Station Bulletin 122 August, 1914

Oregon Agricultural College

EXPERIMENT STATION

DEPARTMENT OF AGRONOMY

Irrigation and Soil-Moisture Investigations in Western Oregon

By W. L. POWERS
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By H. D. Scudder, Agronomist, Oregon Experiment Station

The gradual transformation of Western Oregon, in recent years, from a grain growing region to the highly diversified and more intensive forms of agriculture, has aroused considerable interest in the use of irrigation as a means of increasing production.

The climate of Western Oregon is humid. The average annual precipitation in the Willamette Valley is 44 inches; in the Umpqua, 35 inches; and in the Rogue River Valley, 26 inches. This rainfall, combined, as it is, with an extremely mild winter season and moist spring weather, is sufficient for excellent crop yields where the proper farming methods are used. The distribution of the rainfall through the year, however, is not the most favorable for all crops. While abundant from October to June, the precipitation is very scanty during the summer months, July, August, and September, totaling for this period, 2.8 inches in the Willamette Valley; 1.8 inches in the Umpqua; and 1.5 inches in the Rogue River Valley.

This dry summer season is an advantage with some crops and a disadvantage with others. It permits the harvesting of hay, clover seed, vetch seed, the small grains, and other crops which mature during July and August, with practically no danger of injury from rain. On the other hand, for those crops such as corn, kale, mangels, rape, rutabagas, hops, potatoes, truck crops of many kinds, and the second crops of clover, alfalfa, etc.,—all of which make their main growth from July to September—the scantiness of the rainfall at this season is the limiting factor in production, where the other requirements, fertility, proper cultural methods, etc., are met.

While it is true that excellent yields of all of these summer-season crops may be obtained where proper moisture-conserving methods are followed, yet the use of irrigation water as a *supplement* to the limited summer rainfall and to thorough tillage methods, seemed to offer promise of increased production and profits.

With these facts in mind, experiments were undertaken by the Oregon Experiment Station in 1907 on the Station farm at Corvallis, in cooperation with the United States Department of Agriculture, Office of Irrigation Investigations. During 1907 the work was carried out by Prof. F. L. Kent of the Oregon Station and Mr. A. P. Stover of the United States Office of Irrigation Investigations, and during 1908 and 1909 by Mr. Stover and the writer. The results of these first three years' experiments are reported in detail in Office of Experiment Stations Bulletin 226.

A pumping plant, consisting of a small gas engine and centrifugal pump, was installed, which lifted the water used approximately 20 feet from a small creek flowing through the Station farm. Details as to the plant, method of distribution, amounts applied, etc., may be found in the bulletin named. The soil, a gray silt loam moderately well drained but with some "white land" areas, is typical of the major portion of the Willamette Valley floor.

Compactly summarized, the results obtained may be found in the following table:

RESULTS OF IRRIGATION EXPERIMENTS—CORVALLIS, 1907-1909.

Year	Crop	Pounds per acre		Per cent Increase
		Unirrigated	Irrigated	
1907	Corn (green fodder)	5647	9666	71
1908	Corn (green fodder)	7280	9640	32
1909	Corn (green fodder)	11125	14153	27
1909	Sweet Corn (green fodder)	7000	13750	96
	Av. of Three Years	....	....	56
1907	Potatoes	2604	7500	180
1908	Potatoes	3626	5041	39
1909	Potatoes	9000	12900	43
	Av. of Three Years	....	....	87
1908	Mangels	2725	4309	58
1908	Clover (second crop)	1260	4040	220

As these preliminary results seemed to warrant a more careful investigation, in 1910, Mr. W. L. Powers of the Agronomy staff, with increased funds for the work, was assigned to the problem. The cooperation with the United States Department of Agriculture having been discontinued after 1909, the Oregon Station has carried the experiment on for four years until now detailed data and conclusive results have been obtained. These are reported by Mr. Powers in the pages following. The experiments were enlarged to include studies of: The effect of irrigation upon soil moisture movements; moisture consumption by the crop; best time and amount of application for different crops; costs and profits; etc.

That irrigation, as a *supplement* to the scanty summer rainfall of Western Oregon, may be profitably used can now no longer be questioned. That it is highly feasible so to irrigate Western Oregon lands, either by pumping plants from the numerous small streams found in every section of the region, or by gravity systems from storage reservoirs or stream diversions, is also undoubtedly the fact. With better transportation and marketing facilities, higher priced lands and smaller farms, it is certain that in the resulting intensive and diversified type of agriculture that will prevail, supplementary irrigation of summer-season crops in Western Oregon, whether for forage or truck production, will become of steadily increasing importance.

On the other hand, it is equally true that the wholesale irrigation of Western Oregon (particularly Willamette Valley) lands is neither necessary nor advisable. There are large areas of good agricultural lands in this region which are not irrigable, but from which excellent crop yields will always be obtained with ordinary good farming practices. There are many irrigable farms which will always be more profitably operated without irrigation, because the type of farming or kind of crops to which they are devoted will have no requirement for supplemental irrigation. There are still other lands, and the area of these is very large, on which thorough under drainage is of far greater importance, primarily, at least, and will bring far larger profits than will irrigation. In fact, on most of the irrigable lands of the Willamette Valley, irrigation water must be used conservatively,—minimums observed both in frequency and amounts applied, combined with thorough tillage and humus restoring rotations,—if positive injury to the soil through lack of aeration, is to be avoided.

But for many forms of intensive farming, the results so far obtained indicate that supplementary irrigation wisely used, on most summer-season crops, will prove profitable and form an important addition to Western Oregon farming practice.

August 15, 1914.

Irrigation and Soil-Moisture Investigations in Western Oregon

By W. L. Powers, Assistant Professor of Irrigation and Drainage.

SEC. II.—INTRODUCTORY

The work herein reported is a continuation of the investigation inaugurated by the Office of Experiment Stations, in cooperation with the Oregon Experiment Station, in 1907, with the purpose of determining the value of irrigation "for increasing and insuring productiveness" of the agricultural lands in the semi-humid Willamette Valley and other similar valleys of Western Oregon.[1]

Importance of Soil Moisture in Crop Production. Of all factors affecting the productive capacity of the soil there is none more important than soil moisture. It is only in recent years that farmers have come fully to realize its importance. We have more crop shortage from lack of moisture than from any other one factor. On the most intensive truck farms in states east of the Missouri River, some supplementary irrigation is used in dry seasons; and in these states, perhaps one year out of four, irrigation for meadow crops would be of value. It is desirable for soils to have a large supply of the plant-food elements; but it is just as desirable that they have a favorable supply of water to dissolve and convey these plant foods in the soil to the ramifications of the plant. After performing this service, the greater part of the water in the plant passes off through the pores of the leaves, thus modifying the temperature of the plant. It has been found that from 400 to 900 pounds of water are required in Western Oregon to produce one pound of dry matter. The best development of the plant is impossible without the required amount of water during all periods of growth; for growth depends upon the turgidity of the cells, which in turn depends upon the absorption of water by the roots. Most plants contain from 70 to 90% water. For example, fresh clover and alfalfa contain about 71%, potatoes 78%, and kale 89% of water. Soil bacteria require moisture to make nitrogen and the mineral elements of plant food available. Water softens the crusted surface soil, redissolves plant food, and reestablishes capillarity with the subsoil. There is the closest relation betwen moisture in the soil, and growth.

The economical utilization of soil moisture will always be a matter of vital importance to the farmers of Oregon. Dry farming is only made practicable through the saving of moisture. In Western Oregon we get the needed quantity of rain, but the necessity of irrigation can only be obviated by careful storage of this moisture until needed. In the arid parts of the State the cultivated area is limited to the amount of water available for irrigation, and not to the amount of land. In the first two districts water saved means increased yields. Under irrigation, saving 50% of the water now used would make it possible almost to double the irrigated areas.

Meaning and Value of Irrigation. The aim in irrigation should be to get the highest possible efficiency out of every inch of rainfall and

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[1]The results of previous years were reported by Mr. A. P. Stover, Office of Exp. Stas. Bul. 226, (1910).

supplementary acre inch of irrigation, and to use the least amount of the latter necessary to maintain a favorable moisture content throughout the main part of the growing season, while still permitting the soil to dry out sufficiently to mature the crop. Irrigation should be applied when the soil moisture content drops to near the wilting point; and in just a sufficient amount to raise the moisture content to the maximum usable water capacity of the soil throughout the root zone. Proper irrigation supplies a favorable moisture condition and encourages the growth of feeding roots, bacterial activity, and liberation of plant food. Improper irrigation checks these processes and often causes unfavorable soil temperature and drainage problems, or the leaching of plant food; in strictly arid districts it may even result in failure. Proper irrigation is a good means of soil moisture control.

Success in irrigation farming often depends as much on the personal factor as upon the soil and climatic conditions. A person must be accustomed to this method of farming or serve an apprenticeship; for it requires skill to handle water successfully or to manage pumping machinery efficiently. Irrigation farming reaches its highest development with intensive farming where large crops are removed and large amounts of refuse must be used to keep up the usable water capacity and maintain fertility. There is always a tendency for irrigation to compact the soil and exclude the air, especially in heavier soils such as are found in Western Oregon. It is exceedingly important under irrigation, therefore, to practice rotation, including soil-building crops which will offset this tendency of the soil to compact, and to make it practicable even to maintain a higher state of tilth and a higher percentage of organic matter with irrigation than is possible without it. Such a rotation also permits growing a good proportion of row crops of low water requirement, which permit moisture-conserving tillage.

Plan of Study. The original experiment to test the value of irrigation was enlarged in 1910 to include a study of weather, soil, and soil moisture, in order to make the results applicable to a variety of conditions. The original experiment to determine the value of irrigation vs. no irrigation for potatoes, corn, clover, and beets was continued, and alfalfa, kale, carrots, beans, and pumpkins were added to the list of crops grown with and without irrigation. Only one or two irrigations should be required in this climate, and the value of one as compared with two irrigations has therefore been studied. It is difficult to determine the time to irrigate by the appearance of crops in this climate, and so an experiment was planned to test the value of the moisture content of the soil as a means of determining the exact time to irrigate. Special experiments were planned to determine the best time, frequency, and amount of irrigation for alfalfa, potatoes, clover, and beans. A study was outlined to determine the most economical and maximum irrigations, and to determine the water requirement of the increase from irrigation and of the whole crop. It was planned to study the effect of irrigation upon soil and crop. The cost, value, and profit for each acre inch and for the total crop from irrigation were to be determined, both with electricity and gasoline.

Experiments, therefore, were enlarged primarily to include the following questions: Will it pay to irrigate under our soil and climatic conditions? Which crop will give the largest returns with the amount of water used? Can the time of irrigation for a given crop be determined accurately by the moisture content? What is the minimum amount of irrigation which, in combination with the best time and manner of use and of cultivation, would give the most economical production of dry matter and the highest net return?

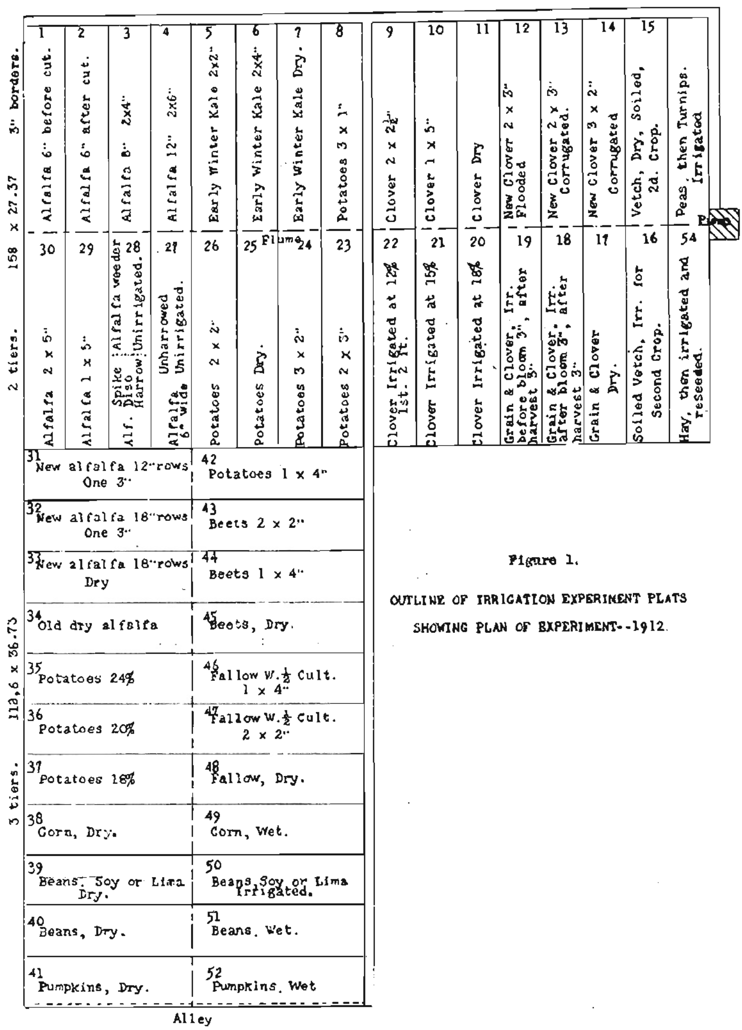


Figure 1.

OUTLINE OF IRRIGATION EXPERIMENT PLATS SHOWING PLAN OF EXPERIMENT--1912.

Location. The main experiments were conducted on a tract of about ten acres on the Experiment Station Farm, which lies just west of Corvallis. The tract occupies a slightly elevated area on the south side of the Corvallis & Eastern Railroad track. Water is secured from Oak Creek by means of a pumping plant. The water is lifted 19 feet and discharged into a rectangular flume which extends across the highest part of the tract toward the east. The surface of the ground slopes away from the flume gently to the south and to the northwest, effecting good drainage. The tract is fully exposed to the wind, sun, and rain. Figure 1 shows the location of the flume and arrangement of tenth-acre plats, as well as the topography of the surface. The plats were from a quarter-acre to an acre in size previous to 1911. Thereafter, all plats were a tenth-acre in area. In the course of these experiments approximately 250 individual plat trials have been made.

Soil. The main body of the soil employed in these experiments was rather heavy gray silt loam, uniform horizontally and vertically in type, and representative of many thousands of acres of slightly elevated undulating lands in the floor of the Willamette Valley. The subsoil is a yellow heavy silt loam, and is slightly heavier at the west edge of the plats toward the creek and at the lower edge of the plats to the northwest. The mechanical analyses of eight soils and eight subsoils in various parts of the tract, as determined by Mr. James Koeber, former assistant in Agronomy, show that the soils in these plats are very uniform in texture. There is not a variation of three per cent in the physical composition of the different soils. This makes them very valuable for moisture study. The average mechanical analysis is as follows:

TABLE 1.—AVERAGE PHYSICAL COMPOSITION OF WILLAMETTE VALLEY SILT LOAM SOIL FROM IRRIGATION PLATS

(Figures are in per cent.)

	Fine gravel 2-1 mm.	Course sand 1-5 mm.	Medium sand .5-.25 mm.	Fine sand .25-.1 mm.	Very F. sand .1-.05 mm.	Total sand	Silt .05-.005	Clay .005-0 mm.	Total inorganic matter	Loss on ignition
	%	%	%	%	%	%	%	%	%	%
Surface	.0	.4	.5	2.1	2.0	5.0	74.9	20.7	100.6	5.45
Subsoil	.0	.3	.4	1.9	1.9	4.4	70.7	24.9	100.0	4.25

The average weight of this soil for each cubic foot is about 80 lbs., a figure which is used in making calculations in this bulletin. The average maximum water retaining capacity of the surface soil under field conditions is about 34%, and of the subsoil about 31%; but over 27% of moisture is rarely found after the soil is dry enough for seeding; the optimum moisture content being about 23%. The drouth point is at about 14% of moisture, and the average minimum field capacity of the first foot is at about 11%. The actual usable

water capacity is a little below two acre inches in the first acre foot under field conditions; while that of the subsoil is usually a little lower. The soil is retentive, but only fairly free-working, and heavier than the ideal soil for irrigation. It takes up water at a moderate rate.

The land had been in pasture for about 15 years previous to its use in these experiments. It was plowed and cropped in oats one year before being platted. The soil is strong from a plant-food standpoint; and is uniform in composition, as indicated by the uniform yield of barley on the various plats when grain was used as a nurse crop. The average plant-food content of this valley silt loam from the College Farm, as given in Oregon Station Bulletin No. 112, is as follows:

TABLE 2.—PLANT FOOD CONTENT OF WILLAMETTE VALLEY SILT LOAM.

	Total	Acid Soluble	Available
	%	%	%
Nitrogen (N)	0.224	......	....
Potash (K2O)	2.77	0.30	0.035
Phos. Acid (P2O2)	0.44	0.29	0.070
Lime (CaO)	1.10	0.52	....
Humus	3.19	......	....

A short distance south of the plats is some black clay soil containing a good percentage of organic matter, and locally called gumbo. The rice plat was on this type of soil in 1911, and the irrigated and unirrigated corn was also on this type of soil. In 1912 and 1913 the plats were extended northward to include some slightly heavier soil, which is a type intermediate between the valley silt loam, and the so-called "white land." This intermediate type of soil would classify as a silt clay. The crops grown on it were beans and pumpkins. These plats were not employed in the regular soil-moisture studies. The rice plat in 1913 was located on almost typical "white land."

Climate. The warm mean temperature, high percentage of sunshine, low percentage of relative humidity, and strong sea-breezes of the summer season favor rapid evaporation of the supply of water received during the extremely opposite conditions of the rainy season, and bring a change to which it is difficult for plants to adjust themselves. The mean annual rainfall at Corvallis, as determined from our record for 25 years, is 42.92 inches, while the mean for the three summer months is 2.03 inches. Hence the moisture for crops during our long growing season must be largely stored in the soil or be supplied artificially during the growing season. The summary of weather data for the seven seasons during which time this experiment has been continued may be found in Table 3. The table shows that during these seven years, there were four years when the rainfall for the three summer months was above normal and three years when it was below normal, while for the seven-year period the summer rainfall was .43 of an inch above normal. It is thought that the experiment has been run long enough to represent average weather conditions. The summer temperature for these seven seasons averages .4 of a degree below normal, for three years being above and for three below normal, while it was normal for one year. The evaporation from the water surface

TABLE 3.—CLIMATOLOGICAL DATA FOR SEVEN SEASONS, (MAY 1-OCT. 1), SHOWING WET AND DRY SEASONS AND DEPARTURE FROM NORMAL

Year	Rainfall in Inches							Temperature F.o						Mean relative humidity	Mean sunshine—per cent.	Mean wind—hourly miles	Total evaporation—water surf. nches
								June, July and August		5 Months		June, July and August					
	May	June	July	August	September	Total, 5 months	Departure from normal	Total	Departure	Mean	Departure	Mean	Departure				
1907....	1.27	1.11	.24	1.15	1.17	4.94	— .58	2.50	+ .61	61.8	+ .8	63.7	+ .3	....	....	....	....
1908....	2.89	1.38	.00	1.00	.23	5.50	— .02	2.38	+ .49	60.6	.4	64.3	+ .9	....	....	....	....
1909....	1.39	.30	1.11	.11	1.16	4.06	—1.46	1.51	— .38	59.8	—1.2	61.8	—1.6	....	....	....	....
1910....	.83	1.73	†T	.01	.85	3.42	—1.10	1.74	— .15	60.6	— .4	62.1	—1.3	....	....	....	....
1911....	4.21	1.05	.03	.02	4.27	9.58	+ 4.06	1.10	— .79	59.0	—2.0	63.4	.0	62.3	71.2	8.4	23.77
1912....	2.14	1.48	.17	2.18	1.94	7.91	+ 2.39	3.83	+1.94	60.0	—1.0	61.8	—1.6	68.4	63.0	6.8	23.73
1913....	1.89	2.88	.93	.37	2.34	8.41	+ 2.89	4.18	+2.29	60.6	— .4	64.2	+ .8	72.7	59.3	....	20.00*
														71.5	54.7	....	23.00
Seven yr. av.	2.09	1.42	.35	.69	1.71	6.40	+ .88	2.46	+ .43	60.4	— .6	63.0	— .4	68.7	62.0	7.6	22.62
Departure from Normal	—.16	+.23	+.07	+.27	+.33	+.88	....	+ .43	....	— .6	— .6	— .4	....	....	....	....	....

*Interpolated partly.
†T- -Trace or less than .01 inch.

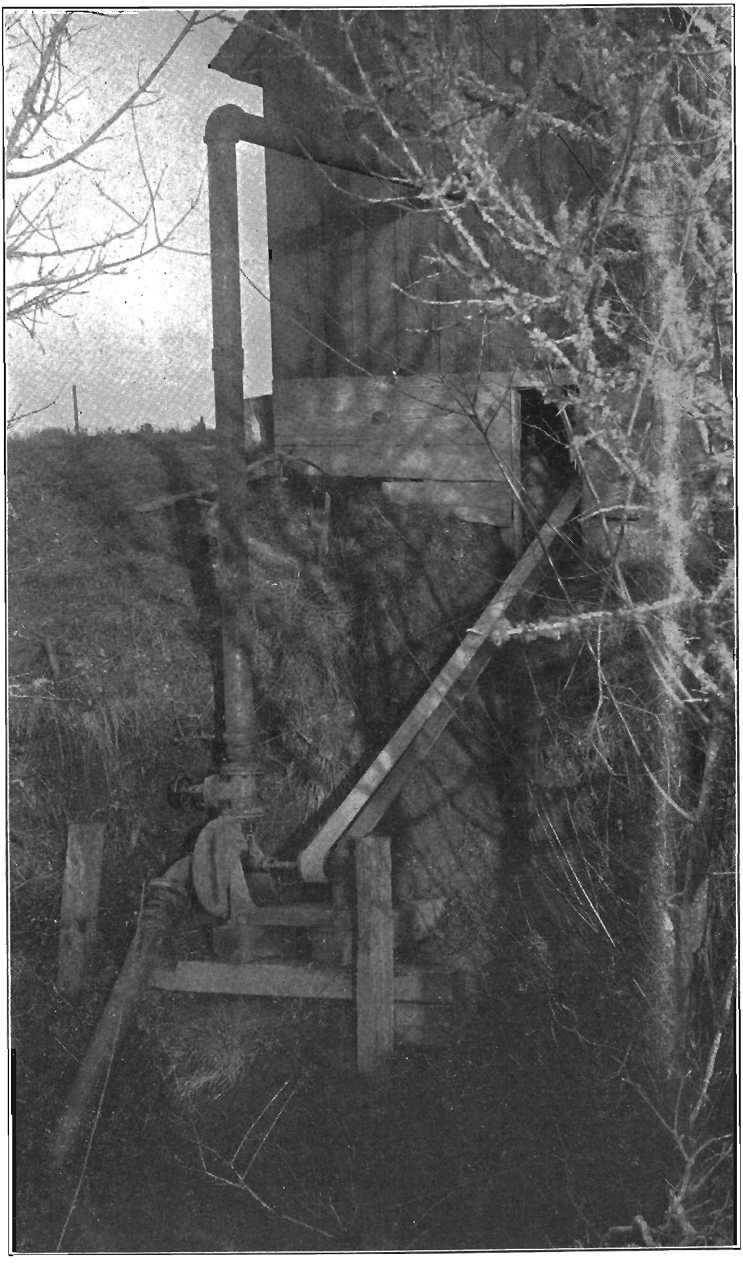


Fig. 2.—IRRIGATION PUMPING PLANT, OREGON EXPERIMENT STATION

gives a good mean effect of all weather conditions that cause loss of soil moisture. This mean evaporation from May 1 to October 1 has been found to average nearly two feet. The general climatic and soil conditions of this region are very favorable for soil-moisture and irrigation experiments.

Equipment. The pumping plant shown in Figure 2 is located at a bend in the stream where there is a deep pool. The suction and discharge pipes are six inches in diameter. The water is lifted by means of a three-inch horizontal centrifugal pump, driven by a four-horse-power gasoline engine. During the last two years this engine was replaced by a five-horse-power single-phase electrical motor. At the foot of the suction pipe is a foot valve, and just above the pump is a straight-way ground valve to hold the water in the discharge pipe for priming and to close the discharge pipe so that a vacuum may be produced. The flume is an ordinary wooden structure. The trapezoidal weir and weir box is located at the end of the main flume, making it possible to measure the net amount of water applied to the plats. Soil samples were taken with the extension auger, except when the soil was very dry. At such times a tube was found to work to good advantage, or a guard casing was used on the auger. The soil samples for moisture determination were taken and conveyed to the laboratory in half-pound salve boxes which were air-tight, and the total moisture content determined in the ordinary manner.

Method of Irrigation. The row crops were irrigated by means of furrows and the meadows by flooding the plats, except in special experiments, when they were irrigated by means of portable, slip-joint pipes or with canvas hose. The pumping plant delivered about one-half cubic foot a second, which was a rather large head of water for the cultivated plats, amounting to a one-inch irrigation in 12 to 15 minutes. So it was often divided in irrigating these plats by use of a small portable metal weir (shown in Figure 3) after passing over a standard weir. The total head was none too large for the meadow plats.

In the furrow irrigation of cultivated crops, water was allowed to run in six or eight furrows until it reached nearly to the lower end, when most of it was turned away into other furrows. A one-inch stream continued to run into the wetted furrow until irrigation was completed. As soon as the ground had dried enough to permit cultivation, these furrows were filled in and the surface mulched by the use of a one-row cultivator. The dry plats were always cultivated at the same time that the irrigated plats were mulched. The single irrigations were ordinarily applied when it seemed that they would do the most good. Very good distribution was secured except on some meadow plats where the burrows of pocket gophers interfered. (Soluble strychnine in carrots and raisins was used regularly to combat the gophers, with fair success early in the season. Later in the season, traps were more successful, although they required considerable attention.) The approximate average length of irrigation season and growing season is shown in the following table:

Figure 3.—SMALL PORTABLE WEIR USED IN SUB-DIVIDING A STREAM OF WATER

TABLE 4.—APPROXIMATE AVERAGE GROWING AND IRRIGATING SEASONS.

CROP	GROWING SEASON	IRRIGATION SEASON
Alfalfa	April 1-October 15	July 8-August 12
Clover	April 1-October 15	July 8-August 12
Potatoes	May 15-October 1	July 20-August 10
Corn	May 17-October 5	July 25-August 15
Early Kale	April 15-September 30	July 18-August 10
Winter Kale	June 5-March 30	July 25-August 15
Beets	April 26-October 10	July 20-August 20
Carrots	April 26-October 10	July 20-August 20
Beans	June 3-September 20	July 20-August 1
Pumpkins	June 1-October 10	July 20-August 1
	Mean Irrigation Season	July 8-August 17 or 40 days.

Meterological Observations. Since weather conditions determine largely the rate and total amount of loss of soil moisture, careful records of all weather elements affecting evaporation were kept as accurately as possible with the instruments at hand. Temperature records were obtained daily from standard maximum and minimum thermometers located in a standard shelter with proper exposure. The relative humidity was determined at 7 a. m. and 6 p. m. by means of a sling psychrometer. Wind velocity was measured during two seasons by means of an electrical recording anemometer located on the turret of the Agricultural building, 115 feet above ground and fully exposed to the wind. The percentage of sunshine was determined daily by non-instrumental observations, and the amount of rainfall was measured with a standard weather-bureau gauge having a good exposure. Evaporation from a free water surface was measured by means of a cylindrical galvanized iron tank, having a mean depth of 27 inches and a mean diameter of two feet, which was set near-by, flush with the surface of the ground. The readings were taken with a diagonal scale, which was graduated to 5-100 inches, and which could be read to within 1-100 of an inch. Readings were taken regularly every Saturday noon and also in midweek during dry weather. After a reading, the tank was at once filled with water to the zero point of the scale; this brought the water to within ¾ of an inch of the top of the tank.

Methods of Sampling. In sampling for moisture determinations a core of soil was taken representing each foot down to six feet, or, after irrigation, to drier dirt. These samples were taken regularly every Saturday during the growing season. Additional samples were taken before irrigation and 24 and 48 hours after irrigation; also at various other times in the irrigated plats to determine the distribution and rate of percolation of the irrigation water and the percentage of irrigation stored in the soil. Moisture samples taken at seed time and harvest time in duplicate gave a measure of the loss in inches of water during the growing season. During the past four years a total of some 9,650 soil-moisture determinations have been made. The probable error of mean percentage moisture in these determinations would be about one-half per cent.

SEC. III.—SOIL MOISTURE

General Moisture Conditions During the Growing Season. At the beginning of the growing season, when the soil was dry enough to permit cultivation, it had an average moisture content of about 28%.[2] This amount decreased rapidly in the uncultivated meadows; but the frequent working of the cultivated soil in preparing the ground and planting crops, formed a good mulch, and in some cases moisture actually accumulated in the three-foot stratum under this mulch during June. (See detailed data for 1910, Table 2.) The clover and alfalfa took moisture from the soil rapidly and left the remaining supply rather unevenly distributed. The decrease in the moisture content in the meadows was 2% some weeks, and in the ten weeks following May 7, the percentage of moisture in the first three feet dropped 10% or 12%. The decrease of moisture in the meadows the latter part of June and the first part of July was very great. The value of cultivation in conserving moisture is markedly shown by the less rapid loss which occurred at this time from cultivated plats.

When the surface two feet of soil on the unirrigated plats had become too dry for growth and when the third and fourth foot had been considerably dried, capillary movement seemed to be choked off. The moisture content of unirrigated soils decreased very little after July 15, although for several weeks following there was equally dry weather. Capillary action through the subsoil was too slow in this fine-grained soil to supply moisture for growth, and the crop stood still even though the fourth, fifth, and sixth foot of soil was still well supplied with moisture. Grass on the College campus fired and ceased growing early in July, when the moisture content of the first two feet dropped to about the 11% point. Little capillary movement occurred after this. It seemed that the plant food had gone out of solution and was dried to the soil particles in unavailable form.

The value of early plowing in conserving moisture was shown by the fact that alfalfa and clover plats that received early plowing in February or March had a higher amount of moisture than other plats in all seasons.

The effect of rains on soil moisture was frequently measured. The rainfall on June 4 to 11, 1910, was .94 inches, and penetrated to a depth of 5 inches in meadows and 10 inches in cultivated ground, giving a gain in moisture content in the dry meadow plats equivalent to approximately one acre inch.

Seasonal Average Moisture Content. The seasonal average moisture content was lowest in the dry meadow plats, but varied considerably with wet and dry seasons. The weekly 6-foot average of the dry alfalfa plat was 17.6% in 1910, in 1911 it was 22.4%, in 1912 it was 24.8%, and in 1913 it was 23%, the last two seasons being wetter than normal. The weekly moisture content of the first, third, and fifth foot of one unirrigated alfalfa plat (No. 29) and one irrigated alfalfa plat (No. 27) for the season of 1911, is shown in Figs. 4 and 5. It will be noticed that there is usuable moisture in the subsoil of the unirrigated plat throughout the season. The moisture curves for the irrigated

[2]Moisture percentages are based on dry weight.

plat show the increase in moisture by irrigation. The increase in moisture due to irrigation was confined mainly to the first three feet of soil.

Irrigation when the moisture content dropped to 20% in the first two feet gave a very favorable and uniform moisture content. The seasonal average moisture content of the potato plats irrigated when the moisture content dropped to 23%, 20%, and 17% for the first foot is shown diagrammatically in Figure 6. The uniform moisture content in the 20% plat was associated with the largest yield.

In all cases the cultivated plats had much greater moisture content than the uncultivated. The value of the early cultivation of alfalfa was thoroughly demonstrated. The harrowing of alfalfa at the beginning of the season gave an average gain in moisture in August for the 3-foot stratum of 2.3%. Early spring plowing in February, or early in March, has resulted in an exceptionally high seasonal moisture content.

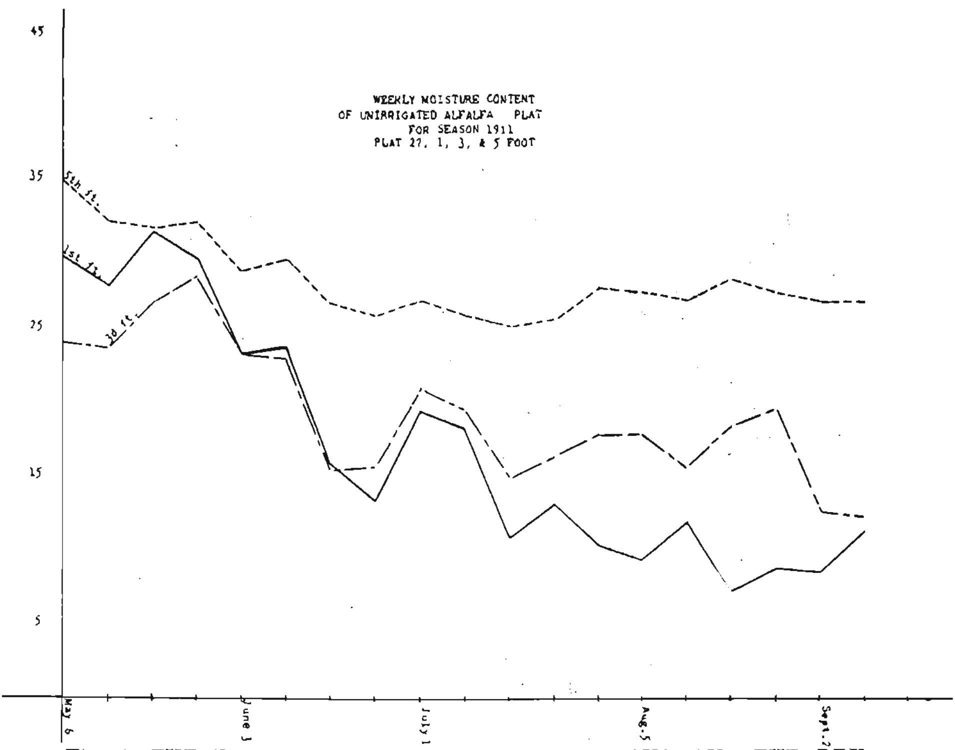


Fig. 4—THE FIFTH FOOT REMAINS MOIST THROUGHOUT THE DRY SEASON. RAIN INCREASED MOISTURE CONTENT THE LAST WEEK IN JUNE.

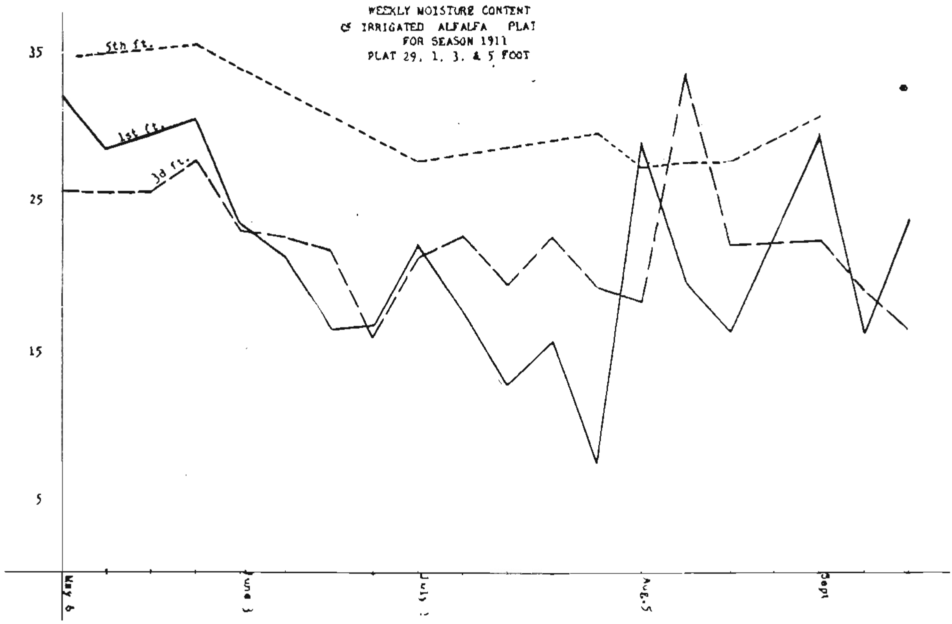


Fig. 5—IRRIGATION IN JULY INCREASED THE SOIL MOISTURE CONTENT

When irrigation water was applied, the upward capillary movement in the subsoil was renewed after the first two or three days, and the average moisture content of the soil was thereby increased in the meadows and also appreciably increased in most of the cultivated plats. The amount of increase in moisture content from irrigation was greatest with rather light irrigations, and the gain from irrigation decreased with the distance from the surface, being scarcely traceable in the subsoil of cultivated plats. Ten inches of irrigation[3] increased the percentage of soil moisture considerably more than 5 inches in the meadows, and a 2½-inch irrigation had a lesser effect than one 5-inch irrigation in cultivated fields. This irrigation water entered largely into the extra crop or was lost in the case of fallow plats by causing excessive evaporation on account of being in excess. The value of irrigation is more apparent when compared with subsequent yields.

Manured land retained moisture from spring rains longer than did unmanured land. Manured beet and kale plats, as judged from the soil-moisture standpoint, show more advantage where irrigated a little later in the season than other crops, as the manured ground retained moisture well; and these crops make the greatest demand for moisture in the later part of the season. Irrigated alfalfa sod when plowed up has given an advantage over dry alfalfa sod land in seasonal moisture content due to greater supply of organic matter and improved tilth. Cultivated

[3]**Inches irrigation in this bulletin refers to depth in inches over the surface—the same as inches rainfall.** In tables 2x5" = two 5-inch irrigations.

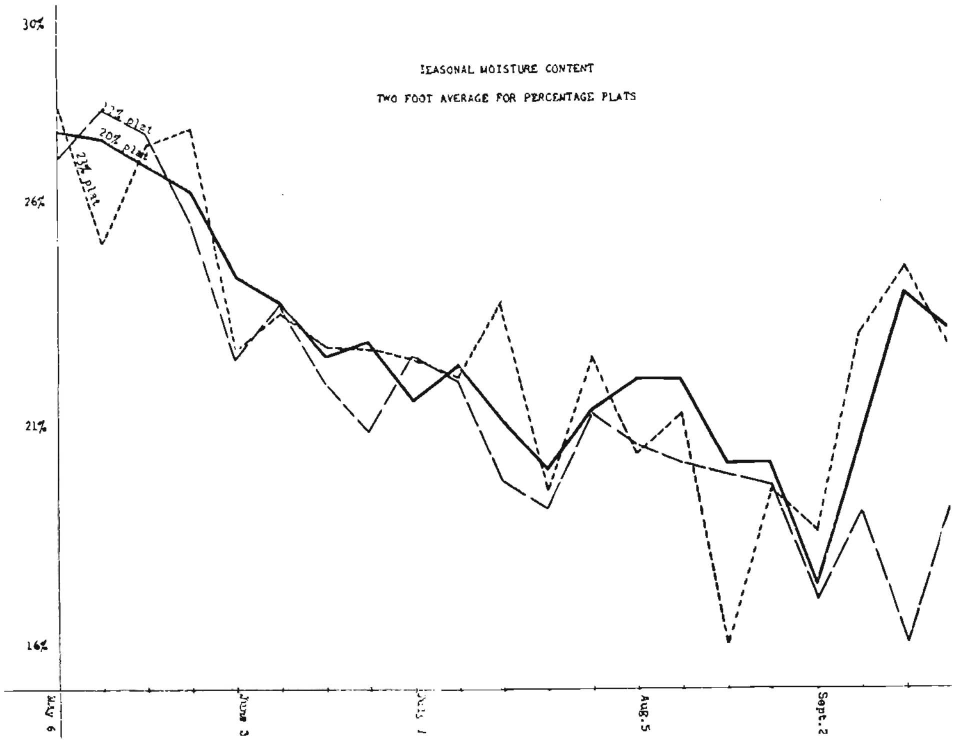


Fig. 6—THE MOST UNIFORM MOISTURE CONTENT AND LARGEST YIELD WERE SECURED BY IRRIGATING POTATOES WHEN THE MOISTURE CONTENT DROPPED TO 20%.

fallow receiving 5 inches irrigation had the highest seasonal average moisture content, although only one per cent more than the dry cultivated fallow, it being difficult to store moisture any length of time above the 27% point even in fallow land. Dividing the 5-inch irrigation into two 2½-inch (2x2½") applications gave little advantage in seasonal moisture content in the bare fallow and no advantage in the cultivated fallow. It was impossible to maintain a bare fallow and keep it free from weeds, or to store much irrigation within the usable water capacity of the cultivated fallow; so these plats did not afford the best means of measuring the water cost of increase from irrigation.

Gain From Irrigation. On an average about 70% of the irrigation water was found stored in the soil 48 hours after irrigation, the percentage stored being higher with light irrigations and when applied to the drier soils. When water was applied, upward capillary movement in the subsoil seemed temporarily to be reversed. The water near the surface, moving down by capillarity and percolation, seems to push the dry air before it and modify the capillary action, so that capillary movement below the newly moistened strata is reversed. This, and the continued drain on the moisture of the subsoil by roots, gives a temporary loss in the subsoil following irrigation. By superimposing samples taken 48 hours after irrigation upon those taken just before irrigation, the amount gained from irrigation was found. A typical example of this is as follows:

TABLE 5.—TYPICAL GAIN IN MOISTURE CONTENT 48 HOURS AFTER IRRIGATION.

	Alfalfa (2x5")	Alfalfa (Dry)	Potatoes (2x2½")	Potatoes (Dry)
	Sample and Irrigation Aug. 3 Sample, Aug. 5	Sample. Aug. 6 Sample. Aug. 12	Sample and Irr., June 8 Sample, July 10	Sample. July 8 Sample. July 15
1st. ft.	+17.2%	—1.3%	+3.9%	—2.3%
2d. ft.	+10.3%	+1.5%	+4.6%	—0.5%
3d. ft.	+ 0.0%	—2.4%	+1.0%	+0.0%
4th ft.	— 0.3%	+0.2%	—0.3%	+0.7%
5th ft.	— 5.3%	—0.6%	—0.9%	+0.0%
6th ft.	— 1.0%	—0.8%	—0.8%	—1.3%
Total..............	20.9%=3.2"	—3.4%=—.5"	+17.5%=1.8"	—3.6%=—.5"

The writer has previously found similar losses in working with arid soils of a sandy character, and in taking borings to greater depths.

Loss Between Irrigations. The loss from the surface soil was most rapid the first few days after irrigation, but the soil retained the irrigation water fairly well. The second irrigation was applied usually after the soil had lost most of its irrigation water and the surface soil was approaching the drouth point. In normal seasons, little irrigation water remained in the soil unused at harvest time. The average inches of irrigation found remaining in 6 feet of soil at harvest time varied from zero to as much as two inches, the higher figures usually being associated with over-irrigation. The surface evaporation after irrigation encouraged upward capillary movement to begin and the deeper subsoil frequently showed an actual gain between irrigations, partly from the irrigation water continuing its downward movement; but more largely, probably, from reestablished upward capillary movement. By superimposing all samples taken after irrigation upon those taken just before the second irrigation, we found the amount of loss between irrigations. The subsoil usually gained water instead of losing it. The plus or minus value of a typical comparison of this kind is as follows:

TABLE 6.—TYPICAL LOSS IN MOISTURE CONTENT BETWEEN IRRIGATIONS.

	Alfalfa (2x5")	Alfalfa (Dry)	Potatoes (2x2½")	Potatoes (Dry)
	Sample after Irr July 12 Sample before Irr. July 29	Sample, July 15 Sample, July 29	Sample after Irr. July 13 Sample before Irr. August 5	Sample, July 15 Sample, Aug. 6
1st ft.	— 6.2%	— 3.3%	— 7.3%	— 2.7%
2d ft.	— 9.8%	— 0.9%	— 2.9%	— 6.4%
3d ft.	— 5.9%	— 0.9%	— 4.3%	— 8.9%
4th ft.	— 1.3%	— 1.1%	— 2.7%	— 1.0%
5th ft.	+ 3.3%	+ 0.0%	+ 0.5%	— 1.1%
6th ft.	— 1.3%	— 1.3%	+ 1.9%	— 0.8%
Total	—21.2%=—3.3"	— 7.5%=—1.1"	—15.2%=—2.4"	—20.9%=—2.8"

Percolation. Five- and six-inch irrigations were found to penetrate three to four feet in the meadows at the end of 48 hours, while the four-inch irrigations had penetrated about two feet. This movement was more rapid in the fairly moist cultivated fields, but the influence of irrigation was almost negligible in the cultivated plats below four feet. The heavier irrigations in the meadow plats were sometimes traceable to a depth of seven feet, but ordinarily moisture determinations failed to reveal any gain below six feet, and in the later years, samples were not taken below this point. The deep subsoil, always being very moist, tended to obscure any gain. Percolation below six feet, therefore, with a moderate irrigation, is practically negligible in this soil. The most serious loss from percolation was through gopher tunnels, which gave a high percentage of loss in some cases where earthen channels were used.

Percolation losses may be largely controlled in irrigation by keeping up the usable water capacity; by applying moderate amounts in proportion to water capacity of soil; and by using a small enough head in proportion to the plot irrigated, so that the water will all be permitted to soak in by the time it reaches the lower end of the plot without runoff.

Capillarity. Movement of moisture by capillarity in this soil was rather slow. The amount of gain or loss from irrigation, or between irrigations, indicates to some extent the amount of this movement. The maximum lateral capillary movement of this soil in the field does not exceed 18 inches. The drying of the surface soil seems to choke off the upward capillary movement, and light irrigation seems to reestablish capillarity with the moist subsoil.

RELATIONS BETWEEN WEATHER CONDITIONS, IRRIGATION, AND SOIL MOISTURE.

Detailed weather data for the season of 1910 are arranged in Table 7, together with the average moisture content of comparative plats, to show the relations between weather, moisture, and irrigation. These conditions prevailed from season to season, though a higher moisture content in wet seasons was associated with higher yields of dry plats than in 1910. The mean weekly weather condition is taken from Saturday noon until the following Saturday noon, because soil samples and evaporation readings were taken nearer noontime than midnight,

TABLE 7.—SOIL MOISTURE AND METEOROLOGICAL DATA.

RELATION BETWEEN WEATHER CONDITIONS, IRRIGATION, AND SOIL MOISTURE

Date	Mean Temp. F°.	Rel. Hum. Mean % A.M.&P.M.	Mean Sky % Clear	WIND		Rain Inches	Evap. Water Surf.	Per cent Moisture in Soil at Week's End: Three ft. Ave. and Six ft. Ave.							
								ALFALFA				POTATOES			
								Irrigated		Unirrigated		Irrigated		Unirrigated	
				Mean Daily	Mean H'rly			3 ft. av.	6 ft. av.	3 ft. av.	6 ft. av.	3 ft. av.	6 ft. av.	3 ft. av.	6 ft. av.
						Pre-irrigation Period, April 30-July 16 (11 weeks).									
4-30—5-7	54	....	30	breeze		1.01	.55	23.4	....	20.5	....	20.5	....	20.5	....
5-7 —5-14	58	69	80	breeze		.16	.86	....	....	....	....	....	....	....	....
5-14—5-21	54	50	80	mild		....	.80	22.6	....	19.7	....	22.4	....	21.5	....
5-21—5-28	57	57	22	breeze		.12	.92	21.5	....	19.3	....	23.3	....	19.8	....
5-28—6-4	60	59	85	breeze		....	1.00	16.4	....	16.1	....	20.7	....	22.1	....
6-4 —6-11	59	56	80	breeze		.94	1.00	17.5	....	18.6	....	23.7	....	24.6	....
6-11—6-18	57	57	30	mild		T	1.04	16.4	....	15.5	....	20.3	....	23.6	....
6-18—6-25	57	57	50	breeze		.79	.80	16.9	....	14.5	....	24.8	....	21.9	....
6-25—7-2	64	59	70	breeze		....	1.10	16.7	....	13.0	....	21.1	....	21.9	....
7-2 —7-9	64	....	80	breeze		....	1.20	10.5	....	11.3	....	20.6	....	19.9	....
7-9 —7-16	68	....	90	windy		....	1.55	10.3	18.6	11.7	18.1	18.9	26.8	21.7	26.7
Totals....	....	....	....	....		3.02	10.82	....	....	....	....	....	....	....	....
Mean......	59.3	58.0	66.1	breeze		.27	.98	17.2	....	16.0	....	21.6	....	21.7	....
Gain or loss, from irrigation, for period..................						....	....	1.2	....	....	....	—0.1	....	....	....

Irrigation Period, July 16-October 1 (11 weeks).

7-16—7-23	70	....	75	272	11.3	T	1.55	24.1*	24.6*	11.2	18 4	18.6	....	21.4	....
7-23—7-30	65	64	100	194	8.2	....	1.25	24.6	26.7	12.0	19.1	19.8	....	15.1	....
7-30—8-6	61	66	90	207	8.6	....	1.53	19.8	22.4	11.6	18.5	18.8	26.5	19.4	26.4
8-6 —8-13	62	63	95	198	8.3	....	1.55	15.5	19.5	11.2	17.3	23.9*	28.5*	21.9	27.9
8-13—8-20	64	58	70	229	9.5	....	1.38	28.0*	26.6*	11.4	18.3	24.0	30.0	19.1	25.6
8-20—8-27	62	57	100	244	10.2	....	1.33	23.5	25.7	11.8	18.2	22.2	28.4	21.4	28 0
8-27—9-3	61	56	95	224	9.3	.01	1.15	24.2	27.5	11.8	19.1	21.0	26.8	21.6	26.7
9-3 —9-10	59	64	85	194	8 2	T.	1.16	19.5	22.5	10.6	15.9	20.2	26.6	17.8	23.5
9-10—9-17	59	75	60	185	7.7	.23	.85	16.2	....	11.0	16.1	18.7	25.7	16.1	22.7
9-17—9-24	60	77	43	139	5.8	.59	.47	15.9	21.2	14.1	18.7	22.6	27.6	20.1	24.7
9-24—10-1	56	78	57	137	5.7	.16	.73	19.0	23.5	11.4	17.6	21.6	27.5	dug	....
Totals....	....	....	....	......	....	.99	12.95	....	....	....	....	....	....	....	....
Mean......	61.7	65.8	79.1	202	8.4	.09	1.18	20.9	24.0	11.6	17.9	21.0	27.5	19.4	25.7
Gain, due to irrigation, for period						....	....	9.3	6.1	....	....	1.6	1.8	....	....
Grand Totals....	....	....	....	......	....	4.01	23.77	....	....	....	....	....	....	....	....
Season Mean......	60.5	62.3	71.2	202.1	8.4	.18	1.08	19.2	23.5	13.7	17.8	21.3	27.4	20.5	25.9
Seasonal gain, due to irrigation						....	....	5.5	5.7	....	....	0.8	1.5	....	....

*Means irrigations.

TABLE 8.—RELATIONS BETWEEN WATER RECEIVED, EVAPORATION, SOIL MOISTURE, AND YIELDS. 1910.

CROPS	Water received: Depth in inch — Irrigation	Water received: Depth in inch — Rain Apr. 1 Oct. 1	Evaporation: Water free surface Apr. 1 to Oct. 1	Seasonal Moisture Content: Growing season — 3' Ave. %	Seasonal Moisture Content: Growing season — Gain %	Seasonal Moisture Content: Irrigation season — 6' Ave. %	Seasonal Moisture Content: Irrigation season — Gain %	Yields: Cutting	Yields: Tons per acre	Yields: Total tons	Yields: Gain in tons	Yields: Gain %
Irrigated Alfalfa	10.42	4.01	23.79	19.2	5.5	23.5	5.7	1st	7.940	....	....	....
								2nd	3.550	....	11.977	240
								3rd	3.560	....	....	....
								4th	1.902	16.952	....	....
Unirrigated Alfalfa	....	4.01	23.79	13.7	....	17.8	....	1st	3.205	....	....	....
								2nd	1.769	4.975	....	....
Irrigated Clover	9.91	4.01	23.79	19.3	6.3	26.5	9.1	1st	7.995	....	....	....
								2nd	1.268	....	....	....
								3rd	0.939	10.202	5.887	133
Unirrigated Clover	....	4.01	23.79	13.0	....	17.4	....	1st	3.928	....	....	....
								2nd	.395	4.323	....	....
Irrigated Potatoes	5.35	4.01	23.79	21.3	....	27.4	1.5	....	140.02*	140*	84.04*	150
Unirrigated Potatoes	....	4.01	23.79	20.5	0.8	25.9	....	....	55.98*	55.98*	....	....
Irrigated Corn	5.35	4.01	23.79	22.0	1.4	27.9	1.4	....	43.09*	43.09*	17.36*	67.4
Unirrigated Corn	....	4.01	23.79	20.6	....	26.5	....	....	25.73*	....	....	....

*Bushels.

although the latter is the time of division used by the Weather Bureau. The three-foot average moisture content represents the average of the first, second, and third foot, while the six-foot average is determined from six determinations by a similar process. Any marked deviation in soil moisture content from that of the previous week should be accounted for by the mean weekly weather conditions in the same horizontal line. The whole season of 22 weeks is conveniently divided into (1) a pre-irrigation period of 11 weeks leading up to the first irrigation, and (2) the irrigation season of 11 weeks extending from the first irrigation to harvest.

The mean temperature and wind movement reached a maximum and the relative humidity a minimum about the middle of July, while the highest percentage of sunshine occurred in August. This is found true of the past four seasons. Evaporation from a free water surface reaches a maximum the later part of July, and this time is the least subject to rainfall. Evaporation was about six times the rainfall for the whole growing season in 1910. The effect of spring and fall rains upon the moisture content of the soil can be readily seen. The loss of moisture was the greatest from June 1 to July 15. Winter rains had destroyed any difference in moisture content from irrigation water applied the previous season, but the effect of the previous irrigations in securing a stand of clover or alfalfa was very marked. The difference in moisture content due to irrigation during the irrigation season was very marked in the case of clover and alfalfa, and was also very noticeable in its effect on cultivated land. By the middle of July the dry meadow plats were practically as dry as they could get. There was little further loss of moisture, and little additional growth occurred later in the season on these plats.

RELATION BETWEEN WATER RECEIVED, EVAPORATION, SOIL MOISTURE, AND YIELDS.

These relations are illustrated in Table 8 (1910). The rainfall and irrigation water, taken collectively, represent the total amount of water received. The evaporation from the water surface gives a fairly good mean effect of all weather conditions causing a loss of soil moisture. The mean moisture content represents the average amount of moisture actually present. The column of gains gives the additional amount of growth due to a definite increase in percentage of moisture present.

An average increase in the first six feet of 9% moisture from irrigation in clover and of 6% in the alfalfa made a growth of two more cuttings possible. The addition of moisture to the cultivated ground gave an increased yield when the unirrigated plat had a moisture content of 17% in a three-foot stratum, and about 24% for the six-foot stratum. The greatest benefit seems to be derived from the increase of moisture in the surface stratum. This indicates that crops did not secure the food and moisture needed without irrigation, due to slow upward capillary movement. This movement seems to be choked off in the surface layer where the roots are present. When little growth was secured from the unirrigated check plat, 10.4 acre inches of water applied to alfalfa in two irrigations gave a yield of 5.16 tons in the third and fourth cutting. This is one-half ton of alfalfa an acre for each acre inch used. About 10 acre inches applied to clover increased the yield about 3-10 of a ton an acre inch, while with potatoes there was an increase of 16 bushels an acre inch. The relation of moisture to yield is most influenced by the moisture of the first three or four feet. The fifth and sixth feet are always fairly moist, as the moisture content even in dry plats increases rapidly with depth.

THE EFFECT OF IRRIGATION ON SOIL TEMPERATURE.

Soil temperature is so closely related to evaporation and growth that it was thought desirable to study the effect of irrigation on soil temperature. The temperature of water as it came from the pump August 20, 1910, was 63° F.; at the outlet of the flume the temperature had raised about one-half of one degree; and the standing water in the check being irrigated had a temperature of 65°. The water was warmed somewhat by the heat in the surface soil.

The soil temperatures were obtained by placing the thermometer bulb in the soil at the side of the auger hole at a depth of 3 inches from the surface of the ground. This depth is thought to give the maximum difference in temperature encountered by plant roots in irrigated and unirrigated soils.

TABLE 9.—EFFECT OF IRRIGATION ON SOIL TEMPERATURE. 1910.

Soil temperatures taken at a depth of three inches. F°

Air in shade	Alfalfa		Clover		Potatoes		Corn		Date		Hour
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry			
84	80	80	79.5	80	....	....	....	....	July	16	2 p. m.
82	74	84	71	76	....	....	....	....	July	23	4 p. m.
79.5	77	82	76	82	....	....	....	....	July	30	11 a. m.
71.5	68	72	67	73	....	....	....	....	Aug.	6	11 a. m.
76	76	78	75	77	74	76	75	78½	Aug.	13	5 p. m.
68.6	70	77	69	77	74	76	76	78	Aug.	20	4 p. m.
71.5	73	83	75	85	74	74	74	75	Aug.	27	11 a. m.
76.5	68	75	69	74	72	73	70	71	Sept.	3	11 a. m.
67	60	67	61	66	64	65	63	64	Sept.	10	11 a. m.

Temperature of water at pump, August 20..........63.0°
Temperature of water at outlet of flume, August 20..........63.5°
Temperature of water on the soil, August 20..........64.5°

The presence of irrigation water and the resulting evaporation tends to give a low uniform temperature, but the difference due to irrigation would decrease with the depth. The maximum difference between irrigated and unirrigated plats is 10 degrees in the meadow and 3½ degrees in the cultivated soil. This would have little effect on the growth of crops except possibly the corn.

Control of Evaporation by Mulches. Moisture determinations were made regularly in 1910 to determine the relative value of different mulches in conserving moisture. A sod plot had the lowest moisture content in the three-foot stratum in August. One with a cover crop of vetch was drier than where straw was used for a mulch, while the highest moisture content prevailed in connection with clean cultivation.

The cultivated soil mulch offers the most practicable means of controlling loss by evaporation. To be most effective on the silt loam soil this mulch should be provided just as soon as the soil is dry enough to crumble. It should contain a good proportion of crumbs from the size of a pea to the size of a hickory nut and should be kept dry throughout its entire depth by frequent cultivation. This cultivation should be made with a tool that will invert the mulch somewhat, to hasten drying, and should leave the surface soil fairly level.

Wind-breaks offer another practicable means of checking evaporation losses. A measure was made of the effect of a three-foot glass wind-break in checking the loss by evaporation from a second tank placed near the regular evaporation tank. This lowered the loss 20%. Two ounces of oil placed on the surface of a third water tank saved 68% of the loss from the unprotected tank. Control of transpiration will be taken up later on.

SEC. IV.—RESULTS OF EXPERIMENTS RELATIVE TO VALUE AND ECONOMICAL USE OF WATER

IRRIGATION vs. NO IRRIGATION.—Table 10.

Prior to 1910, the value of irrigation on the College Farm had been tested with potatoes, red clover, beets, and corn. Including 1910 and subsequent to that year alfalfa, kale, and beans have also been employed in this trial. A trial was made also with carrots and pumpkins in 1913.

Summarized data, showing the increase in yield from irrigation for all comparative plats, may be found in Table 10. This table gives a summary of seven years' experiments with irrigation. The second column shows the number of seasons the crop was included in the test. Over 200 individual trials have been made at Corvallis during the seven years this experiment has been carried on. **On an average, an irrigation of 5½ acre inches an acre has been used** on an area where about half the land has been in cultivated crops and about half in meadow crops. **Irrigation has given an increase in average yield for all crops included in the trial.**

TABLE 10.—IRRIGATION VS. NO IRRIGATION.
Average, all plats. (Summary later gives all comparisons.)

CROP	Years tested	Yield (tons or bushels) per acre		Gain in tons or bushels	
		Irrigated	Dry	Per acre	Per A. inch
Potatoes	7	222.2 †	122.0 †	100.2 †	21.7 †
Carrots	1	23.425	13.025	10.400	3.466
*Red Clover	5	10.840	5.508	5.332	.905
Beans	3	18.92 †	11.98 †	6.94 †	1.504†
*Alfalfa	4	6.060	3.325	2.735	.349
Beets	4	15.614	10.978	4.636	.863
Kale	4	13.430	10.417	3.013	.680
Corn	7	8.556	6.023	2.533	.461
Pumpkins	1	17.220	15.400	1.820	.364

*Part green feed, part hay.
†Bushels.

From a seven years' average, including all trials, 5½ acre inches of irrigation have given an average increase of 100 bushels of potatoes, or 21.7 bushels per acre inch. Potatoes, although a cultivated crop, gave a greater return than any other crop included in the trial.

Carrots gave an increase in yield of 3.46 tons for each inch of irrigation where 3 inches of irrigation were applied in 1913, or a total increase of over 10 tons an acre. Beans have been included in the trial three years, and have given an average increase of about 7 bushels an acre, or 1.5 bushels for each acre inch. Mangels gave an average increase of 4.3 tons or .86 ton per acre inch as a four-year average. The average increase of clover has been 5.3 tons, the yield being about .9 ton per acre inch. With alfalfa the increase has been 2.7 tons,[3] or an average increase of .34 ton an acre inch. Kale, corn, and pumpkins, have all shown an increase from irrigation, but not always in amounts sufficient to pay for the irrigation cost, as shown later. The margin

[3]Clover and alfalfa were fed green in rainy weather and cured for hay in dry weather.

Figure 7 A.—IRRIGATED CLOVER, SEPTEMBER 24, 1911, BEFORE THIRD CUTTING. YIELD .939 TONS AN ACRE.

Figure 7 B.—UNIRRIGATED CLOVER, SEPTEMBER 28, 1911, BEFORE CUTTING. YIELD NONE.

Figure 8 A.—IRRIGATED KALE, PHOTOGRAPHED SEPTEMBER 10, 1913.

Figure 8 B.—UNIRRIGATED KALE, PHOTOGRAPHED SEPTEMBER 10, 1913.

of profit from irrigation with these crops is relatively small. The average increase an acre with kale has been .4 ton; with corn 2.5 tons; and with pumpkins one year's trial in 1913 gave 1.8 tons. The yield for each acre inch of irrigation has been .68 ton for kale, .46 ton for corn, and .46 ton for pumpkins. The visible effect of irrigation upon the chief crops tried may be found in Figures 7 to 11.

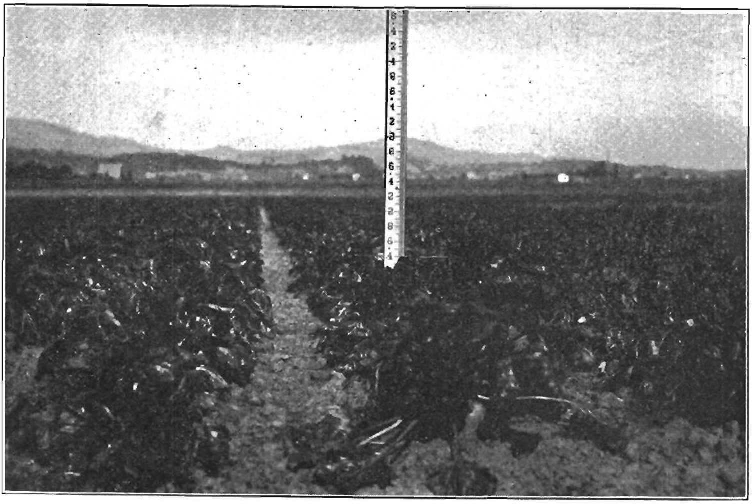


Figure 9 A.—BEETS GIVEN 6.5 INCHES IRRIGATION IN 1911 YIELDED 16.648 TONS AN ACRE.

Figure 9 B.—UNIRRIGATED BEETS IN 1911 YIELDED 10.192 TONS AN ACRE

Figure 10.—IRRIGATED CORN AT THE RIGHT YIELDED 17.18 TONS FODDER OR 74 BUSHELS EAR CORN AN ACRE IN 1913. UNIRRIGATED CORN AT LEFT YIELDED 11.19 TONS FODDER OR 56.3 BUSHELS AN ACRE.

VALUE OF ONE VS. TWO IRRIGATIONS.—TABLE 11.

Under conditions of soil and climate in this region, it would be anticipated that but one or two irrigations would be required. An experiment was outlined, therefore, to determine the value of one as compared with two irrigations. Five crops were used in the experiment, which extended through three seasons; the results may be found in Table 11.

Two irrigations applied to meadow crops gave a larger total yield than was obtained from one irrigation. Usually, twice the water was used in obtaining this yield, so that **the greatest yield an acre inch and the most economical increase was obtained from nearly all trials with a single irrigation.** Clover gave distinctly more economical increase from a single irrigation, while alfalfa showed little difference. Potatoes gave largest yields with soils having a moderate, uniform moisture content, and gave larger returns where the water was divided between two applications than where the same amount was applied at a single appliction.

Beets and kale were included in this experiment. These crops make their maximum growth late in the season and require the maximum amount of moisture in August. A single application with both of these crops shows a decided advantage over applying the same amount in two equal parts, showing that the most economical returns will be secured from beets and kale by a single, rather late irrigation, but the

TABLE 11.—VALUE OF ONE VS. TWO IRRIGATIONS.

Crop	Irrigation treatment			Yield—tons					
	1911	1912	1913	1911	1912	1913	Average	Av. gain tons	Gain per acre —inch
Alfalfa	2x5"	2x5"	2x4"	4.995	10.300	4.225	6.507	3.732	.4
	1x5"	1x5"	1x4"	4.360	5.175	3.800	4.445	1.670	.358
	Dry	--------	--------	2.175	4.00	2.775	--------	--------	--------
Clover	2x5"	2x2½"	2x4"	5.144	12.630	5.700	7.825	1.775	.231
	1x5"	1x5"	1x4"	4.794	12.950	5.325	7.690	1.640	.351
	Dry	--------	--------	2.700	10.450	5.000	9.050	--------	--------
Potatoes	2x2½"	2x2½"	2x2"	240.7†	--------	145.2†	192.9†	70.5†	15.1†
	1x5"	1x5"	1x2"	190.9†	--------	172.2†	181.5†	59.1†	14.775†
	Dry	--------	--------	135.1†	--------	109.8†	122.4†	--------	--------
Beets	2x2½ and 1½"	2x2½"	2x2"	16.648	17.96*	16.200	16.424	2.883	.186
	1x5 and 1½"	1x5"	1x2"	15.592	25.86	15.825	18.926	5.385	.398
	Dry	--------	--------	10.192	17.73	12.70	13.541	--------	--------
W. Kale	2x2½"	2x2½"	2x2"	11.245	18.00	10.75	13.332	.89	.1909
	1x5"	1x5"	1x2"	12.725	20.55	13.75	15.675	3.89	.9725
	Dry	--------	--------	8.675	16.70	9.86	11.745	--------	--------

*Not in average.
†Bushels.

largest and most economical return may be secured from potatoes by applying the water in two irrigations. Where water is at all valuable, a single application would give the most economical return with clover and alfalfa, but a second irrigation would be expected to give a moderate increase in yield.

THE VALUE OF THE SOIL MOISTURE CONTENT AS AN INDICATOR OF TIME TO IRRIGATE.—Table 12.

Since it is difficult to determine the best time to irrigate by the appearance of the crop in this humid climate, an experiment was planned to test the possibility of determining the exact time to irrigate by the soil moisture content. Potatoes and clover were used in this experiment, which extended over three seasons. From the history of the soil moisture content obtained in 1910, it appeared that clover began to wilt when the moisture content for the first two feet decreased to about 14%, and the potatoes began to show indications of firing when the moisture content of the first foot dropped to 17%. It was planned, therefore, to irrigate one plat of potatoes whenever the moisture content dropped to 17%, the second plat whenever the moisture content dropped to 20%, and the third to 23%. The clover was to be irrigated when the moisture content of the first two feet decreased to 14%, 17%, and 20% respectively. Results of this experiment may be found in Table 12.

TABLE 12.—VALUE OF SOIL-MOISTURE DETERMINATIONS IN DETERMINING EXACT TIME TO IRRIGATE.

Crop	Treatment	Yield total bu. per A.	Gain over dry plat bu.	Gain % over dry plat	Bu. per A. in	Total crop-ratio water to dry matter
(1911)						
Potatoes,	Irrigated 23% (Recd. 3x3" or 9")	292.5	157.4	117	**17.5**	**1058**
Potatoes,	Irrigated 20% (Recd. 2x3" or 6")	308.5	173.4	128	**28.9**	**799**
Potatoes,	Irrigated 17% (Recd. 1x3")	176.4	41.3	31	**13.8**	**1326**
Potatoes (1913)	(Recd. 2x2" 23%)	260.0	—40.5	—13.0	**—10.1**	**973**
	(Recd. 1x2" 20%)	342.0	41.5	18.0	**10.4**	**655**
	(Recd. none 17%)	300.5	....	....	....	**629**
		(green)				
Clover, 1912,	1x4" 20%	17.05(T)	6.60(T)	63	**1.85 (T)**	**338**
	1x4" 17%	19.37(T)	8.92(T)	85	**2.23**	**306**
	1x4" 14%	19.62(T)	9.17(T)	88	**2.29**	**303**
1913	2x5" 20%	4.925	....	....	....	**514**
	1x5" 17%	5.175	(No	dry plat, 2d	crop year.)	**539**
	1x5" 14%	5.100	....	....	....	**459**

"T" in this table indicates tons.

In a summer of low precipitation (1911) 1-, 2-, and 3-inch irrigations were used on the potatoes. The 17% plat required one three-inch irrigation (1x3") and yielded 176 bushels, and the 20% plat, required two three-inch (2x3") irrigations and yielded 308.5 bushels, and the 23% plat required three three-inch (3x3") irrigations, or a total of nine inches of irrigation, and yielded 292 bushels. About 11 bushels more potatoes were secured for each additional per cent of moisture from 17% up to 20%, but there was a decrease in yield above this point. **The 20% plat gave the greatest number of bushels an acre inch and also the most economical production of dry matter.** The total amount of water received as rain and irrigation, and lost through evaporation and transpiration by this plat during the season (1911) amounted to 799 pounds of water for each pound of dry matter produced. This was lower than the companion plats.

In a summer of high precipitation (1913), the 17% plat did not reach a point where it required irrigation at all, while the 20% plat needed water once and was given a two-inch (1x2") irrigation, the 23% plat required two two-inch (2x2") irrigations. The yield for the 17% plat (unirrigated) was 300 bushels, for the 20% plat 342 bushels, and for the 23% plat 260 bushels, or 40 bushels less than the unirrigated plat, showing that the 23% plat was over-irrigated. The most economical increase for each acre inch was with the 20% plat, but the 17% plat gave a little more economical production of dry matter. From this experiment it appears that **the 20% moisture content seems to be the optimum for potatoes on this soil, and the moisture content is shown to be an indicator of the exact time to irrigate this crop.** The 20% plat had the most uniform moisture content throughout the season, as may be seen from the curves shown in Figure 5. Potatoes do best with a very uniform moisture content.

The experiment with potatoes also gives some indication as to the amount of irrigation for this crop, as well as the value of early or late irrigation, and altogether this constitutes one of the most interesting experiments conducted.

A farmer could determine the maximum, minimum, and optimum moisture content by taking a soil sample through each foot of soil in the root zone just before the crop was in need of irrigation; and again, just after irrigation; and third, when the crop was in a flourishing condition; then by weighing and air-drying these samples the percentage of moisture could be determined in each case. With practice a person can learn to judge the percentage of moisture, and it is worth while to make this test in order to avoid the injuries of over-irrigation.

No yields were obtained from the clover in 1911, as the crop was newly seeded that season. In both 1912 and 1913, the 14% plat gave a slightly higher yield than the 17% plat, and a considerably better yield than the 20% plat. Both these summers were more rainy than normal, but **it appears that at 14% or 15% moisture for the first two feet would be about the best time for irrigation of clover.** For clover, two five-inch (2x5") irrigations in 1913 were not only more than the most economical amount of water, but were more than the amount that would give the maximum yield. The plat was over-irrigated and the yield was decreased by the second irrigation.

THE PROPER AMOUNT AND FREQUENCY OF IRRIGATION FOR POTATOES.—Table 13.

Yields of plats with different amounts of irrigation for a dry year (1911) and for a wet year (1913) are given in Table 13.

The most economical yield of potatoes obtained in the course of the experiment was secured with the aid of three one-inch (3x1") irrigations, applied ten days apart, and gave a yield of 38.6 bushels per acre inch. The yield of each acre for this plat was 250 bushels, or nearly as much as was obtained with five inches of water in other plats, and 75 bushels more than was obtained where three inches was given in one (1x3") late application when the moisture content reached the 17% point. Applying five acre inches an acre to potatoes in two equal parts made 50 bushels more than where the water was given in one application. Three two-inch (3x2") irrigations gave four bushels less than the same amount applied in two applications of three acre inches each (2x3"), and at the additional cost of an extra application. Two three-inch (2x3") irrigations added at the 20% soil moisture point gave the maximum yield, or 308.5 bushels, and three three-inch (3x3") irrigations gave a slightly lower yield than was obtained from the two three-inch (2x3") irrigations. The maximum yield in the dry season was obtained with a total of six acre inches of irrigation, but the most economical yield was obtained with three one-inch (3x1") irrigations.

TABLE 13.—PROPER AMOUNT AND FREQUENCY OF IRRIGATION FOR POTATOES.

Treatment	Yield bu.	Gain over dry		
		Bu.	%	Bu. per A.
POTATOES—1911—(Dry Season).				
Dry	135.1	....	....	....
3x1"	250.9	115.8	85	38.6
1x3" 17%	176.4	41.3	31	13.8
2x2½"	240.7	105.6	78	21.1
1x5"	190.9	55.8	41	11.2
3x2"	254.9	119.8	89	20.0
2x3"	258.1	123.0	91	20.5
2x3" 20% after irrigated clover	308.5	173.4	128	28.9
3x3" 23% after irrigated clover	292.5	157.4	117	17.5
POTATOES—1913—(Wet Season).				
Dry, after dry alfalfa	109.8	....	....	....
1x2", after dry alfalfa	172.2	62.4	57	28.5
1x3", after dry alfalfa	213.3	105.5	96	35.2
2x2", after dry alfalfa	145.2	35.4	32	8.8
After irrigated alfalfa.				
Dry, irr. at 17%	300.5	....	....	....
1x2", at 20%	342.0	41.5	14	10.4
3x1", 10 days apart	329.0	28.5	10	9.7
2x2", at 23%	260.0	—40.5	—13	—10.1

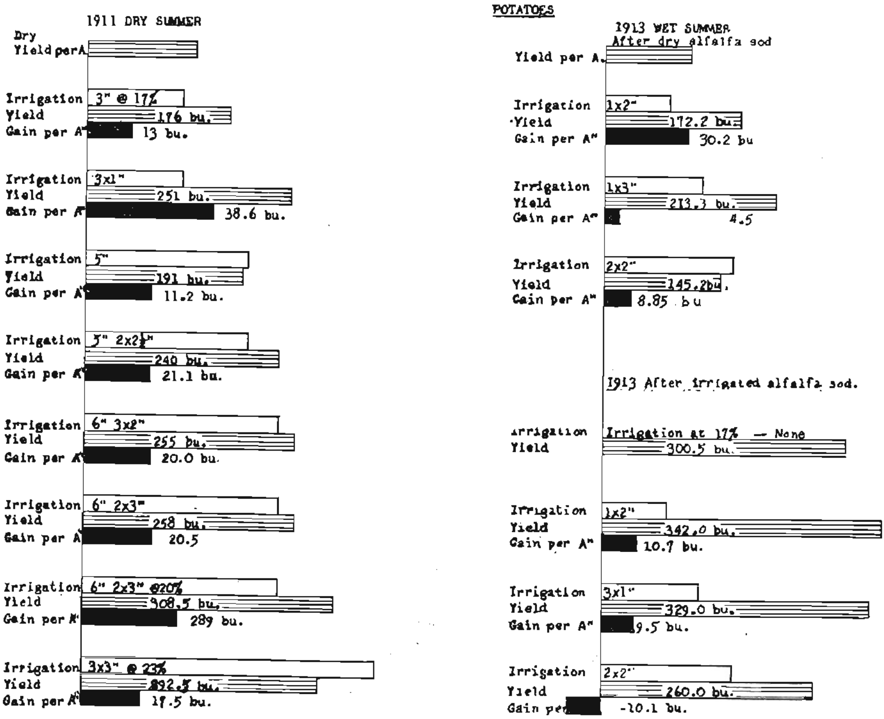
The rainfall during the summer 1913 was above normal, while for 1911 it was below normal. Four of the potato plats were on alfalfa sod that had been unirrigated four years, and four were on alfalfa sod that had been irrigated four years. The amount of water that the plan called for was modified on account of the high rainfall, and the same amounts of irrigation were used on each series of plats. These irrigations were applied at practically the same time, so that a good test was made, showing the value of irrigated alfalfa as against dry alfalfa in rotation. The alfalfa ground that had been irrigated had a higher organic matter content; a higher moisture content throughout the season; and produced a better growth of vines, which continued later in the season than on the plats following unirrigated alfalfa. The average yield after unirrigated alfalfa was 160.1 bushels, and after irrigated alfalfa was 307.9 bushels, or nearly twice the yield on dry alfalfa sod. The maximum increase was obtained from one three-inch

(1x3") irrigation on the dry alfalfa sod land and with one two-inch (1x2") irrigation applied at the 20% moisture point on the irrigated alfalfa sod land. **The maximum yield for the wet season, which was 342 bushels (1913), was secured with two inches of water, while in a dry season (1911) it was with six inches of water.** The same amount of irrigation that gave the largest yield in 1913 gave also the most economical yield, except that one two-inch (1x2") irrigation of potatoes on the dry alfalfa sod land gave a more economical increase than the one two-inch (1x2") irrigation applied to potatoes after irrigated alfalfa sod land, because the latter was not so badly in need of moisture.

Judging from these experiments it appears that **two or three inches of irrigation would be the best amount in a wet summer and about five or six inches would be the best amount in a dry summer.** More economical use of the water will be secured with potatoes where the application is divided into two or three applications. The experiments show very economical returns from three one-inch (3x1") irrigations in all seasons. The relation of water to most economical yield and a maximum yield of potatoes is shown in Figure 11.

AVERAGE DEPTH OF IRRIGATION AND NET PROFIT PER ACRE INCH
4-YEAR SUMMARY.

Figure 11 MOST ECONOMICAL AND MAXIMUM YIELD PER A" FROM IRRIGATION



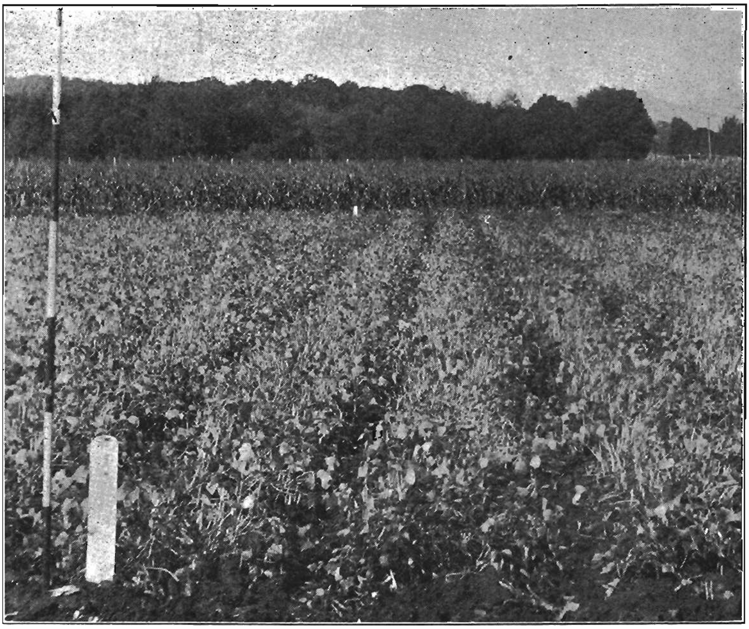


Figure 12 A.—BEANS IRRIGATED 3½" 1913

Figure 12 B.—BEANS UNIRRIGATED 1913.

As a rule it will not pay to irrigate enough to produce the maximum yield, and even where water is plentiful it would be better to limit the irrigation to the point where any extra irrigation would not increase the yield enough to pay for applying the extra water. Where water is at all costly, nothing above the least amount that will give the most economical yield for each unit of water should be used.

THE PROPER AMOUNT OF IRRIGATION FOR BEANS.—Table 14.

In 1913, two inches, three and one-half inches, and five inches of water were applied to small white field beans. The yields were as follows:

TABLE 14.—PROPER AMOUNT OF IRRIGATION FOR BEANS.

Treatment	Yield, bushels	Gain over dry		
		Gain bushels	Gain %	Bushels per A"
Beans, dry	14.92	....	....	....
1x2"	19.41	4.49	40	2.25
(Ground lumpy) 1x3½"	16.25	1.33	9	.38
2x2½"	22.78	7.86	53	1.57

The lightest irrigation, two acre inches an acre, gave 2¼ bushels an acre inch, or a total increase of 4½ bushels. The 3½ inch (1x3½") irrigation was on rather cloddy ground and gave an increase of only 1⅓ bushels, or about ⅓ bushel per acre inch. The five inches of irrigation were applied in two irrigations of 2½ inches (2x2½") each and gave an increase of 7.8 bushels, or an increase of about 1.6 bushels an acre inch. The dry plat and plat receiving 3½" depth of irrigation are shown in Figure 12.

In this experiment **the most economical return was secured by means of the two-inch irrigation, but the largest return was secured from the five inches of irrigation.** The amount that would be best would depend on the cost of the water. Beans are the most responsive to irrigation when it is applied just as they come into full bloom, and they will usually mature more uniformly and more completely if no later irrigation is given.

THE BEST TIME, AMOUNT, AND METHOD OF IRRIGATION AND TREATMENT FOR MEADOWS.—Table 15.

Results of experiments conducted to determine the best method of handling meadows under irrigation, and the best irrigation treatment for alfalfa, are summarized in Table 15.

In this table the yield of each cutting is shown. The chief difference in yield due to irrigation occurs in the later cuttings.

The Value of Irrigation and of Harrowing for New Seeding. Section "A" of Table 15, gives the yield for alfalfa plats in 1911-1912 which received irrigation when seeded (in 1909) and during the first season thereafter. These plots were unirrigated in 1911. The yield for the various cuttings shows that the rate of growth throughout the season and the gain in tons over the dry seeded plat are the result of irrigation the previous season which established a more vigorous

TABLE 15.—BEST TIME, AMOUNT, AND METHOD OF IRRIGATION AND TREATMENT FOR MEADOWS.

Crop Year Treatment	Yield, tons				Gain over dry plat			
	1st Cut	2d Cut	3d Cut	Total tons	Tons	Per cent.	Per A. inch	Gain over companion
B. Value of Harrowing and Irrigating for New Seeding—								
Alfalfa—								
1911 (Seeded 1909 without irrigation)	......	......	None	2.175	......	......	......	......
1911 (Seeded 1909 with irri., harrowed)	3.085	.900	.180	4.165	1.990	92	Clear	.08
1911 (Seeded 1909 with irri., unharrowed)	3.035	.925	.125	4.085	1.910	88	Clear	......
*1912 (Seeded 1909 without irrigation)	3.750	.250	None	4.000	......	......	......	......
*1912 (Seeded 1909 with irri., harrowed)	4.725	.700	Little feed	5.425	1.425	36	Clear	1.325
*1912 (Seeded 1909 with irri., unharrowed)	3.750	.350	Little feed	4.100	.100	2.5	Clear	......
B. Irrigation before vs. after cutting—								
Alfalfa—								
1911, 6" before cutting	3.060	.825	.525	4.410	2.235	103	.37	......
1911, 6" after cutting	3.060	.835	.700	4.595	2.420	112	.40	.185
*1912, (2x5) before cutting	9.375	1.000	Some feed	10.375	6.375	159	.625	.105
*1912, (2x5) after cutting	9.000	1.300	Some feed	10.300	6.300	157.5	.520	......
Clover—								
1913, (1x5) before cutting	3.550	1.125	.500	5.175	no check	......	......	.075
1913, (1x5) after cutting	3.500	.900	.700	5.100	......	......	......	......
C. Amount of Irrigation for Alfalfa—								
Alfalfa—								
1911, 2x4 total 8"	3.055	1.025	.425	4.505	2.330	107	.29	......
1911, 3x4 total 12"	3.060	1.285	.875	5.220	3.045	140	.25	.715
*1912, 2x4 total 8"	5.500	1.200	Some feed	6.700	2.700	67	.84	......
*1912, 2x6 total 12"	5.750	2.000	Some feed	7.750	3.750	94	.65	1.050
1913 (seeded 1909 without irrigation)	1.500	.475	.175	2.150	......	......	......	......
1913, 1x4 total 4"	2.425	.925	.450	3.800	1.650	97	.26	......
1913, 1x6 total 6"	3.050	.650	.525	4.225	2.075	97	.35	.425
1913, 2x4 total 8"	3.125	.625	.475	4.225	2.075	77	.41	......
D. Furrows vs. Flooding—								
Alfalfa—								
*1912, 1x5" Furrows	5.750	.625	Some feed	6.375	2.370	53	.45	1.195
*1912, 1x5" Flooded	4.300	.875	Some feed	5.175	1.175	28	.22	......

*Alfalfa was weighed as green feed in 1912, and as cured hay in 1911 and 1913.

and more nearly perfect stand of alfalfa. There was an increase of nearly two tons in 1911 as the result of irrigation previous years. One plat was unharrowed and one plat was harrowed in 1911 and 1912. Harrowing resulted in an advantage of 1-10 ton of hay in 1911 and about 1.3 tons of green feed in 1912. The value of irrigation on the new seeding continued to show its effect the second year after irrigation had ceased, giving an increase of 36% for the harrowed dry plat and of 2.2% over the unharrowed dry plat that was never irrigated.

Irrigation, Before Cutting vs. After Cutting. It is a common practice in alfalfa districts of the State to irrigate meadows before cutting, but in most of these experiments the small areas could be harvested and removed promptly, so the irrigations were usually applied after cutting. An experiment was outlined to test the value of irrigation before as compared with irrigation after cutting, and yields of alfalfa with both treatments were obtained in 1911 and 1912, and with clover

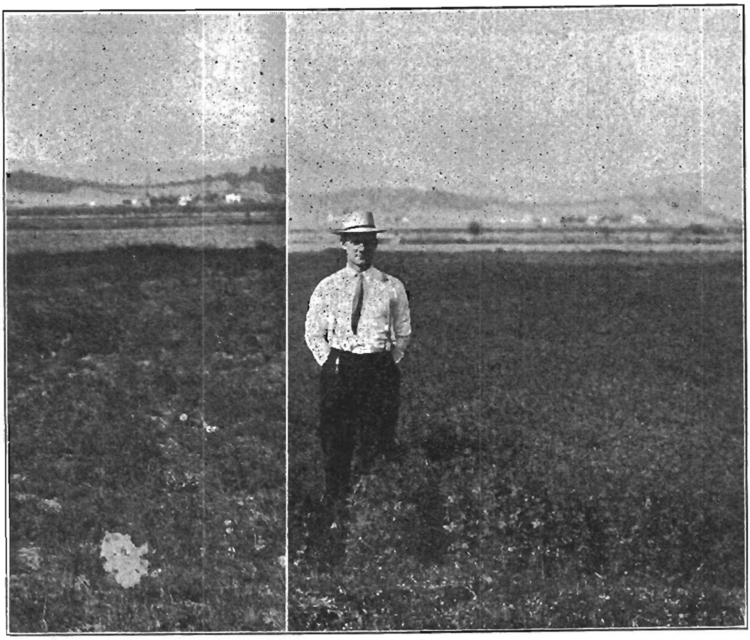


Figure 13 A.—UNIRRIGATED ALFALFA AT LEFT AND (B) IRRIGATED ALFALFA AT RIGHT, BEFORE FOURTH CUTTING SEPTEMBER 24, 1910.

in 1913. In 1911 the alfalfa, irrigated after cutting, yielded about 2-10 of a ton more hay than the one irrigated before cutting, but in 1912 and 1913 there was an advantage of about 1-10 of a ton where irrigation was applied before cutting. When the crop is nearly mature and is shading the ground, there is little evaporation, but after cutting, the ground is left bare; hence irrigation at this time may be associated with greater evaporation losses. If the land is carefully leveled and

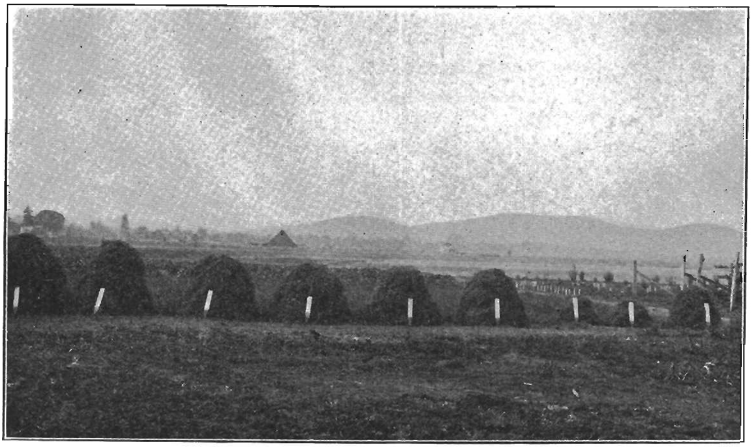


Figure 13C.—ALFALFA HAY FROM TENTH-ACRE PLATS, THIRD CUT, 1911. YIELD AN ACRE FOR THIRD CUT (RIGHT TO LEFT), (1) CLOVER; (2) DRY UNHARROWED, .125 TON; (3) DRY HARROWED, .180 TON; (4) IRRIGATED 2x4", .425 TON; (5) IRRIGATED 1x5", .475 TON; (6) IRRIGATED 6" BEFORE CUTTING, .525 TON; (7) IRRIGATED 2x5", .575 TON; (8) IRRIGATED 6" AFTER CUTTING, .700 TON; (9) IRRIGATED 3x4" AFTER CUTTING, .975 TON.

can be irrigated without injuring the crop, irrigation before cutting is to be desired and has proved best in this experiment. The negative yield in 1911 was probably due to the irrigation after cutting coming later in the season, when the soil was drier and when it would do more good. The irrigation was applied about five days after the comparison plat was irrigated; whereas, in farm practice it might be a week or ten days before the hay crop could be removed, so that the land could be irrigated. Cutting checks the growth of alfalfa and irrigation also checks the growth temporarily, so that if irrigation comes just before cutting it is believed that the growth of the crop will be interfered with to the least extent.

The Best Amount of Irrigation for Alfalfa. In Section 3 of Table 15, the miscellaneous trials of different amounts of water on alfalfa are summarized. An irrigation of 12 inches depth in 1911 gave about .7 of a ton more than was secured with 8 inches, the slight increase being a decidedly less economical return. There was an increase of about one ton of green feed from the use of 12 inches in 1912, as against 8 inches of irrigation, but again this larger yield was less economical. An irrigation of six inches gave an increase of about .4 of a ton over a four-inch irrigation in 1913, but an eight-inch irrigation showed no advantage over a six-inch irrigation, and in fact the eight-inch plat was practically over-irrigated for this wet season.

The maximum yield of alfalfa in all trials has been secured in the dry seasons with 10 or 12 inches of water, but in wet seasons with six inches of water. The most economical increase in yield with irrigation has been secured with four to six inches of water. These relationships of the amount of irrigation to maximum, and to the most economical yields, are more clearly shown by bars in Figure 14.

Methods of Irrigating Meadows. Pocket gophers disturbed the surface and tunneled meadow plats so that it was rather difficult to flood the surface evenly without using an excess of water. Experiments were conducted with alfalfa and other meadow crops to test the value of furrowing the plat after leveling it to one plane as compared with flooding. Furrow irrigation in 1912 gave an advantage of 1.2 tons over flooding. With furrow irrigation in 1913 it was possible to cover the surface of a new seeding of clover with 2½ inches irrigation, while it required five inches irrigation with the flooded plat. It appears that about one-third of the water can be saved by using the furrow method, while a more equal distribution is secured. Portable distribution pipe (Fig. 15) has been used with success on mature meadows; a canvas hose has also been used with success, but these

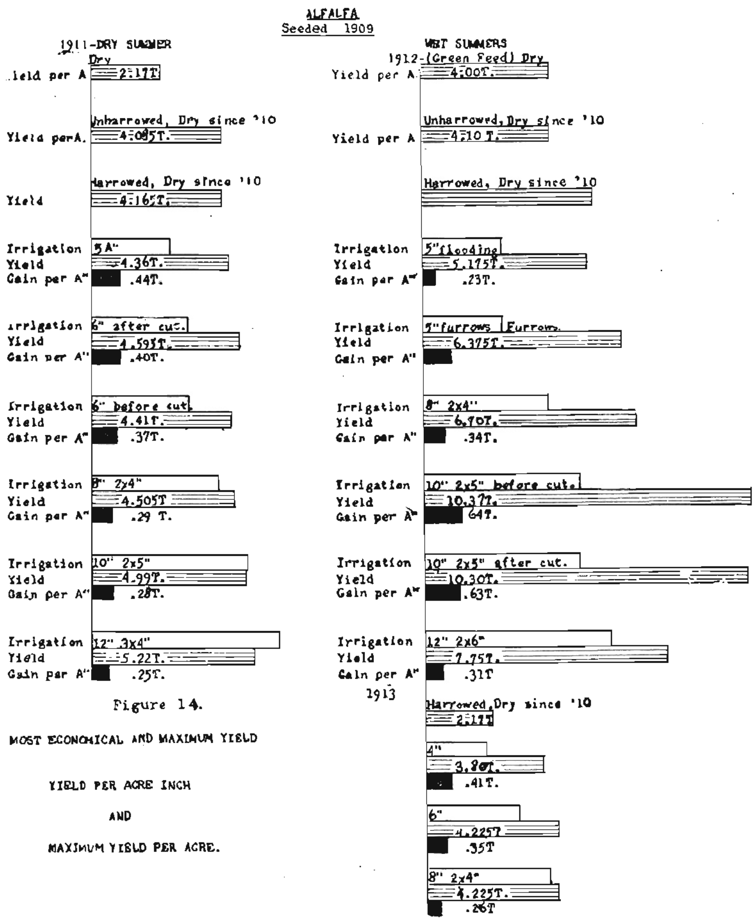


Figure 14.—RELATION OF AMOUNT OF IRRIGATION TO MAXIMUM YIELD, AND TO MOST ECONOMICAL YIELD.

cause erosion and puddling, which result in injury to the tender plants on new seeding, even where canvas aprons are used. **For this type of soil the furrow method, with furrows about four to five feet apart, is found to be the most economical and practicable method of distributing water over meadows.** The portable pipe would be second in favor.

Methods of Seeding Meadows. A trial was made of growing alfalfa in double rows at different distances apart, to conserve moisture and facilitate furrow irrigation. The experiment was started and a good stand secured on the four plats used for the trial in 1911. The following summer was a wet one, and it was so difficult to keep the crop free from weeds that seeding in rows was found to be impracticable.

MISCELLANEOUS IRRIGATION EXPERIMENTS.—Table 16.

Double Cropping With the Aid of Irrigation. It has been found possible to raise two crops on the same land, with the aid of irrigation and manure, during our long growing season. During two different seasons, a crop of winter kale has been planted after field peas have been cut for soiling, and in one season kale was planted following a crop of vetch. Where the kale has been planted promptly, a successful crop has been secured. A trial was also made in planting turnips after a hay crop had been removed, and, in this way, considerable late feed has been produced. Turnips were seeded on three plats after digging potatoes August 1, 1913. The land was irrigated before reseeding. The turnips grew well and produced about eight tons to the acre of roots. Winter cabbage could be grown following hay where the land is manured, irrigated, and set to this crop. Irrigation reaches its highest development in this way in connection with intensive farming.

Irrigation of Gumbo Soil. There was a good crop of corn on the gumbo soil in 1913. Two tenth-acre plats were selected and one of these was given a five-inch irrigation about August 1, which resulted in an increase of one and four-tenths tons of fodder. This was insufficient to pay for the irrigation cost at the maximum price used in this bulletin. This soil has a fairly high moisture content without irrigation, and being a sticky soil, it is doubtful whether irrigation could be successfully used on this type of land.

TABLE 16.—EFFECT OF IRRIGATION ON MISCELLANEOUS CROPS AND SOILS.

Year	Crop	Treatment	Yield	Gain over dry		
			Total tons	Tons	%	Per A.
1911	Summer Kale	2x2½"	7.025	.600	9	.12
1911	Summer Kale	Dry	6.425	....	....	....
1911	Corn (on Gumbo soil)	1x5"	11.300	1.400	14	.28
1911	Corn (on Gumbo soil)	Dry	9.900	....	....	....
1911	White Beans	2x3+2"	17.26 *	8.224*	91	1.03
1911	White Beans	Dry	9.03	....	....	....
1913	Field Carrots	1x3"	23.425	10.400	80	3.46
1913	Field Carrots	Dry	13.025	....	....	....
1913	Pumpkins	2x2½"	17.225	1.825	12	.365
1913	Pumpkins	Dry	15.400	....	....	....

*Bushels.

Sig. 4

Figure 15.—PORTABLE DISTRIBUTION PIPE USED WITH SUCCESS IN IRRIGATING MEADOWS

Irrigation of White Land. During three seasons beans have been grown on a heavy soil approaching the character of "white land." Irrigation of beans on this type of soil has given a very good increase and profitable returns. It has been necessary to cultivate very carefully after irrigation, and where the soil is cultivated just at the right time the tilth of the soil may even be improved, but where it is too wet a second cultivation is necessary to reduce the soil to a good mulch. Irrigation of pumpkins in 1913 on this type of soil did not give a profitable increase. They were seeded late, however, and proved to be a poor variety, thus not making a very fair trial.

Irrigation of Rice. There has been considerable inquiry as to the possibility of growing rice on the heavy soils of Western Oregon, so a trial was made of the possibility of growing rice under irrigation, the experiment being conducted in cooperation with the Department of Agriculture, which supplied the seed. In 1911 the rice plat was on gumbo soil. The dikes surrounding this plat did not have time to settle and as the soil contained a good deal of organic matter there was a high loss of water by seepage. Twelve varieties of rice were tried. They were not planted as early in the season as might have been possible and none of them headed out. The plat was kept moist up to August 4, and was inundated from then till October 27, when frost ended the experiment. Only a few of the hardiest varieties started to form heads. The quantity of water applied to this plat amounted to a depth of 12 feet over the surface. Evaporation during the season was about two feet.

The rice plat was on white land in 1913. Three hardy varieties were seeded on June 3. The season was rather cool and only a few plants headed out before frost. This white land held the water applied much better than the gumbo soil. The total depth of water applied was about seven feet. Rice was planted in a soil tank in 1913 which was the same size as the evaporation tank located close by. After the rice jointed, it was kept under water, and it was therefore possible to measure transpiration. It developed late in the season that part of the growth in the tank was millet.

The millet and a few of the rice plants headed out. The rate of transpiration was about four times the evaporation from the water surface in the adjoining tank. The trials seem to show that there is little probability that rice will succeed in this climate.

SEC. V.—WATER CONSUMPTION OF CROPS UNDER FIELD CONDITIONS

The writer made some water cost determinations with crops grown in tanks, while working with Professor J. D. Tinsley at the New Mexico station in 1908-09,[4] and experienced difficulty in securing uniform compactness of soil and also a uniform stand of grain in different tanks. On account of these difficulties, the writer outlined these experiments in the spring of 1910 to include methods for determining water costs of dry matter under field conditions. Moisture samples were taken from practically all the bearing plats in these experiments at the time the crops appeared above ground and again in duplicate at harvest time, to a depth of six feet, and these gave a measure of water lost from the soil during the growing season. The inches of rainfall and inches of irrigation were measured. Determinations of the moisture content of tops and vines, as well as the marketable product of the irrigated and unirrigated crops, in connection with the above data, made it possible to calculate the water consumption for each pound of increase of dry matter from irrigation, and also for each pound of dry matter for the total crop. The water cost was obtained from dry check plats as well as from irrigated plats. Furthermore, an attempt was made to check the transpiration by means of fallow plats. Four years' data are now at hand.

Water Consumption of Increase in Dry Matter Due to Irrigation. The water consumption for each pound of dry matter for the increase obtained from adding definite amounts of irrigation water has been obtained by comparing the number of pounds of irrigation with the number of pounds of increase of dry matter. This represents the transpiration mainly and gives a fairly good measure of the transpiration where economical yields and a good stand are obtained. As far as known, this method of calculation of water consumption of increase has never before been used.

This method of calculation eliminates a large part of the evaporation loss, as the dry plat suffers almost as much loss from evaporation as the irrigated plat. It eliminates errors associated with moisture determinations and rains and gives a delicate measure of the efficiency secured from the water applied. Samples taken 48 hours after irrigation did not give a more accurate measure of the transpiration, or a very satisfactory method of correcting for increased evaporation in the irrigated plat following the irrigation treatment.

WATER CONSUMPTION OF INCREASE AND OF TOTAL CROP.— Table 17.

Comparing the water consumption of the increase from irrigation with the consumption for the whole crop, it is found that **there is more economical increase in production of dry matter by irrigation. This is generallly associated with the largest yields an acre inch.** High water consumption for each pound of increase in dry matter from irrigation indicates that water was applied which did not enter into the crop, but remained in the soil unused. Certain irrigated plats were found to contain from zero to two acre inches per acre more water at harvest

[4]Humbert, E. P., and Willard, R. E., New Mexico Station Bul. No. 86 (1913).

TABLE 17.—WATER REQUIREMENTS OF CROPS UNDER FIELD CONDITIONS.

The water consumption of the increase is transpiration mainly, while the water consumption of the whole crop is evaporation and transpiration.

WATER CONSUMPTION OF ALFALFA

Year	Treatment	Increase per acre inch	Ratio increase lbs. water per lb. dry matter	Total water used inches	Yield	Ratio total crop lbs. water per lb. dry matter
1910	Dry	1.	....	14.51	4.97	1135
	2x5"	1.15	339	19.51	16.95	448
1911	Dry	....	....	12.15	2.17	814
	Irr. till 1911, unharo.	....	....	17.06	4.09	620
	Irr. till 1911, haro.	....	....	17.13	4.17	607
	1x5"	.45	331	18.54	4.36	622
	1x6", after cutting	.40	364	17.70	4.59	563
	1x6", before cutting	.37	394	17.79	4.41	588
	2x4"	.29	503	22.46	4.51	730
	2x5"	.28	517	24.46	4.99	716
	3x4"	.25	584	23.15	5.22	648
‡1912	Dry	....	....	13.80*	4.00	1317
	Dry since 1910, unharo.	....	....	13.80	4.10	1314
	Dry since 1910, haro.	....	....	13.80	5.425	989
	One 5" furrow	.45 (green)	865	16.30	6.375	996
	1x5" flood	1.04	374	16.30	5.175	....
	2x4"	.84	464	17.80	6.700	1035
	2x5"	1.25	312	16.30	10.375	726
	2x6"	.65	600	20.80	7.750	1045
1913	Dry haro.	....	....	16.92	2.15	1111
	1x4"	.41	344	19.26	3.800	716
	1x6"	.35	406	25.19	4.225	843
	2x4"	.26	546	25.93	4.225	866
	Ave. { Without 1912	....	433	....	....	735
	Ave. { With 1912	....	456	....	....	839

WATER CONSUMPTION OF CLOVER

Year	Treatment	Increase per acre inch	Ratio increase lbs. water per lb. dry matter	Total water used inches	Yield	Ratio total crop lbs. water per lb. dry matter
1910	Dry	....	....	11.86	4.32	1068
	2x5"	.59	380	19.44	10.20	741
1911	Dry	....	....	13.08	2.70	742
	1x5"	.42	350	17.35	4.79	554
	2x5"	.24	637	24.93	5.14	743
1912	Dry	....	....	13.80	10.45	517
	1x4", 20%	1.85	269	14.80	17.05	338
	1x4", 17%	2.23	175	14.80	19.37	306
	1x4", 14%	2.29	170	14.80	19.62	303
	2x2½"	.44	886	16.30	12.63	503
	1x5"	.50	779	16.30	12.95	490
1913	Dry, 2d crop yr.	....	....	15.90	5.00	447
	1x4", 20% 2d crop yr.	....	....	17.90	....	514
	1x4", 17% 2d crop yr.	....	....	19.72	....	539
	1x4", 14% 2d crop yr.	....	....	16.58	....	459
	1x4", 1st crop yr.	.08	†1745	19.16	....	509
	2x4" 1st crop yr.	.09	†1600	†1600	5.33	538
	Ave.	....	456	....	5.70	548

*Partly interpolated 1912.
†Not in average.
‡Wet season, poor grassy crop.
°Pounds of irrigation per pound of increase in dry matter. Shows efficiency of water applied.

TABLE 17.—(Continued).

WATER CONSUMPTION OF POTATOES

Year	Treatment	Increase per acre inch	Ratio increase lbs. water per lb. dry matter	Total water used inches	Yield bu.	Ratio total crop lbs. water per lb. dry matter
1910	Dry	…	…	7.50	56	1797
	1x5"	15.9	309	10.27	140	985
1911	Dry	…	…	15.02	135	1493
	1x3", 17%	13.8	1076	15.58	176	1326
	3x1"	38.6	350	17.20	251	930
	2x2½"	21.1	697	16.89	241	1034
	1x5"	11.2	1275	17.06	191	1263
	2x3", 20%	28.9	450	…	309	799
	2x3", 15 da.	20.5	789	19.08	258	1212
	3x2", 10 da.	20.0	772	18.81	255	1294
	3x3", 23%	17.5	930	…	293	1056
1913	Dry after dry rota.	…	…	10.18	110	1139
	Dry after irriga. rota.	…	…	13.60	300	629
	1x2" after dry rota.	28.5	414	11.72	172	783
	1x2" after irriga. rota.	10.4	1370	15.69	342	655
	1x3" after dry rota.	35.2	337	14.56	213	806
	3x1" after irriga. rota.	9.7	1566	15.86	329	683
	2x2" after dry rota.	10.1	1225	14.00	145	1101
	2x2" after irriga. rota.	8.9	1438	17.42	260	973
	Ave.	…	866	…	…	1050
	WATER CONSUMPTION OF KALE				Tons	
1911	Dry	…	…	7.82	8.67	930
	2x2½"	.51	2009	11.85	11.25	1087
	1x5"	.81	1264	10.47	12.73	848
1912	Dry	…	…	8.67	16.70	527
	2x2½"	.26	…	11.67	18.00	665
	1x5"	.77	1336	11.67	20.55	433
1913	Dry	…	…	13.20	9.86	1380
	1x2"	1.945	530	15.20	13.75	1142
	2x2"	.222	4618	15.17	10.75	1449
	Ave.	…	1951	…	…	940
	WATER CONSUMPTION OF CORN					
1910	Dry	…	…	5.72	2.57	840
	1x5"	.33	1156	9.82	4.31	856
1912	Dry	…	…	9.21	9.05	380
	1x3"	1.02	376	9.87	12.07	307
1913	Dry	…	37	11.00*	11.19	528
	1x3"+1"	1.50	377	14.00*	17.18	438
	Ave.	…	487	…	…	558

*Interpolated.

time than accompanying dry plats. On the other hand, low water consumption for each pound of increase in dry matter from irrigation indicated increased upward capillary movement and increased root development, causing more efficient use of available soil water. The irrigated plats, giving most economical consumption of water for each pound of increase, were often found to have the usable soil moisture more completely used up at harvest time than the accompanying dry plats.

The ratio of water to dry matter in the total crop includes the evaporation and transpiration, there being practically no loss by percolation. The most economical increase is frequently associated with the most economical production of dry matter in the total crop. Beginning with the dry plats where the water consumption is relatively high, there is a decrease in the water consumption up to the most economical amounts of irrigation; and above this the water consumption increases again as we go from the most economical to the excessive irrigations. For example, the water consumption of alfalfa for each pound of dry matter produced in 1912 was 1317 pounds for the dry plat; 726 pounds with two five-inch (2x5") irrigations; and 1,111 pounds with two six-inch (2x6") irrigations.

A Comparison of Irrigation With No Irrigation on Water Consumption. A more favorable moisture content has been maintained by irrigation during the best growing weather of the season. This has given a more economical production of dry matter, as illustrated by the following data:

TABLE 18.—WATER CONSUMPTION OF WHOLE CROP—AVERAGE OF ALL PARTS.

	Lbs. Water to One of Dry Matter	
	Irrigated	Unirrigated
Clover	503	693
Potatoes	927	1265
Alfalfa	753	1094
W. Kale	936	946
Corn	533	583
Beets	671	748
Carrots	579	754
Average	700	869

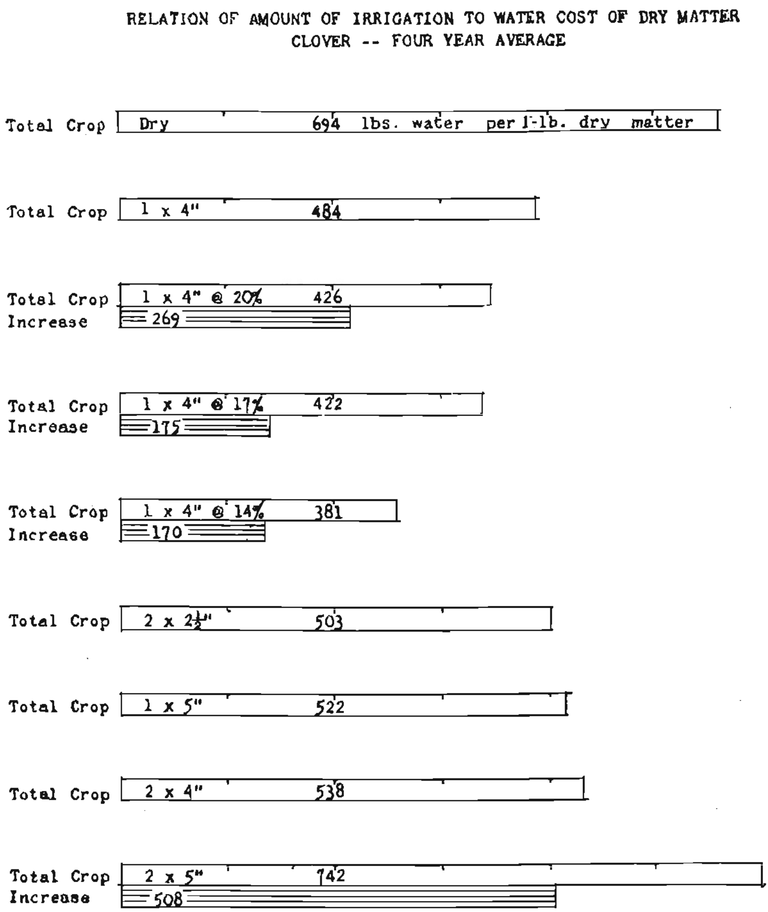
It will be seen that **the water consumption of the total crop has in general been lower with moderate amounts of irrigation than with the dry plats.**

Effect of Amount of Irrigation on Water Consumed. The relation of irrigation to water consumption of increase of dry matter is similar to the yield per acre inch, the lowest water consumption being obtained with the most economical irrigation and the greatest gain per acre inch. The dry plat having unfavorably low moisture content gives very high water consumption. The heavier irrigated plats also give less economical use of water. This has been true, in general, throughout the four years' trial with the different crops. **Nearly twice as much water was required in the case of clover, as a four-year average for the dry plat, and over twice as much was required for the dry matter for the ten-inch plat as was required in the case of the four-inch plat.** This is illustrated by the relation of the amount of irrigation to water consumption for each pound of dry matter with clover in Figure 16.

This figure gives the average returns for different amounts of water for all seasons. The most economical increase, and the most economical production of total crop, from the water consumption standpoint, was obtained with clover by the use of one four-inch irrigation applied when the moisture content of the first two feet dropped to 14%. **The water consumption increased rapidly above eight inches of irrigation and below four inches of irrigation.** This agrees with the relation of the amount of irrigation to water requirement, as worked out simultaneously and elaborately at the Utah Station.[5] In the experi-

[5]Widtsoe, J. A., Utah Buls. Nos. 116 to 120 (1913).

ments at Corvallis, the soil moisture used during the season was carefully measured by weekly moisture determinations throughout the season. Samples were taken before and after irrigation in irrigated plats and in dry check plats. During two seasons fallow plats were used in connection with irrigation and no irrigation.



Figue 16.—RELATION OF AMOUNT OF IRRIGATION TO WATER COST OF DRY MATTER.

Effect of Time of Irrigation on Water Consumed. The time of irrigation, as well as the amount of irrigation, has a direct bearing upon the economical production of dry matter, as shown by the detailed data. An example of this follows:

TABLE 19.—RELATION OF TIME OF IRRIGATION AS INDICATED BY THE SOIL MOISTURE CONTENT TO WATER COST.

Treatment—	Lbs. of water per lbs. total crop
POTATOES (1911)	
1x3" @ 17%	1326
2x3" @ 20%	799
3x3" @ 23%	1056
CLOVER	
1x4" @ 14%	303
1x4" @ 17%	306
1x4" @ 20%	338

It will be noticed from these figures that in the 20% plat of potatoes the water cost was about one-half the water cost for the 17% plat. From this, it appears that the most economical water cost is obtained when the water is applied just at the time it is needed. **The percentage of moisture content has proved a most valuable indicator of the best time to irrigate.**

Effect of Frequency of Irrigation on Water Consumed. The frequency of irrigation of crops, such as potatoes, is related to economical water cost just as it is to most economical yield per acre inch. **As judged by the water cost, the most economical treatment for potatoes has been three one-inch (3x1") irrigations.** This may be seen from the detailed data, which appear in Table 17. As shown earlier, two irrigations have done better for alfalfa than one irrigation, although for late crops, such as beets and kale, one application of water has given better returns than two. This holds true in regard to water consumption for each pound of dry matter; and also, in a general way, in regard to water cost.

Effect of Irrigated Legumes in Rotation on Water Consumed. The potato plats in 1911 were nearly all on irrigated clover sod land. On the other hand, those receiving different amounts of irrigation were on clover sod where clover had not been irrigated. It was found that the yield of potatoes was much larger following the irrigated clover sod than following the dry clover sod.

The same point is even more clearly shown by the following data for potatoes for 1913 following irrigated alfalfa and dry alfalfa.

TABLE 20.—EFFECT ON WATER CONSUMPTION OF IRRIGATED LEGUMES IN ROTATION—POTATOES, 1913.

Treatment	Increase per A" bushels	Total water	Yield per acre bushels	Ratio—total crop Water to dry matter
Dry after dry alfalfa	....	10.18	110	1139
Dry after irriga. alfalfa	....	13.60	300	629
1x2" after dry alfalfa	28.5	11.72	172	783
1x2" after irriga. alfalfa	10.4	15.69	342	655
1x3" after dry alfalfa	35.2	14.56	213	806
1x3" after irriga. alfalfa	9.7	15.86	329	683
2x2" after dry alfalfa	10.1	14.00	145	1101
2x2" after irriga. alfalfa	8.9	17.12	260	973

With unirrigated potatoes after irrigated alfalfa, the water used was 629 pounds for each pound of dry matter, while unirrigated potatoes after unirrigated alfalfa gave a water consumption of 1139 pounds for each pound of dry matter. With the different amounts of irrigation this same relation was found to occur, the lowest water consumption for the total product being secured following irrigated alfalfa in rotation. This shows the benefit of soil-building crops in connection with irrigation, and emphasizes the importance of crop rotation for the irrigation farmer. **It is probable that the water requirement may be decreased one-third where a good crop rotation is practiced.** In connection with irrigation farming, there is often too high a proportion of permanent meadow.

Water Consumption of Different Crops Under Field Conditions. The water consumption of increase and total yield by crops is shown in the following summary table, which gives averages of all representative trials:

TABLE 21.—WATER COST SUMMARY.

CROP	Number of trials	Average water consumption of increase. (Transpiration mainly)	Number of trials	Average water consumption of whole crop. (Evaporation and transpiration)
Clover	8	456	17	548
Potatoes	15	866	19	1050
Alfalfa	10	433	15	735
W. Kale	....	....	9	940
Corn	4	487	6	558
Beets (all varieties)	....	....	22	665
Carrots	1	327	2	666
Beans	....	....	2	248

Corn and beans are crops of low water requirement. Numerous investigators have obtained similar results with corn grown in tanks in other parts of the country. Beans were planted here June 1, and this eliminated evaporation early in the season. The data indicate that the potato has a high water requirement. Certain investigators, however, have found the water requirement of potatoes when grown in tanks to be lower. This difference can be partly accounted for in this case because of the loss by the evaporation of rainfall which did not penetrate the soil mulch in the potato ground, and because of the soil moisture lost prior to the potatoes being fully up. Water lost was charged to the crop from the time the potato plants first appeared above the ground. Data on the average water consumed by alfalfa and clover are in all probability good mean figures for this district. Kale is a plant of high water requirement. The writer has been unable to find records of prior experiments conducted to determine the water requirement of kale. The water cost of several of these crops has been determined simultaneously for Utah conditions, and water consumption experiments have also been conducted in India[6] and Colorado[7] under field conditions, although the work done at the Utah[8] Station will afford the best comparisons.

TABLE 22.—EFFECT OF VARIETY ON ECONOMIC USE OF WATER AND WATER COST PER POUND DRY MATTER—BEETS.

UNDER FIELD CONDITIONS

Year	Inches irrigation	Yield tons	Gain tons	Tons per acre inches	Lbs. water per lb. dry matter each trial	Season average 1911	Season average 1912	Season average 1913
Long Red Mangles—								
1911	1x5"+1½"	16.650	5.890	.906	**596**			
1911	2x2½"+1½"	15.999	5.339	.821	**447**			
1911	Dry	10.660			**1098**			
						714		
1912	1x5"	23.090	5.380	1.076	**380**			
1912	2x2½"	15.030	2.680	.536	**446**			
1912	Dry	17.710			**936**			
							587	
1913	1x3½"	17.397	3.890	1.110	**547**			
1913	Dry	13.507			**582**			
	Ave.	16.130	4.636	.901	**629**			565
Golden Tankard—								
1911	1x5"+1½"	16.783	3.098	.476	**588**			
1911	2x2½"+1½"	16.411	2.726	.419	**538**			
1911	Dry	13.685			**832**			
						659		
1913	1x2½"	14.578	2.661	1.060	**635**			
1913	Dry	11.917			**588**			
	Ave.	14.679	2.828	.652	**636**			608
Yellow Globe—								
1911	1x5½"+1½"	15.050	7.625	1.170	**688**			
1911	2x2½"+1½"	12.200	4.725	.727	**748**			
1911	Dry	7.425			**1617**			
						1017		
1912	1x5"	28.640	10.890	2.180	**372**			
1912	2x2½"	20.900	3.150	.630				
1912	Dry	17.750			**373**			
	Ave.	16.994	6.597	1.177	**695**		372	
Half Sugar								
1911	1x5"+1½"	12.033	3.983	.613	**824**			
1911	2x2½"+1½"	14.983	6.933	1.066	**587**			
1911	Dry	8.050			**1424**			
	Ave.	11.689	5.458	.839	**945**	945		
Sugar Beets—								
1913	1x3½"	13.572	.557	.159	**597**			
1913	Dry	12.995			**467**			
	Ave.	13.283	.557	.159	**532**			532
	Ave. all varieties		4.636	.863	**665**			

[6]Leather, J. W.—Memoirs, Dept. of Agric., India Chemical Series, Vol. I, Nos. 8 and 10 (1910-1911).
[7]Briggs, L. J., and Shantz, H. L.—U. S. D. A., Bur. Pl. Indues, Bul. No. 284 (1913).
[8]Widtsoe, J. A., *et al.*—Utah Sta. Bul. No. 116-120 (1913).

The water cost of the increase in the above summary is about 70% of the water cost of the total crop. It includes some evaporation in addition to the total transpiration. The irrigation water is applied in the best growing weather and is more efficiently utilized than is the total water consumed.

Effect of Variety on the Water Cost Under Field Conditions. (Table 22). Ranked according to low water requirement, sugar beets were first, with Golden Tankards, Long Red, Yellow Globe, and Half Sugar following in the order named. Ranked according to yield for each acre inch, Yellow Globe stood first, Long Red second, and sugar beets third. In one trial Yellow Globe stood first, Mangels second, and Tankard third. The Yellow Globe was found to have a lower proportion of leaves and of skin than other varieties, while the sugar beets had the highest percentage of dry matter in the roots.

Control of Water Requirement. The loss of water from transpiration is enormous. It has been regarded as beyond control by the farmer, but transpiration experiments show that the best methods of farming result in more efficient use of water and decreased water cost. In these experiments in the field a light irrigation has given an increase in the efficiency of the total usable water at hand. Less water is needed where applied just at the right time, and where applied to a perfect stand and to the best crops and best crop varieties. A greater efficiency can be secured where water is applied in known amounts and at proper intervals. Whenever less energy is required by the plant to get its nourishment—due to good tilth, thorough cultivation, good state of fertility, or with crops grown in irrigated rotation—the water consumption is less. **The saving by applying these principles is from one-third to one-half of the total water used.**

SEC. VI.—COST, VALUE, AND PROFIT CONNECTED WITH IRRIGATION

COST

The first problem facing the man who contemplates the construction of a pumping plant, or other development for irrigation, in Western Oregon is: "Does it pay?" Every effort should be made to deal with the problem fairly, even at the risk of finding out that the irrigation is not as profitable as may at first be supposed. Where the cost of irrigation is low and the crop raised or the amount of increase due to irrigation is valuable, it undoubtedly will pay. If it will pay to pump water for ordinary field crops, it should certainly pay to irrigate where the water can be secured by gravity, or in connection with intensive dairying and truck growing under similar conditions. A proper selection of a pumping plant depends upon the source of the water, the proper capacity of the pumping plant, with the fixed charges, attendance and fuel cost considered. With the short irrigation season of the Willamette Valley, the cost of attendance will usually be more than the fuel cost for moderate-sized plants; while the labor cost, if greater than the overhead charges, may be cut down by increasing the size of the plant and shortening the hours of operation. The labor cost will vary with the period of irrigation, while the fuel cost will vary with the quantity of water pumped. In order to direct attention to the various operation and maintenance charges involved in pumping for irrigation treatment in these experiments, the items of expense are here given:

(A) *First Cost.* This includes engine, pump, flume, etc.

(B) *Operating Expenses.* This includes labor, fuel, and lubricating oil.

(C) *Maintenance Charges.* This includes interest on the first cost, depreciation, and repairs.

(D) *Total Annual Cost.* This is the sum of B (operating expenses) and C (maintenance charges).

A. *The first cost* of the Experiment Station pumping plant according to recent quotations from the manufacturers, and other data at hand, is:

4 H. P. Gasoline Engine	$215.00
Pump, 3½" Horizontal Centrifugal	66.00
Forty feet of 6" Black Iron Pipe	20.00
Straightway Ground Valve, 6"	15.30
Foot Valve and Strainer, 6"	12.55
1500 feet lumber at $13. Flume and Shelter	19.50
Setting Engine and Pump	5.00
Carpenter Labor	6.00
Leveling Land	10.00
Total First Cost	$369.35

Where a well is involved this additional expense will need to be added to the first cost. In any case, it will be useless to invest in expensive machinery unless a sufficient supply of water is assured. The engine is the largest single item of expense, and this could be used for other farm purposes outside the irrigation season. With the Station electric plant, a $150 motor and 600 feet of power line, instead of the engine, bring the first cost to practically the same total figure.

B. *Operating Expenses.*

	Per Hr.
Labor, $2.00 per day	$ .20
Fuel, ½-gal. distillate (1 pt. per H. P. per hr.)	.05
Lubricant, $.0005 per H. P. per hr.	.002
Total	$ .252

Where a gasoline engine is used, a small pumping plant will demand less than half of one man's time when in running order, and the same man can look after the distribution of water, where land is prepared properly for irrigation. In 1911 the Station plant pumped 104 hours and used approximately 54 gallons of distillate, and for another run of 60 hours used 30 gallons of distillate, which is very close to the above allowance. A pumping plant of this kind will lift water 20 feet at the rate of about one-half cubic foot per second, and this will cover an acre a foot deep in 24 hours. It cost $6.05 at this rate for running expenses per acre foot pumped.

C. Interest on the first cost at 6%, plus 10% depreciation and repairs (if renewed in 10 years), or 16% on $369.35, amounts to $59.09. The plant is used only a few weeks in the year and is sheltered; so that this percentage is considered conservative and is used for calculating overhead expenses for comparison also.

D. In figuring the annual cost, the maintenance charges and operating expenses must both be taken into consideration. The total annual cost calculated on a 10-acre basis is:

Maintenance—	
Interest on plant at 6%	$ 22.16
Depreciation and Repairs (if renewed in 10 years)	36.93
Operation—	
Fuel, 5c per hr., 10 hrs., 24 days	12.00
Lubricant .002 x 10 x 24 days	.48
Labor at .20 x 10 x 24 days	48.00
Total Annual Cost of Irrigation (ten acres one foot deep)	$119.57
or,	
Cost per acre foot	11.95
or,	
Cost per acre inch	1.00
Cost per acre foot per foot of lift	.58

The cost per acre inch would be less if larger areas were irrigated and larger pumping plants were used. If the plant was used regularly during the 40 days irrigation season, 20 acre feet could be pumped and the cost would be 77c per acre inch. With electrical power this cost for pumping 10 acre feet is 92c, and for pumping 20 acre feet 71c an acre inch, with electricity secured at the local meter rate. Pumping 30 acre feet with electricity at 2c a kilowatt would place the cost at 48c per acre inch. The profit on pumping will depend on the amount of lift, market, and soil conditions, and the economical use of water. The maximum cost of one dollar an acre inch, however, is used in calculating the profit from irrigation of crops described in this bulletin.

COST, VALUE, AND PROFIT FROM IRRIGATION FOR THE INCREASE AND FOR THE TOTAL CROP.—Table 23.

The yield of plats included in experiments in the past seven years are given by crops in Table 23, a, b, c, d, and e. These give comparisons of economy in the use of water, and show which irrigation treatments were most profitable. (The readers who are interested only in averages may find these in the summary, Table 24). The results are calculated on the acre basis. It would be difficult to obtain an average in many cases for a given treatment during all seasons, because of the fact that the quantity of water required fluctuates with wet and dry years. In section (a) of Table 23 is shown the detailed yields from alfalfa plats arranged by seasons, and according to the amount of water used.

Columns 3, 4, and 5 show a steady decrease in the gain in yields from irrigation of alfalfa with increasing amounts of irrigation, especially in wet seasons, when there is no further increase from use of more than six inches of water. Irrigation increased the yield of alfalfa on an average 99%. The most economical increase of green feed was 1.15 tons per acre inch in 1911, while the most economical increase in hay from irrigation was .44 ton secured from use of a single, five-inch (1x5") irrigation.

The total cost of production (Column 7) has been carefully estimated from all field operations required for good farming. For unirrigated alfalfa this is placed at $7 an acre; for clover, $6; potatoes, carrots, and beets, $20; beans and kale, $15; and for corn and pumpkins, $10 per acre. The maximum total annual cost of $1 per acre inch is charged for irrigation; and for harvesting the increase due to irrigation 25c a ton for forage and 3c a bushel for potatoes and beans, is charged.

The value of the total crop and of the increase (Columns 8 and 9) is obtained by multiplying the yield by the average market value per ton, which for alfalfa and clover when fed green is placed at $4 a ton, and when used as hay at $10 a ton. Potatoes are figured at the average price of 50c a bushel, and beans at 5c a pound, while corn, kale, pumpkins, and root crops are valued at $2.50 per ton. The average value of the increase from irrigation of alfalfa was $19.60. The net profit on the increase over the irrigation cost of alfalfa averages $12.62, or an average of 158%. In one instance a poor stand of alfalfa shows a slight loss, but otherwise there is a net profit over the cost of the irrigation treatment for alfalfa of from 40c to $34.48 per acre.

Profit per Acre Inch. **The net profit on the increase per acre inch** (column 12) or per dollar of total annual cost of irrigation, **gives the most absolute basis at hand for judging the value of irrigation.** For every acre inch applied to alfalfa, or every dollar total annual cost, an average profit of $1.80 over the cost of treatment has been made. In one instance there was a slight loss and in two others a narrow margin, but in three instances the profit ran over $3 net profit per acre inch for alfalfa. The greatest net profit was obtained with two 5-inch (2x5") irrigations in 1910, with one 5-inch (1x5") irrigation in 1911, and with one 4-inch (1x4") irrigation in 1913, the latter being a wet season.

TABLE 23.

Profit on Increase from Irrigation and on Total Crop.

Column I	II Irrigation	Yields III Total tons per acre	IV Gain tons over dry plat	V Gain, per cent
1910 Green	2 Irr. 10.42"	16.952	11.917	241
	Dry	4.975	....	....
1911 Hay	2x5"	4.995	2.820	130
	1x5"	4.360	2.185	100
	Dry	2.175	....	....
Harrowed	Irr. Dry since 1911	4.165	1.990	92
Unharrowed	Irr. Dry since 1911	4.085	1.910	88
	1x6" before cut	4.410	2.235	103
	1x6" after cut	4.595	2.420	112
	2x4"	4.505	2.330	107
	3x4"	5.220	3.045	140
1912 Green	1x5" furrow	6.375	2.375	59
	1x5" flooded	5.175	1.175	28
	Dry	4.000	....	....
Harrowed	Dry since 1910	5.425	1.425	36
Unharrowed	Dry since 1910	4.100	.100	....
	2x5" before cut	10.375	6.375	159
	2x5" after cut	10.300	6.300	157
	2x4"	6.700	2.700	67
	2x6"	7.750	3.750	94
1913 Hay	Two 4"	4.225	2.075	97
	One 6"	4.225	2.075	97
	One 4"	3.800	1.650	77
	Dry since 1911	2.150	....	....
Average	**7.84"**	....	**3.03**	**99**

The net profit on the whole crop shows alfalfa to be a very profitable crop, but in most cases, decidedly more profitable with irrigation. The net profit above fertilizer value (column 14) is obtained by subtracting the value of the fertility removed by the crop from the apparent profit on the whole crop (column 13). In calculating the net profit over fertilizer value, the phosphorus and potash are figured as 5c a pound and nitrogen at 15c a pound. It was assumed that the legumes left as much nitrogen in the soil as there was when they started. These data emphasize the value of legumes as soil improvers when used in connection with irrigation.

(a)—ALFALFA.

Summary of Experiments, Calculated to Acre Basis.

Yields	Cost	Value		Net profit on increase			Net profit	
VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Total tons per acre inch	Total cost. production and Irrigation	Value total crop	Value increase	Dollars over irrigation cost	Per cent on increase	Per acre inch	Whole crop	Net profit above Fert. value
1.15	$20.42	$67.80	$47.90	$34.48	257	**$ 3.31**	$47.42	$42.92
....	7.00	19.90	....	....	....	....	12.90	9.27
.28	17.75	49.95	28.20	17.45	163	**1.74**	32.20	23.80
.44	12.50	43.60	21.85	16.35	297	**3.27**	31.10	21.40
....	7.00	21.75	....	....	....	....	14.75	10.00
....	7.50	41.65	19.90	19.40	Clear	....	34.15	23.80
....	7.50	40.85	19.10	18.70	Clear	....	33.35	24.40
.37	13.50	44.10	22.35	15.85	243	**2.64**	30.60	28.38
.40	13.50	45.95	24.20	17.70	272	**2.95**	32.45	22.30
.29	15.50	45.05	23.30	14.80	174	**1.85**	29.55	19.60
.25	19.75	52.20	30.45	17.70	139	**1.48**	32.45	21.05
.45	12.50	25.50	9.50	4.00	73	**.80**	13.00	8.35
.23	12.25	20.70	4.70	— .55	— 10	**— .11**	7.85	4.07
....	7.00	16.00	....	....	....	....	9.00	6.09
....	7.25	21.70	5.70	5.45	....	....	14.45	10.49
....	7.00	16.40	.40	.40	....	....	9.40	6.40
.64	18.50	41.50	25.50	14.00	122	**1.40**	23.00	15.42
.63	18.50	41.20	25.20	13.70	119	**1.37**	22.70	....
.34	15.75	26.80	10.80	2.05	24	**.26**	11.05	6.17
.31	20.00	31.00	15.00	2.00	15	**.25**	11.00	5.35
.26	15.50	42.25	20.75	12.25	144	**1.53**	26.75	17.49
.35	13.50	42.25	20.75	14.25	219	**2.37**	28.75	19.49
.41	11.50	38.00	16.50	12.00	266	**3.08**	26.50	18.17
....	7.00	21.50	....	....	....	....	14.50	9.79
.41	....	....	**$19.60**	**$12.62**	**158**	**$ 1.80**	....	....

Irrigation of Alfalfa. Alfalfa is a good crop to use on naturally drained ground under irrigation in Western Oregon. It establishes itself early in the season, makes rapid growth, and may be cut three times for hay, or four times for green feed where irrigated. The most **economical** increase has been secured in wet seasons on the silt loam with four to six inches of water; in dry seasons with from six to eight inches of water; while the **maximum** yield in wet seasons has been with from six to eight inches of water, and in dry years with 12 inches of water. Rather heavy irrigation is required to cover the surface of a meadow and to wet to a depth of several feet the soil that has been dried out by the deep roots of alfalfa. Furrows have been of great advantage in securing an even distribution and economical use of water for the irrigation of alfalfa.

TABLE 23.

Profit on Increase from Irrigation and on Total Crop.

Column I	II Irrigation	Yields III Total tons per acre	I Gain tons over dry plat	V Gain per cent
1909, Hay	Irr.	6.460	1.390	27
	Dry	5.070	....	....
1910, Green	2 Irr. 9.91"	10.202	5.879	136
	Dry	4.323	....	....
1911, Hay	2x5"	5.144	2.444	91
	1x5"	4.794	2.094	77
	Dry	2.700	....	....
1912, Green	2x2½"	12.630	2.180	19
	1x5"	12.950	2.500	24
	Dry	10.450	....	....
	1x4" @ 20%	17.050	6.600	63
	1x4"	19.370	8.920	85
	1x4"	19.620	9.170	88
1913, One year old hay	2x4"	5.700	.700	14
	1x4"	5.325	.325	7
	Dry	5.000	....	....
Average	**5.89"**	....	**3.835**	**57**

Irrigation of clover has given an average increase of 57%, and an average of .87 ton per acre inch. This, valued at $19.67 per acre, represents a net profit of $12.59, or 2.05% on the cost of irrigation. The average profit per acre inch or per dollar irrigation cost has been $2.71. This profit is considerably above that of alfalfa, due largely to more perfect stands being secured and maintained. The most economical irrigations for clover on the silt loam have been obtained with

(b)—CLOVER.

Summary of Experiments, Calculated to Acre Basis.

Yields	Cost	Value		Net profit on increase			Net profit	
VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Total tons per acre inch	Total cost produc-tion and irriga-tion	Value total crop	Value increase	Dollars over irriga-tion cost	Per cent on increase	Per acre inch	Whole crop	Net profit above Fert. value
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
.59	$17.41	$40.81	$23.55	$12.14	107	**$1.23**	$23.40	$14.64
....	6.00	17.29	....	....	....	....	11.29	7.60
.24	16.30	51.44	24.44	13.94	133	**1.39**	34.94	21.59
.42	11.50	47.94	20.94	15.44	280	**3.08**	36.44	25.09
....	6.00	27.00	....	....	....	....	21.00	13.70
.44	11.50	50.52	8.72	3.22	58	**.64**	39.02	31.51
.50	11.50	51.80	10.00	4.50	82	**.90**	40.30	28.91
....	6.00	41.80	....	....	....	....	35.80	26.81
1.85	11.75	68.20	26.40	20.75	361	**5.19**	56.45	42.13
2.23	12.25	77.48	35.68	29.43	472	**7.36**	65.23	48.58
2.29	12.25	78.48	36.68	30.43	487	**7.61**	66.23	49.35
.088	14.25	57.00	7.00	—1.25	—15	**—.15**	42.75	28.04
.081	10.00	53.25	3.25	— .75	—18	**—.19**	43.25	29.52
....	6.00	50.00	....	....	....	....	44.00	31.10
.872..	....	....	**$19.67..**	**$12.59..**	**205**	**$ 2.71**	....	....

four inches of water, and the maximum yields have been secured with 10 inches. The greatest profit per acre inch was secured with four inches, applied when the moisture content dropped to 14%, which seems to be the best moisture content at which to irrigate clover. Clover will make a light third cutting of hay and a light fourth cutting of green feed where irrigated, and is one of the best field crops to use under irrigation in Western Oregon.

TABLE 23.

Profit on Increase from Irrigation and on Total Crop.

Column I	II	Yields		
		III	IV	V
	Irrigation	Total bushels per acre	Gain bushels over dry plat	Gain per cent
1907	Irr.	125.0	82.0	190
	Dry	43.0		
1908	Irr.	86.0	26.0	43
	Dry	60.0		
1909	Irr.	215.0	65.0	43
	Dry	150.0		
1910	5.35"	140.0	84.1	150
	Dry	55.9		
1911	2x2½"	240.7	105.6	78
	1x5"	190.9	55.8	41
	Dry	135.1		
	3x1"	250.9	115.8	87
	2x3"	258.1	123.0	91
	3x2"	254.9	119.8	89
	3x3"=9"@23%	292.5	157.4	117
	2x3"=6"@20%	308.5	173.4	128
	1x3"=3"@17%	176.4	41.3	31
1913	3x1" After Irri. Alfalfa	329.0	28.5	10
	2x2"@23%	260.0	—40.5	—13
	1x2"@20%	342.0	41.5	14
	None@17%	300.5		
	2x2" After Dry Alfalfa	145.2	35.4	32
	1x3"	213.3	103.5	94
	1x2"	172.2	62.4	57
	Dry	109.8		
Average	**4.69"**		**76.7**	**71.2**

Irrigation of Potatoes. The potato, being a money crop, has given the largest returns from irrigation of any crop employed in these trials. As a seven-year average this crop has given a profit of $7.75 per acre inch. The most economical yields have been secured with two or three inches of water in wet seasons, or with five or six inches of water in dry seasons. The best returns have been secured when this water was applied in two or three applications, so as to maintain a uniform moisture content and keep the plants growing at a uniform rate. Very economical returns have been secured by applying the water when the moisture content dropped to the 20% point in the (c)—POTATOES.

Summary of Experiments, Calculated to Acre Basis.

Yields	Cost	Value		Net profit on increase			Net profit	
VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Total bushels per acre inch	Total cost produc-tion and irri-gation	Value total crop	Value increase	Dollars over irriga-tion cost	Per cent on increase	Per acre Inch	Whole crop	Net profit above Fert. value
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
10	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
15.7	$27.85	$70.00	$42.02	$34.17	435	**$ 6.38**	$ 42.15	$ 35.67
....	20.00	27.95	....	....	....	....	7.99	5.45
21.1	28.15	120.35	52.80	44.65	548	**8.93**	92.20	81.15
11.2	26.67	95.45	27.90	21.23	318	**4.25**	68.78	60.03
....	20.00	67.55	....	....	....	....	47.55	41.30
38.6	26.45	125.45	57.90	51.45	794	**17.15**	99.00	87.45
20.5	29.70	129.05	61.50	51.80	534	**8.63**	99.35	87.50
20.0	29.60	127.45	59.90	50.30	524	**8.38**	97.85	86.15
17.5	33.70	146.25	78.70	65.00	474	**7.22**	112.55	99.05
28.9	31.20	154.25	86.70	75.50	674	**12.58**	123.05	108.85
13.8	24.24	88.20	20.65	16.41	387	**5.47**	63.96	56.01
9.5	23.85	164.50	14.25	10.40	270	**3.46**	140.65	125.51
— 10.1	24.00	130.00	—20.25	—24.25	—606	**—6.06**	106.00	94.04
10.7	23.25	171.00	20.75	17.50	538	**8.76**	147.75	141.96
....	20.00	150.25	....	....	....	....	130.25	116.35
8.85	25.06	72.60	17.70	12.64	250	**3.16**	47.54	39.85
34.5	26.10	106.65	51.75	45.68	748	**15.23**	80.55	70.63
30.2	23.87	86.10	31.20	27.33	706	**13.67**	62.23	54.29
....	20.00	54.90	....	....	....	....	34.90	29.85
18.1	....	....	**$41.51**	**$33.31**	**440**	**$ 7.75**	....	....

first foot. The maximum yield was secured in a dry year with six inches of water, and in a wet year with three inches of water. Potatoes should be planted so that they will be kept growing at a uniform rate, and should be allowed about 50 or 60 days to dry and mature after the last irrigation is applied. The greatest profit per acre inch was secured from potatoes with three one-inch irrigations in 1911. Two two-inch irrigations in 1913 resulted in an excess of moisture; and this over-irrigation reduced the yield below that of the dry companion plat, resulting in the only negative yield experienced from the irrigation of the potato.

TABLE 23.

Profit on Increase from Irrigation and on Total Crop.

Column I	II	Yields		
		III	IV	V
	Irrigation	Total tons per acre	Gain, tons or bushels over dry plat	Gain, per cent
1913 Carrots	1x3"	23.425	10.400	80
	Dry	13.025		
Average	**3"**		**10.400**	**80**
		Bushels	Bushels	
1911 W. Beans	2x4"	17.260	8.224	91
		9.036		
1913	2x2½"	22.780	7.860	53
	3½"	16.250	1.330	9
	1x2"	19.410	4.490	30
	Dry	14.920		
Average	**4.62"**		**5.476**	**46**
1908 Beets	Irr.	2.150	.790	58
	Dry	1.360		
1911	2x2½"+1½"	16.648	6.456	63
	1x5"+1½"	15.592	5.400	53
	Dry	10.192		
1912	2x2½" Plat Ave	17.960	0.230	1
	1x5"	25.860	8.130	46
	Dry	17.730		
	1x4"	16.200	3.500	28
	1x2"	15.325	2.625	21
	Dry	12.700		
	2½"	15.182	2.409	20
	Dry	12.773		
Average	**4.5"**		**3.692**	**36**

Irrigation of Carrots, Beans, and Beets. Carrots, beans, and beets have all given good returns with irrigation, and with proper care may be depended upon to pay a reasonable profit on moderate amounts of irrigation. The single trial with carrots gave an increase of 10 4-10 tons from a three-inch irrigation, representing a gain of 80%, or an increase of 3.46 tons for each inch. Carrots and beets make their maximum growth late in the season, and hence require irrigation a little later than other row crops. They should have plenty of moisture early in August.

Beets have given an average increase of about 3 7-10 tons, or 36%, representing a net profit of $1.15 per acre inch. In one instance in 1912 they failed to pay for the water, but otherwise they have given a profit of from 88c to $2.66 per acre inch, the maximum rate (d)—CARROTS, BEANS, BEETS.

Summary of Experiments, Calculated to Acre Basis.

Yields	Cost	Value		Net profit on increase			Net profit	
VI Total tons per acre inch	VII Total cost production and Irrigation	VIII Value total crop	IX Value increase	X Dollars over irrigation cost	XI Per cent on increase	XII Per acre inch	XIII Whole crop	XIV Net profit above Fert. value
3.46	$25.50	$58.56	$26.00	$20.50	374	**$6.83**	$33.06	$ 8.47
....	20.00	32.56	....	....	....	....	12.56	—4.11
3.46	....	....	**$26.00**	**$20.50**	**374**	**$6.83**	....	....
Bushels 1.03	$23.82	$51.78	$24.67	$15.85	414	**$1.98**	$27.96	$26.71
....	15.00	27.11	....	....	....	....	12.11	11.46
1.57	20.78	68.34	23.58	17.80	308	**3.56**	47.56	45.87
.38	18.68	48.75	3.99	.31	8	**.09**	30.07	28.91
2.245	17.44	58.23	13.47	11.03	452	**5.51**	40.79	39.25
....	15.00	44.76	....	....	....	....	29.76	28.66
1.31	....	....	**$16.43**	**$11.25**	**295**	**$2.79**	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
.99	$28.00	$41.62	$16.14	$ 8.14	102	**$1.25**	$13.62	—$2.78
.83	27.75	38.98	13.50	5.75	74	**.88**	11.23	—5.02
....	20.00	25.48	....	....	....	....	5.48	—5.12
.05	25.00	44.90	.57	—4.43	—88	**—.88**	19.90	1.24
1.63	27.00	64.65	20.32	13.32	190	**2.66**	37.65	10.73
....	20.00	44.32	....	....	....	....	24.32	5.90
.87	24.75	40.50	8.75	4.00	84	**1.00**	15.75	—1.00
1.31	22.75	38.31	6.56	3.81	142	**1.90**	15.66	—.32
....	20.00	31.75	....	....	....	....	11.75	—2.16
.96	23.00	37.96	6.02	3.02	101	**1.21**	14.96	—.76
....	20.00	32.00	....	....	....	....	12.00	—1.32
.95	....	....	**$ 7.41**	**$ 4.80**	**86.3**	**$1.15**	....	....

being secured with one five-inch irrigation, which was applied early in August. This seems to be about the best treatment for the beet crop. Carrots and beets require rather large amounts of available plant food, and low yields would not show a profit above fertilizer value removed. This margin is likely to be small in any case. It follows, therefore, that these crops should be fed on the farm if they are to pay, especially if the value of the removed plant food is taken into consideration.

Beans have been grown on a heavy soil approaching the character of white land, but the yields have been good. They have given an average net profit per acre inch of $2.79; while increase from irrigation has averaged 46%. Being a leguminous crop, beans have given a good profit above the value of the plant food removed.

TABLE 23.

Profit on Increase from Irrigation and on Total Crop.

Column I	II Irrigation	Yields III Total tons per acre	IV Gain tons over dry plat	V Gain per cent
1911 W. Kale	2x2½"	11.245	2.57	30
W. Kale	1x5"	12.725	4.05	47
W. Kale	Dry	8.675	....	....
E. Kale	2x2¼"	7.025	0.60	9
E. Kale	Dry	6.425	....	....
1912 W. Kale	2x2½"	18.000	1.30	8
W. Kale	1x5"	20.550	3.85	23
W. Kale	Dry	16.700	....	....
1913 Kale	2x2"	10.750	.89	9
Kale	1x2"	13.750	3.89	39
Kale	Dry	9.860	....	....
Average	**4.43"**	....	**2.45**	**24**
1907 Corn Fodder	Irr.	4.830	2.01	71
Corn Fodder	Dry	2.820	....	....
1908 Corn Fodder	Irr.	4.820	1.18	32
Corn Fodder	Dry	3.640	....	....
1909 Corn Fodder	7.8"	7.070	1.56	36
Corn Fodder	Dry	5.510	....	....
Sweet Corn	7.8"	6.870	3.37	96
Sweet Corn	Dry	3.500	....	....
1910 Corn Fodder	5.35"	4.309	1.74	67
Corn Fodder	Dry	2.573	....	....
1911 Corn Fodder	1x5"	11.300	1.40	14
Corn Fodder	Dry	9.900	....	....
1912 Corn Fodder	1x3"	12.070	3.02	33
Corn Fodder	Dry	9.050	....	....
1913 Corn Fodder	1x3"+1"	17.180	5.99	53
Corn Fodder	Dry	11.190	....	....
Average	**5.49"**	....	**2.533**	**50**
1913 Pumpkins	2x2½"	17.225	1.825	12
Pumpkins	Dry	15.400	....	....
Average	**5.00"**	....	**1.825**	**12**

Irrigation of Kale, Corn, and Pumpkins. Kale, corn, and pumpkins are crops that cannot be relied on to give much profit from irrigation if the water is costly. On an average, a moderate profit has been obtained from both kale and corn. The greatest profit per acre inch was secured from kale with the use of one two-inch (1x2") irrigation in 1913. Two two-inch (2x2") irrigations were little better than no irrigation. This treatment, therefore, did not pay, as the crop was over-irrigated. Irrigation is useful in forcing early kale for feed in September. When this is desired, the ground can be irrigated and (e)—KALE, CORN, PUMPKINS.

Summary of Experiments, Calculated to Acre Basis.

Yields	Cost	Value		Net profit on increase			Net Profit	
VI	VII	VIII	IX	X	XI	XII	XIII	XIV
Total tons per acre inch	Total cost production and irrigation	Value total crop	Value increase	Dollars over irrigation cost	Per cent on increase	Per acre inch	Whole crop	Net profit above Fert. value
.51	$20.75	$28.11	$ 6.43	$ .68	12	**$ .13**	$ 7.46	—$12.19
.81	21.00	31.87	10.13	4.13	69	**.83**	10.87	—11.58
....	15.00	21.69	....	....	....	....	6.69	— 7.76
.12	20.25	17.56	1.50	—3.75	—71	**—.75**	—2.59	—14.89
....	15.00	16.06	....	....	....	....	1.06	—10.24
.26	20.25	45.00	3.25	—2.00	—39	**.40**	24.75	— 7.02
.77	21.00	51.37	9.62	3.62	60	**.72**	30.14	— 5.38
....	15.00	41.75	....	....	....	....	....	— 2.69
.22	19.25	26.86	2.23	—2.02	47	**—.50**	7.71	—11.27
1.945	18.00	33.38	9.73	6.73	224	**3.37**	15.38	— 8.88
....	15.00	24.65	....	....	....	....	9.65	— 7.75
.662	....	....	**$ 6.13**	**$ 1.16**	**43**	**$ .60**	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
.20	....	....	....	....	....	**—.50**	....	....
....	....	....	....	....	....	....	....	....
.43	....	....	....	....	....	**.07**	....	....
....	....	....	....	....	....	....	....	....
.32	15.85	10.77	4.34	—1.51	—25	**—.28**	—5.08	—2.20
....	10.00	6.43	....	....	....	....	3.57	.77
.28	15.25	28.25	3.50	—1.75	—34	**—.35**	12.90	—6.23
....	10.00	24.70	....	....	....	....	14.70	—2.05
1.01	13.75	30.18	7.55	3.80	101	**1.27**	16.43	—4.00
....	10.00	22.62	....	....	....	....	....	—2.73
1.50	15.50	42.90	14.95	9.45	171	**2.36**	27.40	—1.86
....	10.00	27.95	....	....	....	....	17.95	—4.25
.623	....	....	**$ 7.59**	**$ 2.50**	**51**	**$ .43**	....	....
.365	15.50	43.06	4.56	—.50	—10	**—.10**	27.56	16.65
....	10.00	38.50	....	....	....	....	28.50	18.97
.365	....	....	**$ 4.56**	**$—.50**	**—10**	**$—.10**	....	....

manured after a hay crop is removed in June, and can be set to winter kale in July. Where this has been done. fairly good results have been secured in both cases. A moderate amount of irrigation, if carefully applied to kale, would give a small margin of profit.

Corn may be expected to give a profit for irrigation where the yields obtained are from 10 to 12, or more, tons of fodder per acre. During the earlier years of this experiment the yields were low, and the profits were uncertain; but during the past two seasons, due to improvement of the soil and seed and to favorable weather, larger

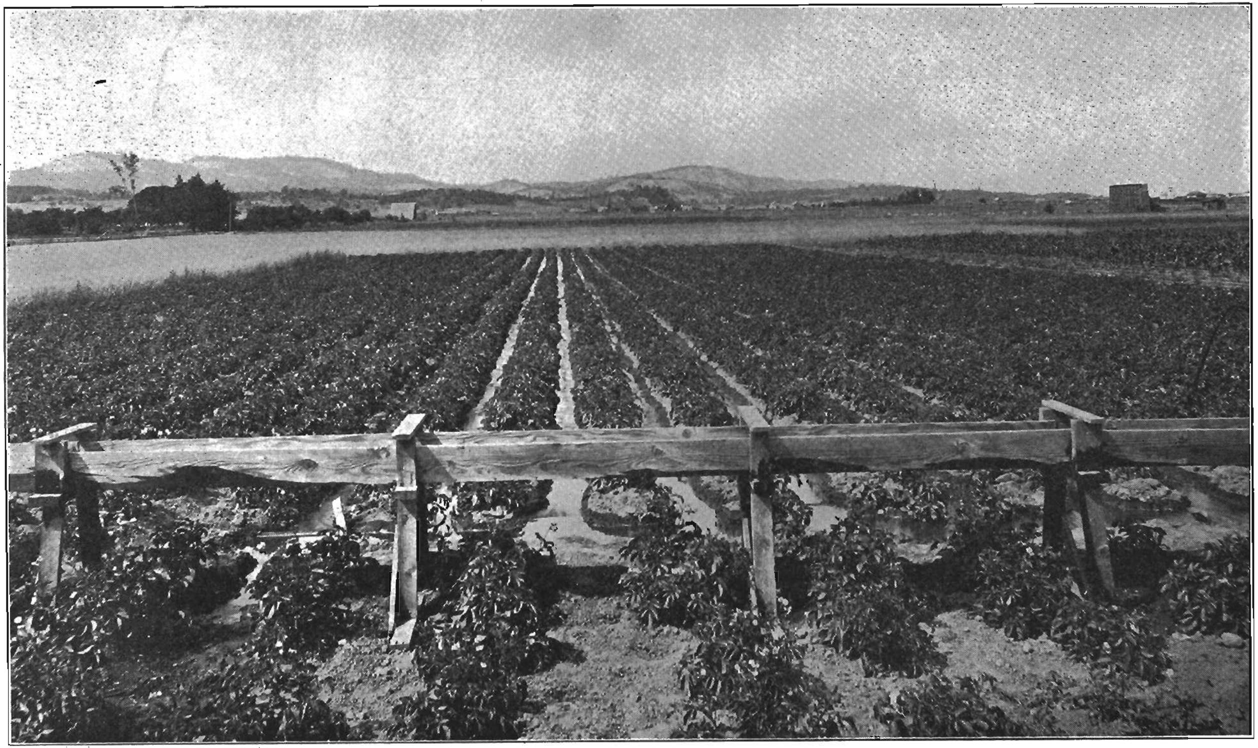


Figure 17.—IRRIGATION OF POTATOES. THE FURROWS ARE FED FROM A HEAD LATERAL BY LITTLE LATH TUBES

yields have been secured. These increased yields have given a good margin of profit, and have left a general margin of profit from irrigation. Since corn makes its maximum growth in August, it requires water about the first of this month. One three-inch (1x3") irrigation in the wet seasons, or nearly twice as much in two applications in the dry seasons, would be about the proper amounts for corn on valley silt loam soil. In 1913 the dry plat yielded 53 bushels of ear corn to the acre, and the irrigated plat yielded 74 bushels per acre. Irrigation of corn pays better on free working soils and with cheaper water.

A single trial of irrigation of pumpkins in 1913 gave an increase of nearly two tons. This represents a slight loss for the amount of water applied. The plat had too much water, and as a result the plants ran to vines and continued to bloom, where irrigated, instead of developing pumpkins. The seed was planted late and proved to be a late variety, which in part accounts for this unfavorable showing. It is believed, nevertheless, that they could be made to bring a moderate return for irrigation; and, in all likelihood, they will be experimented with in the future.

SUMMARY OF SEVEN YEARS IRRIGATION EXPERIMENTS.—Table 24.

As an average of all trials extending over a period of seven years, the depth of water used is 5.56 acre inches per acre each season. This is a net duty, and allowing about 20% loss in delivery, this would be a duty of 7 acre inches per acre delivered at the high point of the farm unit. All crops have given an increase with irrigation. The average increase ranges from 12 to 100%, averaging 53% by crops, or 65% by all trials as the average increase due to irrigation. The highest single percentage increase was with alfalfa, and the lowest percentage of increase with pumpkins. Potatoes and carrots also gave a percentage of increase that was above the average of all crops.

TABLE 24.—SUMMARY OF SEVEN YEARS' IRRIGATION EXPERIMENTS; AVERAGE OF ALL COMPARISONS.

(Department of Agronomy, Oregon Agricultural College.)

Crop	Years tested	Irrigation inches average depth	Yields per acre, tons		Increase from irrigation, tons			
			Dry plat	Irrigated plat	Per acre	Per cent	Per acre inch	Dollars per acre inch
Potatoes	1907-1913	4.62	145.6*	222.2 *	76.7 *	71	18.13*	**$7.75**
Carrots	1913	3.00	13.025	23.425	10.4	80	3.46	**6.83**
Beans	1911-1913	4.62	*13.449	18.92*	5.47*	48	1.31*	**2.79**
Red Clover	1908-1913	5.89	7.003	10.84	3.83	57	.87	**2.71**
Alfalfa	1910-1913	7.84	3.03	6.06	3.03	99	.41	**1.80**
Beets	1908-1913	4.50	11.922	15.614	3.692	36	.95	**1.15**
Kale	1911-1913	4.43	10.985	13.43	2.45	24	.662	**.60**
Corn	1913	5.49	6.023	8.556	2.533	50	.62	**.43**
Pumpkins		5.00	15.40	17.22	1.825	12	.365	**—.10**
Average by crops		**5.04**	....	....	....	**53**	....	**2.66**
Average all irrigated plats		**5.56**	....	....	....	**65**	....	**3.11**

*Bushels.

Note.—To check this table with Table 12, the dry plat average is obtained by repeating dry yield each season the same number of times as there are numbers of irrigated plats for the season to compare with it.

An average depth of 4.62 acre inches with potatoes shows an increase of 76.7 bushels, or 18.1 bushels per acre inch. Three acre inches with carrots has given an increase of 10.4 tons, or 3.46 per acre inch. One irrigation of about 6 inches applied to clover has given an average of 3.83 tons of partly cured feed, or .87 ton per acre inch. Alfalfa has given an average increase of .41 ton per acre inch, mangels .95 ton per acre inch, kale .66 ton, corn .62 ton, and pumpkins increased .36 ton per acre inch of water applied.

The net profit per acre inch based on the increase, or per dollar total annual cost for irrigation, has been 43c for corn, and 60c for kale. There has been a loss of 10c per acre inch with pumpkins. Irrigation of beets has given a profit of $1.15 per dollar of total cost, and with alfalfa the profit was $1.80 per dollar total irrigation cost. When applied to red clover water has brought a return of $2.71 net profit per acre inch, to beans $2.79, to carrots $3.46 per acre inch, and to potatoes $7.75 per acre inch, or per dollar total annual irrigation cost. **The average net profits by crops has been $2.66 per acre inch, or per dollar irrigation cost.** The one profit for all trials is higher, as a large number of trials with potatoes are included.

With a more thorough trial of carrots this crop might drop to about fifth in rank, leaving the money crops, potatoes and beans, at the top, with the meadow crops, clover and alfalfa, next in rank according to profit per acre inch. With one exception, there was a profit on the investment in irrigation with all of the crops employed. The data show that more expensive irrigation can be employed for pota-

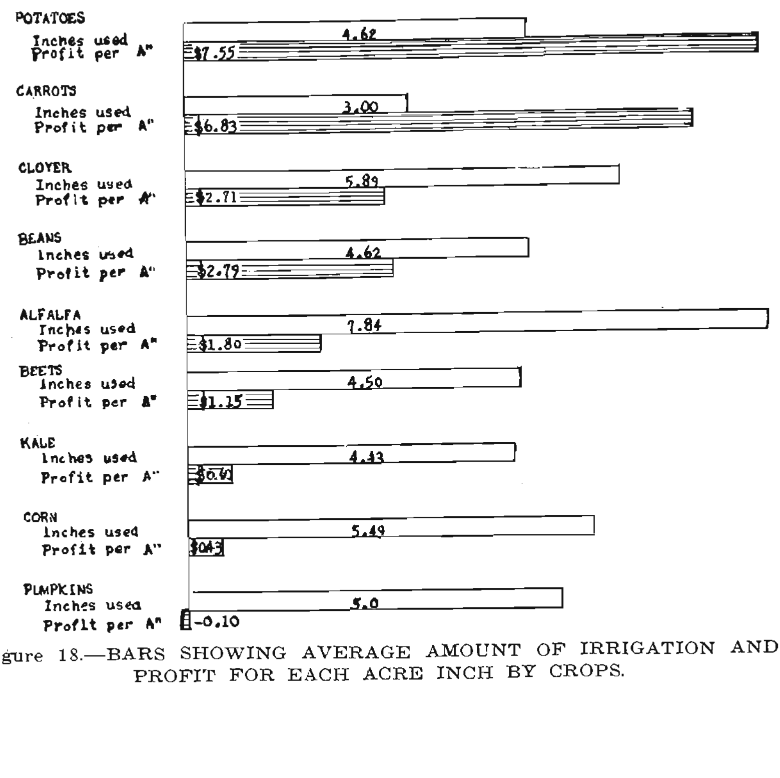


Figure 18.—BARS SHOWING AVERAGE AMOUNT OF IRRIGATION AND PROFIT FOR EACH ACRE INCH BY CROPS.

toes, or other money crops, than for other ordinary field crops. Potatoes, beans, carrots, clover, and alfalfa have given a very large margin of profit and can be very safely irrigated. Mangels, under Willamette Valley conditions, were also very profitably irrigated, but less highly profitable than the above named; while kale, corn, and pumpkins did not respond as well to irrigation, and cannot be profitably irrigated in the Willamette Valley if water is expensive. The average net profit per acre inch for different crops is shown diagrammatically in Figure 18.

GASOLINE ENGINES vs. ELECTRIC MOTORS

A study of gasoline for power is here given, as compared with electricity; for the cost of operation was made in connection with these experiments, with some guidance by Professor Hillebrand of the Electrical Engineering department of the College. The General Electric Company, through their Portland Agency, kindly loaned the motor employed in making these tests. A three and one-half inch centrifugal pump operating against a 19-foot lift, or a total head of about 23 feet, was used in the test. The engine and motor were located so that either could be connected by the same belt without relacing, and at a distance of some 20 feet from the pump. The pump had a six-inch pulley, and ran at nearly its rated economic speed with the engine, or 700 revolutions per minute. When connected to the motor, the pump ran about 800 revolutions per minute.

From two seasons' running it had been found that the engine, which was a 4 h. p. International, used half a gallon of distillate per hour, with the pump discharging about .49 second feet. At this rate, it took 20 ten-hour days to pump ten acre feet; and the cost for fuel was $12.00.

The motor was a single-phase five-horse motor, and used energy at the rate of 2.8 kilowatts when turning the pump 800 revolutions per minute, with a discharge of .57 second feet. At this rate, it would use 594 K. W. H. in pumping ten acre feet, and dividing the above cost of gasoline fuel ($12) by this, gives a cost af 2.02 cents per K. W. H. as equivalent to distillate for energy at 10 cents per gallon. At the local meter rate which was charged, 594 K. W. H., if all used one month, costs $22.77, making the fuel bill for pumping ten acre feet with electricity nearly twice the fuel bill where distillate is used. **The saving in labor, however, with the small plant where electricity was used, amounted to more than the total fuel bill.** The gasoline plant gave an efficiency of 40.6%, while the electric plant efficiency was 39.7%. The pump gave an efficiency of 56% at 700 revolutions, and of 43% at 800 revolutions per minute.

In this test, the motor was at a disadvantage by being belted. This could be avoided by connecting direct, unless the motor was used for other purposes also.

Whenever located so that electric power can be obtained, the convenience of the electric motor should recommend it above other motive power, providing the price of electricity can be brought low enough to compare with fuels such as distillate. Direct-connected electric motors avoid loss in belting and are very reliable, requiring little attention. Where electricity can be secured that has been generated by water power and used in direct-connected motors, it will usually be obtainable at a rate that will make it preferable to the gasoline engine. The electric plant may be a little higher in first cost, but it can be run almost constantly. Low cost per acre with electric plants is secured by keeping the size of plant down and operating almost continuously. Electric energy can best be used where it is to be purchased during a large part of the year; for a flat rate under such conditions is easier to secure. If power is to be used for only two months in the year, it would be cheaper for the consumer, providing he could get an installation, to pay for what he used, measuring it by meter and paying according to a sliding scale. If a rate could be made based on consumption per H. P., it would seem to be about the best arrangement for both parties concerned. The advantage of electricity becomes greater with larger installations.

SEC. VII.—EFFECTS OF IRRIGATION ON CROPS

There are numerous inquiries as to whether irrigation injures the quality and marketability of various products. Careful studies of this subject have been made by the writer.

Effect of Irrigation on Palatability. At the suggestion of Director Withycombe, samples of irrigated and unirrigated potatoes were delivered to 14 different householders in 1911, with the understanding that these householders should cook each of the samples in the same manner and determine any possible difference in eating quality. The dry potatoes were designated (Y), and the irrigated ones from the plat receiving two 2½-inch (2x2½") irrigations were designated (X). The parties testing these were not informed as to the difference in the mode of production until after their reports were made. Four favored the irrigated product, five the unirrigated, and five were unable to detect any difference. The difference of opinion is illustrated by the two following replies:

Reply No. 7:—

"We tried the two samples of potatoes in two different ways; namely, as baked and as mashed potatoes. We could not see any difference in the flavor of the two samples, but it is our judgment that the sample labeled 'Y' was considerably better in texture than that labeled 'X.' Although perhaps a trifle coarser in texture, it was more mealy, the difference being especially evident when coming on the table as mashed potatoes."

Reply No. 14:—

"Our observations on the cooking qualities of the two samples, one marked 'X' and one 'Y,' indicate that 'X' seemed to be the more mealy and to work up whiter than 'Y.' The difference betwen the two seemed to be very slight."

From these replies it appears that the palatability of potatoes due to a moderate amount of irrigation is very slight indeed. Where crops are given the proper amount of moisture for growth, and where the soil receives no water within 50 or 60 days of time to harvest, so that the crop will mature, it does not matter whether this needed moisture comes as rain or as irrigation. Amounts above the optimum may be detrimental.

Effect of Irrigation on Composition. Analyses of potatoes from the same plat used in the above tests were made by H. V. Tartar, the Station chemist, and are submitted herewith:

TABLE 25.—CHEMICAL COMPOSITION OF IRRIGATED AND UNIRRIGATED POTATOES.

	Two 2½" Irr. Plat 32	Dry Plat 34
Moisture	78.12	75.61
Protein	2.01	2.557
Fat	.044	.044
Ash	.92	1.04
Fiber	.27	.34
Starch	16.85	18.00
Undetermined	1.79	2.409

Irrigation appears to have caused a slight increase in the water content and a corresponding decrease in starch, protein, and other constituents except fat. Irrigated and unirrigated hops from the yard of a cooperative farmer at Independence were analyzed by the Station chemist, H. V. Tartar, who states that the unirrigated hops had more hard resin than the irrigated hops, and a high percentage of hard resin is objectionable.

A study of the moisture content of irrigated and unirrigated products in the different plats for the different seasons was made at harvest time. The moisture content of the products, as affected by different amounts of irrigation, may be illustrated by the moisture content of potatoes.

TABLE 26.—EFFECT OF DIFFERENT AMOUNTS OF IRRIGATION ON MOISTURE CONTENT OF PRODUCT.

Crop	Irrigations	% Moisture in product
1911		
Potatoes	Dry	80.00
Potatoes	2x2½"	80.84
Potatoes	1x5"	80.00
Potatoes	3x1"	79.15
Potatoes	2x3"	82.80
Potatoes	3x2"	81.57
Potatoes	1x3"	81.05
Potatoes	2x3"	78.34
Potatoes	3x3"	82.66
1912		
Potato vines	Dry	77.9
Potato vines	3x1"	79.9
Potato vines	2x2½"	80.2
1913		
Dry Sod Potatoes	Dry	76.9
Dry Sod Potatoes	1x2"	75.2
Dry Sod Potatoes	1x3"	76.2
Dry Sod Potatoes	2x2"	75.2
Irrigated Sod Potatoes	Dry	79.6
Irrigated Sod Potatoes	1x2"	80.2
Irrigated Sod Potatoes	3x1"	79.6
Irrigated Sod Potatoes	2x2"	80.5

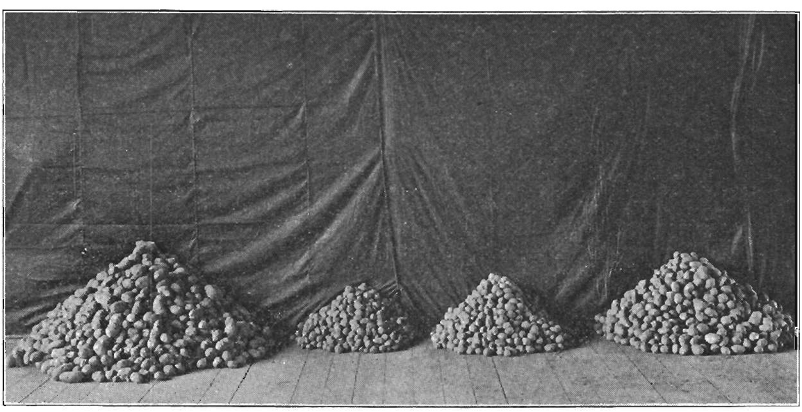
From these determinations, it appears that **the moisture content is not appreciably increased by irrigation except where more than the most economical amount of water is applied.** This has held true for other crops employed in these experiments. Irrigation, up to the point where it has given the most economical returns, has had no appreciable effect on the moisture content of the product; but above this there has been a slight increase in the moisture content and as much as 2% more moisture with the maximum irrigations. Over-irrigation is associated with immaturity, this being especially noticeable with potatoes. These tubers do not have as firm a skin and are not so solid as those properly irrigated or produced without irrigation. Data for other crops were secured which verify the evidence given above for potatoes.

Effect of Irrigation on Marketability. During several seasons the potato crop has been sorted to determine the percentage of culls in each plat employed in this experiment. The ill-shaped potatoes, and those as small as a hen's egg, or smaller, having been left on the ground during the harvesting, were picked up separately. The results for 1911 represent the largest number of potato plats for a single season and are here given:

TABLE 27—EFFECT OF IRRIGATION ON PER CENT OF CULL POTATOES.

1911		% CULLS
	Dry	15.0
17%	1x3"	17.9
	3x1"	14.6
	3x2"	13.4
	2x3"	12.2
	1x5"	11.9
23%	3x3"	11.2
	2x2½"	10.8
20%	2x3"	7.1

From the above data it can be seen that the dry plat has the highest percentage of culls, with the exception of the 17% plat which was irrigated after it began to fire, the irrigation resulting in "second growth." It will be noticed that **the percentage of small potatoes and cull potatoes decreases with the amount of irrigation up to the most economical amount of irrigation.** It seems to remain about constant or to decrease a little with the heavier irrigations. This is most clearly brought out in the dry seasons; but it is safe to say that irriga-



IRRIGATED — UNIRRIGATED
Marketable — Culls — Culls — Marketable

Figure 19.—RESULT OF GRADING TENTH-ACRE IRRIGATED POTATOES AT LEFT, AND TENTH-ACRE UNIRRIGATED POTATOES AT RIGHT. IRRIGATION DECREASES THE PERCENTAGE OF CULLS.

tion will greatly decrease the percentage of small potatoes. With proper irrigation, there is more control over winter growth than without irrigation. Cultivation, or fluctuations in the soil moisture content, seems to encourage second growth; and the light, frequent irrigations that have given the most economical returns have also given the lowest percentage of culls. The result of grading plats of irrigated and unirrigated potatoes is shown in Figure 19.

Effect of Irrigation on Appearance of Plants. Irrigation usually caused larger-sized plants; this fact is shown by the photographs in this bulletin of irrigated and unirrigated crops. The potatoes and pumpkins are inclined to make more vine growth with irrigation. The root crops developed larger roots without much change in the appearance of tops. The kale plants became large and succulent with irrigation, and the leaves became very thick and smooth. There are fewer curly leaves on the kale plants where they are irrigated. Usually also the leaves will be of a healthy green appearance. Over-irrigation with most crops has caused development of stalk instead of fruit, and prevented development of the fruit of the plant.

Effect of Irrigation on Ratio of Parts. In the study of dry matter it was necessary to determine the proportion of potato vines, bean vines, beet tops, and the percentage of moisture in these. The effect of irrigation upon the ratio of parts in these crops is shown by the following data:

TABLE 28.—EFFECT OF IRRIGATION ON RATIO OF DRY MATTER IN PLANT PARTS.

		Parts roots to one of tops
Long Red beets	2x2½"	3.3
Long Red beets	1x5"	3.8
Long Red beets	Dry	2.7
Yellow Globe beets	2x2½"	5.8
Yellow Globe beets	1x5"	7.4
Yellow Globe beets	Dry	5.1
		Parts tubers to one of vines
Potatoes	2x2½"	2.5
Potatoes	2x1"	2.6
Potatoes	Dry	2.8
		Parts beans to one of vines
Beans	8"	1.0
Beans	Dry	0.7
		Parts corn to one of stalks
Corn	4"	.44
Corn	Dry	.56

Irrigation of potatoes above the most economical amount seems to have caused an increase in proportion of dry matter in the tops as compared to the tubers. Where there is any irrigation water left in the soil at harvest time, the vines are likely to be later in dying and to make larger growth. Irrigation of beets causes a greater root development without as much increase in the leaves. In case of beans, irrigation results in a greater increase of pods than of tops; and the proportion of marketability of the product is increased by irrigation in the beans as it is in the beets. Irrigation of corn has increased the yield in corn stover more than it has in the percentage of ears, or has caused a greater amount of stalks in proportion to ears.

Effect of Irrigation on Seed Condition. Irrigated potatoes have frequently been used for seed purposes. Potatoes irrigated more than the most economical amount have had better size and have been as firm and desirable as unirrigated potatoes for seed purposes. Potatoes where over-irrigated to such an extent as to cause sogginess and slipping of the skin, are less desirable for this purpose.

A germination test was made of irrigated and unirrigated beans to determine the effect of irrigation on vitality. The irrigated beans in 1911 gave a germination test of 97%, unirrigated beans a test of 99%. There were a few more dark colored beans in the irrigated plat. If the beans are not irrigated after bloom, and harvested when they become dry enough to shatter, there is not apt to be much difference in germinating power. The beans tested were irrigated a little more, and a little later, than was best.

A germination test of irrigated and unirrigated corn grown in 1913 gave a test March 1, 1914, of 95% for the unirrigated and 98% for the irrigated plat. The irrigated corn was more perfectly developed, and the usable soil moisture more completely utilized in the irrigated corn plat.

SEC. VIII.—EFFECTS OF IRRIGATION ON SOIL

Physical Effects of Irrigation. The question has arisen: "Will irrigation injure the tilth or structure of this soil?" Consequently a study has been made of the physical properties of soils from irrigated and unirrigated plats. The soils included in these studies are in most cases those that have been irrigated five years. These were compared with the soils of unirrigated companion plats. If irrigation causes the soil to become more consolidated and the finer particles to filter in between the coarser, it will increase the weight per cubic foot and will decrease the water capacity.

The determinations of the volume weight and water capacity were made with the soil as nearly as possible under field conditions. In sampling the soil, cylinders six inches in diameter and one foot in length were used. The samples were taken by pressing these cylinders into the soil gently and digging away the dirt surrounding them as the cylinder was worked down into the soil. In this way, cores extending through the first, second, and third foot of soil were secured. When the cylinder was filled flush with the surface a perforated disc was placed under one end of the cylinder after the soil was trimmed off flush with the surface. These samples were removed to the laboratory, saturated with water, and allowed to drain to constant weight in a saturated atmosphere, after which they were oven dried. About 50 determinations of volume weight and water capacity were thus obtained.

TABLE 29.—EFFECT OF FIVE YEARS' IRRIGATION ON VOLUME, WEIGHT AND WATER—RETAINING CAPACITY OF SOILS UNDER FIELD CONDITIONS.

	Irrigated		Unirrigated	
	First foot	Third foot	First foot	Third foot
Weight, lbs. per cubic foot.... (Average of 9 trials)	77.3	83.1	76.1	82.1
Difference, lbs.	1.2	1.0		
Water retaining capacity %.. (Average of 9 trials)	34.7	30.1	33.2	30.8
Difference, per cent	1.5	—.7		

It is rather difficult to make determination of this nature that will approach field conditions, but by taking the samples at the same time from the plats to be compared, fairly consistent results have been obtained. The greatest variation has been found in the surface foot of soil, which is altered by cultivation and root growth to the greatest extent. As an average of some 27 comparisons of determinations from soils devoted to various crops, five years' irrigation appears to have increased the weight per cubic foot about one pound, and to have decreased the water-holding capacity ½%. The difference is so small that it is within the limit of error. A careful study of the detailed data, in connection with observations in the field, leads us to conclude that where the soil is devoted to kale and corn, there is a tendency with irrigation for the soil to become a little more compact. On the other hand, where clover and alfalfa are grown there has been a tendency for the irrigated soils to increase in water-holding capacity and become lighter per cubic foot, due to the greater root development.

In some cases, where water has been improperly applied, and where the land has been trampled upon in irrigating after it has become wet, the physical condition of the soil has been somewhat injured. The white land, where the irrigation of beans was tested, has required cultivation at just the right moisture content after irrigation in order to remake a mellow soil mulch. It has been necessary in some cases to cultivate twice in order to secure a suitable soil mulch after irrigation.

Water capacity should vary with the pore space; and if irrigation decreased the water capacity, it is reasonable to assume that the pore space would be decreased. A few determinations of the effect of five years' irrigation on the percentage of pore space were made and are as follows:

TABLE 30.—EFFECT OF IRRIGATION ON PORE SPACE IN SOIL.

		Percentage Pore Space	
		Irrigated (5")	Dry
Alfalfa, four years; Plat 29 irrigated and 34 dry (Oct. 12, 1912)	First foot	53.39 50.89	57.64 50.52
	Second foot	56.83 42.00	48.55 44.00
	Mean	50.78	50.18

Chemical Effects of Irrigation. Since the soils of Western Oregon are usually slightly acid in their reaction, the tendency with irrigation might be to exclude the air and increase acidity in the soil. In order to determine the effect of five years' irrigation on the reaction of the soil, a number of determinations were made from representative plats by Dr. M. M. McCool, of the Agronomy department. The provisional method of analysis was used. The acidity (expressed in lime requirements) of certain irrigated and unirrigated plats is as follows:

TABLE 31.—ACIDITY IN IRRIGATED AND UNIRRIGATED SOILS.

Plat	Crop	Treatment	Lime Requirement Pounds
9	Clover 2 years, Kale 1 year	Irrigated 3 years	784
11	Clover 2 years, Kale 1 year	Dry 3 years	600
1	Alfalfa 4 years, Potatoes 1 year	Irrigated 5 years	730
34	Alfalfa 4 years, Potatoes 1 year	Dry 5 years	899
29	Alfalfa 5 years	Irrigated 5 years	800
27	Alfalfa 5 years	Irr. 2 years, Dry 3 years	1,200
13	Cult. 2 years, Clover 1 year	Irrigated 3 years	600
17	Cult. 2 years, Clover 1 year	Dry 3 years	1,200

It seems that the slope of the land with relation to the sun, and small differences in natural drainage have more influence on acidity than five years' irrigation has had. **The results of these studies show no relation between five years' irrigation and the amount of acidity with adjacent plats devoted to the same crops during each year of the period.** The amount of water applied has been sufficient to penetrate to from three to six feet in the soil, and in no case has irrigation caused the rise of the water table in the irrigation season. Usually, the irrigation has improved the soil moisture content of the soil and has not been so excessive as to exclude the air for any length of time.

The effect of five years' irrigation on the leaching of the soil has been investigated. Composite samples, taken from representative plats in alfalfa during four different years, and in potatoes during one year, were submitted to the Station chemist, Professor H. V. Tartar, for analysis. The samples were analyzed for available plant food by using fifth normal nitric acid as a solvent, with the following results:

TABLE 32.—EFFECT OF 5 YEARS' IRRIGATION ON AVAILABILITY OF PLANT FOOD.

	Irrigated Plat 8	Dry Plat 34
Available potash	0.0385%	0.0384%
Available phosphoric acid	0.0767%	0.0530%

The amount of potash seems to be practically the same, but there appears to be more soluble phosphoric acid in the irrigated plats. This determination agrees very closely with the determination for this type of soil quoted earlier in the bulletin. Apparently there has been no downward translocation of plant food by the water applied.

The Effect of Irrigation on Organic Matter Content. This was determined from samples collected by the writer from representative irrigated and unirrigated plats, by Dr. McCool, typical determinations from representative plats being as follows:

TABLE 33.—ORGANIC MATTER IN IRRIGATED AND UNIRRIGATED SOILS.

Plat	Crop	Treatment	Loss on ignition
			%
1	Alfalfa 4 years, Potatoes 1 year	Irri. 5 years	6.00
34	Alfalfa 4 years, Potatoes 1 year	Dry 5 years	5.50
1	Alfalfa 4 years	Irri. 5 years	6.06
34	Alfalfa 4 years	Dry 5 years	5.60
4	Alfalfa 4 years, Potatoes 1 year	Irri. 5 years	......
34	Alfalfa 4 years, Potatoes 1 year	Dry 5 years	6.00
13	Fallow 2 years, Barley 1 year	Irri. 3 years	5.90
14	Fallow 2 years, Barley 1 year	Dry 3 years	5.70
9	Clover 2 years, Kale 1 year	Irri. 3 years	5.68*
11	Clover 2 years, Kale 1 year	Dry 3 years	6.20

*Thin clover followed by heavy kale crop.

From these determinations it appears that alfalfa and clover have increased the organic matter content with the aid of irrigation about ½% for the five year period. The heavy yield of potatoes following irrigated alfalfa, as compared with the yield after dry alfalfa, is largely explained by this increase of organic matter and the various beneficial effects obtained as the result of its presence. On the other hand, rank feeding crops like kale show a tendency to exhaust the supply of organic matter.

SEC. IX.—IRRIGATION PRACTICE IN THE WILLAMETTE VALLEY

REPORTS OF IRRIGATORS

In 1911 a circular letter was mailed to more than one hundred farmers in the Willamette Valley who had filed on water for irrigation purposes, or were said to be practicing irrigation. These letters were sent out for the purpose of learning something of the extent and success of irrigation. Over half of these circular letters were answered, about 30 of them giving detailed answers to most of the questions asked. The replies were from farmers with one to 20 years of experience with irrigation. The average acreage irrigated was 25 acres a farm, the average size of the total farm being 138 acres. The replies cover experience with approximately 1,000 acres, and show that several times this area is in process of improvement by this method. Ninety per cent of the land reported upon was naturally drained, the remainder being artificially drained. Fifty per cent was sandy loam, about 45% was silt loam, and about 5% was clay loam. Sixteen obtained their water from streams, four from wells, and others from various sources. The majority of the irrigators are using an individual pumping plant. The estimated annual depth of water used according to these replies runs from three acre inches to 24 acre inches per acre for the season. The average depth used, as shown by the reports, is 12¼ inches, or approximately an acre foot per acre during the season. This is about twice the amount used on the College Farm, but in some cases water was used on a sandier soil.

Question No. 7 in the circular letter reads, "**Is the quality of irrigated crops as good as the unirrigated product?**" Twenty answered this question. Nine replied "Yes"; nine replied "Better"; one reply, coming from a farmer of red hill clay soil, replied "No"; and one replied "Some better, some not so good."

Question 8 read, "**Are irrigated products as marketable as unirrigated?**" To this 18 replies were received. Thirteen answered "Yes"; one replied "50% more so"; one replied "Some better"; one replied "Except potatoes"; and two stated that "The irrigated product is far superior."

Question 9 read, "**Has irrigation improved or injured soil conditions?**" Eighteen answers to this question were received from irrigators. Seven reported that they could find no difference; six stated that the soil had improved with irrigation; and one reply, coming from a farmer of clay soil, stated that "Irrigation had injured the soil condition."

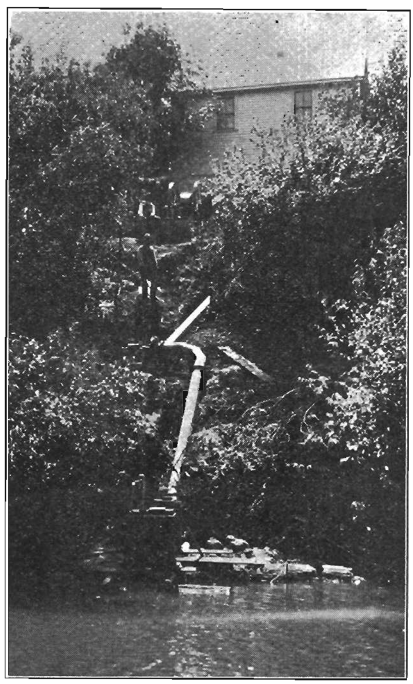
Question 10 read, "**Do you consider irrigation in this valley profitable?**" Out of the 17 replies to this question, 15 answered "Yes"; one modified his statement by saying ,"Yes, in places," and one replied, "Yes, where rightly applied."

Question 11 read, "**What is your hardest problem in irrigation farming?**" Sixteen replies were received to this question. Seven named "Distribution of the water"; three named "Leveling"; three replied "Getting the water"; two reported "Difficulty with the pumping proposition," and one found the greatest difficulty in "Getting the water applied at the proper time."

Question 12 read, **"To what extent do you think farmers should engage in irrigation in your district?"** The replies received were as follows:

"Water supply is limited. It pays to use it."
"As far as there is water."
"Depends on kind of crop grown."
"Wherever they can."
"On a small scale."
"Should start with a few acres and work up with experience."
"It depends upon locality and cost.'
"All they can handle economically."
"All crops."
"All, as far as water will go."
"Limited only to experience."
"All they can."
"Too small a stream is not economical."
'To irrigate every acre possible."

(A)



(B)

Figure 20.—SMALL IRRIGATION PUMPING PLANTS IN THE WILLAMETTE VALLEY. (a) PLANT OF MR. CAMPBELL, FOREST GROVE; (b) PLANT OF MR. BASSFORD, HILLSBORO.

Question 13 read, **"What field crops may be most successfully irrigated?"** In replying to this question, five mentioned "Potatoes"; five "Alfalfa"; four named "Clover"; three, "Truck"; and two, "Root crops." Other crops named were, vetch, peas, kale, corn, and berries.

Question 14 read, **"What kind of crops are grown with the aid of irrigation?"** Six replies to this question were, "Truck crops"; five mentioned "Meadows"; four named "Potatoes"; two mentioned "Hops"; while most of the ordinary cultivated field crops were named.

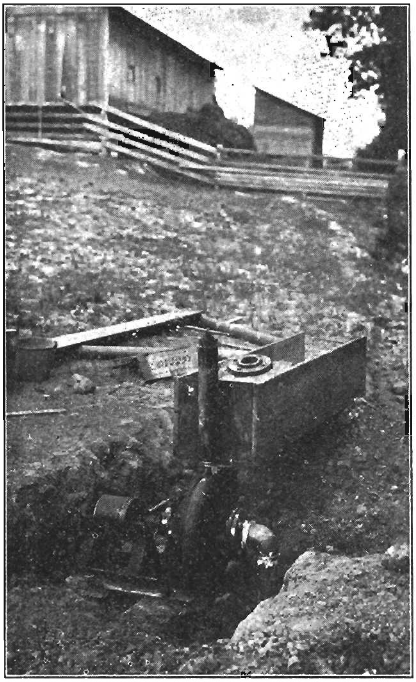


Figure 20 C.—PUMP ATTACHED TO DRIVEN WELL CASING. NOTE PRIMING DEVICE.

In addition to the answers to the questions the letters of others who replied without filling out the blanks provided contained some information that should prove of interest.

Mr. J. W. Jenkins, of McCoy, replied, "There is no question in my mind as to the beneficial results of irrigation."

Mr. W. K. Newell, of Gaston, replied, "I have used a centrifugal pump to water alfalfa and clover, with fairly good results."

Mr. J. H. Brown, of Dallas, Oregon, writes. "We have 60 acres which we keep irrigated. Have used water mostly on garden truck and loganberries and the product is far superior to dry land. Irrigated potatoes have not kept as well. We have irrigated wheat and increased the yield fully 50%. Irrigated clover, corn, and beans, and most everything has paid, including prunes, peaches, and almond trees. Most people use too much water and too often. This makes the soil soggy and hard to work, requiring more fertilizer."

Mr. C. C. Beers, of Cornelius, replied, "I think it will pay for all we can irrigate here. I believe it will pay to irrigate light and often and follow irrigation, where possible, with cultivation as soon as the ground is dry enough. There is a whole lot in knowing when to put water on any crop. For instance, if you let potatoes get a little too dry and then water, it makes a lot of rough, knotty potatoes; and again, if you water too soon you are liable to set too many and have a lot of small potatoes and very few large ones. I expect to irrigate quite a lot the coming season."

Sloper Brothers, of Independence, said, "We figure an increase on hops of about 50% with late irrigation; and one row irrigated in June and again in August increased in yield nearly 100%. Potatoes, planted

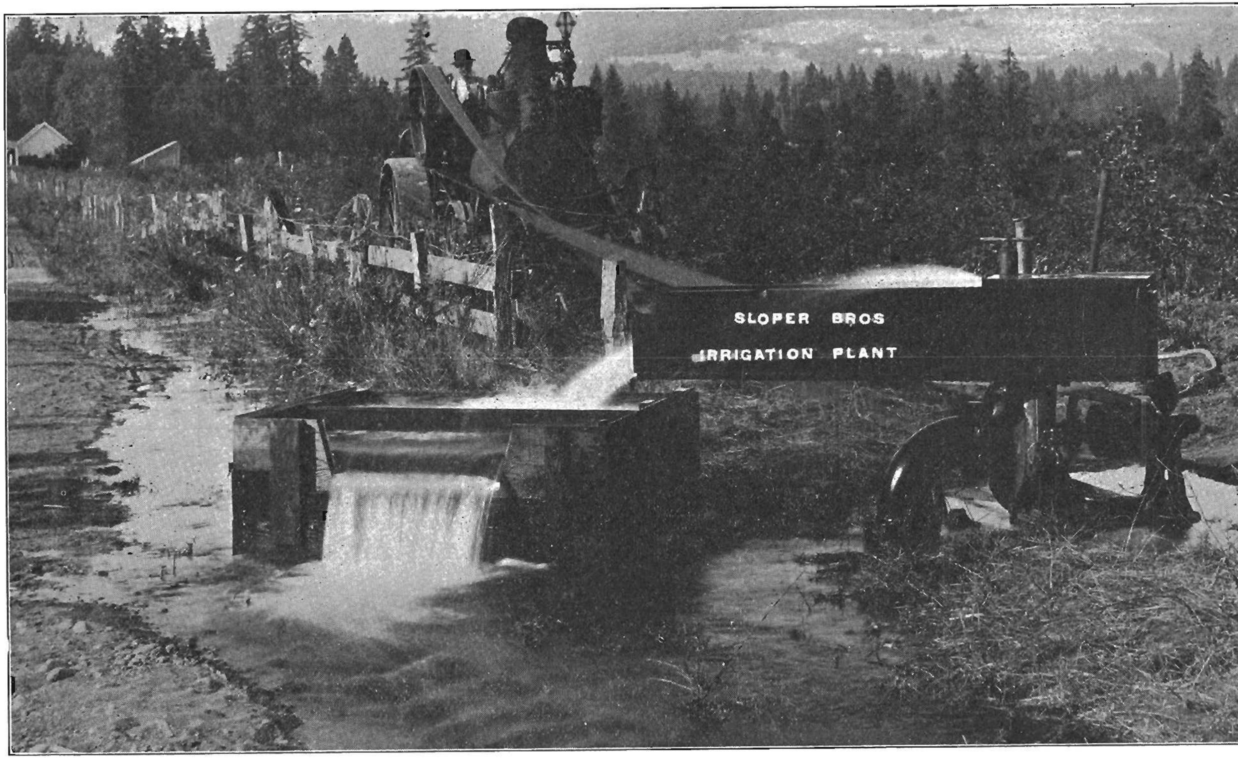


Figure 21.—WEIR AND PUMPING PLANT NEAR INDEPENDENCE, PUMPING 500 GALLONS A MINUTE FROM DRIVEN WELL.

on March 5 and irrigated June 20 and July 25, were harvested August 20 and made 200 bushels per acre, practically all marketable and very smooth." This land is a sandy, river deposit. The hops referred to yielded 1700 pounds per acre. The total annual cost of irrigation was about 40c per acre inch, and about $2 per acre was expended for irrigation. The water was drawn from the underflow, being pumped from a driven well, as shown in Figure 21.

Mr. John Campbell, Forest Grove, replied, "Our irrigated corn attained a growth of from 10 to 14 feet high, and I had over 20 tons per acre, or over 60 tons on three acres, while the unirrigated did not make one-half the yield, or about nine tons to the acre, and was from five to seven feet high. Irrigation pays big."

FIELD OBSERVATIONS

In the fall of 1911 the writer took a trip over the Willamette Valley to make a study of the value of irrigation where practiced. As indicated by the majority of the above replies, the majority of the farmers who have used irrigation are enthusiastic believers in it. We have a large number of pumping plants already installed in the Willamette Valley and two large gravity irrigation projects under way. The replies of about twenty who did not answer the questions above were to the effect that they were installing some system of irrigation. The practice of irrigation is developing along streams in connection with intensive dairying, hop raising, and trucking. It is succeeding best in the Valley upon the fairly free-working soils that are not too sticky and clayey on the one hand, and not too sieve-like on the other. The ideal soil for irrigation is the fine, sandy, silt loam, with a good amount of organic matter. Irrigation will develop more and more with intensive farming of this type of soil in Western Oregon, since it is most successfully used with intensive methods.

SEC. X.—IRRIGATION EXPERIMENTS WITH FIELD CROPS AT WEST STAYTON IN 1911

GENERAL CONDITIONS

Through an agreement with the Director and other officers of the Oregon Experiment Station on the one hand, and the officers of the Willamette Valley Irrigated Land Company on the other, cooperative experiments were supervised on a six-acre tract of land belonging to the company at West Stayton. The experiments were carried on during one season. The departments of Agronomy and Horticulture outlined and supervised the work for the College; and the Agronomy experiments are hereinafter described. These experiments were outlined to determine the value of irrigation in the vicinity of West Stayton, and to determine the time and amount of water to use in irrigation, as well as the fertilizer and cropping treatments which were best for soil in that section. Fertilizer experiments were outlined by direction of the Station Agronomist, Professor H. D. Scudder, who also gave written instructions for the cultural treatment of plants. The irrigation experiments were outlined by the writer, who acted as field agent under the general direction of the Agronomist. The tract of land used is located opposite the West Stayton depot along the east side of the railroad, and is nearly level, having a very gentle slope toward the west and a uniform exposure to the weather.

Soil and Subsoil Conditions. The soil of this tract is loose, gravelly loam, containing 5 to 12% organic matter, and is fairly typical of large areas in the district. There is some variation in the percentage of gravel, both in the surface and in the subsoil. Weather conditions were practically the same, or a little cooler, than in Corvallis in 1911. The crops employed in this experiment were corn, kale, potatoes, beets, and newly seeded meadows. Due to a series of delays, planting was done rather late in the season.

Irrigation. Water was applied to the cultivated crops from an earthen lateral by the furrow method, and was measured roughly by means of a portable trapezoidal weir placed near the plats to be irrigated.

Movement and Distribution of Soil Water. Irrigation of cultivated crops by the furrow method was found to work nicely in this soil. A two-inch irrigation was just sufficient to wet down all the furrows to the lower end of the plats, which were eight rods long. A head of nearly a cubic foot per second was used in irrigating the tenth-acre plats, and about one-half this head was used with the twentieth-acre plats. Three acre inches depth per irrigation seemed to be about the best amount of water for cultivated crops on this soil. A four-inch irrigation was about all the water that could be held on the plat without running off when irrigated with a head of one cubic foot per second. Moisture moves through this soil freely; and a good head of water must be used and the surface carefully leveled to one plane, in order that flooding may be successfully practiced. It would be best to irrigate by furrows wherever possible. Irrigation of meadows by means of furrows will effect more economical use of water than flooding. The soil takes up water nicely and conveys it sidewise from the furrows into the crop rows remarkably well. Water was found spread horizontally by capillarity 15 to 18 inches; whereas this movement in many sandy, arid soils, when irrigated, is only seven or eight inches. Percolation and capillarity downward are rather rapid, and since this il is not very retentive of moisture, comparatively light and frequent irrigations should be used. It was found necessary to use three-inch irrigations every 15 or 18 days on cultivated crops, from June 1 to August 15, while the meadows required four to five acre inches per acre each three to four weeks.

Appearance of Crops. The beets had to be reseeded, and as a consequence made only a fairly good crop. The meadow crops failed to make a good stand, largely because they were broadcasted instead of drilled, and the soil was so poorly leveled that the seedlings were not provided with moisture or plant food enough to establish themselves. Other crops had a very thrifty appearance and were very uniform until the different experimental treatments caused difference between the growth of various plats. Late in the season the effects of different amounts of water and fertilizer were very evident. The soil had apparently been cropped for a great many years, was foul with weeds, and in a lower state of fertility than was at first supposed. The appearance of the corn crop is illustrated in Figure 22. The kale plants all had a thrifty, uniform appearance until the lack of moisture checked the growth of the dry plat. The potato plats were fairly uniform, but they were all rather fine vined. There was no second growth. The corn made a rapid, healthy growth. A plat treated with manure pushed ahead of its neighbors and developed into one of the best plats. The plat treated with lime, nitrogen, and phosphorus developed into one of the best plats and the foliage had a rich, dark green color. The plat treated with lime and phosphorous yielded especially well. Kale and corn were harvested about September 25, and the potatoes and beets were harvested October 16. The yields may be found in Table 34.

RESULTS OF EXPERIMENTS AT WEST STAYTON.—Table 34.

In considering these yields it should be kept in mind that the plats were planted late and harvested early, so the main value lies in the difference in yields of companion plats under different treatments. The kale was harvested 135 days after planting, and although the yields were not large they were considered fairly good for that time of the year and they show consistently the advantage of light irrigations. Unusually early fall rains lessened the effect of irrigation on these plats. With kale, a foot of water applied in three four-inch (3x4") irrigations gave a gain in yield of 1.82 tons per acre over the unirrigated, or about 19% increase. The same amount applied in six two-inch (6x2") irrigations, 10 days apart, made a gain of 3.8 tons, or about 40%. When applied in three-inch (3") irrigations, 15 days apart, an acre foot of water gave an increase of 4.97 tons, or 51.6%. The yields of this trial were about the most valuable results obtained in these experiments, and indicate very clearly that **a three-inch (1x3")**

Figure 22.—IRRIGATED CORN AT WEST STAYTON.

Figure 23.—DROP IN IRRIGATION DITCH AT WEST STAYTON

TABLE 34.—YIELDS OF FIELD CROPS IN IRRIGATION EXPERIMENT AT WEST STAYTON, 1911.

Crop	Plat No.	Treatment	No. rows wt'd	Total tons per acre	Gain over dry		Gain over unfert'd	
					per acre	per acre	per acre	per acre
A					Tons	%	Tons	%
Kale....	4	**Unirrigated**	4	9.65	....	....	....	....
Kale....	3	6x2" 10 days............	4	13.45	3.800	39.4	....	....
Kale....	5	4x3" 15 days............	4	14.625	4.975	51.6	....	....
Kale....	6	3x4" 20 days............	4	11.475	1.925	18.9	....	....
				Bu.	Bu.			
Potato	8	**Unirrigated**	8	67.66	....	....	....	....
Potato	7	6x2" 10 days............	8	90.86	+23.20	34.3	....	....
Potato	9	4x3" 15 days............	10	52.43	—15.23	—22.5	....	....
Potato	10	3x4" 20 days............	10	69.48	+ 1.82	+ 2.7	....	....
B				Tons				
Beets..	2	**Unirrigated**	1	2.585	....	....	....	....
Beets..	1	Irri. as nec............ (4x3")	1	6.710	4.125	159.6	....	....
C								
Corn ..	12	**Unirrigated**	2	4.221	....	....	....	....
Corn ..	11	Irri. as nec............ (All rec'd 3x3")	2	7.020	2.799	66.3	....	....
Corn ..	18	Lime, Nitro. Potas...	2	7.480	3.259	77.2	0.460	6.5
Corn ..	13	Lime	2	7.672	3.451	381.7	0.652	9.2
Corn ..	16	Lime, Nitro. Phos...	2	7.878	3.657	86.6	0.559	12.2
Corn ..	19	Lime, Potas.	2	8.470	4.249	100.7	1.450	20.6
Corn ..	15	Lime, Nitrogen	2	8.868	4.647	110.1	1.848	26.3
Corn ..	17	Lime, Phos.	2	9.267	5.046	119.5	2.247	32.0
Corn ..	14	Manure	2	9.487	5.266	124.7	2.467	35.1
Corn ..	20	Lime, Phos., Potas...	2	14.368	10.147	240.5	7.348	104.6*
Corn ..	22	Nitro., Phos., Potas.	2	17.696	13.475	319.3	10.676	150.0*

*Plats 20 and 22 were seeded ten days later than other plats and were very green when harvested.

irrigation every 15 days is about the best amount and frequency of irrigation for the given soil and this class of crops. Results from the potato trials were not consistent and scarcely warrant any conclusion. The light, frequent irrigations seemed to do best. Continued cropping had left the soil in poor condition for potatoes, and the yield of all plats, therefore, was rather low. Potatoes do best with moderate amounts of water, and, in fact, have given very profitable results in other experiments from the use of small amounts of irrigation.

The late seeding of beets, together with the packed and gravelly condition of the ground, caused low yields in the beet plats. Irrigation gave an increase of 4⅛ tons per acre, or about 160%, and was secured by four three-inch (4x3") applications. Ordinarily, with such treatment, an increase of 50 to 100% might be expected.

The yield of corn compared quite well with the results obtained in other irrigation experiments. The increase was some 2.8 tons per acre, or about 69%, and was secured with the use of three two-inch (3x2") irrigations.

The effectiveness of lime was about doubled when used with potassium, about trebled with nitrogen, and about quadrupled with phosphorus. Nitrogen had a 6% advantage over potassium, and phosphorus had a 10% advantage over potassium. Manure was slightly more beneficial than lime and phosphorus; but had a little less effect than lime, phosphorus, and potassium used collectively. Phosphorus proved better than potassium to use with nitrogen, and potassium gave more favorable results than nitrogen in combination with lime and phosphorus. **The order of improvement seems to be: manure first, lime second, and phosphorus third**—at least as judged by corn.

The experiment was successful in that it gave clear indications as to the best amount and frequency of irrigation, as well as the best kind of fertilization in connection with irrigation of this soil. **The quantity of water used for cultivated crops on this gravelly loam was about twice the amount used for the same crop on the silt loam soil at Corvallis the same season.** The irrigation season for this sandy soil seemed to be nearly twice as long as for the silt loam, and would extend from June 1 to the middle of August.

SEC. XI.—SOIL-MOISTURE EXPERIMENTS IN THE ROGUE RIVER VALLEY

GENERAL CONDITIONS

In the summer of 1910 a study was made of soil moisture and soil temperature in certain orchards, embracing several types of soil found in the Rogue River Valley in Southern Oregon. These experiments were carried on in cooperation with the Horticultural department. The field observations and moisture samples were taken by members of that department, while the moisture determinations and tabulations of the moisture and temperature data were made by the Agronomy department. The Agronomy work was outlined to include determinations of the minimum, optimum, and maximum moisture conditions for the several soil types, and the effect of the irrigations of trees and cultivations on the seasonal moisture content and movements of soil moisture. The effects of water, temperature, shading, and irrigation on soil temperature during the season were also studied.

The moisture samples were taken from each foot of soil; and a series of borings consisted of a 3-foot sample taken four feet from the tree, a 6-foot sample taken eight feet from the tree, and a 3-foot sample taken twelve feet from the tree. The ground temperature was taken after the soil sample was removed from each foot in each boring. The soil samples were then placed in air-tight containers and shipped within 24 hours to the Soil Laboratory at Corvallis. Average soil areas and trees were selected for boring in each plat. Complete samplings were taken of all irrigated and unirrigated plats in several orchards before and after each irrigation and at the close of the season. Each plat was sampled about every two weeks during the irrigation season, making a total of about 800 moisture determinations, and an equal number of soil temperatures were taken. The exposure and character of the various orchards and the cultivation and irrigation methods are given in detail in bulletin No. 113 of this Station, which contains a report of the horticultural phases of these experiments.

Records were kept of the weather conditions. The rainfall for the period during which soil-moisture determinations were made; namely, July 20 to September 20, amounted to .64 of an inch. It came in six light showers and was practically negligible. The weather conditions were very similar to those at Corvallis, except for being a little drier and warmer.

SOIL MOISTURE CONDITIONS.

Relations Between Soil Texture and Moisture. While the moisture work was commenced rather late in the season, and probably no perfectly saturated soils were obtained, yet the determinations show the actual range under the field conditions, and from the determinations made, the average moisture content, as well as the range for irrigated and unirrigated plats, has in general been learned for the different soil types. The summarized moisture conditions are given in Table 35.

TABLE 35.—RELATION BETWEEN MEAN SOIL TEXTURE, MOISTURE AND TEMPERATURE CONDITIONS.

(Showing Seasonal Moisture Content; Range: Content of 3′ and 6′ Ave.)

MOISTURE

Orchard	Plat	Texture	Water applied per tree*	Detph in acre inches	Temperature	Average total	Maximum content	Minimum content	Range	3′ Average	6′ Average
Judy Newt	1	Silt loam	1x1200 gals	3.12	64	11.7	16.1	7.2	8.9	10.7	11.9
Judy Newt	2	G. Silt loam	1x 900 gals	2.33	67	11.5	14.4	7.3	7.6	10.9	12.0
Judy Newt	3	S. Silt loam	1x 600 gals	1.56	65	13.2	17.2	9.5	7.7	12.1	11.4
Judy Newt	4	Silt loam	Dry	......	67	11.7	15.3	6.3	9.0	10.9	11.6
Judy Spitz	1	G. Silt loam	2x 600 gals	3.12	67	10.9	17.1	7.2	9.9	10.0	11.1
Judy Spitz	2	S. Silt loam	1000g.+900g	4.93	65	10.5	17.8	6.9	10.9	10.4	10.4
Talent	1	S. Silt loam	2x 600 gals	1.91	67	10.2	16.7	7.1	9.6	10.7	9.6
Talent	2	Silt loam, mixed	1200g.+1000g	3.50	67	11.0	16.9	6.3	10.6	10.7	10.5
Talent	3	Silt loam	Dry	......	68	10.2	11.1	5.9	5.2	8.1	8.9
Bennets	1	S. Silt loam	2x 600 gals	3.12	67	18.2	30.9	1.2	19.7	20.1	18.2
Bennets	2	S. Silt loam	2x1500 gals	7.78	66	19.7	32.6	2.2	20.4	21.4	19.8
Hillcrest	1	Clay loam	Dry	......	69	21.2	27.7	13.5	14.2	22.6	20.0
Hillcrest	2	Clay loam	Dry	......	67	23.1	30.0	16.9	13.1	23.5	22.8
Hillcrest	3	H. Clay loam	Dry	......	67	26.4	33.8	18.5	15.3	29.2	26.3
Hillcrest	4	Clay	Dry	......	69	24.4	30.7	16.0	14.7	24.4	24.4
Bear Creek	--	Clay	Dry	......	66	24.9	32.1	19.7	......	25.5	24.9

*Tree Space.
Judy and Bennets Set- -25′x25′.
Talent Set—32′x32′.

In this table the average texture, moisture, and temperature conditions are arranged to show their relationships. From the average seasonal moisture content, as well as that of the three-foot and six-foot average, it will be seen that irrigation gave only a slight increase in the seasonal moisture content in most cases. The temporary increase, however, is more marked.

The Talent Orchard had the lowest mean moisture content, and the Judy Orchard was next to the lowest, while **the Hillcrest and Bear-Creek Orchards, although unirrigated had considerably the highest** seasonal **moisture content due to their heavy texture.** This relation of texture to moisture content is perhaps the most interesting thing which the season's work has demonstrated.

The seasonal mean temperature shows consistently lower temperatures for irrigated plats.

The greatest comparative increase in moisture appears to have resulted from light irrigations.

Gain in Moisture Due to Irrigation. In order to show the temporary gain in moisture due to irrigation and to show the movements of moisture during the season, as well as the comparative increase in the different amounts of irrigation, the difference in moisture content at the sampling proceeding and following each irrigation, was calculated. Space will not permit use of detailed data.

The average of all comparisons is as follows:

TABLE 36.—GAIN (OR LOSS) IN PERCENTAGE OF SOIL MOISTURE FROM IRRIGATION.

First Irrigation—			
Distance from tree	8'	8'	12'
(Fifteen Comparisons)	3' Ave. 0.5	First 3' Ave. 1.1 Second 3' Ave. -0.4	3' Ave. -1.3
Second Irrigation—			
(Fifteen Comparisons)	3' Ave. 2.0	First 8' Ave. 1.3 Second 3' Ave. 0.5	8' Ave. -0.5

Soils of coarser texture give the greatest temporary increase due to irrigation and increase in the heavier soils was primarily in the first two feet of the surface. In most cases irrigation increased the moisture content three feet from the tree throughout the entire depth of the three-foot boring. The surface soil at a distance of eight feet from the tree shows some gain in moisture after irrigation, while the deep subsoil shows a continual loss of moisture into the roots of the trees in spite of the irrigation. Positive figures in the borings eight feet from the tree indicate the depth to which the moisture content was appreciably increased by irrigation to be three or four feet.

Loss (or Gain) in Moisture Content During Season. In most cases irrigated orchards had a higher moisture content throughout the greater part of the irrigated soil, at the end of the irrigation season than at the beginning in spite of the greater amount of soil moisture utilized by the trees. The values given below were secured by comparing the moisture in each foot at the first sampling with the corresponding sample for each series at the close of the season. Plus values stand for higher moisture content at the end of the season, which in most cases was due to irrigation. The negative values indicate the loss of evaporation and the sapping of moisture by the trees. The general average gain or loss during the season for all plats is as follows:

IRRIGATED

Gen. ave. gain or loss. Volume of 3′ ave. +.1 %
Volume of 6′ ave. —.05%

UNIRRIGATED

Ave. gain or loss 3′ strata —4.0%
Ave. gain or loss 6′ strata —4.0%

From the general average it will be seen that all irrigated plats went through the season with a loss of only .05 per cent in the six-foot strata, and a gain of .10 per cent in the three-foot strata. In contrast with this, the unirrigated plats show a loss of four per cent in the three- and also in the six-foot strata. There was more moisture in the soil near the trees, or in the shade, in both irrigated and unirrigated plats, and this continued to the end of the season.

The coarse subsoils had a lower moisture content than the surface strata, notwithstanding the fact that the former were protected from surface evaporation.

TEMPERATURE CONDITIONS

Since the movements and loss of soil moisture are affected by temperature, a study of temperature conditions was made. The data collected serve to measure the effect of moisture on temperature in an interesting way. From the temperature study four things are strikingly shown.

First: *The Temporary Effect of Irrigation Water on Soil Temperature.* The objection is often made that irrigation lowers the temperature of the soil to a point that is detrimental. In order to study the effect of cold irrigation water on soil temperatures, a study was made of the temperature of water as it came from the source of supply, as it entered the irrigation furrow, and as it entered the soil at the lower end of the furrow. This average temperature is given below in Fahrenheit degrees:

At Source	Head of Furrow	Lower End of Furrow
65.0	65.9	71.7

The temperature at the head of the furrow, in most cases, was one or two degrees warmer than at the source of supply; and by the time the water percolated into the ground it had absorbed heat from the surface soil of the furrow and from contact with the air until its temperature had increased eight or ten degrees more. The effect, temporarily, was to cool the surface soil, but in some cases to absorb heat and carry it into the subsoil.

Second: *The Effect of Irrigation on Soil Temperatures.* It was observed in most cases, that irrigated soil was some degrees cooler than the unirrigated soil, and so a comparison of soil temperatures before and after irrigation was made. This loss of temperature is most marked close to the trees and in the surface soils where the maximum amount of water and evaporation is found. The depth at which the loss of temperature occurs in most cases, corresponds with the depth at which the water percolated. The moisture content seems to have more effect on temperature than does shade.

Third: *The Effect of Sun and Shade on Temperature.* It was found on unirrigated plats, and also to some extent on the irrigated plats, that temperatures were lower in the borings close to the trees. The average temperature of the borings taken four, eight, and twelve feet, from the trees for each plat in each orchard is given to illustrate this point:

Distance away from trees	4'	8'	12'
	Temperature F°		
Mean of all plats, 3' average	68°	68.1°	69°

The borings twelve feet from the tree, in some cases, were four degrees higher than the average temperature four feet from the tree. The general average shows an appreciable increase in temperature away from the tree where exposed to the sun.

Fourth: *The Gain or Loss of Temperature During the Season.* At the beginning of the season the deep subsoil was found to be very cool, while the surface soil was heated to a temperature approaching that of the air. Late in the season a reversion of this condition occurs; and **the heat absorbed by the soil during the summer is found to linger in the deep subsoil,** while the temperature of the surface stratum falls several degrees with the approach of cool weather. The comparison of the temperatures at the beginning and close of the season has been made in Table 37, to illustrate the storage of heat in the subsoil.

In this table the gain or loss of temperature for the season for each foot of each plat is given. The prevailing negative values for the surface stratum show a cooling out at the surface at the close of the season as compared with the beginning of the season, while the positive values in the deep subsoil show the gain in temperature at the end as compared with the beginning. Mulches help to retain this heat.

Table 37.—Gain or Loss in Soil Temperature During Irrigation Season. July 12 to September 23.

(Showing reversion of temperature or storing of heat in soil under mulch.)

Depth in Feet	Bear Creek Plat I Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Bennets Plat I Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Bennets Plat II Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Hillcrest Plat I Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Hillcrest Plat II Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Hillcrest Plat III Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Hillcrest Plat IV Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Talent Plat II Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*
1	-5 -5 -6	-9 -6 -7	-6 -7 -2	-8 -7 -6	-9 -6 -5	-4 -3 -5	-6 -5 -	-14-13-12
2	-5 -5 -5	-7 -4 -5	-3 -2 -1	-4 -5 -4	-5 -3 -2	-4 -3 -4	-6 -3 -	- 9- 8- 8
3	-4 -4 0	-4 0 -3	-5 1 -1	-1 -2 0	-2 -1 -2	-1 -2 -2	-3 -1 -	- 6- 5- 5
4	4	1	2	0	1	1	1	- 3
5	2	1	4	1	4	2	3	0
6	0	3	5	..	0	4	0	0

Depth in Feet	Judy Newts. Plat I Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Judy Newts. Plat II Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Judy Newts. Plat III Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Judy Newts. Plat IV, Dry Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Judy Spitz Plat I Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Judy Spitz Plat II Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Talent Plat II Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*	Talent Plat III Gain or Loss Degrees F. 4 8 12 Ft. Ft. Ft.*
1	-12-12-12	-10-10 -9	-8 -8 -6	-9 -8-10	-12-13-10	-14-13-13	-13-12-13	-3 -7-11
2	- 9- 8- 8	- 8- 8 -6	-5 -4 -3	-7 -7- 8	- 8-10- 5	-12-12-10	-12- 8- 8	-8 -4- 7
3	- 4- 2- 6	- 6- 8 -4	-1 -2 -1	-4 -4- 7	- 4- 5- 5	- 9- 7- 7	- 8- 5- 4	-1 -2- 4
4	0	- 4	-1	-3		- 4	- 1	0
5	1	- 1	2	-3		- 3	- 2	1
6	3	- 1	4	0		--	--	--

*Distance of borings from tree.

SEC. XII.—A SCIENTIFIC SYSTEM OF IRRIGATION FARMING

From observations made in the field and laboratory in connection with these experiments, it appears that proper irrigation will provide a more favorable moisture content; and, in addition, will aid in the liberation of plant food and in its solution and conveyance to the plants. It will also increase the bacterial activity, as well as the root and top development of the plant. This extra root development will tend to offset any running-together of the soil due to irrigation. With irrigation farming, the crops removed are larger, and, as a result, larger amounts of fertilizer must be returned to the land in refuse. It is more important in irrigation farming, than in other methods, to practice a careful rotation of crops that will permit the growing of clover, or some other soil-building crop, on the land every few years, and, furthermore, that will permit plowing up the land deeply at frequent intervals so as to maintain a good state of tilth. This rotation should also permit the growing of a good proportion of cultivated crops each year, as such crops will require less water and will use it later in the season than do the meadow crops. A rotation of soil-building crops, together with the application of manure, maintains the water-holding capacity and fertility, and lowers the water cost of dry matter. Larger amounts of manure can be used without making the soil too open where irrigation is practiced. By the use of rotation, including legumes, and the use of manure, a free-working soil can be built up and kept in a higher state of productivity with the aid of proper irrigation. Irrigation farming reaches its highest development in connection with intensive farming. It will become of increasing importance in Western Oregon on all free-working soils in connection with intensive dairying, hop production, and truck farming.

SEC. XIII.—SUMMARY

1. Evaporation from the water surface from April 30 to October 1, averages about twenty-four inches at Corvallis. The average rainfall for this period is 5.52 inches.

2. The valley silt loam under field conditions has several important moisture points: the maximum capillary water content, which is about 34%; the maximum amount for proper cultivation, about 27%; the optimum water content, about 23%; the drouth point, about 14%, and the minimum moisture content, about 11%.

3. Irrigation gave a higher seasonal moisture content, and this was associated with higher yields.

4. Irrigation is associated with a temporary loss in moisture in the subsoil, due to capillary movement into the deeper soil layers and the continued consumption of moisture by the subsoil roots. There is a gain in moisture content in the subsoil between irrigations, due to renewed upward capillary movement.

5. The highest seasonal moisture content in irrigated plats has been obtained in connection with early spring plowing, manuring, crop rotations, including legumes, and frequent cultivation to maintain a crumby soil mulch two and one-half to three inches in depth over the surface.

6. Irrigation caused a lowering of the temperature of the surface soil as much as four degrees in cultivated plats, and as much as ten degrees in meadow plats.

7. Irrigation caused an increase in yield of all crops. From a seven-year average the increase of all crops has been 65%.

8. One irrigation has been better than two irrigations for kale, clover, and beets; and two irrigations have proved best for potatoes.

9. The most **economical** increase of alfalfa from irrigation has been obtained from the use of four acre inches per acre in the wet season, and about six acre inches in dry seasons, while the **maximum** yield has been obtained with six inches in a wet season and twelve inches in a dry season.

10. The most **economical** return with potatoes has been secured with two inches in a wet season, and with three or four inches in a dry season, while the **maximum** yield with potatoes has been secured with three inches in a wet season and six inches in a dry season.

10. The best time to irrigate clover on the gray silt loam is when the moisture content of the first two feet drops to about 14%, while the best time to irrigate potatoes on this soil is when the moisture content of the first foot drops to the 20% point. Potatoes do best with a uniform moisture content, and with light, frequent irrigations. Two irrigations have proved better than one, and three light irrigations have given very economical returns with this crop.

12. The corrugation method has proved the best for distributing water over this soil.

13. Irrigation has made it possible to raise two different crops in one season, and not only to get a cutting from new seeding of clover or alfalfa the first season, but also to secure a more perfect stand.

14. The water cost of dry matter under field conditions has been greatly reduced by the use of a moderate amount of irrigation. The water cost of dry matter varies about as the most economical returns per acre inch. Above the most economical yield per acre inch the water cost increases.

15. The time and the frequency of irrigation also affect the water cost. The 20% point has proved the best time to irrigate potatoes, as judged by the water cost.

16. Growing crops in an irrigated rotation, including a legume, has greatly decreased the water cost of dry matter as compared to growing crops in an unirrigated rotation, following an unirrigated legume crop.

17. The water cost under field conditions varies with the different crops, and also with the different crop varieties. Kale has proved to be a crop of high water requirement, and potatoes have given higher water cost than has been found to be the case elsewhere. Corn and beans have proved to be crops of low water requirement in the Willamette Valley.

18. The water consumption per pound of dry matter can be greatly reduced in irrigation farming by practicing a good rotation, including soil-building crops; by using good varieties; by maintaining a good state of fertility; and practicing good farm methods.

19. Irrigation has made a profit of $2.66 per acre inch on an average, with pumped water applied to ordinary field crops where the cost has been figured at a maximum price of one dollar per acre inch.

20. Electricity has proved more economical than gasoline as a source of energy for a small pumping plant where the labor cost was more important than the fuel cost.

21. Proper irrigation has not injured the palatability of potatoes.

22. Irrigation has decreased the percentage of culls.

23. Irrigation has not increased the moisture content of crops except where excessive irrigation was used. Above the most economical amount of irrigation the moisture content has increased.

24. Irrigation has altered the shape and size of plants, and has affected the seed product, causing better shaped ears and a higher percentage germination in corn and a lower percentage germination in beans.

25. Irrigation has altered the percentage of marketable product, causing more beans in proportion to plant, more beet in proportion to top, but more vines with potatoes in proportion to tubers. Irrigation has also caused a slight change in the chemical composition of the products.

26. The soil has shown a slight tendency to decrease in water capacity and increase in volume weight with irrigation where rank feeding crops were grown, but to be improved in this respect where soil-building crops were grown.

27. Irrigation had little appreciable effect on the acidity, and little effect on the content of available plant food.

28. Irrigation has caused a decided increase in organic content where leguminous crops, as compared to unirrigated legumes, were grown.

29. In experiments at West Stayton on gravelly loam soil, three three-inch irrigations proved about the right amount for cultivated crops, and 18 inches in three applications seemed to be about right for meadow crops.

30. This gravelly loam soil was found to conduct the moisture sidewise nicely when irrigated, and was found to irrigate best by the furrow method.

31. The soil responded most to fertilization with manure and lime. Other chemical fertilizers had less effect.

32. In soil moisture experiments in Southern Oregon, close relation was found between the texture of the soil and its moisture content and responsiveness to irrigation. Light irrigations had the greatest relative effect on the moisture content.

33. The soil temperature was lowered by irrigation more than by shading of trees.

34. There was a storage of heat in the soil near the close of the season in the fall, the subsoil being cool in the spring and warm in the fall as compared with the surface soil.

35. Irrigation, to be of much value in the Willamette Valley, must be used only in a supplemental and proper way.

ACKNOWLEDGMENTS.

Experiments herein described were carried on under direct charge of the writer the past four years, and under the general direction of Professor H. D. Scudder. Many helpful suggestions regarding the crop work have been given by Professor G. R. Hyslop.

In the field work connected with the experiments, the writer was assisted by Mr. James Koeber in 1910; N. D. Vale in 1911; M. A. McCall in 1912; and J. E. Cooter in 1913. In these experiments previous to 1910, Mr. A. P. Stover represented the Office of Experiment Stations in the cooperation of that office.

Helpful suggestions have been received from numerous other members of the Station staff. To all these associates, the author extends sincere appreciation.

SEC. XIV.—APPENDIX

TABLE 37.—TABLE FOR CONVERTING LOSS ON 100 GRAMS OF MOIST SOIL TO PERCENTAGE DRY WEIGHT.

Note.—Applicable to any other unit or material.

Loss	Loss %	Loss	Loss %	Loss	Loss %	Loss	Loss %	Loss	Loss %
1.0	**1.0**	**2.0**	**2.04**	**3.0**	**3.1**	**4.0**	**4.2**	**5.0**	**5.3**
......	......	.1	......	.1	.2	.1	.3	.1	.4
......	......	.2	......	.2	.3	.2	.4	.2	5
	......	.3	......	.3	.4	.3	.5	.3	.6
......	......	.4	......	.4	.5	.4	.6	.4	.7
......	......	.5	.6	.5	.6	.5	.7	.5	.8
......	......	.6	.7	.6	.7	.6	.8	.6	.9
......	......	.7	.8	.7	.8	.7	.9	.7	6.0
......	......	.8	.9	.8	.9	.8	5.0	.8	6.2
......	......	.9	3.0	.9	4.1	.9	5.1	.9	6.3
6.0	**6.4**	**7.0**	**7.5**	**8.0**	**8.7**	**9.0**	**9.9**	**10.0**	**11.1**
.1	.5	.1	.6	.1	.8	.1	10.0	.1	.2
.2	.6	.2	.8	.2	.9	.2	10.1	.2	.4
.3	.7	.3	.9	.3	9.0	.3	.2	.3	.5
.4	.8	.4	8.0	.4	.2	.4	.4	.4	.6
.5	.9	.5	.1	.5	.3	.5	.5	.5	.7
.6	7.1	.6	.2	.6	.4	.6	.6	.6	.9
.7	.2	.7	.3	.7	.5	.7	.7	.7	12.0
.8	.3	.8	.5	.8	.6	.8	.9	.8	.1
.9	.4	.9	.6	.9	.8	.9	11.0	.9	12.2
11.0	**12.4**	**12.0**	**13.6**	**13.0**	**14.9**	**14.0**	**16.3**	**15.0**	**17.6**
.1	.5	.1	.8	.1	15.1	.1	.4	.1	.8
.2	.6	.2	.9	.2	.2	.2	.5	.2	.9
.3	.7	.3	14.0	.3	.3	.3	.7	.3	18.1
.4	.9	.4	.2	.4	.5	.4	.8	.4	.2
.5	13.0	.5	.3	.5	.6	.5	17.0	.5	.3
.6	.1	.6	.4	.6	.7	.6	.1	.6	.5
.7	.2	.7	.5	.7	.9	.7	.2	.7	.6
.8	.4	.8	.7	.8	16.0	.8	.4	.8	.8
.9	.5	.9	.8	.9	.1	.9	.5	.9	.9
16.0	**19.1**	**17.0**	**20.5**	**18.0**	**21.9**	**19.0**	**23.4**	**20.0**	**25.0**
.1	19.2	.1	.6	.1	22.1	.1	.6	.1	.1
.2	3	.2	.7	.2	.2	.2	.7	.2	.3
.3	.4	.3	.9	.3	.3	.3	.9	.3	.4
.4	.6	.4	21.0	.4	.4	.4	24.0	.4	.6
.5	.7	.5	.2	.5	.6	.5	.2	.5	.7
.6	.8	.6	.3	.6	.8	.6	.3	.6	.9
.7	20.0	.7	.5	.7	23.0	.7	.5	.7	26.1
.8	2	.8	.6	.8	.1	.8	.6	.8	.2
.9	.4	.9	.8	.9	.3	.9	.8	.9	.4
21.0	**26.5**	**22.0**	**28.2**	**23.0**	**29.8**	**24.0**	**31.5**	**25.0**	**33.3**
.1	.7	.1	.3	.1	30.0	.1	.7	.1	.5
.2	.8	.2	.5	.2	.2	.2	.9	.2	.7
.3	27.0	.3	.7	.3	.3	.3	32.1	.3	.9
.4	.2	.4	.8	.4	.5	.4	.2	.4	34.0
.5	.3	.5	29.0	.5	.7	.5	.4	.5	.2
.6	.5	.6	.1	.6	.8	.6	.6	.6	.4
.7	.7	.7	.3	.7	31.0	.7	.8	.7	.6
.8	.8	.8	.5	.8	.2	.8	33.0	.8	.8
.9	28.0	.9	.7	.9	.4	.9	.2	.9	35.0

Loss	Loss %	Loss	Loss %	Loss	Loss %	Loss	Loss %	Loss	Loss %
26.0	**35.1**	**27.0**	**37.0**	**28.0**	**38.9**	**29.0**	**40.8**	**30.0**	**42.8**
.1	.3	.1	.2	.1	39.1	.1	.9	.1	43.0
.2	.5	.2	.4	.2	.3	.2	41.2	.2	.3
.3	.7	.3	.6	.3	.5	.3	.4	.3	.5
.4	.9	.4	.7	.4	.7	.4	.6	.4	.7
.5	36.1	.5	.9	.5	.9	.5	.8	.5	.9
.6	.3	.6	38.1	.6	40.1	.6	42.0	.6	44.1
.7	.4	.7	.3	.7	.2	.7	.2	.7	.3
.8	.6	.8	.5	.8	.4	.8	.4	.8	.5
.9	.8	.9	.7	.9	.6	.9	.6	.9	.7
31.0	**44.9**	**32.0**	**47.0**	**33.0**	**49.2**	**34.0**	**51.5**	**35.0**	**53.8**
.1	45.1	.1	.3	.1	.5	.1	.7	.1	54.1
.2	.3	.2	.5	.2	.7	.2	52.0	.2	.3
.3	.5	.3	.7	.3	.8	.3	.2	.3	.5
.4	.8	.4	.9	.4	50.1	.4	.4	.4	.7
.5	46.0	.5	48.2	.5	.4	.5	.7	.5	55.0
.6	.2	.6	.4	.6	.6	.6	.9	.6	.3
.7	.4	.7	.6	.7	.8	.7	53.1	.7	.5
.8	.6	.8	.8	.8	51.0	.8	.4	.8	.8
.9	.8	.9	49.0	.9	.3	.9	.6	.9	.9