil in situ. However, the results indicate that depth of water-table must be the prime factor in determining the capillary rise of moisture to the surface, which goes to prove that ground-water is not lost thru capillarity when it stands at a considerable distance below the surface.

It seems probable that in a given soil, capillarity will carry water only to a given height, beyond which height, all loss of moisture occurs in the form of water vapor caused by evaporation into the air circulating in the interstitial spaces thruout the soil mass.

Also, that in the field where the water is at a considerable depth below the surface, the loss of moisture thru evaporation occurs largely from the surface foot of soil, and that below this depth very little is lost by evaporation. Undoubtedly the per cent of moisture in the soil is a very important factor, capillary movement decreasing with decreasing moisture content. Where the surface foot or two of soil is very moist capillarity may for a time act in carrying a considerable amount of this water to the surface.

Experiment II.

Loss of Water thru Capillarity with and against gravity.

Gravity and its effect in removing the free moisture from the soil is recognized and its constant pulling force in removing minute amounts of water long after the excess has been drained away has often been observed. However, the fact that it may control most of the soil moisture, after it has passed the upper twelve to eighteen inches of soil has not received much attention.

Rotmistrov has come out very strongly against the idea of the power of capillarity in removing the soil moisture from the lower layers of the soil in his work on the "Circulation of Water", as well as in his later work on "The Nature of Drought". He* states that, "there is a constant and steady movement of water downwards, not only in the deep soil layers which cannot be dried, but in the upper layers as well." As the result of several experiments, he** holds that the downward movement not only takes place from depths of 95 to 105 centimeters (38 to 42 inches), but from the small depth of 35 to 45 centimeters (14 to 18 inches), and states that the speed with which the water moves is from 15 to 20 centimeters (6 to 8 inches) per month on old ploughed fields, but more slowly on unploughed soil. In concluding he*** states that "water percolating to a depth of 40 to 50 centimeters (16 to 20 inches)

* Nature of Drought, p. 20.

** Circulation of Water, pp. 30 and 81.

*** Nature of Drought, p. 20.

does not return to the surface except by the way of roots; all the water not seized by the roots goes down into the deep layers, moving at the rate of about 7 feet yearly."

It was largely because of Rotmistrov's results that this experiment was planned and undertaken, the object being to determine, if possible, how important gravity was in controlling soil moisture under well defined conditions.

Plan of Experiment -

The general plan adopted was to take two columns of soil, containing a maximum amount of capillary moisture, and allow one to dry out with the aid of gravity and the other in the usual way against gravity.

Accordingly, two galvanized iron cylinders were constructed, six feet in length and six inches in diameter with one end of each can closed air tight. Forty-four one-inch holes were cut in each of the cylinders, being arranged in eleven horizontal series of fours, six inches apart. An iron band with a one-fourth inch lip was made to slip down over the top of the cylinders, and was bolted to the inverted cylinder to prevent the soil from dropping out. In the case of the erect cylinder it was used only to keep the exposed surface area equal for both cans. Two-inch adhesive tape was used to cover the holes, this being wrapped horizontally around the cylinders covering each series of four holes as a separate unit. The tape was covered with a heavy coating of paraffin to insure no loss of moisture thru the holes.

The moisture samples were taken from each vertical row of holes at monthly intervals to determine the movement of

moisture upwards or downwards. A fine sandy loam soil was used, and a regular, short handle, one-inch soil augur was used in removing the samples.

Experimental Methods -

The fine sandy loam soil used was obtained from a creek bottom. It was sifted and placed in the greenhouse in a pile to reach a uniform moisture content. When the moisture became uniform thruout the pile, three samples were taken and the moisture content determined. They were dried in an electric oven for 8 hours at a temperature from 105 to 110 degrees centigrade. The per cent of moisture in the samples, varied from 16.09 to 16.88 - average 16.59.

To find the optimum moisture content of this soil several samples were taken and different amounts of water added to each successive sample, increasing or decreasing the amount of water, until the optimum content was obtained. The water content finally selected was 27.08 per cent. A sufficient amount of soil was then weighed to fill both cylinders and spread out in a four-inch layer on a large table. The necessary amount of distilled water was added to bring the entire mass up to the optimum content. The soil was covered with an oil cloth and allowed to stand ten days to insure uniform distribution of the water. In the meantime the soil was mixed and turned several times to aid in the distribution.

On February 12, 1916, three samples of the soil were taken from different parts of the mass and their moisture content determined. The moisture percentages obtained were 22.97, 23.07, and 22.91 - average 22.98. Both cylinders were

filled with the soil at this moisture content by the same method as used in Experiment I, page 32, the tamp used and the process of compaction being the same.

After the cylinders were filled they were placed in a small room where the atmospheric conditions were practically uniform. One cylinder was set on the floor in an erect position, the upper end being open; the other, was hung in an inverted position from an iron pipe which crossed the upper part of the room, the lower end being open. The open ends of the cylinders came within one foot of each other, and no draughts or rapid temperature changes were allowed to effect them. During the first month temperature and water evaporation records were made at the respective levels of the open ends of the two cylinders, which showed no appreciable differences, thus showing that conditions for evaporation were the same for each.

In sampling the cylinders were laid on a long table (a great deal of care was used in the handling of the cylinders to prevent rupture of the soil columns) and after the removal of the sample which was taken to a depth of two to three inches, the hole was filled with melted paraffin. As soon as paraffin hardened, the tape was placed back over the hole and another thin coating of paraffin was applied. Care was taken to weigh the samples immediately after they were removed from the cylinder. After all the samples had been taken and weighed, they were placed in an electric oven and dried for six hours at a temperature of 105 to 110 degrees centigrade. Cylinders were returned to there original position after each sampling.

Soon after the experiment started the soil in the erect

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cylinder seem to shrink away from the sides, leaving a slight crack between the soil column and the cylinder wall. Also, the surface soil in both cylinders shrunk away from the lip that overlapped the surface. These openings were filled with paraffin as often as required.

After the last set of samples were taken a sample two and one-half inches deep was taken from the surface layer of each cylinder.

Experimental data-

The following pages contain tables of results obtained.

Table 10. Evaporation loss, With and Against Gravity.

(Per cent Moisture in the Soil)

* Measurement from open end.

** Estimated.

Time	No. of Sam- ple	Depth* inches	A - Erect Cylinder			B - Inverted Cylinder		
			Moisture content	Loss of moist. per month	Loss of moisture since be- ginning	Moisture content	Loss of moist. per month	Loss of moisture since be- ginning
1916								
March								
11	1	6	18.09	4.89	4.89	19.78	3.20	3.20
	2	12	19.11	3.87	3.87	20.85	2.13	2.13
	3	18	19.46	3.52	3.52	19.88	3.10	3.10
	4	24	20.24	2.74	2.74	21.56	1.42	1.42
	5	30	20.30	2.68	2.68	19.80	3.18	3.18
	6	36	20.88	2.10	2.10	21.38	1.60	1.60
	7	42	20.81	2.17	2.17	20.42	2.56	2.56
	8	48	21.00**	1.98	1.98	21.42	1.56	1.56
	9	54	21.31	1.67	1.67	20.17	2.81	2.81
	10	60	24.12	+1.14	1.14	21.46	1.52	1.52
	11	66	24.57	+1.59	1.59	20.24	2.74	2.74
April								
8	1	6	17.65	0.44	5.33	16.81	2.97	6.17
	2	12	17.74	1.07	5.24	19.38	1.47	3.60
	3	18	18.46	1.00	4.52	19.05	0.83	3.93
	4	24	18.58	1.66	4.40	19.65	1.91	3.33
	5	30	19.01	1.29	3.97	19.17	0.63	3.81
	6	36	19.44	1.44	3.54	19.88	1.50	3.10
	7	42	19.66	1.15	3.32	19.81	0.61	3.17
	8	48	21.11	+0.11	1.87	19.73	1.69	3.25
	9	54	20.72	0.59	2.26	19.52	0.65	3.46
	10	60	21.79	2.33	1.19	19.75	1.71	3.23
	11	66	22.14	2.33	0.74	19.42	0.82	3.56
May 6								
	1	6	16.53	1.12	6.45	18.96	+ 2.15	4.02
	2	12	16.91	0.83	6.07	19.53	+ 0.15	3.45
	3	18	17.98	0.48	5.00	18.98	0.07	4.00
	4	24	18.15	0.43	4.73	18.90	0.75	4.08
	5	30	18.37	0.64	4.61	19.50	+ 0.33	3.48
	6	36	18.84	0.60	4.14	19.70	0.18	3.28
	7	42	18.95	0.71	4.03	19.15	0.66	3.83
	8	48	19.76	1.35	3.22	19.71	0.02	3.27
	9	54	19.63	1.09	3.35	19.34	0.18	3.64
	10	60	20.43	1.36	2.55	19.46	0.29	3.52
	11	66	21.05	1.09	1.83	18.67	0.75	4.31
June 3								
	1	6	14.96	1.57	8.02	15.32	3.68	7.70
	2	12	15.39	1.52	7.59	18.86	0.67	4.12
	3	18	16.42	1.56	6.56	16.33	2.65	6.65
	4	24	16.90	1.25	6.08	16.62	2.28	6.36
	5	30	17.68	0.69	5.30	18.41	1.09	4.57
	6	36	17.56	1.28	5.42	19.05	0.65	3.93
	7	42	18.51	0.44	4.47	20.58	+ 1.43	2.40
	8	48	18.44	1.32	4.54	19.19	0.52	3.79
	9	54	19.11	0.52	3.87	19.31	0.03	3.67
	10	60	19.36	1.07	3.62	18.84	0.62	4.14
	11	66	19.69	1.36	3.19	18.55	0.12	4.43

PLATE-V

LOSS of MOISTURE
WITH
GRAVITATION.

Initial Moisture Content

LOSS of MOISTURE
AGAINST
GRAVITATION.

Table 11. - Summary of Table 10.

(Per cent Moisture in the Soil)

Month	<u>A - Erect Cylinder</u>		<u>B - Inverted Cylinder</u>	
	Average en- tire column	Average loss per month	Average en- tire column	Average loss per month
Initial content	22.98		22.98	
First	20.90	2.08	20.63	2.35
Second	19.66	1.24	19.29	1.34
Third	18.78	0.88	19.28	0.01
Fourth	17.64	1.14	18.28	1.00

General Observations and Discussion of Results -

The results as shown in Table 10 and graphically illustrated on Plate V, page 59, makes clear a difference in the factors controlling the evaporation from cylinders under the conditions. It will be noted that in the four different sets of samples taken from the erect cylinder that the moisture content increased gradually from the open end of the cylinder to the closed end, except for samples No. 9 (probably due to excess in sample No. 8) on April 8th, and May 6th, and samples Nos. 6 and 8 on June 3d which were slightly less than the samples immediately above them. These were the only samples that interrupted the gradual increasing moisture content running from the open to the closed end of the cylinder. In the inverted cylinder an entirely different situation was in evidence. The aid of gravity was evident as is clearly shown by the chart. During the first month all the respective six-inch soil layers of the erect cylinder lost moisture except layers represented by

samples Nos. 10 and 11 which were at the bottom of the cylinder. These increased 1.14% and 1.59% respectively over the initial moisture content. No doubt there was a movement of moisture downward into these layers from the ones immediately above, which is reemphasized by the fact that sample No. 11 contained almost one-half per cent more moisture than sample No. 10. The layers of soil represented by samples Nos. 1 to 9, inclusive, lost moisture with decreasing amounts commencing at the surface. The per cent of moisture varied from 18.09% to 24.57%, a range of 6.48%.

During the second month all layers lost moisture except the layer represented by sample No. 8, which gained 0.11%. Except for this sample the moisture gradient was gradual from top to bottom of column, the lowest moisture content being at the top and gradually increasing until the highest was reached at the bottom. The per cent of moisture varied from 17.65% to 22.14%, a range of 4.49%. The greatest loss was not at the top as in the case of the first month's results, but at the bottom of the column in the layers which gained during the first month.

During the third month, all layers lost moisture without exception. The moisture gradient was gradual, increasing from top to bottom with the exception of sample No. 9 which was 0.13% less than sample No. 8. The reason for this may be explained by the fact that sample No. 8 contained a slight excess of moisture at the previous sampling, and due to the same cause it still contained an excess amount in comparison to the layer immediately below. The per cent of moisture varied from 16.53% to 21.05%, a range of 4.52% which was practically equal to the

previous month. The greatest losses occurred in the surface layer and the four bottom layers, or in those layers which lost the least the previous month.

During the fourth month, all layers lost moisture without exception. The moisture gradient was gradual, increasing from top to bottom, excepting samples Nos. 6 and 8 which contained a lesser per cent of moisture than the layers immediately above them by 0.13% and 0.07% respectively. The per cent of moisture varied from 14.96% to 19.69%, a range of 4.73%, slightly more than the previous two months, due probably to the increased room temperature. The loss from the different layers bore no particular relation to the loss of the previous month, the greatest loss occurring in the surface three layers.

In examining the loss of moisture from the inverted cylinder something unusual is noted in the first month's results. There was a loss from every layer, but the losses was not like those from the erect cylinder. The moisture by layers increased and decreased successively from the open to the closed end. The average total loss of moisture thruout the column was 0.37% more than in the case of the first month's results of the erect cylinder. The per cent of moisture varied from 19.78% to 21.46%, a range of 1.68%. The moisture remaining in the column is more evenly distributed thruout the column than in erect cylinder which is evidence of the effect of gravity.

During the second month, similar results to the first month were obtained, all layers losing moisture, the largest amount being from the layer next to the open end. The moisture content of the various samples commencing at the open end varied successively up and down until sample No. 6 was reached, after

which there was a regular decrease until sample No. 8 was reached, at which point the former procedure was restored. The total loss was 0.10% greater than the loss from the erect cylinder. The per cent of loss varied from 16.81% to 19.83%, a range of 3.07% which is considerably larger than the range of the first month.

The moisture conditions at the end of the third month period were somewhat irregular. Samples Nos. 1, 3, and 5, showed an increase in those respective layers; the rest lost in varying amounts. The total loss was almost negligible, while the per cent of loss varied from 18.96% to 19.71%, a range of only 0.75%.

During the fourth month moisture was lost thruout the entire column, except in the layer represented by sample No. 7 which showed an increase of 1.43%. The total loss was greater than the previous month by almost 1.00%, but less than the loss from the erect cylinder, the difference being 0.14%. The per cent of moisture varied from 15.32% in the surface to 20.58% in sample No. 7, a range of 5.26%. As was noted in the third month's results, there seems to be an accumulation of moisture occurring within the column, either due to gravity or some other force. This month the accumulation seems to be at the place represented by sample No. 7. The greatest loss occurred in those layers which contained a surplus the previous month or which lost very little.

Inasmuch as this was the end of the experiment samples of soil were taken from the surface two and one-half inches of each column, along with the fourth month's samples, and their moisture content determined. There was 13.58% in

the sample from the erect cylinder, and 7.08% in the case of the sample of the inverted cylinder, a difference of 6.50%. In comparing these percentages to those at a distance six inches from the surface, there is no marked difference in the inverted cylinder. The surface of the inverted cylinder containing only 7.08% is practically air dry, while three and one-half inches further up a moisture content of 15.33% is present. In taking the sample from the inverted cylinder a great deal of difficulty was experienced. The soil seemed to be very compact, hard, and dry. This compaction or settling of the soil must ~~XX~~^{have} begun soon after the experiment started and continued thruout. Such a condition would hinder somewhat the loss of moisture as resulting from diffusion, as well as alter the loss by capillarity working with gravity.

The following points of note are observed from these results: (1) In the case of the erect cylinder where the loss of moisture by evaporation is either thru diffusion or partly by the suppose^d force of capillarity, the greatest difference between the moisture content of any two layers, is found to be between six and twelve inches below the surface (as is the case in the first month's results), or between twelve and eighteen inches (as is the case in the other three months). This would indicate that the greatest loss of moisture is occurring in the surface eighteen inches. (2) The total loss of moisture from the respective layers of the erect cylinder varied almost directly with the height, the greatest being at the top and the least at the bottom. It would seem that if capillarity was the important means by which moisture escaped from the soil,

that there should be a more constant loss thruout the different layers of the entire soil column. However, as this isn't the condition it would indicate that the loss by diffusion is the more important. (3) Diffusion and capillarity being two forces which supposedly will act equally well in either direction will not explain the results obtained from the inverted cylinder. Gravity is at work as is plainly seen in the first two month's results. Soon after the experiment was started the moisture must have begun moving downwards, evidently with a speed of about six inches plus per month (see Rotmistrov conclusions page 54). This regular movement decreased as the moisture content became lower which produced the irregularity of the results during the third and fourth months, and caused increased amounts of moisture over the previous month to occur at different places along the column (note samples Nos. 1, 2, and 5, of May 6th, and No. 7 of June 3d). (4) If capillarity is an important force in the loss of soil moisture, it would seem that a greater loss should have occurred from the inverted cylinder during the last two months. (5) A comparison of the range between the maximum and minimum moisture contents for the different months gives further proof of the effect of gravity. In the case of the erect cylinder, a range of 6.48% occurred during the first month, due to the rapid drying out of the surface layer and the accumulation of an excess at the foot of the column. The second month the range, 4.49%, was considerable less, almost 2.00%. The third and fourth months showed a small increase, 0.03% and 0.31% respectively, **over** the previous month. In the case of the inverted cylinder the situation is

entirely different. The range by months being 1.68%, 3.07%, 0.75%, 5.23% respectively for the first, second, third, and fourth months. Why the maximum range occurred during the last month rather than the first month as in the case of the erect cylinder, was probably due to the effect of gravity.

(6) The total loss of moisture from the inverted cylinder was greater during the first two months than from the erect cylinder. Inasmuch as there was a higher per cent of moisture within the column during this time, the force of gravity was more noticeable. The loss during the last two months was less and was probably due to the decreasing effect of gravity upon the movement of the film moisture within the soil, as well as to the compaction and settling of the soil in this cylinder.

FIELD EXPERIMENTS.

Experiment III.

A study of the absorption, run-off, and loss of moisture under field conditions.

In the experiment described below the moisture problem is studied under the conditions of the field. The plan was to determine not only the per cent of the rainfall penetrating the soil, but what becomes of the water which enters. Further it was proposed to find the exact effect of the water running off the surface upon the soil itself.

It is realized that the area of land subjected to study is small and that the results apply to but one type of soil. However, the important forces that control the movement of moisture must be the same everywhere, therefore, the character of the results obtained will be applicable to a greater or lesser extent to other types of soil.

Plan of Experiment -(Description of Plots)

Four plots, 91 feet in length and 5 1/2 feet in width were carefully laid out on the eastern slope of a hill whose inclination was about 4 1/2 degrees. The upper end of the plots commenced just at the brow of the hill and extended down the hill to its base or to the point where the slope ceased. Two plots, A-1 and B-1, were enclosed within a 6-inch board wall. The boards used were ordinary white pine boards, and were 16 feet

in length and 6 inches in width. They were entrenched 4 inches and allowed to extend 2 inches above the surface of the ground. In order to have boards remain securely in position strong stakes, 18 inches in length and 2 inches in width, were driven in the ground at the ends and in the middle of each board, to which the boards were nailed. After the boards were entrenched, the soil removed was placed back in the trench and tamped, so as to prevent excess washing next to the boards.

At the lower end of the plots concrete platforms, triangular in shape, were built with a slight slope. The upper sides were left flush with the surface of the ground while the other sides were built with an eight-inch concrete wall. At the lower points of the platforms, four-inch galvanized iron pipes, 9 feet in length, were placed in the concrete and cemented to the platforms. The pipes extended to galvanized iron tanks sunk in the ground and provided with covers.

The tanks were used to catch the run-off and erosion. These tanks were placed in the ground, 9 feet from the platforms, and were buried deep enuf so as to allow the proper drop (3 inches) for the pipes which led from the platforms and entered the tanks thru four-inch holes located just beneath the rim of the tanks. The pipes were securely fastened and soldered to the tanks so as to prevent any water loss by excessive run-off. The tanks were drained by inch and one-half iron pipes connected to the bottom of the tank and extending underground to a small roadside ditch 12 feet away. On the outlets of the pipes faucets were placed. Within the tanks, where the water entered the drain, a 1-inch iron pipe one inch in length, was fitted so as to screw into the drain. This device was used in separating the soil

DIAGRAM OF FIELD PLOTS.

from the water. A rubber stopper was placed in the upper end of the short pipe. The covers of the tanks were fastened down by hooks.

Plots A-2 and B-2 were not enclosed, but were treated in every way the same as plots A-1 and B-1. These outside unenclosed plots were used for determining the moisture in the soil during the season since it was not considered wise to penetrate the enclosed plots with the sampler.

Lysimeter Construction

Two lysimeters, 16 x 18 inches in area (0.004,59 acre) were constructed near the lower end of the drainage plots. A plot of ground 6 x 6 1/2 feet was laid out, and all the soil within this plot down to a depth of 4 1/2 feet was removed, except two columns of soil 18 x 20 inches. These two columns were carefully pared down until they were exactly 16 x 18 inches square. A long bladed corn knife was found very useful in paring the columns. Square board encasements, 22 x 24 inches, were placed around each column which permitted a space of 3 inches to exist entirely around the soil columns. This space was filled with concrete. The concrete was re-enforced perpendicularly on each side, at the corners, and horizontally at four different levels with No. 9 galvanized iron wire. Square galvanized iron bands, four inches in width, and just the size of the soil columns were embedded in the concrete at the top and allowed to extend two inches above columns of soil. After the concrete had set, the columns were laid over on their sides and a concrete bottom, 4 inches thick, was placed in them. In the center of the bottoms, an inch iron pipe, 6 inches in length, was embedded

in the concrete. This pipe extended one inch below the bottoms and served as an outlet for the percolating water. In order to prevent the soil from entering the pipe, a small pack of glass wool was placed at the upper end of the pipe. Columns were raised and placed on an 8-inch foundation. After the board encasements were removed, the columns were painted twice with a rich mixture of cement and then covered with a coat of coal tar. The lysimeters were thereby made water tight.

The dirt removed was returned to the pit and carefully tamped around the columns, excepting on the south side where the pit was unfilled to give access to the bottoms. The percolation water was caught in a two quart jar, closed with a rubber stopper and connected to the outlet in the bottom of the columns with properly bent glass tubing.

Weather Apparatus

Weather apparatus was stationed at the end of these plots, consisting of a rain-gauge, an evaporation pan and measuring device, and an anemometer. These were enclosed within a 4 foot wire fence. Observations were made daily at 7:15 am.

The Soil

The soil is classified as a "Silty Phase of the Shelby Loam". It consists of a fine sandy or silty loam of a gray or brown color from 7 to 8 inches deep, grading into a reddish-yellow sandy clay, which extends to a depth of 3 feet or more. The type is of glacial origin and belongs to the Glacial & Loessial Province. It has been in wheat continually for the past 15 years. After the wheat was harvested during the forepart of July, 1915, the ground was immediately plowed, disked, and sowed to cowpeas, these being turned under in the fall

PLATE - VII.

DIAGRAM OF LYSIMETERS

PLAN

SIDE VIEW

SCALE 1" = 2'.

just previous to the drilling of the wheat.

(Measuring Water Run-off and Soil Erosion)

Immediately after each rain the amount of water that ran off the enclosed plots was measured. This was done by a rule graduated in inches and tenths, measuring down to the top of the one-inch pipe. After the depth of water was determined, ten to forty grams of Calcium Oxide was added (depending upon amount of water in tank) to flocculate the soil particles and to clarify the water. After several hours (5 to 10) the rubber cork in the upper end of the iron pipe was removed, faucet to the outlet opened, and the tanks were allowed to drain. When water had drained away down to the top of the one-inch pipe, ten-gallon cans, weighed, were placed under the drain outlet, the one-inch pipe unscrewed, and the remaining muddy water and sediment was allowed to drain out. After drainage ceased and the tanks were cleaned, the cans were removed, weighed, and allowed to stand for a few hours, after which all excess water was drained from the cans by siphon and cans reweighed. The wet soil remaining in the bottom was then thoroly mixed and two samples of approximately 200 grams were taken. Their moisture content was determined and the average of the two was used in calculating the total water in the mixture and the amount of eroded soil (oven dry). The amount of water draining from the tanks, plus the amount removed by siphoning, plus the amount in the wet soil, equals the total run-off.

Soil Sampling

Soil samples were taken regularly twice a week and after each rain of importance in plots A-2 and B-2. The sampling was done with a King sampler and samples were taken every

foot to a depth of four feet. The ordinary slip cap, seamless tin, soil cans were used. Three sets of samples of four each each were taken in each of the two outside plots at intervals of thirty feet, commencing near the upper end of the plots and working down. After samples were taken the holes were re-filled with loose soil and tamped. Short stakes were placed in the holes to indicate the place of sampling. The following set of samples taken on the next date of sampling were taken twenty-two inches from the last set. This method was continued across the plot, until four holes had been made, and then the process was repeated twenty-four inches lower down the hill from the previous row of holes. This plan was followed thruout the experiment.

The samples were taken to the laboratory and weighed. Covers were removed and they were placed in an electric oven and dried for ten hours at an approximate temperature of 105 degrees centigrade. They were then removed, cooled, reweighed, and their moisture content determined. A torsion balance accurate to one-tenth of a gram was used during the fore part of the experiment, later it was found that this point of accuracy was unnecessary and a torsion balance, accurate to one-half gram was used.

Determination of Water-Holding Capacity of Field Soil

The soil samples taken on July 8th were used in determining the water-holding capacity of the field soil. After the moisture content was determined, the samples were pulverized in an iron mortar, and passed thru a 20-mesh sieve. The fine portion of the three different samples of each plot which represented the first-foot section were thorly mixed together and

placed in a bottle with air-tight stopper. The same was done for the other respective foot-sections. The W.H.C. of these mixtures was determined in duplicate by the Hilgard method*. Small cylinders, one centimeter in depth and 4.84 centimeters in width with perforated bottoms were used. They were filled with the dry soil, allowed to drop fifteen times from a height of one-half inch, weighed, placed in a shallow pan containing water one centimeter in depth until fully saturated, removed, allowed to drain ten seconds, wiped dry outside of cylinder, and reweighed. The difference in the two weighings represented the amount of water absorbed. The calculations were made on an oven dry basis. From the W.H.C. figures, the wilting coefficient was calculated by formula given by Briggs and Shantz**, viz:

$$\text{Wilting Coeff.} = \frac{\text{W. H. C. (Hilgard method)} - 21}{2.9} (\text{error } 8.3\%)$$

Table 12. - Water-Holding Capacity
and Wilting Point of Field Soil.

	<u>Scraped Plot</u>				<u>Fallow Plot</u>			
	First foot	Second foot	Third foot	Fourth foot	First foot	Second foot	Third foot	Fourth foot
	%	%	%	%	%	%	%	%
W.H.C.	42.63	57.56	52.25	54.74	44.43	53.97	50.65	49.44
W.P.	7.46	12.61	10.78	11.63	8.08	11.37	10.22	9.81

* Soils, p. 209.

** U.S.D.A., Bur. of Plant Industry, Bul. 230, 1912.

Experimental Methods -

During the winter of 1915, wheat grew upon the four plots, but just as early as possible in the spring of 1916, the plots were scraped, the wheat plants removed, and the surface of the soil placed in a smooth, bare condition. By April 15th, the construction work was completed and the experiment was ready to start, except for the lysimeters.

In order to see how closely the two enclosed plots were going to check both were left bare until April 26th (see Tables 13 and 14 for results). On this date, plots B-1 and B-2 were spaded to a depth of 6 inches. The surface was more or less smoothed with a rake and left in this condition.

On May 10th the lysimeters were completed and ready for operation. The surface of B was placed in the same condition as the B plots. A was scraped as in the case of the A plots. Thruout the experiment the respective lysimeters received the identical treatment as the plots.

During the fore part of the experiment weeds started growing here and there upon the bare plots. As soon as they became noticeable, the plots were gone over with a sharp hoe, care being used not to loosen any more soil than necessary. On May 17th and 31st when the plots were scraped the loosened soil was not removed (see Table 13 for effects upon amount of erosion in rains of May 28th and June 2d), but thereafter they were swept off by the use of a broom and all loosened soil removed.

As often as necessary plots B-1 and B-2, as well as lysimeter B, were cultivated, thus destroying all weeds and at the same time keeping the soil in good tilth.

On June 6th and August 8th considerable soil had collected on the platforms of the enclosed plots. This was removed, weighed, and moisture content determined, from which the amount of air dry soil calculated. This was added to the erosion column as may be noted in Tables 13 and 14.

In taking the sample of the 3d foot in plot B-3 on June 28th, the soil sampler was broken and it was impossible to take samples of the third and fourth feet, as well as samples from other plot for this day. Samples of the first and second feet at the upper end of plots were taken on June 29th from plot A-3 with another augur. Due to indications of rain on July 1st samples were also taken from the first and second feet at the upper end of both plots. On July 3d the sampling was continued as usual and no further trouble of this character was encountered.

In determining the pounds of water lost from the plots and lysimeters, 95.6* pounds was used as the average weight per cubic foot of the top four feet of soil. Inasmuch as the area of the plots was 500 square feet, this layer contained 191,200 pounds of soil. The lysimeters contained 764.8 pounds each. Also, 5.2 pounds was used as the weight of an inch of water covering an area one foot square.

*"Soils, their properties and Management", Lyon, Fippin, and Buckman, p. 117.

Experimental data -Table 13. - Effects of Rainfall upon Scraped Plot.

Date	Rainfall Inches	Run-off Cu. ft.	Run-off Surf. In	Run-off Percent	Erosion Pounds	Erosion Inches	Remarks
1916							
Apr. 15							Started
16	0.56	9.995	0.2345	41.87	4.781	0.001,460	
17-19	0.55	8.020	0.1924	34.99	included in 16th		
20	0.30	6.335	0.1520	50.68	2.578	0.000,785	
21	0.04	0	0	0	0	0	
26	0.02	0	0	0	0	0	
26							Scraped
May 1	0.96	12.341	0.2894	30.15	3.285	0.000,997	
3	0.31	3.187	0.0766	24.71	included in 1st		
8	0.20	0.678	0.0162	8.14	0.298	0.000,091	
12,13	1.14	22.301	0.5352	46.95	5.370	0.001,634	
14	0.04	0	0	0	0	0	
15	0.08	0	0	0	0	0	
17							Scraped
20	0.16	0	0	0	0	0	
21	0.05	0	0	0	0	0	
22	0.19	0	0	0	0	0	
27,28	1.46	34.287	0.8029	56.36	61.610	0.018,750	
29	1.12	35.850	0.8603	76.81	included in 27,28		
30	0.01	0	0	0	0	0	
31							Scraped
June 3	0.47	17.162	0.4119	87.64	210.040	0.063,940	
6	1.65	38.850	0.9324	56.51	33.680	0.010,025	
6					9.180	0.002,794	Cleaned plat-
7	0.24	3.625	0.0870	36.25	included in 6th		form
8	0.04	0	0	0	0	0	
9	0.01	0	0	0	0	0	
11	0.03	0	0	0	0	0	
14	0.03	0	0	0	0	0	
17	0.14	1.217	0.0292	20.87	2.024	0.000,616	
17							Scraped
20	0.17	1.998	0.0480	28.22	2.922	0.000,889	
21	0.03	0	0	0	0	0	
23	0.04	0	0	0	0	0	
24	0.65	19.325	0.4640	71.38	15.406	0.007,733	
July 4	0.04	0	0	0	0	0	
8							Scraped
18	0.57	6.327	0.1518	26.64	11.359	0.003,456	
19	0.04	0	0	0	0	0	
29	0.09	0	0	0	0	0	
Aug. 1	0.03	0	0	0	0	0	
8					7.275	0.002,214	Cleaned plat-
8	0.02	0	0	0	0	0	form
11	0.02	0	0	0	0	0	
13	0.01	0	0	0	0	0	
14,15	1.65	37.413	0.8979	54.42	62.271	0.018,950	
16	0.01	0	0	0	0	0	
Total since	11.70	234.561	5.6028	48.12	424.720	0.132,089	
May 1, (108 days)							

Table 14. - Effects of Rainfall upon Cultivated Plot.

Date	Rainfall Inches	Run-off Cu. ft.	Run-off Surf. In	Run-off Percent	Erosion Pounds	Erosion Inches	Remarks
1916							
Apr. 15							Started
16	0.56	9.464	0.2272	40.57	8.103	0.002,466	
17-19	0.55	6.930	0.1663	30.24	included in 16th		
20	0.30	6.204	0.1489	49.63	1.431	0.000,436	
21	0.04	0	0	0	0	0	
26	0.08	0	0	0	0	0	
26							Spaded 6" deep
May 1	0.96	0.042	0.0010	0.11	0.236	0.000,072	
3	0.31	included in 1st					
8	0.20	0	0	0	0	0	
12,13	1.14	0.372	0.0089	0.78	0.002	0.000,001	
14	0.04	0	0	0	0	0	
15	0.08	0	0	0	0	0	
17							Cultivated
20	0.16	0	0	0	0	0	
21	0.05	0	0	0	0	0	
22	0.19	0	0	0	0	0	
27,28	1.46	2.248	0.0540	3.70	9.810	0.002,986	
29	1.12	13.750	0.3299	29.46	included in 27,28th		
30	0.01	0	0	0	0	0	
June 2	0.47	13.610	0.3267	69.51	32.800	0.009,982	
6	1.65	24.980	0.5996	36.34	2.9600	0.000,901	
6					3.930	0.001,196	
7	0.24	1.835	0.0439	18.30	included in 6th		Cleaned plat- form
8	0.04	0	0	0	0	0	
9	0.01	0	0	0	0	0	
10							Cultivated
11	0.03	0	0	0	0	0	
14	0.03	0	0	0	0	0	
17	0.14	0	0	0	0	0	
20	0.17	0	0	0	0	0	
21							Cultivated
21	0.03	0	0	0	0	0	
23	0.04	0	0	0	0	0	
24	0.65	0.494	0.0031	1.82	0	0	Mostly plat- form run-off
28							Cultivated
July 4	0.04	0	0	0	0	0	
8							Cultivated
16	0.57	0	0	0	0	0	
19	0.04	0	0	0	0	0	
20							Cultivated
29	0.09	0	0	0	0	0	
Aug. 1	0.03	0	0	0	0	0	
8							Cleaned plat- form
8	0.02	0	0	0	0	0	
11	0.02	0	0	0	0	0	
13	0.01	0	0	0	0	0	
14,15	1.65	18.369	0.4409	26.72	30.718	0.009,349	
16	0.01	0	0	0	0	0	
Total since May 1, (108 days)	11.70	75.695	1.8080	15.53	82.256	0.024,676	

PLATE - VII

RELATIONSHIP OF RAINFALL
 RUN-OFF, PENETRATION^{TO} AND EROSION ON
 CULTIVATED AND UNCULTIVATED SOIL.

Table 15.- Percentage of Moisture in Soil Samples taken from Plot A-3.

Date	Top of Hill				Center of Hill				Bottom of Hill			
	1st foot	2nd foot	3rd foot	4th foot	1st foot	2nd foot	3rd foot	4th foot	1st foot	2nd foot	3rd foot	4th foot
16 April												
26	17.83	22.59	20.75	18.95	18.11	26.60	21.06	19.85	19.35	24.75	16.77	20.79
29	16.46	22.30	20.24	19.40	20.07	22.34	26.74	17.07	17.43	23.27	18.02	19.92
May												
1	22.57	23.90	25.34	26.59	20.61	20.15	21.93	20.78	21.04	24.03	20.79	19.68
3	21.83	23.95	21.30	18.90	22.33	27.47	23.00	21.07	22.68	25.08	24.85	26.90
6	20.03	23.70	19.96	18.41	19.46	26.02	20.66	18.92	18.75	22.73	17.97	28.66
10	18.97	24.65	22.55	19.05	18.18	27.73	21.97	21.22	18.44	24.67	20.36	21.60
13	20.33	22.29	20.32	19.13	20.68	27.33	20.68	20.01	20.03	23.27	18.29	20.19
17	18.15	22.46	22.34	19.48	19.09	27.84	20.39	19.51	19.06	22.84	19.04	21.84
20	16.25	21.90	20.21	19.65	18.09	25.36	19.05	20.14	17.34	22.70	18.39	19.93
24	17.26	23.56	21.30	17.90	17.41	26.08	23.86	21.01	18.20	23.49	*	*
29	19.99	24.38	22.65	20.01	20.64	27.75	21.49	19.91	20.91	23.56	18.21	22.41
31	17.74	23.04	20.19	19.56	19.06	26.80	19.73	20.17	19.25	24.29	24.24	22.38
June												
3	16.80	21.68	18.39	14.98	17.72	23.88	18.07	17.70	17.17	22.15	18.31	19.29
7	21.59	23.77	20.21	17.85	21.98	28.67	21.85	20.07	23.35	23.63	19.46	21.14
10	19.63	23.44	21.91	18.17	20.06	28.32	21.49	19.52	19.93	24.92	19.25	21.62
14	18.06	23.34	20.92	19.17	19.47	26.60	20.81	19.17	19.86	24.21	18.38	24.66
15	18.71	24.04	21.42	18.69	19.23	27.15	20.13	19.43	18.45	23.87	18.37	20.96
17	16.29	23.11	20.57	19.66	16.65	28.93	19.87	19.46	17.79	23.53	20.98	22.53
21	16.23	23.53	20.82	18.31	16.98	27.85	20.60	20.62	16.27	22.84	17.48	20.74
24	16.87	24.62	22.13	19.55	17.63	28.12	21.74	19.43	18.07	24.36	18.66	23.47
29	15.56	24.28	**	-	-	-	-	-	-	-	-	-
July												
1	13.62	23.41	***	-	-	-	-	-	-	-	-	-
3	14.01	25.00	23.65	19.29	14.78	28.20	21.47	20.72	14.02	23.28	19.57	24.73
8	13.46	24.02	21.20	18.81	13.14	28.99	21.65	19.07	14.51	21.95	18.75	22.33
12	12.38	23.42	20.11	19.46	12.77	27.23	22.80	16.41	13.19	21.69	20.29	19.80
15	12.34	25.00	21.77	18.75	12.81	25.32	19.94	16.09	12.99	23.91	18.99	22.43
18	16.10	24.56	22.32	19.62	14.71	27.31	21.81	22.44	14.83	24.36	21.45	21.19
20	12.12	25.22	22.03	19.07	12.58	28.77	21.24	19.28	13.90	22.11	17.11	21.16
22	12.28	22.69	16.44	18.18	13.10	27.49	20.63	20.36	14.20	23.79	18.91	22.49
26	13.46	23.74	17.03	18.01	12.58	27.35	20.81	19.91	13.15	22.84	19.17	24.09
29	13.56	23.98	22.36	19.93	12.85	27.81	20.69	18.34	15.41	23.21	20.83	22.40
Aug.												
5	11.36	23.85	20.48	17.57	11.59	26.38	19.88	18.41	12.30	22.30	18.13	19.96
9	11.22	25.10	20.44	16.83	13.08	26.48	20.27	19.58	12.44	25.33	19.73	19.26
12	12.64	21.37	19.66	16.09	11.22	26.39	20.60	20.82	11.66	17.75	20.27	24.20
14	14.66	24.14	18.92	16.88	16.02	24.25	18.75	19.54	15.34	21.47	19.55	20.05
16	13.23	14.68	17.76	15.33	14.55	23.21	17.45	14.98	16.50	14.63	14.73	14.68

King Sampler broken.

Head of King Sampler was twisted off.

*Due to indications of rain, samples were taken of first and second feet from hole at upper end of plots.

Table 16.- Percentage of Moisture in Soil Samples taken
from Plot B-2.

Plot	Top of Hill				Center of Hill				Bottom of Hill			
	1st foot	2nd foot	3rd foot	4th foot	1st foot	2nd foot	3rd foot	4th foot	1st foot	2nd foot	3rd foot	4th foot
1	18.08	21.46	19.97	25.31	18.74	25.39	23.69	23.49	23.40	24.50	21.25	18.93
2	15.51	26.94	18.95	17.43	16.34	24.52	25.59	23.62	19.59	23.75	22.79	17.90
3	21.26	19.00	20.00	18.24	22.26	24.89	24.35	21.32	23.99	24.26	24.51	23.85
4	21.74	22.65	18.20	17.16	23.54	25.21	25.39	20.38	25.54	25.96	23.83	21.24
5	19.17	21.29	19.79	19.44	21.13	26.91	23.87	21.28	23.64	22.90	20.16	19.41
6	17.77	22.27	19.54	18.78	19.75	27.21	23.88	22.10	21.22	23.05	23.32	18.47
7	21.05	24.40	20.72	18.60	24.05	37.18	24.55	22.67	25.41	25.34	21.14	17.24
8	18.26	22.22	20.80	24.37	21.44	26.65	24.42	20.73	23.32	26.84	23.15	19.23
9	18.70	22.09	19.17	18.08	20.57	24.34	24.77	21.39	21.59	26.27	23.40	20.48
10	20.97	25.30	20.85	16.95	17.87	27.36	25.33	21.16	20.77	25.48	19.93	15.99
11	22.63	25.31	20.03	17.26	23.80	26.97	22.43	18.72	26.68	27.25	21.63	20.86
12	20.47	23.35	19.56	16.64	21.77	27.04	26.47	22.08	24.41	28.16	23.28	20.09
13	16.82	17.34	14.73	11.14	20.67	21.43	19.97	13.49	20.06	19.31	16.83	13.13
14	24.38	26.29	20.81	18.00	24.94	22.71	24.26	21.28	25.20	29.69	26.02	19.86
15	20.06	23.22	19.00	15.38	21.97	26.21	23.56	19.21	22.75	24.83	22.79	18.85
16	16.25	20.29	16.49	14.21	17.32	20.25	22.12	15.90	18.54	19.95	19.25	20.70
17	19.63	22.65	19.83	16.52	22.29	25.32	23.65	18.82	20.93	25.00	22.49	22.39
18	18.71	23.08	18.72	17.23	20.08	25.45	24.22	20.32	21.38	25.88	20.22	23.21
19	17.29	22.40	18.93	16.75	17.96	23.71	24.39	19.42	20.29	22.90	21.19	22.53
20	21.35	22.65	18.70	17.68	21.26	25.73	24.09	21.96	22.19	25.00	*	22.22
21	16.67	23.70	19.05	17.03	17.63	24.32	22.45	21.47	19.22	23.95	**	**
22	15.15	18.94	***	-	-	-	-	-	-	-	-	-
23	15.84	24.67	16.85	16.55	17.29	25.09	25.37	22.09	17.87	25.09	23.45	22.44
24	15.11	23.11	19.19	16.87	16.37	25.69	23.13	18.82	17.99	26.19	22.86	22.04
25	14.38	22.49	20.21	18.18	16.46	24.44	23.39	19.41	16.48	26.25	24.32	21.79
26	15.38	25.00	19.68	18.43	16.33	24.80	23.51	19.81	17.69	25.45	20.82	23.23
27	17.99	22.96	19.15	17.99	18.81	24.27	23.57	20.52	19.49	25.58	24.08	22.15
28	16.02	23.87	19.90	15.86	16.73	23.68	23.96	22.36	18.08	22.30	20.29	22.66
29	17.05	23.90	17.55	17.94	17.74	25.10	24.29	20.26	18.85	26.39	21.04	22.22
30	15.18	24.63	21.22	17.20	16.35	25.59	24.56	21.39	17.43	24.56	17.50	20.00
31	14.97	25.24	25.07	18.45	15.46	24.12	23.28	19.62	16.29	21.78	19.88	17.07
32	14.38	23.83	21.98	17.62	14.96	24.89	25.12	19.08	16.10	23.00	21.67	24.72
33	9.94	25.20	24.56	18.60	15.18	23.69	25.88	22.61	15.07	23.74	21.58	22.71
34	10.81	23.46	13.32	14.59	14.58	18.75	20.59	17.91	13.13	17.13	16.67	17.31
35	18.98	23.14	20.06	19.49	25.85	26.60	19.16	22.16	21.00	22.63	21.17	22.70
36	19.28	25.41	23.01	20.05	23.24	25.46	23.66	19.51	20.37	24.38	22.51	22.80

truck rock and could go no further.

King Sampler broken.

Due to indications of rain, samples were taken of first and second feet from hole at upper end of plots.

Table 17. - Average percentage of moisture in soil samples.

Date	Plot A-2 Scraped				Plot B-2 Cultivated				
	1st foot	2nd foot	3rd foot	4th foot	1st foot	2nd foot	3rd foot	4th foot	

1916									
April	26	18.43	24.65	19.53	19.86	20.07	23.95	21.64	22.58
	29	16.99	24.10	20.20	19.79	17.15	25.07	22.44	19.65
May	1	21.41	22.69	22.69	22.35	22.48	22.38	22.95	21.14
	3	22.28	25.50	23.05	22.29	23.61	24.61	22.44	19.59
	6	19.41	24.15	19.53	21.99	21.31	23.70	21.27	20.04
	10	18.53	25.68	21.63	20.62	19.58	24.18	22.28	19.78
	13	20.35	24.29	19.76	19.78	23.50	28.97	22.14	19.50
	17	18.77	24.38	20.59	20.28	21.01	25.24	22.79	21.64
	20	17.29	23.32	19.22	19.91	20.29	24.23	22.45	19.98
	24	17.62	24.38	22.58	19.45	19.87	26.05	22.04	18.03
	29	20.51	25.23	20.78	20.68	24.37	26.71	21.35	18.95
	31	18.68	24.71	21.39	20.70	22.22	26.18	23.10	19.60
June	3	17.23	22.57	18.26	17.32	19.18	19.53	17.18	12.60
	7	22.31	25.36	20.51	19.69	24.84	28.23	23.93	19.71
	10	19.87	25.56	20.88	19.77	21.58	24.77	21.78	17.81
	14	19.13	24.72	20.04	21.01	17.37	20.33	19.29	16.94
	15	18.79	25.02	19.97	19.69	20.95	24.32	21.99	19.24
	17	16.91	25.19	20.47	20.55	20.06	24.80	21.25	20.25
	21	16.47	24.74	19.63	19.89	18.51	23.01	21.50	19.57
	24	17.52	25.70	20.84	20.82	21.60	24.46	21.39	20.62
	29	15.56	24.28	*	*	17.84	23.99	20.75	19.25
July	1	13.62	23.41	*	*	15.15	18.94	*	*
	3	14.27	25.49	21.56	21.58	17.00	24.95	21.89	20.36
	8	13.70	24.97	20.53	20.07	16.49	24.99	21.73	19.24
	12	12.78	24.11	21.07	18.56	15.77	24.37	22.64	19.79
	15	12.71	24.41	20.23	19.09	16.63	25.08	21.34	20.49
	18	15.21	25.41	21.86	21.08	18.76	24.27	22.27	20.22
	20	12.87	25.37	20.13	19.84	16.94	23.28	21.38	20.29
	22	13.19	24.66	18.66	20.34	17.88	25.13	21.29	20.14
	26	13.06	24.64	19.00	20.67	16.32	24.93	21.09	19.53
	29	13.94	25.00	21.29	20.22	15.57	23.38	22.78	18.38
Aug.	5	11.75	24.18	19.49	18.65	15.15	23.91	22.92	20.47
	9	12.44	25.33	19.73	19.26	13.39	24.21	24.01	21.31
	12	11.84	21.84	20.18	20.37	12.84	19.78	16.86	16.60
	14	15.34	23.29	19.07	18.82	21.94	24.12	20.13	21.45
	16	14.76	17.51	16.65	15.00	20.96	25.08	23.06	20.79

Total mean									
average		16.54	24.38	20.35	20.00	18.53	24.20	21.70	19.59
for Season									

* See footnotes bottom of Tables 15 and 16.

Plate-IX

Storage of Moisture in Plots.

Natural
 Evaporation
 Fallow
 Scraped
 Seasonal Average Fallow
 " " Scraped

Evaporation. First Foot Second Foot Third Foot Fourth Foot

Table 18. - Evaporation effects upon plots*.

Plot	Average Moisture Content May 1st	Average Moisture Content Aug. 14th	Amount Rainfall penetra- ing soil	Total loss Including absorption	Loss Exclusive of absorption
	per cent	per cent	inches	per cent	per cent
Scraped	22.29	19.13	6.10	3.16	11.47
Cultivated	22.24	21.91	9.90	0.33	12.41

* Calculated upon basis that no moisture was lost thru percolation.

Table 19. - Moisture conditions in soil after six weeks of
drying weather - June 25th to August 4th.

Depth of Section		Plot A-2 Scraped	Plot B-2 Cultivated
Feet	Inches	Per cent	Per cent
1.....	{ 1-3	6.05	7.90
	{ 3-6	9.79	14.19
	{ 6-9	15.55	14.53
	{ 9-12	18.40	17.28
2.....	{ 12-15	24.02	22.77
	{ 15-18	25.14	25.85
	{ 18-24	23.45	23.38
Ave.	1-12	11.19	13.50
Ave.	12-24	24.20	24.00

Table 20. - Moisture conditions in Lysimeters.

Depth of section		Taken near Lysim- eters at begin- ning - Apr. 24th	Taken from Lysim- eter A (scraped) Aug. 8th	Taken from Lysim- eter B (cultivated) Aug. 8th
Feet	Inches	Per cent	Per cent	Per cent
1.....	{ 1-3		9.09	6.67
	{ 3-6		16.28	11.91
	{ 6-9		16.31	11.83
	{ 9-12		16.41	17.02
2.....	{ 12-15		19.35	18.00
	{ 15-18		23.94	22.08
	{ 18-24		25.33	27.78
Average	1-12	21.64	14.52	11.86
	12-24	25.00	22.87	22.62
	24-36	25.00	18.94	24.91
	36-48	20.70	21.00	18.29
Mean Average		23.085	19.44	19.42
Difference*	1-12		-7.12	-9.78
	12-24		-2.13	-2.38
	24-36		-6.06	-0.09
	36-48		+0.30	-2.41

* Equals difference in moisture content of the respective foot sections of soil at the beginning and end of experiment.

Table 21. - Evaporation effects upon Lysimeters.

(May 10th to Aug. 8th, incl.)

Lysimeter	Average Moisture content at beginning	Average Moisture content at end	Rainfall during period	Total loss from soil including rainfall	Loss Exclusive of rainfall
	Per cent	Per cent	Inches	Per cent	Per cent
Scraped	23.085	19.44	8.54	3.645	16.615
Cultivated	23.085	19.42	8.54	3.665	16.515

Table 22- Record of Weather Observations.

Daily Precipitation Inches					Daily Wind Velocity*** miles per hour					Daily Evaporation Inches				
Apr.	May	June	July	Aug.	Apr.	May	June	July	Aug.	Apr.	May	June	July	Aug.
.34*	.96	T	.0	.03	3.2	4.2	1.0	2.2		.084	.114	.277	.301	
.05	T	.47	0	0	3.0	2.5	1.3	2.0		.095	.319	.278	.300	
.01	.31	0	0	0	4.6	1.8	1.4	1.8		.042	.242	.254	.200	
.01	T	0	.04	0	1.5	0.4	2.0	1.6		.038	.153	.198	.296	
T	0	0	0	0	3.1	1.6	2.3	2.7		.215	.283	.259	.388	
.01	0	1.65	0	0	1.7	5.9	3.0	2.4		.246	.087	.388	.342	
0	0	.34	0	0	3.9	4.2	3.0	3.5		.234	.056	.392	.263	
.31	.20	.04	0	.02	3.2	2.8	2.1	2.7		.300	.238	.323	.331	
.02	0	.01	0	0	4.0	2.5	2.3	1.8		.266	.141	.313	.291	
0	T	0	0	0	5.3	1.1	2.4	3.1		.252	.194	.366	.454	
0	0	.03	0	.02	4.5	1.0	1.3	3.3		.268	.153	.314	.320	
0	.31	0	0	0	3.3	2.9	1.1	3.9		.120	.123	.304	.470	
T	.83	0	0	.01	6.0	2.2	1.3	3.4		.050	.245	.317	.276	
.13	.04	.03	0	1.48	2.6	1.5	1.3	3.5		.176	.120	.334	.200*	
T	.08	0	0	.17	4.2	2.1	2.3	3.0		.205	.223	.321	.077	
.56	0	.14	0	.01	3.8	4.2	3.9	1.3	2.3	.047*	.245	.275	.291	.179
.01	0	0	0		5.4	4.2	3.7	1.4		.169	.267	.288	.276	
.37	0	0	.57		4.3	2.9	2.4	1.6		.283	.200	.262	.340	
.17	0	0	.04		6.2	1.1	2.3	1.6		.198	.195	.204	.294	
.30	.16	.17	T		8.3	2.4	2.4	1.5		.287	.100	.050	.158	
.04	.05	.03	0		8.5	3.7	4.3	2.7		.116	.190	.246	.273	
T	.19	0	0		6.6	3.3	5.3	1.5		.104	.140	.191	.264	
0	0	.04	0		3.1	1.5	3.6	1.3		.193	.224	.274	.304	
0	0	.65	0		2.3	3.4	1.3	1.3		.173	.246	.117	.318	
T	0	0	0		3.5	1.4	2.0	1.4		.124	.226	.285	.306	
.08	0	0	0		5.4	1.5	2.3	1.2		.095	.268	.247	.332	
T	.71	0	0		4.0	2.0	2.6	1.7		.047	.057	.257	.365	
T	.75	0	0		1.9	1.0	2.3	1.8		.103	.053	.313	.375	
0	1.12	0	.09		2.0	1.3	1.7	1.3		.199	.244	.244	.366	
0	.01	0	0		4.0	0.9	1.4	1.5		.242	.180	.284	.297	
0	0	0	0		2.1		1.3			.267		.246		
1.53	5.72	3.50	.74	1.74	4.6	2.9	2.61	2.67	2.70	1.530	5.693	6.228	9.443	4.688

*Rainfall April 1 - 14, incl., taken from U.S.W. Bur. Report.

*Estimated.

*Total at bottom represents Mean hourly wind velocity for the respective months.

General Observations -

As will be observed from Tables 13 and 14 the plots checked with each other with reasonable closeness during the preliminary period. With a rainfall of 0.56 inches the day following the beginning of the experiment, 41.87% ran off the A-1 plot, while 40.57% ran off of B-1. On April 20th, 0.30 inches fell, with run-off of 50.68% and 49.63%. The amount of soil eroded did not check so closely, however, in each case it accompanied the largest run-off.

Table 13 gives the results of rain falling upon the scraped plot. With a rainfall of 11.70 inches, occurring within a period of 108 days, almost one-half (5.60 inches) was loss by surface run-off. The ratio of rainfall to run-off being 48.12%. The erosion totaled 424.721 pounds, a layer of soil 0.132 inches in depth over the entire surface area of the plot. The amount of run-off varied directly with the amount of rainfall, the rapidity with which it came, and the surface condition of the soil. In every instance where the rainfall totaled an inch or more, the run-off exceeded 50%, except on May 12th when the per cent of run-off was 47.95% which may be accounted for by the extended period during which it fell. The highest per cent occurred June 2nd when 87.64% of the rainfall was caught as run-off. The rainfall amounted to only 0.47 inches, but it came with a dash and fell within a limit of 36 minutes, from 6:31 a.m. until 7:07 a.m. In striking contrast to this, on July 18th with a rainfall of 0.57 inches falling during a period of 2 hours and 17 minutes, only 26.64% ran off, and likewise the amount of erosion was a great deal less, about one-twentieth as much. Less than 0.10 inches of rainfall produced no run-off.

Much depended upon the condition of the soil as whether it was wet or dry as to the run-off. On May 8th and June 7th the rainfall was 0.20 and 0.24 inches respectively. The run-off from the former was 8.14% and the latter 36.25%. Both were preceded by a rainy period, but in the case of the latter it was more extended. On May 20th and 22nd with rainfalls of 0.16 and 0.19 inches no run-off occurred, the period preceding being dry. There are undoubtedly cases, particularly where the rainfalls in a short time, that a dry soil would absorb less than one which was moist but not saturated at the surface.

Table 14 gives the results of rain falling upon the cultivated plot. A striking difference is noticed in the results as compared with the scraped plot. Only 1.8080 surface inches was caught as run-off during the period of 108 days. The ratio of rainfall to run-off being 15.53%. The erosion totaled 82.256 pounds or about one-fifth the amount that occurred on the scraped plot. The amount of run-off varied directly with the amount and the rapidity of the rainfall, altho, not so closely as in the case of the scraped plot. The maximum run-off was 69.51%, occurring on June 2nd when the duration of the rainfall was 36 minutes. With this exception the run-off never exceeded 37%. The run-off was practically nil from rains less than one inch, especially when soil was not compact and wet from a previous rain. The erosion varied directly with the runoff. The season being dry, the rainfall was never sufficient to give much run-off on the cultivated plot. It is very probable that had the rainfall at times been very heavy the erosion on the cultivated plot might have greatly ex-

ceeded that on the scraped plot.

The moisture conditions in the soil on the different days of sampling are shown in Tables 15 and 16. Table 17 gives the average of the first-foot, second-foot, third-foot, and fourth-foot samples of each plot on the respective days of sampling, as well as the mean average for each foot thruout the period.

As is clearly shown by Plate IX, page 84, the surface foot of the cultivated contained considerable more moisture than the scraped one, which is proof that the decreased run-off in the case of the cultivated plot was noticeably affecting this layer. The fluctuation of both curves due to rainfall and evaporation are almost identical. Both vary with small amounts of rainfall. From the beginning until June 15th both were considerable above the average. Thereafter, there was a gradual decrease due to the continued dry spell until the rain of August 14th when both increased. The rain of July 18th caused the amount to increase in the surface foot of both plots, but caused little or no effect on the lower layers. The mean seasonal average was 16.54% for the scraped plot and 18.53% for the cultivated plot.

The moisture in the second-foot layers of soil did not fluctuate nearly as much as in the surface foot, which goes to show that the rainfall and evaporation changes did not affect it nearly as much as the surface foot. This layer in both plots contained by far the most moisture, containing at times as much as 28% to 29%, and rarely falling below 20%. The mean average was 24.38% for the scraped plot and 24.20 for the cultivated plot.

The third-foot layers varied still less than those of the second. Thruout the season they were nearly constant. On June 3rd the samples for all the feet were low which is unexplainable unless possibly ^{due} to an error in drying. The mean seasonal average was 20.35% for the scraped plot and 21.70% for the cultivated plot. The latter being 1.35% greater. The curves of the fourth feet run nearly in unison varying slightly from the average. The mean average for the scraped plot was 20.00% and 19.59% for the cultivated plot. The long dry spell during the summer had no particular effect upon lowering the moisture content of the three lower layers below the seasonal average. The cultivated plot contains the most moisture, and most of that is in the first and third-foot layers.

The total percentage loss from the top four feet for both plots between May 1st and August 14th, inclusive, is shown in Table 18. The fact that there is such a great difference in the readings of the scraped plot is due to the fact that the run-off was high on the scraped plot. In the case of the cultivated plot 3.80 inches more rain penetrated the soil than did in the scraped plot.

Table 19 shows the condition of moisture within the soil after six weeks of very drying weather. In order to obtain a representative sample from which to make the moisture determination, a composite sample of soil taken from three different holes was used. In the surface three inches there was 1.85% more moisture in the cultivated plot than in the scraped plot. From three to six inches the cultivated plot contained 4.40% more moisture. From six to nine inches they were about equal,

there being a slight percentage in favor of the scraped plot. The percentages of moisture in the other depths were nearly the same. The average per cent in the surface foot of the scraped plot was 11.19% and in the cultivated plot 13.50%, 2.31% more moisture in the latter. The second and third feet of both showed they were practically equal.

During this time 0.77 inches of rain fell, all of which occurred in five light showers. The largest was 0.57 inches on July 17th. The balance came in four showers of 0.04, 0.04, 0.09, and 0.03 inches respectively. The mean temperature was 81.5 degrees F., the total evaporation from free-water-surface 12.17 inches, and the mean hourly wind velocity 1.88 miles.

There was no percolation thru the lysimeters during the period of their operation. All the rain which fell entered the soil and was either lost by evaporation or retained in the soil mass. The moisture content of the soil before it was encased, as well as the moisture content near the end of the experiment, is shown in Table 20. Lysimeter A shows a higher percentage of moisture than B in each of the 3-inch samples of the surface foot except the last. The average for the entire foot was 2.66% in favor of A. In the second foot, samples 12-15 and 15-18 inches in A contained more moisture than those of B, however, the layer from 18-24 inches in B contained 2.45% more moisture than A. The average for the entire foot was slightly in favor of A. The third foot of B contained 5.97% more moisture than A. In the fourth foot A contained 2.71% more moisture than B. The averages for the entire columns were practically equal, 19.44% in A and 19.43% in B. In Table 21 the amount of moisture that has been lost due to evap-

ation is shown. The striking thing is that the loss from both lysimeters, irrespective of the condition of their surface, is practically equal. If anything the cultivated lysimeter lost slightly more moisture than the scraped one. The total loss including rainfall was 3.645% from A, and 3.665% from B. The total rainfall for this period, May 10th to August 8th inclusive, was 8.54 inches, and the evaporation from the free-water-surface was 22.365 inches.

Tabel 22 gives the daily precipitation, daily wind velocity, and daily evaporation from a free-water-surface. The total rainfall from May 1st to August 16th inclusive, was 11.70 inches; the mean average wind velocity was 2.71 miles per hour; and the total evaporation was 26.052 inches. The greatest rainfall occurred during the month of May, totaling 5.72 inches, the smallest during July when 0.74 inches fell. The maximum rain, 1.65 inches, fell on June 6th. The longest period without rain was 13 days, from July 5th to 17th. From June 25th to August 14th only 0.82 inches fell which was one of the longest dry periods ever occurring in this region.

The wind reached its highest mean hourly velocity during April, an average of 4.67 miles per hour. During May, June, July, and August, the average mean hourly velocities were practically equal. The maximum mean hourly velocity for one day occurred on April 21st, the minimum on June 4th, it being 8.5 miles on the former date and 0.4 miles on the latter.

The largest evaporation occurred during July, the month of least rainfall. 9.443 inches evaporated, over 12 times the amount of rainfall during this month. The least occurred during April. Every month the evaporation exceed-

ed the rainfall except during May when the rainfall was the most by 0.37 inches.

Discussion of Results -

The results obtained from the field experiments show several interesting things. The relation of rainfall to run-off is affected very noticeably by the surface condition of the soil. The condition of the surface is the important factor in controlling run-off and erosion, thus increasing or decreasing the moisture content of the productive layers of soil and the great waste of the humus layer of soil. The run-off was over three times as great and the erosion five times as much on the scraped plot as upon the cultivated plot. Next to the condition of the surface in controlling the run-off, is the amount and rapidity of the rain. If large or small amounts come suddenly, not giving the soil time to absorb it, most of it runs off and is of little avail. When it comes slowly, most of it is absorbed. The power of absorption depending directly upon the surface, the more compact the surface, the sooner the water starts running upon the surface and leaves the soil as run-off. This seems and no doubt is a great function of the dust mulch.

The results obtained from the lysimeters, as well as the moisture conditions of the soil after six weeks of drying weather, would clearly indicate that very little water is being lost by evaporation thru capillary action. In the case of the lysimeters where the entire rainfall entered the soil, the evaporation losses were practically equal under both conditions.

There was a greater decrease in the moisture content in the layers of the scraped plot than from the cultivated plot, however, which is clearly and conclusively explained by the fact that more rain penetrated the cultivated plot to replenish the loss due to the continued evaporation.

The curves showing the variation of moisture within the different foot layers are proof that the great loss of moisture by evaporation is occurring in the surface foot of both plots irrespective of their surface condition. The second foot contained an abundant and constant supply of moisture irrespective of the decreasing supply in the first foot.

It would seem that if capillarity was an important factor in controlling the evaporation loss, and if the mulch serves as a means of controlling evaporation losses, that the moisture content of the scraped soil should have been more noticeably affected during the dry period. This was an ideal condition under which to operate, little rain, low humidity, and a high mean temperature.

From the results one must conclude that capillarity plays a very minor part in the evaporation losses of the soil where the water-table is far below the surface; and, that the great importance and significance of surface mulch, excepting as it affects weeds, is not that the evaporation is controlled thru the breaking of capillary tubes, but that it places the surface in a condition such that it may absorb rain most readily. Surface mulching and cultivation, other than killing weeds, should be given with the aim of keeping the surface in as ideal condition as possible for absorbing

the rain that falls. By so doing the moisture content of the soil is not only replenished and increased, but the great loss due to erosion is impeded in a large way.

SUMMARY AND CONCLUSIONS.

Capillary studies were carried on under laboratory conditions with 2-foot, 4-foot, and 6-foot cylinders of soil in duplicates with their bases in standing water. There was a constant and perfect movement of water thru the 2-foot cylinders, the evaporation loss being practically equal to the water-table loss. The movement thru the 4-foot cylinders was not regular, and the evaporation loss was considerably more than the water-table loss. The loss from the 6-foot cylinders was in great excess of the amount that moved up into the cylinder from the water-table. The results clearly showed that the depth of water-table was a deciding factor upon the rate and amount of water lost by capillarity, the loss thru capillarity decreasing with depth of water-table and being almost negligible at 6 feet.

The study of gravity as a factor in preventing soil moisture from returning to the surface after it has passed thru the surface foot of soil was ^{carried out} ~~studied~~ by taking two 6-foot cylinders of soil and allowing one to lose moisture in an erect position while the other was inverted. By taking samples at regular intervals thruout the length of the cylinders, the effects of gravity were determined. The loss from the erect cylinder was greatest at the surface and gradually increased until the least was lost in the bottom layer. The loss from the inverted cylinder was more or less constant thruout its entire length. There seems to be little doubt that gravity is playing a far more important part in removing soil moisture and in

controlling its movements than has commonly been believed.

From two enclosed plots, one scraped and one cultivated, 500 square feet in area, and situated on a hill with an inclination of approximately $4\frac{1}{2}$ degrees, 48.12% of a total rainfall of 11.70 inches was caught as run-off from the former, and 15.53% from the latter. The erosion resulting was 424.72 pounds in the case of the scraped plot and 82.36 pounds from the cultivated plot.

The evaporation losses of the plots as influenced by the condition of the surface seem to be negligible. The far more important function of the mulch seems to be in the control of the run-off and erosion. Thru the use of the mulch the surface is kept in a better condition for absorbing water. The moisture content of the layers of soil below the second foot were nearly constant thruout the sampling studies, which indicates that very little loss is occurring from them thru capillarity and evaporation.

It seems almost conclusively demonstrated that the moisture is lost from the soil under average conditions with a water-table several feet below the surface, not thru the aid of capillarity, but in a gaseous state as water vapor, this loss being greatest from the surface foot and decreasing rapidly downward.

If the above conclusions are correct, the value of a mulch in regions where the water-table is deep has been over emphasized so far as preventing the evaporation of moisture is concerned. Further, the cultural methods that have been used supposedly to decrease the capillary rise of moisture, probably assist mainly in causing a greater water absorption.

No. 1. - Soil Cylinders used in
Experiment I on platform in greenhouse.

No. 2. - Soil cylinders used in Experiment II.

No. 4. - Looking east across field plots. Weather apparatus in fore ground.

No. 5. - Lower end of field plots, showing catching apparatus for run-off, and lysimeters.

No. 6. - Position of lysimeters when bottoms were installed.

No. 7 - Lysimeters on foundation before replacing soil.

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COLLEGE OF AGRICULTURE
AGRICULTURAL EXPERIMENT STATION
DEPARTMENT OF SOILS

May 15, 1917

Dean Walter Miller
Academic Hall

Dear Sir:

The thesis of Mr. Vifquain is not particularly well organized. He has included no regular bibliography. A note from him says that this was delayed. The material he has presented is good enough, in my opinion, and I think the thesis is passable. I will therefore approve it.

Yours very truly,

A handwritten signature in cursive script, appearing to read 'M. F. Miller', written in dark ink.

Professor of Soils

M. F. Miller:NB

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