Studies of Moisture Requirements of Sugar Beets[1]

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Experiments dealing with soil-moisture relationships of sugar beets have been conducted in 1940 and 1941 on two fields similar in soil type and contour located near Scottsbluff, Nebr. In these experiments, irrigation water has been applied at the rates of 3, 4.5. and 6 acre-inches of water per irrigation, and each rate of application has been used with a series of sugar-beet plots in which the plants had reduced the available soil moisture to a 50, 25, or 0 percentage level. This study has been conducted only 2 years and on one type of soil, hence additional and wider tests are needed before the findings are to be used as an indicator of the proper method of irrigation of sugar beets under varied climatic conditions, and on varied types of soils.

However, certain principles have been revealed concerning the relations between the amount of moisture available in the soil and the relative growth of the beet crop, which should hold true for almost any soil and for many different climatic conditions. A correlative finding from the study indicates that temperature and air humidity el'fects, as they influence plant moisture requirements, need be taken into consideration in any conclusions to be drawn.

From a practical standpoint, it is clear that more careful applications of irrigation water should be given if plants are to obtain their necessary moisture supplies efficiently. In this connection, it is very important to know the minimum amounts of water that can be used in irrigation applications which will serve to produce maximum yields of sugar beets, since the supply of water for irrigation is often limited, and the application of water to land requires considerable labor. The customary plan of irrigation of sugar beets in western Nebraska which is now in vogue seems to be based more upon available supply of water in the ditch than any other factor. Irrigation is usually begun about July 1, unless a dry planting season occurs and watering is required to induce germination of seed. After July 1, the crop is irrigated approximately every 10 days until the middle of September. Three acre-inches of water are considered a very light irrigation and 6 acre-inches are a very common irrigation, while sometimes as much as 12 acre-inches are applied.

'These experiments wore conducted in cooperation with the Great Western Sugar Company. II. W. Dahlberg. Manager of Research, supplied equipment and assisted in planning the experiment, and N. J. Muscavitch. chemist at the Scottsbduff factory, assisted in the laboratory and fieldwork.

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Much improvement has been made in the methods of irrigation as more scientific information has become available. It is reasonable to believe that in the future farmers, in applying irrigation water to fields, will give more attention to such factors as: Available soil moisture present at different soil levels, and also to the existing climatic conditions and their marked influence upon the use of moisture by the plants.

The experiments conducted in 1940 and 1941, where available soil-moisture levels were accurately checked by the use of recently perfected equipment, furnish some new information regarding the minimum amount of water required to produce maximum yields of sugar beets in western Nebraska.

Experimental Work

The amount of moisture in the soil at the time of planting of the beet seed, has a considerable effect upon the early growth of the plants during the time which elapses before irrigation is necessary. In these experiments the fields were both fall irrigated and at the time of planting, so the soil was amply supplied with moisture to a depth of 3 feet or more. Test borings were made to a depth of 7 feet to determine that, there was no watertable or seepage.

The crop was planted in April in 1940, the seedlings emerged before May 1, and were harvested November 1, which provided a growing period of 180 days for the sugar beets. There was no frost injury to the crop from May 1 to November 1 in 1940, and a similar condition existed in 191]. The 1941 beets were planted in early May, had emerged on May 15. and were harvested on November 4. which provided a slightly shorter growing season than that of 1940. The irrigations were begun in 1940. on July 5. and in 1941. on July 7. The climatic conditions in this area in the season of 1940 and in the season of 1941 were both accompanied by more than normal seasonal rainfall which reduced the requirements for irrigation.

The fields selected for this series of experiments were relatively uniform and located so that a supply of irrigation water could be obtained whenever desired. The same series of 36 plots were laid off each year in fields where there was a good stand of sugar' beets, thinned to approximately 12 inches in the row and rows 20 inches apart. Each plot was approximately 60 feet long and consisted of 12 rows in 1940 and l5 rows in 1941. Plots were diked so there was no run-off of irrigation water.

There was some slope to parts of the field but no more than 2 inches in any plot, and the water was run on each plot very slowly so as to provide for penetration. However, it must be admitted that the low end of the plots sometimes received more water than the high end.

The irrigaition water was conveyed to the plots by use of metal flumes in which there were outlets which could be set to distribute the water equally to each row of the plot. The amount of water used was calculated carefully in gallons of flow per minute from the outlet of the flume to the furrow.

There were nine treatments with four replications of each treatment. The treatments fall into interrelated series as to the rates of water application and situation as to the soil moisture when the various applications are made. Twelve plots were irrigated with 3 inches of water per application. 12 plots received 4.5-inch applications, and 12 plots, 6-inch applications. The differential rates of watering were subdivided so that four plots for each application rate were irrigated while the soil still contained a high-moisture content (50 percent, approximately, of total available moisture still present). Four were irrigated when approximately 75 percent of the available moisture had been used; and four received irrigation water only when the soil began to approach the wilting point.

Plaster-of-paris blocks to permit the readings on soil moisture by the electric-resistance method were placed in the ground at depths of 12, *24.* and 36 inches, which made possible a study of the distribution of the water in the soil to the depth of 36 inches. The reading of the block at the 12-inch depth was the one most often used to determine time at which the appropriate irrigation should be applied to a plot. In 1940, a block was set at a depth of 6 inches while in 1941 this block was not used. Two sets of blocks were placed in each plot in 1941. one set at each end of the plot. In 1940. only one set of blocks was used.

Method of Soil-Moisture Determinations

The electrical-resistance method for measurement of soil moisture as developed by Bouyoucos and Mick (1) was used in this experiment.[3] in this method, small plaster-of-paris blocks, in which electrical connections are embedded, are placed permanently in the soil. These blocks absorb or release water approximately as does the surrounding soil. The ohms of electrical resistance between the fixed terminals in the absorption blocks are measured by means of a special type of Wheatstone bridge. There are certain necessary precautions to be taken in the construction of the blocks and their placement in the, soil in order to obtain readings of resistance that can be translated into soil-moisture percentage readings.

A block embedded in soil from this field when in saturated condition gave a resistance reading from 350 to 500 ohms, and at the wilting point of this soil the resistance varied from 00,000 to as high as 100,000 ohms. When approximately 50 percent of the available moisture had been removed the readings varied from 1,500 to as

[3]Figures in parentheses refer to Literature Cited

much as 3,500 ohms. Readings from 5,000 to 10,000 ohms indicated that approximately 75 percent of the available soil moisture had been removed. A soil with a 30 percent water-holding capacity requires a higher reading- 1o indicate that a given percentage of the available soil moisture had been removed Ihan does a soil with a 15 percent water-holding capacity.[1] Willi a table calculated from proper basic information for given soil, it is possible to translate quickly the readings of a block into available soil-moisture percentages. Ordinarily in this experiment 250 blocks were read in approximately one-half day.

The basic information needed to interpret properly a reading in ohms of resistance of an absorption block in the soil was obtained by utilizing as samples the soil removed when the plaster-of-paris blocks were placed. Moisture equivalents and hygroscopic coefficients were determined for the soil samples. These are recognized as indicating respectively the approximate amount of water the soil retains after saturation and the amount of water the soil retains after plants have removed the maximum available amount.

The approximate moisture equivalent for these fields in which these experiments were conducted is 20 percent for the top foot of soil. 13 percent for the soil between 12 and 24 inches in depth, and 11 percent for the third foot. The hygroscopic coefficient for this same field is 8 percent for the top foot, 6 percent for the second foot, and 5 percent for the third foot of soil.

By subtracting the hygroscopic-coefficient percentage of moisture in the soil from the moisture equivalent of the same soil, it is possible io obtain an approximation of the available moisture, or in other words, the amount of water that plants can remove from this particular type of soil. From these data, it was estimated that the plants could remove from the soil of this field approximately 12 percent of moisture from the surface foot of soil, 7 percent from the second foot, and G percent from the third foot. These figures indicate that the plants could remove slightly in excess of one-half of the total moisture held by the soil when saturated. It is also shown that more moisture was available for the plants from the top foot of soil than from the lower depths. This condition is due to the field having a sandy or almost pure sand type of soil below the surface foot. There are many fields in this area which have a greater water-holding capacity in the lower soil strata than in the surface foot of soil.

[4]Bouyoucos and Mirk (loc. cit. page 15) comment that changes in concentration of the soil solution in alkali and saline- soils may, however, be large enough to make use of this method impractical. Salinity concentrations of the soil solutions in the field under consideration and their changes throughout the season are believed to be such as not materially to have influenced the readings. The prevailingly high yields obtained, together with the general course of individual readings taken throughout the test, strongly bear out this assumption.

Actual determinations of the wilting point, using sunflower plants, were also made with samples of the soil to check the other determinations that were made. The sunflower plants were grown in mason jars. In some of the jars, absorption blocks were placed to determine the relations between the readings of resistance and the amounts of water in the soil. When the soil was in a saturated condition, the blocks had a resistance reading of approximately 400 ohms. When the plants had reached the wilting point the ohms of resistance had risen above 75,000 in all instances. The moisture remaining in the surface foot of soil when the plants had reached the permanent wilting point was approximately 10 percent, in the second foot it was 8 percent, and in the third foot it was 7 percent. This indicated that the plants could not remove one-half of the total moisture in saturated soil.

The hygroscopic-coefficient method of study of soil moisture indicated that slightly more than one-half of the total moisture held by the soil when saturated could be used by the plants, whereas the wilting point determinations indicated that less than one-half of the total moisture was available to plants, Under field conditions, however, it is often assumed that one-half of the moisture held by a saturated soil is available for plant growth.

Comparison of 1940 and 1941 Weather Record

The weather-recording instruments were located about 1 mile from the field, which provides a close approximation of the field conditions. A record of precipitation and temperature is essential for interpretation of an irrigation experiment.

The rainfall for April, May, and June in both 1940 and 1941, was sufficient to maintain a saturated condition of the soil to a depth of 3 feet or more, since it was a saturated soil to this depth on April 1. In 1940 the total June rainfall was 1.32 inches while in 1941 it was 4.96 inches. The July precipitation in 1940 was 1.56 inches and in 1941 it was .92 inch. The August precipitation in 1940 was .41 inch and the 1941 precipitation was 1.28 inches. The September precipitation for 1940 was 2.77 and in 1941 it was 1.25 inches. The total rainfall for June, July, August, and September was 6.06 inches in 1940 and 8.41 inches in 1941.

The 1940 season was of higher temperatures than the season of 1941 for the months of June, July, August, and September. The mean maximum temperature for June 1940 was 7 degrees higher than that for the same month in 1941, while the same measure of temperature for 1940 was 4 degrees higher for July; 3 degrees higher for August; and 7 degrees higher for September than it was in 1941. The mean minimum temperatures were also lower for June, July, August, and September for 1941 than they were in 1940.

The climatic conditions in 1940 and 1941 were such that the period in which sugar beets required irrigation was shorter than is normally expected. It was not necessary to irrigate before the first week in July, and in 1940 there was no indication that there were any benefits from irrigation after August 16, while in 1941 no irrigations were applied to the 36 testplots after August 5. Some other testplots in the same field were irrigated on September 3 in comparison to adjacent plots which had had similar treatment previously throughout the season. There was no significant increase in sugar obtained by irrigating on September 3.

Quantities of Irrigation Water Used

Less water was used on the experimental plots in 1941 than in 1940. To maintain the available soil-moisture level at 50 percent, a total of 24.13 acre-inches of water was used in 1940 and 13.13 acre-inches in 1941. In the plots where the irrigation water was applied when 75 percent of the available moisture had been used, 18.50 acre-inches were applied in 1940, and 9.42 acre-inches in 1941. In those plots which were permitted to approach exhaustion of the available soil moisture to a depth of 12 inches, 13.38 acre-inches of water were applied in 1940, and only 7 acre-inches of water were applied in 1941. The mean amount of water applied to all plots in 1940 was 18.67 acre-inches and in 1941 the mean amount applied was 9.85 acre-inches. Approximately 50 percent as much water was used in 1941 as in 1940, and regardless of this fact, the average block readings were slightly lower in 1941 than in 1940.

The tons of beet roots harvested were 22.30 tons per acre in 1940 and 21.15 tons in 1941, which is a relatively small difference. The fields were very similar, although the 1941 field was planted approximately 25 days later than the 1940 field. These irrigations were conducted so that water was applied when a need for it was indicated by the soil-moisture blocks, and in 1941 plots did not indicate that as many applications were necessary to maintain the proper moisture level; therefore, less was applied.

There immediately arises the question as to why less water was necessary in 1941 than in 1940. It is impossible definitely to answer such a question ; however, some substantiating evidence can be placed in the discussion.

Numerous experiments have shown that the use of water by plants is regulated by a number of factors such as available moisture in the soil, temperature, and humidity. Miller (2) found that plants used approximately the same amount of moisture whether the soil was saturated or only in a good tilth, and other investigators have found similar conditions. They have also found that to decrease the available soil moisture to below that for good tilth lowers the rate of transpiration. Wilted plants have a much lower rate of transpiration than those with an optimum amount of moisture. In the driest plots in the 1940 experiment, there were certain days when some of the plants were .severely wilted while in 1941 much less wilting occurred.

The entire Nebraska territory in 1941 produced a higher yield of sugar beets than in 1940. In 1941 there were very few fields in the area that ever indicated any severe lack of moisture by excessive wilting of the plants. There was a period of about 1 week during the latter part of July and the first part of August when the temperatures and humidity were sufficiently high to cause some wilting of commercial beet fields where the supply of water was inadequate In 1940 much more of this wilting was prevalent in the commercial beet fields.

Kiesselbach (3) found that plants in a greenhouse with relative humidity of 58 percent required 56 percent more moisture than plants grown in a greenhouse with a relative humidity of 37 percent, Briggs and Shantz (4) at Akron, Ohio, found that the range of water requirements during different years due to prevailing climatic conditions is very great. For example, the lowest year at Akron averaged only 61 percent of that of the highest year. These men found that due to changes in weather conditions the loss of water from plants varied as much as 600 percent on successive days. In this respect, liriggs and Shantz found that during a period of 10 days many crop plants lost as much as 25 percent of the total water transpired during the entire growing season. Richardson (5) working in Australia, found that alfalfa in bloom transpired as much as 25 percent of the total seasonal water in 3 days.

These various experiments in plant physiology are quoted to substantiate the probability of their use as an explanation for the variation in use of water by the sugar-beet crop grown in these experiments in 1940 and 1941.

Another probability which would be suggested by men in irrigated territories is that there would be a rise in the ground level of the water-table in this particular field so that the plants were able to obtain moisture from an underground source, hi this field there were 5 holes drilled to a depth of 7 feet, and at no time during the growing season was 1 here wafer found in these holes. The blocks which were placed in the ground to a depth of 36 inches on the particularly *dry* plots had continued high readings during the entire month of August, reaching readings which indicated that more than 75 percent of the available moisture had been used.

There is nothing to indicate that there is any lack of the reliability of the determination of the amount of moisture available in the soil by the use of blocks; therefore the indications are that the differences are due to a lesser requirement of irrigation water by the plants in 1941 than that of 1940. A greater use of rainfall water may have occurred in 1941.

Table 1.—Sugar-beet yields from irrigation experiment at Scottsbluff,Nebraska, 1940, in which irrigation water was applied at different rates, and at different levels of exhaustion of available soil moisture.

Approximate moisture at 12-inch level when irrigation was made	Application rate in acre-inches 3	4 1/2%	6	12-plot averages
	Water Applied			
percentage	inches	inches	inches	inches
50	18.00	25.8S	28,50	24.13
25	12.75	20.25	22.50	18.50
0	11.25	12.38	16.50	13.38
12-plot averages	14.00	19~50	22.50	
	Calculated Acre-Yield of Gross Sugar			
	tons	tons	tons	tons
50	3.843	4.061	3.908	3.957
25	3.295	3.304	3.581	3.413
0	3.011)	3.187	3.284	3.163
12-plot averages	3.386	3.537	3.611	. . . .
	Calculated Acre-Yield of Roots			
	tons	tons	tons	tons
50	23.8	24.2	24.4	24.1
25	21.8	21.8	22.7	22.1
0	20.2	20.5	21.4	20.7
12-plot averages	21.9	22.2	22.8	. . . . . .
	Sucrose Percentage as Determined from Samples			
	percentage	percentage	percentage	percentage
50	16.2	16.8	16.3	16.4
25	15.0	15.4	15.7	15.4
0	15.0	15.5	15.3	15.3
12-plot averages	15.4	15.9	15.8	
Differences required for significance	gross sugar	tons roots	percentage sucrose	
4-plot averages	0.540	2.48	1.28	. . . . . .
12-plot averages, inches of water per irrigation	0.320	1.36	0.68	. . . . . .
12-plot averages, level of soil moisture	0.264	1.10	0.65	

Table 2.—Sugar-beet yields from irrigation experiment at Seottsbluff,Nebraska, 1941, in which irrigation water was applied at different rates, and at different levels of exhaustion of available soil moisture.

Approximate moisture at 12-inch level when irrigation was made	Application rate in acre-inches 3	4%	0	12-plot averages
	Water Applied			
percentage	inches	inches	inches	inches
50	10.50	12.38	16,50	13.13
25	6.00	10.33	12.00	9.42
0	5.33	6.75	9.00	7.00
12-plot averages	7.25	9.70	12.50	
	Calculated Acre-Yield of Gross Sugar			
	tons	tons	tons	tons
50	3.734	3.655	3.756	3.715
25	3.595	3.667	3.548	3.603
0	3,571	3.701	3.791	3.687
12-plot averages	3.633	3.674	3.698	". . . . .
	Calculated Acre-Yield of Roots			
	tons	tons	tons	tons
50	21.53	21.17	21.73	21.47
25	20.70	21.33	20.77	20.93
0	20.3S	21.12	21.72	21.07
12-plot averages	20.87	21.20	21.40	
	Sucrose Percentage as Determined from Samples			
	percentage	percentage	percentage	percentage
50	17.38	17.26	17.30	17.31
25	17.3S	17.20	17.10	17.22
0	17.50	17.53	17.48	17.50
12-plot averages	17.42	17.33	17.29	....
Differences required for significance	gross sugar	tons roots	percentage sucrose	
4-plot averages	0.805	1.43	0.77	. . . . . .
12-plot averages, inches of water per irrigation	0.148	0.75	0.35	
12-plot averages, level of soil moisture	0.145	0.88	0.42	

Plants can maintain a normal growing condition in soils which do not have a large amount of water available, provided the temperature and humidity are such that no excessive amount of water is demanded to keep the plants in a turgid condition. However, in the practice of irrigation the grower does not know when a hot, dry period may begin, and he prefers to keep a sufficient amount of soil moisture available to meet the occasional maximum demands since a large field of beets cannot be immediately irrigated when wilting begins to appear. However, the grower can practice light irrigations when he knows that the lower soil levels have a sufficient supply.

Sugar-Beet Yields

The sugar-beet-root yields obtained in these two experiments were high, and the sucrose percentages were average for the season. The results are given for 1940 in table 1, and the results for 1941 are given in table 2. In 1940 there were significant differences due to treatment, while in 1941 there were no significant differences due to treatment. This can be taken as an indication that in 1940 the maximum yield was obtained only by application of more than the minimum amount of moisture, while in 1941 the maximum yield was obtained by the use of the minimum amount of moisture.

In 1940 the most efficient use of water was obtained by application of only 3 inches of water per application, while the application of $4^1/_2$ inches or 6 acre-inches of water per irrigation gave no increased benefits. The same can be said in regard to the experiment conducted in 1941.

Production Per Unit of Land

In 1941 the maximum yield of gross sugar per acre was obtained where the irrigations were maintained at frequencies sufficient to keep the available soil moisture at at least 50 percent of the total, available, moisture-holding capacity of the soil. In 1941 there were no significant differences in relation to the amount of moisture available; however, there were no long periods in which the available moisture had dropped close to the wilting point. The irrigations on these plots were applied during the period of highest temperatures and lowest humidities, and the successive rain during the month of August tended to maintain many of the plants at a rather high level of available moisture.

There should be a vast difference in the effect upon the crop as to whether it was permitted at one time during the season to reduce the available soil moisture to the approximate wilting point, or whether it had to carry practically through the entire season while growing in soil with a very low available moisture content. In 1941 some plots did not have very high amount of available moisture at any time during the latter half of July or August and September;

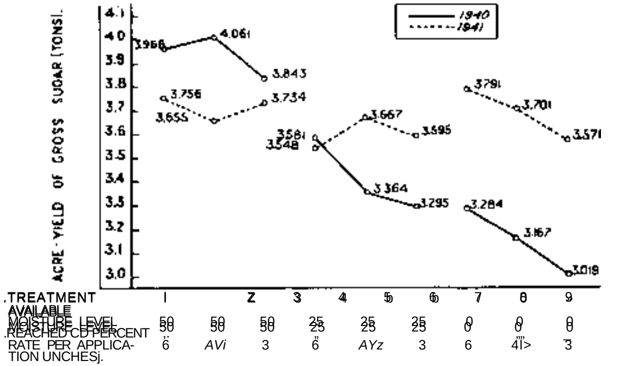


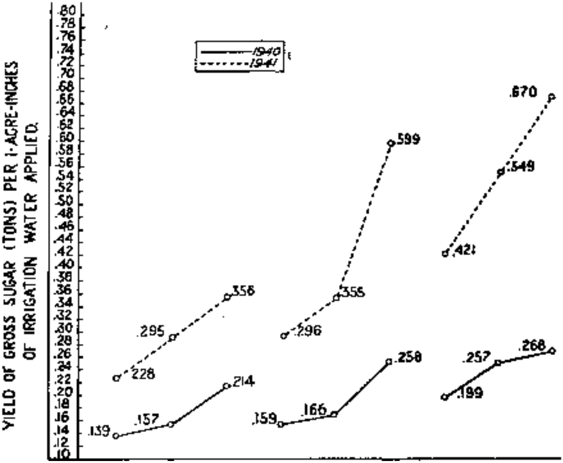
Figure 1 .- Acre-yield of gross sugar in tons for the 9 different irrigation methods used

however, the yield of 21 tons oi' roots per acre does not indicate that they suffered very severely. The effect of the different applications of irrigation water upon the gross sugar from 1 acre of land is shown by the curves. (Figure 1.)

Production Per Unit of Irrigation Water

An acre-inch of water is considered a unit in calculation of returns from water applied by irrigation, and the curves indicate that there is a considerable difference in the returns in 1940 from that in 1941 in the experiments conducted. (Figure 2.) This does not take into consideration the water which was available in the soil at the time the crop was planted, or the precipitation which fell upon the field during the season.

In 1940 the minimum amount of gross sugar produced by the use of 1 acre-inch of water was .135 ton which was obtained where water was applied at the rate of 6 acre-inches per irrigation, and in frequencies sufficient to maintain the soil-moisture level at 50 percent or above. The maximum efficiency of water was obtained with a production of approximately twice the amount of gross sugar obtained by 6 applications where .268 ton of gross sugar was obtained for each acre-inch of water applied at the rate of 3 acre-inches of water per irrigation, and when the soil-moisture level approached exhaustion before another application of water was made. In 1941 the minimum and maximum utilizations were obtained by identical treatments. The application of water at the rate of 6 acre-inches, and maintaining the soil moisture level at 50 percent or above, pro-



TREATMENT	1	2	3	4	5	6	7	8	9
AVAILABLE MOISTURE LEVEL REACHED CD PERCENT	50	50	50	25	25	25	0	0	0
RATE PER APPLICATION (INCHES)	6	4½	3	6	4½	3	6	4½	3

Figure 2.—Yield of gross sugar in tons for quotas of 1 acre-inch of irrigation water as used in these experiments.

dnced .228 ton of gross sugar per each acre-inch of water applied, while the application of water at the rate of 3 inches when the moisture level had approached zero, produced .670 ton of gross sugar for each acre-inch of water used.

Summary

The results of these experiments are based upon the amount of irrigation water applied where run-off was prevented and no account taken of losses from percolation of water to depths beyond recovery by plants. The application rate for each irrigation was either 6, 4^, or 3 acre-inches. The effects on yield of the amount of water per irrigation were only slight and differences were not significant. Since the amount of water used per field unit w-as less with light irrigations, possibilities of irrigation methods which will supply more land area with a given quantity of water are clearly indicated.

In 1940 the maintenance of soil moisture at the higher levels was essential for the higher production of gross sugar, while in 1941 this was not essential. The differences in rainfall, temperature, **and** humidity may explain the reasons for this difference.

In 1940 the maximum amounts of water for the season produced greatest yields of gross sugar per acre, and in contrast, minimum amounts of water per season produced the greatest yield per acre-inch of water used. The greatest efficiency in use of both water and land seems to he obtained by frequent irrigations with the minimum application rate 3 inches. In this experiment, the advantageous treatment consisted of six irrigations per season with 3 acre-inches of water per irrigation, or a total use of I8.00 acre-inches of water for the season, as contrasted with more Lavish water use in certain treatments and scanty applications in others.

In 1941 there was no significant difference in Hie yields of gross sugar per acre. The lavish use of water in certain treatments and the scanty use in others indicate that the use of more than 3 inches of water per irrigation was not essential, and that the seasonal rainfall was such that only one irrigation was necessary during the entire growing season.

These experiments indicate that the use of the soil-moisture blocks and application of the water only when needed make it possible to grow maximum yields of sugar beets in western Nebraska with a smaller amount of irrigation water than is somelimes applied. The fact that in 1940 and 1941. in these experiments where soil-moisture blocks were used, the irrigations were greatly reduced or discontinued early in August and maximum yields of sugar beets obtained, indicates that by the use of information regarding the amount of available soil moisture, the use of irrigation waler may be reduced.

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