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EXPERIMENT STATION

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CHEMICAL DEPARTMENT.

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SOIL MOISTURE.

IN Bulletin 68 issued by this department, the chief results of its experiments upon soil moisture up to that time were detailed. During the past two years some of those experiments have been continued and others have been inaugurated, and the following pages exhibit the most important results. Two important phases have been under study, the effect of various fertilizers, and the influence of different kinds of tillage.

EXPERIMENTS TO SHOW THE EFFECT OF FERTILIZERS.

Basing their opinions upon slight differences in the heights to which pure water and water containing various salts in solution will rise in capillary tubes, some writers have held that the loss of water

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from soil by evaporation and drainage could be very much modified by appropriate use of fertilizers. Our most extended series of experiments have been directed toward a practical solution of this problem, or at least toward the accumulation of facts pointing to its solution. One series has been a continuation of experiments reported on in Bulletin 68, namely, observations on the rates of evaporation from soils in pots, in which a certain amount of a fertilizer was added to each pot, and the daily loss of water ascertained by weighing the pots with their contents. These experiments evidently involve only the effect of the fertilizer upon the rise of water by capillary attraction, and its evaporation from a solution of the fertilizers, assuming the conditions of the soil to be the same in each pot. The other series was executed with small plats of ground which were treated with the fertilizers. These plats involved all the conditions that the pots did, and in addition we had the influence, if any, of the fertilizers upon drainage, as well as the greater difficulty of insuring uniformity of condition of the soil, and the effect of rainfall.

In addition to these experiments with fertilizers a large number of observations upon the influence of tillage upon soil moisture have been made, both with small plats and under field conditions.

Experiments With Soil in Pots.

The pot experiments were performed in much the same way as those of previous years, but still greater care was taken to insure uniformity of conditions. The pots were galvanized iron pails. The soil was a fairly fertile one from an upland field, carefully sifted to free it from sticks, stones and other extraneous matter, finely pulverized and very thoroly mixed. In this state, and air-dry, it weighed 77.8 pounds per cubic foot. The moisture in it being determined, an amount equivalent to ten kilograms, or about 22 pounds of dry earth, was put in each of the pots. The chemicals, the effect of which was to be tested, were dissolved in the water added, or intimately mixed with the soil if insoluble to that extent in water. Water was added in such amount that with the moisture of the soil, the total amount was 2½ kilograms, or 25 per cent of the weight of the dry soil. Previous observations (Bulletin 68) had shown the extreme difficulty of exposing pots for evaporation under such conditions that there will be no error due to the position of the individual

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pot. In this experiment the pots were placed in a basement, where direct sunlight never struck near them, and where they were not subject to the effects of draughts of air to any great extent. The position of the pots was varied systematically from day to day so as to compensate for any slight differences that might exist in the tendency to evaporation due to position. The pots were weighed daily for about one hundred days. The weight of the dry soil being 10,000 grams, a loss of ten grams represented one-tenth of one per cent. As the scale used enabled us to weigh readily within two grams, it is evident that the rate of evaporation could be observed with great accuracy. The position in the basement was one which permitted but relatively slow evaporation, and full opportunity was thus afforded for the manifestation of any effect of the fertilizers added upon evaporation. One pot had no fertilizer added to it and was left without any special treatment, another to which no fertilizer was added had its surface pulverized to a depth of about 1½ inches, after the ground had dried sufficiently, and illustrated the effect of a dust mulch.

The results obtained have been plotted, but the curves exhibiting the loss of water are so nearly alike as make it impracticable to present even four on a plate with any clearness unless the scale is made quite large. We have therefore collected an abstract of the results in the accompanying table, page 4. The percentages given are calculated on the weight of the dry soil. Following is a statement of the amounts of each fertilizer added, and its equivalent per acre, taking the soil to the depth of eight inches and weighing 77.8 pounds per cubic foot:

Pot 1, 4 grams potassium chloride, equivalent to 904 pounds per acre.
Pot 2, 4 grams superphosphate, equivalent to 904 pounds per acre.
Pot 3, 4 grams slaked lime, equivalent to about 12 bushels per acre.
Pot 4, 4 grams potassium chloride, equivalent to 904 pounds per acre.
Pot 5, 4 grams potassium sulphate, equivalent to 904 pounds per acre.
Pot 6, 4 grams common salt, equivalent to 904 pounds per acre.
Pot 7, 4 grams magnesium chloride, equivalent to 904 pounds per acre.
Pot 8, 4 grams kainite, equivalent to 904 pounds per acre.
Pot 9, 4 grams carnallite, equivalent to 904 pounds per acre.
Pot 10, 250 grams dry barnyard manure, equivalent to about 28 tons per acre.
Pot 11, nothing added, but surface stirred for dust mulch.
Pot 12, nothing added, and surface not stirred.

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TABLE I.—Showing percentage losses of water from pots of soil to which certain fertilizers were added.

DATE.	Pot 1—Gypsum.	Pot 2—Superphosphate.	Pot 3—Slaked lime	Pot 4.—Potassium chloride.	Pot 5.—Potassium sulphate	Pot 6—Sodium chloride	Pot 7—Magnesium chloride.	Pot 8.—Kainite.	Pot 9—Carnallite.	Pot 10—Barnyard manure	Pot 11—Nothing Dust mulch.	Pot 12—Nothing
Aug. 12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
" 14	0.5	0.4	0.3	0.3	0.3	0.4	0.4	0.3	0.5	0.4	0.3	0.3
" 16	0.7	0.7	0.8	0.8	0.7	0.8	0.7	0.5	0.7	0.7	0.7	0.6
" 18	1.3	1.3	1.2	1.3	1.2	1.3	1.3	1.0	1.2	1.3	1.2	1.0
" 20	1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.3	1.5	1.6	1.4	1.4
" 22	1.9	1.9	1.9	2.0	1.9	2.0	1.9	1.7	1.9	2.0	2.0	1.9
" 24	2.5	2.5	2.5	2.5	2.4	2.5	2.5	2.3	2.5	2.6	2.5	2.4
" 26	3.0	3.0	3.0	3.0	3.0	3.1	3.1	2.9	3.0	3.2	3.0	2.9
" 28	3.6	3.7	3.6	3.7	3.5	3.6	3.6	3.3	3.6	3.7	3.6	3.6
" 30	4.3	4.3	4.2	4.4	4.3	4.4	4.4	4.1	4.4	4.5	4.1	4.3
Sept 1	5.0	5.0	4.9	5.1	5.1	5.0	5.0	4.8	5.1	5.3	4.7	5.0
" 3	5.7	5.7	5.7	5.8	5.8	5.8	5.7	5.5	5.9	6.0	5.2	5.7
" 5	6.4	6.4	6.4	6.5	6.5	6.4	6.5	6.3	6.6	6.7	5.8	6.4
" 7	7.2	7.2	7.1	7.3	7.2	7.3	7.2	7.0	7.3	7.4	6.3	7.1
" 9	7.9	7.9	7.9	8.0	8.0	8.1	7.9	7.8	8.0	8.1	6.8	7.9
" 10	8.1	8.0	8.0	8.1	8.1	8.2	8.1	7.9	8.2	8.3	6.9	8.1
" 12	8.3	8.2	8.2	8.3	8.2	8.3	8.2	8.0	8.3	8.3	7.1	8.3
" 14	8.4	8.5	8.4	8.5	8.4	8.5	8.6	8.3	8.6	8.6	7.3	8.5
" 16	8.6	8.7	8.6	8.8	8.7	8.7	8.7	8.5	8.8	8.8	7.5	8.7
" 18	9.1	9.0	8.9	9.1	9.1	9.0	9.2	9.0	9.2	9.1	7.8	9.1
" 20	9.4	9.3	9.3	9.5	9.4	9.4	9.4	9.3	9.4	9.4	8.0	9.4
" 22	9.7	9.6	9.6	9.7	9.6	9.7	9.7	9.6	9.8	9.7	8.3	9.7
" 24	10.0	9.9	9.9	10.1	10.0	9.9	9.9	9.8	10.0	9.9	8.5	10.0
" 26	10.2	10.1	10.1	10.2	10.2	10.2	10.2	10.1	10.3	10.2	8.8	10.3
" 28	10.5	10.5	10.4	10.6	10.6	10.6	10.6	10.5	10.7	10.7	9.0	10.6
" 30	10.8	10.7	10.8	10.9	10.8	10.9	10.9	10.7	10.9	10.9	9.3	10.9
Oct. 2	11.0	11.0	11.1	11.2	11.0	11.1	11.1	11.0	11.1	11.1	9.6	11.2
" 4	11.4	11.3	11.4	11.5	11.4	11.4	11.4	11.3	11.5	11.4	9.8	11.5
" 6	11.5	11.4	11.5	11.6	11.5	11.6	11.6	11.4	11.6	11.5	10.0	11.6
" 8	11.6	11.5	11.5	11.7	11.6	11.6	11.6	11.5	11.6	11.6	10.1	11.7
" 10	11.8	11.7	11.7	11.9	11.8	11.8	11.8	11.7	11.8	11.7	10.3	11.8
" 12	11.9	11.8	11.9	12.0	12.0	12.0	12.0	11.8	11.8	11.8	10.4	12.0
" 14	12.1	12.0	12.1	12.2	12.1	12.1	12.2	12.0	12.1	12.1	10.7	12.3
" 16	12.4	12.3	12.4	12.5	12.4	12.3	12.4	12.3	12.3	12.3	11.0	12.5
" 18	12.5	12.5	12.6	12.6	12.6	12.6	12.6	12.4	12.6	12.5	11.1	12.6
" 20	12.6	12.6	12.6	12.7	12.6	12.6	12.6	12.5	12.6	12.5	11.3	12.7
" 22	12.8	12.7	12.8	12.8	12.8	12.8	12.7	12.6	12.7	12.6	11.4	12.9
" 24	12.9	12.8	13.0	13.0	13.0	12.9	12.9	12.8	12.9	12.8	11.6	13.0
" 26	13.0	13.0	13.0	13.1	13.1	13.0	13.0	12.9	13.0	12.9	11.7	13.1
" 28	13.1	13.0	13.1	13.1	13.2	13.1	13.2	13.1	13.1	13.0	11.9	13.2
" 30	13.4	13.3	13.4	13.4	13.4	13.4	13.4	13.3	13.2	13.3	12.0	13.4
Nov. 1	13.5	13.4	13.5	13.6	13.5	13.5	13.5	13.4	13.5	13.4	12.3	13.6
" 3	13.7	13.6	13.7	13.7	13.8	13.7	13.7	13.6	13.7	13.6	12.5	13.8
" 5	13.8	13.7	13.8	13.8	13.8	13.8	13.9	13.8	13.8	13.6	12.6	13.9
" 6	14.0	13.9	14.0	14.0	14.0	13.9	14.0	13.8	14.0	13.8	12.8	14.0
" 9	14.2	14.1	14.2	14.3	14.2	14.2	14.2	14.1	14.1	14.0	13.0	14.2
" 11	14.3	14.2	14.2	14.3	14.3	14.3	14.2	14.2	14.3	14.1	13.1	14.3
" 13	14.3	14.3	14.4	14.4	14.4	14.4	14.4	14.3	14.3	14.2	13.3	14.4
" 15	14.5	14.4	14.4	14.5	14.5	14.5	14.5	14.4	14.5	14.4	13.4	14.5
" 17	14.7	14.5	14.6	14.7	14.7	14.6	14.6	14.5	14.6	14.5	13.6	14.7
" 19	14.8	14.7	14.8	14.8	14.7	14.7	14.8	14.7	14.7	14.6	13.8	14.9
" 21	14.9	14.8	14.9	14.9	14.9	14.9	14.9	14.8	14.8	14.7	13.8	14.9

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Conclusions from the Experiments in Pots.

A consideration of the results set forth in Table I can lead to but one conclusion, namely that the rate of evaporation is not affected by the addition of the fertilizers tried, even when added in the unusually large proportions employed. We cannot expect to protect the moisture of the soil against loss by evaporation by the addition of fertilizers. Even in the cases of the highly hygroscopic substances, magnesium chloride, carnallite and kainite, their tendency to absorb water seems to have no influence upon the rate or extent of the loss of moisture. At the conclusion of the weighings the soils contained only about ten per cent of moisture, being very dry.

Experiments with Fertilized Plats of Soil

While the experiments with soil in pots seem to show conclusively that the addition of certain fertilizers does not influence the loss of water by evaporation, they leave uncertain whether or not, in field conditions, where drainage as well as evaporation is involved, soil moisture may be influenced by appropriate manuring. To throw light upon this point, the following described experiments were executed.

The ground on which these experiments were tried was subsoiled in 1891, and was planted to sugar beets that year and the two succeeding. It has not been cropped since. In 1895 it was especially prepared for use in soil moisture tests, but no fertilizers were added to it. In 1896 it was not used. In 1897 previous to July 1, it was twice plowed, and about July 1 was raked, rolled, smoothed and put in as nearly a uniform state as possible. August 20 the few weeds upon it were cut off and raked to one side, and 15 plats of one two-thousandth of an acre were laid off with paths two feet wide between and around them. The soil in these little plats was put in as fine and uniform condition as possible, and various fertilizers worked in to the depth of four inches. The barnyard manure and the leaf mold was incorporated to a depth of 5 or 6 inches. The history of the soil as to fertilization is not known to us farther back than 1888, but we know of the application of none at any time, and there has certainly been none applied since 1888. The fertilizers were put on August 20 and 21, 1897.

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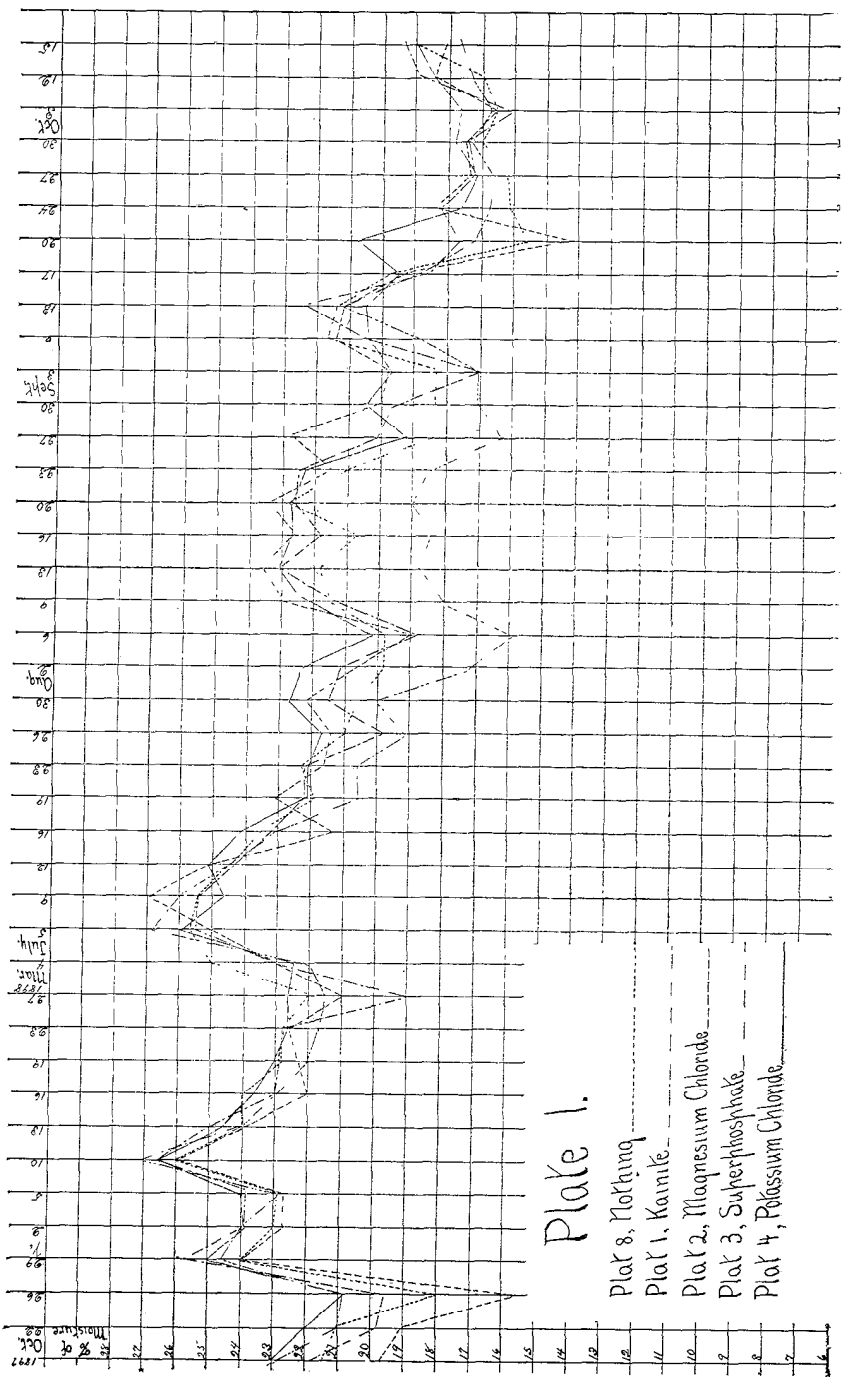
The following statement shows the fertilizers added to the several plats in pounds per acre, and the relative position of the plats, numbers 1, 2 and 3 being at the east end, and 13, 14 and 15 at the west end.

PLAT 1. 500 lb Kainite.	PLAT 2. 500 lb Magnesium chloride.	PLAT 3. 500 lb Superphosphate.
PLAT 4. 500 lb Potassium chloride.	PLAT 5. 500 lb Sodium chloride (common salt).	PLAT 6. 500 lb Plaster of Paris.
PLAT 7. 500 lb Potassium sulphate.	PLAT 8. Nothing.	PLAT 9. 2000 lb Lime.
PLAT 10. 500 lb Potassium nitrate (saltpeter).	PLAT 11. 500 lb Sodium nitrate, (Chili saltpeter).	PLAT 12. 500 lb Ammonium sulphate.
PLAT 13. 2000 lb Unleached ashes.	PLAT 14. 40,000 lb Barnyard manure.	PLAT 15. 40,000 lb Leaf mold.

The plats were prepared and fertilized during a period of dry weather and allowed to stand unsampled until a rain came which was sufficient in amount to give opportunity for the effect of the fertilizers to be manifested. Sampling was begun Oct. 19, 1897, and continued twice a week until November 2. Freezing weather came on at that time and no more samples were taken until March 4, 1898, when a sample was taken from each plat. June 27, 1898, the plats were refertilized with the same manures, and in the same quantities. A good rain came July 2, and semiweekly sampling was begun July 5, and continued until October 3. Plates I, II, III and IV show by means of curves the percentages of water, calculated on the dry soil at the several dates. Plat 8 to which nothing was applied is shown on all of the plates for comparison with the treated plats.

A study of the curves and of the figures from which they are plotted has thus far failed to show us any connection between the loss of moisture and the character of the fertilizer applied, or indeed to show any difference between the plat to which no fertilizer at all was applied and any of the others, except in one case. Plat 13, to which the unleached wood ashes were applied, showed no material effect the first year, but the second year it seems to have less moist-



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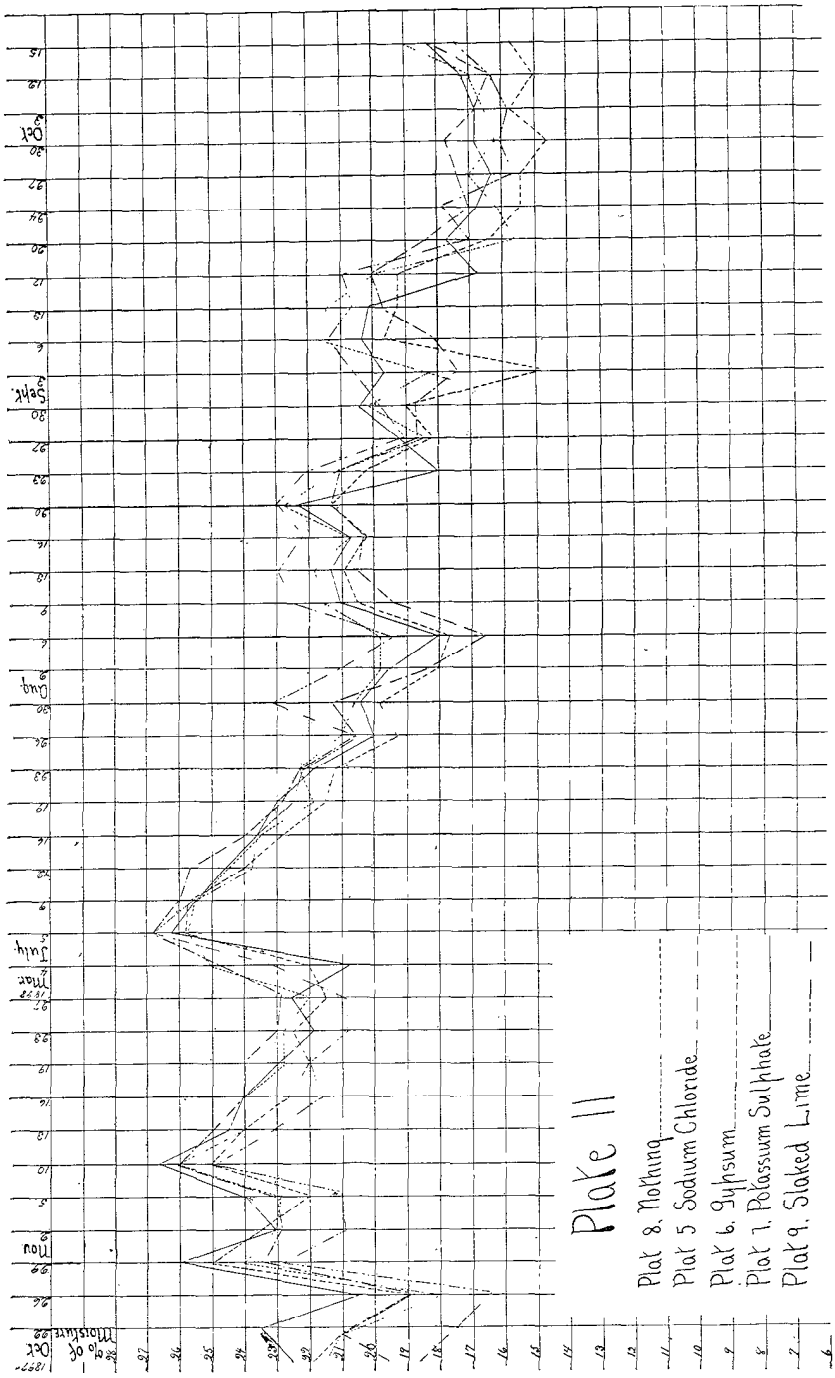

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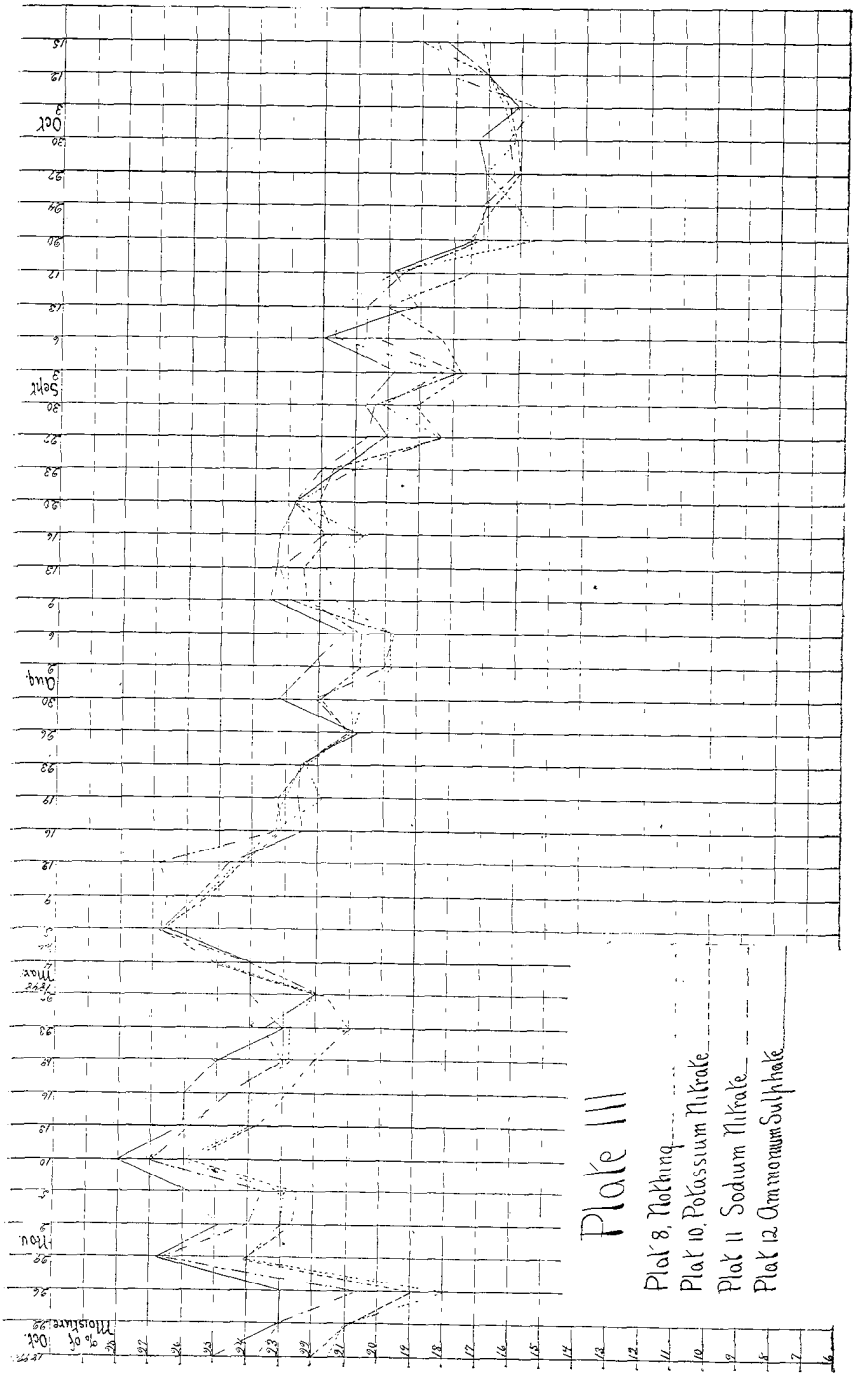

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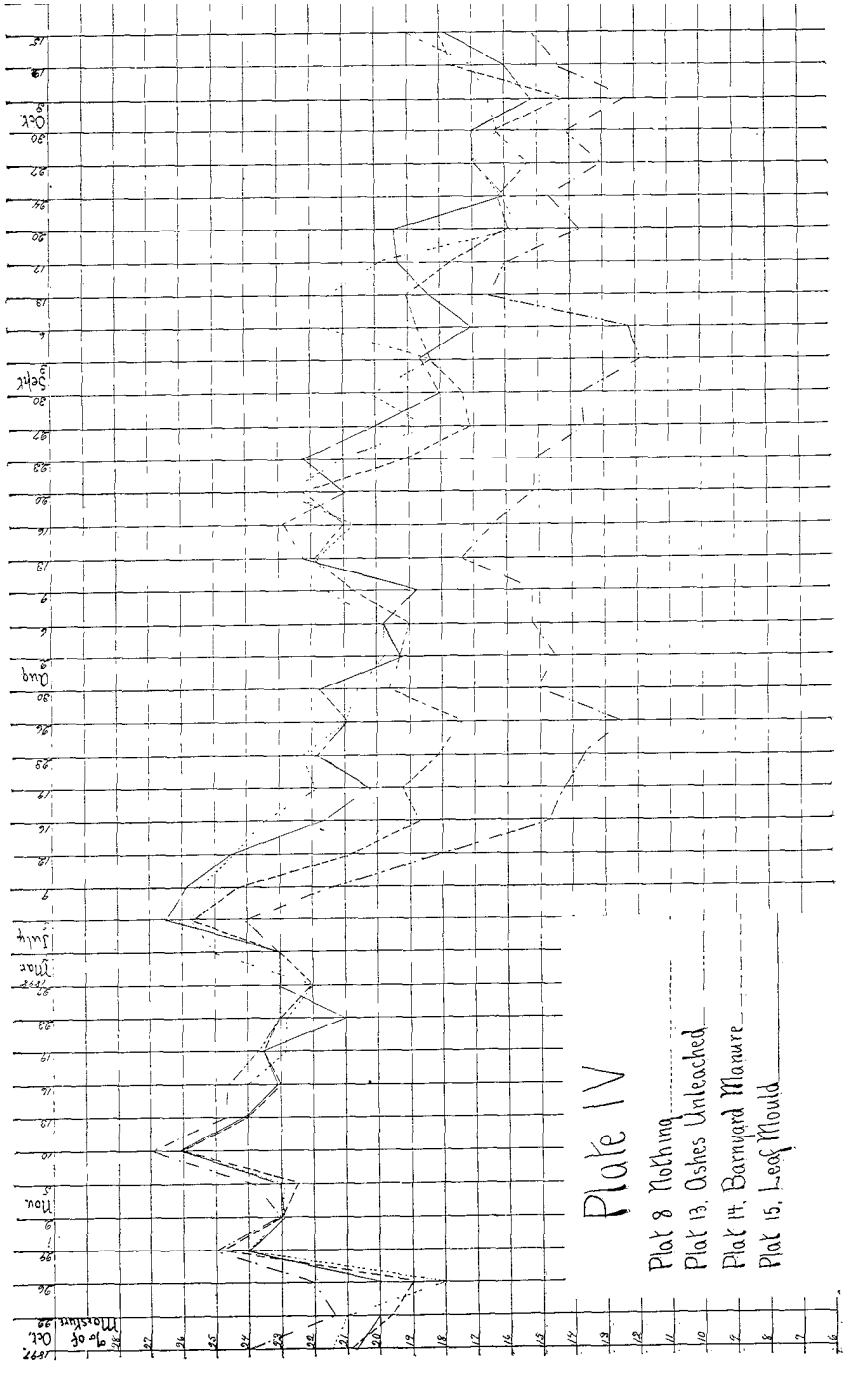

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ure thruout. The variations in the curves, and their crossings and recrossings of each other show the effect of rains and the difficulties inherent in investigations of soil-moisture problems in fields or plats. It is difficult to get fair and comparable samples from the plats. In this experiment but one sample was taken from each plat at a time. The first year this was taken by Whitney's tube, which consists essentially of a brass tube with a cutting edge of less diameter than the rest of the tube, so that the core as cut may slide up into the tube as the tube is driven to the desired depth into the ground. The tube cuts a core three-fourths of an inch in diameter. In 1898 we used tubes of larger diameter, cutting a one-inch core, and have found them much less likely to choke and give inaccurate samples. To obviate in part errors due to difficulty of sampling, and perhaps other accidental causes of variation, the average amount of moisture in each of the plats for the periods named has been calculated, and is presented in the table below:

YEAR.	1—Kainite	2—Magnesium chloride	3—Superphosphate	4—Potassium chloride	5—Common salt	6—Plaster of Paris	7—Potassium sulphate	8—Nothing	9—Lime	10—Saltpeter	11—Chili saltpeter	12—Ammonium sulphate	13—Unleached ashes	14—Barnyard manure	15—Leaf mold
1897 . . .	22.8	21.9	22.9	23.5	22.8	22.5	23.5	22.7	20.9	22.4	24.1	25.0	23.8	22.6	22.6
1898. . . .	20.7	20.9	19.2	21.2	20.3	19.3	20.1	20.5	20.6	20.4	20.9	21.1	15.4	19.0	19.9
1897-8. . .	21.3	21.2	20.3	21.9	20.5	20.2	21.1	21.1	20.7	21.0	21.8	22.3	17.8	20.1	20.7

EXPERIMENTS SHOWING EFFECTS OF CULTURE.

In studying the effect of tillage upon the conservation of soil moisture many sets of samples have been taken which have led to no definite result owing to the inherent obstacles to such work. Rains may so modify the physical state of the soil as to make plats, designed to be different, practically identical: the difficulty of having plats strictly comparable as to conditions; the difficulty in sampling; these and other obstacles have conspired to make many of our results of little general interest or value. Our chief aim has been to learn what treatment available to the average farmer will most effectively and cheaply assist in conserving the moisture of his soil. This section of this bulletin will include an account of an experiment

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with small plats to study the effect of a mulch of hay and of a soil mulch: a comparison of several modes of tillage, and a study of the effects of early plowing as compared with late plowing on soil moisture.

An experiment reported in Bulletin No. 68, showed that a dry soil. mulch is quite as effective in conserving soil moisture as a hay or straw mulch, and that by its application immediately after a rain, a very considerable amount of moisture can be held in the soil for the use of growing plants during a drouth, or to germinate seed that. might be planted. During the summer of 1897 this experiment was repeated in a modified form. Four small plats were laid off in a field where conditions were as nearly uniform as possible. A mulch of green grass about four inches deep was placed upon No. 1: No. 2 was left untreated; No. 3 was cultivated about 4 inches deep, with a hoe, and No. 4 was raked about 1 inch deep with a garden rake. The treatment, given Plats 3 and 4 was repeated after every rain as soon as the crust became dry enough to work without puddling.

The percentage of moisture was determined in each plat every other day. The samples were taken with a Whitney tube, and the holes filled with moist soil. The spots were marked with a small stick so that later samples could be taken near without cutting into them. One sample was taken from each plat for each determination. The variations in the moisture of the plats are represented graphically in Plate V, and the percentages present at certain dates were as in the following table :

NUMBER AND TREATMENT.	July 10.	Aug. 13.	Aug. 14.	Sept. 1.	Sept. 3.	Oct. 15.
No. 1. Mulched	27.7	24.7	29.1	23.4	20.9	12.9
No. 2. Untreated	27.1	19.3	23.3	18.0	17.0	12.6
No. 3. Deep tilled.....	27 9	20.2	23 9	20.8	20.9	17.5
No. 4. Shallow tilled...	27.4	19.6	23 7	20.0	20.0	18 0

It will be seen that at the beginning of the experiment, July 10, the plats were of practically the same moisture-content, but by August 13 there was a decided advantage in favor of the mulched plat. A rainfall of 0.65 in. occurred on that date after the sampling, but from that date until October 17 was a period of almost unbroken drouth. The change in the moisture-content of the plats during this. period is of special interest and value.

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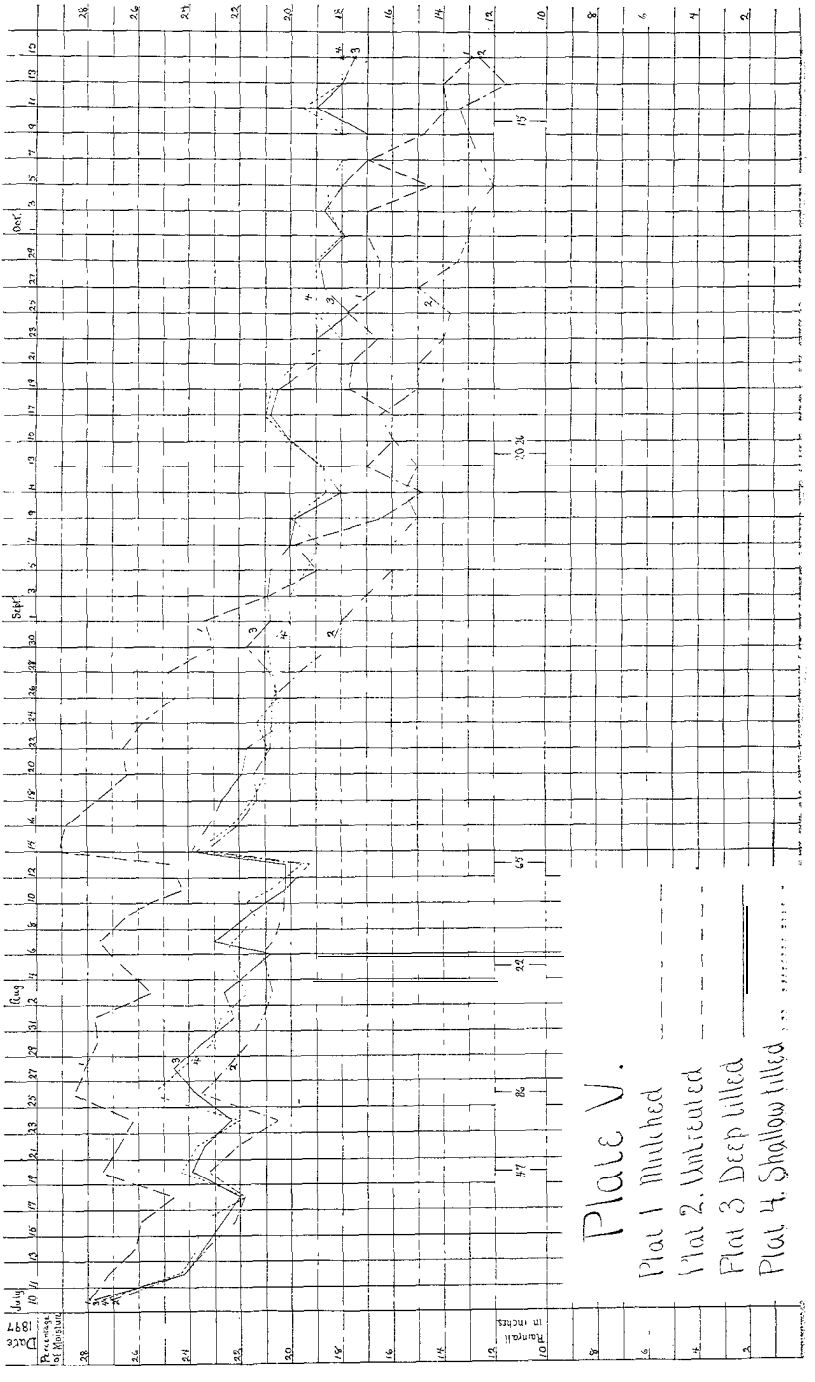

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August 14 the mulched plat contained about 5½ per cent more moisture than the others, and it continued to maintain about this advantage over the untreated plat up to September 1. The cultivated plats lost water at a much slower rate than the mulched plat, so that by September 3, the three had practically the same amount. From that date on, the tilled plats showed an increasing advantage over the other plats. October 15 the mulched plat was as dry as the untreated one, while the tilled plats contained 5 per cent more than the others. The dry soil covering was thus very effective thruout the entire period in conserving the moisture. The untreated plat was dry to the depth of the sample, one foot, while the tilled plats were in excellent condition for seeding below the soil mulch. The soil mulch was very dry, and as it was a part of the sample in cutting a core to the depth of a foot, the part of the sample below the dry covering was more moist than the figures would suggest if compared with determinations of water in soil in the ordinary state. The soil from the lower 8 inches was moist enough to stick together when compressed with the hand.

During the period from September 9 to October 1, a period during which nearly all the wheat in this locality is sown, there was an average of 19.2 per cent of moisture in the cultivated plats, while the untreated plat contained an average of only 15 per cent, a difference of 4.2 per cent. If this difference is calculated upon the basis of the total moisture in the untreated plat, we find that the amount of moisture in the cultivated plats was 28 per cent more than that in the untreated plat. While wheat would have grown well in the tilled plats it would probably not have germinated if planted in the untreated one.

Field Experiments.

Experiments on the larger scale always appeal more strongly to one's confidence, and in coöperation with the Farm department we have made a considerable number of investigations of the effect of cultural treatment on soil. We have also continued experiments begun under the previous organization of this department, and planned new ones of similar character, in which large plats were given various kinds of treatment, the soil not being cropped at the same time. The object of these experiments was to study the effectiveness of the different modes of tillage, without the disturbing element of a crop which would make accurate sampling so much more diffi-

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cult. The sampling of soils in fields is a difficult problem at best. During 1897 we used Whitney's method, taking samples to the depth of one foot. In 1898 we used the same method, but a wider tube, so that a core one inch in diameter was cut instead of but three-fourths of an inch. We found this much more certain to cut the proper sample. With the narrower tube there is great liability that the tube will become choked, and then simpiy drive into the ground like a stake instead of cutting out a core.

Another principle which we adopted looking toward fair sampling, was the taking of composite samples. To facilitate this, collecting cans were made with screw tops, and with a bail for carrying them. Whenever a field or large plat was to be sampled, cores were cut by means of the tube from six to ten different places and put in the can. After being brought to the laboratory this large composite sample was quickly and intimately mixed, and a portion taken for the estimation of water. In this way it is believed that representative samples have been secured, especially since the wider sampling tube was adopted.

While not being as sure two years ago as now that the hope that soil moisture could be affected to a practical extent with our soil, by the application of suitable fertilizers, was without foundation, we have from the first recognized that practical methods of conserving soil moisture in our state are limited to modifications of soil culture, and with small areas, mulching.

Both last year and the year before a series of plats was prepared by plowing and then treating in various ways. In 1897 nine plats were prepared as follows Plat 7 was plowed only; plats 1 and 5 were plowed and planked; plats 2 and 8 were plowed and packed once with Campbell's subsurface packer; plats 3 and 9 were plowed and packed 3 times with Campbell's subsurface packer; plat 4 was plowed and rolled; plat 6 was plowed, disked and planked. Composite samples were taken from each plat weekly during the months of August, September, October and November. Rains of considerable amount, setting in October 17, make comparisons before that date of more value. Averaging the results where more than one plat was given the same treatment, the percentages of water in the soil from August 16 to October 11 averaged as follows for the several modes of treatment: Plowed only, 11.5; plowed and rolled, 14.2; plowed and planked, 10.8; plowed, disked and planked, 12.1; plowed, packed

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once and planked, 12.0; plowed, packed 3 times, and planked 12.5

These results show no marked differences in the average moisture-content except in the case of the rolled plat, which is noticeably higher. As this is contrary to what is usually expected, and to the results obtained the next year, it may be taken as an example of the difficulties attending such experiments. The land used for these experiments was not in ideal condition, having grown up somewhat to weeds and crab-grass so that the roots held the soil in a slight sod to some extent. It would fairly represent the conditions under which much plowing is done, however. The rolling under these conditions probably pressed the sod down so as to close open places without

TABLE II.—Rainfall and percentage of water in soils given different kinds of culture.

DATE. 1898.	Rainfall in inches	1—Packed	2—Deep harrowed	3—Shallow harrowed	4—Rolled	5—Planked	6—Plowed only
June 6		22.5	21.1	22.7	23.3	21.9	23.0
" 8	1.75						
" 24		25.8	26.3	27.2	25.7	26.9	27.3
" 30		22.3	23.5	23.9	22.0	23.5	23.7
July 3	1.33						
" 5		24.3	25.0	24.6	23.4	24.5	23.5
" 6	0.57						
" 9		24.5	25.6	26.4	24.0	25.1	24.3
" 12		23.7	24.6	25.7	23.3	24.2	23.2
" 16		22.6	23.2	24.0	22.6	23.7	22.7
" 19		21.7	22.9	23.7	21.1	21.9	21.9
" 23		21.6	21.8	22.3	19.8	21.2	21.5
" 26		21.2	20.5	21.0	18.2	20.9	20.4
" 29	0.48						
" 30		22.8	23.8	23.1	20.3	22.0	23.6
Aug. 2		21.2	21.6	22.1	18.9	20.6	22.0
" 6			20.4	19.0	17.3	16.9	20.6
" 6	0.54						
" 9		21.8	21.0	21.5	19.0	20.3	23.4
" 12	0.23						
" 13		22.2	20.7	21.5	20.1	19.4	24.9
" 16		19.6	16.8	16.5	15.2	15.4	21.8
" 17	0.58						
" 18	0.24						
" 20		18.5	16.7	17.9	18.5	17.0	22.0
" 23		15.3	15.0	14.5	13.3	14.2	20.0
" 27		13.0	13.0	13.0	12.8	12.5	18.4
" 30		13.3	12.4	12.3	12.5	12.4	17.0
Sept. 3		12.4	12.0	12.0	12.1	12.0	15.7
" 4	0.27						
" 6		13.5	13.0	14.3	14.4	14.0	15.0
Averages		20.1	19.9	20.3	18.8	19.5	21.4

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making it so compact as to facilitate the loss of water thru increased capillary rise.

In 1898 the same soil was plowed in good condition, June 4, and certain parts given additional treatment calculated to show the effect of tillage. The moisture-content of the several plats was determined frequently up to September 6, with the results given in Table II. These plats were of ample size, each determination of moisture was by means of composite samples made up of six samples taken with our large tube, and it is believed that the results fairly represent the actual moisture conditions as affected by treatment of our soil, which is a fertile upland, with stiff clay subsoil. The results are so nearly the same on the different, plats as to make it difficult on the whole to be sure that there is any real difference due to culture. The rolled plat is the lowest, and that simply plowed the highest on the average.

The effectiveness of simple plowing as a means of conserving soil moisture, as shown here and in other of our observations is a fact worthy of serious notice. It is not necessary to go to large additional expense in both tools and labor in order to preserve the moisture, but it is necessary to do the plowing promptly, while the moisture is still in the soil. Experiments involving a large number of determinations of moisture which are not detailed in this bulletin have shown that once out of the soil even daily tillage does not suffice to increase the amount perceptibly over similar land given ordinary treatment.

Early and Late Plowing.

Two experiments, one in the summer of 1897, and the other in the summer of 1898, have been carried out to determine the relative effect of early and late plowing on the moisture-content of the soil.

In 1897 four plats were laid off, numbers 1 and 3 plowed July 30, and numbers 2 and 4 about October 1. The soil in plats 1 and 3 appeared extremely dry, and turned up hard and lumpy when plowed. They were disked, planked, disked, and harrowed with the Acme harrow, at various dates, previous to August 14 when they were harrowed with a spring-tooth harrow which left them in good condition. No further treatment was given them, except on August 31 when they were again harrowed with an Acme harrow.

The moisture was determined in all the plats at irregular intervals until August 21, a composite sample, made up of six, being ta-

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ken from each plat. From this time on, samples were taken twice a week until the close of the experiment, October 13. Heavy rains occurring the latter part of October brought the plats to nearly the same degree of moisture. Table III shows the results in detail.

TABLE III.—Showing percentage of moisture in plats plowed at different dates, and rainfall for the period.

1897.	Rainfall in inches.	1—Plowed July 30.	3—Plowed July 30.	2—Plowed about Oct. 1.	4—Plowed about Oct. 1.	1897.	Rainfall in inches.	1—Plowed July 30.	3—Plowed July 30.	2—Plowed about Oct. 1.	4—Plowed about Oct. 1.
July 30	....	13.9	12.0	13.9	13.7	Sept. 14	.20	.....	.....	.....	.....
Aug. 4	....	11.3	11.7	10.5	10.2	" 15	.....	11.4	11.9	8.7	8.7
" 5	.22	.....	.....	.....	.....	" 15	.26	.....	.....	.....	.....
" 12	....	12.1	12.1	9.6	12.0	" 18	....	11.0	10.9	8.0	9.5
" 13	.65	.....	.....	.....	.....	" 22	....	12.0	11.9	8.9	8.4
" 14	....	17.1	16.7	14.6	13.0	" 25	.....	9.8	12.0	8.5	8.0
" 18	....	13.0	11.7	11.0	11.0	" 29	.....	10.0	12.0	8.5	9.5
" 21	.....	12.0	12.0	9.7	10.6	Oct. 2	..	10.0	11.0	8.0	8.0
" 24	....	13.0	9.9	8.9	8.7	" 6	....	10.0	9.0	7.9	8.0
" 28	.....	11.8	12.9	8.5	9.4	" 9	.....	11.0	11.6	8.0	8.0
Sept. 1	.....	11.2	10.0	7.8	8.0	" 10	.15	.....	.....	.....	.....
" 8	.....	10.9	10.9	7.9	8.0	" 13	....	11.0	13.0	8.0	8.0
" 11	.07	.....	.....	.....	.....						
" 11	.....	10.5	11.5	8.0	8.0	Averages	.....	11.7	11.7	9 2	9.4

It will be seen that at the beginning of the experiment the average moisture in plats 1 and 3 was 13 per cent, while plats 2 and 4 contained 13.8 per cent. At the close of the experiment, October 13, plats 1 and 3 contained an average of 12 per cent of moisture, while plats 2 and 4 contained only 8 per cent; a difference of 4 per cent in favor of the early plowing. A close study of the table, however, will disclose the fact that there are striking variations at times in the percentage of moisture.

It will be noticed that on August 14, immediately after the last rain before the period of drouth, the early-plowed plats contained an average of 16.9 per cent of moisture, while the late-plowed plats contained only 13.8 per cent. This gives the early-plowed plats an advantage of 3.1 per cent upon entering the period of drouth, a difference which they little more than maintained, having only 4 per cent more at the close of the period.

The average percentages of moisture in the plats during the whole period probably yield the most reliable conclusions. The early-plowed plats contained an average of 11.7 per cent of moisture

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during the whole period; the late-plowed plats contained an average of 9.3 per cent, a difference of 2.4 per cent in favor of the early plowing.

In the foregoing, we have referred to the plowing July 30 as the "early plowing." It is so only relatively. The soil having had its moisture reduced to such an extent as to cause the field to turn up cloddy, there being less than 14 per cent, the plowing was evidently not done early enough. Plowing to be early enough to give its greatest advantage must be done before the summer drouth, which we almost always have, begins. This will usually require that it be done during the first half of July. To obtain more definite results, if possible, and results based upon observations upon soil plowed while still charged with moisture, a similar experiment was performed in 1898.

Three long narrow plats were laid off adjoining each other. The first one was disked June 27, in order to see if moisture might be profitably conserved by disking early in the season, in cases where the plowing can not be done until later in the season. The second plat was left untreated until August 23, when it was plowed and harrowed till the surface was in fair condition. The third plat was plowed July 7, harrowed July 8, and planked July 14. The moisture in each plat was determined twice a week, composite samples being taken for every determination. Table IV shows the results obtained.

The table can be studied best by selecting periods between rains. At the beginning of the experiment, July 7, the plats contained practically the same percentage of moisture. On Aug. 2, a date which is very near the close of a four-weeks' drouth, plat 1 contained 18.6 per cent of moisture, plat 2, 15.3 per cent and plat 3, 20.9 per cent. This is a difference of 5.6 per cent in favor of the early plowing compared with the late. The disked plat shows a difference of 3.3 per cent in its favor. The average per cent of moisture for the period is as follows: Disked plat 21.1 per cent; late-plowed, 18.5 per cent; early-plowed, 22.1 per cent. This shows a difference of 3.6 per cent of moisture in favor of the early plowing, and 2.6 per cent in favor of the disked plat when compared with the late-plowed plat, which had not been treated up to that date.

A study of the next period, extending from Aug. 9 to Sept. 3, inclusive, shows results equally as interesting as those of the first

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TABLE IV.—Showing the effects of disking, early plowing, and late plowing on the moisture of soils.

1898.	Rainfall in inches	1—Disked June 27	2—Plowed Aug. 23	3—Plowed July 7
June 25*	.....	26.6	26.6	26.6
" 27*	.....	26.7	26.0	26.0
July 2*	.....	22.7	19.8	19.8
" 3	1.33	.....	.....	.....
" 5*	.....	23.9	21.9	21.9
" 6	0.57	.....	.....	.....
" 7	.....	26.6	26.8	25.7
" 12	.....	23.8	22.9	22.9
" 16	.....	22.0	19.0	22.1
" 19	.....	21.4	16.7	22.1
" 23	.....	18.6	15.8	20.5
" 26	.....	17.8	14.3	20.0
" 29	0.48	.....	.....	.....
" 30	.....	19.1	17.2	22.6
Aug. 2	.....	18.6	15.3	20.9
Avs. July 7 to Aug. 2	.....	21.1	18.5	22.1
Aug. 6	0.54	.....	.....	.....
" 9	.....	20.6	19.0	24.0
" 12	0.23	.....	.....	.....
" 13	.....	20.0	18.0	23.8
" 16	.....	18.5	15.6	22.1
" 17	0.58	.....	.....	.....

1898.	Rainfall in inches	1—Disked June 27	2—Plowed Aug. 23	3—Plowed July 7
Aug. 18	0.24	.....	.....	.....
" 20	.....	17.6	17.8	22.8
" 23	.....	15.6	14.1	20.9
" 27	.....	12.7	13.1	19.2
" 30	.....	12.7	13.3	16.6
Sept. 3	.....	12.3	12.3	15.6
Avs. Aug. 9 to Sept. 3	.....	16.3	15.4	20.6
Sept. 4	0.27	.....	.....	.....
" 6	.....	12.7	13.0	16.3
" 10	0.76	.....	.....	.....
" 12	1.07	.....	.....	.....
" 14	.....	23.2	21.6	26.6
" 16	0.80	.....	.....	.....
" 17	.....	24.2	24.2	27.0
" 20	.....	21.8	21.4	23.9
" 24	.....	18.3	19.5	22.0
" 26	.....	17.8	20.0	19.0
" 30	.....	16.7	19.5	17.8
Oct. 3	.....	15.9	20.0	15.9
Avs. Sept. 17 to Oct. 3	.....	19.1	20.8	20.9
Avs. July 7 to Oct. 3	.....	18.7	18.0	21.3

*The samples taken on these dates were from larger areas than the later ones, and while showing the moisture conditions of the several kinds of plats, are not included in the averages. They show the moisture-conserving powers of disking as a treatment for soils.

period. At the beginning of the period, the disked plat contained 20.6 per cent of moisture; the late-plowed plat, 19 per cent; and the early-plowed plat, 24 per cent. At its close the moisture in the disked plat had dropped to 12.3 per cent; the late-plowed plat contained the same amount, while the early-plowed plat contained 15.6 per cent, a difference in its favor of 3.3 per cent. It had a difference of 5 per cent in its favor at the beginning of the experiment, so that it has really lost more moisture during the period than either of the other two plats. The average percentage of moisture for the period was as follows: Disked plat, 16.3 per cent; late-plowed plat, 15.4 per cent; early-plowed plat 20.6 per cent. Compared with the late-plowed plat the early-plowed plat has a difference of 5.2 per cent of moisture in its favor. If crops had been planted upon these plats about Aug. 9, the average percentage of moisture for the whole period is perhaps the most important point to be considered. If they had not been planted, however, till Sept. 3, then the relative percentage of moisture in the plats at that date becomes the most

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important point to be considered, for the moisture in plats 1 and 2 is becoming low enough to endanger safe germination of seeds.

The results obtained in the third period, extending from Sept. 17 to Oct. 3, inclusive, are fully as interesting as those obtained in the first two periods. It will be remembered that plat 2 was plowed on Aug. 23, and harrowed till the soil was in fair condition. Heavy rains fell on several dates between Sept. 3 and Sept. 17, so that the soil in all the plats was pretty thoroly soaked with water. Nevertheless, plat 3 entered the third period with almost 3 per cent more moisture than either of the other two plats. On Sept. 17, the beginning of the period, the disked plat contained 24.2 per cent of moisture, the late-plowed plat contained the same amount and the early-plowed plat contained 27 per cent. At the close of the period. Oct. 3, the disked plat contained 15.9 per cent of moisture, the early-plowed plat, the same, and the late plowed plat 20 per cent, a difference in favor of the late-plowed plat of 4.1 per cent. These results become more striking when we consider the total amount of moisture lost from the plats during the period. The disked plat lost 8.3 per cent. the early-plowed plat lost 11.1 per cent, while the late-plowed plat lost only 4.2 per cent. This complete reverse from the results obtained in the first two periods of the experiment was due to the fact that the hard rains of the several rain periods, which plats 1 and 3 had passed thru, had run the soil particles together and had at length reëstablished connection for capillary attraction between the surface and the subsoil, while the one period which plat 2 had passed thru was insufficient to accomplish this result to any great extent.

The experiment indicates that the disk harrow may be a valuable means of conserving moisture, especially if it is used soon after the last rain preceding a period of drouth. A fair comparison between disking and early plowing cannot be made from this experiment, because the good effects of the disking were largely obliterated by a heavy rain which fell on July 3, before the experiment with early plowing began. The results of the two experiments of 1897 and 1898 certainly show that, so far as the effect upon soil moisture is concerned, early fall plowing is certainly much better that late, and especially is this true when there is a drouth thru the months of July and August. In addition to this the much better condition of the soil obtained by the early plowing should have considerable weight

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towards inducing farmers to push their fall plowing as early in the season as possible. The experiment of 1898 also strikingly illustrates the fact that all effective methods of culture to preserve moisture must break the connection for capillary attraction between the surface and the subsoil and the culture must be repeated after every heavy rain to continue the effectiveness of the treatment.

SUMMARY.

The experiments described in this bulletin are of two types, those to test the effects of the addition of certain fertilizers to soils, with reference to soil moisture, and those to show the effects of tillage.

Experiments with soil in pots tried under the most rigid conditions available showed that the rate of evaporation of water from soils is not sensibly affected by the addition to the soil of relatively large amounts of the substances ordinarily used as fertilizers, nor by certain others.

Experiments with out door plats where both evaporation and drainage came into play, showed no decided effect from the fertilizers except with the plat to which unleached ashes were applied, which lost water more readily than any of the others.

Experiments to test the relative efficiency of different kinds of culture in conserving soil moisture showed that simple plowing while the soil was in good condition was as efficacious as plowing followed by planking, rolling, harrowing or subsurface packing. Disking was found to be a good means of saving moisture but was not equal to plowing.

The importance of plowing stubble ground as early as possible while moisture is still in the soil was shown by experiments in two years. Early plowing left the ground in good condition, as regards soil moisture, for wheat seeding, while late-plowed ground was dangerously dry.

The efficiency of the dry soil or dust mulch, and its superiority in the long run over a straw mulch were strikingly shown.