Bulletin No. 159 - Soil Moisture Studies Under Irrigation

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Soil Moisture Studies Under Irrigation

BY
F. S. HARRIS and A. F. BRACKEN

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UTAH AGRICULTURAL EXPERIMENT STATION

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Under normal precipitation the variety of crops which can be successfully grown in the West is limited. Of necessity, irrigation was practised and with it came many complex problems. The water requirements of different crops, the water-holding capacity of soils, the movement of soil moisture, and numerous other related problems have given themselves up for investigational work.

Plants depend primarily upon the moisture in the soil for their growth, and since moisture is constantly being agitated by a great variety of complex forces each tending to cause it to act differently, soil moisture movement has been, and still needs to be, given considerable attention. This bulletin discusses a few of these problems of soil moisture movement and distribution under field conditions.

The experiments from which the information herein reported was collected were conducted at the Greenville farm of the Utah Experiment Station at North Logan. The soil is a deep, rich clay loam, dark in color and uniform in texture to a depth of at least ten feet. The soil contains about 40 per cent of calcium and magnesium carbonates. These features make it almost ideal for soil moisture study.

Except when stated otherwise, all soil moisture samples were taken to the depth of ten feet. The foot-sections of soil in sampling were placed in tight glass jars and moisture determined in the usual way. All moisture percentages for these experiments were calculated on the dry basis.

The water applied for the irrigation experiments was distributed to the plats through a Cippoletti weir by means of wooden flumes especially built to allow accurate measurement of the water. The amounts given represent the depth of water applied to the plats.

*The authors are indebted to many faithful and efficient helpers who have during the years of the experiment assisted in taking samples and making moisture determinations.
For many years the problem of soil moisture movement has been given attention by a number of investigators. The literature covering these investigations is extremely valuable, but is so voluminous that only a brief resume of the parts bearing on the work which follows can be given in this bulletin. In general, the review of the literature will be discussed in the order of the discussion in this bulletin.

**Effect of Irrigation**

King\(^{(a)}\), one of the foremost investigators in soil moisture work, observed a very slow rate of penetration in a gravelly clay soil after 1.4 inches of rain, while the lateral movement did not exceed three feet. With a sandy loam soil Loughbridge\(^{(b)}\) found the downward movement of irrigation water to be very irregular in its rate of movement as well as in the amount retained at various depths. In furrow irrigation he found that water did not move outward more than two feet, and that the relative proportion of dry soil to the wet increased at first, then decreased with depth. He also observed that when downward movement had apparently ceased there was always the greatest amount of water in the upper two feet with a diminution as depth increased.

Widtsoe and McLaughlin\(^{(c)}\) pointed out that irrigation water penetrated very rapidly to a depth of six feet; that distribution of water is greatest near the surface and decreases in percentage downward; that with a given quantity of irrigation water on a given soil the percentage distribution is always the same for each foot shortly after irrigation; that the lateral movement of moisture increases with depth; and that the movement of moisture is very slow in the Greenville soil when the percentage is as low as 12.75.

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The experiments conducted by Allen\(^\text{(d)}\) indicate that with 2.5 inches, 5 inches, and 10 inches in an irrigation the same quantity of water is retained in the upper four feet of soil after a period of twenty-four hours.

**Effect of Cultural Method and Mulches**

From King’s\(^\text{(e)}\) investigations it is evident that cultivation, because it keeps the soil cooler below the surface and thus strengthens capillarity, tends to decrease the downward percolation of water. As a result of this increased capillary power the soil water was moved upward at a faster rate and through longer distances. He\(^\text{(f)}\) also found that the soil immediately below a 3-inch cultivation was more moist than below a 1\(\frac{1}{2}\)-inch cultivation, but that the third and fourth feet below the 3-inch cultivation were drier than below the 1\(\frac{1}{2}\)-inch cultivation. Thus, the more moist surface soil gained moisture at the expense of the lower soil.

In laboratory experiments King\(^\text{(e)}\) showed a 1-inch cultivation to be the most effective in conserving moisture. Kedzie’s field experiments\(^\text{(h)}\) indicated cultivated plats, to a depth of six inches, had three per cent more moisture than naked fallow; and that the former actually gained two per cent moisture in the top foot, while the naked fallow gained one-tenth of one per cent during a period of drought. The work of Chilcott and Holm\(^\text{(i)}\) supports King’s conclusions that the moisture was bulked in the first foot when deep cultivation was given the plats, while the lower depths were actually drier than the corresponding depths of shallow-cul-


\(^\text{(e)}\) King, F. H., 1890. Soil water. Wis. Sta. 7th Ann. Rpt., 1890, pp. 139-147.


tivated plats. All cultivated plats contained more water than the uncultivated fallow.

Hays\(^{(j)}\) found that the cultivated plats had no more moisture late in the season than the uncultivated fallow, and plats with straw mulches four inches deep contained 5 per cent more moisture than bare fallow. Cardon\(^{(k)}\) found no advantage in deep plowing or subsoiling over shallow plowing so far as moisture conservation was concerned.

**Effect of Manure**

After twenty-five years of experimentation, K. T. Mankovski\(^{(l)}\) concluded that the influence of manure freshly plowed under on the moisture of the soil during the period of fallow cannot be considered favorable. If, however, in wet periods the moisture of the tilled layer of the soil on the manured fallow is higher, the drying out of the upper layer of the soil on the fallow is more rapid during a period of drought, and about the time of seeding the manured fallow soils are drier than the unmanured fallows. The manure apparently produced no appreciable influence on the moisture of the deeper layers of the soil. Whitney\(^{(m)}\) showed that manure, on account of the urine present, lowers the surface tension of the water in the upper layers of soil, thereby allowing movement from the surface to lower depths. The same authority\(^{(n)}\) later concludes that the urine in the manure has a tendency to deflocculate the soil particles, which in turn prevents the moisture from being lost by downward movement. King's experiments\(^{(o)}\) in the field and in cylinders indicate that manure has a considerable influence in increasing the water content of the soil even down to a depth of four feet, and


that this influence is still exerted a year after manuring. He later says that the surface foot of manured fallow ground the second and third foot will contain much more moisture than the corresponding depths of unmanured soil. He also shows that manure tends to decrease the water of the succeeding three feet and that wetting the surface of sand with liquid that leached from manure reduced the upward movement of moisture by capillarity by sixteen inches and reduced the rate of evaporation from the surface by 49.6 per cent. Snyder also found that manuring increased the moisture over unmanured soil during a period of drought.

EXPERIMENTAL RESULTS

Potatoes and Beets under Irrigation

Figures 1, 2, 3, and 4 give the results of a 2-year test (1912 and 1913) with beets and potatoes grown under irrigation with water applied in furrows. The plats used in this experiment were 41F to 45F and 61F to 65F inclusive. Each plat was 30 by 58.08 feet, making 1-25 of an acre.

As indicated in the figures, weekly irrigation of 1, 2½, 5, and 7½ inches were given for a period of five weeks, making a total of about 5, 12½, 25, 37½ inches of water for the respective irrigations. Irrigation began as soon as the crops showed need of it.

Variations due to soil were eliminated by planting beet on plats 41F to 45F and potatoes on plats 61F to 65F inclusive in 1912 with an interchanging of crops in 1913.

To study the distribution and efficiency of these different treatments, soil samples were taken to a depth of ten feet immediately before, 24 hours after, and one week after irrigation. The samples were taken from three different parts of each plat in foot sections. All corresponding sections were mixed to make a composite sample. The data given in Figures 1 and 2 are averages of all of these results for the two years.

As would be expected, increasing the amount of water applied caused an increase in the moisture content of the soil to the full depth of sampling for these plats. Figures 1 and 2 are quite

similar in this respect. The striking thing brought out in both figures is the rapidity with which the water entered the soil. Even an irrigation as small as 1 inch caused an increase of almost 1 per cent to a depth of 10 feet in twenty-four hours after irrigation. The 1-inch irrigation showed the largest average gain for the water applied. The $2\frac{1}{2}$-, 5-, and $7\frac{1}{2}$-inch applications

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**Fig. 1.—Diagram showing distribution of moisture in soil cropped to potatoes 24 hours before, 24 hours after, and one week after irrigation. Average of two years' results.**

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- **1 INCH WATER WEEKLY**
- **2\frac{1}{2} INCHES WATER WEEKLY**
- **5 INCHES WATER WEEKLY**
- **7\frac{1}{2} INCHES WATER WEEKLY**
SOIL MOISTURE STUDIES UNDER IRRIGATION

PERCENTAGE MOISTURE

Fig. 2.—Diagram showing distribution of moisture in soil cropped to beets 24 hours before, 24 hours after, and one week after irrigation. Average of two years' results.

produced an increase over the 1-inch irrigation, but the gain in the total moisture was not in proportion to the water applied.

The distribution of moisture in Figures 1 and 2 is practically identical for every depth making only one discussion necessary for both. Twenty-four hours after irrigation the surface foot in almost every test showed the highest percentage moisture and the seventh foot lowest with a gradual increase both ways from
this point. One week after irrigation the third foot from the surface contained the highest percentage moisture in almost every test with a decrease toward the surface; otherwise, the distribution was about the same as 24 hours after. When sampled before irrigation the figures indicate that the distribution of moisture was almost identical with that one week after.

Since plants obtain most of their moisture from near the surface and evaporation is almost entirely from this point, the high percentage moisture of the top two feet just after irrigation is reduced to below that in the third foot by the end of one week. But as depth increased below 3 feet the percentage of moisture decreased to the eighth foot due to the fact that friction, surface tension, and perhaps other retarding forces equalize within certain limits the action of gravity. The loss of moisture was inversely as the depth near the surface, but after a certain point was reached—about 3 feet—the loss was more uniform throughout. Or, in other words, the third foot seems to be a point of equilibrium between the forces which tend to draw the moisture upward and the forces which tend to draw it downward; one force had not sufficient power to make movement possible when it had friction and other forces to overcome.

Figure 3, taken from Figures 1 and 2, is an average for both crops. This figure shows the average variation and distribution of moisture 24 hours before and 24 hours after irrigation. It shows more strikingly: (1) that 24 hours after irrigation an increase in moisture content took place to the full depth sampled except for the 2 1/2-inch application where there was a decrease below the seventh foot; (2) that the surface foot showed the largest increase in moisture with a gradual decrease downward; (3) that the largest
proportionate increase occurred under the 1-inch application; and (4) that before irrigation the third foot contained the highest percentage moisture and the seventh foot least with gradual change to these points.

Figure 4, taken from Figures 1 and 2, shows the influence of cropping to beets and potatoes on the soil moisture. The data represented in the figure are averages for all depths, before, 24 hours after, and one week after irrigation for 1, 2 1/2, 5, and 7 1/2 inches of water weekly. As indicated in the figure, the differences between the two crops is so small that it is almost negligible. With the two small irrigations—1 and 2 1/2 inches weekly—plats growing potatoes contained the highest percentage of moisture by a small margin; with 5 inches weekly beet plats contained the most moisture, while with 7 1/2 inches of water weekly the plats growing potatoes again showed the most moisture.

There was very little difference in the moisture content of soils producing beets and potatoes; differences existed but they were small and variable. The largest proportionate increase in moisture occurred after the 1-inch irrigation; that is, as the amount of water applied increased its efficiency decreased. Comparing the yields for beets and potatoes grown under the different treatments, it was found that 1 inch of water weekly gave larger yields than any of the other irrigation treatments.

The data for Figure 5 were collected from plats 41F to 45F and 61F to 65F inclusive to show the relationship between the initial percentage of moisture in the soil and the water retained after different irrigations. The soil samples were taken to a depth of ten feet 24 hours before, and 24 hours after irrigation. Each initial percentage represents the average moisture content to the full depth sampled.
In every irrigation treatment, and for almost every initial percentage, the moisture content after irrigation increased with the initial percentage. Comparing the 15-16 initial percentages after the 1-inch irrigation there was an increase of 0.8 of one percent; after the 2½-inch irrigation there was a gain of 1.2 per cent; and after the 5-inch irrigation there was a gain of 3.6 per cent. Under the 5-inch irrigation the 12-13 initial percentage shows a gain of 1.1 per cent, and as the initial percentage increased up to 15-16 the gain also increased after irrigation. From this point a decrease took place until at 20-21 the gain was only 1.2 per cent. For the 1-inch irrigation, averaged for all initial percentages, there was a gain in moisture of 1.3 per cent; for the 2½-inch irrigation a gain of 1.0 per cent; for the 5-inch irrigation a gain of 2.2 per cent; and for the 7½-inch irrigation a gain of 2.0 per cent. Where the increase of soil moisture as spoken of after a 1-inch irrigation, both in the general averages and when applied to soil containing an initial amount of 15-16 per cent, the percentage increase is greater than can be accounted for when the amount applied is considered. Experimental error seems to be the reason.

The extremes for the initial percentage—low and high—are only given for the 5-inch application of water, and from the figure the soil which retained most moisture after irrigation had an initial percentage between 15 and 16.
From a practical standpoint this experiment shows that soil when too dry or too wet does not increase in moisture content after irrigation as much as if the moisture content were just right. The 5-inch application in the table shows this point.

Distribution and Movement of Moisture in Furrow Irrigation

The data given in Figure 6 were taken from an experiment conducted on plat 89G. Two inches of water were applied in furrows which were three feet apart. As indicated by the figure samples were taken to a depth of ten feet 24 hours, one week, and two weeks after irrigation. The figure shows that the area under the furrow contains a higher percentage of moisture than the area under the ridge 24 hours after irrigation. The average percentage for the furrows to a depth of ten feet was 13.7; for the ridges 11.0 per cent. Twenty-four hours after irrigation the surface foot in the furrow contained the highest percentage of moisture with a gradual decrease with depth until the fifth foot was reached where an increase began. The surface foot of the ridges was apparently not affected by the irrigation in ridges 24 hours, one week, and two weeks after two inches of water were applied. Average of one year's results.

After irrigation the difference between the surface foot under the ridge and under the furrow was only 1 per cent, but the furrows are practically one foot deep which means that the second foot under the ridge was at about the same level as the first foot under the furrow. Comparing soil on the same level there was a difference of almost 1 per cent in favor of the ridge.

With the soil under the furrows there was a gradual decrease
in moisture with the time. Twenty-four hours after irrigation the average percentage of moisture to the full sampled depth was 13.7; one week after 13.3; two weeks after irrigation 13.1. With the soil area under the ridge, averaged for all depths, there was a gradual increase; 24 hours after irrigation the moisture percentage was 11.0; one week after 12.1; two weeks after 13.4 per cent. This increase in the area under the ridges took place in almost every foot to the full depth sampled, but the greatest increase occurred in the second, third, fourth, and tenth foot areas.

The wetter the soil, especially when the difference in the water of two soils is near the surface, the more rapidly does it lose soil moisture. Figure 6 indicates this and also that for the same amount of moisture furrow irrigation is a more efficient method of applying water than flooding. In one case the whole area is made wet which allows evaporation from the whole soil surface; in the other only a small part of the soil surface allows evaporation. Where intertilled crops, such as beets and potatoes, are grown and where water is scarce the furrow method of irrigation should be used wherever possible.

The data given in Figure 7 were taken from plat 89G irrigated with furrows three feet apart. Two inches of water for the whole area were applied between 10:15 and 10:30 A.M. Five foot-samples of the soil were taken hourly from 1:00 P.M. until 5:00 P.M. In giving the data the second foot under the ridge is compared with the first foot under the furrow, making five one-foot samples for the ridges and four one-foot samples for the furrows.

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Fig. 7.—Diagram showing distribution of moisture after irrigation to a depth of five feet for furrows and ridges. The time opposite the legends represents the hours sampled. Average of one year's results.

The surface foot under the ridges did not appear to have been influenced very much by the irrigation. Below this depth the
moisture content increased until the third foot was reached after which a decrease began. The surface foot under the furrow showed a decided increase over the corresponding area under the ridge for all hours of sampling. The percentage moisture in the surface foot under the furrow decreased with time, but not regularly. The area under the ridges changed considerably less during this period than did that under the furrows.

**Movement and Distribution of Moisture after Flooding**

Figure 8 gives the distribution of moisture on plat 88G two weeks after four inches of water were applied to the center of the plat. Distance from border indicates the distance in feet from point of application of water. Practically all of the distances from the center of the plat appear to be quite similar in moisture content and in distribution. In comparing the center of the plat with the other places of sampling a bulking of moisture was noticed in the first foot, but otherwise it was similar to all other samplings. At all distances from the point of application of water there was a striking uniformity in distribution of moisture. All of the borings showed an increase of moisture to the third foot, then a decrease to the fifth foot with a tendency to increase, culminating in a decided increase at the tenth foot. From this experiment it was evident that lateral movement in this soil was not very pronounced to distances even as small as 1 foot in two weeks' time.
Figure 9 represents results which were also obtained from plat 88G. Two inches of water were applied to the center of the plat and soil samples were taken in the middle, two feet north and two feet south from the middle, and four feet north and four feet south from the middle of plat, 24 hours, 48 hours, 8-days, and 15 days after irrigation. Twenty-four hours after irrigation the percentage moisture in the middle of the plat tended to vary inversely with the depth, while two feet each way and four feet each way the moisture percentage varied directly with the depth to the third foot before the decrease began.

Forty-eight hours after irrigation, although the surface foot had lost 2 per cent, it was still highest in moisture content. From the surface foot down there was considerable fluctuation with the third and tenth feet containing the highest percentages of moisture.

The samples taken eight and fifteen days after irrigation were quite similar in distribution of moisture showing that practically all moisture movement had ceased before this time. In both samples the moisture percentage for almost every depth decreased with the distance from the point of application of the
water. The third foot contained the highest percentage moisture of any foot with a decrease both upward and downward until the tenth foot was reached, where as usual an increase took place.

The data represented in Figure 10 were taken from plats 81G, 82G, 83G, 86G, and 87G. The water applied to these plats varied from one to five inches. The black line drawn opposite the moisture percentages represents the original average moisture content before irrigation. Therefore, the moisture percentages to the right of the line indicate the increase in moisture due to irrigation.

Fig. 10.—Diagram showing distribution of moisture one day, eight days, and fifteen days after irrigation of one to five inches. Averages of one year's results.

In the test eight days after a 1-inch irrigation the moisture percentages for the last two feet are not given because gravel was struck at that depth.

As indicated by the figure, an increase in the water applied
caused an increase in the moisture percentage, especially in the upper feet. Subtracting the original moisture content from that one day after irrigation an average increase for each foot of 1.0 per cent was found; for the 3-inch application an increase of 2.2 per cent for each foot; and for the 5-inch application an increase for each foot of 2.8 per cent. From these data it is evident that the loss of moisture from a soil surface varies directly with the time and the amount of water applied.

Calculating the same for eight days after irrigation, a loss of 1.3 per cent for each foot is found for the 1-inch irrigation; for the 3-inch irrigation a loss of 0.5 per cent; and for the 5-inch irrigation a loss for each foot of 1.6 per cent. Fifteen days after irrigation the 1-inch irrigation showed an average loss for each foot of 1.8 per cent; the 3-inch irrigation showed a loss for each foot of 2.3 per cent; and for the 5-inch irrigation a loss for each foot of 2.8 per cent.

In distribution of moisture directly after irrigation Figure 10 shows that the moisture percentage varied directly with the depth until the ninth and tenth feet were reached when an increase was noted. Eight and fifteen days after irrigation most of the moisture is bulked in the second, third, fourth, and fifth feet.

**Effect of Mulches in Conserving Moisture**

Figure 11 represents data collected from plat 97G on the effect of a 5-inch straw mulch, a 2-inch cultivation, and no cultivation with weeds pulled before, 24 hours after, and eight days after a 5-inch irrigation. The figure represents the average to a depth of ten feet.

Before irrigation the average moisture percentages were rather similar, but after irrigation the part of the plat with the straw mulch contained 2.0 per cent more moisture than the cul-

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**PERCENTAGE MOISTURE**

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**24 HOURS AFTER IRRIGATION**

**6 DAYS AFTER IRRIGATION**

![Fig. 11.—Diagram showing the effects of a 5-inch straw mulch, a 2-inch cultivation, and no cultivation with weeds pulled in conserving moisture. Average of one year's results.](image-url)
tivated part, and 3.0 per cent more than the part which was not cultivated but had the weeds pulled. Eight days after irrigation there was a difference of about 1 per cent between the straw mulch and the cultivated soil and exactly 1 per cent between the cultivated and that not cultivated.

Figure 12 gives the distribution of moisture of the above treatments to the full sampling depth. This figure is the result of averages before, twenty-four hours after, and eight days after irrigation. At most depths the straw mulch was the most effective in preventing evaporation, with the 2-inch cultivation and no mulch with weeds pulled following in order. Again there was a variation of about 1 per cent between the first and second, and the second and third treatment. From this experiment it is evident that a straw mulch is more effective than either one of the other two treatments mentioned, and that a cultivation of two inches is more effective in conserving moisture than no cultivation with weeds pulled. The differences, however, in favor of one or the other are so small after a period of eight days that the advisability of mulching hinges on the question of labor.

Figure 13 represents data taken from plats 79G and 80G which received no irrigation water. As the figure indicates there were four parts to the experiment which necessitated dividing each plat into two parts.

In comparing the plat receiving no cultivation and weeds pulled with the plat cultivated 1 inch deep the uncultivated plat had about 2 per cent less moisture than the one cultivated 1 inch deep. This difference decreased to the third foot, then the relation of the two treatments was reversed from what it was in the upper feet and increased to the sixth foot. But when the averages for the full sampled depth are compared there was only a difference of 0.1 per cent in favor of the cultivated plat; these results are corroborated by the work of King given in the liter-

![Figure 12](image.png)
ature review. The averages for the plats cultivated 2 and 6 inches deep show practically no difference, and all variations are rather irregular. When the two deep-cultivated plats are compared with the first treatments there is a striking difference. Only in the top two feet is the moisture under the deep-cultivated plats as great as for the shallow-cultivated and uncultivated plats, and below the fifth foot section the difference is quite noticeable.

Comparison of Cropped and Fallow Soils

The data represented in Figure 14 were collected during the years 1913 to 1915 inclusive. The plats used in the experiment were 61G to 73G inclusive each of which was subdivided into six parts, each part receiving a definite treatment. As divided there were 36 sub-plats cropped to corn, leaving 42 uncropped. The mixed cow and horse manure used in the manuring treatments was fairly well rotted. It was applied early in the spring and later disked and plowed under. The quantity of irrigation water given varied from none to 40 inches and was applied from wooden flumes as follows: For cropped plats receiving 5 inches, 2½ inches each at beginning of tasseling and roasting ear stage; for plats receiving 10 inches, 5 inches each at the above stages; for plats receiving 20 inches, 5 inches each when the plants were twelve inches high, at bloom, and at roasting ear stage.

For plats receiving 30 inches the application was the same as for 20 inches, except 5 inches ten days later than the last for the 20 inches, and for the plats receiving 40 inches, applications began when plants were twelve inches high and five inches were applied each week until the full 40 inches had been added. The fallow plats were irrigated exactly in the same manner and at
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In this experiment the plats were sampled in the fall after all the irrigation water had been applied, in order to study the final distribution.

In the figure the 10- and 30-inch applications are not given because those considered are representative of the distribution.

For each amount of water added to both cropped and fallow plats there were three amounts of manure as follows: none, 5 tons, and 15 tons. The data in Figure 14 are averages of all manuring treatments.

From Figure 14 the increase in the amount of water applied showed an increase in the percentage moisture for all depths on both cropped and fallowed plats. The irrigations increased the moisture in the upper depths of the soil more than the lower depths, and the first five inches applied had a greater influence in proportion to the amount than the larger applications. As was expected, the fallow plats contained the highest total percentage moisture although from the eighth foot downward there was a marginal difference in favor of the cropped plats. This was more apparent in the plats which received 20 and 40 inches of water. In the cropped plats receiving no water there was a decrease in moisture from the surface to the fourth foot, then an increase. For the unirrigated, fallowed soil the opposite was true—first an increase in moisture, then a decrease. The same condition existed in the plats receiving 5 inches of water, but the lower percentage occurred in the fifth and sixth feet for the cropped. For the 20- and 40-inch applications there was a fluctuating decrease from the surface to the full sampled depth.

The difference between cropped and fallow soils decreased as the irrigation water applied increased. In the first two cropped irrigation treatments the plants seemed to have used
most of the available moisture, while in the last two the irrigation was sufficient to supply all needs of the plants and at the same time leave considerable moisture in the soil. The first two treatments also show the soil zone in which plants extract most moisture.

The data given in Figure 15 are derived from the same source as Figure 14. The data represented are the averages for the full depth sampled for each quantity of water applied. The figure shows the percentage moisture increased regularly with the water given for both fallowed and cropped soils. This figure shows more clearly that the difference in moisture content between the cropped and fallowed plats increased inversely with the quantity applied. The plants used most of the available moisture of the smaller applications, but as the water increased the demands of the plants were satisfied with a smaller percentage of the total water applied, thus leaving larger quantities in the soil not used.

From the figures given to represent this experiment it is evident that the efficiency of water increased inversely with the amount applied. This is not only true from the standpoint of soil moisture, but also true from the crop production point of view.

At the end of the season the cropped plats which received 5 inches of water during the season contained to the full depth sampled about 12 per cent moisture; those receiving 10 inches about 14.5 per cent; those receiving 20 inches about 15.6 per cent; those receiving 30 inches about 17 per cent; and those receiving 40 inches about 17.2 per cent. Even at the end of the growing season the 10-inch irrigation still had enough moisture—14.5 per cent—to support plant growth and each 10 inches of water added gave only an increase of 1 per cent until 40 inches were applied.
where an increase of only .2 per cent was shown over the 30-inch application. This shows that a 30-inch irrigation was as efficient as a 40-inch irrigation.

Effect of Manure

The influence of manure on the moisture content of soil was studied for the same three years and on the same plats described in the last discussion by averaging all irrigations. As before, the moisture determinations were made about the first of September just after the corn crop had been removed.

The data given in Figure 16 are averages for the full depth sampled showing the effects of varying amounts of manure—none, 5, and 15 tons—and different amounts of water from none to a total of 40 inches on the final moisture content of cropped soil.

In every test except the last, there was a uniform increase in moisture content as the amount of water applied was increased for all amounts of manure. The striking feature of the diagram is the difference in percentage moisture between no water applied, to 40 inches. The plats receiving no manure contained about 4 per cent more moisture than those receiving 5 tons, and the difference is about the same for each irrigation. The plats which received 15 tons of manure contained less moisture than the other two treatments when no water was given. With 5 inches of water the 5 and 15 tons of manured plats were the same, and with the 10 inches or more of water 15 tons of manure showed a moisture percentage about equal to that for no manure.

The data represented in Figure 17 show the results from soils receiving the same treatments as in Figure 16 except that fallow plats are shown in Figure 17 and cropped in Figure 16. As expected, the fallow plats showed an increase in moisture over that in the cropped plats, but the general gain in moisture
was about the same; as the amount of water increased the percentage of moisture in the soil also increased. The manure, however, showed some difference when compared with the cropped plats discussed under Figure 16. For most irrigations, except one, the 5-ton application of manure where no water was applied resulted in a lower moisture percentage than no manure or 15 tons. With the 5-inch application of water the plats receiving 15 tons of manure showed a higher percentage of moisture than either no manure or 5 tons, and this increase is maintained for all irrigations. The plats receiving 5 tons of manure tended to increase faster in moisture than the unmanured or plats manured at the rate of 15 tons until 20 inches of water were added after which there was practically no appreciable increase.

The next amount of water given—20 inches—showed that the plats which received no manure were lowest in moisture, followed by 5 tons, then by 15 tons of manure. Plats receiving 30 and 40 inches of water showed the moisture content lowest in plats receiving 5 tons of manure and highest in those receiving 15 tons.

Figure 18 shows the distribution of moisture to a depth of ten feet for both fallow and cropped plats when no manure, 5 tons, and 15 tons were used. The data represented in this figure are averages of all irrigation treatments. The most striking thing brought out in this figure is the difference in distribution of moisture at different depths between the fallowed plats receiving no manure and those manured. With no manure there is a fluctuating bulking of the moisture in the second and the seventh feet with a decrease both upward and downward from these points. With both 5 and 15 tons of manure the same bulking occurred in the same zone with a marked decrease in moisture content in the eight-foot section, then a regular increase to the full sampled depth.
In distribution of moisture the cropped plats were as peculiar as the fallowed. With no manure the first five feet contained almost exactly the same percentage of moisture with a marked increase in the sixth and seventh feet, then a decrease to the tenth foot. The cropped plats receiving 5 and 15 tons of manure were quite similar in distribution of moisture. In both tests about the same moisture content was maintained to the third or fourth foot when a rapid decrease took place, then a fluctuating increase.

Although manured land did not show any increase in moisture when compared with that unmanured there is no reason for believing manure of no value. The benefits of manure are numerous. It decreases the water cost of dry matter by increasing the fertility of the soil; it corrects physical conditions in the soil, such as extreme lightness and heaviness; and it stimulates bacterial action.
BULLETIN NO. 159

SUMMARY

1. This bulletin contains results of several thousand moisture determinations of cropped and uncropped soil during a number of years under irrigation.

2. Important literature bearing on the subject is reviewed.

3. A great similarity was found in the content and distribution of moisture in soil producing potatoes and sugar beets.

4. The efficiency of water decreased with the amount applied. On beets and potatoes 1 inch weekly showed a higher increase in moisture to a depth of 10 feet in proportion to the amount applied than either 2½, 5, or 7½ inches weekly. It also gave a higher yield of the crops.

5. The initial per cent of moisture in the soil affected the distribution of the water applied by irrigation.

6. Furrow irrigation was more effective in conserving moisture than flooding.

7. The lateral movement of moisture in the soil after an irrigation was slow, particularly in the upper feet.

8. A straw mulch was more effective in conserving moisture than an earth mulch.

9. On soil to which irrigation water was applied, cultivation was more effective in conserving moisture than pulling the weeds; but where the soil was not irrigated, the soil retained as much water where the weeds were pulled as where the land was cultivated.

10. The crop was able to reduce the moisture to a depth of 10 feet.

11. The difference in the moisture of the cropped and the uncropped soil was decreased with an increase in the amount of irrigation.

12. Manure had very little effect on the distribution of moisture in the soil.

13. The application of more irrigation water than is actually needed by the crop is a wasteful practice.

14. The farmer should study the moisture requirements of his soil and then try to supply those requirements as efficiently as possible.

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