Bulletin No. 146 - The Irrigation of Wheat

F. S. Harris

Follow this and additional works at: https://digitalcommons.usu.edu/uaes_bulletins

Part of the Agricultural Science Commons

Recommended Citation
https://digitalcommons.usu.edu/uaes_bulletins/112
THE IRRIGATION
OF WHEAT

By
F. S. HARRIS
DEPARTMENT OF PUBLIC WORKS
DIVISION OF ENGINEERING AND IRRIGATION

Logan, Utah, September, 1916.

Lehi Sun Print
Lehi, Utah.
UTAH AGRICULTURAL EXPERIMENT STATION

BOARD OF TRUSTEES.

LORENZO N. STOHL ............................................ Salt Lake City
THOMAS SMART ................................................ Logan
JOHN Q. ADAMS .............................................. Logan
ELIZABETH C. McCUNE ......................................... Salt Lake City
JOHN DERN .................................................. Salt Lake City
JOHN C. SHARP ............................................... Salt Lake City
ANGUS T. WRIGHT ........................................... Ogden
J. M. PETERSON ............................................. Richfield
ANNIE K. HARDY ............................................ Salt Lake City
GEO. T. ODELL ............................................... Salt Lake City
JOSEPH QUINNEY, JR. ....................................... Logan
DAVID MATTSON, Secretary of State, (Ex-officio) .... Salt Lake City

OFFICERS OF THE BOARD.

LORENZO N. STOHL ............................................ President
ELIZABETH C. McCUNE ........................................ Vice-President
JOHN L. COBURN ............................................... Secretary
HYRUM E. CROCKETT ......................................... Treasurer

EXPERIMENT STATION STAFF

E. G. PETERSON, Ph. D., President of the College.

F. S. HARRIS, Ph. D. ........................................... Director and Agronomist
WM. PETERSON, B. S. ......................................... Consulting Geologist
H. J. FREDERICK, D. V. M. ................................... Veterinarian
E. G. TITUS, Sc. D. ........................................... Entomologist
F. L. WEST, Ph. D. ........................................... Meteorologist
J. E. GREAVES, Ph. D. ......................................... Chemist and Bacteriologist
W. E. CARROLL, Ph. D. ........................................ Animal Husbandman
BYRON ALDER, B. S. .......................................... Poultymnan
G. R. HILL, JR., Ph. D. ...................................... Plant Pathologist
E. P. TAYLOR, M. S. .......................................... Horticulturist
O. W. ISRAELSEN ................................忙....t Irrigation and Drainage
C. T. HIRST, M. S. ........................................... Associate Chemist
H. J. MAUGHAN, B. S. ........................................ Assistant Agronomist
B. L. RICHARDS, B. S. ........................................ Assistant Plant Pathologist
GEORGE STEWART, B. S. ..................................... Assistant Agronomist
GEORGE B. CAINE, M. A. ..................................... Assistant Animal Husbandman
EZRA G. CARTER, B. S. ........................................ Assistant Bacteriologist
WM. GOODSPEED, B. S. ........................................ Assistant Horticulturist
AARON BRACKEN, B. S. ........................................ Assistant Agronomist
H. R. HAGAN, B. S. ........................................... Assistant Entomologist
N. I. BUTT, B. S. ............................................. Assistant Agronomist
D. W. PITTMAN, M. S. ........................................ Assistant Agronomist
H. P. ANDERSON, B. S. ....................................... Assistant Chemist and Bacteriologist
ORSON P. MADSEN, B. S. .................................... Assistant Poultyman
N. E. EDELESEN, B. S. ........................................ Assistant Meteorologist
O. BLANCHE CONDIT, B. A. ................................... Clerk
W. J. MERRILL ................................................. Secretary to the Director

IN CHARGE OF CO-OPERATIVE INVESTIGATIONS WITH U. S. DEPARTMENT OF AGRICULTURE.

L. M. WINSOR, B. S. ........................................... Irrigation Engineer
J. W. JONES, B. S. ........................................... Assistant Agronomist
THE IRRIGATION OF WHEAT
BY F. S. HARRIS.*

I. INTRODUCTION

The economical use of irrigation water is one of the chief problems of agriculture in arid regions. Much more land is available than can be irrigated by the supply of water even when methods of greatest economy are employed. The total crop of arid regions is, therefore, limited not by land but by water; and the welfare of these regions demands that the irrigation water be used as efficiently as possible.

Maximum economy can be obtained only by a full understanding of the intimate relations of plant, soil, and moisture. Experiments covering every phase of this relationship must be carried on and the data brought together with painstaking care in order to determine exactly what the results will be under each set of conditions. It is impossible to lay down a few dogmatic rules to cover all cases since conditions vary much, and since a practice that would be economical under one condition would be wasteful under another. A shallow sand cannot be irrigated in the same way as a deep loam, nor should sugar beets and wheat have water applied in just the same manner. One method of irrigation gives certain properties to crops, while a different method gives other properties. The quality of the crop desired must help to determine the method of irrigation.

In the past, wheat has been raised extensively under irriga-

---

*The author wishes to acknowledge his indebtedness to his assistants A. E. Bowman, H. W. Stucki, and H. J. Maughan for faithfulness in connection with field work and to N. I. Butt for help in preparing the material for publication.
tion, but it is probable that it will gradually be driven from the high-priced irrigated lands to cheaper lands where it will be raised largely by dry-farm methods. Doubtless some wheat will always be raised under irrigation in order to fit in rotations and because it is a convenient crop to raise; hence, it is desirable to obtain as much information as possible on the irrigation of this crop, partly as a means of conserving water for use on other crops.

II. GENERAL LITERATURE

1. Amount of Water

Since the scientific investigation of crops first began, numerous experiments have been conducted to solve the important yet extremely difficult problem of the amount of water needed for the best growth of plants.

Gain, \(^{(a)}\) in 1895, found that the increase in dry weight of plants was checked by too much as well as by too little water. In his conclusions he states that "The root is especially influenced by the water content of the soil. With drought there is a great weakening of the root after flowering, the period of growth is considerably shortened, and the vitality of the entire plant is soon lessened." He found that high humidity of soil increases the fresh weight more than the dry weight, and the tops more than the roots.

Pot experiments to study the influence of various degrees of soil saturation on the growth of grain, as reported by Mayer \(^{(b)}\) in 1898, show that in general the less the moisture the greater the relative growth of grain to straw and consequently the less the percentage of fiber and the greater the percentage of protein and pure albuminoids. The presence of large quantities of water in the soil—up to 96 per cent of saturation—apparently tended to check seed production and lengthen the growing period. Wheat, for the best results, seemed to require that the soil be about 80 per cent saturated with moisture.


The experiments of Prianishnikov (c) seem to contradict other investigators in that he found, from two years' work, that there was a steady rise in the percentage of grain with the increase of soil water and that an increase in absolute weight of grain also resulted from the larger quantity of water. A higher percentage of nitrogen and a shortening of the time required to mature by the lower quantities of water were noted.

The field experiments in New Mexico (d) from 1900 to 1904 show that too much water causes growing wheat to turn yellow, retards ripening a few days, and causes a decreased yield of grain. An adobe soil three-fourths saturated throughout the year was too wet for wheat. When the soil was kept fairly moist at the time the grain was filling, the yield was about as high as when the high moisture content was maintained throughout the season. Irrigating wheat oftener than once in three weeks after it began to head increased the yield, but scarcely enough to pay for the additional irrigations. The greatest yield for each inch of water resulted from 24 inches and, while 29 and 35 inches gave greater yields, the grain for each inch of water was decidedly less.

Observations by Seelhorst and Bunger (e) in 1907 indicate that the number of kernels to the head increases with the moisture content of the soil, that there are usually more kernels to the head with a thin stand, and that there are more kernels in the large heads. High moisture increased the weight of 1000 kernels on nitrogen-rich soil, while a thick stand usually lessened the weight of kernels.

Seelhorst (f) in a report of the Gottengen experiments for the 14 years prior to 1911 states that soil moisture was capable of influencing the ripening period to such an extent that varietal characteristics were lost. On soil containing 55 per cent of its water-holding capacity of moisture, there was little difference in the ripening period of four different varieties of spring wheat, but on soil with more moisture, especially with 70 per cent of the

---

(d) New Mexico Experiment Station. Bulletins 31, 38, 46, 48, and 54.
water-holding capacity, a difference in period of maturity was marked.

2. TIME OF APPLICATION

Among the numerous experiments to discover the proper time to apply water to grain the following are important:

Pot experiments by Seelhorst (g) in 1900 show that a high percentage of water during early growth increases the number of internodes, and during heading it increases the length and strength of the culm. The number of spikelets is increased by a high percentage of water during early growth while the number of blossoms developed in the spikelets is relatively much greater when the water content of the soil is high at the time of heading. It was found that great length of head depends on high water content during the early vegetative period. The specific gravity of grain is smallest where the soil moisture is highest at heading time. General conclusions drawn by the author are that a high percentage of soil water at the time of heading is very important in increasing the yields of straw and grain.

The influence of varying the water content of soils of different degrees of fertility on the development of spring wheat was studied in 1908 by Preul. (h) He found that rich soils require less water to produce a gram of dry plant substance than poor soils. Abundant soil moisture after a dry period, produces a high grain yield; yet if the dry period begins at the time of heading, the reverse is true. The length of stems depends on the moisture content of the soil at the time of sprouting and the length of head is influenced by the degree of soil moisture during the early stages of growth. A lack of water during later stages of growth lowers the weight of 1000 kernels, especially on rich soils. Lowering the quantity of moisture at a late stage of growth may lower the nitrogen content of the grain.

True (i) concluded in 1911 that wheat irrigated three times before heading and twice after heading with an application of 1.41 feet of water gave larger yields of grain than by any other

THE IRRIGATION OF WHEAT

method of applying water. He states in 1913 that the largest yield of wheat was obtained with two irrigations before, and two after heading, the total application being 0.92 feet, and that the smallest yield was with one irrigation before, and one after heading, where 1.08 feet of water were applied.

In a report of the field work of the Canadian Experiment Stations for 1912 Grisdale (j) shows that a moderately dry soil accompanied by high temperatures during the period in which the grain is filling, tends to arrest the vegetative growth of the plant, to hasten maturity, and to produce a hard berry with a high percentage of gluten and a high baking value.

Harris (k) working with a clay loam soil in pots found that wheat matured sixteen days earlier with 20 per cent moisture in the soil than with either 11 per cent or 45 per cent, and the period at which high moisture was applied had considerable effect on the date of ripening. The number of kernels to each head was greatest on a soil with medium moisture, but the weight of 100 kernels was greatest on the driest, and lowest on the wettest soil. These soils were maintained at a constant moisture content.

III. PREVIOUS WORK AT THE UTAH STATION

The importance of accurate experimental work to help solve the perplexing problems encountered in irrigating, was seen by the first director of this Station and rather comprehensive experiments covering different phases of irrigation were begun almost as soon as the Station was established. The earlier experiments were conducted on a very shallow soil and are therefore not so reliable as later investigations which were conducted on a deeper and more uniform soil.

Bulletin 21 (l) published in 1893 gives the first results on the irrigation of grain. Here it was found that the yield of grain was slightly greater on the plats irrigated by day than by night but a little more straw resulted from night irrigation. The total yield was about 15 per cent greater on the plats irrigated at night. There were 120 pounds of straw to each bushel of grain

when the irrigating was done at night and but 89 pounds for each bushel of grain under day irrigation.

In Bulletin 23 (p) published the same year, Sanborn reports that very early irrigation is not economical; for, although it slightly increased the yield of grain and the ratio of grain to straw, it did not increase the total yield of grain and straw.

Bulletin 24 (m) shows that where one and one-half feet of water were applied, the highest yield of grain was secured, but the yield of straw was the smallest of any of the irrigation treatments.

Results on the sub-irrigation of wheat up to 1893, as shown in Bulletin 26 (n) indicate that whether done by large open drains or by the cement pipe system, sub-irrigation fails to supply enough moisture for growing crops in well-drained soils.

Sanborn points out in Bulletin 27 (o) that there is a decided gain by early and late (May 30 and July 24) watering and this gain is more in the seed than the straw. The earlier (May 20) watering gave an increase of wheat and a decrease of straw.

Data in Bulletin 29 (p) shows that 15.86 inches of water is equivalent to larger quantities for grain production, although it is probable that this amount will give less straw than a larger application.

The work of Mills, as presented in Bulletin 39 (q) shows that 26.82 inches of water gave the highest yield of grain and straw. On a sandy clay soil the yield of grain increased as the water increased up to 40 inches, though the maximum yield of straw was produced with 16 inches of water. On poor, gravelly, clay soil, the greatest yield of grain was obtained by irrigating every six days while the greatest yield of straw came from twelve day periods. There was but little difference in total yield with six, nine, twelve, and fifteen day periods between irrigations. With a good clay soil, the twelve day periods gave the best results for both grain and straw. Irrigating spring wheat three times on a poor.

gravelly clay gave the maximum yield for both grain and straw. Allowing the grain to become "burnt" before water was applied, decreased the yield by nearly one half regardless of the later irrigations.

In 1898 (r) Merrill states in Bulletin 56 that one irrigation in the fall gave but little better results than no irrigation at all except where there had not been enough rain to bring the grain up until late. The increased yield due to fall irrigation was not sufficient to justify the expense of irrigation.

Bulletin 80 (s) by Widtsoe and other members of the staff gives considerable valuable data concerning irrigation on a shallow soil. Wheat and oats, which mature early, use less total water than the crops with longer growing periods but the amount used in a day or any other definite period was larger for the cereals than for the legumes and root crops.

It was found that heavy irrigation increased the weight of the heads of wheat while light irrigation increased the relative weight of leaves and stalks. The yield of wheat and the percentage of grain increased with irrigation up to 30 inches. In the early stages of growth the relative proportion of heads was not affected to any great extent by different amounts of water, while toward the end of the growing season, the plants that received the most water had the highest percentage of heads.

In Bulletin 86, (t) a gradual decrease in the proportion of gluten in wheat was found to result from increasing the amount of water applied from 5 to 35 inches.

Bulletin 105 (u) gives a study of the factors influencing evaporation and transpiration as found by Widtsoe's tank experiments.

Increasing the moisture content of the soil from 10 to 20 per cent increased the yields of wheat, corn, and peas about two and one-fourth times. The total amounts of water used to produce a pound of dry matter with soil moisture contents of 10 per cent and 20 per cent were almost identical for wheat and sugar beets and nearly so for corn and peas.

In no case did 15 per cent, or the maximum degree of saturation of sand, produce the largest yield of dry matter. With clay, the largest yield of dry matter was from the highest saturation degree but the yield was not in proportion to the amount of water used. The net results of the tank tests indicate that the higher saturation degrees, considered with reference to the quantity of water for each pound of dry matter produced, are essentially wasteful. On fertile soils it is not so wasteful to apply water heavily as it is on infertile soils.

Probably the most important irrigation results published by the Station are those contained in Bulletins 115 to 120. Some of the conclusions touching on the water relations of grain as found by Widtsoe and McLaughlin and reported in Bulletin 115 (v) are that the grain crops seem to have the power of exhausting the soil more thoroughly of water than the roots or tubers.

Bulletin 116 (w) shows that in wheat the total yield of dry matter gradually increased from 4969 pounds to the acre where 5 acre inches of water were used to 7999 pounds for 50 inches. The corresponding yield for each inch of water, however, decreased from 994 pounds to 160 pounds.

There was a gradual decrease in the percentage of grain from 44.5 per cent where 5 inches of water were added to 32.89 per cent where 50 inches were applied. The amount of water required to produce a pound of dry matter rose from 856 with the least water to 1809 with the most.

The work of Widtsoe and Merrill in Bulletin 117 (x) shows that about 84 per cent of the grain and 86 per cent of the straw produced by 7.5 inches of irrigation water is due to the natural precipitation according to a 5 year average. Increasing the applications of water from 5 to 50 inches increased the yield of grain from about 38 bushels an acre to 49 bushels, but decreased the yield for each inch of water from 7.56 to .99 bushels. The proportion of grain decreased as an increasing quantity of water was applied.

In Bulletin 118 (y) it is shown that 3.5 inches of water applied about the middle of June gave a yield of nearly 3 bushels an acre more than this amount at the "filling out" time of the grain, but the yield of straw was approximately 461 pounds less by the earlier irrigation. Using 6.5 inches of water, there was an increase of about two bushels of wheat to the acre, but the yield of straw was somewhat decreased by applying the water in two irrigations rather than in one. An application of 7.5 inches of water was given in three different ways: first, in two equal irrigations; second, one light and one heavy; third, one heavy and the other light. The highest yield came from the two equal irrigations and the next highest when the lighter irrigation came first.

One irrigation immediately after the opening of the irrigation season and the other near the time of the "filling out" of grain—each application amounting to 5 inches—gave the largest yield of grain for 10 inches of irrigation water. The next largest yield resulted from 2.5 inches, the first irrigation coming when the grain was filling. Neither the number nor the order of the applications seemed to affect the production of straw.

The best return of grain with 15 inches of water came from applying one-fourth of the total amount in each of the first two irrigations and the remaining half in a third irrigation. The smallest yield came from three equal irrigations.

Comparing flooding with furrow irrigation, for 10, 15, and 25 inches of water, there was an increase in grain amounting to 2.3, 19.1, and 10.2 bushels to the acre respectively and an increase of 1213, 2866, and 634 pounds respectively of straw in favor of the flooding method.

Experiments to test the value of early irrigation showed that the application of 7.5 inches of water immediately before planting gave a smaller yield of grain and of straw than where no water was used. One irrigation of 7.5 inches before planting and another 7.5 inches in two applications during the season increased the yield 72 per cent over non-irrigation. When 7.5 inches were applied soon after planting and 7.5 in two later irrigations a still larger yield was obtained. With an application of 7.5 inches on June 10, and then 7.5 in two later irrigations, the yield was still greater. Applications of 7.5 inches on June 10,

and then 7.5 inches in two subsequent irrigations gave intermediate results.

Bulletin 119 (z) by Widtsoe and Stewart shows that more water is required to produce a pound of dry matter where large applications of water are given than with smaller amounts. The young plant requires much more water to produce a pound of dry matter than an older one. As the water was decreased, the proportion of heads increased and the leaves and stalks decreased. The increased leafiness due to heavy applications of water is not so noticeable in the first stage of development as later.

Bulletin 120 (A) gives some very important data on the effect of irrigation water in modifying the composition of wheat and other crops.

IV. EXPERIMENTAL

1. Description of the Experiment

The experimental work reported in this bulletin was conducted on the Greenville Experimental Farm two miles north of Logan, Cache County, Utah. The soil of this farm has been described in detail in previous publications of this Station (Utah Sta. Bul. No. 115). It is a uniform loam to considerable depth and carries about 22 per cent of moisture as a maximum under field conditions. The plats were 29 feet wide by 57 feet long;


this gives an area of 1.26.35 of an acre in each plat exclusive of a seven foot space between each.

The water was measured by means of a Cippoletti weir and taken to the land in wooden flumes where it was added to the wheat by the flooding method. All of the water was retained on the plats by banks around the edges. To a number of plats, water was added each week during the growing season, but the time of applying water to most of the plats depended on the stage of development of the plants.

The wheat plant was divided into four stages as follows: first, the stage when five leaves had developed and the plants were six or eight inches high; second, the early boot stage when the plants were just swelling preparatory to heading; third, the bloom stage when most of the plants were in bloom; and fourth, when the plants were in the dough stage.

A five-inch irrigation was used as a standard at these stages. An application of this amount was given at each stage, at each two stages, at each three stages, and at all of the four stages, thus giving quite a number of different combinations. It is possible, therefore, from the results obtained to determine which stages are best when either one, two, or three irrigations are used.

In the weekly irrigations, one plat received 1 inch, another 2½ inches, another 5 inches, and another 7½ inches of water each week during the season, beginning when the wheat was five or six inches high and continuing until it began to turn yellow.

During the three of the four years of this experiment, three manured plats were included. They received manure at the rate of 5, 15, and 40 tons to the acre respectively each year. These
plats received 2½ inches of water each week; hence they can be compared with the unmanured plat receiving the same quantity of water.

The experiment was begun in 1912 and carried through 1913, 1914, and 1915, giving four years’ results. Conditions during these years were made as uniform as possible in every respect.

2. Precipitation

Table I gives the precipitation during the four years of the experiment, 1912-1915.

<table>
<thead>
<tr>
<th>Month</th>
<th>Precipitation</th>
<th>1912</th>
<th>1913</th>
<th>1914</th>
<th>1915</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan.</td>
<td>.95</td>
<td>.69</td>
<td></td>
<td>3.80</td>
<td>1.06</td>
<td>1.63</td>
</tr>
<tr>
<td>Feb.</td>
<td>.93</td>
<td>.92</td>
<td></td>
<td>1.40</td>
<td>1.32</td>
<td>1.14</td>
</tr>
<tr>
<td>Mar.</td>
<td>2.02</td>
<td>3.09</td>
<td></td>
<td>1.73</td>
<td>.59</td>
<td>1.86</td>
</tr>
<tr>
<td>Apr.</td>
<td>2.25</td>
<td>1.65</td>
<td></td>
<td>2.29</td>
<td>1.94</td>
<td>2.03</td>
</tr>
<tr>
<td>May</td>
<td>2.22</td>
<td>1.03</td>
<td></td>
<td>.41</td>
<td>2.98</td>
<td>1.66</td>
</tr>
<tr>
<td>June</td>
<td>1.02</td>
<td>2.53</td>
<td></td>
<td>2.97</td>
<td>1.12</td>
<td>1.91</td>
</tr>
<tr>
<td>July</td>
<td>1.88</td>
<td>.95</td>
<td></td>
<td>1.98</td>
<td>.22</td>
<td>1.26</td>
</tr>
<tr>
<td>Aug.</td>
<td>1.95</td>
<td>.27</td>
<td></td>
<td>.05</td>
<td>.00</td>
<td>.57</td>
</tr>
<tr>
<td>Sept.</td>
<td>.54</td>
<td>1.48</td>
<td></td>
<td>1.51</td>
<td>3.81</td>
<td>1.84</td>
</tr>
<tr>
<td>Oct.</td>
<td>3.04</td>
<td>2.14</td>
<td></td>
<td>2.21</td>
<td>.05</td>
<td>1.86</td>
</tr>
<tr>
<td>Nov.</td>
<td>2.40</td>
<td>1.84</td>
<td></td>
<td>.00</td>
<td>1.37</td>
<td>1.40</td>
</tr>
<tr>
<td>Dec.</td>
<td>.35</td>
<td>.88</td>
<td></td>
<td>.55</td>
<td>.78</td>
<td>.64</td>
</tr>
<tr>
<td>Total</td>
<td>19.55</td>
<td>17.47</td>
<td></td>
<td>18.90</td>
<td>15.24</td>
<td>17.79</td>
</tr>
</tbody>
</table>
THE IRRIGATION OF WHEAT

experiment. It shows a total precipitation of 19.55 inches in 1912, 17.47 inches in 1913, 18.90 inches in 1914, and 15.24 inches in 1915 with an average of 17.79 inches for the four years. An examination of the table shows that the greater part of the precipitation fell during the winter and spring months, only about four or five inches falling during the growing season. The high winter and spring rainfall leaves the soil fairly well saturated in the spring when the crop is planted. This condition naturally has considerable influence on the method of irrigation.

3. Yield of Crop

Probably the most important consideration in connection with irrigation experiment is crop yield, since on this profits primarily depend. The relative yield of straw and grain is also worth consideration, the straw having considerable value, but not nearly that of the grain. The total yield of grain produced is doubtless the chief standard to use in judging the value of any treatment. Of course the expense attached to a treatment and the economy in the use of water must be taken into consideration in deciding what method of irrigation is best.

In reporting these experiments, the results are separated into two divisions, (1) the plats receiving regular weekly irrigations and (2) those receiving water only at certain periods in the growth of the plants.

Figure 5 shows the average yield of grain and straw for

![Graph showing yield of wheat grain and straw](image)

**Fig. 5.—Yield of wheat grain and straw on plats receiving different quantities of irrigation water weekly.**
four years with no irrigation, and with weekly irrigations of 1, 2½, 5, and 7½ inches which total 9, 22½, 45 and 67½ inches of water respectively during the season. Where no water was added, there was an average yield of 37.3 bushels of grain to the acre and 4,043 pounds of straw. With the irrigation treatments the yields were as follows: for 1 inch weekly, 44.3 bushels of grain and 5,689 pounds of straw; for 2½ inches weekly, 44.6 bushels of grain and 6,757 pounds of straw; for 5 inches weekly, 45.8 bushels of grain and 6,250 pounds of straw; and for 7½ inches weekly, 43.5 bushels of grain and 5,794 pounds of straw.

It will be noted that 1 inch of water weekly produced almost as high a yield as larger quantities and the yield was higher than that for 7½ inches weekly. The least total straw as well as the least in proportion to grain was produced with no irrigation while the most straw, both absolutely and in proportion to the grain, was produced with 2½ inches of water weekly.

Figure 6 shows the yield of grain and straw on the plats to which water was applied during various stages in the growth of the plants. It will be noted that no water was applied to one plat, and that single irrigations of five inches were applied after planting the grain before it came up, and at the first, the second, the third, and the fourth stages. There were also plats receiving two irrigations of five inches each at various combinations of
stages, as well as plats receiving three and four irrigations. The reason for these various combinations was to determine the best time to irrigate wheat in case the farmer could give it but one, two, or three irrigations.

One striking thing about this figure is the relatively high yield on the plat receiving no irrigation. It will be remembered that the soil on which these experiments were conducted was deep and uniform and of a nature suited to the holding of much water. The precipitation for the four years of the experiment averaged 17.79 inches which was sufficient for a fairly good crop without irrigation.

The figure shows that the yields were decidedly reduced by watering the crop up. The plat irrigated at the fourth stage, when

![Fig. 7.—Making measurements of plants in the field.](image)

the wheat was ripening, gave a yield almost exactly the same as the unirrigated plat.

A careful examination of the figure shows the best yield for one irrigation to be when the water was applied at the first stage, and the best yield for two stages, when irrigated at the first two. Likewise the first three stages were better than any other three. Indeed, the highest yield of both grain and straw was obtained with fifteen inches of water applied during the first three stages. Irrigation at the last stage seemed in every case to be the least favorable time. That is, on a soil of this type, and under the conditions of the experiment, the early irrigations determine largely
what the yield of wheat will be. Whenever the first stage was included with any other stage, the yield was always higher than if this stage was left out. Just the opposite was true of the fourth stage.

The economic considerations involved in these varying yields for different irrigations are discussed later.

4. Height of Plants

The height of plants was determined by selecting in each plat three typical places one yard square and measuring every plant in these areas; from these measurements the averages were obtained.

Figure 8 gives the height of plants on plats receiving weekly irrigations. It shows the non-irrigated plants to be the shortest and those receiving 2½ inches of water weekly to be the highest, although the height did not vary greatly in any of the irrigated plats.

The height of plants irrigated at various stages, as shown in Figure 9, indicates that early irrigations make the higher plants. Compared with no irrigation, some applications produced slightly shorter plants when water was added.

5. Kind of Grain

The effect of various quantities of water applied weekly on the weight of 1000 kernels of wheat and on the weight per bushel
Fig. 9.—Height of plants on plats receiving various quantities of irrigation water at different stages.

Fig. 10.—Weight of 100 kernels, and pounds per bushel of wheat on plats receiving different quantities of irrigation water weekly.

of the grain is shown in Figure 10. The largest kernels in the weekly irrigation test were produced with 2½ inches of water; but the plat receiving no irrigation produced the heaviest grain per bushel, while that receiving 2½ inches of water each week produced the second heaviest.
An examination of Figure 11 shows the same determinations on plats receiving five inch irrigations at various stages. The heaviest kernels were produced on the plats receiving five inches of irrigation water according to the chart. The heaviest kernels were produced on the plats receiving five inches of water, with the weight varying from 40 to 67 2/3 grams per 1000 kernels. The lightest kernels were found on the plat receiving irrigation after the grain was planted before it came up. The heaviest grain per bushel was on the plat receiving an irrigation at each of the first, second, and fourth stages, while the lightest was on the plat irrigated only at the second stage.

![Figure 11: Weight of 1000 kernels, and pounds per bushel of wheat on plats receiving various quantities of irrigation water at different stages.](image)

![Figure 12: Length of head in inches, number of spikelets per head, and number of kernels per head on plats receiving different quantities of irrigation water weekly.](image)
6. Nature of Head

The growth of the head, including its length and the number of spikelets and kernels produced, is shown in Figures 12 and 13. Where no water was applied, the heads averaged 3.52 inches long; with one inch of water weekly, 3.50 inches; with two and one half inches weekly, 3.40 inches; with 5 inches weekly, 3.20 inches; and with seven and one half inches weekly, 3.26 inches long. The number of spikelets in each head was not greatly influenced by the irrigation, but the number of kernels of wheat in each head was affected to considerable extent. On the plats that were watered weekly, the ones receiving most water produced heads with fewest kernels. They did not produce the most heads, however.

An examination of Figure 13 shows that the number of kernels in each head is usually increased by the early irrigations. This is contrary to a popular idea held by some farmers, who think that an irrigation at heading time increases the number of kernels in the heads. These results, however, agree with those of von Seelhorst.

7. Date of Maturity

The date of maturity of grain is rather important in regions
having short seasons. Often ten days difference in the ripening period makes the difference between success and failure. Where this condition is found, it may be desirable to irrigate in the way that will hasten maturity almost regardless of yield.

![Fig. 14](image)

Fig. 14.—Days for wheat to mature on plats receiving different quantities of irrigation water weekly.

![Fig. 15](image)

Fig. 15.—Days for wheat to mature on plats receiving various quantities of irrigation water at different stages.

Figures 14 and 15 show that in general the plats receiving
the higher irrigations had longer growing seasons than those which were not irrigated or which received but little water. The unirrigated wheat matured in 117 days, while 128 days were required where either five or seven and one half inches of water were applied each week. All the plats receiving only five inches of water matured their wheat in less time than any of those receiving ten, fifteen, or twenty inches. This corresponds with the common experience of farmers that dry-farm wheat matures earlier than irrigated.

8. Effect of Manure

During the years 1912, 1913, and 1914, manure was applied to a number of plats in order that a comparison might be made with the unmanured plats. As already stated, 5, 15, and 40 tons to the acre were applied to the respective plats. These manured plats had for a number of years previous to 1912 been raising potatoes and had received the same quantities of manure that were applied to the wheat. All the plats received a two and one half inch irrigation each week during the growing season. For the three years there was an average of 9.67 irrigations each year, in which 24.18 inches of water were applied.

Figure 16 and Table II give the results obtained in the manuring test. They show an average yield of 38.1 bushels of wheat with no manure, 48.1 bushels with five tons, 55.1 bushels with fifteen tons, and 51.4 bushels with forty tons of manure. Thus when compared with fifteen tons, the yield of grain was actually decreased when as much as forty tons of manure were applied every year. This is probably due in part to the fact
that excessive manuring caused the straw to grow so rank that it lodged considerably and rusted.

![Grain and straw yield chart]

Fig. 16.—Effect of manure on the yield of grain and straw.

The height of plants and the number of heads to the square yard were greatest with the most manure, but the length of heads, the number of kernels, the weight of 1000 kernels, and the weight to a bushel of grain were highest with 15 tons of manure. The unmanured wheat had more kernel to the spikelet than any receiving manure. The greatest gain in yield for each ton of manure was produced with five tons, which increased the yield two bushels for each ton of manure, while forty tons increased the yield only .33 of a bushel for each ton.

9. Producing Power of Natural Precipitation

Irrigation at best is only supplementary to the rainfall; the greater part of the water used by crops usually comes from natural precipitation which falls during the growing season or is stored in the soil. Irrigation water should be applied in such a way that it will use the rainfall to best advantage.

Figure 17 shows the percentage of the entire crop that is produced by the natural precipitation. In determining this, the yield of the unirrigated land was taken as the standard for the crop
produced by the un-supplemented rainfall and from this the percentages were computed. In every case over 75 per cent of the crop was produced by the precipitation while over 95 per cent was produced by it where only five inches of irrigation water were applied.

10. Economic Considerations

(a) Water spread over different areas. The importance of using irrigation water economically to supplement the natural precipitation is brought out in Figure 18.

The total crop produced by the natural precipitation in conjunction with 20 acre-inches of water where it is used on one acre, one and one-third acres, two acres, and four acres respectively is shown. The total yield was more than three times as much where 20 acre-inches were used on four acres as where the water was all applied to one acre.

(b) Increase in yield for each acre-inch of water. Where water is scarce and land plentiful, the real test of efficiency is not yield to the acre of land but yield to the acre-inch of water.
Fig. 18.—Amount of wheat produced by twenty acre-inches of water when applied to one acre, one and one-third acres, two acres, and four acres of land.

Fig. 19.—Yield of wheat grain and straw for each inch of water on plats receiving different quantities of irrigation water weekly.
Since in arid regions water is the chief limiting factor of production, its manner of use determines largely the population that can be supported.

Figures 19 and 20 show the increase in yield of grain and straw for each inch of water above the yield where no water was applied.

Fig. 20.—Yield of wheat grain and straw for each inch of water on plats receiving various quantities of water at different stages.

Fig. 21.—Section of Pinte Reservoir, Sevier River. In order to use river water most economically for irrigation, the flood waters should be stored in reservoirs.
applied. In Figure 19 the results for weekly irrigations are given, and in figure 20 the results are shown for plats receiving water at various stages.

When seven and one-half inches of water were applied weekly, each acre-inch of water produced only .09 of a bushel of grain while one inch weekly produced .78 of a bushel of grain for each acre-inch of water.

Figure 20 brings out in a very striking manner the relative economy of different methods of irrigation. The importance of the five-leaf stage in wheat as a time to irrigate is made clear on the plats receiving five and ten inches of water. The treatment giving the most economical use of water was three irrigations of five inches each applied during the first three stages in the growth of the crop. This was also the treatment giving the highest yield to the acre of land; consequently here we have the method of irrigation that should be applied to wheat under the conditions of this experiment. This is the most profitable when either the acre of land or the acre-inch of water is used as the standard.

**V. SUMMARY**

1. Wheat should probably not be raised extensively under irrigation; but a knowledge of its water requirement is important, because some wheat will probably always be raised on irrigated land,
2. The main literature on the subject, including seventeen bulletins of the Utah Station, is reviewed.
3. Results of four years' work conducted at the Greenville (North Logan) Experimental Farm are reported.
4. The highest yield of wheat was produced with three irrigations of five inches each, applied at the five-leaf, the early boot, and the bloom stages.
5. Irrigation water applied after the grain was planted before it was up, and that applied after the dough stage, decreased the yield.
6. Where only one irrigation was given the best time to give it was at the five-leaf stage.
7. Where two irrigations were applied, the five-leaf and the boot stages were best.
8. Where three irrigations were given, the five-leaf, the boot, and the bloom stages were best.
9. Water applied during early growth of wheat increased its height more than that applied at any other time.
10. The number of kernels in each head is decidedly affected by irrigation water applied during early growth, and less so by that applied later.
11. The date of maturity of wheat was retarded by excessive irrigation.
12. Economy in the use of water was increased by the use of barnyard manure.
13. From 75 to 95 per cent of the yield of irrigated wheat under various systems of irrigation was produced by the natural precipitation.
14. Twenty acre-inches of water spread over four acres of land produced more than three times as much wheat as where it was all used on one acre.
15. These experiments show rather conclusively that on the deep soils of Utah the best system of irrigating wheat is to apply three irrigations of about five inches each, beginning when the wheat is six or eight inches high and stopping about the time it is in blossom.
APPENDIX. DETAILED DATA REGARDING CROP ON EACH PLAT FOR EACH OF THE FOUR YEARS OF THE EXPERIMENT.

<table>
<thead>
<tr>
<th>Irrigation</th>
<th>Yield of Grain (bu. per Acre)</th>
<th>Yield of Straw (lbs. per Acre)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plat</td>
<td>Treatment</td>
<td>1912</td>
</tr>
<tr>
<td>1</td>
<td>1 in. wkly.</td>
<td>58</td>
</tr>
<tr>
<td>2</td>
<td>2½ in. wkly.</td>
<td>42</td>
</tr>
<tr>
<td>3</td>
<td>5 in. wkly.</td>
<td>45</td>
</tr>
<tr>
<td>4</td>
<td>7½ in. wkly.</td>
<td>41</td>
</tr>
<tr>
<td>5</td>
<td>No water</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>5 in. after planting and before comp'g up</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>5 in. at 5-leaf stage</td>
<td>55</td>
</tr>
<tr>
<td>8</td>
<td>5 in. at early boot stage</td>
<td>58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weight of 1000 Kernels (gr.)</th>
<th>Weight per Bushel</th>
<th>Height of Plants (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plat</td>
<td>1912</td>
<td>1913</td>
</tr>
<tr>
<td>1</td>
<td>50.3</td>
<td>48.6</td>
</tr>
<tr>
<td>2</td>
<td>51.9</td>
<td>47.6</td>
</tr>
<tr>
<td>3</td>
<td>52.2</td>
<td>49.1</td>
</tr>
<tr>
<td>4</td>
<td>49.2</td>
<td>47.3</td>
</tr>
<tr>
<td>5</td>
<td>51.0</td>
<td>46.4</td>
</tr>
<tr>
<td>6</td>
<td>52.2</td>
<td>43.2</td>
</tr>
<tr>
<td>7</td>
<td>60.5</td>
<td>47.5</td>
</tr>
<tr>
<td>8</td>
<td>49.1</td>
<td>46.5</td>
</tr>
<tr>
<td>9</td>
<td>51.3</td>
<td>44.4</td>
</tr>
<tr>
<td>10</td>
<td>55.9</td>
<td>44.8</td>
</tr>
<tr>
<td>11</td>
<td>54.4</td>
<td>46.8</td>
</tr>
<tr>
<td>12</td>
<td>54.1</td>
<td>44.8</td>
</tr>
<tr>
<td>13</td>
<td>50.6</td>
<td>45.2</td>
</tr>
<tr>
<td>14</td>
<td>54.6</td>
<td>46.7</td>
</tr>
<tr>
<td>15</td>
<td>55.2</td>
<td>46.5</td>
</tr>
<tr>
<td>16</td>
<td>56.0</td>
<td>46.0</td>
</tr>
<tr>
<td>17</td>
<td>55.2</td>
<td>44.7</td>
</tr>
<tr>
<td>18</td>
<td>57.3</td>
<td>43.9</td>
</tr>
<tr>
<td>19</td>
<td>61.7</td>
<td>45.6</td>
</tr>
<tr>
<td>20</td>
<td>55.2</td>
<td>44.0</td>
</tr>
<tr>
<td>Av'ge</td>
<td>53.8</td>
<td>44.5</td>
</tr>
</tbody>
</table>

**Note:** The table includes data on the yield of grain and straw, as well as the weight of 1000 kernels, weight per bushel, and height of plants for different irrigation treatments and stages of the experiment.
## THE IRRIGATION OF WHEAT

### Table: Length of Heads (in.) and Spikelets per Head

<table>
<thead>
<tr>
<th>Plat</th>
<th>1912</th>
<th>1913</th>
<th>1914</th>
<th>1915 Av.</th>
<th>1912</th>
<th>1913</th>
<th>1914</th>
<th>1915 Av.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3.48</td>
<td>3.53</td>
<td>3.27</td>
<td>3.73</td>
<td>3.50</td>
<td>16.80</td>
<td>15.15</td>
<td>14.81</td>
</tr>
<tr>
<td>2</td>
<td>3.26</td>
<td>3.41</td>
<td>3.27</td>
<td>4.00</td>
<td>3.49</td>
<td>15.52</td>
<td>14.56</td>
<td>15.00</td>
</tr>
<tr>
<td>3</td>
<td>2.96</td>
<td>2.98</td>
<td>3.09</td>
<td>3.78</td>
<td>3.20</td>
<td>15.12</td>
<td>14.38</td>
<td>15.14</td>
</tr>
<tr>
<td>4</td>
<td>2.89</td>
<td>3.11</td>
<td>3.19</td>
<td>3.94</td>
<td>3.26</td>
<td>15.72</td>
<td>14.37</td>
<td>15.06</td>
</tr>
<tr>
<td>5</td>
<td>3.78</td>
<td>3.13</td>
<td>3.25</td>
<td>3.93</td>
<td>3.52</td>
<td>17.50</td>
<td>12.48</td>
<td>13.70</td>
</tr>
<tr>
<td>6</td>
<td>3.64</td>
<td>3.29</td>
<td>3.47</td>
<td>4.30</td>
<td>3.68</td>
<td>17.00</td>
<td>14.55</td>
<td>14.46</td>
</tr>
<tr>
<td>7</td>
<td>3.54</td>
<td>3.23</td>
<td>3.25</td>
<td>4.28</td>
<td>3.58</td>
<td>16.04</td>
<td>14.56</td>
<td>14.49</td>
</tr>
<tr>
<td>8</td>
<td>3.45</td>
<td>2.97</td>
<td>3.07</td>
<td>4.33</td>
<td>3.46</td>
<td>15.68</td>
<td>13.51</td>
<td>13.95</td>
</tr>
<tr>
<td>9</td>
<td>2.9829.72</td>
<td>3.18</td>
<td>3.94</td>
<td>3.27</td>
<td>15.25</td>
<td>13.09</td>
<td>14.13</td>
<td>15.64</td>
</tr>
<tr>
<td>10</td>
<td>3.04</td>
<td>3.06</td>
<td>3.30</td>
<td>4.02</td>
<td>3.36</td>
<td>14.36</td>
<td>13.18</td>
<td>14.38</td>
</tr>
<tr>
<td>11</td>
<td>2.98</td>
<td>2.98</td>
<td>3.15</td>
<td>3.27</td>
<td>3.21</td>
<td>14.53</td>
<td>13.54</td>
<td>14.26</td>
</tr>
<tr>
<td>12</td>
<td>3.14</td>
<td>3.16</td>
<td>3.18</td>
<td>3.49</td>
<td>3.54</td>
<td>16.28</td>
<td>12.63</td>
<td>14.15</td>
</tr>
<tr>
<td>15</td>
<td>3.54</td>
<td>3.26</td>
<td>3.20</td>
<td>3.92</td>
<td>3.63</td>
<td>15.32</td>
<td>14.74</td>
<td>15.19</td>
</tr>
<tr>
<td>16</td>
<td>3.24</td>
<td>3.15</td>
<td>3.18</td>
<td>3.87</td>
<td>3.26</td>
<td>15.00</td>
<td>14.23</td>
<td>14.82</td>
</tr>
<tr>
<td>17</td>
<td>3.06</td>
<td>3.01</td>
<td>3.19</td>
<td>4.08</td>
<td>3.24</td>
<td>14.23</td>
<td>13.49</td>
<td>13.92</td>
</tr>
<tr>
<td>18</td>
<td>3.25</td>
<td>3.00</td>
<td>3.22</td>
<td>4.51</td>
<td>3.52</td>
<td>15.12</td>
<td>14.43</td>
<td>14.82</td>
</tr>
<tr>
<td>19</td>
<td>3.27</td>
<td>3.05</td>
<td>3.46</td>
<td>3.83</td>
<td>3.40</td>
<td>15.56</td>
<td>14.09</td>
<td>15.45</td>
</tr>
<tr>
<td>20</td>
<td>3.50</td>
<td>3.20</td>
<td>3.27</td>
<td>4.09</td>
<td>3.47</td>
<td>15.89</td>
<td>14.07</td>
<td>15.19</td>
</tr>
</tbody>
</table>

### Table: Heads Per Square Yard.

<table>
<thead>
<tr>
<th>Plat</th>
<th>1912</th>
<th>1913</th>
<th>1914</th>
<th>1915 Avge</th>
<th>Days to Mature. 1912</th>
<th>1913</th>
<th>1914</th>
<th>1915 Avge</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>198</td>
<td>193</td>
<td>188</td>
<td>358.6</td>
<td>233</td>
<td>1232</td>
<td>123</td>
<td>121</td>
</tr>
<tr>
<td>2</td>
<td>199</td>
<td>199</td>
<td>199</td>
<td>337.6</td>
<td>234</td>
<td>132</td>
<td>123</td>
<td>121</td>
</tr>
<tr>
<td>3</td>
<td>176</td>
<td>187</td>
<td>215</td>
<td>346.3</td>
<td>231</td>
<td>133</td>
<td>123</td>
<td>121</td>
</tr>
<tr>
<td>4</td>
<td>175</td>
<td>175</td>
<td>196</td>
<td>318.3</td>
<td>216</td>
<td>133</td>
<td>123</td>
<td>121</td>
</tr>
<tr>
<td>5</td>
<td>186</td>
<td>186</td>
<td>208</td>
<td>305.3</td>
<td>221</td>
<td>115</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>6</td>
<td>191</td>
<td>191</td>
<td>204</td>
<td>273.0</td>
<td>217</td>
<td>115</td>
<td>117</td>
<td>118</td>
</tr>
<tr>
<td>7</td>
<td>189</td>
<td>189</td>
<td>240</td>
<td>271.0</td>
<td>222</td>
<td>116</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>8</td>
<td>202</td>
<td>202</td>
<td>211</td>
<td>263.6</td>
<td>219</td>
<td>121</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>9</td>
<td>172</td>
<td>162</td>
<td>214</td>
<td>318.6</td>
<td>217</td>
<td>116</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>10</td>
<td>216</td>
<td>196</td>
<td>194</td>
<td>285.6</td>
<td>223</td>
<td>116</td>
<td>116</td>
<td>120</td>
</tr>
<tr>
<td>11</td>
<td>166</td>
<td>166</td>
<td>196</td>
<td>306.0</td>
<td>209</td>
<td>122</td>
<td>121</td>
<td>121</td>
</tr>
<tr>
<td>12</td>
<td>183</td>
<td>169</td>
<td>215</td>
<td>314</td>
<td>245</td>
<td>122</td>
<td>121</td>
<td>131</td>
</tr>
<tr>
<td>13</td>
<td>161</td>
<td>161</td>
<td>172</td>
<td>321.3</td>
<td>204</td>
<td>122</td>
<td>122</td>
<td>131</td>
</tr>
<tr>
<td>14</td>
<td>143</td>
<td>143</td>
<td>198</td>
<td>257.0</td>
<td>185</td>
<td>122</td>
<td>122</td>
<td>131</td>
</tr>
<tr>
<td>15</td>
<td>199</td>
<td>199</td>
<td>212</td>
<td>291.0</td>
<td>225</td>
<td>122</td>
<td>122</td>
<td>129</td>
</tr>
<tr>
<td>16</td>
<td>194</td>
<td>194</td>
<td>208</td>
<td>329.3</td>
<td>231</td>
<td>121</td>
<td>119</td>
<td>125</td>
</tr>
<tr>
<td>17</td>
<td>178</td>
<td>178</td>
<td>188</td>
<td>309.0</td>
<td>213</td>
<td>121</td>
<td>119</td>
<td>125</td>
</tr>
<tr>
<td>18</td>
<td>180</td>
<td>180</td>
<td>184</td>
<td>309.0</td>
<td>213</td>
<td>116</td>
<td>119</td>
<td>126</td>
</tr>
<tr>
<td>19</td>
<td>175</td>
<td>175</td>
<td>201</td>
<td>298</td>
<td>212</td>
<td>119</td>
<td>117</td>
<td>129</td>
</tr>
<tr>
<td>20</td>
<td>176</td>
<td>176</td>
<td>201</td>
<td>315.6</td>
<td>217</td>
<td>119</td>
<td>119</td>
<td>128</td>
</tr>
</tbody>
</table>

**Average**: 183.7, 183, 204, 306.4, 219.3, 121.8, 119.6, 120.8, 122.6
Utah Bulletins Dealing With Irrigation of Wheat.

Utah Experiment Station.

**Bulletin Nos.**

27. Irrigation: Early, Late, and Usual. (1894) J. W. Sanborn.
56. Field Experiments with Wheat, Oats, and Barley. (1898) L. A. Merrill.
80. Irrigation Investigations in 1901. (1902) J. A. Widtsoe et al.
86. The Right Way to Irrigate. (1903) J. A. Widtsoe et al.
120. The Chemical Composition of Crops as Affected by Different Quantities of Irrigation Water. (1912) J. A. Widtsoe and R. Stewart.