12-1902

Bulletin No. 80 - Irrigation Investigations in 1901

John A. Widtsoe

Irrigation

EXPERIMENT STATION

—OF—

THE AGRICULTURAL COLLEGE

OF UTAH.

BULLETIN NO. 80.

Plate 1.--Snow Banks in Midsummer. One Source of Irrigation Water.

Irrigation Investigations

in 1901.

(ON THE COLLEGE FARM.)

DECEMBER, 1902.

LOGAN, UTAH.

6816--THE SKELTON PUB CO.,
PROVO UTAH.

The Agricultural Experiment Station of Utah.

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Plate 2. A Utah Mountain Stream in July.

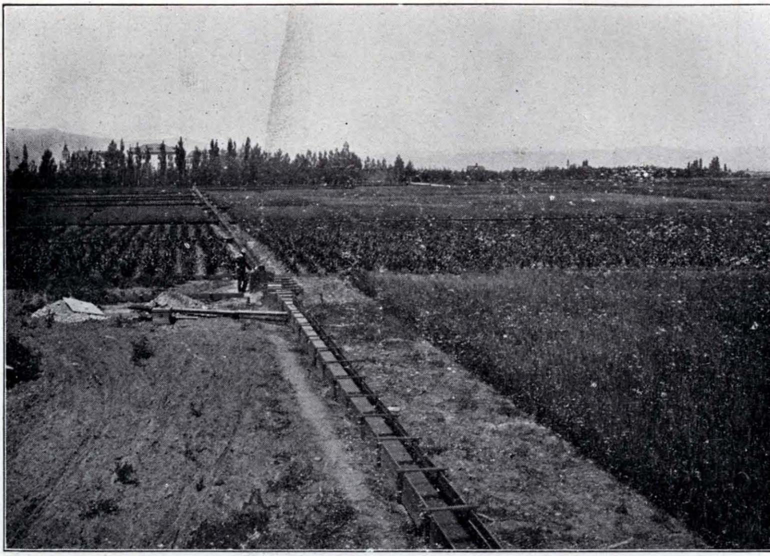

Plate 3. The approach to the head weir, showing the main flume and laterals of the irrigation system.

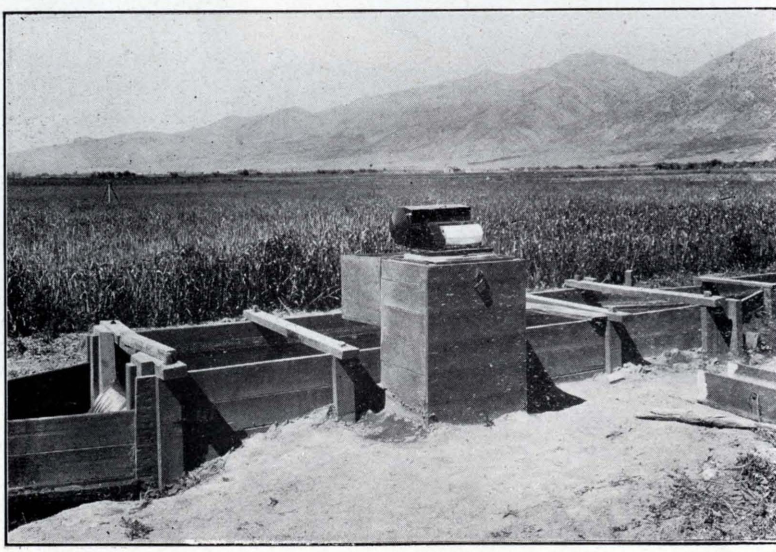

Plate 4. Head Weir and Register.

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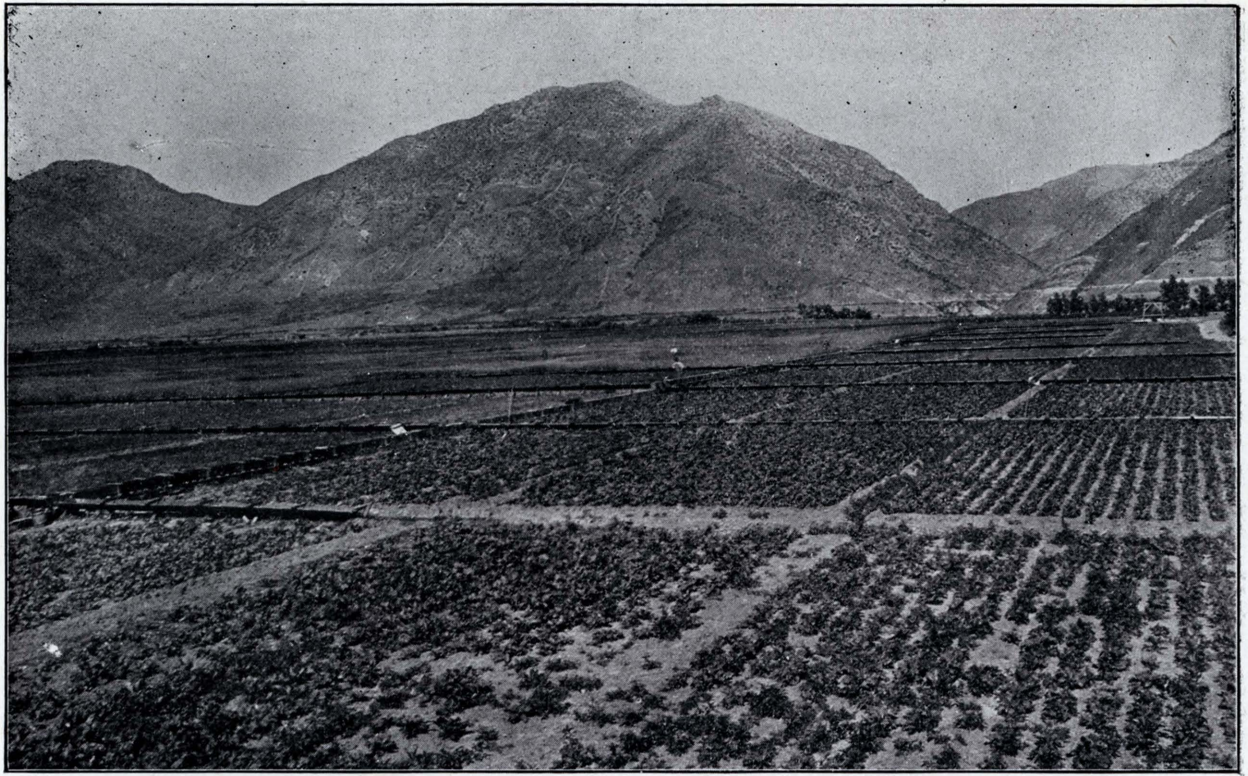

Plate 6. A part of the irrigation system. (Looking North-east.)

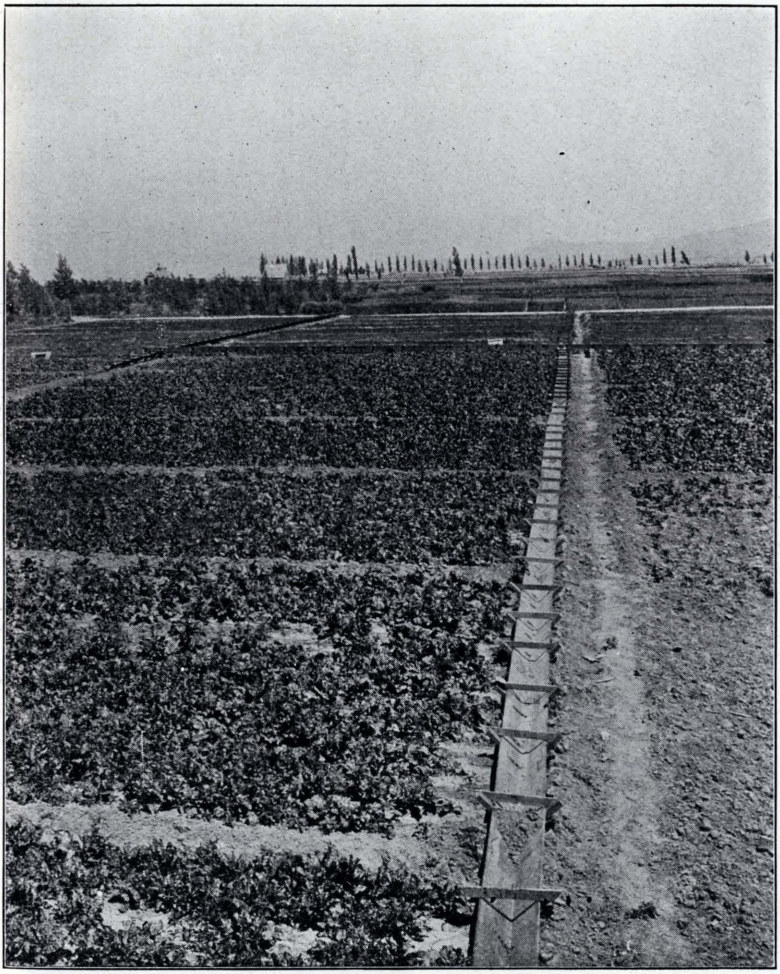

Plate 7. A lateral flume.

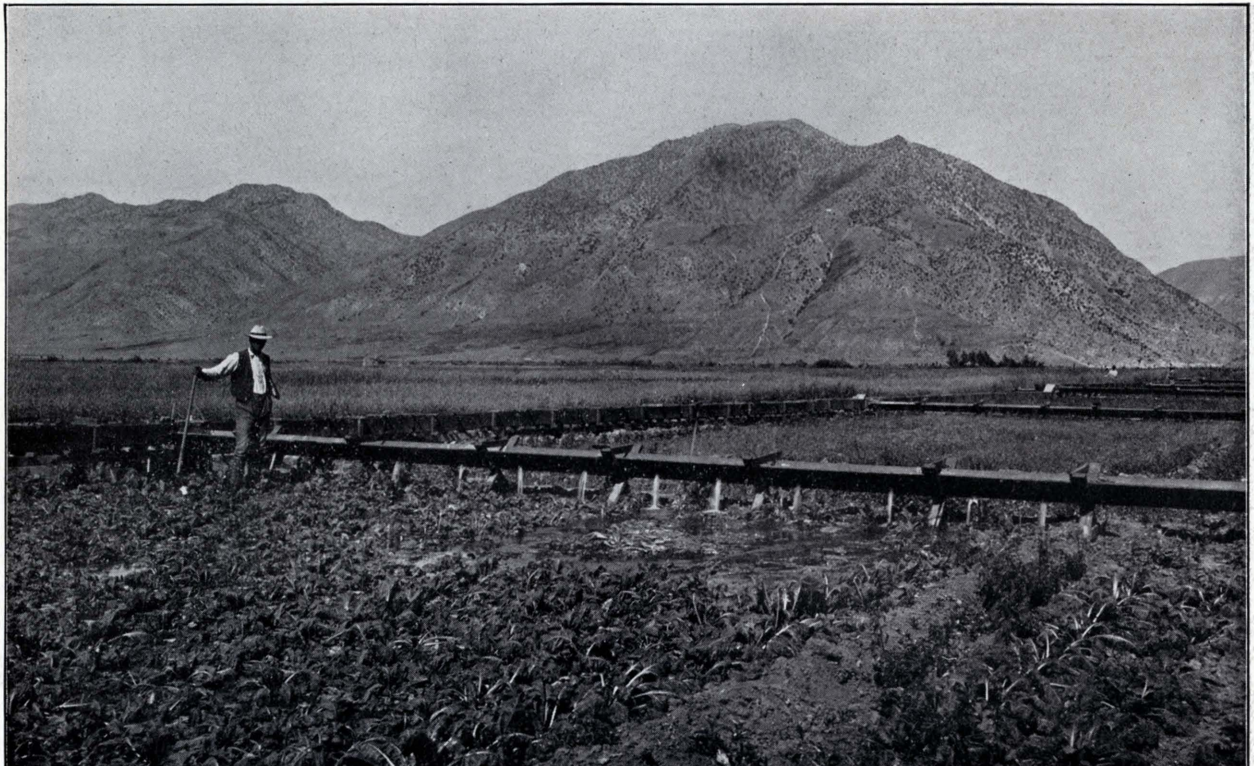

Plate 8. Method of applying measured quantities to the experimental plats.

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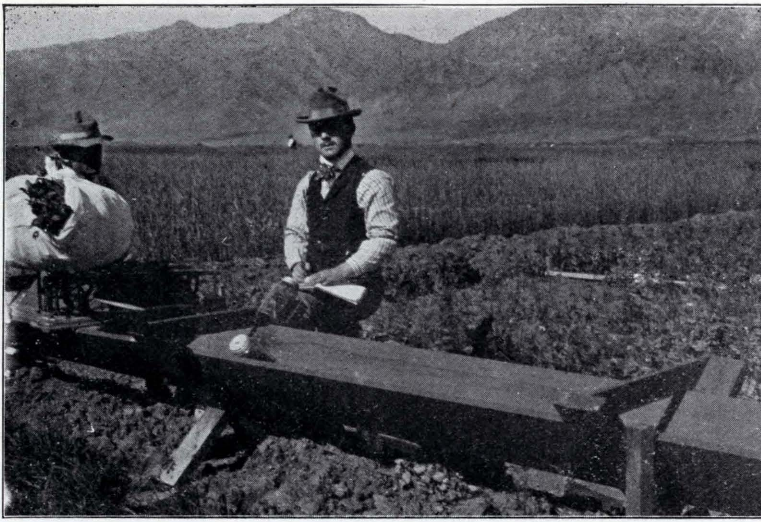

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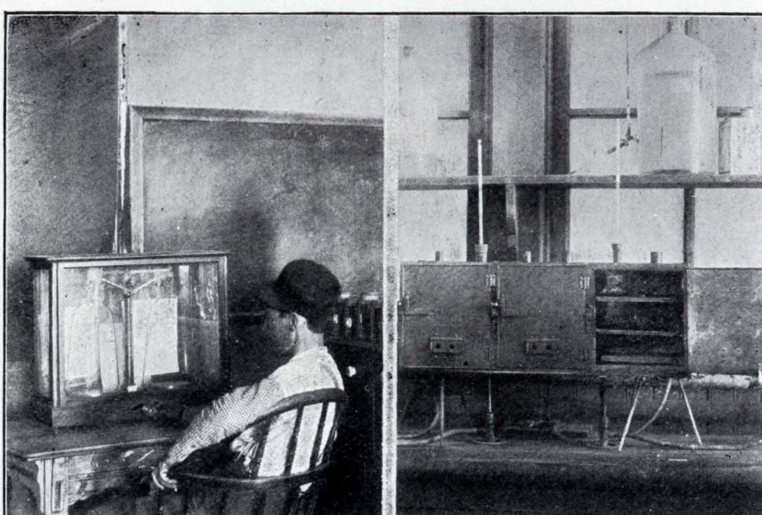

Plate 12. Method of weighing and drying soil samples.

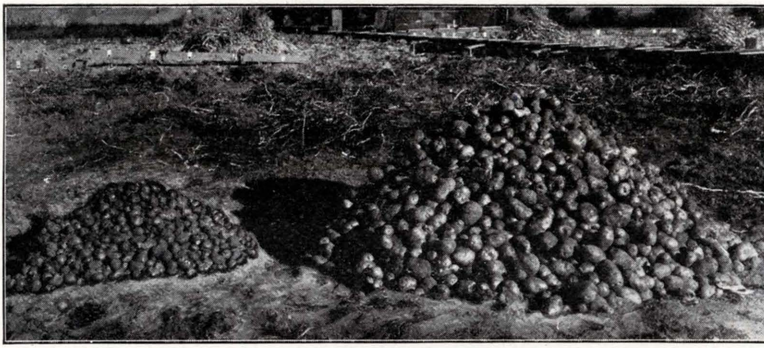

Plate 13. Potatoes grown with 19.98 inches of water.

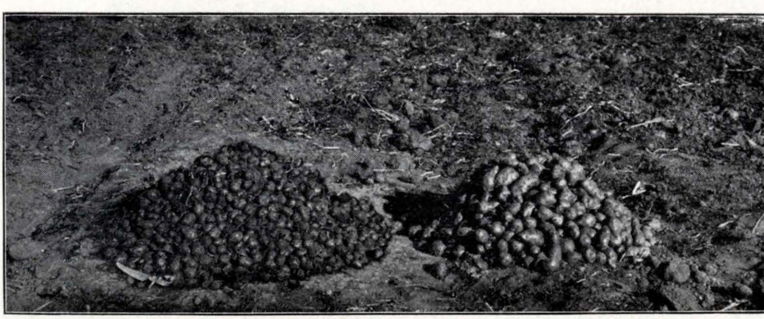

Plate 14. Potatoes grown with 15 inches of water.

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PREFATORY NOTE.

The fact that the ancient and, to arid countries, indispensible art of irrigation lacks a scientific basis, is the justification of the decision taken two years ago by the officers of the Utah Experiment Station, to make irrigation the central subject of their investigations.*

It seemed also eminently proper that Utah, the pioneer irrigation state, should lead out in such work.

The difficulty of searching out natural laws and developing principles, upon which may rest the practice of so complex an art as is irrigation, made it necessary to draw into service all the departments of the Station. The work reported in this bulletin was planned and executed, and the results prepared for publication, jointly, by three departments, which have now worked together for two years, in the most harmonious manner, for the elucidation of the principles of the art of irrigation. This bulletin may, therefore, be said to represent, also, the successful outcome of an experiment in scientific cooperation—the first attempted at this Station.

The work herein reported has been divided as follows: The construction of the wiers and flumes, and the measurement of the water applied to the experimental plats have been in charge of George L. Swendsen and William D. Beers, of the Department of Irrigation Engineering; all field operations, plowing, tillage, harvesting, and the proper application of water, have been in charge of Lewis A. Merrill, of the Department

*The earlier bulletins on irrigation, published by the Utah Station, are the following: 24, Irrigation; 26, Sub-Irrigation; 29, Irrigation; 38, Seepage waters and the Underflow of Rivers; 39, Farm and Orchard Irrigation; 46, Earthen Dams; 50, The Water Supply of Cache Valley; 71, Carrying Capacities of Irrigation Canals. All, with the exception of No. 71, are out of print.

af Agronomy; all soil sampling, soil moisture determinations; field and laboratory studies of the life histories and chemical composition of the crops have been in charge of John A. Widtsoe, W. W. McLaughlin and Osborne Widtsoe, of the Department of Chemistry.* The results of the investigations have been prepared by the heads of the departments, each preparing the work done by his own department. In numerous cases the lines of work have so overlapped that the departments have been obliged to render each other important assistance. In such instances, the best adjustment possible has been made.

JOHN A. WIDTSOE,
Director.

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*Acknowledgments should be made to Dr. P. A. Yoder, who made the carbo-hydrate determinations in the potatoes and sugar beets and the mechanical analyses of three samples of soil. Mr. Robert Stewart made the chemical analyses of the same samples.

IRRIGATION EXPERIMENTS IN 1901.

(ON THE COLLEGE FARM.)

A. INTRODUCTION.

Irrigation studies fall into three main divisions, as follows:

Irrigation Studies
1. The Conservation of Atmospheric Precipitation.
2. The Conveyance of Water to the Farms.
3. The Use of Water on the Farms.

The third division, which in position, though not in importance, is nearest the farmer, has received most attention from the Utah Experiment Station, during the past two years.

This bulletin is the first report of the recent irrigation investigations of this Station, and deals, wholly, with the proper use of water, by the farmer. The results herein presented were obtained from the irrigation plats on the College farm during the season of 1901.

1. THE GEOLOGICAL HISTORY OF THE FARM.

When Lake Bonneville filled the valleys of Utah, the Logan river formed a large deposit of gravel and sand near its mouth, where it left the canyon and met the quiet waters of the lake. When the lake fell to what is known as the Provo level, the top of this deposit or delta, was levelled by the action of the waves as they dragged upon the top of the hill, which formed the bottom of the shallow waters near the lake shore. When the lake fell still lower, another level terrace was formed on the side of the delta, by the action of the waves; and as the lake fell still lower, yet another terrace was formed. Further, the Logan river with the falling of the lake, cut a channel for itself in the delta which it had formerly constructed. This is known as the present Logan river hollow. North of the hollow, on the first terrace, formed during the Provo level of Lake Bonneville, lies the College farm, on which the experiments recorded in this bulletin were conducted.

As would be expected from the history of its origin, the hill is a great gravel and sand bed, nearly 300 feet deep, in which the materials are found distributed with little reference to their sizes. Occasionally there are found pockets of sand or clay in which beautiful evidences of sedimentation are observed; but these cases are very few.

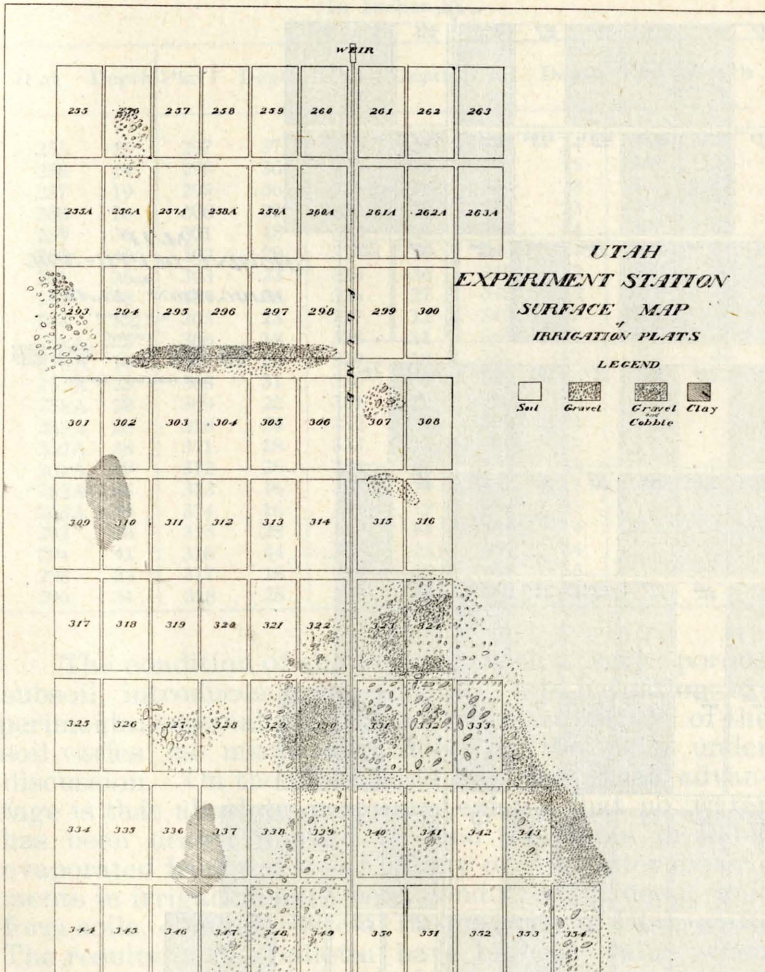
On the top of the hill, ages of weathering have produced a thin layer of gravelly soil, varying in thickness from nine inches to six feet where there happens to be an outcrop of a sand or clay pocket. During the last fourteen years, the persistent efforts of the Station workers have resulted in the removal of most of the surface rocks on the irrigation plats; and the addition of countless loads of manure has deepened and given life to the soil. The college farm is typical "bench land," of which there are many thousands of acres in Utah. In most cases, these benches have been caused by Lake Bonneville, or else bear definite relationship to periods in the history of this ancient lake.

2. HISTORY AND SOIL CONDITIONS OF THE IRRIGATION PLATS.

Ninety plats, 2x4 rods, and eight plats, 2x5 rods, were set apart for the irrigation work. The distances between the plats were 2½ feet east and west and 6 feet north and south. These plats are situated in the southwest corner of the farm, where the best and deepest soils are found. The soil was first broken in 1890. Its agricultural history since then will be found under the discussion of water versus the yield of dry matter and crop.

The surface conditions of the irrigation plats, as observed in early spring and late fall, when no crops are growing, are shown in Fig. 1.

By the use of long 1½ inch augers, the average depth to gravel on each plat, was determined. Table 1 gives the results obtained; and Fig. 2 shows graphically the same results.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EXPERIMENT STATION
SURFACE MAP
of
IRRIGATION PLATS
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Gravel
Gravel and Cobble
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BEERS.

FIG. 1

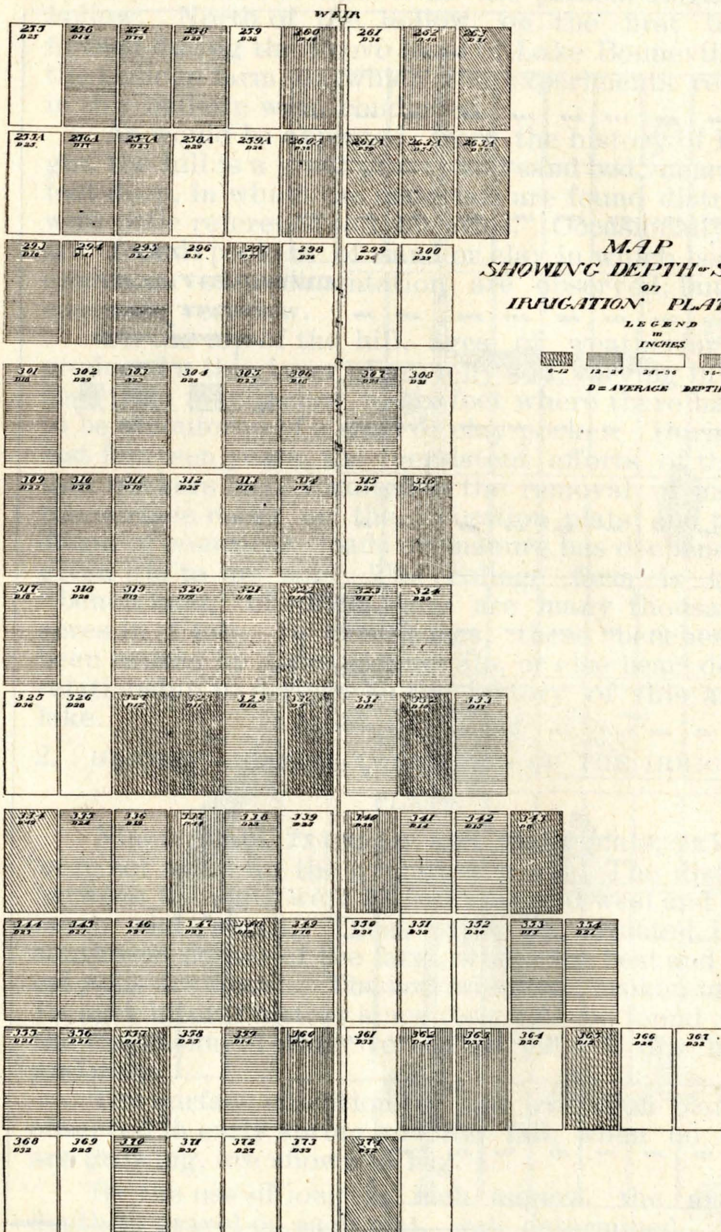

WEIR
MAP
SHOWING DEPTH OF SOIL
ON
IRRIGATION PLATS
LEGEND
IN
INCHES
0-12
12-24
24-36
D = AVERAGE DEPTH
BEERS.

FIG. 2.

TABLE NO 1.—DEPTH OF IRRIGATION PLATS.

(In Inches.)

Plat	Depth	Plat	Depth	Plat	Depth	Plat	Depth	Plat	Depth
255	25	297	37	319	19	341	14	363	37
256	14	298	36	320	19	342	15	364	26
257	19	299	36	321	18	343	8	365	12
258	20	300	29	322	10	344	23	366	25
259	36	301	18	323	14	345	24	367	32
260	40	302	29	324	20	346	24	368	32
261	36	303	23	325	36	347	22	369	25
262	48	304	26	326	27	348	12	370	18
263	51	305	23	327	12	349	17	371	31
255A	25	306	18	328	11	350	31	372	27
256A	17	307	20	329	18	351	32	373	33
257A	23	308	31	330	9	352	30	374	52
258A	29	309	22	331	19	353	15		
259A	26	310	20	332	9	354	21		
260A	38	311	18	333	17	355	21		
261A	59	312	25	334	49	356	21		
262A	54	313	16	335	24	357	11		
263A	59	314	16	336	19	358	25		
293	16	315	28	337	44	359	14		
294	41	316	44	338	23	360	44		
295	23	317	18	339	25	461	33		
296	34	318	28	340	39	362	41		

The condition of shallow soil, with a very porous subsoil, introduces great difficulty into irrigation experiments; especially is this so, when the depth of the soil varies as much as it does on the plats under discussion. On the other hand, the one great advantage is that absolute certainty exists, that no water has been drawn upward to feed the plants, or to be evaporated from the soils. Many of the later experiments in irrigation have been conducted on deep, uniform soils, characteristic of the majority of Utah soils. The results in this bulletin have highest value when applied to the bench lands of the state; though many of the conclusions drawn can be applied to all irrigated districts. It is specially mentioned in the text, when a result can be applied only to a certain class of soils.

The gravel underlying the soil is composed of rather large waterworn pieces of limestone, from the Silurian period, as evidenced by the frequent occurrence of characteristic fossils. Occasionally, pieces of quartzite have been encountered. Crystalline rocks appear to be absent.

Samples of soil were taken from each plat in the irrigation series, and a composite sample obtained, which was subjected to chemical and physical tests. Iron cylinders, six inches in diameter, and one, two and three feet long, were also driven into the soil in various places, then brought into the laboratory with the soil approximately undisturbed. These cylinders of soil were saturated with water, weighed, dried, weighed and the process repeated, until concordant results were obtained. In this manner, the specific gravity and absolute water capacity of the soil under consideration in these experiments were determined.

The following table exhibits the physical constants, determined in the investigation.

TABLE NO. 2.—PHYSICAL COMPOSITION OF SOIL OF IRRIGATION PLATS.

Laboratory Number	19669	19670	19671
Depth.	First foot	Second foot	Third foot
Medium sand (0.1 to 0.5 m m.)	28.1	29.7	31.6
Fine sand (0.032- -0.1 m m.)	25.6	26.4	29.6
Coarse silt (0.01 to 0.032 m m.)	19.2	16.4	14.6
Medium silt (0.0032 to 0.01 m m.)	10.2	6.6	6.6
Fine silt (0.001 to 0.0032 m m.)	2.6	5.6	6.5
Clay (Below 0.001 m m.)	8.4	8.8	8.6
Moisture	4.7	4.3	1.8
Soluble and lost	1.2	2.2	0.7

Average weight of one cubic foot of dry soil 88.9 lbs.
Average absolute water capacity............28.56 per cent.

The composite sample was also subjected to chemical analysis, according to the methods of the Association of Official Agricultural Chemists.

TABLE NO. 3.—CHEMICAL COMPOSITION OF THE SOIL OF THE IRRIGATION PLATS.

(All percents are referred to the water free soil).

	First foot	Second foot	Third foot
Laboratory number	19669	19670	19671
Insoluble matter	68.42	65.66	56.49
Potash K_2O	0.65	0.57	0.43
Soda Na_2O	0.55	0.53	0.60
Lime CaO	6.07	8.20	14.81
Magnesia MgO	5.13	4.13	3.32
Alumina Al_2O_3	3.13	2.36	2.39
Iron oxide Fe_2O_3	2.33	2.65	1.72
Phosphoric acid P_2O_5	0.20	0.15	0.24
Sulphuric acid SO_3	0.10	0.11	0.08
Carbon dioxide CO_2	10.00	12.74	17.90
Organic matter	3.86	2.99	2.12
Total	100.44	100.09	100.10
Humus	3.72	1.18	1.06
Nitrogen	0.149	0.100	0.072
Water at 100 C	1.85	1.91	1.69

3. THE METEOROLOGICAL CONDITIONS.

The following tables give the data for temperature, relative humidity, sunshine, and evaporation at Logan, during the irrigation season, June, July, August and September, and for rainfall from April 1st, to October 30th. The instruments were about one-fifth mile removed from the irrigation plats, but on the College hill, and, therefore, under practically the same conditions as those that prevailed at the experimental plats.

TABLE NO. 4.—TEMPERATURE, RELATIVE HUMIDITY, AND SUNSHINE IN 1901.

	Temperature				Relative Humidity.				Hours of Sunshine.			
1.	June	July	Aug.	Sept.	June	July	August	Sept.	June	July	August	Sept.
1.	59.0	69.0	79.0	70.5	54	40	62	43	7.0	10.4	8.5	12.1
2.	59.0	81.5	75.0	66.5	77	34	71	50	1.0	10.5	2.0	6.2
3.	55.5	69.0	77.5	65.0	69	38	56	68	3.5	10.2	10.0	8.1
4.	58.0	62.0	77.5	60.0	42	49	48	61	8.2	10.0	9.4	9.5
5.	47.0	66.0	77.0	63.0	47	44	50	47	10.4	10.2	6.5	9.4
6.	57.5	75.5	72.0	71·0	56	39	71	28	10.8	9.6	0.0	8.0
7.	68.0	78.5	76.0	59.5	36	42	58	46	9.4	9.0	9.7	9.7
8.	60.5	82.5	75.0	63.5	53	31	61	52	10.2	8.0	7.0	4.5
9.	60.0	76.5	73.0	58.5	50	46	53	51	4.8	9.7	6.0	6.5
10.	53.5	75.5	74.0	59.0	72	49	52	39	1.3	8.8	10.8	4.3
11.	54.0	75.5	72.0	59.5	44	38	50	46	10.5	9.9	0.0	4.5
12.	54.5	79.0	70.5	64.0	67	40	51	58	0.0	7.7	11.4	7.1
13.	50.0	78.0	74.0	58.5	61	28	40	50	3.0	9.0	3.0	9.0
14.	53.5	73.5	76.5	55.0	43	34	36	51	10.3	8.9	5.5	9.6
15.	56.0	73.5	72.5	59.5	38	37	53	45	9.2	9.4	4.2	9.1
16.	63.5	74.5	74·0	54.0	41	29	60	48	9.4	9,3	4.5	9.5
17.	67 0	76.5	73.5	56 5	44	39	50	43	7.8	9.2	9.5	8.8
18.	69.5	79.0	71.0	60.5	48	38	60	44	7.4	9.0	0.0	9.2
19.	70.5	79.0	71.5	62.5	44	39	89	38	7.2	9.2	5.0	6.2
20.	68.5	80.5	66.5	65.5	44	41	61	34	9.3	8.4	9.0	3.7
21.	70.5	82.0	67.0	70.0	43	39	43	30	10.0	6.0	10.5	4.7
22.	72.5	83.0	74.0	52.0	40	42		70	10.0	4.0	9.7	8.9
23.	71.0	80.5	73.5	57.0	32	41		51	10.4	4.2	10.5	5.5
24.	65.0	78.5	74.5	45.0	49	61	52	71	7.0	0 0	3.0	5.4
25.	59.0	80.0	74.5	51.0	58	65	46	57	6.0	6.5	10.5	5.5
26.	56.0	77.0	77.5	56.0	45	54	42	57	11.0	5.7	9.3	5.6
27.	62.5	75.5	69.0	52.5	38	44	40	57	10.5	6.8	9.0	9.7
28.	67.5	77.5	62.0	52.5	39	40	48	51	10.8	8.8	9.7	7.0
29.	67.0	77.5	74.5	58.5	36	38	44	54	10.4	8.3	8.8	6.1
30.	66.5	82.5	73.5	61.0	40	44	51	54	9.3	9.7	10.0	8.0
31.		81.5	69.5			41	49			8.0	10.2	

TABLE NO. 5.—RAINFALL DURING THE EXPERIMENTAL SEASON OF 1901.

April	3rd, 0.48	8th, 0.24	13th 0.35	26th and 27th 0.28			Total 1.35
May	3rd	4th 2.00	21st 0.05	27th 0.08	28th 0.25		Total 2.43
June	2nd 0.13	13th 0.28					Total 0.51
July	25th 0.07						Total 0.07
August	2nd 0.15	3rd 0.38	6th 0.12	15th 0.02	20th 0.93		Total 1.60
September	3rd 0.06	22nd 0.14	23 and 24th 0.83				Total 1.03
October	4th 0.56	6th 0.03	8th 0.03	26th Trace	28th 1.00	29th 0.21	Total 1.83

TABLE NO. 6.—EVAPORATION OF WATER FROM TANKS SUNK IN THE GROUND, 1901.

(In inches; rainfall added to each month.)

TANK A.

(Covered at night; open during the day.)

Month	Total Evaporation	Temp. F.	Remarks,
July	6.968	79 ¼	Placed cover on tank on the 11th.
Aug.	6.883	77	
Sept.	5.266876	66	
Oct.	3.59708	57	Discontinued cover on tank Oct. 1st.
Nov.	1.58336	45	

TANK B

(Open night and day.)

Month	Total Evaporation	Temp. F.	Remarks
March	4.69972		No temperature recorded
April	4.54328		" " "
May	5.72972		" " "
June	5.24876		" " "
July	5.32360	78	No record of 1st two weeks as we were moving tank.
Aug.	7.98640	73	
Sept.	5.40786	60	
Oct.	3.55776	51	
Nov.	1.37792	44	

4. THE COMPOSITION OF THE IRRIGATION WATER.

The water used for irrigation came from the Logan river. Earlier investigations * had shown the composition of the water from this stream; but to possess full knowledge of all the factors entering into the work, samples were taken weekly from the water passing over the main weir. Part of these samples were accidentally lost. The analytical results obtained from the remaining samples are given in tables 7 and 8.

TABLE NO. 7.—TOTAL SOLIDS IN IRRIGATION WATER, 1901,

Parts per Million.

	Total residue	Non-volatile residue	Volatile residue
June 6th	187	138	49
June 13th	175	115	60
June 20th	211	148	63
June 27th	189	148	41
July 5th	191	167	24
July 18th	225	146	80
July 25th	172	104	68
Aug. 1st	252	164	88
Aug. 8th	205	155	50
Aug. 15th	227	141	86
Aug. 22nd	258	156	102
Aug. 29th	264	161	103
Average	213	145	68

TABLE NO. 8.--COMPOSITION OF IRRIGATION WATER, 1901.

Parts per Million.

	June 13th.	August 8th.
Total residue	175	205
Non-volatile	115	155
Loss on Ignition	60	50
Silica (SiO_2)	5	4
Iron oxide and alumni	None	None
Lime (Ca 0)	32	29
Magnesia (MgO)	23	27
Phosphoric acid (P_2O_3)	4	Trace
Sulphuric acid (SO_3)	7	11
Potash (K_2O)	1.3	2.1
Soda (Na_2O)	3	5
Ammonia	None	None
Nitric acid (N_2O_5)	None	Trace
Nitrous acid (N_2O_3)	None	None
Chlorine	Trace	17
Undetermined	99	109.91
Carbon dioxide (CO_2) (fully bound)	108	54.

* Utah Station, 8th Annual Report, pp. 30 and 31.

These tables show that the composition of the irrigation water was quite constant during the irrigating season. Nitrogen was absent; phosphoric acid and potash were present only in small quantities. The fertilizing value of the water was therefore, very small. The water from Logan river may be taken to represent the waters in the majority of the mountain streams of Utah. They are of exceptional purity; and desirable for man or beast or plant.

Using the data of tables seven and eight, a simple calculation will show the amounts of fertilizing ingredients added to the soil in a year's irrigation. In table 9, water is assumed to weigh 62.5 pounds per cubic foot; and averages of the two complete analyses have been used. Fifteen inches represent a moderate irrigation for one year; and 30 inches a liberal one.

TABLE NO. 9.—FERTILIZING INGREDIENTS THAT MAY BE ADDED TO SOIL BY IRRIGATION.

(Pounds per Acre.)

	By 15 inches of water	By 30 inches of water
Total solid matter	724	1448
Lime (Ca 0)	104	208
Magnesia (Mg 0)	85	170
Phosphoric acid (P_2O_5)	7	14
Potash (K_2O)	6	12
Nitrogen	Traces	Traces

Though the total solid matter left in the soil is quite high, the really valuable substances, nitrogen, potash and phosphoric acid, are insignificant in amount. When land has good drainage, some of the irrigation water may drain away, and will then probably carry off more fertilizing ingredients than have been added by the original volume of water.

5. THE METHOD OF MEASURING THE WATER.

(See illustrations in front of this bulletin.)

All the water used on the plats was measured by means of a very carefully constructed cippoletti weir, so located that the distribution to the whole area was made from this one source.

The crest of the weir is 1.50 feet long, and is covered with heavy sheet iron cut to a sharp edge, so that the construction is perfect all around.

The approach to the weir is five feet wide, 1.20 feet deep below the crest of the weir, built of dressed tongue and grooved material, to a point twelve feet from the crest, where it narrows down to a width of 1.66 feet and extends for a distance of 60 feet. Very careful measurements of the surface velocity of approach show it to be less than 0.10 feet per second.

An effort was made to have the weir so constructed as to make the very best conditions for accurate measurements. The weir opening is perpendicular to the course of the water in the channel of approach, and the edge of the weir from the sides of the channel is more than four times the greatest depth of water on the crest. The bottom of the channel is a safe distance below the weir crest.

To avoid settlement or disarrangement of the weir after it was set in place, the foundation was given considerable attention. Four longitudinal rows of sills were firmly imbedded in the bottom of the channel and brought to a level both laterally and longitudinally. On this the weir was placed and firmly fastened. Proper submerged wings and aprons were built at the approach to the weir, and every precaution taken against movement in any direction. The metal crest was then put in place and brought to a perfect level. In each and every particular, it is thought that the weir was so constructed and placed in position with such care as to secure results within a very low limit of error.

A register of the Leitz pattern was placed in such a way as to record continuously the depth of water on the crest. The instrument used was the regular eight day machine, but the mechanism was so changed that the pencil passed over the eight inch space in twelve hours, or one fourth of an inch in each fifteen minutes, and the sheets for the record were ruled accordingly. By this means a record on a large scale was obtained and thus very slight variations of depth were detected.

THE DISTRIBUTION SYSTEM.

The water was distributed entirely in small wooden flumes. One main flume passes across the whole system of plats, and lateral branches supply the different belts on either side of the main line. The main flume is rectangular in section, 15 inches wide, and ten inches deep; great care was observed in its construction so that the leakage was reduced to such a small amount that it can be readily disregarded in results. The entire line was thoroughly painted with mineral paint and the inside was entirely covered about one-sixteenth of an inch thick with coal tar that had been boiled one hour and a quarter. All joints of sections were covered with sheets of tin and by the use of other precautions and continuous attention the main line of the distribution was very successfully operated.

Gates made of galvanized sheet iron were used to control the subdivision from the main line. These however were not satisfactory, from the fact that the surfaces were not fitted with sufficient accuracy to prevent leakage. It is our opinion that wooden gates would have been more serviceable.

The branch flumes were of right triangular section with one foot sides. They were of very simple construction and the results from their use were quite satisfactory. They were set a short distance above the ground, and the water distributed to the different portions of the plats through 2 inch holes at intervals of three feet along the line of the flume. These openings were controlled by small tin gates sliding into a tin frame over the opening. As in the case of the main line gates these gates also were a source of difficulty, and required a great deal of attention. The branch flumes were also painted and the boiled tar brought into requisition with great success to stop all leakage in the joints of the structures.

6. THE OPERATION OF THE DISTRIBUTION SYSTEM.

In the operation of the system, one plat was irrigated at a time, and the duration very carefully figured so as to cover the plat to a depth as nearly as possible to that designated by the Division of Agronomy. To facilitate the operation, each plat was surrounded by a dyke of sufficient height to retain all the water on the plat. The space between the plats was found too narrow to obtain the best results in this particular—it should have been six feet instead of two and one-half, and in many cases the dyke encroached on the plat area in order to get sufficient thickness to afford the stability necessary to prevent losses by percolation through the dyke, but with few exceptions the entire volume of water was kept on the plat.

In the measurement, the recorder was not entirely depended upon for results, but direct observations of the depth on the weir were made and an overflow provided above the weir in order to regulate the depth of water on the weir and maintain such depth as nearly constant as possible during the irrigation.

The depth designated for a single irrigation varied all the way from 2½ inches to ten inches, and to attain the exact depth, especially near the two extremes, required careful manipulation. When a great depth was required, it was necessary to use a small stream, allowing it more time to percolate as it spread over the plat. With very small depths, however, the greatest difficulties were encountered; it being necessary to use a large stream to crowd the water over quickly, giving every attention necessary to removing slight obstructions and otherwise facilitating the distribution of the water over the plat.

In some cases it was not possible to cover the entire plat with the designated volume; and, in such cases, the irrigation was continued until the plat was covered. In such cases it might have been possible to attain the desired results by the aid of sub-branches extending from the main branches to near the middle of the plat, or by some such means, in effect reducing the flooded sections.

In furrow irrigation great difficulty was found in attempting to apply the maximum depths designated, and even with the greatest precautions as many as eight to ten repetitions were frequently necessary.

8. RESULTS IN THE METHOD OF APPLYING WATER.

Our experience of the year has taught us that inch material is entirely too light for the flumes in an experiment. The entire system would have been more effective if built of two inch materials.

Again we are convinced that our method of making the bottom of the flume extend out under the sides and using bolts with which to draw the joint together is not only expensive but ineffectual. The sides should extend to the sill and the bottom be placed between them, so that nails can be used to draw the bottom and sides together. Furthermore, the sediment will sooner stop the vertical than the horizontal joint, and where tar is used as in this case, it is more effective and easier deposited in the vertical than in the horizontal joint.

As mentioned before, our gates were not effectual. It is probable that corks could be used in the the small openings of the laterals, but in the main diversion gates, we must either use expensive metal gates or carefully fitted wooden gates. It is our opinion that the wooden ones will be the more effective.

The use of coal tar to prevent leakage proved eminently satisfactory. We experimented on the question of its application, whether it should be heated or put on in its commercial state, also as to the degree of heat. Our results indicate quite positively:

1st. That in its crude state, it will not prevent leakage, nor will it operate to preserve the wood for any length of time. It evaporates very rapidly.

2nd. Our experiments with boiling covered periods of from one-half hour to two hours; but the best results were from boiling about one hour and a quarter.

The heat was kept just great enough to maintain the boiling. In such a state the tar was poured in the flume and spread with brooms. It covered the joints fully one-sixteenth inch thick, and was always solid, though not brittle and was not affected by the sun or water. If boiled for a longer period than 1¼ hours it became brittle; if less, both water and sun affected it.

In boiling, care must be taken not to inhale the fumes too freely, as they congeal in the respiratory channels and have a rather unpleasant effect. Too great heat will burn the tar and ruin it for the purpose. The entire cost of the tar used on the flumes during the year was $7.00.

Where large openings occurred, oakum was used in connection with the tar, and, of course, proved effectual.

All the flumes were painted with mineral paint mixed in the proportion of six pounds of mineral red to one gallon of raw linseed oil. Though much of the lumber was not entirely seasoned, this mixture of paint was very effective in preventing checks and warping. Its durability will be a matter for future consideration.

The weir used was larger than necessary. With plats of the size used, and the conditions prevailing, a foot weir would be amply large.

9. THE TEMPERATURE OF THE IRRIGATION WATER.

At every irrigation the temperature of the water was taken, at the head of the main weir of the irrigation system. The results obtained represent the temperature of the water in the farmer's ditches, in and about Logan, during the season of 1901. The following table, which contains the average temperature of the water for each day during the irrigation season, shows considerable fluctuations in temperature from day to day, though it rises gradually from May until the end of August when it again falls.

All calculations in the following pages have been made with the weight of water at 39.2 deg. F.

TABLE NO. 10.—TEMPERATURE OF IRRIGATION WATER: 1901.

Date	Degrees Fahrenheit	Date	Degrees Fahrenheit	Date	Degrees Fahrenheit	Date	Degrees Fahrenheit
May		June		July		Aug.	
23	55	19	57	11	61	8	64
24	55	21	61	12	58	12	69
26	53	22	60	13	61	14	59
27	50	24	56	15	58	15	62
28	52	25	56	16	57	16	58
29	56	26	54	18	59	17	61
June		27	55	19	61	20	62
3	52	28	59	20	59	21	63
4	52	29	58	22	61	23	61
7	55	July		23	60	29	58
8	55	1	59	25	64	Sept.	
10	48	2	61	26	62	8	56
11	55	3	55	27	68	9	55
12	47	5	61	29	62	10	54
13	47	6	59	30	69	11	53
14	51	8	63	31	58	12	51
15	51	9	60	Aug.		May Average	54
		10	59	7	67	June "	54
						July "	60
						Aug "	62
						Sept. "	54

B. IRRIGATION VS. SOIL MOISTURE.

10. THE METHOD.

It was attempted, in these experiments, to follow in considerable detail the movements of the water applied to the soil. The method of investigation adopted and followed was as follows: Several 1½ and 1¾ inch wood augers had their shafts lengthened to 3, 5 or more feet. With these augers, borings were made in the soil, and samples obtained to any desired depth. The sample drawn from the ground was quickly placed in a Mason fruit jar of proper size, which was sealed, labelled and sent to the laboratory. Here, the sample was well mixed, in the bottle, and exactly 50 grams weighed out on a 3½ inch watch glass, and dried for about six hours at a temperature varying from 110 deg. C to 120 deg. C. The loss in weight, doubled, was the per cent of water in the wet scil. Numerous trials convinced the workers that this method of sampling and analysis gave results that were as trustworthy as those obtained by more complicated and time-consuming methods. Considering the possible errors in other parts of the experiments, this method of finding the amount of water in the the soil was thought to be sufficiently accurate. The per cents in the following tables are ordinarily accurate to within 0.05 of one per cent.

The slope of the plats, and the fact that the water was applied at one end, made it practically impossible for the same depth of water to be applied to every part of the plats. The end nearest the flume, in the majority of plats, was wetter after an irrigation than the end farthest removed from the flume. In a few cases, where the slope was great, the water would rush down the plat and form a small pond against the lower dyke. These conditions made the problem of obtaining a sample of soil with a per cent of water corresponding to the total amount applied, very difficult of solution. It was finally decided to take all samples near the centers of the plats, so that those from the same plat would be comparable with each other. In many cases the samples taken near the center of a plat contained a per cent of water nearly the same as the average for the whole plat, based on a great number of samples; in many other cases, there was considerable difference between the average per cent of water in the plat and that in the center of the plat.

Nearly 6000 soil moisture determinations were made during 1901, in connection with the irrigation experiments. To print tables giving all these results would be very expensive, and would interest only specialists in the subject. Only summarized tables are therefore used in the following discussions.

Except when otherwise stated, all moisture per cents are referred to dry soil; that is, 10% of water means that 10 pounds of water occurred with 100 pounds of the water-free soil. The reason for reducing all analyses to water-free substance, is that the relation of per cents then represents the relation of the actual weights of water in the soil. Thus, a cubic foot of soil, with 10% of water, contains twice as much water by weight as a cubic foot of the same soil, with 5% water. This would not be true if the percents were based on the wet soil as found in the field.

All borings were made in twelve, six or three inch sections, down to the gravel bottom. Samples were always taken just before and after each irrigation and at harvesting; and on many plats, at stated intervals between the irrigations.

11. SOIL MOISTURE IN EARLY SPRING, AND AT HARVESTING.

The whole field, devoted to irrigation experiments, was sampled on March 20th, April 16th and 24th, to learn the moisture conditions of the soil in early spring. The average results are shown in the following table.

TABLE NO. 11—MOISTURE IN IRRIGATION PLATS IN EARLY SPRING, 1901.

	Per cent of Water.			
Date	1st foot	2nd foot	3rd foot	4th foot
March 20th................	17.99	19.20	17.51	
April 16th................	20.24	19.09	19.69	
April 24tn................	17.38	17.04	17.68	15.96

All the plats, with the exception of those on which sugar beets grew, were sampled on the day of harvesting. The moisture conditions for some of the crops are shown herewith.

TABLE NO. 12.—AVERAGE PER CENT OF WATER IN SOIL AT TIME OF HARVESTING.

Crop	Fall Wheat	Spring Wheat	Corn	Potatoes	Oats
Per cent of Water.	4.35	5.51	10.11	10.13	7.44

The amount of water in a soil, at the time of harvesting, is largely dependent upon the time that has elapsed since the last irrigation; yet since most crops are allowed to remain in the soil for several days or weeks after the last irrigation, the above table shows in a general way the power of different plants at their period of ripeness to drain the soil of the water it contains.

12. THE MOISTURE IN SOIL AT FIRST IRRIGATION.

The first irrigation was applied at the time when the Agronomist thought the crops needed water. It represents, therefore, the practice of the practical irrigators of this locality. The day before the irrigation, soil samples were taken from every plat, and in table No. 13. the average results of the moisture determinations are found.

TABLE NO. 13—MOISTURE CONTENT OF SOILS JUST BEFORE FIRST IRRIGATION.

Crop	Number of observations	Date	Per cent of water
Spring Wheat	14	June 3-8	7.67
Oats	8	June 12	7.32
Corn	8	June 20 July 1st	10.09
Fall Wheat	10	June 3	9.96
Potatoes	9	June 26	11.73
Sugar Beets	12	June 13-15	14.99
Mixed Clovers and Grasses	10	May 26-29	9.28
Lucern	7	May 23 June 23	12.02
Timothy	5	May 23-28	10.29

Spring wheat soil contained 7.76 per cent of water at the time of irrigation; and oat soil, which was irrigated about a week later contained 7.32 per cent. Fall wheat soil contained, at the time of the first irrigation of spring wheat, 9.66 per cent.

The corn plats, were irrigated from three to four weeks after the wheat plats; yet they contained 2.33 percent more water. This is due partly to the less rapid rate of transpiration of the corn, but chiefly to the earlier stage of growth of the corn plants. This observation illustrates also the fact that the direct evaporation of water from the soil is very small compared with the amount lost by transpiration through plants.

The potato plats were irrigated somewhat earlier than the corn plats, and the sugar beet plats, about a week later than the wheat plats. The soil from the potato and sugar beet plats, respectively, contained 11.73 and 14.99 per cent of water. The reason for these high per cents is the same as that given under the discussion of the corn plats, though it must be remembered that a slight shower occurred on June 13th. These per cents also emphasize the statements made regarding the relative importance of direct evaporation from the soil, and of transpiration, as causes of the loss of soil moisture. Later in the season, when the plants were large and growing vigorously, there seemed to be little difference in the different crops respecting their power to drain soils of water. It may be that plants when young, and with their root systems only partly developed, cannot reduce the water content of soils as much as they can later when they are more fully developed.

The per cent of moisture in the soil at the first irrigation was invariably much higher than the per cent found in the soil just before later irrigations. Whether, in common practice, the first irrigation is applied earlier than is necessary, or that the young crops cannot endure so dry a soil as older plants, is a question that cannot well be settled with the data at our command.

It is interesting to note that the plats on which perennial plants were growing—clovers and grasses mixed, lucern and timothy—contained higher per cents of water than did wheat, oats and corn, and practically as much as was found in the potato and sugar beet plats. This would indicate a low rate of transpiration in early spring and summer, for perennial plants.

The conditions of soil moisture, represented in table No. 13, are those that prevailed when irrigation began, and with which the discussions of the following pages begin.

13. DOWNWARD MOVEMENT OF WATER.

In the great majority of irrigations, water was applied to the plats at the rate of about 12 inches per hour. As would naturally be expected from the conditions of shallow soil and loose gravelly subsoil, the excess of water drained through the soil very quickly. In several cases a plat was irrigated three times in one day, each irrigation piling the water against the dikes three to four inches high, and in the evening all the water had soaked into the soil. The dry soil took up water much more readily than the soil which was partly saturated with water.

The day after irrigation the soil was invariably dry enough to allow a man to go out upon it, and take the necessary soil samples. The results obtained from this sampling showed that in its downward movement, water obeys the generally accepted laws.

Water, when brought upon a soil, first wets the upper layer of soil particles, i. e. envelops them with a water film; then the interstitial spaces are filled; under the influence of gravity, the water moves downward, first wetting new soil particles as they are reached, and then filling the spaces between them. A soil section just after irrigation, would show the upper layer completely filled with water, while a lower part would be simply wetted.

After irrigation has ceased, the water filling the interstitial space in the upper part of the soil, in obedience to the the pull of gravity, moves downward, wetting new soil particles in its descent. In time, if the soil is deep enough, this will result in all the water added by an irrigation, clinging around the soil particles, and none filling the spaces between, i. e. all the water will be in the capillary condition, and not subject directly to the law of gravity. In time, were no other forces at work, save gravity and the mutual attraction between soil and water, this capillary water would distribute itself quite uniformly through the whole depth of the soil. With growing plants on the soil, subjected to sunshine and wind, such a state of equilibrium is not possible. The soil samples were, therefore, taken the day after irrigation, before the water had had time to distribute itself as uniformly as was possible.

Should a very heavy irrigation be applied on a shallow soil, all the soil pores from top to bottom might be filled with water. In that case water would drain into the gravelly subsoil leaving the capillary water quite uniformly distributed in the soil. This condition is shown by the average results obtained from two plats, 18 inches deep, on which ten inches of water were applied, though the capacity of the soil was only 7.3 inches. It will be observed that, although the second foot is not so wet as the first foot, yet it is wetter than the upper three inches (see table 16) of plats on which moderate amounts of water had been applied.

TABLE NO. 14.

Average depth of plats	Water applied	Capacity of plat.	Per cent of water in	
			1st foot	2nd foot
18 inches.	10 inches.	7.3 inches.	26.00 inches	23.18 inches.

The maximum capacity for capillary water, sometimes called the absolute water capacity, was found to be 28.56% for the soil on which the experiments here recorded were made. The highest per cent of water found in the first three inches the day after irrigation, was 29.28 while the average per cent was 22.45. It seems to be true, therefore, that the amount of water in the upper three inches of soil, one day after irrigation, is only about 80% of the absolute water capacity. Considering the whole depth of soil, only from 60% to 75% of the absolute water capacity is utilized on the day after irrigation.

TABLE NO. 15.—DISTRIBUTION OF WATER IN SOIL.

(Just after irrigation, in percents of dry soil.)

Whole number of plats.	Average depth of plats.	No. of single tests.	1st. foot.	2nd. foot.	3rd. foot.	4th foot.	5th. foot.
24	22 in.	93	21.65	19.63			
22	34 "	76	20.59	19.10	17.23		
5	44 "	20	19.59	17.79	17.72	17.56	
2	56 "	7	19.16	18.55	18.07	19.42	16.87

The above table, which is based on numerous single tests, shows that in soil two feet or less in depth, the second foot contains two per cent of water less than does the first foot. In soil three feet deep there is a similar though more gradual diminution, from 20.59% in the first foot to 17.23 % in the third. The same law seems to hold with the plats four feet deep, though the per cents of water in the second, third and fourth feet, are nearly of the same magnitude. The last line in the tables shows the behavior of water in plats five feet deep; but, since the results are based on work with two plats, and seven single trials, only, little weight can be given them.

It is worthy of note that the per cents of water in the first and second feet become smaller as the soil becomes deeper. Consequently, the deeper the soil, the smaller would be the possible relative wetting. As a confimation of theory, the data are interesting.

TABLE NO. 16.—DISTRIBUTION OF WATER IN THE TOP FOOT OF SOIL.

(Just after irrigation.)

No. of Plats	Average depth of plats	No. of single tests	Percent of water in 0-3 in.	3-6 in.	6-9 in.	9-12 in
20	29	62	22.45	21.56	20.41	18.77

This table teaches that there is a gradual diminution of water in the top foot of soil, from the surface to the lower limit. Studying this table in connection with the one which precedes, it appears justifiable to conclude that the per cent of water in soils three or four feet deep, just after irrigation, becomes smaller as the depth increases. The rate of change is more rapid in the first foot, however, than in the succeeding feet.

To what depth the soil moisture will be affected by the application of water to the top soil is an interesting question that arises in connection with the study of the distribution of water in soils. The smallest amount of water that could be made to cover 2x4 rods, was a trifle less than two inches; this quantity, in every case, increased the per cent of water in every foot of soil down to the gravel bottom, even with the deepest plats which were about five feet in depth. To study the effect of smaller applications, it was necessary to depend on the few showers that occurred during the season. No special attempts were made to study this question exhaustively; the following table represents, therefore, only such plats as happened to be sampled just before and after a shower. As indicated in table 18, 0.14 inches of rain fell on September 22nd; 0.97 inches on September 24th, and 0.93 inches on August 20th.

TABLE NO. 17.—EFFECT OF SMALL APPLICATIONS OF WATER ON SOIL MOISTURE.

Plat No.	Depth	Date	Per cent of water in Soil inches. 0–3	3–6	6–9	9–12	12–24	24–36	Increase of water lbs per sq. ft.	Rainfall lbs. per sq.ft.	in.
255A	25	Sept. 19	3.36	4.76	5.48	6.04	6.44				
		Sept. 23	4.76	5.59	6.15	6.61	6 83		1.15	0.73	0.14
		Increase	1.40	0.83	0.67	0.57	0.39				
256A	17	Sept. 19	3.09	4.60	5.03	5.14	4.76				
		Sept. 23	5.54	6.95	6.66	6.38	6.38		2.31	0.73	0.14
		Increase	2 45	2.35	1.63	1.24	1.62				
257A	23	Sept. 19	3.73	5.70	5.76	5.82	6.04				
		Sept. 23	6.32	7.23	7.93	9.17	7.64		2.25	0.73	0.14
		Increase	2.59	1.53	2.17	3.35	1.60				
259A	26	Sept. 19	2.72	4.27	4.81	5.26	5.76				
		Sept. 23	4.05	5.76	5.93	6.21	6.72		2.08	0.73	0.14
		Increase	1.33	1.49	1.12	0.95	0.96				
255A	25	Aug. 15	4.49	5.59	5.70	5.82	6.15				
		" 20	15.34	13.51	11.33	8.64	8.64		8.43	4.84	0.93
		Increase	10.85	7.92	5.53	2.82	2.49				
256A	17	Aug. 15	4.32	6.44	6.55	6.38	6.38				
		" 20	17.86	14.03	11.99	10.19	10.19		8.17	4.84	0.93
		Increase	13.54	7.59	5.44	3.81	3.81				
258A	29	Aug. 15	5.48	5.37	7.28	8.70	7.93	7.93			
		" 20	15.94	13.90	12.62	11.48	9.00	7.93	7.45	4.84	0.93
		Increase	10.46	8.53	5.34	2.78	1.07	0.00			
259A	26	Aug. 15	7.93	12.05	8.70	7.28	7.76	7.76			
		" 20	17.37	14.54	11.80	9.95	8.52	8.52	4.73	4.84	0.93
		Increase	9.44	2.49	3.10	2.67	0.76	0.76			
255A	25	Sept. 19	3.36	4.76	5.48	6.04	6.44				
		" 26	12.36	12.49	11.99	11.05	10.68		10.36	5.05	0.97
		Increase	9.00	7.73	6.51	5.01	4.24				
256	17	Sept. 19	3.09	4.60	5.03	5.14	4.76				
		" 26	13.00	11.80	10.44	8.70	6.77		6.56	5.05	0.97
		Increase	9.91	7.20	5.41	3.56	2.01				
257A	23	Sept. 19	3.73	5.70	5.76	5.82	6.04				
		" 26	13.83	13.00	11.11	8.70	8.82		7.97	5.05	0.97
		Increase	10.10	7.30	5.35	2.88	2.78				
258A	29	Sept. 19	3.31	4.21	4.71	5.14	4.54	4.54			
		" 26	13.00	11.99	10.62	9.65	7 70	7.70	6.16	5.05	0.97
		Increase	9.69	7.78	5.91	4.51	3.16	3.16			
259A	26	Sept. 19	2.72	4.27	4.81	5.26	5.76	5.76			
		" 26	13.77	13.51	11.11	8.11	7.41	7.41	8.26	5.05	0.97
		Increase	11.05	9.24	6.30	2.85	1.65	1.65			

A study of this table will reveal that 0.14 inches of rain increased slightly the per cent of moisture down to a depth of 26 inches—the depth of the deepest plat. The increase, as would be expected from the preceding discussion, became less as the depth increased. After the shower on August 20th, there was a very marked increase throughout the whole depth of the plats, amounting in one case to 3.81 % in the second foot. The combined showers on September 22nd, and 24th affected the soil moisture in the same manner. Just how small a precipitation is necessary to affect the moisture of the first foot only is not evident from these observations except that it must be less than 0.14 inches.

The continuous film of water that surrounds every soil grain is constantly seeking a condition of equilibrium, and it is very sensitive to all causes that tend to destroy the balance of capillary forces. The slightest moistening of the top, or any other part of the soil, will lead to immediate thickening or thinnings of the water film that will continue until it is in the nearest possible condition of equilibrium. Because 0.14 inches of rainfall leads to an increase of moisture in the second or third foot of soil, it does not follow that the rain has soaked down to that depth, but, rather, that the whole mass of soil moisture has moved down a trifle to compensate for the extra amount received by the top.

TABLE NO. 18.—INCREASE IN SOIL MOISTURE DUE TO RAINFALL.

Date of rainfall	Depth of rainfall	Pounds of water per sq. ft. from rainfall.	Increase of water. Pounds per sq. ft. by analysis.
Sept. 22nd.	0.14 in.	0.73	1.95
Aug. 20th.	0.93 in.	4.84	7.19
Sept. 24th.	0.97 in.	5.05	9.83

It must not be overlooked, in the study of table No. 18, that the increase in the amount of water, as determined by analysis, is higher than that indicated by the rain guage. Averaging all the results, twice as much water has been added to the soil according to analysis as would be possible if the record of the rain guage be accepted as being correct. There are several possible sources of error on the analytical side, such as imperfect sampling and soil variation, but since twelve out of thirteen observations based upon analytical data show a very good agreement, it seems hardly possible that the difference can be accounted for without taking into account also the possibility of error in the rain guage. The rain guage used by the Station is situated about one-fifth of a mile west of the irrigation plats; it is of the ordinary pattern furnished voluntary observers by the U. S. Weather Bureau. Much has been written about the trustworthiness of the standard rain guage; the data here presented cannot dispose of the matter, but the question may certainly be asked, "Is the ordinary rain guage a satisfactory guide in studying atmospheric precipitation?"

14. LATERAL MOVEMENTS.

As shown in the preceding sections, water, applied to soil, is pulled downward by gravity, but at the moment it enters the soil, capillarity is awakened which pulls the water in all directions from the wetted center. The actual motion of the water, not considering the special behavior of that portion which fills the soil pores, and is therefore under the immediate influence of gravity, is a resultant of the vertically downward, and the more or less horizontal pulls. This results in a lateral movement of soil water, which is of special importance in furrow irrigation.

That the lateral capillary movement of soil water cannot be very great was evident from the fact that the edges of unirrigated plats of wheat, only three or four feet removed from plats which received abundant irrigations, did not seem to be at all benefited by water that might have moved laterally from the irrigated soil. This observation which had frequently been made in past seasons warranted the close proximity of the plats of the experiments recorded in this bulletin.

No special experiments were made on the lateral movements of water, but data obtained from the plats used for furrow irrigation, threw some light on the subject. These results are shown in table 19.

TABLE NO. 19.—THE LATERAL MOVEMENT OF SOIL WATER.

No. of plats	Average depth of soil (inches)	Single observations	Per cent of water in			
			First foot		Second foot	
			Furrow	Row	Furrow	Row
6	23	12	19.29	14.24	17.45	13.88
Difference			5.05		3.57	

The average distance between rows was about 36 inches—making the distance between the middle of row and furrow about 18 inches. During irrigation the furrows were well filled with water so that the distance between the edge of the water and the middle of row was never very much more than 12 inches. Table No. 19 shows that the first foot of the furrow contained 19.29% water, while the row contained only 14.24 %, which is equivalent to a decrease of 5.05% in a distance less than 18 inches. If the same rate of decrease continued, and assuming that capillary action ceases at 4 % (see section 25,) the lateral spreading of the water of the first foot would not extend beyond 4½ feet, and probably not beyond 3 feet. When it is considered that the water is soaking laterally from two furrows 36 inches apart, the per cent of moisture at the point midway is in all probability higher than it would be if only one furrow contained water; and, likewise, the calculation made above probably gives too high a figure.

In the second foot, the furrow contained 17.45 % water, and the row 13.88 %, a difference of 3.57 % in favor of the furrow. Using the method of calculation followed in the preceding paragraph the lateral spreading of the water of the second foot would be less than 6 feet. The lateral movement of the water increases, therefore, with the depth of the soil. This is in full accord with theoretical deductions. The shallow nature of the soil made observations on lower soil sections impossible. A mass of earth moistened by water from above would correspond in general to a truncated cone, the upper surface of which is the area that was under water, while the lower surface, height and slope vary with the amount of water applied, and the nature of the soil.

Two furrow-irrigated plats were sampled every three inches to a depth of one foot. The results obtained as presented in table No. 20, confirm the conclusion drawn from the data of table No. 6; namely, that the extent of the lateral spreading of soil water increases with the depth of the soil.

TABLE NO. 20.—THE LATERAL MOVEMENT OF SOIL WATER.

No. of plats	Average depth in.	Single observations.	Per cent of water in							
			1st. 3 in.		2nd. 3 in.		3rd. 3 in.		4th. 3 in	
			Furrow	Row	Furrow	Row	Furrow	Row	Furrow	Row
2	20	5	23.35	13.56	20.24	12.96	19.63	13 84	17.07	13.89
Difference			9.79		7.28		5.79		3.18	

The lateral movement of capillary soil moisture does not appear to be a factor of much importance to the irrigation farmer who deals with bench lands.

15. CAUSES OF LOSS OF SOIL WATER.

Soils may lose the water applied to them in three way.

1st. If an excess of water be added, especially to shallow soils, a large portion may drain into the gravelly subsoil, and thus be lost. With deep soils, it may happen that the water drains so deeply into the soil, as to be beyond the reach of plant roots.

2nd. By capillary action, the water stored in the soil is brought to the surface, and there evaporated under the influence of sunshine, wind and other meterological factors.

3rd. Plant roots take large quantities of water from the soil, which are evaporated from the plant leaves.

The *rate of loss* from any one of these causes depends on numerous factors, some of which are briefly considered in the following pages.

1. Rate of drainage from soils depends upon,
   a. Nature of soil.
   b. Depth of soil.
   c. Nature of subsoil.
2. Rate of evaporation from bare soils. Discussed in later reports of these irrigation investigations.

3. Rate of loss from soil on which plants are growing depends on,

a. Nature of soil.
b. Initial per cent of water.
c. Depth of soil.
d. Time.
e. Meteorological conditions.
   1. Temperature
   2. Sunshine.
   3. Relative Humidity.
   4. Showers.
   5. Wind.
f. Condition of top soil and subsoil
   1. Plowing.
   2. Cultivation.
g. Kind of crop.
h. Age of crop.

The nature of the soil, as a factor in the rate of loss of soil moisture, is not discussed in the following pages, for the reason that the experiments were conducted on a very uniform piece of ground. Pot experiments with various soils have given data that will be presented in later reports of these irrigation investigations.

16. LOSSES DUE TO DRAINAGE.

This subject, which involves a comparative study of soils, is part of a general investigation on the relations of irrigation, drainage, and alkali lands, which will be published later. Facts of importance to all who own bench lands were emphasized in this investigation; these will be briefly mentioned.

Using the data given in Part A of this bulletin, it is known that one inch of water will saturate about 2.46 inches of the soil of the College bench-land farm. The average depth of the 100 plats used in the irrigation investigations of 1901, is a trifle more than 26 inches. Between 10 and 11 inches of water would then be enough to saturate the soil. The shallowest plat is 8 inches deep and the deepest only 59 inches, which would be saturated, respectively, by 3.25 and 23.95 inches of water. It has been found, however, that under ordinary field conditions the absolute water capacity is reduced to between 65 % and 80 % of what it is under laboratory conditions. This would make about 8 inches of water sufficient to saturate the average plat of the farm. An ordinary irrigation, usually represents more than 8 inches, and should be materially reduced in view of the shallower portions, through which the water will drain rapidly.

On shallow lands, with gravelly subsoils, that characterize the bench lands of Utah, it is very inadvisable to apply water in excess of the quantity which is necessary to saturate the soil, for any excess simply drains into the subsoil without benefiting the crop and raises the standing water table of the valleys, which is already too high. Besides, large quantities of plant food are leached out by excessive irrigation to reappear in the valley as alkali—to the injury of both high and low farmer.

Excessive irrigation on bench lands is an evil which affects the irrigator and his neighbor who lives lower down. It is much better and more economical to irrigate more frequently, using less water at the time, than to let the water run for hours on a piece of ground, in the belief that large crops will result.

The seepage from the College farm, on which these experiments were conducted, has been so great in past years as to convert a street and the fields just under the College hill into a swamp, which had to be reclaimed by a system of tile drainage.

17. THE EFFECT OF THE INITIAL PER CENT OF MOISTURE.

All the soil moisture determinations made on the irrigation plats agreed in showing that the daily loss of water varied directly with the average per cent of water found in the soil on the day after irrigation—all other conditions being as nearly the same as it was possible to obtain them. By the average per cent is meant the average from the top to the gravel subsoil.

Table 21 exhibits in detail the data upon which the above statement is based.

TABLE NO. 21.—EFFECT OF INITIAL PER CENT OF WATER ON THE RATE OF LOSS OF SOIL MOISTURE.

Crop	Number of plat	Depth of plat (in.)	Number of days	Average per cent water at beginning.	Total weight water lost sq. ft. (in lbs)	Daily loss of water per sq. ft. (in lbs)	Daily loss of water per sq. ft. & per cent (in lbs)
Wheat	306	18	30	26.20	28.17	0.939	0.0358
"	319	19	30	21.71	20.81	0.694	0.0319
"	317	18	31	19.30	17.51	0.565	0.0293
"	320	19	27	24.05	25.05	0.928	0.0386
"	321	18	27	22.63	22.52	0.834	0.0369
"	306	18	23	25.35	24.66	1.072	0.0423
"	321	18	24	18.35	17.91	0.746	0.0406
"	328	11	20	26.51	15.81	0.791	0.0298
"	322	10	20	22.79	11.87	0 594	0.0261
Oats	296	34	19	19.48	27.63	1.454	0.0746
"	297	37	19	13.21	20.17	1.062	0.0804
"	299	36	13	23.02	28.93	2.225	0.0967
"	297	37	14	20.93	25.68	1.834	0.0876
"	297	37	11	16.01	21.69	1.972	0 1232
"	298	36	11	13.83	16.98	1.544	0.1116
Young Lucern	323	14	28	24.27	20.09	0.718	0.0296
	323	14	28	11.55	5.87	0.210	0.0132
" "	315	28	21	20.20	21.76	1.036	0.0513
" "	315	28	20	12.51	12.30	0.615	0.0492
" "	307	20	20	16.34	15.74	0.787	0.0482
" "	307	20	20	9.48	7.71	0.386	0.0407
Sugar Beets	361	33	24	18.13	26.88	1.120	0.0618
" "	367	32	24	16.77	25.17	1.049	0.0626
" "	352	30	23	24.11	24.69	1.073	0.0445
" "	350	31	33	20.64	22.75	0.987	0.0478
" "	367	32	17	22.56	30.93	1.718	0.0762
" "	351	32	18	20.56	23.68	1.593	0.0775
Potatoes	255a	25	10	12.51	11.29	1.129	0.0923
"	259a	29	10	16 75	20.99	2.099	0.1250

In the last column numbers are found which have been obtained by dividing the daily loss of water by the initial per cent of moisture. These numbers, considered in sets, are remarkably uniform, and indicate the close adherence to the rule that the initial per cent of moisture is an important factor in determining the rate of loss of soil moisture.

The reason for this effect of the initial percent can be fairly well understood. The fine roots and root hairs come into contact with a comparatively small area of the soil moisture film, hence, as water is drawn into the plant, there must be a motion or flow of moisture towards the place of contact. If the film is thick, the water will move with some freedom and the plant. in a given time, and with the expenditure of a given amount of energy, will obtain a larger amount of water than is possible, if the film is thin, and as a consequence, the motion of the soil moisture more difficult. The same principle holds in the case of the water evaporated from the surface of the soil; the thicker the water film, the more rapid will be the evaporation; the thinner the film, the slower the evaporation.

The thickness of the film of water around the soil grains varies directly with the per cent of water contained by the soil; hence, the correctness of the law, that *the rate of loss of water from soils varies directly with the initial per cent of moisture in the soil.* This is equivalent to saying that the more moisture there is in the soil, to a given depth, the more is lost, in a given time by plant and sun action. As far as these experiments have been carried, this has been true in every case where the amount of water was less than the absolute water capacity. It seems that plants are not able to regulate the amount of water taken up by them, but that not considering meteorological influences the rate of transpiration varies with the ease with which water may be obtained. If this be the case, plants may, under certain circumstances, waste water.

In shallow soils, or in soils with a hardpan near the surface, a given amount of water is not given the chance of wetting the soil to considerable depths, and, as a consequence, the per cent of moisture is higher, which causes a more rapid loss of soil moisture. Shallow soils or soils underlaid by hardpan are, therefore, less economical than deep ones, considered from the point of view of the conservation of soil moisture. This matter, which has an important bearing on the economical use of water, will be discussed later and more fully in this and succeeding reports of these investigations.

The last column of table 8 shows that the rate of loss per per cent,in most cases is higher when the total initial per cent of water is highest. That is, from a soil containing 20 % of water, the loss of soil moisture in a given period of time will be more than twice as much as that lost by a soil containing 10 % of water. This principle finds application in the practice of furrow irrigation.

18. EFFECT OF DEPTH OF SOIL.

If it be true that the rate of loss of soil moisture varies with the initial per cent of water in the soil, it follows that a deep soil will lose water more rapidly than a shallow soil having the same initial per cent of water.

This may be shown in the following manner:

Two soils have the depths d and $d+d'$. The per cent of moisture is the same in both, at the beginning of the test, namely P. During the first interval of time, one hour we may say, the losses of moisture from the two plats may be said to be equal or nearly equal and represented by L.

Pd and $P(d+d')$ are the amounts of water in the two soils at the beginning: after the first interval, they have become $Pd-L$ and $P(d+d')-L$. If these latter amounts be divided by the respective depths of soil, the new per cents of moisture will be found:

$$\frac{Pd+L}{d} \text{ and } \frac{P(d+d')-L}{d+d'} = \frac{P-L}{d} \text{ and } \frac{P-L}{d+d'}.$$

It is evident that the per cent of moisture is larger in the deeper soil than in the shallow, for

$$\frac{P-L}{d} \text{ is smaller than } \frac{P-L}{d+d'}$$

At the beginning of the second interval, then, the deeper soil, having a higher per cent of moisture than has the shallower soil, will lose its moisture more rapidly. This difference will continue and become greater as the length of time increases.

This result may be understood without the use of the algebraic demonstration. If two soils are one and and two feet deep respectively, and both contain an average of 10 % of moisture, they will contain respectively, per square foot of surface, ten and twenty pounds of water (one cubic foot of soil weighing 100 pounds.) During the first day each soil may lose two pounds of water, in accordance with the law stated in the preceding section. In the shallow soil, will remain, then, eight pounds, and in the deep eighteen pounds of water, which represents 8 % and 9 %. The deeper soil, having a higher per cent of moisture at the beginning of the second day, will lose more water during that day, than will the shallow soil with a lower per cent of moisture.

While it is unquestionably true that the greater rate of loss of moisture from deep soils may be explained as above, yet it must not be forgotten that in a deep soil, a fuller development of the root systems of the crops is possible, and that, therefore, a larger feeding surface is produced which naturally would draw more rapidly upon the stock of soil moisture.

It thus becomes evident that several factors are involved in the law that the rate of loss of soil moisture increases with the depth of the soil.

In table No. 22, experimental data on the relation between depth of soil and rate of loss of soil moisture are represented.

TABLE NO. 22.—EFFECT OF DEPTH OF SOIL ON RATE OF LOSS OF SOIL MOISTURE.

	Number of plat	Depth of plat inches	Number of days	Average per cent water at beginning	Total weight of water lost in lbs. per sq. ft.	Daily loss of water in lbs. per sq. ft	Daily loss of water per cubic ft. in lbs.
Wheat	325	36	30	21.33	27.31	0.910	0.303
"	319	19	30	21.71	20.81	0.694	0.438
"	318	28	25	17.90	21.92	0.877	0.376
"	321	18	24	18.35	17.91	0.746	0.497
"	314	16	20	21.44	16.58	0.829	0.623
"	322	10	20	22.79	11.87	0.594	0.713
"	327	12	17	26.09	17.16	1.010	1.010
"	330	9	17	25.95	10.47	0.616	0.821
"	326	27	7	23.61	28.46	4.066	1.807
"	330	9	5	23.60	4.70	0.940	1.253
Oats	296	34	27	22.21	44.28	1.640	0.579
"	295	23	27	24.43	33.81	1.252	0.653
"	293	16	27	20.38	19.73	0.731	0.550
"	297	37	19	13.21	20.17	1.062	0.344
"	293	16	19	11.38	8.77	0.462	0.347
"	294	41	19	17.16	31.33	1.649	0.483
"	296	34	19	19.48	27.63	1.454	0.513
"	294	41	14	22.27	27.87	1.991	0.583
"	299	36	14	20.65	23.96	1.711	0.570
"	294	41	11	17.68	23.44	2.131	0.624
"	297	37	11	16.01	21.69	1.972	0.640
Young	323	14	28	24.27	20.09	0.718	0.615
Lucern	332	9	28	23.60	12.67	0.453	0.604
"	315	28	21	20.20	21.76	1.036	0.444
"	323	14	20	23.52	16.58	0.829	0.710
"	307	20	20	16.34	15.74	0.787	0.472
"	332	9	20	15.00	6.94	0.347	0.463
"	307	20	15	17.53	18.51	1.234	0.740
"	323	14	15	19.98	14.38	0.959	0.822
Timothy	371	31	81	19.21	31.87	0.393	0.152
"	372	27	80	19.87	30.64	0.383	0.170
"	348	12	47	21.06	14.63	0.311	0.311
"	349	17	47	20.62	16.53	0.352	0.249
"	348	12	27	21.14	14.99	0.555	0.555
"	371	31	26	21.81	25.71	0.989	0.383

Table 22 (Continued.)

	Number of plat	Depth of plat inches	Number of days	Average per cent. water in beginning	Total weight of water lost in lbs per. sq. foot.	Daily loss of water in lbs. per sq. foot	Daily loss of Water per cubic foot in lbs.
Sugar Beets	353	15	24	20.12	14.47	0.603	0 482
" "	351	32	24	19.04	24.44	1.018	0.382
" "	364	26	24	18.59	23.28	0.970	0.448
" "	361	33	24	18.13	26.81	1.117	0.405
" "	363	37	24	17.05	31.46	1.311	0.425
" "	367	32	24	16.77	25.17	1.049	0.393
" "	353	15	23	23.84	17.36	0.755	0.604
" "	352	30	23	24.11	24 69	1.073	0.429
" "	364	26	22	19 94	20.07	0.912	0.421
" "	361	33	22	19.34	26.34	1.197	0.435
" "	367	32	18	22.56	30.93	1.718	0.644
" "	353	15	18	22.83	17.08	0.949	0 759
" "	363	37	18	18.09	30.57	1.698	0.551
" "	364	26	18	18 82	22.26	1.237	0.571
" "	361	33	18	17.89	17.46	0.970	0.353
" "	374	52	18	16.14	25.17	1.398	0.323
" "	353	15	16	23 31	15.13	0.946	0.757
" "	365	12	16	22 94	12.02	0.751	0.751
" "	367	32	16	17.90	14 29	0.893	0.335
" "	374	52	16	17.31	27.20	1.700	0.392
Potatoes	257 a	23	21	21.10	23.70	1.129	0.589
"	259 a	26	21	19.30	24.13	1.149	0.530
"	258 a	29	21	20.96	25.33	1.206	0.499
"	260 a	38	22	21.11	29 15	1.325	0 418
"	257 a	23	18	26.21	28.73	1.596	0.833
"	263 a	59	17	20.21	38.53	2.266	0.461

As shown in table No. 22, sixty-one observations were found that could be arranged in twenty-eight sets, in each one of which the soil depth was the only variable factor. In every case the loss of soil moisture varied directly with the soil depth. In the last column the ratio between the daily loss of water and the depth of soil is stated. Though there is a general agreement in the numbers so obtained, there are so many exceptions as to make general deductions inadvisable.

A striking confirmation of the law of this relation was furnished by the arid farm plats. These plats were sown to wheat in the fall of 1900, and were allowed to ripen without irrigation. Soil moisture determinations were made on May 8th, and again on July 17th, 1901, when the crops were harvested. The whole period between the first and the last sampling was seventy days. The average per cent of moisture on May 8th was 20.16 and on July 17th, 4.32.

TABLE NO. 23.

Plat number	Depth of plat in.	Total loss of water per sq. ft in lbs.	Daily loss of water per sq. ft. in lbs.	Daily loss of water per cu. ft. in lbs.
301	18	19.63	0.280	0.187
302	29	35.37	0.505	0.209
303	23	28.80	0.411	0.214
305	23	28.95	0.414	0.215
310	20	23.96	0.342	0.205
311	18	20.09	0.258	0.191
313	16	16.97	0.242	0.181

Considering the possible errors due to soil variation, sampling and analysis, these results indicate with surprising distinctness that even a slight increase in the depth of soil is accompanied by a correspondingly increased rate of loss of soil moisture.

19. THE EFFECT OF TIME.

It is evident that the longer the time, the more water is lost from the soil. From the principles laid down in the two preceding paragraphs it is also clear that the rate of loss will diminish with the time. The data on hand furnish averages that indicate the varying rate of loss of soil moisture for averages of all the crops and plats used in the irrigation investigations. Since no special experiments were made on this subject, it was found difficult to eliminate all factors other than time in the table to be presented, yet the results obtained can be relied on to show the truth for average farm conditions, under the prevailing conditions on the College farm.

TABLE NO. 24.—THE EFFECT OF TIME ON THE RATE OF LOSS OF SOIL MOISTURE.

Depth of soil (inches)	No. of observations	Per cent of water at beginning.	Total weight of water lost per sq. ft. lbs	Daily loss of water per sq. foot lbs.	Days after irrigation.	Crops.
			Semi-weekly periods.			
28	25	20.28	6.96	2.32	1–3	Wheat, potatoes, corn.
22	19	15.75	6.52	1.63	4–7	Wheat, potatoes.
22	14	13.19	4.77	1 59	8–10	Wheat, potatoes.
22	15	11.07	3.67	0.92	11–14	Wheat, potatoes.
			Weekly periods.			
25	66	20.15	11.81	1.69	1–7	Timothy, young and old lucern, potatoes, corn.
21	46	13.08	7.59	1.09	8–14	Wheat, young lucern, potatoes.
22	15	8.92	4.24	0.61	15–21	Wheat, young lucern.
18	4	7.71	2.45	0.35	22–28	Young lucern.
			Bi-weekly period.			
27	86	20.69	21.61	1.54	1–14	Wheat, oats, young lucern, corn, Potatoes.
			18-Day period.			
26	19	21.04	22.74	1.26	1–18	Oats, old lucern, timothy, sugar beets.
			Tri-weekly period.			
23	95	20.31	21.96	1.05	1–21	Wheat, young lucern, English rye, sugar beets, potatoes.
			Four-weekly period.			
23	45	21.78	23 82	0.85	1–28	Wheat, oats, young and old lucern, orchard grass, timothy, red clover, Kentucky blue grass.

Irrigation of the same piece of land is seldom practiced oftener than once a week; more usually, on the bench lands, irrigations are two to four weeks apart. On the deep lands of the valley, irrigation does not need to be performed so often, for more water can be stored in such soils at any one time.

During the first week that elapses after an irrigation on soil approximately twenty-five inches deep, there is a daily loss per square foot of 1.69 pounds. Of this loss, 52% occurs during the first three days, and 48% the last four days. During the second week, on soil twenty-one inches deep, there was a daily loss of 1.09 pounds of water per square foot, of which 57% was lost the first three days, and 43% the last four. During the third week, on soil twenty-two inches deep, the daily loss of water per square foot equalled 0.61 pounds; while, during the fourth week, on soil eighteen inches deep, the daily loss per square foot was only about 0.35 pounds. It will be observed from table No. 11, that different combinations of the data given will give results slightly different from those first quoted. This is due, clearly, to the varying depth of soil, and kind of crop grown.

In the following table the proportions of water lost at different times during one, two, three and four week intervals between irrigations are exhibited.

TABLE NO. 25.—RELATIVE LOSS OF SOIL MOISTURE AT DIFFERENT TIMES DURING VARIOUS INTERVALS BETWEEN IRRIGATIONS.

Interval	Depth of soil	Total loss lbs. per sq. ft.	Per cent loss during 1st week 1–3	1st week 4–7	2nd week 1–3	2nd week 4–7	3rd week 1–3	3rd week 4–7	4th week 1–3	4th week 4–7
One week	25	11.81	52	48						
Two weeks	27	21.61	31	29	23	17				
Three weeks	23	21.96	26	24	17	15	18			
Four weeks	23	23.82	23	22	17	12	16		10	

During a week interval, then, more than one-half of the total loss occurred during the first three days; during a two week interval, fifty per cent was lost the first week, and, during a four week interval, 45% was lost the first week. In every case, more water was lost during the first three days of the first week, than was lost during the next four days.

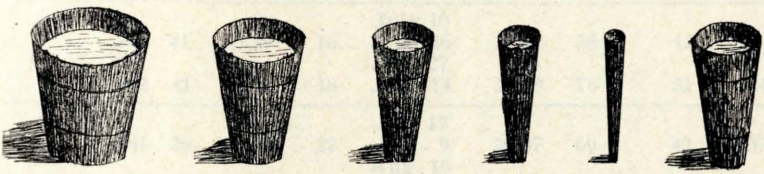
These results teach with emphasis that methods designed to conserve soil moisture, should be put into operation as soon as possible after irrigation. If cultivation is practiced, it should be applied as soon as the soil is dry enough to support the tools; if it is postponed a week from the time of irrigation, more than one-half of the water has been lost. Besides at the end of a week the top soil has been so dried out as to act as a fairly good mulch, and cultivation does not aid greatly in the conservation of the remaining soil moisture, though it may have other very beneficial effects. (See later reports of these investigations.)

FIG. 3.—LOSS OF WATER FROM ONE SQUARE FOOT IN TWO WEEKS.

1. 2. 3. 4. 5. 6.

1. Total loss in 2 weeks.
2. Loss during 1st—3rd days.
3. Loss during 4th—7th days.
4. Loss during 8th—11th days.
5. Loss during 12th—14th days.
6. Loss from water surface in 2 weeks.

FIG. 4.—LOSS OF WATER FROM ONE SQUARE FOOT IN FOUR WEEKS.



1. 2. 3. 4. 5. 6.

1. Total loss in 4 weeks.
2. Loss during 1st week.
3. Loss during 2nd week.
4. Loss during 3rd week.
5. Loss during 4th week.
6. Loss from water surface in 4 weeks.

The extent to which loss of soil moisture may go, is discussed in a later section.

Using the data in table 6, it may be determined that the average weekly rate of evaporation from a free water surface during June, July and August, 1901, was about 9.08 pounds per square foot. This is considerably less than was lost per square foot, from soil the first week after irrigation. This fact emphasizes the great rate at which water is pumped through plants immediately after an irrigation; and shows also, that the amount of water lost by direct evaporation from soils is small when compared with the quantities lost by transpiration.

20. THE EFFECT OF METEOROLOGICAL CONDITIONS.

Meteorological conditions exert a marked influence upon the loss of soil moisture. The relations are so complicated that it is very difficult to eliminate all other factors leaving only those that are directly of a meteorological nature. Special experiments, made with special apparatus, are necessary to establish the quantitative value of meteorological factors as affecting the loss of soil moisture. The special importance of the data to be presented is that the observations were made on soils actually used for crop production, and under field conditions. It must be borne in mind that far-reaching conclusions cannot be drawn from the data of the following tables.

TABLE NO. 26—THE EFFECT OF RELATIVE HUMIDITY.

Temperature and Sunshine constant.

Crop	Number of plat	Depth of plat (inches)	Percent water at beginning	Length of period (days)	Date	Total loss of water per sq. foot (lbs)	Average Temperature F°.	Relative humidity per cent	Hours of sunshine.
Sugar beets	353	15	23.30	16	July 10 July 26	15.13	78	42	129
"	352	15	22.96	16	July 27 Aug. 14	17.08	76	51	124
"	361	33	19.34	22	June 17 July 9	26.34	69	42	207
"	361	33	18.14	24	Aug. 16 Sept. 9	25.88	69	51	199
"	361	33	18.90	16	July 10 July 26	14.64	78	42	129
"	361	33	17.89	18	July 27 Aug. 14	17.46	76	51	124
"	362	41	20.39	16	July 10 July 26	27.82	78	42	129
"	362	41	18.54	18	July 27 Aug. 14	28.39	76	51	124
"	364	26	18.94	22	July 17 July 9	20.07	69	42	207
"	364	26	18.60	24	Aug. 16 Sept. 9	23.28	69	51	199
"	364	26	18.72	16	July 10 July 26	16.19	78	42	129
"	364	26	18.82	18	July 27 Aug. 14	22.26	76	51	124
"	365	12	26.90	22	Aug. 17 July 9	16.39	69	42	207
"	365	12	27.54	24	Aug. 16 Sept. 9	17.73	69	51	199
Averages		27	21.06	18		19.50	74	42	163
		27	20.35	20		21.73	73	51	156

In this table the average temperature and hours of sunshine are nearly constant. The weight of water lost per square foot during the period for which the relative humidity of 51% prevailed, was 21.73 pounds; while for the period of 42% only 19.50 pounds were lost. However, the former period extended over twenty days, and the latter over eighteen days, only. Allowing for this difference in time, it appears that the difference in relative humidity exerted no great influence upon the loss of soil moisture. It would naturally be expected that, under a low relative humidity, which means drier air, the loss of water from soils and plants would be more rapid than when the humidity is higher. A difference of nine points, under Utah conditions, does not confirm this expectation. We are not prepared to give any reason for this. Much certainly depends upon the nature of the crop, the soil, method of making the observations, and other less known factors. We may be justified, perhaps, in drawing the conclusion that a variation in the relative humidity, within ten points, has less effect upon the loss of soil moisture than has a variation in other meteorological conditions.

TABE NO. 27.—THE EFFECT OF SUNSHINE AND RELATIVE HUMIDITY.

Temperature constant.

Crop	Number of plat	Depth of plat (inches)	Per cent water at beginning	Length of period (days)	Dates	Total loss of water per sq. foot (lbs)	Average temperature F°.	Relative huminity per cent	Hours of sunshine.
Young	307	20	17.54	14	July 5 July 19	18.05	77	78	127
Lucern	307	20	16.34	13	July 23 Aug. 5	8.61	78	52	90
Young	315	28	19.57	14	July 5 July 19	19.36	77	78	127
Lucern	315	28	20.19	14	July 23 Aug. 5	18.08	78	53	90
Young	307	20	17.54	7	July 5 July 12	12.52	78	41	63
Lucern	307	20	16.34	6	July 23 July 29	7.72	78	51	36
Young	315	28	19.57	7	July 5 July 12	11.80	78	41	63
Lucern	315	28	20.19	6	July 23 July 29	10.22	78	51	36
Potatoes	262A	54	13.45	14	July 5 July 19	12 89	77	39	127
"	262A	54	14.48	14	July 22 Aug. 5	20.02	78	51	94
Averages		30	17.54	11		14.92	77	56	102
Averages		30	17.51	11		12.94	77	52	69

In table No. 27, the temperature is constant for the five periods; the relative humidity varies only by four points; but there is a difference for the eleven days, of thirty-three hours of sunshine or three hours daily. This larger amount of sunshine seems to have caused a loss of about two pounds of water per square foot of soil, for the period, or about one-seventh of the total amount lost. This difference may, probably, be ascribed safely to the extra sunshine, but the data obtained cannot, with equal safety, be used to determine the value of one hour of sunshine in causing the loss of soil moisture; for, the effect of sunshine naturally varies with the time after irrigation when it is most abundant, its continuous or intermittent nature, the time of the day when it is most abundant, the condition of the sky, the intensity of the light, and with many other factors.

TABLE NO. 28.—THE EFFECT OF TEMPERATURE AND RELATIVE HUMIDITY.

Sunshine constant.

Crop	Number of plat	Depth of plat (inches)	Percent water at beginning	Length of period (days)	Date	Total loss (lbs.)	Average temperature	Relative humidity	Hours of sunshine
Wheat	325	36	21.34	14	June 11 June 25	19.76	64	47	107
"	325	36	19.50	14	July 12 July 26	20.57	78	42	99
"	329	18	24.34	20	June 8-28	22.71	62	47	156
"	329	18	24.93	20	July 12 Aug. 1	25.70	79	43	148
Young lucern	315	28	20.84	7	June 4-11	7.02	57	51	57
Young lucern	315	28	19.57	7	July 5-12	11.80	78	41	63
Potatoes	255A	25	12.18	13	Aug. 20 Sept. 2	8.94	71	46	120
"	255A	25	13.22	13	July 5 July 18	13.20	77	38	118
"	262A	54	14.35	15	Aug. 8 Aug. 23	7.91	72	54	100
"	262A	54	14.48	14	July 22 Aug. 5	20.02	78	51	94
Averages		32	18.61	14		13.27	65	49	108
"		32	18.34	14		18.26	78	43	104

In table No. 28, the factor of sunshine is constant; the relative humidity varies six points only; but there is a difference of 13°F. in the average temperature. The increased loss of soil moisture, per square foot, during the period of higher average temperature, equals five pounds, for the fourteen days, or about 0.3 pounds daily. This higher rate of loss is unquestionably due to the greater average temperature; and it would appear, further, that of the three factors, temperature, sunshine and relative humidity; temperature is of first importance in causing a loss of soil moisture, and relative humidity is last. When the assimilation of carbon be considered, this relation may be changed; the discussion of transpiration of water to carbon assimilation will be found under the heading of Irrigation vs. Yield of Dry Matter and of Crop.

TABLE NO. 29—THE EFFECT OF TEMPERATURE AND SUNSHINE.

Relative humidity constant.

Crop	Number of plat	Depth of plat	Per cent water at beginning	Length of period (days)	Date	Total loss (lbs)	Average temperature	Relative humidity	Hours of sunshine
Wheat	318	28	18.90	21	June 10 July 1	21.10	64	45	180
"	318	28	18.95	21	June 19 July 29	20.29	78	42	159
Young lucern	315	28	20.84	14	June 4 June 18	11.12	58	50	105
"	315	28	20.19	14	July 23 Aug. 6	18.08	78	53	90
"	307	20	17.83	7	June 11 June 18	6 53	59	49	47
"	307	20	16.34	6	July 23 July 29	7.72	78	51	36
"	315	28	20.84	7	June 4 June 11	7.02	57	51	57
"	315	28	20.19	6	July 23 July 29	10.23	78	51	36
"	323	14	24.27	7	June 4 June 11	8.81	57	51	57
"	323	14	23.52	6	July 23 July 29	8.14	78	51	36
Average		29	20.54	11		10.92	59	51	89
		29	19.84	11		12.89	78	50	72

In table No. 29 the relative humidity is constant, while the temperature and sunshine vary. The difference in average temperature is nineteen degrees; in sunshine seventeen hours. It so happened that the greatest amount of sunshine came during the colder period, hence temperature and sunshine were opposed to each other. The difference in the amount of water lost, per square foot, during the periods, is about two pounds. This increase came during the warmer period. It seems conclusive then, that a difference of 19° in the average temperature, for eleven days, is more effective in causing water to leave the soil, than are seventeen hours of sunshine during the same period. Here, again, it must be remarked, that it is useless to establish any quantitative relation, for the factors to be considered are very numerous, and many have not been determined. It must also be remarked that the data contained in the last four tables are not selected, but they represent all the comparable results obtained by the season's work—that is, all the results in which one of the three factors is constant. In the remaining eleven sets, no certain comparisons can be made, and contradictions exist that can only be explained by knowledge beyond that which we now possess. Therefore, the remaining sets are not published.

Showers. Since a shower may be considered a light irrigation, it tends to increase the rate of loss of soil moisture. This loss is not due so much to the increased transpirationof the plant as it is to the establishment of capillary connection between the top soil, and the lower soil layers, by which direct evaporation from the soil is furthered. The observations made on the irrigation plats confirmed this view, but, since the subject will be taken up in a later bulletin, the scanty data obtained in the field during the season of 1901, will not be presented. Between June 1st and September 21st, only nine showers were noted. The smallest was .02 inch, and the largest 0.93 inch. The average was 0.25 inch. Such showers are not of a nature to cause great changes in the soil moisture.

Wind. A strong steady wind from Logan canyon blows almost every night over the experimental fields of the college farm. This wind certainly causes a great loss of soil moisture. No direct field tests were made to learn the extent to which evaporation of water was caused by this wind, but two tanks filled with water were placed at the experimental fields, one of which was covered during the day, while the other was always uncovered. The results of the season's work show, that 13.31 inches of water were evaporated during the period July 14th to Aug 31st from the uncovered tank, while only 10.60 inches were evaporated during the same time from the one covered at night.

21. THE EFFECT OF THE CONDITION OF TOP AND SUB SOIL.

According to many researches, the condition of the top soil influences, very materially, the evaporation of water from soil. It is believed that, if the upper inch or two of soil is very dry, it is difficult for the water to pass through it. If at the same time the top soil be loosened, capillary connection with the lower soil layers is broken, and evaporation is further hindered. Deep and frequent cultivation is, therefore, recommended for arid regions.

Different methods of plowing likewise affect the economical use of irrigation water. By deep plowing the capacity for storing water is increased; and thorough plowing breaks the capillary connections so that direct evaporation from the soil is hindered.

The transpiration of water by plants is not, probably, affected by the condition of the top soil. The condition of the sub-soil on the other hand bears important relations to transpiration.

These and other related problems could not well be studied during the season that the experiments, here reported, were conducted. In fact, no observations on bare plats were made. The treatment of this subject is, therefore, postponed to succeeding reports of these investigations.

22. THE EFFECT OF KIND OF CROP.

Different plants evaporate water at different rates. This depends on various factors. The relation between the extent of the root system and the leaf surface will condition, in a measure, the rate of transpiration. The more or less perfect shading of the soil by the crop determines in part, the evaporation from the soil. Other factors, depending on the nature of the crop, likewise affect the rate at which moisture is lost from the soil.

TABLE NO. 30.—KIND OF CROP AS AFFECTING RATE OF LOSS OF SOIL MOISTURE.

Crop	Depth of plat (inches)	Number of observations	Per cent water at beginning	Total weight water lost per sq. ft. lbs
		Weekly periods.		
Wheat	19	18	20.86	11.60
Young lucern	18	12	19.59	8.43
Old lucern	25	3	19.36	10.78
Potatoes	24	20	20.48	11.90
Wheat	19	12	13.13	7.82
Young lucern	18	11	14.76	5.71
		Bi-weekly periods.		
Wheat	19	30	20.86	19.42
Young lucern	18	13	19.59	14.14
Oats	36	4	22.29	27.98
Corn	36	2	20.60	25.54
		18-Day periods.		
Oats	36	4	16.62	25.00
Sugar beets	31	9	20.09	24.07
Old lucern	18	2	23.87	22.96
Timothy	17	1	23.89	18.69
		Tri-weekly periods.		
Wheat	24	18	16.49	21.10
English rye	21	2	22.68	18.17
Sugar beets	24	7	22.06	19.35
Potatoes	24	4	21.48	23.48
		Four-weekly periods.		
Wheat	18	3	23.10	24.26
Red clover	18	2	22.75	16.26
Oats	25	3	22.34	33.82
Lucern and orchard grass	23	2	23.58	24.87
Timothy	22	6	21.68	21.04

It is extremely difficult to obtain data on this subject that are strictly comparable. Table No. 30 presents a few results that indicate the different effects of various crops upon the loss of soil moisture.

It is s)mewhat surprising to note that the rate of loss from soil on which oats and wheat were growing was larger than from soils carrying young or old lucern, corn, sugar beets, red clover, timothy and English rye grass. Potatoes seem to use soil moisture more rapidly than any other crop in the experiment, and oats seems to come next. A distinction must be made here between the total amount of water used by a crop, and the rate at which that water is used. Wheat and oats, which mature early, use less water than sugar beets and other long growing crops; but the amount of water used in a day, or any other definite period, appears to be larger for the cereals than for the leguminous and root crops. Potatoes are an exception; in that they head the list. It may also be observed that in general the rate of loss is greater for annuals than for biennials and perennials. This would indicate that the rate of loss of soil moisture bears a definite relation to the rate of gain of dry matter, or the sum of the life-processes of the plant. This will be found discussed under the heading of *Irrigation versus the yield of dry matter and crop.*

The crops under discussion may be arranged in order, according to the rate at which they cause a loss of soil moisture. The order will be approximately correct only, and subject to revision as future experiments are made.

The following list begins with the crop which has the highest rate.

1.	Potatoes.	6.	Old lucern.
2.	Oats.	7.	Red clover.
3.	Wheat.	8.	Timothy.
4.	Corn.	9.	English rye grass.
5.	Sugar beets.	10.	Young lucern.

23. THE EFFECT OF THE AGE OF THE CROP.

The discussion of this subject is postponed to a later report, where more data will be available than were obtained during the season of 1901. In general, it may be said, that the rate of loss of soil moisture depends partly upon the age of the crop. When the crop is young and small much less water is removed from the soil by transpiration than is the case when the plant is older and larger. Late in the plant's life there comes a period when ripening sets in, and during this period transpiration again becomes smaller, and, as a consequence, the rate of loss of soil moisture is reduced. The subject is difficult to study under field conditions, for the elimination of other factors is well nigh impossible. Pot experiments, in which the various factors were well controlled, have thrown light on the subject. The results will appear in a later report of these investigations.

24. THE LOSS OF SOIL MOISTURE FROM VARIOUS DEPTHS.

In table No. 15 it was shown that one day after an irrigation, on the shallow soils of the College farm, the first foot contained a little more water than the second foot, and the second a little more than the third and so on. It was also shown that the differences were very small, especially from the second foot downward. It is of interest to know what depths of soil on which crops are grown lose the largest amount of water at different times after irrigation. Table No. 31 has been constructed to furnish a partial answer to this query.

TABLE NO. 31.—PER CENT OF SOIL MOISTURE AT VARIOUS DEPTHS AND AT DIFFERENT TIMES AFTER IRRIGATION.

Days after Irrigation	Number of trials	Percentage of water. 0–3 in.	3–6 in.	6–9 in.	9–12 in.	12–24 in.	24–36 in.
		Corn.					
1	6	21.64	22.69	21.88	16.96	16.39	18.81
8	6	7.95	12.79	12.09	12.41	11.64	14.89
12	6	7.71	10.43	11.43	11.94	12.21	14.53
		Potatoes.					
1	5	21.55	20.02	10.26	17.49	18.76	
5	5	11.85	16.17	15.13	15.07	16.13	
9	5	7.55	13.39	12.07	11.82	14.12	
12	5	7.04	11.12	10.59	10.31	11.34	
19	5	5.15	6.81	8.01	8.03	10.82	
23	5	4.84	6.45	6.98	7.43	8.66	
		Wheat.					
1	4	22.42	21.98	21.59	19.86	18.68	
9	4	13.35	15.03	14.78	14.02	16.12	
16	4	7.51	9.53	11.29	9.99	9.47	
23	4	4.91	7.22	7.13	7.12	7.52	
1	2	27.41	25.71	22.08	21.73		
9	2	15.11	16.08	15.78	13.41		
16	2	5.63	7.85	8.61	7.99		
19	2	5.48	6.68	6.33	6.10		

Table No. 31 reveals that one week after irrigation, the first three inches of soil are very much drier than any lower section; that two weeks after irrigation, the difference is not so marked, and that, in general, the difference becomes less as the time from irrigation increases. The second, third and fourth three-inch sections of the first foot are more nearly alike one week after irrigation, in the moisture that they contain—the differences being on the average less than one per cent. The second foot contains more water than the first, and the third more than the second, thus reversing the conditions that exist immediately after irrigation, before the effects of evaporation and transpiration have become noticeable. These relations remain unchanged until the next irrigation, with the exception that the differences decrease with the increase of time. Twenty-three days after irrigation the average difference in the moisture content of the sections, not considering the top three inches, is less than one per cent; in the wheat plats less than one-half per cent.

It is especially noticeable that one week after irrigation there is a much greater difference between the first and second three inches of soil than between any other two sections. In the corn plats the difference is 4.84%; in the potato plats, 5.84%; and in the deeper wheat plats, 1.68%. The top soil, which is subjected to the direct action of sunshine and wind, would naturally dry out quickly; but the last difference between this top layer and the next following seems to indicate that the dry top soil forms a good protection for the lower lying portions, which, then, in all probability, lose most of their moisture by giving it up to the plant roots. It is not easily believed that water from the lower soil depths will pass readily through a top layer containing less than 10% of moisture, which is the condition one week after irrigation.

That the loss of soil moisture falls with considerable uniformity on the different soil depths, may be explained in two ways. First, by assuming that the tendency of the soil moisture is to distribute itself uniformly over the whole soil body; and, secondly, that the roots penetrate the whole depth of these shallow soils, with uniformity, and draw with an approximately equal vigor on the whole soil body. It is probable that both of these factors are important in causing the nearly equal loss of water from all soil depths; but, from the fact that the uniform loss is just as marked in the drier soils (10% of water and under) in which capillary movements are necessarily very slow, as in the moister soils, it seems safe to conclude that root action is of greater importance in this uniform loss than is capillarity. The results from the shallow wheat plat (12 inches deep), stated at the end of table No. 31, are of interest in that they show an almost identical per cent of water for the three inch sections, during the whole period of experiment.

In deep soils that extend beyond the ordinary foraging limits of plant roots, the conditions will undoubtedly be quite different. (See the later reports of these investigations.)

Table No. 32 shows the actual per cents that were lost at the different soil depths, in the experiments arranged in table No. 31. Its value is that it brings out more clearly the actual amounts of water lost in each soil section.

TABLE NO. 32.—LOSS OF SOIL MOISTURE FROM VARIOUS DEPTHS AND AT DIFFERENT TIMES AFTER IRRIGATION.

Days after irrigation	Number of trials	Percentage of water lost. 0-3 in.	3-6 in.	6-9 in.	9-12 in.	12-24 in.	24-36 in.
				Corn.			
1-8	6	13.69	9.90	9.79	4.55	4.75	3.92
8-3	6	0.24	2.36	0.66	0.47	0.57	0.36
				Potatoes.			
1-5	5	9.63	3.85	5.13	2.42	2 63	
5-9	5	4.30	2.78	3.06	3.25	2.01	
9-12	5	0.51	2.27	1.48	1.51	2.78	
12-19	5	1.89	4.31	2.58	1.48	0.52	
19-23	5	0.31	0.36	1.03	1.40	2.16	
				Wheat.			
1-9	4	9.07	6.95	6 81	5.84	2.56	
9-16	4	5.84	5.50	3.49	4.03	6.65	
16-23	4	2.60	2.31	4.16	2.87	1.95	
1-9	2	12.30	9.63	6.30	8.32		
9-16	2	9.48	8.23	7.17	5.42		
16-19	2	0.15	1.17	2.28	1.89		

The more important fact brought out by this table is that soon after irrigation, the top three inches and upper sections lose most water, while, later, the lower sections lose as much or more. This truth is emphasized especially well in the wheat plats.

The data obtained do not show any marked movements of water from the lower to the upper portions of shallow soils. That such movements do occur is unquestionable, but their effect is overshadowed by the direct action of roots on the soil moisture.

25. THE EXTENT TO WHICH SOILS CAN DRY OUT.

Closely connected with the discussion of the preceding section is the question concerning the extent to which soils can dry out. In table No. 33 is summarized the data obtained by examining the soils of a large number of plats, which had not been irrigated for twenty to thirty-nine days. Owing to occasional rainfalls which wetted the upper layers of soils and thus interfered with the normal drying out, no results are presented from irrigations that occurred later than July 20th.

TABLE NO. 33.—THE EXTENT TO WHICH SOILS DRY OUT.

Date of irrigation	Depth of soil inches	Days after irrig.	Number of trials	Percentage of water. 0–3 in.	3-6 in.	6–9 in.	9–12 in.	12–24 in.
				Wheat.				
June 8-10	25	39	4	3.48	4.34	5.02	5.45	5.75
July 5, 6, 11	25	21	3	3.61	6.52	6.58	6.50	7.68
				Corn.				
June 29	42	20	2	4.46	8.08	10.03	9.84	12.71
				Potatoes.				
July 26	29	24	6	4.93	7.69	8.55	9.44	9.56
July 20	31	21	5	4.83	5.87	6.83	7.19	7.82
				Sugar beets.				
June 14	30	24	6	4.13	7.46	8.59	9.26	11.66

As shown by table No. 33, the upper three inches contain from 3.48 to 4.93 per cent of water, twenty or more days after irrigation. When twenty days have elapsed from the time of last irrigation, a few more days do not affect materially the per cent of moisture in the upper three inches. The second three inches contain from 4.34 to 8.08 per cent of water; and the amounts vary in general with the amounts in the top soil. The third three inches contain from 5.02 to 10.03 per cent of water; the fourth three inches, from 5.45 to 9.84 per cent, and the second foot from 5.75 to 12.71 per cent. There is, then, a gradual increase in the water content in soils from the top to the lower layers, many days after irrigation. The figures of this table may be taken as representing the maximum of dryness in shallow soils, after ordinary irrigations.

The question now naturally presents itself, to what extent is it *possible* for soils to dry out? To obtain some information on this subject the data gathered from the arid farm plats were examined. These plats were sown to wheat in the fall of 1900, and received no irrigation the following spring or summer. The soils were sampled on July 17th, with the average results as shown in the following table.

TABLE NO. 34.—THE EXTENT TO WHICH SOILS CAN DRY OUT.

Wheat (No irrigation.)

Time of sampling	Depth of soil inches	Percentage of water.				
		0–3 in.	3–6 in.	6–9 in.	9–18 in.	18-22 in.
July 17th	22	2.13	3.80	4.11	5.04	4.13
		0–9 in	9–18 in.	18–22 in.		
July 17th	22	3.72	5 47	4.63		

The upper three inches contained 2.13 per cent of water on July 17th; the maximum water content of any section of this soil was 5.04 per cent. In another set, the per cent of water in the first nine inches was 3.72, while the maximum for any section was 5.47. It is interesting to observe that the section 9–18 inches deep contained a higher per cent of water than did the soil above or below it. Why this is so, is not evident.

We may conclude from these results that under the climatic conditions that prevailed at Logan during the summer of 1901, it is impossible to dry the upper three inches of soil in the field so much that it contains less than two per cent of water; and it may be as safely asserted that the second foot will not be dried beyond an amount represented by four per cent of water.

26. THE LOSS OF WATER IN FURROW IRRIGATION.

In the discussion of the lateral movements of water, it was demonstrated that the soil under the furrow is always wetter, just after an irrigation, than is the soil under the row. It was further shown there that the difference between the per cent of water in rows and furrows became smaller, as the depth increased. The question concerning the part of the soil which loses moisture most rapidly is partly answered by the data of the following tables.

TABLE NO. 35.—LOSS OF SOIL MOISTURE FROM ROWS AND FURROWS.

(Between Irrigations.)

Average depth in's.	Days after irrigation	Number of trials.	Initial per cent of water. Row	Initial per cent of water. Furrow	Weight of water lost. lbs. per sq. ft. Row	Weight of water lost. lbs. per sq. ft. Furrow	Amount of loss in furrow over row. lbs.
				Corn			
20	18	5	21.43	20.48	9.17	8.20	0.97
20	14	6	18.00	21.24	10.27	13.32	3.05
18	39	3	17.44	22 44	14.50	20.17	5.67
				Sugar beets.			
23	16	5	11.24	15.93	5.88	14.91	9.03
25	25	1	6.32	16.23	0.82	19.91	19 09
				Potatoes			
59	18	1	12.73	14.89	12.77	14.81	2.04
59	49	1	13.10	15.11	17.32	28.08	10.76

In table No. 35 the losses of water from rows and furrows, during the interval between irrigations, are given. For comparison, the per cents of water just after irrigation are also given. It is strikingly evident from this table that the furrows lose more water than do the rows. This seems to be in accordance with the law already established that the loss of soil moisture is in direct proportion to the initial per cent of water in the soil. The first line under the corn section shows a slightly greater loss by the row than by the furrow; but it is also to be observed that, owing probably to a low row and consequent flooding of the whole area, the initial per cents of water in the row and furrow are almost identical.

Since the law of the greater loss in the furrow has been established, it is of interest to learn to what extent the furrow and the row are drained of their moisture.

TABLE NO. 36.—PER CENT OF WATER IN ROWS AND FURROWS,

After Irrigation.

Average depth of soil. (inches.)	Number of trials.	One day after		Sixteen days after.	
		Row	Furrow	Row	Furrow
20	12	14.74	18.49	9.10	9.39

Table No. 36 is based on twelve observations made one and sixteen days after irrigation. Just after irrigation the furrow contained 3.75 per cent more moisture than did the row, fifteen days later there was a difference of only 0.29 per cent. The plant roots seem, therefore, to be able to draw moisture from row and furrow with equal facility; but the rate at which water is taken from the furrow is greater than that with which it is taken from the row; in sixteen days the rate is practically the same.

TABLE NO. 37.—LOSS OF SOIL MOISTURE FROM ROWS AND FURROWS.

(During different periods after irrigation.)

Average depth of soil in.	Days after irrigation	Number of trials	Weight of water lost lbs. per sq. ft.		Amount of loss in furrow over row. lbs.
			Row	Furrow	
20	1–4	4	5.24	6.64	1.40
	5–7	4	4.55	6.69	2.14
	8–11	4	3.14	1.84	1.30
	1–7	6	5.30	11.45	6.15
	8–14	2	6 04	5.78	0.26
	15–21	2	10.37	7.95	2.42
	22–28	2	4 54	6 86	2.32
	29–35	2	1.83	1.39	0.44

Table No. 37 shows the times after irrigation when the loss of soil moisture from rows or furrows occurs most rapidly. During the first week the loss from the furrow over balances that from the row; during the second week, the row loses slightly more than the furrow. During the later weeks the loss is irregular, falling most heavily, first on the row, then on the furrow, and then on the row again. These later results are based on only two observations, and may be taken to mean that, when the per cent of moisture is about the same in row and furrow, the loss of water from row and furrow is about the same. It may be that sets of rootlets from one plant alternate in providing the plant with moisture.

It may be concluded, safely, from the data of this table that soon after irrigation the furrow loses more moisture than the row; but that, later, the row and furrow lose about the same amount of water in the same interval of time.

TABLE NO. 38.—PER CENT OF WATER IN ROWS AND FURROWS AT DIFFERENT DEPTHS AT DIFFERENT TIMES AFTER IRRIGATION.

Days after irrigation	Number of trials	0-3 inches Rows	0-3 inches Furrows	3-6 inches Rows	3-6 inches Furrows	6-9 inches Rows	6-9 inches Furrows	9-12 inches Rows	9-12 inches Furrows	12-20 inches Rows	12-20 inches Furrows
1	6	12.45	24.77	12 08	21.23	15 60	18.35	16 51	17.52	14.83	18.70
3	5	11.01	15.17	13.15	14.85	15.48	15.49	15 24	14 68	14.21	14.96
8	6	6.86	8.44	9.99	10.76	10.75	11.07	11.71	10.89	8.70	10.53
11	4	6.66	6.99	10.89	9.22	8.74	9.14	9.49	10.12	9.54	11.21
14	4	6 66	9.40	7.11	9.25	8 75	8.47	9.42	9 14	9.23	8.76
19	4	11.53	12.10	11.08	11.07	9.98	9.16	10.55	8.16	9.21	7.85
22	2	11.25	12.97	9.85	11.50	9.54	9.94	9 33	8.18	7.81	7.58
27	2	7.15	7.33	7.04	6.49	7.84	7 50	8 73	7.18	9.76	6.87
30	2	4 83	6.58	6.13	6.76	6 55	7.10	6 94	7 30	7.24	6.33
33	2	5.29	5.90	5.59	6.36	6.83	6.50	7.94	6 60	6 45	5.87

Table No. 38 has been arranged to show the actual per cent of water in rows and furrows, at different soil depths and at different times after irrigation. During the third week, rain fell, which occasioned the irregularities observed from the 14th to the 22nd day after irrigation.

In the upper three inches the per cent of water is always higher in the furrow than in the row, though the difference is very small after the second week.

In the next three-inch section (3—6) the furrow is wetter than the row during the first two weeks; after that time the row is sometimes wetter than the furrow, which may be taken to indicate that the per cents of water in row and furrow are nearly equal.

The third three-inch section (6-9) shows the same relation, except that, in the later periods, the row is more frequently wetter than the furrow.

In the last three-inch section (9-12) the furrow is wetter than the row, the first day after irrigation; but, from that time on, the row contains a higher per cent of water than does the furrow.

The next eight inches (12-20) contain more water in the furrow than the row, the first eleven days after irrigation, from that time on the row contains more water than the furrow. The general result from this table is, that just after irrigation, the furrow contains more water than the row, down to twenty inches, the limit of the soil depth; that, as the time after irrigation increases, the per cents of water in row and furrow become more nearly equal, and that two weeks or more after irrigation, and especially in the lower soil layers, the row contains more water than does the furrow.

In the table which follows, the data of table No. 38 have been arranged so as to exhibit the actual per cents of water lost from the different soil sections, at different times after irrigation.

TABLE NO. 39.—LOSS OF PER CENT OF SOIL MOISTURE FROM VARIOUS DEPTHS AND AT DIFFERENT TIMES AFTER IRRIGATION.

Days after irrigation	Number of trials	0-3 inches Row	0-3 inches Furrow	3-6 inches Row	3-6 inches Furrow	6-9 inches Row	6-9 inches Furrow	9-12 inches Row	9-12 inches Furrow	12-20 inches Row	12-20 inches Furrow
1-3	6	1.44	9.60	1.07	6.38	0.12	2.86	1.27	2.84	0.62	3.74
3-8	5	4.15	6.73	3.16	4.09	4.73	4.42	3.53	3.79	5.51	4.43
8-11	6	0.20	1.45	0.90	1.54	2.01	1.93	2.22	0.77	0.84	0.68
11-14	4	0.00	2.41	3.78	0.03	0.01	0.67	0.07	0.98	0.31	2.45
14-19	4	4.87	2.70	3.[illegible]7	1.82	1.23	0.69	1.13	0.98	0.02	0.91
19-22	4	0.28	0.87	1.23	0.43	0.44	0.78	1.22	0.02	1.40	0.27
22-27	2	4.10	5.64	2.81	5.01	1.70	2.44	0.60	1.00	1.95	0.71
27-30	2	2.32	0.75	0.91	0.27	1.29	0.40	1.79	0.12	2.52	0.54
30-33	2	0.46	0.68	0.54	0.40	0.28	0.60	1.00	0.70	0.79	0.46

The conclusions that may be drawn from the table are, of course, the same as those that may be obtained from table No. 25; but table No. 26 shows with greater force that soon after an irrigation the furrow loses much more water than does the row; and that, after ten to fourteen days when the amount of water in row and furrow is about the same, the loss of water from them is also nearly constant. These observations emphasize, mainly, the law that the rate of loss of soil moisture varies directly with the per cent of water.

The question asked by the practical farmer is: With a given amount of water, by what method of application can the largest yield of crop be obtained? This question is quite fully answered in a later section; yet it may be well to point out the probable answer, as indicated by the soil moisture studies. To apply a given amount of water by the furrow method to a plat of definite size, requires longer time than to apply the same amount of water to the same plat by flooding. This, then, means that the soil in the furrow is kept very wet for a relatively long time.

In any case, the soil in the furrow is much wetter than the soil over the whole plat would be; if the flooding method were followed. From the wet furrow, by the laws already established, water will be lost much more rapidly than from the row; and if the effect per per cent of soil moisture, should happen to be greater when the soil is wet, than when it is drier, it is probable that the furrow method of irrigation would cause the greater loss of soil moisture. Even, should this suggested quantitative relation not hold, the fact of the longer application of water by the furrow method would tend to a greater loss of soil moisture. Future work will throw light on this subject. Meanwhile, it may be said, that in all probability furrowing is generally followed in districts where water is scarce, because, by that method small amounts of water can be made to cover larger areas of land, since, as will be shown hereafter, the duty of the first few inches of water is much higher than that of the later.

C. IRRIGATION VERSUS GROWTH AND COMPOSITION OF CROPS.

The chemical portion of the experiments on irrigation naturally fell into two divisions. First, an attempt was made to follow the chemical life histories of plants grown with different amounts of water; and, secondly, chemical analyses were made of all the crops raised on the irrigation plats.

27.—IRRIGATION VS. CHEMICAL LIFE HISTORY.—INTRODUCTORY.

For this study three plats were sown to wheat, three to peas, and three to sugar beets. It became apparent, early in the season, that soil conditions would make the results from the sugar beet work unreliable, and this part of the investigation was, therefore, abandoned. The experiments with wheat and peas were continued and finished with no serious interruption.

The wheat was grown on plats 334, 335 and 336 and the peas on 337, 338 and 339. The amounts of water received by these plats and the times of application are shown in the following table.

TABLE NO. 40.—TIMES AND AMOUNTS OF IRRIGATION.

	Inches of water applied to plats.					
	No. 334	No. 335	No. 336	No. 337	No. 338	No. 339
June 11th	4.50	6.19	9.50	5.14	8.00	10.19
June 25th		5.00	8.15		7.52	9.00
July 8th			7.50			7.50
July 11th	3.58	5.85	3.73	4.97	6.98	3.87
July 16th			5.50			5.50
July 26th			4.57			3.63
July 30th			1.04			
Total	8.08	17.04	39.99	10.11	22.50	39.69

The plats were laid off in small squares, 12 feet to the side, several of which were cut at regular intervals. The total green weight on each square was accurately determined; and, at the same time, samples of the whole plant, and leaves, stalks and heads, were placed in Mason fruit jars, sealed, and taken to the laboratory for moisture determinations. Later, a large portion of the crop was separated into leaves, stalks and heads, and each portion subjected to complete chemical analysis. By this method, full data were obtained, concerning the growth, total weight and composition of the whole plant and its parts.

Five cuttings were made of the wheat, namely on June 22nd, July 5th and 18th, and August 1st and 23rd. Three cuttings were made of the peas, on June 27th, July 20th and August 14th.

Unfortunately, the plats chosen for this work were very unequal in depth, and besides, contained streaks of gravel. These facts affected the work unfavorably in two ways. First, the plats which received least water were the deepest, and those that received most water were the shallowest. Since the water holding capacity of the deep plats was, of course, the highest; the small applications of water on these deep plats were almost as good as heavier applications on the shallower soils. The result was that the differences in growth, due to unequal irrigations, were largely obliterated. In addition, some irrigations were so heavy as to saturate or over saturate some of the shallower plats.

TABLE NO. 41.—DEPTHS OF PLATS.

Number of plat	334	335	336	337	338	339
Depth in inches	49	24	19	44	23	25
Inches necessary to saturate	20	8	8	18	9	10

The gravelly streaks caused uneven growth and ripening, which made fair averages of the crop almost impossible.

For these reasons, the results are not of the highest value, yet sufficiently important, it is believed, to warrant their introduction into this bulletin. Those who have experience in such work, know that the inherent difficulties are very great, and that when soil variation and other disturbing factors must be considered, it is almost impossible to obtain exact results.

28. THE PERCENTAGE OF WATER.

The following table shows the per cent of water in the green wheat plant and its parts, at different periods of growth, and with unequal irrigations. The whole plant and the plant parts represent two sets of samples.

TABLE NO. 42.—PER CENT OF WATER IN WHEAT.

Date	No. of plat	Whole plant	Leaves	Stalks	Heads
June 22nd	334	71.25	71.78	78.83	83.02
	335	79.50	72.76	82.63	78.11
	336	77.37	72.26	78.62	74.57
July 5th	334	68.12	60.68	77.28	67.21
	335	72.49	66.39	74.03	70.13
	336	74.48	83.93	76.98	76.25
July 18th	334	47.43	10.60	44.05	49.79
	335	54.64	25.35	55.54	54.09
	336	61.93	26.85	63.19	58.33
August 1st	334	10.58	7.98	23.46	8.01
	335	17.51	6.47	24.73	13.41
	336	47.56	12.08	57.54	32.69
August 23rd	334	13.38	9.91	7.64	29.34
	335	15.00	14.27	7.47	13.87
	336	17.95	10.01	35.71	11.69

On every date, excepting June 22nd, the whole plant on the plats that received the heaviest irrigations, contained the most water. The difference varied from less than two, to nearly forty per cent. In the leaves and stalks the variation is more irregular, though the tendency is strongly the same as in the whole plant. The per cent of water in the heads, excepting the first and last cuttings, varies markedly with the amount of water applied to the soil.

Table 43 shows the percentage of water found in the various cuttings of peas.

TABLE NO. 43.—PER CENT OF WATER IN PEAS.

Date	No. of plat	Whole plant	Leaves	Stalks	Heads
June 27th	337	88.83	84.38	88.92	87.12
	338	88.58	89.09	88.40	87.38
	339	87.66	86.22	87.84	87.27
July 20th	337	80.32	75.72	79.13	75.62
	338	83.16	84.15	80.75	80.89
	339	84.15	85.01	83.63	82.81
August 14th	337	53.82	35.78	65.46	38.21
	338	35.44	16.05	37.51	8.52
	339	44.57	57.03	75.16	23.14

With the peas, the coincident variation of amount of water applied, and per cent of moisture in the whole plant does not occur. The leaves, stalks and heads likewise fail to show a regular variation of the kind observed with the wheat plant. True, the tendency of the variation in the plant parts, seems to be the same as that observed in the wheat, but the exceptions are too numerous to allow definite conclusions to be made. Considering the data in tables 42 and 43 it may be safe to assert that, in general, the percentage of water in plants and their parts, increases, as the per cent of water in the soil increases. The authors are inclined to the belief that, with uniform soil conditions, the variation would be more regular and definite.

29. THE RATE OF GROWTH.

The total yield of dry matter as affected by irrigation is considered under another heading in this bulletin; and the data obtained in the experiments with wheat and peas will be inserted simply as a matter of record.

TABLE NO. 44.—TOTAL DRY MATTER IN WHOLE PLANT. (WHEAT.)

(Pounds per acre.)

Number of plat	334	335	336
June 22nd	2,903	1,995	2,452
July 5th	4,756	4,759	4,331
July 18th	4,245	4,903	5,566
August 1st	5,053	5,408	6,008
August 23rd	4,062	4,353	4,375

Certain irregularities appear in the above table which are due to the variation in soil composition and depth already mentioned. The most striking of these irregularities is the yield from plat 334, on July 18th, which is 511 pounds less than the yield on the same plat two weeks earlier. With this exception the successive yields on the plats are quite regular.

On June 22nd, plat 334 had received 4.50, plat 335, 6.19 and plat 336, 9.50 inches of water. The total yields on this date do not vary with the water applied.

When the moisture in the soil is above a certain definite per cent, the young plant is not markedly affected by larger applications of water. As the plant grows older, and more water is required by transpiration, the lower limit of sufficient soil moisture is reached, and the plant responds quickly to increased applications of water. This is well shown by the yields on July 18th and August 1st, which stand in the order of the amounts of water that have been applied.

A large loss occurred between August 1st and 23rd caused in part by over-ripe leaves and heads falling to the ground, and in part by the tranference of nutritive material from the leaves and stalks to the roots.

The results obtained from the work with peas are shown in table No. 45.

TABLE NO. 45.—TOTAL DRY MATTER IN WHOLE PLANTS.
(PEAS.)
(Pounds per acre.)

Number of plat	337	338	339
June 27th	1,172	1,322	1,019
July 20th	1,468	3,326	2,228
August 14th	1,924	1,980	2,171

The data found in this table are so irregular that conclusions of high value cannot be drawn from them. Later reports of these investigations will throw more light on this subject.

30. THE PROPORTION OF LEAVES, STALKS AND HEADS.

The question of the relative development of plant parts under different systems of irrigation, is frequently discussed. It is held by many that crops grown with small quantities of water are more stalky than those that have been irrigated more abundantly. Others again hold the opposite view. Then, again, it is asserted that the less the water applied, the heavier are the heads as compared with the stalks and leaves. In the following tables, some light is thrown on these questions; though it must be distinctly understood that future work may modify, very largely, the conclusions here arrived at.

TABLE NO. 46.—PROPORTION OF LEAVES, STALKS AND HEADS.

(Wheat.)

		Per cent.			Total weight per acre lbs.		
Number of plat		334	335	336	334	335	336
June 22,	Leaves	44.50	38.50	43.46	1295	768	1066
	Stalks	52.90	53.40	47.86	1536	1066	1174
	Heads	2.50	8.08	8.68	73	161	213
July 5,	Leaves	36 41	29.92	37.19	1732	1424	1611
	Stalks	44 80	52.62	46.70	2131	2504	2023
	Heads	18.79	17.46	16.11	894	831	698
July 18	Leaves	19.76	20.21	19.27	818	991	1073
	Stalks	44.68	42.95	49.19	1896	2106	2738
	Heads	36.07	36.84	31.54	1531	1806	1755
August 1	Leaves	14.46	12.97	11.83	731	701	711
	Stalks	45.16	45.53	39.84	2282	2462	2394
	Heads	40.38	41.50	48.33	2041	2244	2904
Aug. 23	Leaves	9.83	10.76	11.18	399	468	489
	Stalks	43 43	44.16	34.67	1764	1922	1517
	Heads	46.74	45.08	54.15	1899	1963	2369

Considering the heads first, the above table shows that on June 22nd, the proportion of heads was smallest on plat 334, which received least water. On July 5th, however, the proportions in the three plats were nearly the same, although the largest was found on plat 334, and, on July 18th, the proportion of heads on plat 334 was much higher than on plat 336, which received most water, and nearly as high as on plat 335, on which the intermediate amount of water was applied. On August 1st, the time at which the crop should have been cut for grain, plat 336 contained the highest proportion of heads, while the proportions on plats 334 and 335 were nearly the same.

All this probably indicates that in the early stages of the plant's growth the relative proportion of heads is not affected to any great degree by different amounts of water, while, toward the end of the growing season, the plants that have received most water have a somewhat higher per cent of heads. This may, in a large measure, be due to the earlier ripening of the crop which receives less water, and which results in an earlier filling out of the heads; and not to any specific influence of water upon the plant.

The total weights of heads per acre, though interesting in themselves, do not furnish data that contradict this explanation.

A study of the proportion of leaves and stalks, fails to show any marked, regular variation due to the different amounts of water applied to the crops. The proportion of leaves on the plants from plat 334, is higher, in three out of five cuttings, than in the other two plats. In the other two cuttings, the difference is very small. This points to the smaller proportional leafiness of plants grown with large amounts of water. The variation, however, is not regular; and the conclusion can only be received tentatively, pending further investigations.

Another method of studying leafiness as affected by water, is to omit the heads altogether and to consider the leaves and stalks only. This has been done for the wheat plats (334–336) in table No 47. This table shows for each date and plat the number of parts of stalks for one part of leaves.

TABLE NO. 47.—PARTS OF STALKS FOR ONE PART OF LEAVES. (WHEAT.)

Date	Plat 334	Plat 335	Plat 336
June 22nd	1.19	1.39	1.10
July 5th	1.23	1.76	1.25
July 18th	2.26	2.12	2.55
Aug. 1st	3.12	3.51	3 37
Aug. 23rd	4.50	4.10	3.10

This table, like table 46, shows the slightly smaller stalkiness of plat 334. The only exception occurred on August 23rd, three weeks after the proper harvesting time.

The data obtained for peas, on the proportion of leaves, stalks and heads, are presented in table No. 48.

TABLE NO. 48.—PROPORTION OF LEAVES, STALKS AND HEADS. (PEAS.)

		Per cent.			Total weight per acre. Lbs.		
Number of plat		337	338	339	337	338	339
June 27	Leaves	61.03	50.16	53.65	715	663	547
	Stalks	36.98	46.40	43.28	433	613	441
	Heads	1.99	3.44	3.07	23	45	31
July 20	Leaves	35.64	23.69	30.28	523	788	675
	Stalks	32.49	27.66	27.40	477	920	610
	Heads	31.87	48.65	42.32	468	1618	943
August 14	Leaves	22.48	18.92	19.11	432	375	415
	Stalks	33.26	28.12	18.76	640	557	407
	Heads	44.26	52.96	62.13	852	1049	1349

A study of this table with reference to the development of the heads, proves that the proportion of heads was highest on the plats which received most water. As the ripening period was approached the truth of this statement became more and more apparent.

It is equally evident, from this table, that plat 337, which received least water, carried plants which invariably contained a higher proportion of leaves than did the plants from the plats which received more water. However, after the first cutting, the crop on plat 337 contained a higher proportion of stalks than did the plants from the other two plats. This is due to the great effect of different amounts of water on the development of the heads.

To bring out the actual relation between leaves and stalks, therefore, table No. 49 has been constructed. It is similar to table No. 47; and shows the parts of stalks for one part of leaves.

TABLE NO. 49.—PARTS OF STALKS FOR ONE PART OF LEAVES. PEAS.

Date	Plat 337	Plat 338	Plat 339
June 27th	0.61	0.93	0.81
July 20th	0.91	1.17	0.90
Aug. 14th	1.48	1.48	0.98

During the earliest period of growth, the crop that received least water contained the highest proportion of leaves; at the second cutting the difference was smaller, and, at the third, plats 337 and 338 were alike in the relative amount of leaves and stalks, while the crop on plat 339, which received most water, contained the lowest number of parts of stalks for each part of leaves. Here, again, it must be remarked that since the crop with least water ripens earlier than crops with heavier irrigations, the cuttings made are not strictly comparable, and, therefore, the late cuttings on the wet plats should be compared with the early cuttings of the dry plat.

The general conclusions that seem warranted by the investigation of the relative development of the plant parts is, that large irrigations tend to produce plants with high proportions of heads and stalks; and small irrigations tend to yield plants with a high proportion of leaves.

31. THE CHEMICAL COMPOSITION OF THE HEADS.

The chemical composition of the whole plant will depend upon the chemical composition and relative proportion of its parts. In table No. 50 will be found the analytical results obtained with wheat heads.

TABLE NO. 50.—THE PERCENTAGE COMPOSITION OF WHEAT HEADS.

Date	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
June 22	334	4.69	13.04	1.97	23.79	56.51
	335	4.69	15.83	1.88	22.73	54.87
	336	4.69	13.04	2.26	39.94	40.07
July 5th	334	5.66	9.45	2.17	31.64	50.98
	335	7.17	12.43	2.29	42.16	35.95
	336	7.16	13.14	2.54	22.05	55.11
July 18	334	5.45	11.28	2.16	21.11	60.00
	335	6.52	10.24	2.00	20.33	60.91
	336	9.27	12.24	2.30	17.78	59.41
Aug. 1st	334	5.32	13.34	1.74	14.44	65.16
	335	6.93	9.97	1.88	11.09	70.13
	336	4.84	10.61	1.71	14.29	68.55
Aug. 23rd	334	4.39	10.14	1.87	14.85	68.75
	335	5.07	12.32	1.83	14.87	65.91
	336	8.81	12.22	1.96	13.08	63.93

The per cent of ash on four out of the five dates, was higher in the heads grown on plats 335 and 336, which received most water, than in those grown on plat 334. On August 1st, the heads taken from plat 336 contained the smallest percentage of ash; though those from plat 335 contained more ash than the heads from plat 334. The conclusion seems warranted that the percentage of ash in wheat heads increases with the increase in the amount of water applied.

The lowest percentage of protein was found on two dates in the heads from plat 334; on two dates in the heads from plat 335, and on June 22nd, the heads from plats 334 and 336, contained the same amount. The highest percentage of protein was found on three dates in the heads from plat 336; once in those from plat 335, and once in those from plat 334. While the data are somewhat conflicting, yet it may be concluded that the larger applications of water tend to increase slightly the percentage of protein in wheat heads.

Though the differences are small, there is a distinct increase in the percentage of ether extract in wheat heads with the increase in the amount of water applied.

The crude fibre appears to be smallest on the plats which receive most water. There are some very marked exceptions to this rule, however, that can not now be explained satisfactorily.

The percentages of nitrogen-free extract are so irregular that no definite law can be drawn from them.

As a general conclusion it may be said that wheat heads grown with different amounts of water, possess, approximately, the same composition.

Table No. 51 gives the composition of the pea pod on plats 337, 338 and 339. The flowers from the cuttings on June 27th were not sufficient in quantity for analysis.

TABLE NO. 51.—THE PERCENTAGE COMPOSITION OF PEA PODS.

Date	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
July 20th	337	5.21	26.28	1.80	19.27	47.44
	338	4.27	33.60	1.84	19.45	40.84
	339	5.83	28.44	2.86	19.04	43.83
Aug. 14th	337	6.07	30.93	2.08	14.14	46.78
	338	5.75	28.56	1.86	13.30	50.53
	339	4.62	10.90	2.42	13.71	68.35

The following conclusions may be drawn from a study of this table.

The percentage of ash becomes smaller as the amount of water applied becomes larger.

In the last stage of growth, the pods grown with the smallest amount of water contain most protein. In the preceding cutting the reverse holds true.

The percentage of ether extract is increased by abundant irrigation.

The percentage of crude fibre is increased by withholding water.

The data for nitrogen-free extract show no regular variation.

32. THE CHEMICAL COMPOSITION OF THE STALKS.

TABLE NO. 52.—THE PERCENTAGE COMPOSITION OF WHEAT STALKS.

Date	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
June 22nd	334	8.84	8.31	1.54	31.88	49.43
	335	9.28	10.69	2.07	32.53	45.43
	336	10.25	9.23	1.06	34.61	55.85
July 5th	334					
	335	8.76	12 31	1.13	45.83	31.97
	336	8.26	9.70	1.18	40.07	40.79
July 18th	334	5.26	4.92	1.11	45 76	42.95
	335	6.01	4.48	1.07	45.56	42.88
	336	6.37	4.42	1.17	43 75	44.28
August 1st	334	4.28	2.22	1.40	52.44	39.66
	335	5.24	2.76	0.62	51.84	39.54
	336	6.17	3.53	1.02	47.07	42.21
August 23rd	334	5.47	2.96	1.37	51.33	38.87
	335	5.39	3.69	1.69	48.38	40.85
	336	7.82	2.23	1.31	51.16	37.47

A study of the above table reveals certain variations in the composition of wheat stalks that they may be stated as follows.

The percentage of ash is highest in the stalks from the well watered plats.

The percentage of protein appears to increase with the amount of water applied; but, several deviations from this rule occur, which make the conclusion unreliable.

The percentage of ether extract is not influenced in any regular manner by irrigation.

Although several irregularities occur, the data tend to show that the percentage of crude fibre is decreased as the amount of water is increased.

The nitrogen-free extract appears to increase with the increase in the amount of water applied.

TABLE NO. 53.—THE PERCENTAGE COMPOSITION OF PEA STALKS.

Date	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
June 27th	337	9.42	14.87	1.83	32.00	41.88
	338	9.93	11.83	1.43	31.21	45.60
	339	9.46	13.56	1.54	33.80	41.64
July 20th	337	12.46	11.64	1.49	45.45	28.96
	338	8.43	9.34	1.23	41.59	39.41
	339	9.13	8.01	1.27	38.62	42.97
Aug. 14th	337	11.27	12.09	1.30	36.81	38.53
	338	9.66	11.53	1.05	31.21	46.55
	339	10.20	8.00	1.73	48.58	31.49

Table No. 53 shows that not all of the conclusions drawn from table No. 52, with respect to wheat stalks, are applicable to pea stalks. Table 53 justifies the following statements.

The percentage of ash tends to diminish as the amount of irrigation water is increased.

The percentage of protein is highest in the stalks from plat 337, which received least water; in two of the three cuttings, it is lowest in the stalks from the plat which received most water.

The differences in the percentage of ether extract are so small that it is difficult to draw definite conclusions from them.

The percentages of crude fibre are also very irregular in their variation. They are invariably higher in plat 337 than in plat 338, but in two cases they are also higher in 339 than in 337. This makes it difficult to draw a definite conclusion.

In general, the relative amount of nitrogen-free extract is highest on the well watered plats.

33. THE COMPOSITION OF LEAVES.

TABLE NO. 54.—THE PERCENTAGE COMPOSITION OF WHEAT LEAVES.

Date of cutting	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
June 22nd	334	18.53	15.38	4.57	23.50	38.02
	335	9.52	14.56	1.49	22.44	51.99
	336	12.99	18.32	4.26	24.23	40.20
July 5th	334	16 87	12.98	5.30	24.24	40.61
	335	15.75	14.70	5.30	23.64	40.61
	336	15.60	16.40	4.65	33.99	29.36
July 18th	334	13.79	8.54	2.75	36.20	38.72
	335	16.40	7.54	3.22	29.40	43.44
	336	15.42	8.98	3.54	30.70	41.36
Aug. 1st	334	15.38	4.21	2.10	36.46	41.85
	335	15 03	5.29	3.00	37.22	39.46
	336	14 71	6.11	2.94	36.80	39.44
Aug. 23rd	334	14.81	2.59	2.62	30.66	49.32
	335	12.07	3.68	2.02	35.95	46.28
	336	18.24	4.41	1.98	20.66	54.71

The following conclusions seem warranted by the data in table No. 54.

The percentage of ash varies more in wheat stalks than in wheat leaves. In three out of the five cuttings, the percentage of ash was highest in the leaves from plat 334, which had received least water. In one of the remaining cuttings, the leaves from plat 334 contained more ash than did the leaves from 335. It may be concluded, therefore, that abundant irrigation tends to decrease the percentage of ash in wheat leaves.

The percentage of protein is highest in the wheat leaves from well watered plats.

The ether extract shows no regular variation caused by varying amounts of irrigation water.

The percentages of crude fibre show some peculiar variations, which are difficult of explanation. Probably, the quantity of water applied has little effect on the relative amounts of crude fibre in wheat leaves.

The variations in the percentage of nitrogen-free extracts are, in most cases. small and do not appear to be connected with the irrigation.

TABLE NO. 55.—THE PERCENTAGE COMPOSITION OF PEA LEAVES.

Date of cutting	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
	337	11.47	32.93	4.85	11.96	38.79
June 27th	338	12.73	28.20	9.24	8.60	41.23
	339	11.38	28.70	5.08	9.25	45.59
	337	17.14	19.59	4.70	12.15	46.42
July 20th	338	15.29	18.43	4.70	12.28	49.30
	339	16.66	20 79	5.66	11.55	45.34
	337	18.99	19.22	3.36	13.53	44.90
Aug. 14th	338	12.79	18.41	3.45	13.63	51.72
	339	15.63	15.94	12.43	14.05	41.95

Table No. 55, which exhibits the composition of pea leaves, leads to the following conclusions.

The percentage of ash tends to diminish as the amount of water applied increases, though the irrigation is not very marked.

The percentage of protein decreases quite regularly with the increase in water.

The data for the ether extract are somewhat irregular, but point to an increase with an increase in water.

The percentages of crude fibre differ but little; and are not markedly affected by irrigation.

The nitrogen-free extract is also irregular and cannot be connected with the amounts of water applied.

34. THE CHEMICAL COMPOSITION OF THE WHOLE PLANT.

In tables 56 and 57, the data obtained for the heads, stalks and leaves have been combined, to show the composition of the whole wheat and pea plants.

TABLE NO. 56.—THE PERCENTAGE COMPOSITION OF THE WHOLE WHEAT PLANT.

Date of cutting	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
June 22nd	334	13.05	11.57	2.89	27.93	44.50
	335	8.99	12.59	1.82	27.84	48.70
	336	11.01	13.50	2 59	30.55	42.41
July 5th	334					
	335	10.56	13.03	2.57	38.55	35 24
	336	10.80	12.75	2.69	34.90	38 83
July 18th	334	6.98	7.91	1.80	35.02	48.28
	335	8.29	7.21	1.85	32.99	49.62
	336	9.02	7.76	1.97	33.02	48.17
Aug. 1st	334	6.29	6.98	1.63	34.76	50.27
	335	7.24	6.06	2.47	33.02	51.18
	336	6.52	7.24	1.56	29.95	54.73
Aug. 23rd	334	5.87	6.29	1.71	32.73	53.40
	335	5.95	7.56	1.77	31.92	52 80
	336	9.51	7.77	1.73	27.08	54.91

In studying this and the next table, it must be remembered that the relative amounts of the plant parts, as well as their chemical composition, have entered into the calculation of the composition of the whole plant. This will explain some of the deviations from the rules developed in the preceding sections.

The variation in the ash in whole wheat is not regular, though in the majority of cases the percentage or ash increases with the amount of water applied.

The percentage of protein differs very little; in three out of five cuttings the percentage of protein is highest in the plants from the well watered plats.

The variation in the ether extract is very small, and does not seem to be connected with the amount of irrigation.

The percentage of the crude fibre is larger, in nearly every case, in the plants from the plats that received least water.

There is no regular variation in the nitrogen-free extract.

TABLE NO. 57.—THE PERCENTAGE COMPOSITION OF THE WHOLE PEA PLANT.

Date of cutting	No. of plat	Ash	Protein	Ether extract	Crude fibre	Nitrogen-free extract
	337	10.55	26.37	3.67	19.68	39.73
June 27th	338	11.10	15 94	5.38	19.75	47.83
	339	10.30	22.48	3.46	20.44	43.32
	337	11.82	19.14	2.73	25.23	41.08
July 20th	338	8.02	23.28	2.34	23.86	42 50
	339	10.01	20.52	3 27	22.14	44.06
	337	11.38	22 78	2.32	19.02	44.50
Aug. 14th	338	8.14	21.84	1.92	18.38	49.72
	339	7.76	11.32	4.19	20.30	56.43

As already observed under the plant parts, the percentage of ash in the whole pea plant varies in the opposite direction from that in the wheat plant. The plats that received most water, carried plants that contained the smallest percentage of ash.

There is a very great and unaccountable variation in the percentages of protein in the whole pea plant. However, the relative amount of protein increases in general as the amount of water applied diminishes.

There are slight indications that the ether extract is increased by large irrigations.

The percentages of crude fibre are very nearly alike and appear to be influenced very little by irrigation.

The percentage of nitrogen-free extract becomes larger as irrigation increases.

35. THE CHEMICAL COMPOSITION OF CORN KERNELS.

The material used in this investigation was obtained from the corn plats used in the regular irrigation experiments. For details of planting, cultivation, irrigation, harvesting etc., see section D.

TABLE NO. 58.—PERCENTAGE COMPOSITION OF CORN KERNELS.

Plat	Irrigation water applied inches	Water in fresh substance	Water-free substance					Method of irrigation
			Ash	Protein	Ether extract	Crude fibre	N-free extract	
259	38.00	13.27	1.66	12.99	5.77	1.94	77.64	Flooding
255	36.53	15.44	1.57	12.05	6.74	1.85	77.79	Furrow
260	19.98	12.93	1.51	13.00	6.38	2.40	76.71	Flooding
256	19.97	13.07	1.60	12.65	6.20	1.98	77.57	Furrow
257	15.00	10.92	1.68	13.17	6.06	1.93	77.16	Furrow
261	15.00	12.39	1.62	13.79	6.15	1.89	76.55	Flooding
262	10.00	11.00	1.59	13.42	5.39	2.23	77.37	Flooding
258	7.50	14.01	1.62	15.08	6.02	1.89	75.39	Furrow
263	None	10.04	1.68	14.52	5.34	2.22	76.24	

Examining the column headed "Water in fresh substance," it is seen that with one exception the percentage of water varies regularly with the amount of water under which the crop was grown; and the less water applied, the less is found in the ripened corn kernels.

The percentage of ash on the other hand is not markedly affected by irrigation.

The case of protein is very different. Comparatively small differences in the amount of irrigation water applied, caused corresponding, but inverse, changes in the percentage of protein. Plats 259 and 255, which received an average of 37.26 inches of water, yielded corn, containing 12.52% of protein; while plat 258, which received 7.50 inches of water, gave corn containing 15.08% of protein. The corn from plats which received intermediate amounts of water, contained intermediate percentages of protein. The corn from the plat which received no water, contained 0.56% protein less than did the corn from the plat which received 7.50 inches. The method of irrigation also had an effect upon the percentage of protein, for it was always lower in the furrow irrigated corn than in the flooded.

The percentage of ether extract was also affected by irrigation. The corn raised on the two plats that received most water contained 6.26% ether extract: while the corn grown without irrigation contained only 5.34%. The variation was somewhat irregular; yet the content of ether extract varied from 6.74% to 5.34%; the higher percentages being found in the corn from plats that had received most water.

The percentages of crude fibre varied slightly, yet not so much that a connection could be established between the variation and the irrigation.

The percentage of nitrogen-free extract also appeared to increase as the amount of irrigation was increased.

The most striking fact brought out by the study of the corn kernel is the great variation in the protein content, made possible by controlling irrigation. The lowest percentage of protein was 12.05, and the highest, 15.08—a difference of 3.06%. Dr. C. G. Hopkins, in his work on the improvement of the corn kernel, succeeded by careful selection to produce two grades of corn with a difference on their percentages of protein of 0.99 and 0.70% respectively, for the crops of two years. These differences are small, when compared with the 3.06% caused by irrigation. If the high and low protein property could be fixed in the kernels for only one or two generations, it would work a revolution in the production of seed corn. That question must, of course, be subjected to experiment.

36. THE CHEMICAL COMPOSITION OF OAT KERNELS.

The material used in this examination was obtained from the plats devoted to oats in the regular irrigation experiments. For cultural and irrigation data refer to section D. The variety used was American Banner.

TABLE NO. 59.—PERCENTAGE COMPOSITION OF THE OAT KERNEL.

No. of plat	Irrigation water applied (inches)	Water in fresh substance	In water-free substance.				
			Ash	Protein	Ether extract	Crude fibre	Nitrogen free extract
293	6.98	8.00	3.26	20.79	3.91	9.02	63.02
296	12.50	7.63	4.33	17.42	4.46	12.52	61.27
294	13.90	7.82	4.71	17.16	3.92	8.99	65.22
295	14.68	7.66	6.03	17.20	3.74	10.75	56.28
297	15.01	8.07	4.68	14.07	4.46	12.61	64.18
298	15.00	8.60	4.39	15.17	4.43	16.84	58.17
299	30.00	8.40	4.49	15.49	4.59	10.92	64.51
300	40.00	8.62	4.55	15.80	4.56	10.38	64.71

The percentage of water in the fresh substance is highest, in general, in the oats grown on the plats that received most water. The one exception is found in the grain from the plat that received least water.

The per cent of ash is not affected by irrigation.

As in the case of corn kernels, the relative amounts of protein are strongly affected by irrigation. The larger the quantity of water applied the smaller the per cent of protein. The highest and lowest per-cents are 14.07 and 20.79– a difference of 6.72%.

The fat content is highest on the well watered plats, and the variation follows quite regularly the amounts of water used. The difference between the highest and lowest per cents, is 0.85%.

The highest per cents of crude fibre are found in the oats grown on the plats that received intermediate amounts of water.

The nitrogen-free extract is highest on the plats that received most water, but the variation is not regular.

As in the case of the corn kernel, the most striking change in the composition of the oat kernel is the variation in the protein content, to conform with the irrigation. This difference, however, is considerably higher than was the case with the corn.

37. THE CHEMICAL COMPOSITION OF THE WHEAT KERNEL.

The samples of wheat used in this study were obtained from the wheat plats in the regular irrigation experiments. For all cultural data refer to section D. The variety used was New Zealand.

TABLE NO. 60.—PERCENTAGE COMPOSITION OF THE WHEAT KERNEL.

No. of plat	Irrigation water applied. in	Water in fresh substance	In water-free substance				
			Ash	Protein	Ether extract	Crude fibre	Nitrogen free extract
Wheat sown in spring.							
317	4.63	7.70	2.70	26.72	2.37	5.44	62.77
319	5.14	8.16	3.32	25.11	5.24	3.05	63.28
320	8.73	8.00	2.74	21.50	5.34	4.54	65.81
318	8.89	8.50	3.18	21.00	1.91	4.22	69.69
321	10 30	8.47	2.54	19.93	2.09	4.47	70.97
325	12.09	7.91	3.51	23.02	2.19	4.99	66.29
322	12.18	8.00	3.11	24.94	2.14	4.45	65.36
326	12.80	8.52	2.74	18.58	2.03	3.49	73.16
327	17.50	7.59	2.79	18.57	2.34	5.88	70.43
328	21.11	6.80	2.50	16.99	1.97	3 92	74.62
329	30.00	8.70	4.50	15.26	1.85	3.19	75.20
330	40.00	8.01	2.72	18.43	1.94	3.42	73.48
Wheat sown in fall.							
301-305 309-313	None	8.49	2.38	19.90	0.70	3.64	73.38
306-314	13.79	7.66	2.69	17.08	0.56	3.17	76.50

There seems to be no regular variation in the per cent water held by the fresh substance to correspond with the amounts of water applied in irrigation; neither does the per cent of ash show any definite connection with the irrigation.

The per cent of protein increases very markedly in the wheat kernel as the amount of water applied to the soil decreases. The plat that received thirty inches of water gave wheat containing 15.26% protein; while the wheat from the plat that received 7.70 inches, contained 26.72%. This difference between the wheat kernels raised without irrigation and with 13.79 inches of water, was 2.82%. The smaller difference is unquestionably due to the abundant soil water in the fall and early spring.

The variations in the ether extract are very irregular. The kernels raised with 5 to 8 inches of water contain the highest percents of fat.

The crude fibre is not strongly affected by irrigation; though the general tendency is for the per cent to decrease, as the amount of irrigation increases.

The per cent of nitrogen-free extract is highest in the wheat from the plats that received most water.

Here again it may be remarked, that the protein is influenced more strongly than any other constituent by irrigation. If, as suggested under the discussion of the corn kernel, the high protein quality of these grains can be retained for one or two generations, with abundant watering, a wide possibility is opened for the production of seed grain under arid conditions for humid and well irrigated districts. This subject will be put to experimental test in the near future.

38. THE CHEMICAL COMPOSITION OF POTATOES.

The potatoes, the analyses of which are reported in the following table, were grown in the irrigation experiments. Full cultural data are given in section D. The variety used was Early Rose.

TABLE NO. 61.—PERCENTAGE COMPOSITION OF POTATOES.

No. of plat	Irrigation water applied inches	Water in fresh substance	Ash	Protein	Ether extract	Crude fibre	Starch	
255A	8.08	76.00	6.68	11.83	0.55	2.69	69.95	8.30
256A	10.00	76.34	4.57	12.57	0.11	2.46	69.55	10.74
257A	15.00	75.01	5.47	13.61	0.16	2.11	69.05	8.70
258A	15.00	75.13	4.89	12.39	0.50	2.05	69.85	10.32
259A	15.00	75.56	4.89	12.27	0.13	2.56	74.93	5.22
261A	15.00	76.46	4.16	11.83	0.52	2.14	75.60	5.75
260A	20.00	76.24	4.29	11.46	0.50	2.56	76.25	4.94
262A	27.00	75.95	4.99	10.77	0.06	1.93	75.10	7.15
263A	39.99	76.00	4.87	8.33	0.79	2.06	76.48	7.47

All the samples were also tested for reducing sugar and sucrose. Of the former, traces were found in all but two of the plats; while of the latter, a trace was found only in one sample.

It is quite noteworthy that the amount of moisture in the fresh potatoes varies little in the different plats. Irrigation, in fact, seems to have little, if any, effect on the moisture content of potatoes.

The per cent of ash does not vary with the amount of water applied.

As in the case of the grains, the relative amount of protein becomes larger as the irrigation becomes smaller. The difference between the maximum and minimum per cents is 5.28%,—sufficient to affect the food value of the potatoes very materially.

The variation of the ether extract is very irregular and does not follow the variation in the amount of water applied.

The crude fibre shows a tendency to decrease on the well irrigated plats.

The per cent of starch, on the other hand, increases very regularly with the increased irrigation. The difference between the highest and the lowest per cents of starch was 6.93—quite sufficent to affect the food value of the tubers.

It will be observed that four plats—257A, 258A, 259A and 261A—received the same amount of water, 15 inches, through the season. Plats 257A and 258A received this amount of water in two irrigations on June 26th and July 20th; while plat 259A received it in three irrigations on June 26th, July 20th and August 8th; and plat 261A received it in six irrigations, from June 27th to August 23rd. The first two plats contained an average of 13.00% protein and 69.90% starch; the next, 12.27% protein and 74.93% starch, and the last, 11.83% protein and 75.60% starch. It is quite evident from these data that a few heavy irrigations produce potatoes rich in protein and poor in starch; while many small irrigations yield tubers poor in protein and rich in starch.

Of one fact table No. 61 offers ample proof, namely, that little water produces potatoes rich in the muscle forming protein; and that much water produces starchy potatoes. For those whose diet is composed, largely of potatoes, it would be best to irrigate lightly; but for all ordinary purposes, the well-watered potatoes are the best.

39. THE CHEMICAL COMPOSITION OF SUGAR BEETS.

Like the samples of the preceding crops, the sugar beets were obtained from the irrigation plats. The variety sown was German Kleinwanzlebener. For all cultural data refer to section D.

The fresh beets were carefully weighed, sliced, strung on thread, and hung up to dry at ordinary room temperature. When dry, they were ground, and the material thus obtained was analyzed according to the usual methods.

TABLE NO. 62.—PERCENTAGE COMPOSITION OF SUGAR BEETS.

No. of plat	Irrigation water applied. in.	Water in fresh substance	Ash	Protein	Ether extract	Crude fibre	Reducing sugars	Sucrose	Starch	Undetermined
430	11.16	77.85	4.58	10.06	0.12	5.85	1.75	58.51	6.78	12.34
366	13.47	74.60	4.94	9.29	0 47	4.89	0.68	63.19	5 87	10.67
351	14.51	75.40	5.35	8.39	0.31	5.06	1.27	62.81	6.21	10.51
350	15 64	75.88	4.94	6.99	0.23	5.36	1.02	66.26	5.60	9.60
352	16.55	76.58	5.14	9.07	0.38	5.31	1.22	60.53	7.16	11.19
362	17.50	76.83	4.32	10.42	0.27	4 64	0.62	61.57	6.57	11.59
354	17.78	73.84	4.44	10.60	0.36	4.96	1.85	61.67	5 80	10.32
353	19 95	77.91	4.91	11.59	0.43	5.44	1.44	59.59	6.57	10.03
363	20.03	77.83	4.31	9.78	0.37	4.82	0.40	59.00	6.12	15.20
365	20.09	74.96	5.62	10.32	0.30	4.94	1.04	61.74	7.12	8.92
361	20.17	75.14	4.75	10.00	0.33	5.02	0.87	63.00	7.84	8.19
341	21.00	78.67	4.98	7.50	0.18	6.02	1.53	57.21	7.46	15.12
364	23 27	73.90	4.71	5.21	0.43	4.89	0.73	64.30	7.84	11.39
374	25 99	77.54	4.18	11.40	0.41	4.94	0.45	61.77	7.02	9.73
367	26.66	75.63	5.17	10.32	0.25	5.11	0.73	62.71	6.44	9.27
342	40.82	77.58	4.69	5.63	0.45	5.68	1.18	62.01	7.05	13 31
343	53 96	73 39	3.79	6.10	0.36	4.79	1.89	60.65	7.07	15.35

The per cents of water in the fresh substance do not follow in general the amounts of water applied in irrigation. The variation itself is very small, being 4.52 between the two extremes.

The per cents of ash are irregular and do not follow the irrigation.

It is rather surprising to note that the per cent of protein in the sugar beets does not vary regularly with the irrigation. It is somewhat higher in the beets from the plats that received from 17 to 20 inches of water, than in those from plats that received more or less than these amounts. Even this statement must be modified; owing to deviations from the rule.

The per cent of ether extract, crude fibre and reducing sugars are likewise, so irregular as to allow of no general law, depending upon irrigation, to be observed.

The sucrose, which, to the manufacturer, is the most important constituent of the beet, constitutes from 57% to 66% of the water-free substance. Regular changes in the irrigations do not seem to cause corresponding regular variations in the sucrose content. This, also, is surprising in view of the comparative regularity with which the nitrogen-free extract in the crops previously studied, has increased with the increase in irrigation.

The starch averages less than 7% in the sugar beet. The per cent is slightly higher on the plats that received most water.

In general, from table No. 62, it would seem safe to conclude that the relative proportions of the constituents of the sugar beet are not affected to any noticeable extent by irrigation. The great regularity that has prevailed in the other crops, leads to some doubt concerning the correctness of this view. The plats on which the sugar beets were grown were very different in depth and in proportion of gravel, and they had been manured differently. Then, the sampling of the beets may present difficulties of which we were not aware. It is fairly well known that, usually, the juice of a large beet contains a smaller percentage of sugar than does that from a small beet, and it may be, that other constituents are affected similarly by the size of the beet. These are matters that must be left for future investigation.

From August 19th to October 16th samples of beets were taken weekly from the irrigation plats, and the juice analyzed for total solids and sucrose or sugar. To eliminate as far a possible the errors due to sampling and analysis; the data obtained for three consecutive weeks have been averaged. In the tables which follow, the per cents of sucrose and purity are the averages of three analyses made on three samples, taken at intervals of one week.

TABLE NO. 63.—PER CENT OF SUCROSE IN THE JUICE FROM SUGAR BEETS.

No. of plat	Irrigation water applied. In.	Aug. 19th to Sept. 13th	Sept. 10th to Sept. 21st	Oct. 2nd to Oct. 16th
340	11.16	13.16	14 42	13 38
366	13.47	11.88	13.28	15.04
351	14.51	10.48	13.08	14.42
350	15.64	11.72	13 92	15 81
352	16.55	10.93	11.07	14.68
362	17.50	11.90	14.27	15.52
354	17.78	9.41	11.93	14.92
353	19.95	12.41	12.20	15.34
363	20.03	13.38	14 13	16 54
362	20.09	12 05	13.50	16 12
362	20.17	12 09	14.70	16.12
341	21.00	15.46	14.24	15.41
364	23.27	13 27	16.02	18.43
374	25.99	9.86	12.13	14.07
367	26.66	12.14	12.80	14 82
342	40.82	15.28	15.40	13.42
343	53.96	11.52	13.84	17.08

During the first period, from August 19th to September 3rd, the per cent of sugar in the juice increased slightly with the increase in irrigation. Some variations from this rule, not yet explained, were noted.

During the second period, from September 10th to September 25th, the plats that received the smallest and the medium amounts of water, carried beets, the juice of which contained approximately the same per cents of sugar; while the plats receiving most water yielded beets with the highest per cent of sugar in the juice.

During the third period, the beets from the plats that received from 20 to 27 inches of water contained more sugar in their juice than did the beets raised with more or less water.

These results are summarized in table No. 64.

TABLE NO. 64.—PER CENT OF SUCROSE IN THE JUICE FROM SUGAR BEETS.

Inches of water applied	Aug. 19th to Sept. 3rd.	Sept. 10th to Sept. 25th	Oct. 2nd to Oct. 16th
11.16 to 17.78	11.35	13.14	14.83
19.95 to 26.66	12.58	13.72	15.86
40.82 to 53.96	13.40	14.62	15.25

As may be observed from the above table, the actual differences in the per cents of sucrose in the juice of beets grown with different amounts of water, are very small—never exceeding 1.23%. In the early stages of ripening, the sucrose per cent increases with the irrigation; in the later stages, the differences are smaller, and in the last period, the plats receiving medium irrigations yielded beets containing the highest per cent of sucrose in the juice. The general result of this investigation seems to favor medium irrigations, so far as the sugar content of the juice is concerned.

It may be worthy of note, that, in conformity with earlier investigations at this station, the sugar content of the beet juice increases late into the fall. From the point of view of the sugar manufacturer in this section, early harvesting of the sugar beet is undesirable.

TABLE NO. 65.—PER CENT PURITY IN JUICE FROM SUGAR BEETS.

No. of plat	Irrigation water applied inches	Aug. 19th to Sept. 3rd.	Sept. 10th to Sept. 25th	Oct. 2nd to Oct. 16th
340	11.16	78.6	78.0	79.4
366	13.47	75.4	76.4	88.7
351	14.51	78.3	79.1	75.7
350	15.64	80.8	81.9	81.7
352	16.55	73.1	74.1	82.7
362	17.50	78.4	82.3	83.5
354	17.78	74.6	73.2	75.8
353	19.95	80.2	80.6	81.7
363	20.03	79.7	81.9	86.2
365	20.09	80.3	78.5	81.0
361	20.17	81.6	81.4	83.6
341	21.00	83.8	81.4	82.0
364	23.27	82.3	85.6	88.5
374	25.99	76.1	77.5	82.4
367	26.66	80.9	78.8	75.7
342	40.82	82.9	82.7	81.7
343	53.96	78.1	82.6	86.6

Table 65 exhibits the percentage purity of the juice from the sugar beets. Each per cent, like those of table No. 64, is an average of three determinations made on these samples taken at intervals of one week. The percentages are very irregular, and do not follow at all closely the amounts of water applied in irrigation. However, the averages show that the plats which received most water yielded beets with the highest purity coefficient. This may be shown better in the following summary table.

TABLE NO. 66.—PER CENT PURITY IN JUICE FROM SUGAR BEETS.

Inches of water applied	Aug. 19th to Sept. 3rd	Sept. 10th to Sept. 25th	Oct. 2nd to Oct. 16th
11.16 to 17.78	77.0	77.9	81.1
19 95 to 26.66	80.6	81.1	82.7
40.82 to 53.96	80.5	82.7	84.2

The differences in the purity of the juice are so small as to be of little consequence in practice. Considering, especially, the great increase in the irrigation water necessary to cause an increase of one or two per cents increase in purity, the lack of economy becomes very evident. Considering the beets only from the point of view of their composition, it is advisable to apply during the season, between 20 and 25 inches of water.

TABLE NO. 67.—AVERAGE WEIGHT OF ONE BEET.

(in grams.)

Inches of water applied	Aug. 19th to Sept. 3rd	Sept. 10th to Sept. 25th	Oct. 2nd to Oct. 16th	Average
11.16 to 17.78	383	399	399	390
19.95 to 26.66	486	468	451	468
40.82 to 53.96	340	379	340	353

The beets, the analyses of which are found in the preceding tables, were weighed as they came into the laboratory, and the average weight of each beet was thus obtained. While the method of sampling and the comparatively small number of samples examined at each time, make the results somewhat uncertain, yet the average weights obtained from about 1300 beets (the number used in the preceeding investigations) should point with some definitness to the weights of one beet as affected by irrigation. It was found that the seven plats, receiving from 11.16 to 17.78 inches of water, yielded beets of an average weight of 390 grams; the weight of the beets from the plats receiving from 91.95 to 26.66 inches, was 468 grams; and the beets from the two plats that received respectively 40.82 and 53.96 inches of water weighed on an average 353 grams. The largest beets were thus grown on the plats receiving intermediate quantities of water. Yet, since they weighed only a trifle more than one pound, they were not too large to be desirable for factory use, but, rather, more nearly the standard size than those grown with less or more water. The data in table No. 67 might lead to the conclusion that the plats receiving intermediate amounts of water also yielded the largest weights of beets per acre. This is confirmed by the discussion of the total yields per acre.

At the conclusion of tl is discussion of the chemical composition of the sugar beets as affected by irrigation, it may be said that the general behavior of the crops, due chiefly to varying soil conditions, was irregular and unsatisfactory, and that the conclusions stated must be accepted with the understanding that future work will, in all likelihood, materially change and add to them.

40. RELATION BETWEEN WATER IN PLANT AND IN SOIL.

During the progress of the experiments, an attempt was made to learn whether the amount of water in the soil had any definite relation to the water in the plants growing on the soil. Samples of wheat were taken at irregular intervals from plat 336, and samples of soil were taken at the same time. The per cent of water was determined in plant and soil, in the usual manner. The results are found in table No. 68.

TABLE NO. 68.—RELATION BETWEEN WATER IN PLANT AND IN SOIL.

	Plat 336 (Depth 19 inches.)		
Date	Water in plant	Water in soil 0-12 inches	12-19 inches
June 25th	77.23	10.06	10.94
June 26th	77 81	20 05	20.32
July 1st	74.39	15.22	16.68
July 3rd	74.87	13.32	14.68
July 9th	72.61	18.18	19.24
July 11th	71 63	17.46	18.42
July 12th	69.30	20.12	19.46
July 13th	69.08	18.54	18.12
July 19th	67.24	20.46	20.46
July 30th	56.22	16.02	15.90

On June 25th; the soil contained between 10% and 11% of water; the plant 77.23%. Immediately after sampling the plat was irrigated. The next day the per cent of water in the plant was 77.81% and that in the soil over 20%. The large increase in the soil water seemed to have a very small effect on the per cent of water in the plant,

On July 1st, the soil contained about 2% less water than it did on July 3rd, yet the wheat contained 0.48% more water. On the dates from July 9th to July 19th, there appeared to be no interdependent variation of the water in plant and soil.

It is generally known that the per cent of water in the plant becomes smaller as the plant grows older. This law appears to be of more consequence in determining the amount of water in the plant, than is the water content of the soil, From the brief series of experiments here recorded; it may be safe to conclude that when the water content of the Station Farm soil varies between 10% and 21%, the per cent of water in the plant, during any given period of growth, is practically constant and independent of the per cent of soil moisture.

It must be remembered, however, that plat 336 was irrigated whenever needed, so that the crop never really suffered from want of water. Should the soil be allowed to remain very dry for any length of time, it is undoubtedly true that the per cent of moisture in the plant would diminish, and finally cause the dangerous condition known as wilting. It further appears from all the work done this season, that plants, in good condition, have a constant stream of water passing through them; when this stream is checked, wilting follows, even though the actual per cent of moisture in the plant has fallen only slightly.

D. IRRIGATION VERSUS YIELD.

41. THE YIELDS OF CORN.

Nine plats, one-twentieth of an acre in size, were devoted to experiments in corn irrigation during the season of 1901. These plats are located on the east side of the irrigation experiment and the corn was exposed to the severe canyon winds which occurred during every night of the growing season. The soil on which this experiment vas conducted has been under cultivation since 1890, before which time it was devoted to sage brush and grease-wood. From 1890 to 1892 inclusive, potatoes were grown on these plats. From 1893 to 1897 inclusive, they were used in some cultural experiments with corn, the results from which are found in Bulletin No. 66 of this Station. For two years they were sown to wheat and the following year to barley. This brings their history up to 1901, when this experiment was begun.

During each winter, barnyard manure has been applied to all the plats and our records show uniform treatment in all other respects during the previous ten years, so that any differences in results cannot reasonably be ascribed to differences in treatment. The variation in the dates of plowing these plats may account for any differences in the moisture content of the soils at date of seeding, though no record of such differences exists. Neither do our field notes show any difference in the growth of the crop prior to the first irrigation.

Plats 255 to 260 inclusive, were plowed from March 19th to March 22nd, but owing to rain storms, plats 261 and 262 were not plowed until April 13th and the plowing of plat 263 was delayed until April 24th.

As is customary here, all the plats were plowed ten inches deep and harrowed with a light smoothing harrow on the same day as plowed. The plats were all seeded to corn on April 30th, except plat 263, which was seeded on May 7th, in check rows three feet apart, a hand corn planter being used for seeding.

The corn used in the experiment was originally obtained from Wm. Watterson of Logan, and is the kind ordinarily grown in the Cache Valley. It is a twelve rowed clear white flint. The ears are large, being about ten inches in length and one and one-half inches in diameter. Variety tests conducted here have resulted in the highest yield for this variety seven years out of ten. It is the earliest maturing variety ever tried here, the number of days from planting to time of cutting being on the average one hundred and sixteen.

On May 24th and 25th, an unusually hot wind severely injured the corn, the leaves being badly torn and presenting a blackened, charred appearance.

The irrigation experiment with corn was intended, primarily, to compare furrow irrigation with flooding, though the duty of water, in this test, as in the case of all the other crops used, was kept in view. It will be seen from table No. 69 that the amounts of water applied varied from 7½ inches to 38 inches. One plat was "dry farmed"; this plat is included for comparison.

TABLE NO. 69.—IRRIGATION VS. YIELDS OF CORN.

Plat No.	Depth of plat	Total amt. water applied inches	Dates of irrigation and amount of water applied (inches).												Method of irrigation	Yield per acre in bu. grain	Yield of corn stover per acre, pounds	Total yield per acre of dry matter
			June 29	July 1	July 15	July 18	July 29	July 31	Aug. 7	Aug. 12	Aug. 16	Aug. 20	Aug. 24	Aug. 29				
263	51	None	......	......	......	......	......	......	......	......	......	......	......	......	......	26.00	2700	4068
258	20	7.50	2 50	......	......	2.50	2.50	......	......	......	......	......	......	......	Furrow	35.14	3000	4914
262	48	10.00	2.50	......	......	2.50	5.00	......	......	......	......	......	......	......	Flood	56.86	4200	7361
261	36	15.00	5.00	......	......	5.00	5 00	......	......	......	......	......	......	......	Flood	58.71	3800	7119
257	19	15 00	......	5.00	......	5.00	5.00	......	......	......	......	......	......	......	Furrow	46.28	2900	5526
256	14	19.97	......	4.66	......	6.21	6.66	......	2.44	......	......	......	......	......	Furrow	49.28	3440	6201
260	40	19 98	6.66	......	......	6.66	6 66	......	......	......	......	......	......	......	Flood	77.00	4400	8811
255	25	36 53	......	7.59	2 81	1.31	2.50	1.33	2 50	2.50	2.50	5.00	5.00	3.49	Furrow	69.28	3500	7515
259	36	38 00	......	8 76	6.33	1.55	2.50	1.33	2 50	......	2.50	5 00	2.58	4.95	Flood	82.71	4700	12140

Flooding vs. Furrow Irrigation:—It will be seen from the table that the yield of ear corn, of dry matter and of stover was the largest in every case, with equal applications of water, by the flooding method.

TABLE NO. 70.—VALUE OF FLOODING OVER FURROW IRRIGATION.

Amount of water applied.	Per cent increase by flooding.		
	Bu. of ear corn	Dry matter	Corn stover
15 inches	26.8	28.8	31.0
20 inches	56.2	42.0	25.7

Formerly the hoed crops, such as corn, potatoes and sugar beets were the only crops to which water was applied by the furrow method, but this system is now commonly practiced in the irrigation of cereals and forage crops in the larger part of the irrigated section of this State. It should be stated in connection with our experiments that the plats were short, (four rods,) and great difficulty was encountered in applying the requisite amount of water by the furrow method. Frequent applications had to be made, but great care was exercised to prevent the water from flooding the plat.

In actual practice, water is turned into twenty to fifty and even one hundred furrows and allowed to run very slowly. The rows are usually directed so as to prevent much fall and thereby reduce the washing as much as possible. Special implements have been devised in connection with this method of irrigating cereals and forage crops, by which the furrows are made at the time of seeding. The opinion is generally entertained that the furrow method is the more economical in the use of water, but the results show for this year, that the reverse is true.

In these experiments, the plats receiving equal applications of water were cultivated the same day, so that any variation in yield could not be ascribed to this factor.

An important consideration, however, one that undoubtedly affords an explanation of the larger yields for the irrigation by flooding, is the difference in the depths of the soil on the comparable plats. Unfortunately, in each case where the two systems of irrigation are compared with equal applications of water, the plat irrigated by the furrow method is much the shallower. So important a factor is this that it would be unwise to draw far-reaching conclusions from the experiment.

Late Irrigation:—Warnings have frequently been given that if water is applied to the corn crop late in the season, the crop will not mature. The last irrigation on all the plats, except 255, 256 and 257, was made on July 29th. Plat 256 received its last irrigation on August 7th. Plats 255 and 259 were irrigated every fourth or fifth day after August 7th during the rest of the month, the last irrigation occurring on August 29th. The corn on all plats was ripe and harvested on September 11th, and we had no evidence of differences in the time of maturity of the crops, though a determination of the moisture content (see table No. 58), shows that the corn receiving late irrigations carried the highest percentage of moisture.

It is probable that the character of the soil would have an important bearing on the question. The soil in this case was a sandy loam underlaid with gravel and through which the water readily passes. Clayey soils, retaining the moisture for a long time and permitting prolonged evaporation, would tend to keep the soil cold and retard the necessary storing of the nutrients for the ripening of the crop. We can safely assume that on soils similar to that of the College farm no injurious results will follow from the late application of water in corn growing. The growing season extended over a period of one hundred and thirty-four days, an unusually long one, for this variety of corn. For most of the plats the irrigations were all made during one month, from June 29th to July 29th.

Effect of varying amounts of water on ear corn and stover:—An examination of the table reveals a very interesting fact regarding the effect of varying amounts of water on the proportion of ears to stover. The following table gives the percentage of ear corn and stover obtained with varying amounts of water.

TABLE NO. 71.—PROPORTION OF EAR CORN TO STOVER.

		Per cent of ear corn in whole plant.	Per cent of stover in whole plant.
No irrigation.........		40.3	59.7
7½ inches of water.....		45.1	54.9
10 " " " ...		48.6	51.4
15 " " " ...	51.9	52.3	47.7
15 " " " ...	52.8		
19.97 " " ...	50.1	52.6	47.4
19.98 " " ...	55.1		
36.53 " " ...	58.1	56.7	43.3
38 " " " ...	55.2		

It will be seen that the proportion of ear corn to fodder increased regularly with the increased application of water. This is rather surprising, the natural supposition being that increased application of water would demand an increased proportional leaf surface for its transpiration. The table shows, however, that the lowest percentage of corn to the fodder was obtained from the minimum water supply and the highest percentage from the maximum water supply. We learn from the above that somewhat more than one-half of the total weight of the corn crop is found in the ears when water is applied in quantities of fifteen acre-inches or more, and somewhat less than one-half when water is applied in less amount.

Effect of varying amounts of water on total yield:—By reference to table 69 it will be seen that the application of 38 inches of water gave the highest yield of ear corn and also the highest yield of stover and dry matter per acre. The second highest yield of corn and also of stover and dry matter was obtained by the application of but .98 of an inch more than one-half of the amount applied to the plat giving the highest yield. It may be that the limit of production was not reached. The table furnishes no evidence that a still further increase of water would not result in an increased yield. A careful study of the table shows that the most profitable use of water for corn lies between 15 and 20 inches of water, though this will depend somewhat upon the method of application. It seems safe to conclude that best returns, considering the amount of water applied and the method of application, are obtained by the use of from 15 to 20 inches of water by the flooding method. Future experiments on soils of more uniform depth may modify this somewhat.

42. THE YIELDS OF OATS.

Oats in this State have, up to the present, been grown only upon irrigated lands. Both corn and wheat are successfully grown on the "arid" farms, but attempts to grow oats without irrigation have so far been unsuccessful. In this experiment, eight of the best plats were devoted to irrigation experiments with oats, the amount of water applied varying from 6.98 inches to 40 inches. The soil on these plats varies from 16 inches to 41 inches, the average depth being 31 inches. The history of these plats, from the time the soil was brought under cultivation, to 1901, is as follows:

Potatoes were grown on all plats during the season of 1890. The three following years, plats 293 and 294 were seeded to wheat, followed by three years of barley, then three years of wheat, and during 1900 peas were grown on these plats. From 1891 to 1897 inclusive, plats 295 to 299, inclusive, were devoted to corn, and the two following years to wheat. During 1900 peas were grown on plats 295 and 296; barnyard millet on plats 297 and 298, and peas and oats as a soiling crop on plats 299 and 300. The record for plat 300 is incomplete.

All of these plats have had an application of barnyard manure each year since they were first cultivated.

The plowing preparatory to this experiment was done on March 21st on all plats except 299 and 300, which were plowed on April 13th. All plats were seeded on April 20th with a "Superior" press drill, at the rate of 12 pecks per acre. One of our most desirable varieties, American Banner, was used. The grain is large, white and plump; it ripens early, has a stiff straw of good length and at the time of seeding, was considered one of our choicest varieties.

The plants made their appearance six days after seeding and during the following month made excellent growth. On May 24th and 25th, the hot winds referred to, greatly injured the crop. The oats seemed to recover from the effects of the wind on all plats equally well, and until June 12th, no differences were noted for the different plats. The first irrigation was made on this day, and it was noted that at this time, the growth on plats 293 and 296 was uneven and the crop on parts of the plats was badly wilted. The growth on plats

295, 297, 298, 299 and 300 was also uneven, but none of these plats seemed to be in need of irrigation.

On July 19th, the oats on plat 293 had an average height of 16 inches, as compared with 34 to 36 inches on the remaining plats, and looked as if they were dying for want of water. All plats were harvested on July 30th. The plants were not affected by disease, and outside the appearance of a few wild oats (avena fatua) due to the fact that the manure was obtained in the town, nothing unusual was noticed.

TABLE NO. 72.—IRRIGATION VS. YIELDS OF OATS.

Plat No.	Average depth of soil in inches	Inches water applied.					Yield of grain per acre bu.	Yield of straw per acre lbs.	Total weight per acre dry matter
		Total	June 12 & 13	June 27 & 28	July 10	July 16			
293	16	6.98	2.93	......	4.05	......	12.50	800	1139
296	34	12 50	6.28	......	6.22	......	47.50	2680	3592
294	41	13.92	5 15	4.17	4.60	......	40.62	2920	3946
295	23	14.68	10 26	......	4.42	......	28.13	2620	3353
298	36	15.00	3.34	4.16	7.50	......	65 00	2720	4508
297	37	15.01	7.52	4.99	2.50	......	48.75	3660	4821
299	36	30 00	6.78	6.20	10.00	7.02	85.00	5340	8050
300	29	40.00	8.64	6.55	10 00	14.85	80 00	4860	7188

Length of the growing season:—The growing season, in the case of oats, was just one hundred days, and the irrigating season but thirty-four days. The first irrigation occurred on June 12th; on which date, and the day following, all plats were irrigated; the last irrigation occurred on July 16th. All plats were irrigated by the flooding method.

Unfortunately, the plat receiving the least amount of water was the most shallow plat, and as will be seen from the table, the yields recorded are the minimum yields of the experiment. The yields do not increase directly as the amount of water increases in every case, but the variations in yield indicate that the depth of the plat is a very great disturbing factor.

Effect of varying amounts of water on the proportion of grain to straw:—In this State oats are grown almost exclusively for the grain; the practice of using the whole plant for forage not having been extensively adopted as is the case in some portions of the West. The effect, then, of the varying amounts of water on the growth of the oat heads and of the straw is an important consideration. An analysis of the table does not reveal as uniform results as was the case with corn, neither does the depth of soil seem to have any bearing on this subject. The highest percentage of oats in the whole plant was found on plat 298, where fifteen inches of water was applied and the lowest percentage on plat 295, which had practically the same application of water, viz., 14.68 inches.

TABLE NO. 73.—PROPORTION OF GRAIN AND STRAW IN OATS.

Plat No.	Avg. depth of soil plat in inches	Inches of water applied	Percentage grain in whole plant	Percentage of straw in whole plant
293	16	6 98	33.33	66.67
296	34	12.50	36 20	63.80
294	41	13.92	30.80	69.20
295	23	14.68	25 60	74.40
298	36	15.00	43.30	56.70
297	37	15 00	29.90	70.10
299	36	30.00	33.70	66.30
300	29	40.00	34.50	65.50

The difference in the proportion of grain to straw on plats 295 and 298 may be due to two factors. It will be noticed that the soil on plat 295 is very shallow, less than two feet, as compared with three feet of soil on plat 298. In the application of water, too, while practically the same amounts were applied, most of the water on plat 295 was applied very early in the season and the plat had but two irrigations. The water was applied to plat 298 in three irrigations, and only in small amounts during the earlier part of the plant's life, but later when large amounts of water were required in transferring the nutrients of the plant desired in the formation of seed, large amounts were applied.

Time of application of water for oats:— Plats 298 and 297 were irrigated on the same day and the total amount of water applied during the season was practically the same. Another important factor in comparing the yields on these two plats is the fact that there is practically no difference in the soil depth. Plat 298 received 3.34 inches of water on June 12th as compared with 7.52 inches on plat 297. The irrigation on June 28th was planned to make the application equal on both plats and the difference in the amount applied is so slight as to make it improbable that it could affect the results. On July 10th, just three weeks before harvesting and at a time when the plants were forming heads, 7.50 inches of water were applied to plat 298 and 2.50 acre-inches to plat 297. The effect is marked. An application of a large amount of water on July 10th, the critical period in the life of the oat crop, resulted in carrying the nutrients stored in the straw to the head and the yield of grain was increased by 33 per cent. A corresponding decrease in the amount of straw is also noted.

Effect of varying amounts of water on total yield:— As with wheat the application of 30 inches of water gave better yields of grain, of straw and of dry matter, than lesser or greater amounts. Water applied in less amounts than 15 inches was evidently insufficient, though the plats vary so much in soil depth that we cannot expect a uniform increase in yield with increased application of water. We are unable to explain why the yield of plat 296 is greater than that of 294, which received more water and which has a greater soil depth. With this exception, the yield varies with the soil depth and with the amount of water applied.

43. THE YIELDS OF WHEAT.

All of the plats used in the irrigation experiment with wheat are shallow, the soil on none of them being deeper than three feet. During the years 1890 and 1891 these plats were grown to clover, the followivg year to wheat, then two years of timothy, then corn, oats, clover, wheat, rape, and during the year preceding these experiments, 1900, corn was grown.

The plats, like those used for irrigation experiments with corn and oats, are one-twentieth of an acre in size. An attempt has been made, each year, to maintain and improve the fertility of the plats by the liberal application of barnyard manure, but the low yields obtained, an average of but 12.86 bushels per acre, is evidence that the plats used in this test are not well adapted to wheat growing.

The variety used was New Zealand, a wheat very generally known in the Cache Valley, but it has never stood very high in the list in our variety tests. This variety is grown here both as a fall and spring wheat, and was selected for this experiment mainly because of the fact that it is so well known.

The plats were plowed eight inches deep on April 13th, and seeded three days later at the rate of five pecks per acre, the seeding being done with a press drill. On April 25th, the record shows all plats well covered with the young wheat plants. On May 24th and 25th, the wheat on all of the plats was greatly injured by a severe wind storm, but as in the case of the other crops, the injury was but temporary.

The following table summarizes the notes taken on the growth of the crop during the season:

TABLE NO. 74.—FIELD NOTES WITH WHEAT.

Date	Plats	Character of Growth	Condition of Plat	Ht. of wheat plants
June 5th	322 330	Even.	Very dry.	6 inches
June 5th	321 329	Uneven.	Parts of plats dry.	12 inches
June 5th	320 328	Uneven.	¾ of plat very dry.	9 inches
June 5th	319 327	Uneven.	Part of plat dry.	7 inches
June 5th	317 326	Uneven.	½ of plat dry.	13 inches
June 5th	325	Uneven.	¼ of plat dry.	15 inches
July 1st	317 321	Uneven.	½ of plats suffering for water.	27 inches
July 1st	318 322 330	Even.	In good condition.	28 inches
July 1st	319 325 327 328 329	Uneven.	Good condition.	30 inches
July 1st	320	Uneven.	⅓ of plat suffering for water.	19 inches
July 1st	326	Uneven.	Medium.	28 inches
July 18th	317 319 325	Wheat dying. Kernel shrunken.	Very dry.	
July 18th	318 322 326 327 328 329 330	Just beginning to ripen. Straw green. Looking well. Kernel in early dough stage.	Fair.	
July 18th	320 321	½ to ⅔ of plat green; balance dry. Kernel shrunken and straw dry and brittle.	Plats dry.	

The first irrigation occurred on June 7th. In the following table when the irrigations are on two successive days, they are placed under one heading for the sake of brevity. The original plan of the experiment contemplated using 2½ inches of water on plat 317, but the plat was so extremely dry in parts that 4.63 inches were required to cover the plat. All plats were irrigated by the flooding method.

Around each of these irrigation plats, embankments were thrown up and occasionally, in order to apply the required amounts, the surface was covered to the depth of several inches with standing water especially on the lower half of the plat. All of the plats were harvested on July 29th and 30th, except 329 and 330, which were harvested on August 5th.

The wheat from plats 317, 319, 320, 325, 326 and 327 was badly shrunken, but from the remaining plats nice plump kernels were secured.

TABLE NO. 75.—IRRIGATION VS. YIELD OF WHEAT.

Plat No.	Average depth of soil in inches	Total inches water applied	Dates of irrigation and amt. of water applied, in inches.						Yield of grain in bu. per acre	Yield of straw in lbs. per acre	Total yield of dry matter in lbs. per acre
			June 7	June 10	June 28	July 6	July 11	July 16			
317	18	4.63	4.63	...	...	...	...	...	4.50	2270	2350
319	19	5.14	5.14	...	...	...	...	...	3.83	2270	2306
320	19	8.73	3.56	...	...	5.17	...	...	10 33	2000	2435
318	28	8 97	3.99	...	...	4.98	...	...	11.33	2960	3378
321	18	10.30	5.30	...	...	5.00	...	...	14.66	2740	3425
325	36	12.09	...	7.60	...	...	4.49	...	11.16	3870	4223
322	10	12.18	4 89	...	3.96	3.33	...	...	11.66	1920	2414
326	28	12 80	4 47	...	4.17	4.16	...	...	13.00	1760	2357
327	12	17.50	5.85	...	5.82	5.83	...	...	15.33	3080	3728
328	11	21.11	7.50	...	6.64	6.97	...	...	17.33	2800	3557
329	18	30 00	10.00	...	7.45	7.14	5.41	...	26 66	3380	4621
330	19	40.00	10 00	...	4.93	7.50	4.15	13.42	14.50	1630	2291

The length of the growing season for wheat was for most of the plats 107 days, though in the case of two of the plats, which received irrigation as late as July 11th and 16th, the harvesting time was delayed for seven days, making the growing season 114 days for the wheat on these plats.

Irrigation was begun on June 7th, and as seen by reference to the notes, all the plats were very dry and in a few instances the wheat was suffering badly for water. The irrigation season for wheat was but 34 days for all of the plats, except 330, in which case it was 39 days.

Careful field notes were taken on the condition of the crop two days before irrigation commenced, again on July 1st, and again two days after the last irrigation.

Plats 322 and 330 were evidently not in good condition when the first irrigation was made, as our notes indicate that the wheat was but six inches high on that date. While the growth was quite even, the soil of these plats was very dry, though moisture determinations made on June 7th, just before irrigation on that date, do not show any material difference in the various plats.

Comparing the first three plats in the table of almost uniform depth, it will be seen that the second irrigation on July 6th, resulted in increasing the yield of grain 129% in one instance and 169% in the other case, as compared with the plats not receiving the second irrigation. In the yield of straw the plat receiving the second irrigation stood below the plats not so irrigated. Water applied about July 6th, evidently aided in transferring the nutrients already in the straw to the head where they were stored in the grain, and resulted in increased yield of grain and decreased yield of straw. Plats 320 and 321 can be compared, as the soil on these plats is practically of the same depth. The irrigations were made on the same day, the only difference being in the amount applied. An increase of 1.57 inches of water resulted in increasing the yield of grain by 41%, the straw by 37% and the dry matter by 40%. The largest yield of straw and of dry matter was obtained from plat 325, and it will be seen that this plat has the deepest soil; there is practically no difference in the yield of grain on this plat and plat 322 which received about the same amount of water. There is a gradual increase in the yield of grain from the application of 12.09 inches of water up to 30 inches, though the yield of straw and of dry matter does not vary in the same direction.

Plats 329 and 330 with practically the same depths of soil varied greatly in yields. The application of ten inches of water late in July did not prove profitable. We can hardly draw definite conclusions from this experiment owing to the great variation in the depth of the soil, though it is interesting to note that the increase in yield of grain did not depend upon depth of soil, this factor seeming to have the greatest bearing upon the yield of straw. The second highest yield of grain was obtained from the plat having but eleven inches of soil.

TABLE NO. 76.—PROPORTION OF GRAIN AND STRAW IN WHEAT.

Plat No.	Average depth of soil on plat.	Inches of water applied.	Percentage of grain in whole plant.	Percentage of straw in whole plant.
317	18	4.63	10.7	89.3
319	19	5.14	9 2	90 8
320	19	8.73	23.3	76.7
318	28	8.97	18.7	81.3
321	18	10.30	24.3	75 7
325	36	12.09	14.8	85.2
322	10	12.18	26 7	73.3
326	28	12 80	30 7	69 3
327	12	17.50	23.0	77.0
328	11	21.11	27.1	72.9
329	18	30.00	32.1	67.9
330	19	40.00	34 8	65 2

As will be seen from above table, the largest application of water resulted in the highest percentage of grain and the lowest percentage of straw. The next highest percentage of grain was obtained from the application of thirty inches of water, and the next highest from 21.11 inches of water regardless of the fact that the soil of this plat was but eleven inches deep. It would seem, though, the data on this point are not by any means conclusive, that increased application of water results in an increased proportion of grain to straw.

Effect of varying amounts of water on total yield.—The highest yield of grain, of straw and of dry matter was obtained by the application of 30 inches of water. More water than this was not only wasted, but a decrease both in grain and straw resulted from its use. It will be seen that, with two exceptions, the yield of wheat increased uniformly as the amount of water applied was increased up to 30 inches. The yield of straw was more variable, however, as will be seen by comparing plats 318 and 328. While plat 328 received 21.11 inches of water as compared with 8.97 inches for plat 318, yet the yield of straw was less on plat 328. It would seem that the use of 30 inches of water in the irrigation of spring wheat on bench lands is not excessive, though greater amounts than this are injurious to the crop.

44. THE YIELDS OF POTATOES.

In one of the first bulletins of this Station,* attention was called to the excellent quality of potatoes grown in this state and the marvelous yields reported. Unfortunately for this crop, however, the price paid is so variable from year to year, that little reliance can be placed upon potatoes as a money producer. Despite this fact it forms one of the principal crops of the Utah farmer and is grown only under irrigated conditions.

Nine of the best plats on the College farm were used in this experiment; the most shallow plat was 17 inches deep and the others varied from this to a depth of five feet.

The history and treatment of these plats have been identical with those used for irrigation experiments with corn, an explanation of which will be found under the section on corn. It is generally conceded that potatoes do best on a sandy loam soil, especially when well drained as is the soil on which these experiments were made. Liberal applications of well-rotted stable manure has served to make this portion of the farm, in the main, well adapted to potato growing.

The variety of potatoes chosen for the experiment, the Early Rose, is one well known in the State and it is generally recognized as one of the leading varieties.

The question as to the effect of varying amounts of water on potatoes is very important, as the dryness and mealiness when cooked, are very important considerations. Potatoes grown in this arid region have for many years been recognized as of superior quality, and this is due largely to the fact that the quality can be determined by the amount of water applied, and the frequency of application. The potatoes were planted on plats 255A and 257A on May 1st, and on the remaining plats on May 7th. The rows were three feet apart and the potatoes in the rows from 12 to 14 inches apart. The potatoes were affected less than the other crops

*Bulletin No. 5.

by the hot wind of May 24th and 25th, and there was seemingly no permanent injury from this cause. Severe frosts on the nights of June 4th and 5th froze the vines, but they quickly recovered from this and there was nothing unusual to affect the experiment after this date.

It should be stated that plat 255A was planted with a spade, the rest of the plats having been furrowed and the potatoes covered with a hoe. On June 22nd, it was noted that the potatoes on plat 255A were in much better condition than on the remaining plats; none of the plants were suffering from water and the vines were about twelve inches high. The remaining plats were beginning to show a need of irrigation, the growth on all of them being rather uneven and altogether in an unsatisfactory condition. The height of the vines on these plats varied from six to eight inches.

The growing season:—The time from planting to harvesting of this crop was 165 days, much longer than in the case of the previous crops discussed. The irrigating season extended over a period of but 24 days in the instance where the minimum yield of potatoes was obtained and 61 days where the maximum yield was secured.

TABLE NO. 77.—IRRIGATION VS. YIELDS OF POTATOES.

Plat No.	Average depth of sil in inches.	Total amount of water applied. (inches.)	Dates of irrigation and amount of water applied to plat in inches.								Yield per acre in bushels potatoes.	Total yield of dry matter in lbs. per acre.
			June 26.	July 15.	July 20.	July 31.	Aug. 8.	Aug. 12.	Aug. 16.	Aug. 23.		
255A	25	8.08	4.82		3.26						159.33	2294
256A	17	10.00	5.00		5.00						89.33	1268
257A	23	15.00	7.49		7.51						·04.33	1564
258A	29	15.00	7.50		7.50						165.33	2467
259A	26	15.00	4.65		6.98		3.37				265.66	3896
261A	59	15.00	2.63		2.13		2.15	2.50	2.50	2.74	332.66	4698
260A	38	20.00	6.27		6.23		7.50				446.33	6363
262A	54	27.00	8.32		6.34		7.38		2.50	2.46	362.66	5233
263A	59	40.00	10.	10.	6.02	5.08	5.00		2.50	1.40	528.00	7603

In this test, the largest yield of potatoes obtained from the plat receiving the largest amount of water, and this plat also received the most frequent applications. The soil on this plat was five feet deep, having, with one exception, the greatest depth of soil in the test. Plat 256A received ten inches of water in two equal applications and from this plat, the smallest yield is recorded. This plat compared with 255A, which received water on the same dates, but in smaller amounts, clearly indicates that depth of soil is, here, a disturbing factor. Plats 257A and 258A differ only in the soil depths and yields obtained, the irrigations being made on the same day and in practically equal amounts. Taking the depth of soil as a basis for reasoning, the yield of plat 259A, which has a soil depth of 26 inches, (midway between 257A and 258A), should be about 135 bushels of potatoes, as it received exactly the same amount of water. The water was applied, however, in smaller amounts on June 26th and July 20th, and an application of 3.37 inches made on August 8th. This method of application resulted in a yield of 265.66 bushels of potatoes, an evident increase of 130 bushels per acre, by applying the water in three irrigations instead of two. While the increase in yield on plat 261A over 259A is undoubtedly due to a certain extent to the increased depth of soil, yet the smaller amounts and more frequent applications were also factors. It is difficult to explain why plat 260A with a soil depth of but 38 inches, an application of water of but 20 inches, and but three applications, should give a greater yield by 23 per cent than plat 262A with a soil depth of 54 inches, an application of water of 27 inches applied in five irrigations. This instance seems to be the only exception to the rule that small amounts and frequent applications give better yields of potatoes than the same amount of water applied in fewer irrigations.

Effect of varying amounts of water on quality of potato crop:—A question of very great importance in potato irrigation is the effect of varying amounts of water on the quality of the potato crop. At the time of harvesting the crop was separated into marketable and unmarketable potatoes, only those of good size, smooth and even, being placed in the marketable basket.

TABLE No. 78.—EFFECT OF VARYING AMOUNTS OF WATER ON THE QUALITY OF THE POTATO CROP.

Plat No.	Average depth of soil in inches.	Inches of water applied.	Total yield of plat in bushels per acre.	Yield of plat in marketable potatoes—bushels per acre.	Yield of plat in unmarketable potatoes—bushels per acre.	Per cent of marketable potatoes.
255A	25	8.08	159.33	79.00	80.33	49.6
256A	17	10.00	89.33	29.66	59.67	33.2
257A	23	15.00	104.33	42.33	62.00	40.5
258A	29	15.00	165.33	108.33	57.00	65.5
259A	26	15.00	265.66	194.66	71.00	73.3
261A	59	15.00	332.66	291.66	41.00	87.7
260A	38	20.00	446.33	399.00	47.33	89.4
262A	54	27.00	362.66	316.00	46.66	87.1
263A	59	40.00	528.00	479.66	48.34	90.8

The per cent of marketable potatoes was the highest on the plat receiving 40 inches of water, though plat 260A, which had just one-half as much water, gave practically the same result. The variation in yield seems to follow more closely the variation in the depth of the soil than it does the varying amounts of water applied. The largest per cent of marketable potatoes was obtained from the plats having the greatest soil depth, while the largest per cent of unmarketable potatoes was obtained from the most shallow soil. A larger per cent of marketable potatoes was obtained from plat 255A with the application of 8.08 inches of water than from 256A with 10 acre-inches. The difference is due to the difference in the soil. Only forty per cent of marketable potatoes was obtained from plat 257A, which had 15 inches of water: the soil on this plat was but 23 inches deep. Plat 259A, with 15 inches of water and but 3 inches more soil than 257A, gave 73 per cent marketable potatoes.

Taking the last four plats in the table, it seems evident that the varying amounts of water applied from 15 ins. to 40 ins., had very little, if any, effect on the per cent of marketable potatoes. The plats receiving less water than 15 inches were evidently affected by the amount of water applied, the larger amount of water applied the greater the per cent of marketable potatoes. Of the four plats receiving 15 inches of water, plat 259A received one more irrigation than plats 257A and 258A, which had practically the same soil depth and this factor may affect the yield of marketable and unmarketable potatoes. Plat 261A also received 15 inches of water, but applied in six irrigations and the per cent of marketable potatoes was much greater than with any of the other plats receiving the same amount of water, and equal to plat 262A, which received 27 inches of water in five irrigations.

It appears that not only soil depth and amount of water applied affect the quality of the crop, but the number of irrigations is also a factor. A study of this question emphasizes the importance of small amounts of water, frequently applied in the irrigation of potatoes.

45. THE YIELDS OF SUGAR BEETS.

Sugar-beet growing has already become well established in this State. Many theories have been advanced regarding the proper methods of culture, irrigating and harvesting this crop, but it cannot be said that these theories have been based on scientific experimentation. The sugar beet is especially susceptible to the influence of water, and, as yet, no data have been obtained bearing on the question as to the proper amount of water to apply, the proper time of application, or the proper mode of applying the water.

It was thought, in planning the irrigation experiments, that the importance of this crop in Utah justified an expenditure of considerable energy and means in attempting to arrive at some definite knowledge concerning its water requirements. For this reason fourteen plats were devoted to experiments in irrigation of sugar beets. These plats are situated on the southwest corner of the farm next to the orchard, and before the underground survey of the farm was made, were considered to be about the best on the College farm. As will be seen by the table, the soil depth varies from eight inches to fifty-two inches, the average depth for all the plats being twenty-eight inches.

During the years of 1890 and 1891, corn was grown on these plats, then followed oats, clover, wheat, timothy for two years, oats, peas, millet, and during the season preceding these experiments, sugar beets were grown on plats 343 and 350 to 354 inclusive, oats on 361 to 365 inclusive, corn on plat 367 and wheat on plat 374. Each year, well-rotted barnyard manure has been applied at the rate of about thirteen tons to the acre.

The plats were one-twentieth of an acre in size, and the beets were planted in rows twenty inches apart.

The variety of sugar beets used in the experiment was German Kleinwanzlebener, a variety representing one of the highest grades of sugar beets. Experiments conducted here show that the tendency of the seed of this variety to produce a rich beet is well marked.

Owing to the necessity of manuring the ground, during the winter of 1900 and 1901, plowing was delayed until April 24th, 1901, and the seeding done on the two following days. A Planet Junior drill was used for seeding, and the seed sown at the rate of fifteen pounds per acre.

The season was favorable for the growing of beets, as evidenced by the yields obtained; the average yield for this particular experiment being 16.48 tons per acre. Owing to the excellent preparation given the land, and the good stand obtained, the hot wind of May 24th and 25th had very little effect, and the beets were all thinned between May 31st and June 5th.

Plats 354 and 366 were irrigated by the furrow method, the remainder of the plats being flooded.

On June 13th, the growth on the following plats was uneven, and gave evidence of a pressing need of irrigation: 343, 353, 354, 365, 366, 367 and 374.

Plat 354 was very gravelly, the gravel coming to the surface over most of the plat. In the above list, five out of the seven plats were the most shallow plats. The sugar beets on the remaining plats were apparently not suffering from water on this date, the growth was even, the tops on the average about six inches high.

TABLE NO. 79.—IRRIGATION VS. YIELDS OF SUGAR BEETS.

Plat No.	Average depth of soil in inches	Amount of water applied (inches)	Dates of irrigation and amount of water applied to plat in inches.															Yield per acre in tons of beets	Total yield of dry matter in lbs. per acre
			June 14	June 19	July 8	July 9	July 15	July 26	Aug. 12	Aug. 14	Aug. 16	Aug. 20	Aug. 23	Aug. 25	Aug. 29	Sept. 9	Sept. 11		
366	25	13.47		2.14		1.95		2.88		3.00							3.50	9.85	5004
351	32	14.51	4.45					4.18		3.18					2.70			11.85	5830
350	31	14.64	2.40			2.60		3.73		3.59					3.32			18.40	8876
352	30	16.55	3.49			4.21				4.84					4.01			15.65	7330
362	41	17.50	4.17			4.15		4.18		2.50					2.50			17.14	7943
354	21	17.78	1.10			2.22		3.54	2.50	2.50		2.35	1.07		2.50			8.45	4421
363	37	20.03	2.91			4.59		5.00		3.11					4.42			21.99	9750
353	15	20.05	4.25			4.09		4.56		3.59					3.46			14.45	6384
365	12	20.09	4.40			4.35		4.38		3.32					3.64			14.69	7357
361	33	20.17	4.18			4.14		4.18		3.94					3.73			30.00	14916
364	26	23.27	5.00			5.00		4.42		3.29					4.56			20.34	10617
374	52	25.99		6.18		3.21		8.11		3.73					4.76			19.11	3596
367	32	26.66		9.26		5.74		3.87		4.15					3.64			19.26	9387
343	8	52.96	6.14			6.63	5.00	4.99	5.02		5.00	5.00		5.00	4.94			13.20	7025

The beets were planted on April 25th and harvested on October 22nd, making a growing season of 180 days; though undoubtedly they could have been harvested a week earlier, without serious detriment either to tonnage or sugar content. The irrigation season was 88 days.

The question of the effect of tillage was also studied in connection with the irrigation work with sugar beets, and the following outline gives the dates of cultivation. The cultivations were made with a hand cultivator.

TABLE NO. 80.—DATES OF CULTIVATION OF SUGAR BEETS.

Plat 366	Plat 351	Plat 350	Plat 352	Plat 362	Plat 354	Plat 363	Plat 353	Plat 365	Plat 361	Plat 364	Plat 374	Plat 367	Plat 343
May 27, June 14, July 5, July 25.	June 20, July 6, July 9, July 11, ... July 13, 16, 18, 20, 23, 25, 27, 30, Aug. 1, 3, 6, 8, 10, 13, 15, 17, 20, Sept. 3, 5,	May 27, June 20, July 11, July 25.	June 20, July 6, July 25.	May 27, July 6, July 9, July 11, ... July 13, 16, 18, 20, 23, 25, 27, 30, Aug. 1, 3, 6, 8, 10, 13, 15, 17, 20, Sept. 3, 5,	June 20, July 6, July 9, July 11, ... July 13, 16, 18, 20, 23, 25, 27, 30, Aug. 1, 3, 6, 8, 10, 13, 15. 17, 20, Sept. 3, 5,	May 27, July 6, July 25.	June 20, July 6, July 25.	May 27, June 14, July 5, July 25.	May 27, July 6, July 25.	May 27, July 6, July 25.	May 27, June 12, June 27, July 6, ... July 25.	May 25, June 14, July 5, July 25.	May 28, June 21, July 8, July 25.

The highest yield of sugar beets was obtained from plat 361. This plat has a little greater depth of soil than the average for all the plats. It received 20.17 inches of water in as nearly five equal distributions of water as it was possible to make. The plat received but three cultivations. The smallest yield came from plat 354 which received 17.78 inches of water in eight irrigations. The small yield may be due to the small amount of water applied on June 14th, when the first irrigation of sugar beets was made. This plat received 23 cultivations.

The difference in yields in plats 351 and 350 may be ascribed either to the difference in the number of irrigations or in the number of cultivations. Practically the same amount of water was applied, the soil was of nearly the same depth, yet, plat 350, which received five irrigations and four cultivations, gave a greater yield by 35 per cent than plat 351, which had four irrigations and twenty-three cultivations.

Plat 354 also received twenty-three cultivations and eight irrigations, yet the yield in this plat was not quite one-half that of plat 362, which received about the same amount of water in five irrigations with the same number of cultivations. The depth of soil of plat 354 was only about one-half of that of 362, and this was evidently a considerable factor, though the method by which the water was applied may have also affected the yield.

The yields of plats 353 and 365 are nearly the same. About the same amount of water was applied in the same number of irrigations, the only difference in treatment being in the extra cultivation which plat 365 received, and, as will be seen, it seemingly had no effect as far as the yield was concerned.

Plats 374 and 367 received as nearly the same amount of water as it was possible to apply. The larger amounts of water were applied on plat 367, during the fore part of the irrigation season. Plat 374 received the smaller applications of water during the early part of the irrigating season and the larger applications during the latter part. If we consider the difference in the depth of the soil on the two plats, it seems safe to conclude that the larger yields are obtained with a given amount of water if the larger appropriations of water are made during the fore part of the irrigating season.

Plat 343 received 52.96 inches of water in ten irrigations. The soil on the plat was very shallow though a fairly good yield was obtained. It is evident, however, that at least one-half and probably more of the water applied to this plat was wasted.

Furrow versus flooding for sugar beets:—Two plats, 354 and 366, were irrigated by the furrow method, the remainder of the plats being flooded. It is rather interesting to note that the smallest yields were obtained from these plats. Plat 354 has already been compared with 362, which received water on the same day and in about the same amount for the season. In this instance best returns were obtained by the flooding method.

Plat 366 gave next to 354 the smallest yield of the experiment. The plat received 13.47 inches of water in five irrigations and was cultivated four times.

The results of this reason's work in irrigating sugar beets were certainly not favorable to the furrow method.

The highest yield of sugar beets was obtained from the plat receiving 20.17 inches of water, and water applied in greater amounts was seemingly ineffective as far as the yield is concerned.

46. THE YIELDS OF GRASSES AND CLOVERS.

According to the report of the value of farm products of Utah, taken from the twelfth census, the value of hay and forage in this state exceeds the value of any other farm product, being equal to $3,862,820 for the census year. In the irrigation of hay and forage crops in general, it has been the custom to make use of the water at such times as it is not needed by other crops of the farm. Many of the meadow lands are situated in low lying places where much of the seepage water from the higher lying lands can be utilized, and it is doubtful if the same importance attaches to the irrigation of grasses and clovers as of other crops of the farm.

The grasses and clovers in this experiment were sown April 6th, 1900, with the exception of the timothy on plats 371, 372 and 373, which was sown on April 19th of the same year. All plats were sown with a Superior press drill. Previous to seeding, the plats had identical treatment from the time cultivation on the farm began. Most of the plats are shallow and the yields reported are exceedingly low in some instances, and in no instance is the yield satisfactory. It should be stated, however, that only the first cutting of lucern is recorded. Table 81 is inserted more as a matter of record than for any other purpose, as most of the irrigations were made after the crop here reported was removed and, of course, had no effect.

TABLE NO. 81.—IRRIGATION OF GRASSES AND CLOVERS.

Plat No.	Total number of inches of water applied to plat.	CROP.	Dates of irrigations—amount of water applied to plat in inches.					
			May 24, 26 and 28	June 21, 22 and 24	July 12 and 13	July 23 and 25	Aug. 17	Sept. 10, 11 and 12
371	15.15	Timothy	5.49	4.56	......	......	......	5.10
372	19.44	Timothy	7.50	5.08	......	......	......	6.86
373	21.98	Timothy	5.00	5.23	5.00	......	......	6.75
348	18.67	Timothy	4.99	6.50	......	3.60	......	3.58
349	36.80	Timothy	10.00	7.88	10.00	3.80	......	5.12
344	16.15	Mixed grasses	4.08	3.18	......	2.93	2.68	3.28
345	29.83	Mixed grasses	8.24	4.01	5.00	3.70	5.00	3.88
357	16.60	Red clover	3.63	3.73	......	3.87	2.68	2.69
358	33.28	Red clover	8.21	5.51	5.00	4.56	5.00	5.00
368	19.25	Alfalfa	5.00	3.32	3.33	3.42	......	4.18
369	29.00	Alfalfa	7.62	4.98	7.50	3.90	......	5.00
370	45.00	Alfalfa	9.82	7.05	10.00	10.01	3.12	5.00
346	20.10	Alf. & Orchard grass	5.86	3.32	......	4.19	3.59	3.14
347	33.45	Alf. & Orchard grass	9.12	4.84	5.00	4.56	5.00	4.93
359	20.18	Kentucky blue grass	5.10	3.73	......	4.15	3.32	3.88
360	37.40	Kentucky blue grass	10.95	5.95	5.00	5.94	5.00	4.56
355	21.43	English rye grass	4.46	4.00	......	4.98	3.70	4.29
356	33.56	English rye grass	8.30	5.26	5.00	4.47	5.00	5.53

The cutting of all the plats was made on June 18th, so only irrigations made prior to this date should be considered in connection with the yields. No yields are reported from these plats for the season of 1900, although all plats made an excellent stand. We considered it better, however, for this experiment, to allow the plats to become well sodded before beginning the experiment. During the season of 1900 each of the plats received three irrigations, though no measurements of the amount of water used are recorded.

TABLE NO. 82.—IRRIGATION VS. YIELD OF GRASSES AND CLOVERS.

Plat No.	CROP.	Average depth of soil on plat in inches	Inches of water applied	Amt of water apl'd in acre inches. May 24	May 26	May 28	Total yield of hay in lbs. per acre.
371	Timothy	31	5.49	5.49			3576
372	Timothy	27	7.50	7.50			6496
373	Timothy	33	5.00	5.00			6096
348	Timothy	12	4.99			4.99	1070
349	Timothy	17	10.00			10.00	2260
357	Red clover	11	3.63		4.63		1470
358	Red clover	25	8.21		8.21		2650
344	Mixed grass	23	4.08			4.08	2010
345	Mixed grass	24	8.24			8.24	2380
368	Alfalfa	32	5.00	5.00			2000
369	Alfalfa	25	7.62		7.62		2624
370	Alfalfa	18	9.82		9.82		2904
346	Alfalfa and orchard grass	24	5.86			5.86	2200
347	Alfalfa and orchard grass	22	9.12			9.12	2840
359	Kentucky blue grass	14	5.10			5.10	2064
360	Kentucky blue grass	44	10.95		10.95		4800
355	English rye grass	21	4.46		4.46		1672
356	English rye grass	21	8.30		8.30		1376

Table No. 82 gives the actual condition showing the depth of soil, the amount of water applied, the dates of irrigation, and the yield. The later irrigations were made in connection with the work in soil moisture determinations, and also to determine the effect of these late irrigations on the yield of the succeeding year.

A study of table No. 82 brings out again the fact that soil depth is an important factor in determining yields. With the timothy plats the smallest yield was obtained from the plat having the least soil depth, although this plat received the greatest application of water. All of the timothy plats were exceedingly dry when the water was applied, and the first application of water was made but three weeks before the crop was harvested. The largest yield of timothy, something over three tons per acre, was obtained from plat 372, which had a soil depth of 27 inches, and which received 7½ inches of water. The second best yield was obtained from plat 373, which had an average soil depth of 33 inches, and which received five acre-inches of water.

It is difficult to explain why the yield of plat 373 is greater than that of plat 371 which has practically the same soil depth, and which received water the same day, although in a slightly greater amount.

With the two plats devoted to red clover there are two factors which account for the greater yield of plat 358. Both the soil depth and the amount of water applied exceed by more than 100 per cent that of plat 357.

In the case of the mixed grass plats, the soil depth is practically the same and a greater yield of plat 345 is undoubtedly due to the larger application of water.

The yield of the alfalfa plats varies directly with the application of water. Although plat 370 had but 18 inches soil depth as compared with 32 inches for plot 368, yet an increase of 4.83 inches of water resulted in increasing the yield at the rate of nine hundred pounds per acre.

The effect of water is again noticeable in the case of the two plats sown to alfalfa and orchard grass. An increase here of 3.26 acre-inches of water resulted in an increased yield of 640 pounds per acre.

With the Kentucky blue grass, part of the increased yield of plat 360 may be due to the greater soil depth of that plat. The other factor is the increased application of water.

Plats 365 and 366, sown to English rye grass, have the same soil depth. In this case the plat receiving the smallest amount of water gave the greater yield. This instance seems to be the only exception to the rule that the greater the quantity of water applied, the greater the yield obtained. In each case it seems evident that the maximum amount of water to be applied was not reached; or at least if the limit was attained, we have no evidence of it in these experiments.

The experiments now in progress in the irrigation of grasses and clovers will undoubtedly bring many facts to light concerning the requisite number of acre-inches of water to use, and the correct time of application.

In a bulletin published by this Station some years ago, the same conclusions were reached as are presented in this table, to the effect that the maximum yield was obtained from those plats receiving the maximum amount of irrigation. If this experiment should be installed on soil having a greater depth than that of the College farm, it may be possible to find a limit of profitable application of water in the irrigation of grasses and clovers.

47. POUNDS OF WATER FOR ONE POUND OF DRY MATTER.

The following table has been constructed in order to furnish ready comparison of our results with those obtained by other investigators, who have expressed their data on the water requirements of plants in terms of the pounds of water for one pound of dry matter. The facts contained by the table have been fully discussed in earlier sections, in which conclusions may be found.

In obtaining the data of the following table, the total amount of irrigation water applied, the rainfall from seeding to harvesting, and the difference in the percentages of soil moisture on the days of seeding and harvesting, have been taken into account. Proper allowance has also been made for soil depth. While the results are not absolutely correct, they cannot be far from the truth, for the care with which the work has been done, and the number of checks employed, would make any irregularity very evident.

TABLE NO. 83.—POUNDS OF WATER USED TO PRODUCE ONE POUND OF DRY MATTER.

Plat No.	Pounds of water per square foot.	lbs. water for one lb. dry matter.	Plat No.	lbs. of water per square foot.	lbs. water for one lb. dry matter.	Plat No.	lbs. of water per square foot.	lbs. water for one lb. dry matter.
Sugar Beets.			Potatoes.			Wheat.		
366	103.70	1904	255A	78.47	1477	317	41.55	767
351	109.11	815	256A	87.95	3070	320	63.74	1140
350	115.00	564	257A	114.22	3[illegible]81	318	66.04	410
352	119.74	712	258A	114.90	2029	319	44.44	709
362	114.27	627	259A	114.34	1278	321	66.44	845
354	126.15	1943	261A	118.61	1100	325	83.47	861
353	137.45	922	260A	142.66	975	322	80.80	1455
363	137.85	616	262A	179.59	1489	327	108.50	1410
365	138.13	818	263A	246.90	1415	328	127.34	1840
361	138.59	472				330	229.20	4358
364	154.74	635	Oats.					
374	168.91	846				Corn.		
367	172.40	800	293	55.79	2134			
343	314.58	2727	296	88.19	1069	259	223.18	801
			294	95.45	1054	255	215.52	1249
			295	97.12	1261	260	129.32	617
			297	101.01	913	256	134.48	945
			298	98.95	956	257	103.38	815
			299	175.88	952	261	103.39	633
			300	288.44	1384	262	64.32	394
						258	64.32	570

An examination of this table shows, as already discussed, that the amount of water required for a definite amount of the crop varies greatly with the total amount of water applied. It is not true, for instance, that doubling the amount of water will double the amount of dry matter, or that any other such regular variations occur. Still, it is true that some plants have greater water requirements than others, independent of the total quantity of water used. Thus, from the above table it would appear that potatoes possess the highest water requirements for one pound of dry matter, and oats, wheat, sugar beets and corn follow in the order named. It is an interesting observation that this is practically the order in which these crops stand, considering the rate with which they take water from the soil. (See section 22.)

It is, of course, to be remembered that the statements for potatoes and sugar beets refer only to tubers and roots. Were the tops added, the number of pounds of water per pound of dry matter would become smaller. Were this correction made, it is probable that potatoes would still head the list; while it is equally probable that sugar beets would stand last.

Professor F. H. King has determined, by pot experiments, that in Wisconsin, about 450 pounds of water are required by the ordinary farm crops, for the production of one pound of dry matter.* During the summer of 1901, a few pot experiments were conducted by the Utah Experiment Station, and it was found that from 817 to 1208 pounds of water were required for one pound of dry matter of sugar beets, corn and wheat, under the climatic conditions of Logan.† Since this amount is much larger than that obtained by Professor King, many questions were asked concerning the validity of our results. The data of table No. 83 confirm the view that under ordinary conditions of irrigation in arid countries more water is required for one pound of dry matter than is the case in humid districts. Elaborate pot experiments on this subject were carried on in 1902, the results of which will be published in a later report.

The fact that the relative rate of loss of soil moisture, and the requirements per pound of dry matter for different crops coincide, leads to the thought that plants, through which water passes slowly, are able to make better use of the water for producing organic substance, than are those through which water passes more rapidly. Why transpiration is greater with some plants than with others, is not yet known.

48. THE VARYING VALUE OF WATER.

It must be clearly understood that in an irrigated country, where a farm is valued not so much for the acres it embraces, as for its water right, it is not so important to obtain the highest yield of a crop per acre, as it is to secure the greatest crop yield for the quantity of water used. The experiments already discussed, demonstrate very clearly that the increase in yield does not keep pace with the increase in irrigation; and that, therefore, the highest acre and water yields are not coincident.

*King, Irrigation and Drainage, p. 46.

†Bulletin No. 75, Utah Station, p. 73.

In the table which follows the results obtained from the work with wheat and oats have been so arranged as to show the different yields of the crops produced by different amounts of water. The conclusions hold, primarily, for Utah bench lands, and may be modified somewhat by later investigations.

TABLE NO. 81.—THE VARYING VALUE OF WATER WITH WHEAT AND OATS.

Plat No.	Average depth of plat in inches	Limits of increase of water	Inches of water applied	Increase dry matter per acre in lbs. — Total	Increase dry matter per acre in lbs. — per inch of water	Increase of bushels of grain per acre. — Total	Increase of bushels of grain per acre. — per inch of water
317				Wheat.			
319	18.5	0.00–4.89	4.89	2328	477	4.17	0.85
320	19.0	4.89–8.73	3.84	107	26	6.16	1.60
321	18.0	8.73–10.30	1.57	990	631	4.33	2.76
329	18.0	10.30–30.00	19.70	1196	511	12.00	0.61
322	10.0	0.00–12.18	12.18	2414	198	11.66	0.95
327	12.0	12.18–17.50	5.32	1314		3.67	0.69
328	11.0	17.50–21.11	3.61	171		2.00	0.53
294				Oats.			
296	37.5	0.00–13.21	13.21	3769	285	44.06	
297							
298	36.5	13.21–15.01	1.80	896	498	12.82	4.34
299	36.0	15.01–30.00	14.99	3385	223	28.12	
293	16.0	0.00–6.98	6.98	1139		12.50	1.79
295	23.0	6.98–14.68	7.70	2204		15.63	2.03
300	29.0	14.68–40.00	25.32	3835	151	51.87	2.05

The first 4.89 inches of water applied to a wheat field with soil between 18 and 19 inches deep, yielded 2333 pounds of dry matter; the next 5.41 inches gave 1092 pounds, and the next 19.70 inches only 1196 pounds of dry matter. Considering bushels of grain, the greatest rate of gain came with the water applied between 8.73 and 10.30 inches. While the first few inches of water applied produced a large amount of dry matter, they were incapable, apparently, of developing large heads. This, then, is left to be done by later applications of water. The first 10.30 inches produced 14.66 bushels of wheat per acre, while the next 19.70 inches produced only 12.00 bushels. In the second part of the section on wheat, dealing with shallower soils, it is shown that the first 12.18 inches of water produced 2114 pounds of dry matter, and 11.66 bushels of grain per acre, while the next 8.93 inches produced only 1144 pounds of dry matter and 5.67 bushels of grain per acre. The rate of increase per inch of water decreased steadily with irrigation beyond the first 12.18 inches. From these results the maximum rate of increase must occur when the amount of water applied lies between 10 and 12 inches.

Of the two sections dealing with oats, only the first is strictly reliable. The second contains plats with varying soil depths, which leads to irregularities that make correct comparisons very difficult.

In the first section, the rate of increase of dry matter and grain increases up to 15.01 inches; it then decreases rapidly. The first 15.01 inches yielded 4665 pounds of dry matter and 56.88 bushels of grain per acre; the next 14.99 inches gave only 3385 pounds of dry matter and 28.88 bushels of grain per acre. This coincides with the results obtained with wheat, though the maximum rate of increase is about 15 inches for oats, as compared with 10 to 12 for wheat.

In the second section under the heading "oats," the total dry matter for the first 14.68 inches is 3353 pounds, while the next 25.32 inches produce 3835 pounds. In yield of grain, however, the last 25 inches are as effective inch for inch, as are the first fifteen. This is due, primarily, to the difference in the depth of the soils on the three plats under consideration; though the very late waterings received by plat 300, may have made possible an extensive translocation of the nutrients. For these reasons reliable conclusions cannot be drawn from this section.

The data for wheat and oats, that have just been discussed, agree in showing that the greatest yield of dry matter and grain, per acre inch, may be obtained with something less than 15 inches of water. Where the farmer can get the water a larger amount is almost invariably used. Professor Elwood Mead in Bulletin No. 119, Office of Experiment Stations, page 25, states that the investigations in his charge have shown that the average use of water in Arizona, Montana, Nevada and Utah, amounts to 34.88 inches for wheat and 23.68 inches for oats. From the investigations reported in this bulletin, it is probable that less water, applied to larger areas, would be more profitable. As an illustration, table No. 85, based on the results of tables Nos. 72 and 75, has been prepared. It shows the relative effect on the yield of wheat and oats, when 30 inches of water are applied to one acre, or 15 inches to two acres.

TABLE NO. 85.—BEST USE OF WATER FOR WHEAT AND OATS.

CROP.	30 inches of water over one acre will produce...	15 inches of water over two acres will produce...
Wheat, dry matter, lbs per acre	4175	6835
Wheat, grain, bushels per acre	24.44	34.96
Oats, dry matter, lbs per acre	8050	9330
Oats, grain, bushels per acre	85 00	113.76

The result as shown in this table is most important. The same amount of water, made to cover twice the area of ground, increased the yield of straw and grain by nearly one-half for wheat, and nearly one-third for oats. Whether the increased cost of plowing, seeding and harvesting the second acre is more than compensated for by the increased yield, is a question which the individual farmer must settle. If it does, we have here a means of extending largely the irrigated area.

Table No. 86 exhibits the data obtained from the experiment with corn.

TABLE NO. 86.—THE VARYING VALUE OF WATER WITH CORN.

Plat No.	Average depth of plat in inches	Limit of the increase water	Inches of water applied	Increased dry matter per acre. Total	Increased dry matter per acre. Per inch of water	Increase of bushels of grain per acre. Total	Increase of bushels of grain per acre. Per inch of water
			Corn.				
258	20	0– 7.50	7.50	4914	655	35.14	4.69
257	19	7.50–15.00	7 50	612	81	11.14	1.48
256	14	15.00–19.97	4 97	675	136	3.00	0.60
255	25	19.97–36.53	16.56	1314	71	20.00	1.21
262	48	0–10.00	10 00	7361	736	57 86	5.69
261	36	10. –15.00	5.00	242	48	1.85	0.37
260	40	15.00–19.98	9.98	1692	170	18.29	1.83
259	36	19.98–38.00	18.02	3329	171	5.71	0.32

The soil depths of the corn plats were quite variable, and the yields of the crop are, therefore, not strictly comparable. An examination of the table is convincing, however, in the lower value of water after the first 10 or 15 inches have been applied. In the first section, with the shallower soils, the first 7.50 inches produced 4.69 bushels of corn per inch of water; the next 7.50 inches, 1.48 bushels per inch; the next 4.97 inches, 0.60 bushels per inch, and the next 16.56 inches, 1.21 bushels per inch. Although the last applications produced more corn per inch than the application just preceding, yet it fell far short of the inch increase of the applications up to 15 inches.

In the second section, the deeper soils, the results are almost the same; though the period of least growth comes between the 10th and 15th inches, instead of the 15th and 20th. In both sections much more than half of the highest yield of corn was produced with the first ten inches of water, and the indications are that the most profitable production of corn is reached with somewhat less water than is the case with wheat and oats. In both sections, also, there was a period, before the maximum yield was obtained, during which the gain per inch of water was at the minimum. Since the two cases coincided with the shallowest plats in the sets the explanation may be found there, and not in any peculiarity of the corn plant.

Table No. 87 shows the possibility of 30 acre inches, when applied to one or two acres of corn.

TABLE NO. 87.—BEST USE OF WATER FOR CORN.

	30 inches of water over one acre will produce	15 inches of water over two acres will produce
Dry matter, lbs. per acre	9101	12645
Corn, bushels per acre	70.77	104.99

Nearly one-half more ear corn, and one-third more dry matter were obtained from 30 acre inches over two acres, than were obtained when the same amount of water was applied to one acre. The amount of water applied to corn in Utah, where water can be obtained is certainly more than 24 inches, and often past 30 inches. Again, the query arises, will the increased yield obtained when 30 acre inches are applied to two acres, compensate the farmer for the extra work of caring for twice the area of soil?

Table No. 88 gives the data obtained with potatoes.

TABLE NO. 88.—THE VARYING VALUE OF WATER WITH POTATOES.

Plat No.	Average depth of plat	Limits of increase of water	Inches of water applied	Increased dry matter: Total	Increased dry matter: Per inch of water	Increased number of bushels: Total	Increased number of bushels: Per inch of water
255A 256A 257A	21	0– 9 04	9.04	123.33	13.75	1781	197
259A	26	9.04–15.00	5.96	60.66	10.18	949	159
261A	59	0–15.00	15.00	523.66	22.18	4699	
262A	54	15.00 27.00	12.00	30.00	2.50	534	
263A	59	27.00–40.00	13.34	165 34	12 18	2370	

The diminished value of the acre inch, as the total amount of irrigation water applied increases, which has been shown to hold for wheat, oats and corn, holds also, though in a more limited degree, for potatoes. Nearly twice as many potatoes were produced with the first 15 inches of water as were produced by the next 28; and in another set, the first 9.04 inches produced nearly two and a half times as many as the next 5.96 inches. There can, therefore be no question regarding the greater value of the first water applied.

TABLE NO. 89.—THE BEST USE OF WATER FOR POTATOES.

	30 inches of water over one acre will produce	15 inches of water over two acres will produce
Dry matter, lbs. per acre	7423	9394
Bushels per acre	406.20	665.32

The total dry matter was one-fourth higher when 30 acre-inches were applied to two acres, than when they were applied to one. The number of bushels was one-half larger. It must be recalled, however, that the yield of potatoes was highest on the plat which received 40 inches of water.

The irrigation investigations of the Office of Experiment Stations have shown* that 47.52 inches of water is the average used for potatoes in Arizona, Nevada and Wyoming. The preceding tables make it very questionable if such large quantities of water are economical in potato production.

TABLE NO. 90.—THE VARYING VALUE OF WATER WITH SUGAR BEETS.

Plat No.	Average depth of plat inches	Limits of increase of water	Inches of water applied	Tons of sugar beets: Total	Tons of sugar beets: Per inch of water	Increase of dry matter per acre, lbs.: Total	Increase of dry matter per acre, lbs.: Per inch of water
350							
351	32	0–14.58	14.58	15.13	1.04	7353	504
352	30	14.58–16.55	1.97	0.52	0.26	23	12
363							
361	35	16.55–20.10	3.55	10.34	2.90	5003	1409
367	32	20.10–26.66	6.56	6 33	10.00	1946	1409
353							
365	14	0–20.07	20.07	14.87	0.73	6971	322
343	8	20.07–52.96	32.89	1.37	0.04	918	56
362	41	0–17.50	17.50	17.14	0.98	7943	453
374	52	17.50–25.99	8.49	1.97	0.23	653	

From table No. 90 it appears that when more than 20 inches of water are applied to sugar beets, there is not only no material increase in the crop, but there may be even a decrease. The irregular soil depths make it somewhat difficult to draw correct conclusions; nevertheless it is quite evident that the first applications have a much higher yield value than the later ones.

For comparison with the preceding tables, the data in table No. 90 have been arranged in a manner that will show the possibility of 30 acre inches in producing sugar beets.

*O. E. S. Bulletin 119, p. 24.

TABLE NO. 91.—THE BEST USE OF WATER FOR SUGAR BEETS.

	30 inches of water over one acre will produce	15 inches of water over two acres will produce
Tons	23.46	30.26

This table shows the yield for 30 inches on one acre somewhat too high, for in the first section of table No. 90 no account was taken of the decrease in yield after the total amount of water reached 20.10 inches, but the highest yield was used in the 30 inch column.

The government bulletin already mentioned, gives 25.80 inches as the average amount used for sugar beets in Arizona and Montana. This number is based on two observations only, and does not probably represent the amount used in Utah. If, however, it is right, it is yet higher than it should be for the most economical use of water.

These conclusions concerning the varying value of water hold primarily for shallow bench lands, yet on deep soils the general variation is like that here explained. It is evident that considering only the crop yield, profitable irrigation ceases when 10 to 15 inches have been applied. The general practice among farmers is to bring upon a field as much water as can possibly be obtained, with the expectation that the yield will be proportional to the amount of water used. As a result, a waste of water occurs; lower lying soils are injured, crops of poor quality are produced, and, worst of all, neighboring thirsting lands are robbed of the water they should receive.

It is not at all improbable that, as more facts are gathered on this subject, and become understood by canal companies and farmers, even with the present water supply, the irrigated area may be increased one-fourth or one-third, or even one-half.

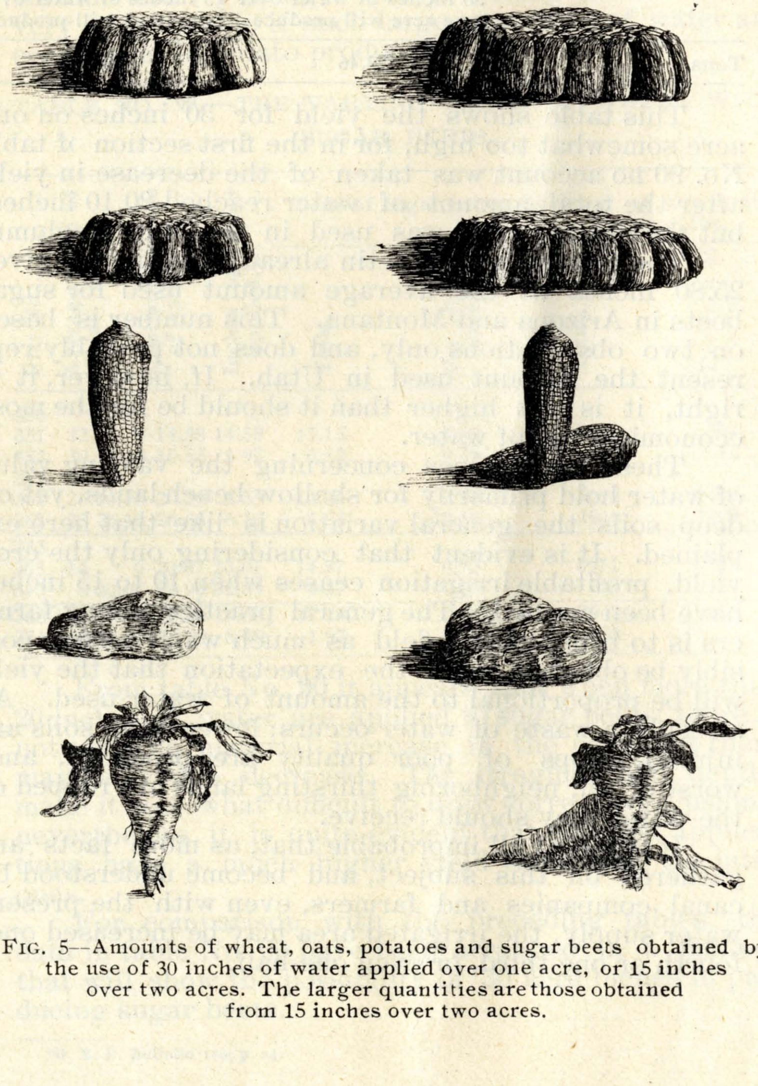


FIG. 5--Amounts of wheat, oats, potatoes and sugar beets obtained by the use of 30 inches of water applied over one acre, or 15 inches over two acres. The larger quantities are those obtained from 15 inches over two acres.

D. SUMMARY OF CONCLUSIONS.

49. SUMMARY.

1. The results of this investigation hold primarily for shallow bench lands.

2. The composition of the irrigation water from the mountain streams is quite constant during the irrigation season.

3. The temperature of the water in farm ditches is about 54° F. for June, 60° F. for July, 62° F. for August, and 54° F. for September.

4. At the time of the first irrigation wheat and oats had drained the soil more completely of its moisture than had corn, potatoes or sugar beets.

5. Perennials use less water in early spring than do annuals.

6. The amount of water held by the soil decreases with the depth.

7. Only about 60% to 75% of the maximum water capacity of the soil are utilized one day after irrigation.

8. The lateral movement of water in the soil of the College farm is about 4½ feet for the first foot; 6 feet for the second foot.

9. On soils like those of the the College farm the lateral movement of the soil water is of little consequence to the farmer.

10. The loss of the soil moisture is greatest from soil which has received most water; and is in direct proportion to the per cent of moisture in the soil immediately after irrigation.

11. Of two soils having the same per cent of moisture, the deeper soil loses most moisture.

12. The longer the time that elapses after an irrigation, the more water is lost.

13. About one-half of the water added in an irrigation is evaporated during the first week.

14. All tillage, having in view the conservation of soil moisture, should be put into operation as soon as possible after irrigation.

15. The effect on the soil moisture in changing the relative humidity a few degrees is very slight.

16. Sunshine is a strong factor in causing a loss of soil moisture.

17. Of the three factors, relative humidity, sunshine and temperature, the last is most potent in causing a loss of soil moisture.

18. Winds cause a large loss of soil moisture.

19. The rate of loss of soil moisture depends upon the kind of crop. The order, beginning with the most wasteful, is following: Potatoes, oats, wheat, corn, sugar beets, old lucern, red clover, timothy and English rye grass.

20. The soil moisture is taken nearly at the same rate from the different depths; though the upper soil layer dies out first.

21. The extent to which soils can dry out was 2.13% for the first three inches; 3.72% for the first foot, and 4.63% for the second.

22. More water is lost from the furrow than from the row, though the soil under the row is quite moist.

23. The percentage of water in plants and in the ripe seeds increases slightly with increase in irrigation.

24. Heavy irrigations increase the percentage weight of the heads of plants; light irrigations increase the relative weight of leaves.

25. Irrigation modifies definitely the composition of plants and plant parts; the seeds are affected more than any other plant part.

26. The percentage of protein in corn kernels was increased from 12.05 to 15.08 as the amount of irrigation decreased; in oat kernels from 14.07 to 20.79; in wheat kernels from 15.26 to 26.72. In all these seeds the fat and nitrogen-free extracts were increased by liberal waterings.

27. Increased irrigation increased the starch content and decreased the protein content of potatoes.

28. The composition of sugar beets seemed to be less strongly affected by irrigation than were other crops. Between 20 and 25 inches of water yielded beets with the highest sugar content.

29. The water in plants is somewhat dependent on the water in the soil.

30. With a given amount of water, better yields of corn were obtained by flooding than by furrowing.

31. Late irrigation did not affect unfavorably the growth and yield of corn.

32. The proportion of ear corn to stover increased regularly with the increased application of water.

33. The best amount of water for corn lies between 20 and 25 inches.

34. Late irrigations were found very beneficial in transferring nutritive materials from oat stalks to the heads.

35. Not less than 15 inches of water should be used for oats, and not more than 30.

36. Late irrigation was beneficial for the wheat crop.

37. The percentage of grain in the wheat crop increased with increased irrigations.

38. The yield of wheat increased up to 30 inches of water.

39. Frequent small irrigations of potatoes produced the best yields.

40. The percentage of marketable potatoes increased with irrigation.

41. The best amount of water for sugar beets is about 20 inches.

42. Crops in an arid district require a greater number of pounds of water for one pound of dry matter than in humid climates.

43. Water has a varying value. The first few inches possess a much higher value than the later ones; and the value continues to decrease as the amount of water increases.

44. By following the indications of the varying value of water it is possible that the irrigated area may be increased one-third or more, with the amount of water now used.

45. The results in this bulletin hold, primarily, for shallow bench lands.