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USE OF IRRIGATION WATER ON FARM CROPS

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DIVISION OF FIELD HUSBANDRY

EXPERIMENTAL FARMS SERVICE

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INTRODUCTION

Each year irrigation is assuming greater importance in the agricultural development of Western Canada. In the ranching days of the eighties and nineties, water was diverted from a few small streams on to adjoining bottom lands to irrigate hay, but the bringing of water into Lethbridge through the canals of the Canadian North West Irrigation Company in 1900 was the beginning of extensive irrigation in Alberta. At the present time, the Canadian Pacific Railway project east of Calgary and the one at Lethbridge, the Eastern Irrigation District at Brooks, the Canadian Land and Irrigation Company project at Vauxhall, the Taber project at Taber, the United project at Glenwoodville and Hillspring, the Lethbridge Northern, and a number of small projects, contain approximately one million acres of irrigable land, situated in Alberta. Since the inauguration of water development under the Prairie Farm Rehabilitation Act by the Dominion Government, numerous small projects have been developed in Saskatchewan and Alberta and continued expansion of irrigation appears imminent.

This development has naturally given rise to numerous questions, among these being the proper use of irrigation water. The problem of the proper use of water has been complicated not only by the usual factors of variation in soil types and climatic conditions, but also by the fact that the irrigated projects have received settlers from different parts of the irrigated west, all of these having brought with them their own ideas of irrigation as worked out in the localities from which they came. Many of the settlers have had no previous irrigation experience and look upon irrigation as something to be avoided except in cases of extreme drought. The whole situation is such that, even in places where irrigation has been practised for over thirty years, no general method has been adopted that seems to be entirely satisfactory although more uniformity is gradually developing.

Because of this situation it seemed necessary that detailed investigations be undertaken to study the problem. Numerous experiments on the use of water have been conducted in the irrigated parts of the United States. Much of their data has been of value in Alberta and is referred to freely in this report. Studies on the duty of water have also been made in Alberta, (46)** at the Department of the Interior Irrigation Experimental Station, Brooks, Alberta, supplemented by shorter experiments at Strathmore and Ronalane and by surveys of water use on farms in other parts of the province.

Purpose of Investigations

The experiments reported here were conducted at the Dominion Experimental Station, Lethbridge, Alberta, and were planned:—

1. To obtain information as to the stage of plant growth when water should be applied to field crops.
2. To study the value of fall irrigation.
3. To determine the number of irrigations required in different years by various crops.

* The experiments were planned by the author under the direction of W. H. Fairfield, Superintendent of the Lethbridge Experimental Station. Dr. Fairfield also made helpful suggestions and criticisms during the progress of the work and has been of material assistance in interpreting the accumulated data, and others, especially T. W. Grindley, R. W. Peake, and P. H. Walker, helped with the conducting of the experiments, tabulating data and preparing the manuscript.

** Reference by number is to "Literature Cited" page ....

4. To investigate certain phases of the inter-relations of soils, soil moisture, and plant growth.
5. To formulate standards of irrigation practice, from the data obtained, as well as from other information available, that will serve as a guide to the farmers in the development of irrigation projects in Western Canada.

These experiments started in 1922, were continued until 1937 when an analysis of the results was made and published as Bulletin 125 N.S. The soil moisture studies and the irrigation tests with alfalfa and sunflowers were discontinued but irrigation experiments with wheat, sugar beets and potatoes were continued with some alterations in the irrigation practice. Most of the data contained in the original publication are republished here. Additional tables are added presenting data secured since the publication of the original material, and the discussions are modified as required to conform to present knowledge.

Experimental Methods

Crops used in the experiment were Marquis spring wheat, Grimm alfalfa, Irish Cobbler potatoes, sugar beets from commercial European seed, and Russian Giant sunflowers.

These crops were grown on plots containing one-twentieth or one forty-sixth of an acre and all tests were made in duplicate. Each plot was completely surrounded by a ditch seven feet wide. The bank of this ditch formed a dike around the plot converting it into a basin. The ground inside the dike was levelled so that a uniform application of water could be made over the entire area.

Description of Soil

The soil where the plots were located is a medium sandy clay loam of chocolate colour. The physical analysis of soil samples taken where the various crops were grown is presented in table 1.

Cropping and Fertility Record of Soil

The wheat grown in 1922 was on land that had been in corn the previous year and in alfalfa for the ten years preceding. For four years before the alfalfa field was broken, it was used as hog pasture and the soil was in a high state of fertility. The wheat following wheat grown in 1923, except the plots that were fall-irrigated, was on this same land. The fall-irrigated plots were on land that supported a heavy crop of white sweet clover cut for hay in 1921 and a crop of wheat in 1922. The fertility of these plots was not quite equal to that of the balance of the field as shown by the uniformly lower yields of wheat on the fall-irrigated plots and on one check plot located in the same area. These plots were abandoned after two years as some underground seepage developed on one end of the field.

The wheat after cultivated crops of 1923 was grown on land that had supported a heavy growth of Russian Giant sunflowers the preceding year. This land was broken from alfalfa in 1921. The alfalfa was seeded in 1918 and had been cut for hay each year. Wheat after wheat in 1924 was seeded on the land just described and in 1925 these plots which contained one-twentieth acre each, were divided by making a ditch seven feet wide down the centre of each plot. The resultant plots contained one forty-sixth acre each.

In 1924 another set of plots was established on an adjoining field which had the same cropping history and the three plot-sets were then rotated with two years of wheat and one year of potatoes.

Potatoes followed wheat each year on the land described above. All wheat and potato plots received a uniform application of twelve tons of well-rotted manure in the spring of 1927 and 20 tons per acre in the fall of 1934 and 1937.

The alfalfa plots were seeded in 1922 on land that had been rotated with oats, potatoes and peas for six years.

Sunflowers were grown on land that had been in a rotation of oats, peas and potatoes. Potatoes were grown on this field in 1922. The sunflowers were grown on the same plots for the two years that they were included in the experiment. Sugar beets were grown on the same plots each year. The field where these plots were located was in beans in 1924, wheat in 1923, sunflowers in 1922 and alfalfa in 1921 and for three years previous. Thirty tons of well-rotted barnyard manure per acre were applied to the field and ploughed under in the fall of 1924, and 20 tons per acre in the fall of 1934 and 1937.

All of the soil and subsoil where the various crops were grown appeared to be of uniform texture, structure and fertility over the entire fields, except as noted where the various crops are discussed in detail.

TABLE 1.—Mechanical Analysis of the top six feet of soils in plots used for Irrigation Experiments, Lethbridge*

Soils from	Depth (ft.)	On air-dried basis: Moisture	On air-dried basis: Loss on ignition	On air-dried basis: Gravel greater than 2 mm.	On water-free basis: Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
		p.c.	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.	p.c.
No. 1—Alfalfa plots	1st	2·26	6·53	0·08	0·15	0·27	2·09	20·49	38·80	21·18	17·62
	2nd	1·96	10·74	nil	0·09	0·28	1·76	35·69	28·87	14·60	18·71
	3rd	1·74	9·65	"	nil	0·14	1·41	16·03	49·26	15·46	17·70
	4th	1·65	8·75	"	0·09	0·22	2·31	26·16	39·92	15·84	15·46
	5th	1·57	8·48	"	0·04	0·12	1·31	31·20	35·21	16·40	15·72
	6th	1·65	8·60	0·01	0·06	0·09	1·10	34·31	31·14	16·25	17·05
No. 2—Alfalfa plots	1st	1·94	11·13	nil	0·05	0·20	1 34	27·66	32·02	19·42	19·31
	2nd	1·48	11·03	"	0·02	0·11	0·78	28·38	37·28	14·74	18·69
	3rd	1·43	9·65	"	nil	0·08	1·20	35·36	29·41	13·34	20·61
	4th	1·36	8·48	"	0·08	0·15	1·33	36·88	32·20	13·52	15·84
	5th	1·45	8·29	"	nil	0·09	1·01	35·94	33·33	12·00	17·63
	6th	1·48	8·27	"	"	0·10	0·79	30·57	38·60	12·10	17·84
No. 3—Wheat and potato plots.	1st	2·29	5·60	0·02	0·06	0·22	1·28	23·77	29·72	26·60	18·35
	2nd	1·84	12·15	nil	nil	0·11	0·97	24·05	35·92	19·64	19·31
	3rd	1·54	10·03	"	"	0·01	0·41	22·40	41·54	18·83	16·81
	4th	1·42	9·36	"	"	0·03	0·45	23·59	40·98	18·83	16·12
	5th	1·52	8·91	"	"	0·07	0·95	26·17	36·72	18·70	17·39
	6th	1·61	8·35	"	"	0·11	1·65	34·00	29·26	15·64	19·34
No. 4—Wheat and potato plots.	1st	2·13	8·38	0·03	0·05	0·26	1·39	23·48	34·94	22·78	17·10
	2nd	1·77	11·81	nil	nil	0·13	0·69	20·46	37·51	21·38	19·73
	3rd	1·47	9·47	"	"	0·07	0·87	30·08	36·58	14·83	17·57
	4th	1·46	8·76	"	"	0·07	0·75	30·14	37·50	13·40	18·14
	5th	1·45	8·62	0·20	0·08	0·22	1·14	39·06	24·73	13·24	21·53
	6th	2·36	5·83	1·06	0·91	1·40	4·12	18·07	19·46	28·28	27·76
No. 5—Wheat and potato plots.	1st	2·60	5·78	nil	0·03	0·21	1·06	17·35	40·94	22·85	17·56
	2nd	1·74	12·42	0·05	0·02	0·06	0·75	18·68	40·58	19·02	20·89
	3rd	1·66	10·48	nil	nil	0·08	0·61	20·80	41·53	16·88	20·10
	4th	1·67	9·12	"	"	0·07	0·56	24·44	40·33	14·88	19·72
	5th	1·48	8·56	"	"	0·04	0·54	31·74	36·38	10·64	20·66
	6th	1·59	8·27	"	"	0·13	0·66	36·11	30·66	10·32	21·92
No. 6—Wheat and potato plots.	1st	2·11	5·00	nil	0·03	0·14	1·02	20·46	38·22	22·40	17·73
	2nd	2·20	4·03	"	0·01	0·13	0·83	17·63	40·39	22·81	18·20
	3rd	1·73	10·81	"	0·01	0·08	0·57	12·63	34·90	27·47	24·32
	4th	1·47	11·06	"	nil	0·03	0·44	17·31	39·34	18·16	24·72
	5th	1·36	9·55	"	"	0·05	0·53	22·53	39·81	15·90	21·18
	6th	1·45	9·02	"	"	0·03	0·61	20·75	41·14	16·75	20·72

NOTE.—Soil series No. 1 and No. 2 were from different parts of the field containing the alfalfa plots. No. 1 also represents the soil of sunflower plots.

Series Nos. 3, 4, 5 and 6 were from different parts of the wheat and potato plots. No. 3 was taken adjacent to the sugar beet plots.

*Analysis by Frank T. Shutt, Dominion Chemist, Central Experimental Farm, Ottawa, Ontario.

Cultural Practices

The cultural methods used on all crops were those which had proved to be best from previous work done at the Station.

Alfalfa was seeded in a well-prepared seed bed on June 23, 1922, on land that had been ploughed the preceding fall and kept free from weeds. Fifteen pounds of Grimm alfalfa seed per acre were sown in drills and without a nurse crop. The plots were given a three-inch irrigation immediately after seeding with the result that a perfect stand of alfalfa was obtained. The weeds and alfalfa on the plots were clipped twice during the first season.

The land prepared for wheat following wheat and for potatoes was ploughed in the spring to a depth of six inches and worked down immediately with a spike-tooth harrow, or was fall ploughed and worked down in the spring. In preparing land for wheat following potatoes, the plots were cultivated with a duck-foot cultivator in the fall after the potatoes were harvested, to assist in checking winter drifting, and were cultivated again in the spring and harrowed before seeding. A pure strain of Marquis wheat was seeded with a 19-run, double disk drill, at the rate of ninety pounds of seed per acre.

Irish Cobbler potatoes were planted in rows three feet apart and to a depth of four inches with a two-man, horse-drawn planter. Certified seed potatoes were used at a rate of 1,300 pounds per acre, the sets having been cut to two eyes to the set. Before cutting the sets, the potatoes were soaked for four hours in a one-to-two-thousand solution of corrosive sublimate. The potato crop was cultivated from three to four times each year and furrows were made between rows for irrigating.

The sugar beet land was ploughed in the fall except for the crop of 1926. In that year, the beet plots were not ploughed but were cultivated in the fall and harrowed in the spring before seeding. The beets were seeded in rows twenty-two inches apart with a special beet drill of the shoe type. Seventeen pounds of seed were used per acre. The beets were thinned when in the four- to six-leaf stage to twelve inches apart in the rows and cultivated and hoed as needed. Furrows were made between the rows before each irrigation.

Before harvesting, a border at least three feet wide was trimmed from the perimeter of each plot of all crops under test.

Irrigation

The water used was obtained from the canal of the Canadian Pacific Railway's Lethbridge project and was led to the fields in earth ditches. Before reaching the plots the stream was passed through a side-overflow weir constructed to give a constant head of water. The water was measured over a rectangular weir of one-foot crest at the head of the alfalfa and sunflower plots and over a movable, triangular-notch weir at the head of the other plots. The amount of water passing over the weir was determined by tables given by Murdock and Barker (37). From these tables other tables were constructed showing the number of minutes required for a given application with varying heads of water.

All alfalfa and grain plots reported here received an application of six acre-inches of water per acre at each application except in 1927 when due to the unusually heavy rainfall the irrigations were reduced to three inches. Potatoes, sugar beets and sunflowers received four inches where but one irrigation was given and three inches where more than one irrigation was made. After 1929 all plots were given approximately a six-inch irrigation at each application.

In every instance, the date of application of water was gauged by a definite stage of plant growth or at a uniform period after such a stage where the habits and growth of the plant made it impractical to specify stages of growth. For example, wheat was irrigated in the one-leaf, three-leaf, five-leaf, shot-blade,

flowering and soft-dough stages. These are all stages of growth easily distinguished. Potatoes were irrigated when the plants were half-grown or starting to bloom, and at fixed intervals after the starting-bloom stage.

The reason for selecting stages of growth instead of fixed dates was that plants appear to have different water requirements at different stages of growth. Investigations conducted by Bark and Palmer* showed that wheat and barley grown in tanks increased their daily use of water as growth increased until the plants reached full height. The use then remained almost constant until ripening commenced when the amount of water used decreased abruptly and became almost nil when the plants were ripe. While working in Idaho, Bark (2) found that grains required the largest amount of water at the flowering or soft-dough stages, but that alfalfa, clover and pasture should be kept uniformly moist throughout the season. According to the experiments of Snelson (46), the water requirements of wheat were greatest in June, while the rate of plant growth was most rapid in July. Widtsoe and Merrill (57) state that "The time at which water is applied to crops determines, largely, the yield" and that "July is the month when most of the water should be applied to a beet field, with August applications following very closely in value, while in September a very small amount, indeed, suffices to maintain growth." In a later publication, Widtsoe and Stewart (58) state that "During the early periods of growth, plants need less water than during later periods."

Buffum (9), writing in 1892, made this interesting statement: "Wheat needs the most water during its early period of growth. Just before heading if the ground does not contain enough moisture to last until the crop will mature, it should be irrigated, as water applied after the heads are formed is liable to induce rust."

Fortier (18) says: "The amount of water required by cereals during the first six weeks of their growth is small if one excepts the heavy loss by evaporation from the surface of newly cultivated and seeded fields. The amount of water required during the last three weeks is likewise small."

From the results of tank and field experiments, Thom and Holtz (48) concluded that the daily amount of water transpired by wheat, corn, oats and peas increased until about the beginning of the ripening period. From this time there was a gradual decrease up to maturity.

Soil Moisure Determinations

Moisture determinations were made of each foot of soil to a depth of six feet in the spring at seeding time, immediately before and after each irrigation, and in the fall after harvest for the first five years of the experiments. From one to four borings were made on each plot at each sampling.

Soil samples were secured with a soil tube of the Briggs type, and the moisture was determined by oven drying to constant weight at 100° C. to 110° C.

Meteorological Observations at Lethbridge

Irrigation water is applied primarily to supply moisture to the soil for plant use. It is, therefore, evident that variations of rainfall and other climatic conditions influencing soil moisture content, evaporation and transpiration, greatly affect the constancy of results obtained from irrigation experiments conducted under field conditions.

The monthly and annual precipitation at Lethbridge for the seventeen years that these experiments have been under way, together with the average precipitation for the thirty-seven years that observations have been made, are presented in table 2. The precipitation for the months when the rainfall has the

* Unpublished Data.

principal effect on the crop of that year, April to August, inclusive, is also given. In table 3 are introduced data on the evaporation from a free water surface for the months of May to October, inclusive. The mean wind velocity and the total hours of bright sunshine for each month are listed in tables 4 and 5 respectively.

The seventeen-year period had eight comparatively dry years, 1922, 1924, 1925, 1930, 1931, 1934, 1935 and 1936, as indicated by the rainfall of the cropping season. The precipitation received in 1926 was supplemented to a marked extent by the unprecedented September and October precipitation of 1925, which was the equivalent of a good fall irrigation. The fall of 1926 was also wet, which condition, coupled with the heavy rainfall of May, 1927, and timely rains of June and July, provided ample moisture without irrigation for potato, sugar beet and grain crops, and for the first cutting of alfalfa.

The precipitation of 1927, 1928 and 1932 was almost ample for crops but in other years irrigation decidedly improved yields.

TABLE 2.—Inches of Precipitation at Lethbridge, 1922-1938

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total for Crop Season	Total for Calendar Year
1922	0·43	0·41	0·81	2·57	0·89	1·87	2·30	0·40	0·81	0·78	0·47	0·60	8·03	12·34
1923	0·48	0·42	0·75	1·09	3·48	4·45	2·55	1·01	0·18	0·55	0·53	0·91	12·58	16·40
1924	0·66	1·04	0·69	0·56	1·17	3·82	0·54	2·91	1·46	0·59	1·02	1·54	9·00	16·00
1925	0·30	0·99	2·26	1·99	0·43	3·40	0·82	1·85	4·86	1·08	0·16	0·62	8·49	18·76
1926	0·26	0·70	0·11	0·34	0·64	4·67	1·15	2·31	4·62	0·31	0·52	0·56	9·11	16·19
1927	0·31	1·39	0·37	1·48	7·32	1·60	1·93	1·74	3·29	0·58	2·88	0·96	14·07	23·85
1928	0·94	0·79	0·93	1·32	0·09	6·79	3·98	1·54	0·24	0·85	0·28	0·33	13·72	18·08
1929	1·08	0·63	1·34	2·55	2·63	3·72	0·52	0·59	2·05	2·20	0·49	1·91	10·01	19·71
1930	0·37	0·20	0·77	1·53	1·54	1·42	1·87	0·57	2·36	0·58	0·92	0·21	6·93	12·34
1931	0·01	0·25	1·40	1·12	1·22	1·55	1·09	0·19	1·99	0·66	1·21	0·73	5·17	11·42
1932	0·81	0·55	1·05	2·73	2·99	2·06	0·74	3·63	1·00	1·07	1·87	0·74	12·15	19·24
1933	0·33	0·38	2·51	2·49	1·80	1·32	0·92	2·64	1·30	2·44	0·77	2·27	9·17	19·17
1934	0·43	0·31	2·30	0·13	0·71	4·00	0·43	0·60	2·97	1·70	1·11	0·59	5·87	15·28
1935	0·47	0·72	1·09	2·46	1·42	0·35	0·70	1·18	0·22	1·70	0·52	0·47	6·11	11·30
1936	1·19	0·62	0·98	0·78	2·01	1·89	0·41	0·90	1·39	0·69	0·48	1·40	5·99	12·74
1937	1·76	0·42	0·79	0·45	2·38	3·19	2·91	0·86	1·10	1·33	0·70	0·38	9·79	16·27
1938	0·91	0·80	1·85	0·88	3·21	1·16	1·28	1·72	0·81	0·96	1·93	0·22	8·25	15·73
Average for 17 years	0·63	0·62	1·18	1·44	2·00	2·78	1·42	1·45	1·80	1·06	0·93	0·85	9·09	16·16
Average for 37 years	0·66	0·63	0·88	1·10	2·34	2·68	1·67	1·63	1·69	0·95	0·75	0·69	9·42	15·67

TABLE 3.—Inches of Water Evaporated from a Free Water Surface at Lethbridge May to October, 1922-1938

Year	May	June	July	Aug.	Sept.	Oct.	Total	Average for 6 months
	in.	in.	in.	in.	in.	in.	in.	in.
1922	4·66	4·94	4·51	4·77	4·05	3·17	26·10	4·35
1923	5·08	5·49	4·52	4·28	3·42	1·74	24·53	4·09
1924	5·97	4·43	6·13	4·14	3·93	2·29	26·89	4·48
1925	3·71	4·82	7·02	6·05	3·44	1·09	26·13	4·34
1926	6·24	5·37	5·60	4·58	1·77	3·05	26·61	4·43
1927	3·36	3·83	4·00	3·78	3·16	2·38	20·51	3·42
1928	5·90	3·65	6·74	4·23	4·97	2·57	28·06	4·68
1929	3·07	4·63	7·89	5·54	3·19	3·63	27·95	4·66
1930	5·03	6·27	8·03	6·77	5·57	1·93	33·60	5·60
1931	6·15	7·06	8·03	6·90	3·22	3·72	35·08	5·85
1932	4·91	5·50	5·84	6·99	3·46	1·36	28·06	4·68
1933	4·97	6·20	7·30	4·67	2·37	1·88	27·39	4·56
1934	5·28	5·50	6·74	5·49	1·98	2·66	27·65	4·61
1935	3·67	4·95	5·33	5·45	4·43	2·18	26·01	4·33
1936	7·50	6·69	8·86	6·47	3·81	4·97	38·30	6·38
1937	5·78	7·26	7·02	4·91	2·60	1·59	29·16	4·86
1938	3·35	4·01	5·77	4·59	2·62	2·24	22·58	3·76
Average for 17 years	4·98	5·33	6·43	5·27	3·41	2·50	27·92	4·65

TABLE 4:—Monthly Mean Velocity of Wind in Miles per Hour at Lethbridge. 1922-1938

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average for 12 months
1922	17·3	9·9	13·9	12·7	13·9	9·6	7·8	10·4	13·4	10·6	12·5	14·4	12·2
1923	14·0	15·0	15·2	11·1	11·8	9·6	5·0	4·5	6·7	10·1	15·9	17·6	11·4
1924	14·2	13·3	8·7	13·6	8·6	7·9	7·3	8·2	10·5	12·4	14·6	11·4	10·9
1925	13·4	10·5	12·6	11·9	11·2	7·8	7·8	9·7	7·9	8·4	13·5	11·4	10·5
1926	14·1	15·3	11·3	11·4	13·5	9·2	8·2	7·8	7·5	12·3	7·8	15·1	11·1
1927	13·7	9·9	13·1	14·4	13·4	9·9	7·0	7·9	10·7	13·4	11·1	12·0	11·4
1928	15·4	13·3	12·9	11·4	11·9	8·0	6·7	6·9	7·8	11·0	12·9	13·8	11·0
1929	8·6	9·6	11·7	10·5	9·0	9·4	8·4	7·5	5·9	11·0	13·1	12·4	9·8
1930	8·7	14·9	10·8	10·8	11·1	9·7	6·9	5·7	7·8	9·7	12·5	15·4	10·3
1931	15·0	11·8	11·8	13·0	10·3	10·0	7·3	6·2	7·9	10·7	8·8	12·3	10·4
1932	11·6	12·9	7·4	12·3	9·0	6·9	7·6	8·0	7·4	10·2	10·6	12·0	9·7
1933	12·9	13·9	10·3	9·5	9·2	8·2	7·0	4·1	6·2	6·0	13·6	8·8	9·1
1934	15·2	10·2	11·3	10·9	10·0	7·6	7·3	6·0	7·2	11·4	9·6	9·6	9·7
1935	9·6	9·9	10·8	10·0	8·4	8·3	7·1	6·9	6·9	10·8	10·5	10·1	9·1
1936	7·3	6·2	11·6	10·7	9·8	7·8	6·7	5·4	6·4	10·3	13·3	11·9	8·9
1937	10·5	11·2	8·5	12·8	10·9	8·8	6·4	7·0	4·8	7·9	6·3	9·4	8·7
1938	9·6	3·9	11·2	9·9	9·4	6·0	5·0	5·3	5·2	7·6	12·5	12·2	8·1
Average for 17 Years	12·4	11·3	11·4	11·6	10·7	8·5	7·0	6·9	7·7	10·2	11·7	12·3	10·1

TABLE 5.—Monthly Hours of Bright Sunshine at Lethbridge. 1922–1938

Year	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Hours
1922	83·7	122·3	165·4	152·6	254·9	267·2	302·1	268·9	198·1	157·3	106·0	69·3	2,147·8
1923	69·6	112·0	164·3	235·6	270·6	235·9	287·6	274·8	212·8	184·4	120·7	110·6	2,278·9
1924	86·2	120·8	154·3	207·9	281·4	226·4	324·4	243·0	227·0	151·9	108·7	61·9	2,193·9
1925	68·1	107·1	136·0	199·1	335·1	279·7	305·0	318·0	151·0	106·2	118·0	93·6	2,216·9
1926	93·8	102·2	184·2	239·8	244·6	292·9	343·7	246·3	160·1	196·9	97·5	103·2	2,305·2
1927	115·2	90·8	188·4	221·4	135·6	287·1	308·5	273·3	182·0	178·7	61·1	87·9	2,130·0
1928	108·8	161·7	174·0	214·6	343·6	225·6	325·6	303·9	283·0	132·3	159·1	112·3	2,544·5
1929	100·9	144·5	149·4	216·2	247·9	279·8	364·7	337·8	192·6	201·5	116·2	87·6	2,439·1
1930	98·9	117·9	153·8	218·3	211·7	268·0	363·5	311·3	165·3	156·9	114·8	133·0	2,313·4
1931	121·3	173·2	150·9	243·8	256·2	301·5	335·5	327·4	187·0	214·1	117·4	117·5	2,545·8
1932	105·7	113·9	115·8	174·2	258·9	262·5	374·5	313·6	241·5	142·7	97·9	100·6	2,301·8
1933	130·6	113·1	163·1	199·1	271·8	346·5	405·5	314·1	205·8	144·7	101·0	46·2	2,441·5
1934	106·2	169·9	137·4	282·5	292·2	263·8	357·5	302·2	140·8	149·5	102·8	96·6	2,401·4
1935	97·6	170·6	171·3	197·4	248·3	263·7	344·7	321·3	229·6	168·2	109·3	113·2	2,435·2
1936	74·0	121·4	127·9	198·0	311·6	303·6	384·9	276·1	202·1	183·7	148·5	85·8	2,417·6
1937	77·7	94·2	123·3	226·5	284·2	301·5	330·1	321·0	203·4	143·0	103·1	70·7	2,278·7
1938	113·0	130·1	177·4	208·0	215·0	250·9	334·3	305·4	283·4	209·4	85·0	78·1	2,390·0
Mean for 17 years	97·1	127·4	155·1	213·8	262·6	273·9	340·7	297·6	203·9	166·0	109·8	92·2	2,340·1
Average Monthly Sunshine for 17 years	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	195·0
Mean for 30 years	98·0	123·7	161·2	211·2	255·6	287·6	339·6	300·6	207·9	166·1	112·1	91·2	2,354·8
Average Monthly Sunshine for 30 years	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	196·2

IRRIGATION OF WHEAT

Much literature is available reporting experiments with the irrigation of wheat. Only that is cited in this paper which seems to bear especially on the problem here involved; that is, the optimum time and frequency of irrigation.

Review of Literature on Irrigation of Wheat

In tests at Brooks and Ronalane, Alberta, Snelson (46) received maximum yields of wheat with five four-inch irrigations. Under the different conditions found in Utah, Widtsoe and Merrill (57) obtained greater yields of grain from one light irrigation of 3·5 inches applied when the heads were filling out than when this irrigation was applied soon after the middle of June when the plants were smaller. Widtsoe (53) states that "it is seldom necessary to give wheat more than three irrigations except, possibly, in the hot climate of Arizona and similar regions. In fact, two irrigations are usual, and one irrigation ordinarily ample wherever the annual precipitation is between 12 and 15 inches." Smith

(45) recommends irrigating wheat when just out of the boot. From experiments conducted in Utah in 1890 to 1893, Sanborn (43) obtained increased yields of wheat in three years out of four when an irrigation in early May was given in addition to three later irrigations as compared to the three later irrigations only.

At the Gooding Substation, Idaho, Welch (51) obtained the best yields with three irrigations applied in the jointing, booting and heading stages. Two irrigations applied in the jointing and heading stages gave but slightly lower yields, while two applied in the booting and heading stages gave 2·3 bushels less than the three irrigations. Where but one irrigation was given, the best yield was secured when this was applied in the jointing stage. One irrigation applied in the booting stage gave better results than a later irrigation. Irrigating at the time of heading appeared to be of no value. Fortier (15) says that "when grain is heading out is the critical period of its irrigation." A field at Lethbridge, Alberta, is reported by Porter (40) that yielded 31 bushels per acre with an irrigation the first week in June. Part of the same field irrigated ten days later yielded 26 bushels per acre and another irrigated on June 17 produced 19 bushels per acre. A part of this field not irrigated gave a yield of 15 bushels per acre.

In a carefully conducted experiment at the Colorado Station, where canvas roofing was used to keep all precipitation off the plots, Kezer and Robertson (28) obtained the highest yield where only one six-inch irrigation was given, when this was applied in the jointing stage. The plots irrigated at heading yielded a little less. Plots irrigated at germination or tillering yielded less than those irrigated at jointing or heading. The difference in yields when water was applied at germination and at tillering was so small that there was no real significance between the two. When water was applied at the filling stage, it was of little benefit to the crop. In a further extension of these experiments, Robertson, Kezer, Sjogren, and Koonce (41) placed the yields of grain with one six-inch irrigation in the descending order of jointing, heading, tillering, blossoming, germination, and filling, and the yields of straw in the order of jointing, tillering, heading, blossoming, germination, and filling.

The greatest yield of wheat was secured by Knight and Hardman (32) in Nevada, when irrigations were applied in the boot, bloom, milk and soft-dough stages. Another irrigation applied in the five-leaf stage did not increase the yield. When only three irrigations were given, the best times of application were at the boot, bloom and milk stages of growth.

In a four years' test (1912-1915) at the Utah Station on a loam soil quite similar to the Lethbridge Station soil and with an annual rainfall also similar, Harris (21) obtained the greatest yield of wheat with three irrigations applied at the five-leaf, the early-boot and the bloom stages. Where only one irrigation was given, the best time to give it was in the five-leaf stage. Where two irrigations were applied, the five-leaf and boot stages were best. Water applied after the grain was planted, but before it was up, and that applied after the dough stage decreased the yield. He also found that water applied during early growth increased the height of wheat more than water applied at any other time and that the maturity of wheat was retarded by excessive irrigation.

The same author (22), when working with a clay loam soil in pots, found that wheat matured sixteen days earlier with 20 per cent moisture in the soil than with either 11 per cent or 45 per cent moisture, and that the period at which high moisture was applied had considerable effect on the date of ripening. The number of kernels to each head was greatest on soil with medium moisture content but the weight of 100 kernels was greatest on the driest and lowest on the wettest soil.

Working in Nevada, in 1911, True (47) obtained the best yields of wheat from three irrigations before heading and two irrigations after heading. In 1913, two irrigations before and two after heading gave the highest yields.

Application of Water to Wheat at Lethbridge

In the first five years of these experiments, wheat received from one to four irrigations applied at one or more of the following periods: in the fall preceding the planting of the crop, or when the crop was in the three-leaf, five-leaf, shot blade, flowering or soft dough stages of growth. Sixteen variations in treatment were made during this five-year period. The four-irrigation treatments and four others then were discontinued as it seemed evident that they were not desirable practices. Nine variations were continued for an additional eleven years making a total of sixteen years that these treatments were compared.

The yearly average yields from replicate plots of each nine treatments together with the sixteen-year averages, are given in table 6 for wheat after a cultivated crop and for wheat after wheat.

TABLE 6.—Yields in Bushels per Acre of Wheat Irrigated at Different Stages of Growth

Year	Stages of Plant Growth when Water was Applied and Number of Irrigations in the Season								
	None	Fall 1	3-leaf 1	5-leaf 1	S.B. 1	Fl. 1	Fall and Fl. 2	5-leaf and Fl. 2	5-leaf S.B. and Fl. 3
Wheat After a Cultivated Crop									
1923	28·6	39·6	31·0	32·2	36·3	33·1	38·5	33·3	38·2
1924	39·2	45·9	42·6	39·4	40·1	41·4	48·4	43·7	36·9
1925	53·1	60·8	58·0	53·3	56·0	44·1	55·8	56·2	54·9
1926	24·2	20·5	34·2	33·2	32·3	30·8	31·1	35·8	44·2
1927	45·0	37·0	48·4	52·8	57·8	49·0	46·8	39·1	49·6
1928	38·7	47·6	41·9	44·5	39·7	44·7	51·7	36·9	42·6
1929	54·6	55·2	51·9	.....	63·0	58·2	61·1	.....	.....
1930	25·9	15·2	38·5	32·9	26·8	26·8	25·1	47·5	56·6
1931	21·3	27·7	28·3	28·9	32·9	23·1	31·8	35·0	36·2
1932	33·8	31·8	30·1	34·1	36·7	40·8	28·1	35·0	40·3
1933	31·5	29·2	30·3	30·1	38·3	32·9	34·0	46·7	53·3
1934	16·5	23·3	20·5	23·5	26·7	25·3	17·0	29·7	31·0
1935	28·2	29·9	37·7	41·5	41·3	35·6	40·7	49·5	56·6
1936	6·2	18·4	22·2	33·7	31·8	5·4	37·6	39·6	49·1
1937	34·2	27·7	31·7	45·6	36·5	37·4	33·6	43·9	48·4
1938	32·3	31·7	36·4	41·9	40·6	39·5	46·2	42·2	49·6
16-years Average	32·1	33·8	36·5	x37·8	39·8	35·5	39·2	x40·9	x45·8
Wheat After Wheat									
1923	39·8	36·9	54·5	47·3	53·6	41·2	40·1	49·8	35·7
1924	4·0	27·5	26·8	28·2	31·3	21·2	35·3	33·4	36·7
1925	38·2	48·2	35·6	43·6	45·0	42·3	36·0	41·8	41·8
1926	28·0	34·3	35·4	33·7	22·8	26·0	27·8	35·6	32·6
1927	39·4	42·4	33·8	46·4	44·0	40·5	33·4	33·4	43·1
1928	38·1	34·1	36·3	36·7	36·2	36·5	34·3	28·0	33·0
1929	38·4	46·8	42·8	.....	45·0	41·9	48·2	.....	.....
1930	33·8	28·9	38·2	39·4	34·7	26·5	30·1	50·2	54·5
1931	22·7	5·3	17·2	21·3	15·7	18·1	11·9	21·7	29·7
1932	33·3	36·2	39·3	37·5	39·9	43·2	46·4	49·0	53·4
1933	17·8	21·0	23·1	27·1	28·0	24·5	29·5	39·9	40·5
1934	25·9	25·5	34·3	31·3	46·5	43·3	46·8	42·8	44·6
1935	27·9	27·2	35·6	39·1	30·6	34·8	34·0	47·0	54·1
1936	11·5	22·1	24·9	22·1	25·5	11·4	22·9	33·8	33·8
1937	15·0	28·9	29·8	39·3	28·9	18·5	19·3	36·9	42·5
1938	29·4	32·6	33·6	41·3	42·9	41·4	39·1	43·9	37·3
16-years Average	27·7	31·1	33·8	x35·6	35·7	31·9	33·4	x39·1	x40·9

Note: xAverage for 15 years.
Fl.—Flowering, S.B.—Shot Blade.

The irrigation requirements of wheat after a cultivated crop were about the same as where wheat followed a wheat crop except that the plants required water earlier to prevent injury from drought where wheat had been grown the preceding year. The yields of all of the plots were better following a cultivated crop than following wheat. This was especially true on the plots that received no irrigation; the average difference between the unirrigated plots and those receiving one irrigation applied the preceding fall having been but 1·6 bushels more in favour of the fall irrigation after a cultivated crop and 3·5 bushels where wheat followed wheat.

The yields of the unirrigated plots were higher than those secured during the same period on the dry land part of the Station. Soil moisture studies made during the first five years definitely indicated that this was not the result of lateral seepage from ditches on irrigated plots, but was due to the residual effect of previous years irrigations. In the last eleven years an attempt was made to overcome this difficulty by maintaining two sets of plots for each crop, one used for irrigation tests, and the other not irrigated that year. The following year, the irrigation tests were conducted on the plots that had received no irrigation. This procedure had the result of unifying the moisture content of the soil but it did not reduce the yields of the unirrigated plots as low as those secured on the dry land. Borings to a depth of 10 feet did not show a water table at that depth but the soil remained moist below the fifth foot after the year of cropping without irrigation. This higher yield for a year or two, on land that has been irrigated, is a common experience in irrigation farming and one that must be considered along with high water tables and other factors in formulating an irrigation practice for any locality.

Value of Fall Irrigation

The wheat seeded on land irrigated the previous fall, gave a slightly lower average yield when but one irrigation was applied than where a single irrigation was given in the three-leaf, five-leaf or shot blade stages, while the fall-irrigated plots gave almost as high an average as the other plots when additional water was applied during the growing season. Fall irrigation sometimes causes the soil to remain wet in the spring and delays cultural operations. This is especially true on heavy soils.

Early Irrigation for Wheat

The opinion has been prevalent among irrigation farmers that it is detri-- mental to grain crops to irrigate them before the plants are high enough to shade the ground. This experiment did not support such an opinion as the plots irrigated when but three leaves had appeared gave practically the same yield as was obtained when the irrigation was postponed until the five-leaf stage, which was approximately two weeks later, or until the shot-blade stage, twenty-five days later. When the water was applied in the three-leaf stage, the plants turned yellow and for a few days appeared to be injured by the water, but within a week they had regained their colour and for the balance of the year were as thrifty as adjoining plots irrigated at a later date. It is undoubtedly this temporary yellowing of the plants that has caused irrigators to think that early irrigation is detrimental to grain.

It should be remembered that these results were obtained on a sandy clay loam soil that does not "bake" or form a crust on the surface to any serious extent after an irrigation. Grain crops on a heavier soil that " bakes " badly may not respond as well to early irrigation.

of water, at the heading to flowering stage, may be required. On soil that is light or low in fertility, three irrigations may be necessary and in extremely dry years, three irrigations may be desirable on any soil.

Undoubtedly the most important item for the irrigation farmer to bear in mind in considering his irrigation practice for wheat is to apply the first irrigation before the crop shows signs of needing water. It seems advisable to irrigate as much of the grain land as possible in the previous fall, and as soon as seeding is finished in the spring to ditch the fields that were not fall-irrigated and start irrigating early enough so that the first irrigation will be completed before any of the grain is injured from lack of water. Should subsequent irrigations be required, they should be made before growth is checked by lack of moisture.

IRRIGATION OF ALFALFA

Of all the factors contributing to the success of irrigation farming, the introduction of alfalfa as a forage and rotation crop is perhaps the greatest. As alfalfa is an important crop in almost all localities where irrigation water is used, it is only to be expected that numerous investigators have attempted to determine satisfactory irrigation practices for this crop. There seems to be a general agreement in the findings of most of the investigators that alfalfa requires a comparatively constant soil-moisture supply throughout the season, necessitating several irrigations where rainfall is light.

Review of Literature on Irrigation of Alfalfa

Working under the different conditions encountered at various stations of the Canadian and American West, investigators of the best number and time of irrigations have arrived at different final recommendations. At Brooks, Alberta, Snelson (46) obtained the greatest yield of alfalfa from five six-inch irrigations, although six four-inch irrigations gave almost the same yield. In New Mexico, Bloodgood and Curry (7) found ten irrigations necessary for maximum yields, while farther north in the lower Snake River Valley of Idaho, Bark (2) reported five irrigations as the general practice. Beckett and Robertson (5) received maximum yields from four nine-inch irrigations on the Davis Farm, California, and another group of workers in the same state (1) recommends that alfalfa planted on very open or impervious soil should be irrigated more than once between cuttings.

Knight and Hardman (32), in Nevada, secured the greatest yields from the maximum application of water, 81 acre-inches per acre. Almost as good yields were obtained with 66 inches applied in eleven six-inch irrigations.

Sometime earlier, Knight (30) reported the use of 102 inches of water in the season on a gravelly soil, while on a sandy clay soil with clay subsoil 36 inches was sufficient for alfalfa. In the same bulletin, he reported yields of from 6·06 tons to 6·63 tons of alfalfa hay per acre when the crop was irrigated so that the plants were never allowed to show signs of needing water, 5·61 to 5·64 tons when plants showed need of water by dark green colour of foliage before being irrigated, and 3·98 to 5·18 tons when plants showed need of water by dark green colouring and drooping of leaves when irrigated.

For Arizona conditions, Smith (45) recommends irrigating alfalfa when two-thirds grown, but not just after cutting.

Widtsoe and Merrill (57) found that it made little difference on the yield of alfalfa at the Utah Station whether water was applied just before or just after cutting the hay crop. Widtsoe (53) considers that it is sufficient under conditions of deep soil and moderate evaporation to give the crop one irrigation for each cutting; two or three light irrigations for each cutting, he does not think objectionable. Regarding fall irrigation he states: "If fall and winter rainfall

is insufficient to saturate the soil, fall or winter irrigation, especially if the winters are mild and open, has been found quite satisfactory."

In 1899, King (29) recommended two irrigations for each crop of alfalfa although he states that the usual practice at that time was to give but one irrigation for each crop. Etcheverry (12) states: "When the alfalfa has established a well-developed root system the common practice on retentive soils is to apply one irrigation either before or after cutting." He also says that "the number of irrigations per year for alfalfa ranges from four in Montana to twelve in parts of California and Arizona." Fortier (17) stated that "The water requirements of alfalfa exceed those of almost any other crop" and advised that "Except during its dormant stages, the plant should be furnished with sufficient water to permit it to grow continuously at a maximum rate." He makes the further interesting observation that "Under ordinary conditions, about 750 tons of water is absorbed by the roots... and mostly transpired through the leaves for each ton of cured hay harvested." Eisenhauer and Freng (11) recommend fall irrigation for alfalfa on well drained soils in Alberta and an additional irrigation immediately after each crop is harvested.

Application of Water to Alfalfa at Lethbridge

In these experiments alfalfa received from one to five irrigations as shown in table 10.

On the plots reported, two crops of alfalfa hay were secured each year. The alfalfa was cut when the plants were from one-half to three-fourths in bloom, raked up as it was cut, and weighed in the green state. A quantity of the green plants was immediately run through a chopper, duplicate two-pound samples of the cut material secured, and the dry matter determined by drying to constant weight at 100° C. The total dry matter produced on each plot was determined and 10 per cent arbitrarily added to this weight to convert it to a hay equivalent. Several tests made of alfalfa hay in the stacks at the station showed well-cured hay to contain approximately 10 per cent of moisture.

The computed tons of hay per acre obtained from each irrigation treatment for the five years that the test has been under way are shown in table 7. The five-year average is also given.

TABLE 7.—Yields in Tons per Acre of Alfalfa, Irrigated at Different Stages of Growth 1923-1927, with 5-year averages

Number of Irrigations	Stages of Plant Growth When Water was applied	5-year Average	1923	1924	1925	1926	1927
None	Dry	1·55	2·10	1·96	0·39	1·30	2·02
1	Fall	3·30	2·71	2·44	4·11	3·92	3·34
1	E.M	3·45	2·85	2·69	4·13	4·38	3·22
1	12″ H	2·99	2·94	3·00	3·38	2·74	2·90
1	B.I.C	2·45	3·32	2·04	1·56	2·46	2·89
1	A.I.C	2·48	2·84	2·73	1·74	2·02	3·08
2	F. 12″ H	3·38	3·22	2·58	4·05	3·82	3·22
2	F. B.I.C	3·17	2·81	2·78	3·11	4·08	3·06
2	F. A.I.C	3·23	2·90	2·69	3·40	3·64	3·51
2	E.M. 12″ H	3·42	2·85	2·87	3·91	4·52	2·96
2	E.M. B.I.C	3·27	2·96	2·43	3·56	3·78	3·64
2	E.M. A.I.C	3·31	3·05	3·52	2·90	4·30	2·76
3	F., 12″ H, A.I.C	3·63	2·92	3·45	3·94	4·52	3·34
3	E.M., 12″ H., A.I.C	3·70	2·90	3·59	4·23	4·44	3·33
4	E.M., 12″H, A.I.C. 2nd, 12″ H	3·45	3·47	3·15	3·97	3·79	2·89
5	F, E.M., 12″ H, A.I.C., 2nd, 12″ H	3·37	3·66	3·05	4·87	3·76	3·33
	Crop needs	3·66	2·99	2·41	4·17	4·92	3·82

Abbreviations used: F—Fall. E.M.—Early May. 12″ H—12″ high.
B.I.C.—Before 1st cutting.
A.I.C.—After 1st cutting. 2nd 12″ H—2nd crop 12″ high.

and a higher yield for the irrigations before cutting in two years. The results of this experiment seem to agree with the findings of Widtsoe and Merrill (57) —that it makes little difference in yield whether irrigations are applied just before or just after cutting. Bingham (6) states that "If irrigation is delayed until after cutting there may be some delay in starting the next crop. On the other hand there may be difficulty in curing the hay if the crop is irrigated too near the time of cutting."

FALL VERSUS SPRING IRRIGATION.—Five comparisons between fall and spring irrigations are shown in table 7, one with only the fall irrigation, three with one additional irrigation and one with two additional irrigations. The five-year average production was greater on each set of plots irrigated in the spring than on those irrigated in the fall. The only difference of yield great enough and constant enough from year to year to be significant, was on the plots receiving but one irrigation. The five-year average yield of hay on the plots receiving one irrigation in the spring was 300 pounds more than the yields on the plots irrigated only in the fall. Not only was the average yield greater, but in four years out of five, the yield was more with spring irrigation. The "wet" year of 1927 was the one year when the plots irrigated only in the fall produced more hay than those irrigated in the spring.

The results of these tests, and especially the observed condition of the crops as they were growing, and the soil moisture studies, indicate that a fall irrigation is not as effective in producing a crop of hay the following year as is an irrigation in the spring. This seems to be due to there being less water available for the crop from a fall irrigation, due to losses between the time when the water is applied in the fall and when growth starts in the spring.

When additional water was applied during the growing season before plant growth was checked by a need of water, the yields obtained were as high on the fall-irrigated plots as on those irrigated in the spring. While an early spring irrigation gave better results than a fall irrigation, if the spring irrigation was postponed until the plants were 12 inches high, the fall irrigation was superior.

The results of these tests would suggest the advisability of irrigating enough of the alfalfa field in the fall so that the balance could be covered with water in the first half of May.

Number of Irrigations Required for Alfalfa

Four irrigations gave the highest five-year average yield of alfalfa, followed closely, even in dry years, by three irrigations, one applied in early May, another when the plants were 12 inches high, and the third immediately after the first crop was harvested. In the drier years, two irrigations were not enough to produce heavy yields, but in the seasons of medium rainfall, two were sufficient.

Suggested Irrigation Practice for Alfalfa

All of the alfalfa should be irrigated in the fall or early May of the following spring, unless an unusually wet fall or wet spring is experienced. If May is dry, another application of water when the crop is about 12 inches high is desirable. If the season continues dry, a third application of water before or just after cutting may be required and if a third crop is to be harvested, another irrigation is usually necessary immediately after the second crop is removed.

IRRIGATION OF POTATOES

Light to medium-textured, well-drained soils in districts suitable for irrigation are usually admirably adapted to the growth of potatoes. Most of the irrigated lands of Alberta will produce good crops of potatoes; in fact it is doubtful if there is an area anywhere on the continent where better yields can be secured, or potatoes of higher quality grown.

Review of Literature on Irrigation of Potatoes

With one or two exceptions, the findings of investigators have been that potatoes require several irrigations, especially after tubers start to form on the stolons of the plants.

The opinions of two Alberta investigators are available on the best irrigation practice for potatoes. Four three-inch irrigations at Brooks and five three-inch irrigations at Ronalane produced the maximum yields of potatoes, according to Snelson (46). Fairfield's recommendation (14) is that: " If possible the first irrigation should not only be very light, but it should not be given until the small potatoes are set and are perhaps the size of peas. This stage is usually about the time the first blooms appear."

Irrigation workers in the United States have recommended a wide variance of irrigation practice for potatoes. Four reports from Utah are available. Widtsoe and Merrill (57) secured the best yield with six irrigations, but four heavier irrigations gave almost as good a yield. Widtsoe, (54) states: "Potatoes need a good supply of water in the soil at planting time..... Little water is needed by potatoes during the first period of growth, provided there is a plentiful supply in the soil at the time of planting..... It is seldom advisable to irrigate oftener than every two weeks, and every three or four weeks frequently gives satisfactory results. Irrigation should cease about the middle of August, leaving about sixty days for the ripening of the potatoes." Working with Stewart, Widtsoe (58) found the percentage of water in the tubers little if any affected by the application of too much water. Two other experimentalists in this state, Harris and Pittman (23) found the practice of watering potatoes before they were up so ruinous that it was dropped from their tests. They also found that applying all the water very early or very late in the season was undesirable. Their best yields were obtained from moderate irrigations given at regular intervals of 7 and 14 days during the dry summer season, beginning when the plants were six inches high and discontinuing about a month before harvest. Fortier (19) states that "Potatoes can be 'irrigated up' more successfully than other crops but it is not good practice" and that "Since potatoes are not deep rooting and are sensitive to drought, they require rather frequent irrigations after the tubers are set." In New Mexico, Bloodgood and Curry (7) obtained the highest yields from four five-inch irrigations distributed over a period of three months. Bark (4) found five or six irrigations necessary for maximum yields in Southern Idaho, while in Nevada, Knight and Hardman (32) obtained the highest yields from five three-inch irrigations given when the plants showed a tendency to wilt or before wilting was noticeable. Working as early as 1892, Buffum (9) explained the effect of early irrigation of potatoes in Wyoming thus: "When irrigated immediately before setting, a greater number of potatoes will be formed than the plant can properly support, few of them becoming large enough for market. When the tubers are allowed to form first and irrigated afterwards, fewer potatoes will form in each hill but a larger crop of marketable potatoes is the result." Etcheverry (12), generalizing on the number of irrigations required for potatoes, says, "The number of irrigations will vary from two to four for ordinary sandy loam, and from four to six light irrigations for a porous sandy soil or shallow soil."

Bingham (6) stresses the importance of a good supply of moisture in the soil, in order to germinate the potato seed pieces and of keeping the ground moist throughout the entire season, to encourage continuous growth.

Application of Water to Potatoes at Lethbridge

In the first five-year period of these experiments, potatoes received from one to six irrigations but six irrigations seemed quite definitely to over irrigate the potatoes, so in 1928 the six irrigations and other applications that were obviously undesirable were dropped. Only those tests that were carried through

the entire time of the experiment are reported here. The time when the potato plants started to bloom was found to be the easiest growth period to determine, so it was used as the basis for specifying the time of all irrigations except the fall irrigation and the one applied when the plants were half grown. The schedule of irrigations together with the yields of the unsorted and marketable tubers are reported in table 8. A serious infestation of psyllids so influenced the yields in 1938 that no data are reported for that year.

TABLE 8.—Yields in Pounds per Acre of Potatoes Irrigated at Different Stages of Growth

STAGES OF PLANT GROWTH WHEN WATER WAS APPLIED AND NUMBER OF IRRIGATIONS IN THE SEASON

Year	None	Fall 1	Tops Half Grown 1	S.B. 1	21 Days S.B. 1	S.B. and 14 ds. S.B. 2	S.B. and Every 21 ds. 3	S.B. and Every 4 ds. 4	S.B. and Every 10 ds. 5
UNSORTED POTATOES									
1923	10,280	20,280	15,940	20,260	20,300	18,310	17,160	18,980	19,290
1924	20,490	26,200	17,340	17,460	23,820	20,700	26,420	17,650	21,800
1925	8,610	18,000	16,970	20,850	19,910	25,990	30,200	30,120	33,450
1926	12,510	14,700	13,920	17,180	13,790	19,160	17,790	22,340	22,340
1927	24,570	24,570	25,960	26,250	28,000	29,670	29,440	24,540	28,670
1928	10,420	14,700	11,880	11,690	10,670	12,150	13,620	12,540	12,580
1929	10,420	11,050	13,200	18,570	18,840	14,520	12,790	10,840	10,500
1930	12,500	12,740	14,270	15,190	18,140	17,620	18,410	18,990	21,730
1931	7,220	10,960	10,050	9,550	15,080	.....	17,380	23,840	22,410
1932	12,870	15,520	12,830	11,470	19,980	20,000	23,500	21,640	23,130
1933	9,980	12,840	11,280	13,480	18,060	22,550	24,910	27,980	26,480
1934	15,160	10,980	11,880	14,630	18,900	18,860	22,410	32,080	28,260
1935	11,190	11,700	11,680	12,260	11,790	17,160	18,790	18,920	17,330
1936	8,340	10,350	12,540	13,200	15,750	21,540	22,010	21,980	19,110
1937	14,490	18,140	15,840	15,670	16,590	19,200	19,990	21,680	19,530
15-year Average	12,600	15,520	14,370	15,850	17,970	*19,820	20,990	21,610	21,770
MARKETABLE POTATOES									
1923	9,010	18,600	14,560	18,490	18,650	16,780	14,750	16,060	16,820
1924	19,380	25,090	16,440	16,680	22,320	18,960	25,140	15,770	20,180
1925	7,260	16,840	15,900	20,180	18,380	24,210	28,680	26,840	31,920
1926	11,650	14,200	13,060	16,740	12,470	18,520	16,740	20,980	20,980
1927	22,970	22,970	24,820	25,000	25,360	26,600	27,480	22,400	25,960
1928	7,850	11,130	9,330	8,230	7,780	9,010	9,690	8,870	8,330
1929	8,790	9,920	11,830	17,200	17,250	12,930	11,420	9,290	9,230
1930	11,910	12,150	13,550	14,040	17,010	16,630	17,330	17,730	20,290
1931	6,410	10,080	8,950	8,330	14,130	.....	16,510	22,550	21,240
1932	11,070	14,170	11,160	9,850	16,920	17,230	20,930	19,890	19,800
1933	8,510	11,370	9,270	12,130	16,800	19,310	22,560	25,570	24,030
1934	13,270	9,410	9,990	12,650	16,920	16,250	19,440	26,950	23,630
1935	10,680	11,090	10,650	10,990	10,260	15,130	17,400	17,550	16,080
1936	7,200	8,820	10,860	11,250	14,700	19,590	20,100	19,650	16,440
1937	12,780	17,210	14,280	14,050	15,360	15,670	18,130	19,390	17,010
15-year Average	11,250	14,200	12,980	14,390	16,290	*17,630	19,090	19,300	19,460

NOTE:—A severe infestation of psyllids made the yield data of 1938 valueless.
*14-year average.
S.B.—Starting to Bloom.
21 ds. S.B.—21 days after starting to bloom.
ds.—Days.

Stage of Plant Growth when Irrigation was most Effective for Potatoes

The lowest average yield from any plot-series irrigated but once was obtained from plots receiving water when the plants were half-grown. There was little difference in the yields of the plots irrigated the previous fall and those irrigated in the starting-bloom period, but where but one irrigation was

given the average yields for the 16 years was greater by about one ton per acre when this application was postponed until 21 days after starting to bloom. In some of the years when the early part of the season was dry the potatoes were injured by drought when irrigation was delayed until 21 days after blooms were first observed, and the yield was lower than was received from one irrigation applied earlier. In most years, however, the potatoes receiving but one early irrigation became too dry later with the result that yields were seriously reduced.

Number of Irrigations required for Potatoes

Two irrigations gave an average yield of about one ton per acre more potatoes than was secured from one irrigation, and three produced just over a half ton more than two irrigations. In the very dry years a fourth irrigation increased yields somewhat but a fifth irrigation did not seem to be beneficial.

Effect of Irrigation Treatment on Quality of Potatoes

Some prejudice has existed in the minds of many people against potatoes grown on irrigated land, as it is thought that the application of water has a tendency to increase the water content of the potatoes and make them "soggy." As already quoted, Widtsoe and Stewart (58) found that the water content of ripe potatoes was not increased by applying too much water.

In 1924 and 1925, the Department of Household Economics of the University of Alberta, under the direction of Miss Mable Patrick, co-operated in the experiment with potatoes by making laboratory and cooking tests of samples of uniform tubers of medium size from each irrigation treatment. Table 15 contains the quality scores of the potatoes submitted for tests for the two years as reported by Miss Patrick. In 1924, only one sample was sent from the duplicate plots receiving the same treatment, but in 1925 tests were made of potatoes from each plot. The two scores shown for each treatment in 1925 are for the duplicate plots.

There was no uniformity of quality for the same treatment in different years nor for duplicate treatments in the same year (table 9). Nor was there any uniform improvement in quality when the number of irrigations was increased or decreased. About the only inference that could be drawn from these data was that the irrigation treatment did not affect the reported quality factors sufficiently to overcome individual differences in the tubers.

In addition to the quality tests made at the University of Alberta, potatoes of uniform appearance from various irrigation treatments were numbered and given to families residing on the Lethbridge Station. Steaming, boiling and baking tests were made by the housewives of these families. Their reports agreed with the laboratory tests reported—that the irrigation treatment had not affected the quality of the potatoes to a noticeable extent.

Each year at harvest the tubers were carefully observed for scab, rhizoctonia sclerotia, misshapen potatoes, secondary growths, and other observable characters that might affect the quality of the potatoes. They were also field and bin inspected for certification each year by a Dominion inspector and the prevalence of disease noted, but there was no apparent difference in the disease occurrence in the crops of various irrigation treatments.

Some second growths, resulting in "knotty" potatoes, were observed in the drier years when the first irrigation was delayed until ten days after full bloom or three weeks after starting bloom. This condition appeared to have been caused by the potatoes starting to ripen due to lack of water and then when the water was applied, sprouting into new growths at the eyes of the partially ripened tubers.

TABLE 9.—Effect of Irrigation Practice on the Quality of Potatoes, 1924 and 1925

Number of irrigations in season	Stage of plant growth when first irrigated	Time of, or intervals between, subsequent irrigations	Average quality score	
			1924	1925
None			86·5	53·4
None			.....	72·0
1	Half-grown		77·8	67·6
1	Half-grown		.....	62·6
1	Starting-bloom		87·5	78·6
1	Starting-bloom		.....	64·2
1	Full-bloom		67·0	75·8
1	Full-bloom		.....	72·0
1	Fall		69·5	66·2
1	Fall		.....	72·4
1	10 days after f.b		69·5	62·4
1	10 days after f.b		.....	70·2
2	Fall	Starting-bloom	69·5	73·0
2	Fall	Starting-bloom	.....	79·0
2	Fall	Full-bloom	66·3	67·6
2	Fall	Full-bloom	.....	68·4
2	Starting-bloom	10 days	69·5	70·6
2	Starting-bloom	10 days	.....	75·6
2	Full-bloom	10 days	67·0	67·2
2	Full-bloom	10 days	.....	73·0
3	Starting-bloom	10 days	58·5	70·8
3	Starting-bloom	10 days	.....	72·2
3	Starting bloom	20 days	68·8	74·2
3	Starting-bloom	20 days	.....	59·6
4	Half-grown	10 days	77·5	76·6
4	Half-grown	10 days	.....	73·4
4	Starting-bloom	10 days	77·3	76·0
4	Starting-bloom	10 days	.....	68·2
5	Starting-bloom	10 days	61·5	83·5
5	Starting-bloom	10 days	.....	78·0
6	Starting-bloom	10 days	82·5	66·6
6	Starting-bloom	10 days	.....	59·6

Another treatment that had a noticeable effect on the appearance of the potatoes was the application of an excessive number of irrigations. Where more than four irrigations were applied, the lenticels became enlarged, forming white spots on the skins of many of the tubers. This condition was apparent on the plots receiving as few as four irrigations in the wet season of 1927.

Suggested Irrigation Practice for Potatoes

These experiments would indicate that a good crop of potatoes can usually be raised on fertile, medium-textured soils without irrigation during the growing season in the years of above average rainfall, if the land has been irrigated the previous fall. The yields were increased in the drier years, however, by irrigating again soon after the plants started to bloom and by giving two more irrigations at intervals of three weeks. In very dry years, four irrigations at intervals of two weeks were desired.

It does not appear to be a good practice to irrigate before the plants start to bloom unless the soil is so dry as to retard growth.

IRRIGATION OF SUGAR BEETS

The Canadian Sugar Factories, Limited, erected a factory for the refining of beet sugar at Raymond, Alberta, in 1925, so sugar beets were included in the irrigation tests after that year. At present two factories are in operation in southern Alberta with a total beet area of about 20,000 acres.

Review of Literature

The sugar beet has become an important crop in most of the irrigated sections of the United States, and its irrigation has been the subject of investigations in a number of localities.

Widtsoe and Merrill (57) found, in tests at the Utah Station, that the greater the number of irrigations up to six, the larger were the yields of sugar beets. When six-inch irrigations were applied bi-monthy to a total of six, the best yields were secured. In the Sevier Valley, Utah which has an average annual precipitation of only 8·34 inches, Israelson and Windsor (25) reported that four or five irrigations were necessary. Harris (20), from five years' experiments in Utah, found that where but one irrigation was given, it was most effective when applied at the time the beets averaged about two inches in diameter. When the water was applied at the proper time, two or three irrigations of five inches each gave as good results as where more water was applied. Maximum yields were secured from the three irrigations applied just before thinning, when the beets averaged two inches in diameter, and when they were nearly ripe. The yields were almost as good when the irrigation before thinning was not given.

Working in Oregon, Powers (39) obtained maximum yields with one irrigation in three years out of five. In the other two years, two irrigations gave the best yields. In Nevada, Knight and Hardman (32) obtained the best yields from six three-inch irrigations. Roeding (42), a Colorado worker, secured higher yield per acre from 11·3 inches of water applied in two irrigations than from larger quantities in three or four irrigations.

Knorr (32) found that the yield of sugar beets on land receiving a fall irrigation and three growing-season irrigations was 1·6 tons greater than when the land received the three summer irrigations without an application of water in the fall. He secured best results when the beets were so irrigated as to keep the plant in good condition from the time of thinning to about three weeks before harvest.

Nuckols and Currier (38), in recommending an irrigation practice for the Billings region of Montana, state that "Beets should not be irrigated until they are too large to cultivate and the leaves have spread out so that they will cover the ground and shade it, so that the heavy crusts will not form in the furrows where the water has run. These beets are usually ready to irrigate about July 15 to 25." After irrigation is begun, they state that it is usually necessary to continue to irrigate every ten to twenty days from the time of the first irrigation until about the first of September.

For general Montana conditions, Bingham (6) advises keeping the beets supplied with ample moisture during the growing season. Brewbaker (8) in a test in Colorado covering two years of deficient rainfall, obtained the greatest yield with a very early (June 15) first application and a very late (September 20) last application, the applications being made at bi-weekly intervals during the season.

Application of Water to Sugar Beets at Lethbridge

From one to five irrigations were applied to sugar beets in these experiments as shown in table 10.

About 30 tons of barnyard manure per acre were ploughed under on the beet plots in the fall of 1924 and 20 tons per acre in the fall of 1931 and 1937. No artificial fertilizer was used until 1935. In that year and each succeeding year, ammonium phosphate was applied at the rate of 100 pounds per acre at the time of seeding the beets.

In every year of these tests except 1927, irrigation was necessary to secure a maximum yield of sugar beets. Irrigating in the fall previous to the year of seeding was of little or no value except in very dry years. Five weeks after

TABLE 10.—Yields in Tons Per Acre of Sugar Beets Irrigated at Different Stages of Growth

STAGES OF PLANT GROWTH WHEN WATER WAS APPLIED AND NUMBER OF IRRIGATIONS IN THE SEASON

Year	None	Fall 1	I.A.T. 1	6 W.A.T. 1	8 W.A.T. 1	5 W.A.T. 9 W.A.T. 2	5 W.A.T. 11 W.A.T. 2	Fall 5 W.A.T. 9 W.A.T. 3	Fall 2 W.A.T. 6 W.A.T 9 W.A.T. 1i W.A.T. 5
1926	10·75	13·47	13·56	12·07	.....	12·69	14·32	13·13	13·43
1927	21·75	19·70	16·95	19·07	.....	20·28	20·30	19·94	22·20
1929	13·47	16·07	13·33	16·38	18·51	16·19	18·25	16·32	16·29
1930	8·10	7·85	7·75	12·80	12·53	12·12	14·39	9·41	14·43
1931	2·95	4·32	16·77	11·25	12·73	11·33	12·29	11·89	14·54
1932	14·55	12·03	13·89	20·10	14·87	20·33	23·51	20·53	20·10
1933	7·15	6·00	7·10	17·23	11·84	13·97	15·41	12·63	13·85
1934	9·51	10·81	11·40	16·59	16·09	17·19	19·59	20·07	22·54
1935	4·51	6·17	6·55	9·41	11·04	13·00	11·69	14·19	15·08
1936	5·85	7·42	9·55	12·88	12·33	15·66	14·23	17·63	17·22
1937	13·47	15·23	14·17	17·98	17·29	16·61	17·03	16·57	19·51
1938	9·79	.....	17·47	20·71	18·39	21·47	20·28	.....	19·78
12-year Average	10·15	10·82x	12·37	15·54	14·56xx	15·90	16·77	15·66x	17·41

NOTE: Cutworms destroyed the crop in 1928.
In 1936 the five irrigation treatment was changed to: 2 W.A.T., 6 W.A.T., 9 W.A.T., 12 W.A.T., 14 W.A.T.
x—Average for 11 years. I.A.T.—Immediately after thinning.
xx—Average for 10 years. W.A.T.—Weeks after thinning.

Sugar Content of Beets

The Canadian Sugar Factories Limited have co-operated in the sugar beet experiments by determining the sugar content and purity of juice of the beets at harvest. Five or more beets were selected at random on each plot and tested for their sugar content and purity.

There was not a wide range of difference in the average per cent of sugar in the beets but it may be significant that the three treatments that had the lowest average sugar content were the ones where the beets suffered most for water, i.e., no irrigation, fall irrigation only, and 8 weeks after thinning. It is also interesting to note that there is no indication of a decrease in per cent sugar with the heavier applications of water or by continuing to irrigate until late in the season. There was a slightly, but not significantly lower average purity of juice in the beets that received the least water.

TABLE 12.—Percentage Purity of Juice in Sugar Beets Irrigated at Different Stages of Growth. 1930–1938 Inclusive With 9-year Average

Number of Irrigations	Stage of Plant Growth When Water Was Applied	9-year Average	1930	1931	1932	1933	1934	1935	1936	1937	1938
		%	%	%	%	%	%	%	%	%	%
0	Dry	83·8	84·5	83·6	83·1	83·6	84·7	84·4	81·7	83·1	85·9
1	Previous Fall	83·5x	81·2	87·3	79·5	80·3	84·1	87·2	.....	84·6	.....
1	I.A.T.	84·7	83·7	87·3	84·6	84·9	84·5	85·1	82·2	83·5	86·2
1	6 W.A.T.	84·9	83·3	84·6	87·0	80·6	86·8	87·3	82·0	86·1	86·3
1	8 W.A.T.	85·5	87·6	86·0	81·1	83·0	86·4	88·3	84·9	85·6	86·7
2	5 W.A.T., 9 W.A.T.	85·4	86·7	86·5	80·7	85·1	84·7	86·3	84·8	87·1	86·6
2	5 W.A.T., 11 W.A.T.	85·8	85·8	83·9	87·5	79·9	86·6	88·7	85·5	86·6	87·3
3	Fall, 5 W.A.T., 9 W.A.T.	86·3x	82·5	85·9	86·9	85·6	86·7	89·7	.....	86·8	.....
5	Fall, 2 W.A.T., 6 W.A.T., 9 W.A.T., 11 W.A.T.	85·9	83·5	85·3	86·8	82·7	85·1	88·7	89·8	83·7	87·5

NOTE.—In 1936 the 5 irrigations' treatment was changed to 2 W.A.T., 6 W.A.T., 9 W.A.T., 12 W.A.T., 14 W.A.T.
x 7-year average.
I.A.T.—Immediately after thinning.
W.A.T.—Weeks after thinning.

IRRIGATION OF SUNFLOWERS

Sunflowers are only a minor crop under irrigation, and, undoubtedly for that reason, very little information is available regarding their water requirements. For Montana, Jensen (27) recommends irrigating before the plants show signs of wilting. He reports that three irrigations were required for sunflowers at the Huntley Experimental Farm in 1918. These were applied on July 9, August 2 and August 8. In 1919, five irrigations were given. Knight of Nevada (31) states that sunflowers should be irrigated like corn.

Application of Water to Sunflowers at Lethbridge

In formulating an irrigation practice for sunflowers, it was found impractical to specify a growth stage. The only distinguishing growth factor was height, and this could not be used as a guide after the plants reached a height of six inches, because growth was so rapid where conditions were favourable and because it varied so much on the plots receiving different treatments. For these reasons, definite intervals of time (after the plants were six inches high) were specified for the applications of water.

The sunflowers were cut for silage when the seeds were partly glazed. The green weights were secured immediately after cutting and are reported in table 13 for the various irrigation treatments for the two years of 1923 and 1924. together with the two-year average yields.

The experiments with sunflowers were discontinued after the second year as yield, cultural and feeding tests at the Station showed that sunflowers were not as good as corn for a silage crop on the irrigated lands of southern Alberta.

It became evident, therefore, that sunflowers would not be as important a farm crop under irrigation as it was thought they would be when the irrigation experiment was started.

TABLE 13.—Yield of Sunflowers in Pounds per Acre (Green Weight) with Various Irrigation Treatments

Number of irrigations		Stage of plant growth or time when water was applied		Two-year average	1923	1924
1923	1924	First irrigation	Subsequent irrigations			
.....	.....	Dry.....	.....	25,715	31,680	19,750
1	1	Fall.....	.....	41,075	58,800	23,350
1	1	6 inches.....	.....	37,750	48,300	27,200
1	1	1 w.a. 6 inches.....	.....	31,350	43,000	19,700
1	1	2 w.a. 6 inches.....	.....	30,375	41,000	19,750
2	2	Fall.....	July 18.....	44,200	60,200	28,200
10	8	6 inches.....	Every week until August 10 to 15....	19,200	20,900	17,500
5	4	6 inches.....	Every two weeks until August 10 to 15.	26,100	30,850	21,350
3	3	6 inches.....	Every three weeks until August 10 to 15.	34,200	44,800	23,600
3	2	6 inches.....	Every three weeks until July 25.....	35,250	46,650	23,850
2	2	6 inches.....	Every three weeks until July 5.....	32,075	40,900	23,250
3	2	6 inches.....	Every four weeks until August 10 to 15.	35,200	46,900	23,500
3	2	2 w.a. 6 inches.....	Every three weeks until August 10 to 15.	29,275	38,550	20,000
2	2	4 w.a. 6 inches.....	Every three weeks until August 10 to 15.	28,075	38,150	18,000
1	1	When crop needed water.	.....	29,325	40,900	17,750

Abbreviations used: 6 inches—Plants 6 inches high. w.a.—weeks after.

Fall Irrigation

In the two years that sunflowers were under test the best yields were obtained from an irrigation in the previous fall and another on July 18. An irrigation in the previous fall without the application of water during the growing season gave the second largest yield in 1923, but was exceeded or equalled in 1924 by all the plots irrigated when the plants were six inches high, except those receiving water every two weeks or every week.

Number of Irrigations Required for Sunflowers

The poorest yields were secured in both years from the plots irrigated every week. The plots irrigated every two weeks were decidedly better than those irrigated every week, but were much inferior to the plots receiving water at three-week intervals or less frequently. It was very evident, by the appearance of the growing crop and the yields secured, that sunflowers could not stand an excess of water and that irrigating as often as every two weeks was detrimental to the crop.

It was also noted that yields were reduced if the first irrigation was withheld until the plants started to wilt. An interesting feature observed, however, was that the sunflower plants, although badly wilted, would revive as soon as the water was applied, and make satisfactory (though retarded) growth. This is in accord with observations made by Matthews (34) at the Dominion Experimental Station, Scott, Saskatchewan, where he noted that the growth of sunflowers on dry land was very slow in the severest part of the drought period, but that they had the ability to revive with the August rains and have always produced a fair crop in the driest years.

Suggested Irrigation Practice for Sunflowers

It appears, from the limited data available, that fall irrigating is a good practice for sunflowers. If a fall irrigation has not been given and if the early spring season is dry, it seems advisable to irrigate the crop by the time the plants are six inches high. It is doubtful if another irrigation will be required unless the season is unusually dry. If the plants show signs of wilting, however, they should be irrigated at once.

SOIL MOISTURE

Soil moisture studies were conducted in connection with the irrigation investigations, primarily to help determine if differences in crop behaviour from various irrigation treatments were due to water relationships of the soil and plant or to other causes. The data and discusions that follow, therefore, are concerned principally with these factors.

The soil moisture data from the sunflower and the sugar beet plots are not included, as these experiments have not been conducted for a long enough period to secure sufficient observation for making satisfactory deductions.

Review of Literature on Soil Moisture

Many investigators have studied the various phases of the soil moisture problem, but only the literature that bears directly on irrigation is referred to here.

The only report of work done under Alberta conditions is that of Snelson (46), who found that a silt loam soil had an available water-holding capacity of 22·63 inches for a six-foot depth, while sand had a water-holding capacity of 8·01 inches for the same depth.

Widtsoe and McLaughlin (55) conducted extensive soil moisture studies on a deep loam soil at the Utah Station, sampling the soil to a depth of eight feet. Some of their important findings were: 1. The maximum amount of water held by the soil under field conditions was about 24 per cent (on a dry basis) and the minimum amount was about 8 per cent except that the top foot of soil dried out to 5·64 per cent. 2. Irrigation was needed whenever the soil moisture fell below 12 per cent, varying to some extent with different crops. 3. When a practical irrigator declared irrigation to be necessary, the soil was found to contain about 13 per cent of water. 4. Different crops leave different percentages of water in the soil at time of harvesting. The rate of loss of soil water varies with the age of the crop. Less water is used during the early and late periods than during the middle one.

In the later experiments in Utah, Israelson and West (26) found that, as a general rule, soils have the capacity to absorb from a half to one and a half inches of water to each foot-depth of soil that needs moistening, the actual capacity for a given soil depending on its texture and structure. They state that "sandy or gravelly soils retain the smaller amounts and clay loam soils retain the larger amounts." They also found that uncropped plots given 36 inches of water held one-third inch more per foot of soil one day after irrigating than was held by plots receiving 12 inches of water, also that a plot receiving 24 inches held one-fourth inch more water per foot of soil than the plot receiving 12 inches of water. Ten days after the irrigations were applied, however, each of the plots held the same amount of available water, namely about one and a half inches per foot in the upper six feet.

In California, Adams *et al* (1) found that the average quantity of water retained in the upper six feet of the lighter and more permeable soils was 0·92 inch for each foot-depth of soil, whereas the clay soils absorbed an average of only 0·37 inch per foot of soil. In the surface foot, however, the light soils

retained 1·04 inches and the heavier soils 1·71 inches. The maximum quantities retained per acre-foot, of soil per irrigation were 1·02 acre-inches for silt loams, with fine sandy subsoils, 0·75 acre-inch for the clay loams, and 0·49 acre-inch for the clays. Scofield (44) has observed that the soil may hold as much as 6 inches of water per foot depth but ordinarily its net effective storage capacity is not much above 2 inches per foot of depth. The rate of penetration of water into a dry soil is found to be influenced not only by the general texture of the soil but even more by the physical reactions of the soil water.

From field tests in Washington, Thom and Holtz (48) concluded that the depth to which field crops took moisture was: wheat—9 feet, oats—8½ feet, barley—8 feet, peas—6 feet, millet—5½ feet, corn—5 feet, and beans—5 feet. They state that "crops that took the soil moisture from the greatest depths also had the greatest water requirement."

Total Water Used by Crops or Lost by Evaporation or Deep Percolation

In the Lethbridge experiments an approximation was made of the water used by the crops, together with that lost from the soil by evaporation and from the top six feet of soil by downward percolation. This approximation was made by determining the amount of water in the soil in the spring and at harvest, and measuring the water supplied by irrigation and precipitation during the season. The summation of the water in the soil in the spring (a), the water applied by irrigation (b), and precipitation (c), less the water in the soil at harvest (d), gave the total water (T) used by the crops (x), plus that evaporated from the soil (y), and lost by percolation below six feet (z).

$$a+b+c-d=x+y+z=T.$$

For convenience, "T" is called the total water used.

Relation of Water used to Yield of Wheat

The data in table 14 indicate the water used for wheat after a cultivated crop and wheat after wheat. Tables 14 and 15 are correlation tables of the total water used in relation to yields of wheat and (Fig. 1) (page 37) pictures this relation graphically.

The data in tables 14, and 15, and 16 show that several good yields of wheat were obtained with a use of 1·00 to 1·25 acre-feet of water, indicating that when water was applied in the proper stages, good yields were obtained with this small amount of water which was the equivalent of about one irrigation plus the precipitation of the plant season. With the wheat after a cultivated crop, the individual plot yields that fell in the higher yield-classes were greater with each increased amount of water used up to 1·75 to 2·00 acre-feet. The wheat after wheat showed as great a percentage of observations in the higher yield-class with 1·00 to 1·25 acre-feet as with the increased amount of water. A larger percentage of observations was in the higher yield-class, however, with 1·50 to 1·75 feet of water than with 1·25 to 1·50 feet.

The course of both curves in fig, 1 shows a distinct increase in the amount of water used with an increase in the yield to about 1,750 pounds per acre in wheat following wheat and to about 2,250 pounds in wheat following a cultivated crop. Higher yields than these showed but little difference in the total water used to produce the crop except on the wheat after cultivated crop where the extremely high yields appear to have been secured with a comparatively low use of water. There were so few individual observations that fell in these high yield-classes, however, that much importance cannot be attached to the downward curve for the higher yields. In fact there were so few individual observations in both the extremely high and extremely low yield classes of all crops reported that the end portions of the various curves may have little significance.

TABLE 14.—Total water used by the crop, evaporated from the soil and percolated below six feet with wheat after a cultivated crop and wheat after wheat, irrigated at different stages of growth, 1923 to 1927 inclusive, with five-year averages of crop yield, yield per acre foot of water and total water used.

Number of irrigations	Stages of plant growth when irrigated	5-year average wheat yield in pounds		Total water used in acre-feet per acre					
		Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
	Wheat After a Cultivated Crop								
0	Dry	2,281	2,304	0·99	1·00	0·98	0·99	0·68	1·31(1)
1	F	2,446	2,005	1·22	1·12	1·47	1·14	1·14	1·24
1	3L	2,570	1,977	1·30	1·32	1·49	0·73	1·26	1·70
1	5L	2,530	1,860	1·36	1·48	1·34	1·33	1·05	1·59
1	S.B	2,670	1,920	1·39	1·39	1·36	1·61	1·22	1·37
1	Fl	2,381	1,764	1·35	1·29	1·37	1·30	1·20	1·58
	Crop needs	2,518	2,031	1·24	1·45	1·41	1·24	1·04	1·07
2	F., S.B	2,545	1,533	1·66	1·61	2·04	1·72	1·46	1·47
2	F., Fl	2,647	1,665	1·59	1·45	1·85	1·38	1·65	1·60
2	5L., Fl	2,497	1,460	1·71	1·63	1·81	1·85	1·72	1·56(1)
2	S.B., Fl	2,600	1,520	1·71	1·78	1·66	1·80	1·56	1·77
3	F., S.B., Fl	2,615	1,414	1·85	1·74	2·33	1·69	1·86	1·63
3	5L., S.B., Fl	2,686	1,285	2·09	1·95	2·12	2·41	2·09	1·89
4	5L., S.B., Fl., S.D	2,707	1,162	2·33	2·40	2·49	2·56	2·38	1·80
4	F., 5L., S.B., Fl	2,552	1,146	2·21	2·13	2·80	2·15	2·32	1·63
	Wheat After Wheat								
1	Dry	1,793	1,907	0·94	1·02	0·84	1·06	0·87	0·92
1	F	2,272	1,535	1·48	1·99	1·56	0·79	1·44	1·64
1	3L	2,233	1,479	1·51	1·46	1·47	1·38	1·52	1·71
1	5L	2,390	1,927	1·24	1·27	1·19	1·06	1·45	1·22
1	S.B	2,360	1,857	1·27	1·20	1·31	1·34	1·29	1·21
1	Fl	2,050	1,723	1·19	1·16	1·28	1·08	1·30	1·15
1	Crop needs	2,240	1,750	1·28	1·38	1·22	1·25	1·30	1·24(2)
2	F., S.B	2,090	1,282	1·63	1·43	2·19	1·25	1·86	1·42
2	F., Fl	2,071	1,319	1·57	1·35	1·99	1·25	1·75	1·50(2)
2	3L., Fl						1·81	1·88	1·70
2	5L., Fl	2,328	1,464	1·59	1·73	1·77	2·06	1·79	1·62
2	S.B., Fl	1,976	1,156	1·71	1·76	1·90	1·62	1·73	1·53(2)
3	F., S.B., Fl	2,279	1,157	1·97	2·01	2·53	1·51	2·22	1·57
3	5L., S.B., Fl	2,508	1,206	2·08	2·21	2·32	2·04	2·18	1·63(2)
4	5L., S.B., Fl., S.D	2,278	908	2·51	2·56	2·60	2·49	2·83	2·08(2)

(1) In 1927, only these had samples in duplicate.
(2) One plot only.

TABLE 15.—Relation of Yield of Wheat Following a Cultivated Crop to the Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet

Yields of Grain in Pounds Per Acre

Total water used in acre-feet per acre	1,000-1,500	1,501-2,000	2,001-2,500	2,501-3,000	3,001-3,500	3,501,4-000	4,001-4,500	Totals	Mean yield
0-0·25									
0·26-0·50									
0·51-0·75	1				1			2	2,250
0·76-1·00		1	1	1	1			4	2,500
1·01-1·25	1	3	3	3		1	1	12	2,458
1·26-1·50		4	7	6	4	1		22	2,545
1·51-1·75		2	6	6	3	1		18	2,611
1·76-2·00		1	2	4	2	1		10	2,750
2·01-2·25			2	3				5	2,550
2·26-2·50			3	1	2			6	2,667
2·51-2·75					2			2	3,250
2·76-3·00				1				1	2,750
Totals	2	11	24	25	15	4	1	82	
Mean water used	0·875	1·352	1·615	1·655	1·708	1·500	1·125		

TABLE 16.—Relation of Yield of Wheat After Wheat to the Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet

YIELDS OF GRAIN IN POUNDS PER ACRE

Total water used in acre-feet per acre	0-500	501-1,000	1,001-1,500	1,501-2,000	2,001-2,500	2,501-3,000	3,001-3,500	Totals	Mean yield
0-0·25	.....	.....	.....	.....	.....	.....	.....	.....	.....
0·26-0·50	.....	.....	.....	.....	.....	.....	.....	.....	.....
0·51-0·75	.....	.....	.....	.....	.....	.....	.....	.....	.....
0·76-1·00	1	.....	.....	1	1	1	.....	4	1,750
1·01-1·25	.....	.....	.....	2	7	5	1	15	1,417
1·26-1·50	.....	.....	2	4	6	4	1	17	2,191
1·51-1·75	.....	.....	1	3	6	4	.....	14	2,214
1·76-2·00	.....	.....	.....	2	6	1	.....	9	2,194
2·01-2·25	.....	.....	.....	4	1	2	1	8	2,500
2·26-2·50	.....	.....	.....	.....	1	1	.....	2	2,500
2·51-2·75	.....	.....	.....	1	1	1	.....	3	2,250
2·76-3·00	.....	.....	.....	.....	1	.....	.....	1	2,250
Totals	1	.....	3	17	30	19	3	73	.....
Mean water used	0·875	.....	1·458	1·669	1·580	1·559	1·542	.....	.....

The wheat-yield curves and the table data show quite clearly that from 1·50 to 1·70 feet of water were required to produce good crops of wheat.

In analysing the data on the water used by the crops, it must be remembered that the irrigation water was applied at different stages of growth, and that the crop yields were often influenced more by the time that the water was given than by the total amount available for the crop during the year. This is shown in table 14 by comparing the plots irrigated but once during the year. The plots not irrigated until the flowering stage had practically as much water available for plant use as did the plants irrigated at earlier stages of plant growth, but the yields were from two to three hundred pounds per acre less.

The frequency distribution of yields with different amounts of water available (tables 15 and 16) shows the same differences in yields with similar amounts of available water.

It is evident, then, that any statement as to the amount of water required for crops under irrigation is of little value unless the time that the irrigation water is to be applied is specified.

The amount of precipitation that fell between planting and harvesting also greatly influenced the number and time of irrigations required to supply the soil moisture needed. Heavy storms that came after the crop was matured also increased the soil moisture carried over for the next year's crop. Another factor of importance was that in some years much of the rainfall came in light showers that merely wet the soil surface and was quickly lost by evaporation.

Relation of Water used to Yield of Alfalfa

The water requirements of alfalfa are indicated in the data presented in tables 17 and 18.

The highest five-year average yield of alfalfa hay was secured with an average of 3·23 acre-feet of water (table 17). The yield was but little less, however, with the use of 2·26 or 2·41 acre-feet. There was little consistent difference in the yields with a water-use of between 1·45 and 2·06 feet, the variations apparently being due to the difference in the time of irrigating. A few high yields are shown in table 17 with a water-use of 1·26 to 1·50 feet. The plots recording a water-use of 1·76 to 2·00 feet had the highest percentage of individuals in the yield-class of from 7,001 to 8,000 pounds of hay per acre. This yield-class was the highest of any having enough observations falling in it to make comparisons worth while.

TABLE 17.—Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet with Alfalfa Irrigated at Different Stages of Growth, 1923 to 1927, with Five-year Averages of Crop Yield, Total Water Used and Yield per Acre-foot of Water.

Number of irrigations and stages of plant growth when irrigated	5-year average alfalfa yield in pounds		Total water used by crop, evaporated and percolated					
	Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
0 Dry	3,108	2,988	1·04	1·33	0·85	0·70	1·07	1·24(1)
1 Fall	6,608	4,557	1·45	1·48	1·62	1·29	1·49	1·38
1 E.S.	6,908	4,486	1·54	1·59	1·32	1·47	1·62	1·70
1 12″ H.	5,984	4,156	1·44	1·65	1·33	1·33	1·48	1·43
1 B.I.C.	4,908	3,385	1·45	1·50	1·33	1·36	1·40	1·64
1 A.I.C.	4,964	3,354	1·48	1·61	1·30	1·29	1·57	1·61
2 F., 12″ H.	6,756	3,518	1·92	1·89	2·18	2·26	1·90	1·38
2 F., B.I.C.	6,336	3,076	2·06	1·88	2·29	2·31	2·07	1·76
2 F., A.I.C.	6,456	3,165	2·04	1·96	2·16	2·31	1·97	1·78
2 E.S., 12″ H.	6,844	3,680	1·86	2·07	1·87	1·89	2·06	1·43
2 E.S., B.I.C.	6,548	3,307	1·98	2·12	1·85	1·91	2·04(1)	1·96
2 E.S., A.I.C.	6,612	3,391	1·95	1·97	1·69	1·98	1·97	2·12
3 F., 12″ H., A.I.C.	7,268	3,216	2·26	2·27	2·45	2·15	2·66	1·78
3 E.S., 12″ H., A.I.C.	7,396	3,069	2·41	2·51	2·26	2·51	2·51	2·25(1)
4 E.S., 12 H., A.I.C., 2nd 12″ H.	6,908	2,587	2·67	2·94	2·66	2·64	2·86	2·25
5 F., E.S., 12″ H., A.I.C., 2nd 12″ H.	7,468	2,457	3·04	3·23	3·45	2·93	3·33	2·27
Crop needs	7,324	5,954	1·23	1·62	0·92(2)	0·58	1·61	1·44

(1) One plot only.
(2) Dry by mistake.

TABLE 18.—Relation of the Yield of Alfalfa to the Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet

YIELDS OF HAY IN POUNDS PER ACRE

Total water used in acre-feet per acre	0-1,000	1,001-2,000	2,001-3,000	3,001-4,000	4,001-5,000	5,001-6,000	6,001, 7,000	7,001-8,000	8,001-9,000	9,001-10,000	Totals	Mean yield
0-0·25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0·26-0·50	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
0·51-0·75	1	.....	.....	.....	.....	.....	.....	.....	1	.....	2	4,500
0·76-1·00	.....	.....	.....	1	1	.....	.....	.....	.....	.....	2	4,000
1·01-1·25	1	.....	1	.....	.....	.....	.....	.....	.....	.....	2	1,500
1·26-1·50	.....	.....	.....	2	3	7	4	2	2	.....	20	5,850
1·51-1·75	.....	.....	.....	.....	2	5	2	1	1	1	12	6·250
1·76-2·00	.....	.....	.....	.....	1	4	4	6	1	.....	16	6·625
2·01-2·25	.....	.....	.....	.....	.....	6	2	2	1	1	12	6,584
2·26-2·50	.....	.....	.....	.....	.....	2	3	1	1	.....	7	6,643
2·51-2·75	.....	.....	.....	.....	.....	1	1	1	2	1	6	6,667
2·76-3·00	.....	.....	.....	.....	.....	.....	1	1	.....	1	3	7,883
3·01-3·25	.....	.....	.....	.....	.....	.....	.....	1	.....	.....	1	7.500
3·26-3·50	.....	.....	.....	.....	.....	.....	1	1	.....	.....	2	7,000
Totals	2	.....	1	3	7	25	18	16	9	4	85	.....
Mean water used	0·875	.....	1·125	1·212	1·446	1·815	2·030	2·141	1·847	2·312	.....	.....

The chart of the mean water used for each yield-class of alfalfa (fig. 2) shows an approximately straight line trend for this crop in contrast to the irregular curves of the other crops. The simultaneous and commensurate increases in water-use and alfalfa yield suggest a fairly high positive correlation of these factors. There is a tendency for the line to flatten out when more than two feet of water are used. The irregular line beyond this point may have been due to the unreliability of the few observations in the higher yield classes.

The data in tables 17 and 18 indicate a water-use of alfalfa of 1·75 to 2·25 acre-feet per acre, or 21 to 27 inches, which is slightly less than was found neces-

sary by Snelson (46) at Brooks, Alberta. With a rainfall of 6 to 15 inches, this would require the addition of one to three irrigations applied at the proper growth periods.

Relation of Water used to the Yield of Potatoes

The data presented in tables 19 and 20 indicate the water required for the production of potatoes.

TABLE 19.—Total Water Used by the Crop, Evaporated from the Soil and Percolated Below Six Feet with Potatoes Irrigated at Different Stages of Growth, 1923 to 1927 inclusive, with Five-year Averages of Crop Yield, Total Water Used and Yield per Acre-foot of Water.

Number of irrigations	First irrigation	Subsequent irrigations	5-year average yields of marketable potatoes in pounds		Total water used by crop, evaporated and percolated					
			Per acre	Per acre-foot water	5-year average	1923	1924	1925	1926	1927
0	Dry		14,055	16,343	0·86	1·20	0·94	0·60	0·88	0·66
1	Fall		19,540	19,939	0·98	0·94	1·33	0·96	0·99	0·66
1	Half-grown		16,956	15,148	1·12	1·24	1·13	0·95	1·26	1·02
1	S.B		19,419	16,457	1·18	1·24	1·31	1·20	1·34	0·80
1	F.B		19,040	16,702	1·14	1·22	1·19	1·12	1·20	0·98
1	10 d.a.F.B		19,435	17,048	1·14	1·22	1·30	1·20	0·98	1·02
2	Fall	S.B	21,516	17,076	1·26	1·35	1·53	1·06	1·58	0·80
2	Fall	F.B	21,253	15,181	1·40	1·37	1·49	1·53	1·64	0·98
2	S.B	F.B	21,014	16,290	1·29	1·29	1·25	1·32	1·48	1·12
2	F.B	In 10 days	20,943	16,110	1·30	1·23	1·36	1·21	1·38	1·33
3	S.B	Every 10 days	20,817	13,695	1·52	1·52	1·34	1·29	2·18	1·25
3	S.B	Every 20 days	22,559	15,558	1·45	1·56	1·46	1·18	1·60	1·45
4	S.B	Every 10 days	20,409	12,005	1·70	1·85	1·80	1·50	1·84	1·53
4	Half-grown	F.B. ev. 10 days	18,830	11,918	1·58	1·66	1·24	1·48	1·78	1·74
5	S.B	Every 10 days	23,171	11,883	1·95	1·75	2·00	1·74	2·07	2·17
6	S.B	Every 10 days	22,254	10,648	2·09	1·68	2·22	1·94	2·13	2·48

The five-year average yields of marketable potatoes increased with an increase of total water used, up to 1·95 acre-feet (table 18). There was a slight decrease in yields with more than 1·95 feet of water. The average yields from 1·45 feet of water were almost as good as from 1·95 feet when the crops were irrigated at intervals of twenty days beginning in the starting-bloom stage.

Of the eleven observations of crops grown with 0·76 to 1·00 foot of water, four (or 36 per cent) gave yields of 21,000 pounds or more (table 20). Of twenty-one observations with 1·01 to 1·25 feet of water, eight (or 38 per cent) had yields above 21,000 pounds. With 1·26 to 1·50 feet of water, eleven of twenty observations (or 56 per cent) had yields above 21,000 pounds, and with 1·50 to 1·75 feet of water, four of twelve observations (or 33 per cent) were in the yield-classes above 21,000 pounds.

The graph representing the mean water used for each yield class of potatoes (fig. 3) is somewhat irregular but shows the general trend of increased water use with increased yield until from 1·30 to 1·50 feet of water were used. From that point higher yields were obtained without any regular increase of water.

The data presented in these tables and the chart indicate a water use by potatoes of about 1·50 acre-feet per acre. A crop season rainfall varying from six inches to fifteen inches would have to be supplemented with from three to twelve inches of irrigation water. This would require from one to three four-inch irrigations given at such times as to be of maximum benefit to the crop. This is in agreement with the number of irrigations found necessary in the irrigation tests.

TABLE 20.—Relation of the Yield of Marketable Potatoes to the Total Water Used by the Crop, Evaporated from the Soil, and Percolated Below Six Feet

YIELD OF MARKETABLE POTATOES IN POUNDS PER ACRE

Total water used in acre-ft. per acre	7,001-9,000	9,001-11,000	11,001-13,000	13,001-15,000	15,001-17,000	17,001-19,000	19,001-21,000	21,001-23,000	23,001-25,000	25,001-27,000	27,001-29,000	29,001-31,000	31,001-33.000	Totals	Mean yield
0-0·25															
0·26-0·50															
0·51-0·75	1							2						3	1,500
0·76-1·00			2	1	2	1	1		2	2				11	1,891
1·01-1·25		1		2	3	5	3	2	1	3	1		1	22	2,009
1·26-1·50				2	3	3	1	3	4	3	1			20	2,090
1·51-1·75				1	5	1	1	2	2			1		13	1,954
1·76-2·00				1	2		2					1		6	1,933
2·01-2·25						1	2	1		1				5	2,120
2·26-3·00									1					1	2,400
Totals	1	1	2	7	15	11	10	10	10	9	2	2	1	81	
Mean water used	0·625	1·125	0·875	1·339	1·402	1·307	1·525	1·300	1·400	1·264	1·250	1·750	1·125		

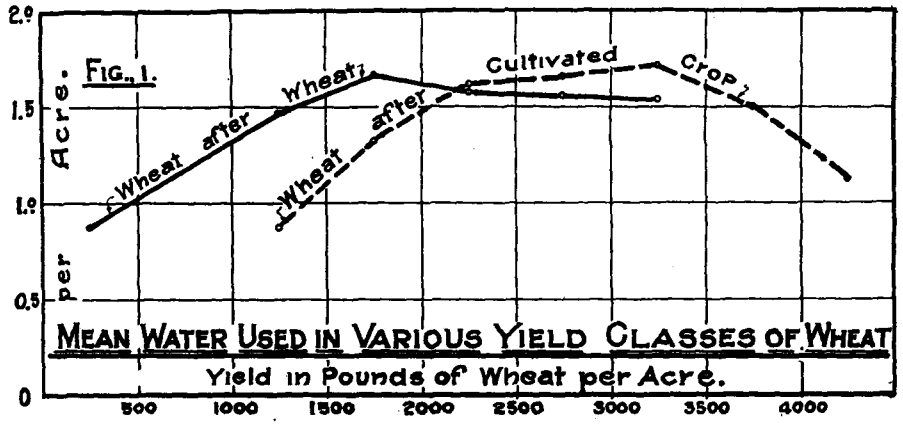
FIG., 1.
Wheat after Wheat
Wheat after Cultivated Crop
Acre.
per
2.0
1.5
1.0
0.5
0
MEAN WATER USED IN VARIOUS YIELD CLASSES OF WHEAT
Yield in Pounds of Wheat per Acre.
500
1000
1500
2000
2500
3000
3500
4000

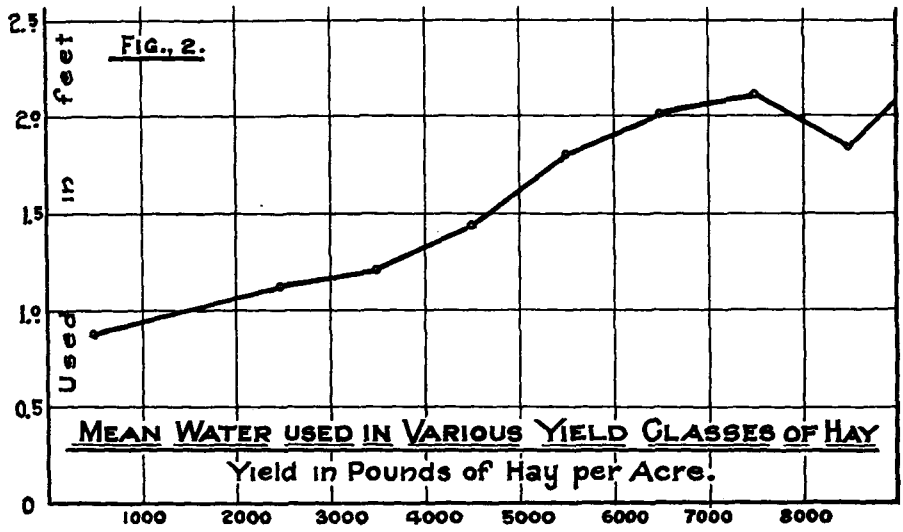
FIG., 2.
Used in feet
2.5
2.0
1.5
1.0
0.5
0
MEAN WATER USED IN VARIOUS YIELD CLASSES OF HAY
Yield in Pounds of Hay per Acre.
1000
2000
3000
4000
5000
6000
7000
8000

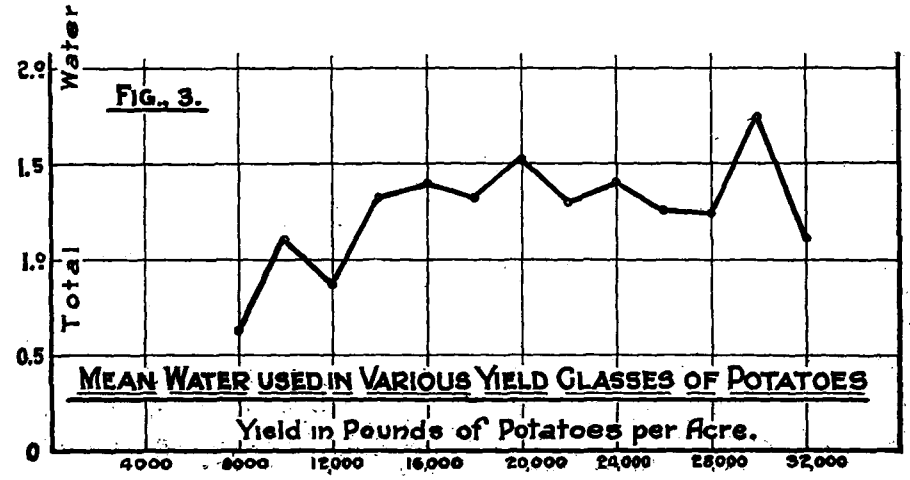
FIG., 3.
Water Total
2.0
1.5
1.0
0.5
0
MEAN WATER USED IN VARIOUS YIELD CLASSES OF POTATOES
Yield in Pounds of Potatoes per Acre.
4000
8000
12,000
16,000
20,000
24,000
28,000
32,000

Depth of Penetration of a Six-inch Irrigation

One of the important reasons for making soil-moisture determinations before and after irrigation in these experiments was to note if the amount of water applied (six acre-inches) was sufficient to penetrate below the principal feeding-zone of the plant roots. Numerous observations made by Weaver (49) and others show that wheat roots may have a working depth of 3·5 to 4·0 feet, potatoes 1 to 4 feet, and sugar beets down to 5 or 6 feet. Sunflowers had the majority of their root system in the top three feet of soil. From the information available, it seemed that the water requirements of the plants would be met, if the water penetrated into the soil to a depth of six feet. Observations during the progress of these experiments have confirmed this opinion even for alfalfa which is known to root much deeper than most field crop plants.

It seemed obvious that the depth to which a given application of water would penetrate would be influenced by the degree of wetness of the soil at the time of irrigating. The data in tables 21 and 22 show the relation between the depth to which the water penetrated into the soil and the percentage of moisture in the soil (dry basis) before irrigating for wheat following a cultivated crop, wheat following wheat, and for alfalfa. The potato, sugar beet, and sunflower plots are not included, as the amount of water applied at each irrigation varied from three to four inches, thus making too few observations available with either depth of application to permit of reliable comparisons. Table 23 is a combination of tables 21 and 22.

The depth to which water penetrated was determined by comparing the percentage of moisture in each foot of the top six feet of soil before irrigation and after irrigation. (The method of securing soil samples and of making moisture determinations is outlined on page nine of this bulletin.) The soil of the different depths secured after irrigation that had appreciably more moisture than the soil from the same depths before irrigation was considered to have received the additional water from the irrigation or the water had penetrated to that depth. In a few instances the samples secured after irrigation showed a lower moisture content in the upper levels of soil than those secured before irrigation. This was shown at times to be due to soil heterogeneity. Some may have been due to errors in sampling or in making the moisture determinations. The number of such observations, however, was not large and they were not used in the data reported. The soil samples taken before irrigation were secured either on the day before irrigating or on the day that the water was applied. Samples after irrigation were obtained from three to five days after irrigating.

The percentages of moisture in the soil presented in tables 21 and 22 are the averages to the depths to which the water percolated as shown by each individual observation. For example, if the water percolated to a depth of four feet, then the moisture percentage shown is the average for the top four feet of soil before irrigation.

A comparison of tables 21 and 22 reveals but little difference in the depth to which a six-inch irrigation penetrated into the soil supporting a crop of alfalfa and into the soil on which wheat was grown, since there is as close an agreement between the data from the wheat plots and the alfalfa plots as between the data from the two series of wheat plots. As the border surrounding each plot prevented any of the water applied from draining off the plot, the fact that the water soaked into the top foot of the uncultivated alfalfa field more slowly than it did into the looser top soil of the grain field, did not appear to influence the depth to which the water had penetrated by the fourth or fifth day.

From the data presented in each of these tables, it is evident that the water applied soaked more deeply into the moist soil than it did into the drier soil. One interesting feature is that if the water failed to penetrate to the full six feet in the drier soils, it usually went down only three or four feet and *seldom*

TABLE 21.—Relation of the Depth of Penetration of a Six-inch Irrigation to the Percentage of Moisture in the Soil Immediately Before Irrigation

Depth of penetration (ft.)	Percentage of moisture in the soil																	Totals
	7·1-8·0	8·1-9·0	9·1-10·0	10·1-11·0	11·1-12·0	12·1-13·0	13·1 14·0	14·1-15·0	15·1-16·0	16·1-17·0	17·1-18·0	18·1-19·0	19·1-20·0	20·1-21·0	21·1 22·0	22·1-23·0	23·1-24·0	
Wheat After a Cultivated Crop																		
-1	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
2	.....	.....	.....	5	3	4	1	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	15
3	.....	2	4	4	2	3	1	1	2	.....	.....	.....	.....	.....	.....	.....	.....	19
4	.....	3	.....	.....	6	4	.....	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	14
5	.....	2	.....	.....	3	5	1	.....	.....	.....	.....	.....	.....	.....	.....	1	1	13
6	1	1	3	7	13	20	24	15	29	30	18	9	10	1	.....	2	.....	183
Totals...	1	8	7	17	27	36	27	16	33	30	18	9	11	1	.....	3	1	245
Wheat After Wheat																		
-1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	.....	.....	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2
3	.....	1	1	1	1	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5
4	1	1	4	4	1	1	.....	1	.....	.....	.....	2	.....	.....	.....	.....	1	16
5	.....	.....	.....	1	1	1	2	1	.....	2	.....	.....	1	.....	.....	.....	.....	9
6	1	1	3	7	11	18	15	18	19	18	21	12	12	5	2	1	2	166
Totals...	2	3	9	14	14	21	17	20	19	20	21	14	13	5	2	1	3	198

TABLE 22.—Relation of the Depth of Penetration of a Six-Inch Irrigation to the Percentage of Moisture in the Soil Immediately Before Irrigation. Alfalfa.

Percentage of moisture in the soil

Depth of penetration (ft.)	5·1-6·0	6·1-7·0	7·1-8·0	8·1-9·0	9·1-10·0	10·1-11·0	11·1-12·0	12·1-13·0	13·1-14·0	14·1-15·0	15·1-16·0	16·1-17·0	17·1-18·0	18·1-19·0	19·1-20·0	Totals
-1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3	2	1	4	11	9	5	2	.....	.....	.....	1	1	.....	1	.....	37
4	1	1	2	11	16	15	6	3	3	1	1	.....	.....	.....	1	61
5	.....	1	5	6	1	5	2	5	.....	.....	.....	.....	.....	.....	.....	25
6	.....	.....	3	9	16	17	18	28	19	4	6	1	.....	1	.....	122
Totals.....	3	3	14	37	42	42	28	36	22	5	8	2	.....	2	1	245

TABLE 23.—Relation of the Depth of Penetration of a Six-Inch Irrigation to the Percentage of Moisture in the Soil Immediately Before Irrigation.

Combination of Tables 21 and 22

Percentage of moisture in the soil

Depth of penetration (ft.)	5·1-6·0	6·1-7·0	7·1 8·0	8·1-9·0	9·1-10·0	10·1-11·0	11·1-12·0	12·1-13·0	13·1-14·0	14·1-15·0	15·1-16·0	16·1-17·0	17·1-18·0	18·1-19·0	19·1-20·0	20·1-21·0	21·1-22·0	22·1-23·0	23·1-24·0	Totals
-1	.....	.....	.....	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1
2	.....	.....	.....	.....	1	6	3	4	1	.....	2	.....	.....	.....	.....	.....	.....	.....	.....	17
3	2	1	4	14	14	10	5	4	1	1	3	1	.....	1	.....	.....	.....	.....	.....	61
4	1	1	3	15	20	19	13	8	3	2	1	.....	.....	2	2	.....	.....	.....	1	91
5	.....	1	5	8	1	6	6	11	3	1	.....	2	.....	.....	1	.....	.....	1	1	47
6	.....	.....	5	11	22	31	42	66	58	37	54	49	39	22	22	6	2	3	2	471
Totals.....	3	3	17	48	58	73	69	93	66	41	60	52	39	25	25	6	2	4	4	688

five feet. This was especially true in the grain plots. The reason for this may have been that the moisture content of the sixth foot of soil supporting a crop was usually higher before irrigating than the moisture content of the third, fourth and fifth feet. The dryness of these depths compared with the sixth foot indicates that the principal working zone of the plant roots was in those foot-depths. If the water percolated into the fifth foot, there appears to have been some movement into the moist sixth foot, thus increasing the moisture content at that depth.

Only six observations are available where the moisture content of the soil before irrigation was seven per cent or less. In none of these plots did the water penetrate six feet, only one was wet down five feet, two were wet four feet and three were wet three feet. Of seventeen observations with a moisture content before irrigation of 7·1 to 8·0 per cent, five (or twenty-nine per cent) showed an increase of water in the sixth foot. Eleven out of forty-eight (or twenty-three per cent) with a moisture content of 8·1 to 9·0 per cent, twenty-two out of fifty-eight (or thirty-eight per cent) with a moisture content of 9·1 to 10·0 per cent and thirty-one out of seventy-three (or sixty-one per cent) with a moisture content of 11·1 to 12·0 per cent, showed that the water applied had penetrated six feet into the soil. The increase in the relative number of observations that showed the water to have gone down six feet was greater between soils with a moisture content of 10·1 to 11·0 and 11·1 to 12·0 than in any other consecutive class-groups. It appears that with a soil-moisture content of less than eleven per cent, the water moved relatively less freely than it did when there was more than eleven per cent of moisture in the soil. The increase from 12·1 to 13·0 per cent and from 13·1 to 14·0 per cent were also important, but not as significant as the increase between the two preceding class-intervals. It seems that when the moisture content was at about eleven to fourteen per cent it was at what Widtsoe and McLaughlin (55) defined as the point of lento-capillarity or the point above which water may move freely from place to place under surface tension. It is interesting to note that these investigators placed this point at between twelve and thirteen per cent for the Greenville Loam.

When the top six feet of soil contained an average of more than fourteen per cent, almost all the observations showed the water to have penetrated to a depth of at least six feet. It would seem, then, that when this type of soil contains less than fourteen per cent moisture, a six-inch irrigation is not sufficient to ensure that the soil will be wet to a depth of six feet, but if the soil moisture is above fourteen per cent, a six-inch irrigation appears to be ample.

Water Retained in the Soil from Fall Irrigation

One of the purposes of these experiments was to test the value of a fall irrigation. Since an important factor affecting the value of fall irrigation is the ability of the soil to retain the water until the following crop season, the moisture in the top six feet of soil of all fall-irrigated plots was determined four or five days after the fall irrigation. Similar moisture determinations were again made in the spring so that the difference in the total water in the soil in the fall and spring could be noted. This difference represents the water that was lost from the top six feet of soil less the water added to the soil by precipitation between the time of securing the fall and spring samples.

In table 24 is presented the number of feet of water in the six feet of soil in the fall after irrigating and in the spring before irrigating together with the difference between the two. There are two observations shown in most cases for each irrigation treatment. These are for duplicate plots. The data for the fall of 1926 and the spring of 1927 are not given as the heavy fall and spring rains of that period made such data of little value.

TABLE 24.— A Comparison of the Fall and Spring Water Content in Acre-feet per Acre of the Top Six Feet of Soil of Fall Irrigated Plots Sampled After Irrigation in the Fall and Before Irrigation the Following Spring.

WHEAT AFTER A CULTIVATED CROP

	Fall, 1922		Spring, 1923		Differences		Fall, 1923		Spring, 1924		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	0·96	1·13	0·96	0·86	0	−0·27	1·71	1·67	1·61	1·50	−0·10	−0·17
Fall, Fl	1·19	1·01	0·95	1·17	−0·24	+0·16	1·71	1·92	1·55	1·67	−0·16	−0·25
Fall, S.B	1·18	1·04	1·17	1·14	−0·01	+0·10	1·60	1·51	1·58	1·57	−0·02	+0·06
Fall, S.B., Fl	1·38	0·93	1·16	0·80	−0·22	−0·07	1·60	1·59	1·54	1·56	−0·06	−0·03
Fall, 5L., S.B., Fl	0·83	1·00	0·98	0·79	+0·15	−0·21	1·72	1·73	1·33	1·50	−0·39	−0·23

WHEAT AFTER A CULTIVATED CROP

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	1·76	1·94	1·69	1·76	−0·07	1·18	1·18	1·42	1·08	1·20	−0·10	−0·22
Fall, Fl	1·94	Samples	1·71	No	−0·23	.....	1·33	1·71	1·06	.....	−0·27	.....
Fall, S.B., Fl	1·88	not	1·85	dupli-	−0·03	.....	1·43	1·07	1·12	1·05	−0·31	−0·02
Fall, S.B., Fl	1·87	taken.	1·68	cates	−0·19	.....	1·44	1·27	1·28	1·07	−0·16	−0·20
Fall, 5L., S.B., Fl	1·65	.....	1·53	seeded.	−0·12	.....	1·64	1·23	1·17	1·22	−0·47	−0·01

WHEAT AFTER WHEAT

	Fall, 1922		Spring, 1923		Differences		Fall, 1923		Spring, 1924		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	1·75	1·90	1·54	1·74	−0·21	−0·16	1·02	1·43	1·14	1·18	+0·12	−0·25
Fall, Fl	1·80	1·88	1·60	1·71	−0·20	−0·17	1·39	1·51	1·32	1·32	−0·07	−0·19
F., S.B	1·95	1·63	1·71	1·65	−0·24	+0·02	1·33	1·34	1·47	1·39	+0·14	+0·05
F., S.B., Fl	1·87	1·87	1·87	1·62	0	−0·25	1·46	1·13	1·41	1·35	−0·05	+0·22
F., 5L., S.B., Fl	1·72	1·79	1·66	1·51	−0·06	−0·28	1·37	1·75	1·26	1·24	−0·11	−0·51

WHEAT AFTER WHEAT

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	1·71	.....	1·48	1·42	−0·23	.....	1·48	1·41	1·08	1·16	−0·40	−0·25
Fall, Fl	1·76	No	.....	.....	.....	.....	1·48	1·59	1·10	1·25	−0·38	−0·34
Fall, S.B	1·79	dupli-	1·71	1·35	−0·08	.....	1·69	1·63	1·13	1·16	−0·56	−0·47
Fall, S.B., Fl	1·82	cates.	1·36	1·38	−0·46	.....	1·56	1·63	1·19	1·07	−0·37	−0·56
Fall, 5L., S.B., Fl	1·52	.....	1·33	1·42	−0·19	.....	1·56	.....	1·18	.....	−0·38	.....

ALFALFA

	Fall, 1922		Spring, 1923		Differences		Fall, 1923	Spring, 1924	Differences
	(1)	(2)	(1)	(2)	(1)	(2)			
Fall	1·21	1·20	1·05	1·07	−0·16	−0·13	1·04	0·88	−0·16
Fall, 12″ H	1·29	1·11	0·99	1·13	−0·30	+0·02	1·18	1·10	−0·08
Fall, B.I.C	1·17	1·10	1·14	1·01	−0·03	−0·09	1·12	1·10	−0·02
Fall, A.I.C	1·08	1·09	1·11	1·10	+0·03	+0·01	1·04	1·10	+0·06
Fall, 12″ H., A.I.C	1·04	0·97	0·99	1·10	−0·05	+0·13	1·05	1·09	+0·04
Fall, E.M., 12″ H., A.I.C., 2nd 12″ H	1·23	1·10	1·09	1·05	−0·14	−0·05	1·15	1·06	−0·09

ALFALFA

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	1·06	1·08	1·22	1·25	+0·16	+0·17	1·32	1·25	1·08	1·11	−0·24	−0·14
Fall, 12" H	1·27	1·26	1·23	1·30	−0·04	+0·04	1·33	1·30	0·89	1·09	−0·44	−0·21
Fall, B.I.C	1·33	1·21	1·30	1·15	−0·03	−0·06	1·26	1·19	1·02	1·07	−0·24	−0·12
Fall, A.I.C	1·19	1·29	1·15	1·30	−0·04	+0·01	1·24	1·18	.....	1·18	.....	.....
Fall, 12" H., A.I.C	1·19	1·03	1·15	1·19	−0·04	+0·16	1·33	1·06	1·22	1·12	−0·11	+0·06
Fall, E.M., 12" H., A.I.C., 2nd. 12" H	1·28	1·40	1·23	1·24	−0·07	−0·16	1·36	1·10	1·08	1·10	−0·28	−0·28

POTATOES

	Fall, 1922		Spring, 1923		Differences		Fall, 1923		Spring, 1924		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	.....	1·51	1·76	1·60	.....	+0·09	1·49	1·99	1·82	1·73	+0·33	−0·26
Fall, S.B	1·44	1·40	1·54	1·54	+0·10	+0·14	1·53	1·78	1·51	1·70	−0·02	−0·08
Fall, B.F	1·45	1·68	1·63	1·62	+0·18	−0·06	1·63	1·50	1·63	1·46	0	−0·04

POTATOES

	Fall, 1924		Spring, 1925		Differences		Fall, 1925		Spring, 1926		Differences	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
Fall	1·54	1·59	1·53	1·36	−0·01	−0·23	1·47	1·37	1·25	1·15	−0·49	−0·22
Fall, S.B	1·41	1·54	1·21	1·26	−0·20	−0·28	1·80	1·53	1·20	1·05	−0·60	−0·48
Fall, F.B	1·59	1·41	1·36	1·35	−0·23	−0·06	1·56	1·55	1·43	1·18	−0·13	−0·37

A total of sixty-eight observations (or differentials between fall and spring water content) on the two series of wheat plots are reported in table 24. The differences of the water contained in the top six feet of soil in the spring from that in the soil the previous fall, as shown by the moisture determinations, varied from a gain of 0·22 feet to a loss of 0·56 acre-feet. Of the sixty-eight observations, seven showed a loss of 0·40 feet or more, six showed a loss of from 0·30 feet to 0·39 feet inclusive, eighteen from 0·20 to 0·29, thirteen from 0·10 to 0·19, and thirteen had a loss under 0·10 feet. Nine wheat plots showed a gain in the spring over the fall sampling and two showed no change.

There were forty-one observations on alfalfa. Of this number, two plots had a water loss in the spring of 0·30 acre-feet or more. Five had a loss of from 0·20 to 0·29 feet inclusive, eight from 0·10 to 0·19, and thirteen had a loss of less than 0·10 feet. Twelve observations showed more water in the spring than in the fall, the greatest gain being 0·17 acre-feet per acre. One observation was the same in the spring as in the preceding fall.

Twenty-three observations on potato plots are recorded in table 24. Of these four showed over 0·30 acre-feet less water in the spring than in the previous fall, six showed a loss of from 0·20 to 0·39 feet inclusive, one a loss of 0·13 feet, six a loss of less than 0·10 feet and five had more water in the spring than in the previous fall. One observation showed no change.

The greatest loss of water appears to have been from the wheat after wheat, the next greatest from the potatoes, the next from wheat after cultivated crop and the least from alfalfa. The greater loss of water from the wheat plots following wheat than from the wheat following a cultivated crop may have been partly due to the fact that the wheat after wheat plots were left in stubble

through the winter each year but one and then spring-ploughed, while the wheat plots after cultivated crop were cultivated in the fall after harvesting the potatoes or other cultivated crop and were not ploughed in the spring before seeding. The potato plots went through the fall and winter as wheat stubble and were ploughed in the spring the same as wheat after wheat, which fact may account for the relatively high water loss from those plots. The alfalfa plots which showed the lowest water loss had the advantage that they were sampled from two to four weeks earlier in the spring than were the wheat plots.

A comparison of the water loss in the different years show no consistent difference except for the period between the fall of 1925 and the spring of 1926. The loss in this period was higher than for any of the other three periods in each series of plots especially in the wheat after wheat and the potato plots. The only apparent reason for the greater loss in the 1925-1926 period was that between the time of securing the samples in the fall of 1925 and in the spring of 1926, there was very little precipitation (a total of but 2·51 inches). In addition the winter was unusually open and warm, with only nine days that the temperature went below zero. High winds were also experienced. It seems quite evident that the dry fall and spring and the windy open winter resulted in greater loss from the soil than is usual.

GENERAL SUMMARY

1. In this bulletin are reported the results of experiments with the irrigation of wheat, alfalfa, potatoes, sugar beets, and sunflowers, conducted at the Dominion Experimental Station, Lethbridge. The experiments cover a period of from two to seventeen years.
2. One irrigation produced a good crop of wheat in the years of average rainfall. In the drier seasons, two or three applications of water were needed.
3. Irrigating in the fall after harvest for the succeeding year's wheat crop proved to be a good practice. If a fall irrigation was not given, and if the precipitation of May and early June was not abnormally high, it was found essential to irrigate after the crop was up in the spring, but before the plants were checked in growth by lack of moisture.
4. Contrary to the usual opinion, irrigating wheat as early as the three-leaf stage did not reduce yields on the sandy clay-loam soils where the experiments were conducted.
5. When wheat needed more than one irrigation, good results were obtained when the second application was made in the flowering stage.
6. Irrigating wheat in the soft-dough stage did not increase yields, but sometimes caused the grain to lodge.
7. In each year of the experiments, except the "wet" year of 1927, alfalfa required at least two irrigations to produce two good crops. It was found necessary to apply one of these the previous fall or in early May to give a heavy first cutting of hay. A second irrigation was required just before or just after cutting the first crop. If May was dry, an irrigation when the first crop was about twelve inches high increased the yields.
8. It seemed to make little difference in the yields of the second crop whether the water was applied ten days before or immediately after cutting the first crop.
9. Irish Cobbler potatoes, irrigated when the plants were half-grown, gave lower yields than were secured if the first irrigation was postponed until the plants were starting to bloom. In the drier seasons an irrigation in the starting-bloom stage and two subsequent irrigations at intervals at three weeks was the most satisfactory practice.

10. There was no consistent difference observable in the cooking quality of potatoes receiving different irrigation treatments. When the plants were retarded in growth from lack of water and then irrigated, second growths, resulting in "knotty" tubers, were prevalent. The potatoes receiving five or six irrigations produced tubers with enlarged lenticels, but the cooking quality did not appear to be impaired. The greater number of irrigations produced more small potatoes than one or two irrigations.
11. Sugar beets have given the best yields and have had the highest sugar content when the soil has been kept moist enough for maximum growth during the entire growing season. In dry years, this has required irrigating as often as every two weeks from the first or second week of July to early September on loam soils.
12. Sunflowers gave best yields on fall-irrigated land or with a spring irrigation when the plants were about six inches high. In the two years of the test with sunflowers, one irrigation in the season was sufficient. This crop wilted noticeably if the soil became too dry, but revived and produced fair yields when water was applied.
13. These experiments indicate that, including the available water in the soil at the beginning of the season, wheat requires from 1·50 to 1·75 acre-feet of water, alfalfa 1·75 to 2·25 acre-feet and potatoes about 1·50 acre-feet to produce good crops.
14. Soil moisture determinations made of each foot-depth of soil to a depth of six feet before and after each irrigation showed that a six-inch application of water failed to penetrate into the soil to a depth of six feet in more than half the plots when the soil moisture content was below eleven per cent at the time of irrigation. With a moisture content between eleven and thirteen per cent, sixty to seventy per cent of the observations showed that the water had penetrated to six feet. The water applied to almost all of the plots having a soil moisture content above thirteen per cent wet down six feet or more.
15. The loss of water from the soil of fall-irrigated land between the time of irrigating in the fall and seeding the following spring was noticeable but usually not important, except in 1925-1926, when the weather between mid-October and early May was very open, dry and windy. During that period, the water-loss from a number of plots was about equal to the irrigation application of the previous fall.

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Four to six irrigations were found necessary by Bloodgood and Curry (7) for highest yields of wheat at the New Mexico Station.

In the Quetta Valley, India, Howard and Howard (24) with a single irrigation and appropriate mulch-producing cultivation obtained 1,450 pounds of wheat per acre. The native average was 1,100 pounds with the customary methods, involving seven irrigations.

Chiritescu-Arva (10) applied different amounts of water to wheat in containers of rolled zinc at three stages of growth—the green-shoot period, the ear-shooting period and the ripening of the ear period. The water optimum had the most beneficial effect on the green-shoot period on the following growth factors: number of ears per plant, total length of ears of single plant, number of fertile spikelets, number of grains per single plant and ear, weight of ears in single plant, average weight of an ear, and grain weight per single plant and ear. The water optimum had a more beneficial effect in the ear-shooting stage than in either of the other stages on the following factors: development of spikelets, density of spikelets, density of grains, number of grains in single spikelets, weight per 1,000 grains, development of ears and grains in proportion to total yield and development of parts above ground and of grains in proportion to weight of ears.

Moliboga (36) obtained better results with wheat by moistening the soil in the shooting stage than by moistening in the tillering, earing or milky-ripeness stages. Fortier (16) from his wide range of experimentation and observation, concludes that the time and frequency of irrigation depend primarily on the kind of crop grown and its need for water at particular stages of growth and secondarily on varying conditions of soil, root system, climate, water supply, water delivery and canal regulations. McLaughlin (35) has observed that holding off the water during early growth shortens the straw and hastens maturity, while excessive irrigation tends to increase the proportion of starch. He has found it good practice to irrigate when the grain is in the early milk but not in the final stages of ripening. For Montana conditions, Bingham (6) states that usually better results will follow three irrigations than two and he recomends that these be given in the 5-leaf, early boot and early to full bloom stage.

Part of wheat plots at harvest, showing ditches ploughed in and borders trimmed. Note that some plots have been harvested before others. In dry years the time of ripening may be materially influenced by the irrigation treatment.

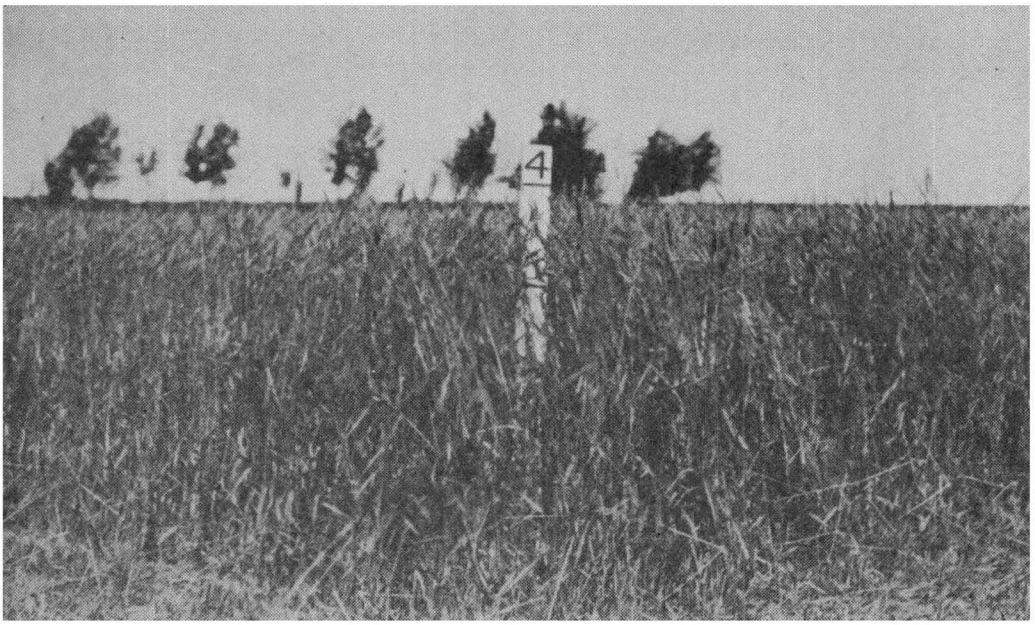
Stage of Plant Growth when Irrigation was most Effective

When but one irrigation was given, there was little difference in the average yields whether the water was applied in the three-leaf, five-leaf of shot-blade stages. If the first irrigation was postponed until the flowering stage, the yields were seriously reduced in the drier years as the plants were materially injured by drought before the water was applied. A first application of water as late as the flowering stage was beneficial, however, and gave an increased yield over the plots receiving no irrigation in fourteen years out of sixteen on the wheat following cultivated crop, and in eleven years out of sixteen on the wheat following wheat.

When two irrigations were given, the best average yields were secured from plots irrigated at the five-leaf and flowering stages. Irrigating the previous fall and again in the flowering stage, gave quite satisfactory results.

Number of Irrigations Required

Three irrigations gave significantly better yields than two in eight of the sixteen seasons with wheat following a cultivated crop and in five years with wheat following wheat. Two irrigations appeared sufficient in two years and one irrigation appeared sufficient in four years following a cultivated crop. Following wheat, two irrigations were necessary in five years, while one seemed sufficient in five years.



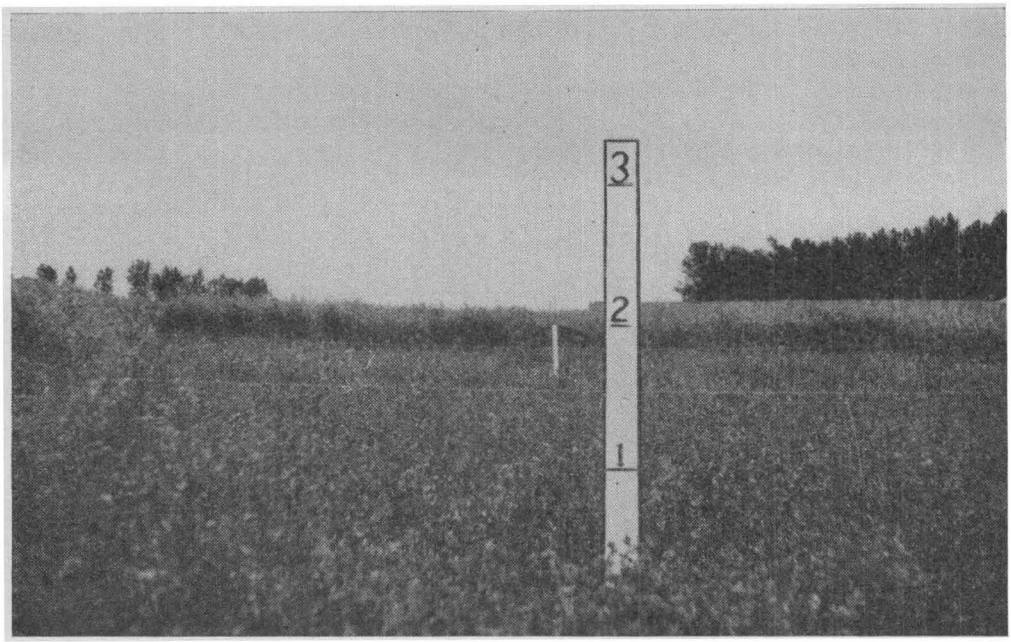
Wheat irrigated soon after coming up. Note the vigorous growth of straw and large heads. The usually accepted idea that irrigating wheat before the plants are large enough to shade the ground reduces yields was not substantiated in these experiments as each year high yields were secured from this early irrigation.

Suggested Irrigation Practice for Wheat

The results of these tests and a study of field irrigation in southern Alberta for the past thirty-five years lead to the conclusion that, on medium and heavy soils, one irrigation, applied in the previous fall or in the spring or early summer, before the crop is seriously in need of water, will produce a good crop in the years of average rainfall. If May and June are dry months, a second application

Stage of Plant Growth when Irrigation was Most Effective

The data in table 7 show that, where only one irrigation was given, the greatest average yield for the five years was obtained when this was applied in early May. The yield from a fall irrigation was almost as good as the spring irrigation, the difference in yield not being significant. Postponing the irrigation until plants were 12 inches high decreased the average yield about one-half ton per acre. When the first irrigation was delayed until just before or just after the first crop was cut, the average yield was reduced almost exactly one ton per acre. The increased yields obtained from the earlier irrigations are



Alfalfa just before cutting the first crop. Plots in the foreground were permitted to become too dry before water was applied and a poor crop resulted. The plot in the background was irrigated early in May and produced a heavy yield.

easily understood and are important in formulating an irrigation practice for alfalfa. When the irrigation was postponed in the spring until the plants suffered for water, the yield of the first cutting of hay was materially reduced. Where heavy early May rains are received as was the case in 1923 and 1927, early irrigations may not be of benefit but if May is a dry month, as it has been in about two-thirds of the year for which records are available at Lethbridge, a May irrigation appears to be essential if a heavy first cutting is to be expected. This is in harmony with the results obtained by Knight (30) in Nevada, where yields were depressed when the plants were allowed to suffer at all for water.

Irrigation Before or After Cutting.—The question of the relative merits of irrigating the alfalfa field just before or just after cutting the first crop of hay is often discussed. Three separate comparisons are possible each year of plots irrigated before, and plots irrigated after cutting. One comparison is of plots irrigated at the cutting stage only, one of plots irrigated in the previous fall and at cutting and one in the spring and at cutting. In each set the five-year average yield was slightly greater on the plots irrigated after cutting than on those irrigated before cutting. These differences are so small, however, that they are not significant. An examination of the yields for the individual years shows a higher yield for each set of plots irrigated after cutting in three years

thinning seemed to be early enough to start irrigation in this locality but occasionally beets showed slight signs of burning when left six weeks and were often seriously injured when irrigation was delayed for eight weeks after thinning. At five weeks after thinning the beets had made sufficient growth to commence to draw quite heavily on the soil moisture so from then on it was necessary to irrigate often enough to prevent the soil from becoming dry. On the medium-textured soils at the Station, this could be accomplished with three or four well-spaced applications, but in very dry years, five irrigations were not too many.

Part of sugar beet plots with wheat plots in left background.

In these tests it appeared desirable to continue irrigation until the first week of September. This kept the beets fresh and crisp until they were dug while beets in dry soils were softer, with a resultant decrease in yields of both beets and sugar. But little difficulty has been experienced with the soil being too wet at digging time where water was applied as late as the first week of September.

TABLE 11.—Percentage of Sugar in Sugar Beets Irrigated at Various Stages of Growth. 1930-1938 Inclusive

Number of Irrigations	Stages of Plant Growth When Irrigated	Average 9 Years	1930	1931	1932	1933	1934	1935	1936	1937	1938
		%	%	%	%	%	%	%	%	%	%
None	Dry	16·7	17·4	18·3	15·7	18·1	14·8	16·8	16·8	15·5	16·9
1	Previous fall	16·7x	16·1	19·3	15·3	15·5	16·3	17·0	.....	17·1	.....
1	I.A.T.	17·0	15·9	19·9	17·1	15·8	15·9	17·5	17·2	16·0	17·5
1	6 W.A.T.	17·0	17·1	18·5	16·5	15·2	16·7	16·4	16·5	18·1	17·6
1	8 W.A.T.	16·8	16·9	17·4	15·7	16·8	15·3	16·5	17·2	17·9	17·9
2	5 W.A.T., 9 W.A.T.	17·2	17·5	18·5	15·5	16·1	16·2	17·3	17·3	17·7	18·5
2	5 W.A.T., 11 W.A.T.	17·3	17·3	17·8	17·7	16·1	16·3	16·7	17·3	17·6	19·1
3	Fall, 5 W.A.T., 9 W.A.T.	17·1x	16·9	18·4	16·3	16·9	15·8	17·5	.....	17·7	.....
5	Fall, 2 W.A.T., 6 W.A.T., 9 W.A.T., 11 W.A.T.	17·1	16·5	18·0	15·1	16·5	15·3	17·9	18·5	16·9	19·3

NOTE.—In 1936, the 5 irrigation treatment was changed to: 2 W.A.T., 6 W.A.T., 9 W.A.T., 12 W.A.T., 14 W.A.T.
x—7-year average.
Abbreviations used: W.A.T.=Weeks after thinning.
I.A.T.=Immediately after thinning.