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KANSAS STATE AGRICULTURAL COLLEGE
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RELATION OF CROP YIELDS TO QUANTITY OF IRRIGATION WATER IN SOUTHWESTERN KANSAS

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RELATION OF CROP YIELDS TO QUANTITY OF IRRIGATION WATER IN SOUTHWESTERN KANSAS[1]

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IRRIGATION IN KANSAS

The acreage of irrigated land in Kansas is so small in comparison with the total area of land in cultivation in the state that little is known about it by most people. The major portion of the 95,138 acres reported as irrigated in 1920 is located in the valley of the Arkansas River in the southwestern part of the state. The principal irrigation counties and the acreage of land irrigated in each in 1920, as reported by the State Irrigation Commissioner, are as follows:

County	Acreage irrigated in 1920
Finney	52,041
Kearny	23,079
Scott	4,921
Hamilton	3,666
Pawnee	2,244
Meade	2,169
Gray	1,936
Sedgwick	685
Other counties	4,397
Total	95,138

The approximate location of the irrigated areas in the counties named above is shown in figure 1.

The present extent of irrigation in Kansas gives little indication of the irrigation possibilities of the state. The existence of large supplies of readily available underground water, especially in the southwestern part of the state, and of moderate supplies of surface water in many districts, together with the comparative aridity of the climate in western Kansas, furnish a good basis for the expectation that the irrigation agriculture of the state will some time be very extensive. This expectation justifies the Kansas Agricultural Experiment Station in maintaining at Garden City, Finney County, a branch station chiefly for the purpose of securing information which will be useful in dealing with both present and prospective irrigation problems.

[1] Contribution No. 140 from the Department of Agronomy.

[2] The author was superintendent of the Garden City Branch Experiment Station during the time this experiment was being conducted.

PURPOSE OF EXPERIMENT

It is a matter of general observation that some crops are better adapted to irrigation than others. Crops that prove satisfactory for dry-land conditions may be unable to produce profitable yields when water is artificially applied, while on the other hand certain plants that cannot be grown successfully under dry-land conditions may prove highly satisfactory under irrigation. Alfalfa is an example of the latter. On the high upland of western Kansas alfalfa cannot always be depended on to remain alive from year to year, much less produce profitable yields, while under irrigation it thrives remarkably well. It is also true that crops that may be success-

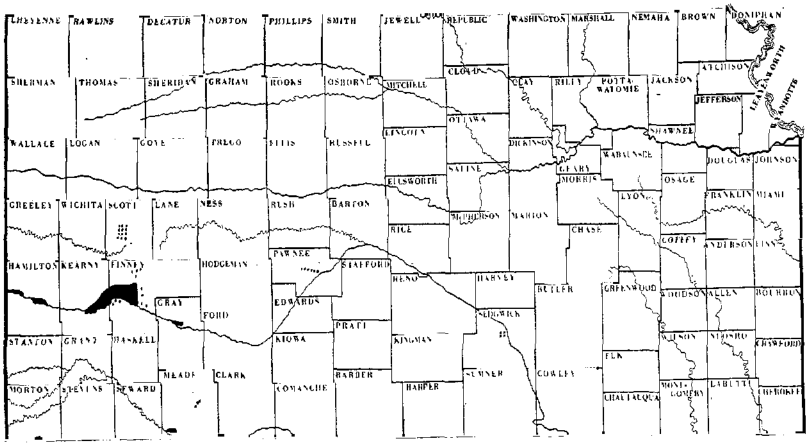

FIG. 1.—Map showing approximate location of irrigated land in eight Kansas counties in 1920, as reported by the State Irrigation Commissioner

fully grown under irrigation differ greatly as regards the amount of water than can be applied to them profitably.

In view of these facts it is evident that there are two questions of primary interest to every irrigation farmer: (1) The types or kinds of crops to raise, and (2) the most economical amounts of water to apply. To aid in answering these questions, a series of experiments were started in 1914 at the Garden City Branch Experiment Station. These experiments were planned to determine the yields produced by different quantities of water when applied to some common farm crops. They were continued for five years. This bulletin reports the results secured. The work was carried on in cooperation with the U. S. Department of Agriculture until 1918, and by the Kansas Agricultural Experiment Station alone after that time.

ENVIRONMENTAL CONDITIONS

RAINFALL

The climate at Garden City has been called semiarid It may be more nearly accurate to say that it is variable. One season may be characterized by almost humid and another by almost arid conditions. The distribution of rainfall during the season is also extremely variable so that there is seldom a season comparable in all respects to the-average for a series of years. The average annual rainfall, 1909 to 1919 inclusive, was 17.99 inches. The maximum during this period was 26.51 inches, in 1915, and the minimum, 9.7 inches, in 1914. The average for the five crop years reported in this bulletin was 18.91 inches. Table I shows the rainfall by months for these five years. It is arranged to show the rainfall by crop years (October 1 to September 30) instead of calendar years, since all precipitation falling after the end of September can be considered of value only to the following crop.

Most of the rainfall, as indicated by the averages, falls in April, May, June, July, and August. Summer rains, however, are frequently torrential, or on the other hand, come in light isolated showers. In either case a large part of the water is lost, as far as the crop is concerned, through surface runoff or by direct evaporation, as the case may be. The effectiveness of the rainfall is de-

TABLE I.—ANNUAL RAINFALL AT THE GARDEN CITY BRANCH EXPERIMENT STATION, 1915 TO 1919

MONTH	Crop year					Average
	1914-15	1915-16	1916-17	1917-18	1918-19	
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
October	1.48	1.79	0.67	0.13	3.23	1.46
November	.0	.12	T	.30	.13	.11
December	.06	.13	.51	.16	3.10	.79
January	.45	1.09	.30	.34	.18	.47
February	2.54	T	.0	.64	1.52	.94
March	.93	.60	.60	2.21	1.53	1.17
April	2.67	2.80	2.71	.79	1.96	2.19
May	4.39	.40	3.27	2.48	.78	2.26
June	2.96	4.21	1.19	1.91	.96	2.25
July	1.66	.20	2.96	3.58	2.96	2.27
August	6.60	3.89	2.99	.64	1.15	3.05
September	2.27	1.16	1.13	2.00	3.20	1.95
Total	26.01	16.39	16.33	15.18	20.70	18.91

creased further, as compared with some other sections of the Great Plains, by hot drying winds which frequently occur during the growing season.

SEASONAL CONDITIONS, 1915 TO 1919

The season of 1915 was the most favorable one for crop production since the experiment station was established in 1907. Good yields were obtained by all cultural methods on unirrigated as well as irrigated land.

Almost the opposite conditions prevailed in 1916. Although the rainfall was only about 3.5 inches below normal, it was, in effect, very deficient because of heavy runoff and light isolated showers which were of little value to growing crops.

General climatic conditions in 1917 were very unfavorable. The seasonal rainfall was slightly more than the preceding year, but most of it was poorly distributed and therefore was of little value. Other climatic conditions also had an unfavorable influence upon crop yields. Cereals produced but small yields under irrigation, and on dry land the crop was a complete failure as far as grain yields were concerned. The season of 1918 was also very unfavorable, although the total precipitation for the year was 21.05 inches, or 3 inches above the average. Much of this, however, came too late to be of any value to the growing crop.

Good yields of all crops were obtained in 1919. Copious rains in the late fall of 1918 filled the soil with moisture, after which the ground was covered with more than a foot of snow until the first of March. When spring arrived the soil was in an ideal condition. Crops made a good growth and in general required less than the usual amount of irrigation water during the season.

SOIL

The Garden City Branch Experiment Station is located on high upland. The soil is a light silt loam, classified as Richfield silt loam.[1] With the exception of the accumulated humus near the surface it is practically uniform to a depth of at least 15 feet. The development of roots is limited only by the depth to which water is available and the character of the crop.

Mechanical analyses of Richfield silt loam in the Garden City area are given in Table II.[2]

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[1] Formerly called Marshall silt loam.

[2] Burgess, James J., and Coffey, George N. Soil survey of the Garden City area. Field operations of the Bureau of Soils, 1904 (Sixth Report). Pp. 895-923. 1905.

TABLE II.—MECHANICAL ANALYSES OF RICHFIELD SILT LOAM IN THE GARDEN CITY AREA

No.	Location of sample	Description and depth of sample	Gravel (*a*)	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
			Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
11108	S. E. cor. Sec. 27, T. 24 S., R. 31 W.	Brown silty loam, 0-16 inches.....	0.2	0.8	0.7	3.7	20.2	54.2	19.9
11100	N. E. ¼ Sec. 8, T. 24 S., R. 31 W.	Brown silty loam, 0-24 inches.....	.0	.3	.3	3.0	19.4	56.3	20.5
11181	Subsoil of 11100...............	Silty loam, 40-72 inches..........	.0	.1	.1	.6	14.6	63.7	20.4
11109	Subsoil of 11108...............	Yellow silt, 16-72 inches..........	.1	1.3	1.1	4.0	15.2	56.6	21.5

(*a*) According to the standard of the United States Bureau of Soils, soil particles are classified as follows: Gravel, 2 to 1 mm. in diameter; coarse sand, 1 to 0.5 mm.; medium sand, 0.5 to 0.25 mm.; fine sand, 0.25 to 0.1 mm.; very fine sand, 0.1 to 0.05 mm.; silt, 0.05 to 0.005 mm.; and clay, 0.005 to 0.0001 mm.

PLAN OF THE EXPERIMENT

The experiment included seven crops; namely, milo, kafir, sumac, Sudan grass, wheat, oats, and barley. They were grown in duplicate series on one-twentieth acre plots. The varieties used were those most commonly grown by farmers in the Garden City area. Winter wheat was sown each year but failed to survive the winter in 1916-17 and 1917-18, and spring wheat was grown in its place. Each crop was grown on four plots, designated as "A," "B," "C," and "D," each of which received a different amount of water. All plots were irrigated during the winter. In addition the "A" plots were irrigated sufficiently during the summer to maintain the moisture content of the soil at about 20 percent; the "B" plots at about 16 percent; and the "C" plots at about 12 percent. The "D" plots were not irrigated during the growing season.

ARRANGEMENT OF PLOTS

The sorghum plots were 33 by 66 feet and the small grain plots, 39 by 56 feet. Duplicate plots were adjacent with no alleys between in the case of the sorghums (milo, kafir, sumac, and Sudan grass), but with 20-foot roadways and 6-foot alleys in the case of the small grains (wheat, oats, and barley). The arrangement of the plots is shown in figures 2 and 3. In irrigating, a small dike or border was thrown on the plot line to prevent water, intended for one plot, from running over an adjoining one.

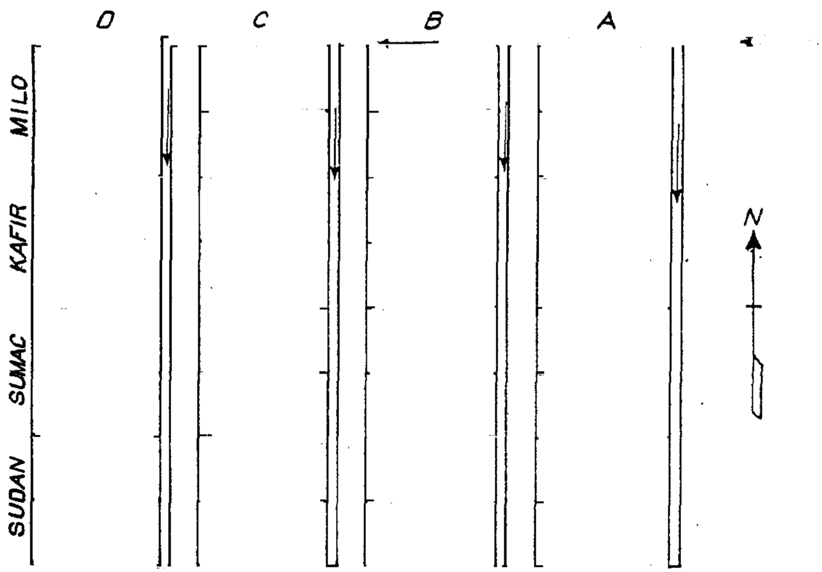

FIG. 2.—Diagram showing arrangement of the four series of duplicate plots planted to milo, kafir, sumac and Sudan grass

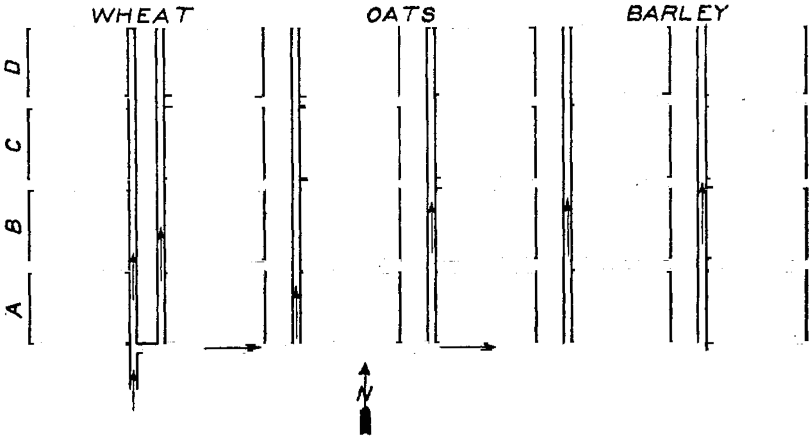

FIG. 3.—Diagram showing arrangement of the four series of duplicate plots sown to wheat, oats, and barley

CULTURAL METHODS

All plots were continuously cropped, no rotation being practiced. The land for the small grain crops was plowed to a depth of about 6 inches soon after harvest each year, and received no further treatment until wheat-seeding time, the latter part of September. The ground was then disked, harrowed, and leveled. The wheat plots were irrigated before sowing the crop. This comprised the winter irrigation for wheat. The other small grain plots were irrigated late in the fall, usually about the first of December, but were not cultivated in any manner until seeding time in the spring.

The sorghum plots were plowed late in the fall or winter and were usually irrigated soon after plowing if weather conditions permitted. In some instances the ground froze soon after plowing and it was necessary to delay the winter irrigation until a warm spell of weather in February or March. The land was prepared for planting by double disking, harrowing, and leveling. The crops were then drilled in rows 44 inches apart with a surface planter—surface planting having been found more satisfactory than listing on winter-irrigated land. During the growing season the crops received sufficient cultivation to prevent weed growth and restore a soil mulch after irrigating.

APPLICATION OF WATER

Because of the seasonal variation of rainfall and the lack of sufficient knowledge concerning the amounts of water required by crops under test, the moisture content of the soil was determined at intervals as a basis for the application of water. This, it was hoped, would show when water was needed by the different crops, as well as the amount of water needed.

The amount of water applied in the winter irrigation was governed largely by soil conditions and varied from year to year. In general it amounted to about 8 inches.[1] The water was flooded over the loosely plowed ground and allowed to run until it had covered the field uniformly. If the land was recently plowed or the soil very dry it absorbed more water before a uniform irrigation was secured than a soil which had become more compact or which had become partly saturated by recent rains.

Soil samples for the determination of moisture were taken by 1-foot sections to a depth of 6 feet at planting time and after harvest. Between these dates samples were taken to a depth of 3 feet as often as was necessary to keep informed on the condition of the soil. Whenever the moisture content dropped a few points below the predetermined amount for that plot or series of plots, the crop was irrigated. A sufficient quantity was applied to raise the moisture content about the same number of points above the fixed amount. In this way from 2 to 4 inches of water was applied at each irrigation.

RESULTS OF THE EXPERIMENT

In conducting this experiment special attention was given to the yields secured by different amounts of water, but much additional interesting and valuable information was secured regarding the adaptability of the various crops to irrigation agriculture and their ability to make efficient use of large quantities of irrigation water. Since there was no great variation in the soil or in other conditions under which the crops were grown, it is reasonable to suppose that most of the differences in yield can be ascribed to a difference in soil moisture conditions resulting from the application of different amounts of water.

RESULTS WITH MILO

In addition to the winter irrigation which was alike on all four plots, the "C" plots of milo received an average of one irrigation during the year, usually about August 1. The "B" series usually required two irrigations, the dates of which were approximately July

[1] Whenever the term "inches" is used in this bulletin to indicate a quantity of irrigation water, it means the depth to which the water applied would have covered the land if no percolation had taken place.

20 and August 10. Usually it required three irrigations to keep the moisture in the "A" series at the required amount, and the dates ranged from about July 10 to September 1. The amounts and dates varied from year to year with varying weather conditions, but there were no noteworthy changes except in 1919 when heavy rains and snow during the preceeding fall and early winter so saturated the soil that winter irrigation was unnecessary, and that the series "C" required no irrigation during the growing season. This was true for all of the sorghum crops included in the experiment in 1919.

The results secured with milo are given in Table III and shown graphically in figure 4. The amount of vegetative growth and appearance of the crop are shown in "I," figure 5.

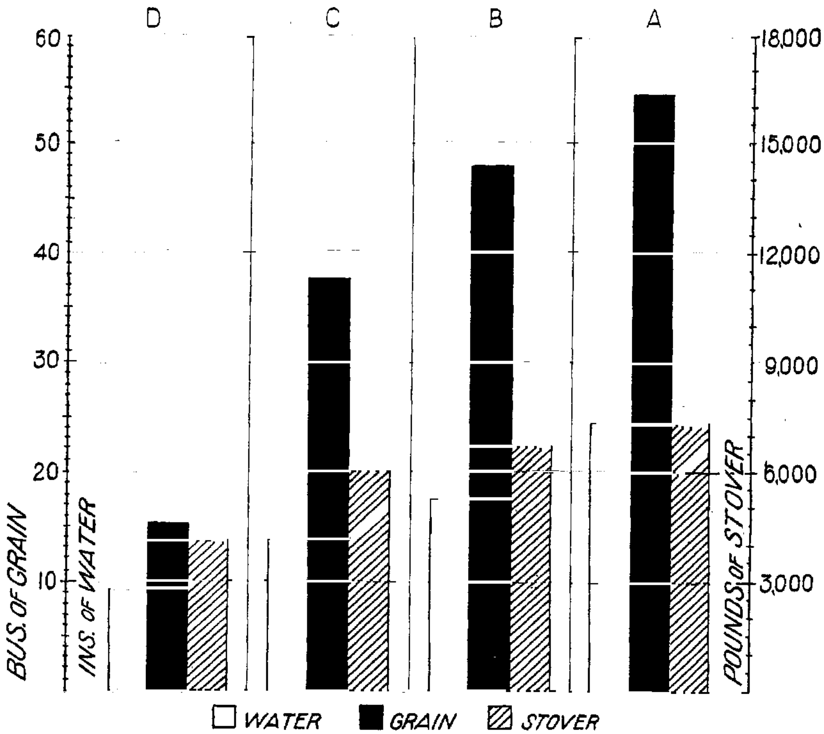

FIG. 4.—Graphs showing the effect of different quantities of irrigation water on yield of milo; average for four seasons, 1915 to 1918

TABLE III.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF MILO

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Grain	Stover		Grain	Stover		Grain	Stover		Grain	Stover
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915	11.5	33.7	6,200	11.5	47.8	7,400	14.9	53.6	8,800	21.1	57.6	9,800
1916	5.2	7.5	4,200	11.3	16.3	5,800	14.3	41.5	6,200	21.3	58.6	8,200
1917	8.2	.0	2,200	13.8	28.8	2,600	21.6	41.8	2,800	29.7	43.7	3,800
1918	12.7	20.1	4,000	18.6	57.8	8,200	21.5	55.4	9,000	26.5	59.1	7,200
1919	......	......	......	.0	52.9	5,000	2.6	44.1	4,400	7.3	49.7	5,600
Av., 1915 to 1918	9.4	15.3	4,150	13.8	37.7	6,000	18.1	48.1	6,700	24.7	54.7	7,250
Av., 1915 to 1919	......	......	......	11.0	40.7	5,800	15.0	47.3	6,240	21.2	53.7	6,920

It will be seen that the "D" plots received an average of 9.4 inches of water in addition to the rainfall. This produced 15.3 bushels of grain and 4,200 pounds of stover per acre. The "A" series received 21.2 inches of water applied by irrigation. These plots produced an

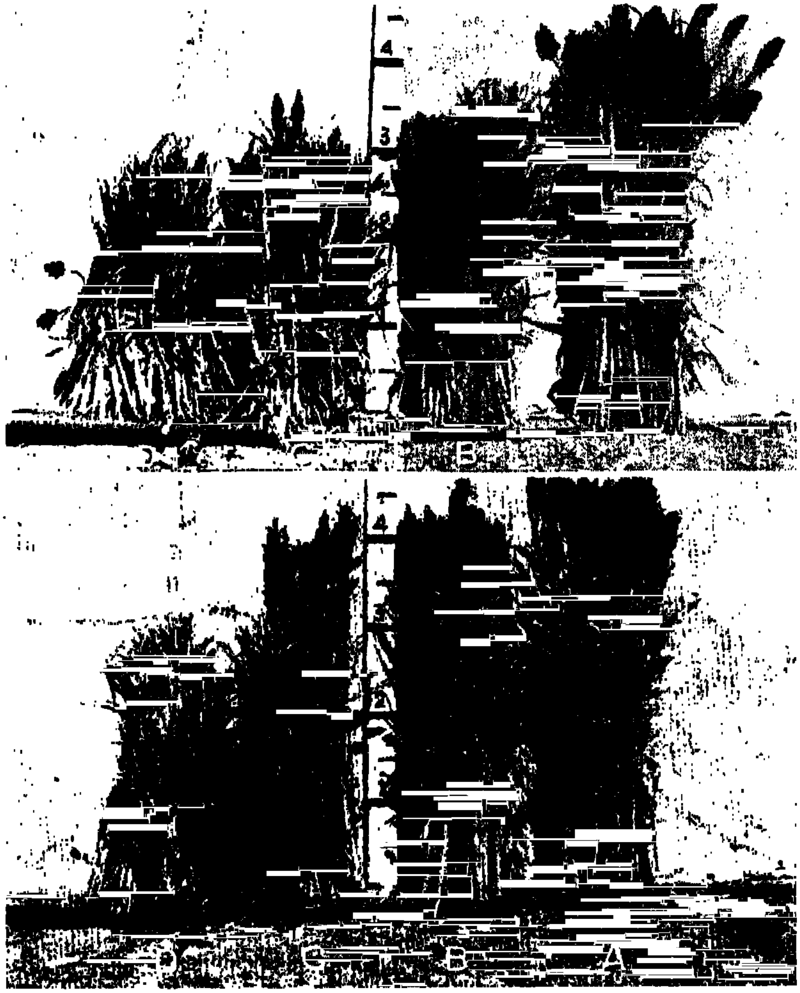

FIG. 5.—Representative samples of milo (I) and kafir (II) produced in 1916 in Series "A," "B," "C," and "D," respectively

average of 53.7 bushels of grain and 7,000 pounds of stover per acre. The amount of water applied and the yields of the other plots ranged between these two, the yield increasing with the application of water. While each increase in amount of water showed a definite increase in yield, it will be noted that the greatest change occurred between the "D" and "C" series, where.an increase of 4.4 inches, or 47 percent, in the amount of water applied increased the yield of grain 22.4 bushels per acre, or 146 percent.

It will also be seen that there was a much greater annual variation in the yield produced in the "D" series than in those receiving higher rates of ratering. This variation is from a complete failure in 1917, to 33.7 bushels per acre, or more than **100** percent above the average, in 1915. In the "C" series the variation was from 16.3 bushels in 1916, to 57.8 bushels in 1918. In the "B" series the variation was from 41.5 to 55.4 and in the "A" series from 43.7 to 59.1 bushels per acre. Without doubt much of the seasonal variation in the "D" series was due to a difference in the amount of water applied in the winter irrigation. The entire variation, however, cannot be due to this alone. The fact that the yearly results become more uniform as the amounts of water increase is strong presumptive evidence that with more copious irrigations the crop becomes less subject to adverse climatic conditions. This did not appear to be true of all crops included in this experiment, however. These characteristics distinguish milo as the most productive irrigated grain crop in the Garden City area.

RESULTS WITH KAFIR

The dates of irrigating kafir correspond very closely with those for milo. The results are given in Table IV and shown graphically in figure 6. The amount of growth and appearance of the crop are shown in "II," figure 5. The data show that the amounts of water applied were almost exactly the same as for milo. However, the yields of kafir were not so large and did not show the wide range of the milo. Notwithstanding this, the two crops showed much the same general characteristics. With kafir there was; as with milo, a definite increase in yield accompanying each increase in the amount of water, and the greatest increase for a given amount of water occurred in the "C" series, where the application of an additional 3 inches increased the yield of grain 8.5 bushels per acre. In other words, increasing the amount of water about 30 percent increased the yield of grain about 65 percent. The "B" plots received 5.3 inches more water than the "C" plots and produced 7.8 bushels more of grain per acre, while the "A" plots received 11.5 inches more water than the "C" plots and produced 11.7 bushels more grain. Although the "C" series of both crops produced the greatest yield per inch of water, it does not follow that this is the most economical amount to apply or that it will produce the great-

TABLE IV.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF KAFIR

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Grain	Stover		Grain	Stover		Grain	Stover		Grain	Stover
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915	11.5	42.5	7,200	11.5	40.1	9,000	14.9	42.7	8,200	21.1	40.5	8,800
1916	5.2	8.5	4,800	11.3	21.1	7,800	14.3	42.4	9,000	21.3	46.2	10,200
1917	8.2	.0	2,200	13.8	23.1	5,000	21.6	22.9	4,800	29.7	29.1	4,600
1918	12.7	2.1	2,000	12.7	3.0	2,400	19.5	9.8	2,600	23.1	18.2	3,800
1919	....	....	....	.0	31.5	5,000	2.5	30.1	4,200	7.3	34.5	4,400
Av., 1915 to 1918,	9.4	13.3	4,050	12.3	21.8	6,050	17.6	29.5	6,150	23.8	33.5	6,850
Av., 1915 to 1919,	....	....	....	9.9	23.8	5,840	14.6	29.6	5,760	20.5	33.7	6,360

est net profit when items other than the cost of water alone are taken into consideration.

There was with kafir, as with milo, a wide annual variation in the yield with the lowest rate of watering and a constant decrease in variation of yields as the amounts of water increased. It will be noted also that the yield of grain increased at a greater rate than the yield of stover.

While the results obtained with kafir agree in many ways with those obtained with milo, the kafir failed to respond to the application of water to the same extent. It appears that kafir is not so

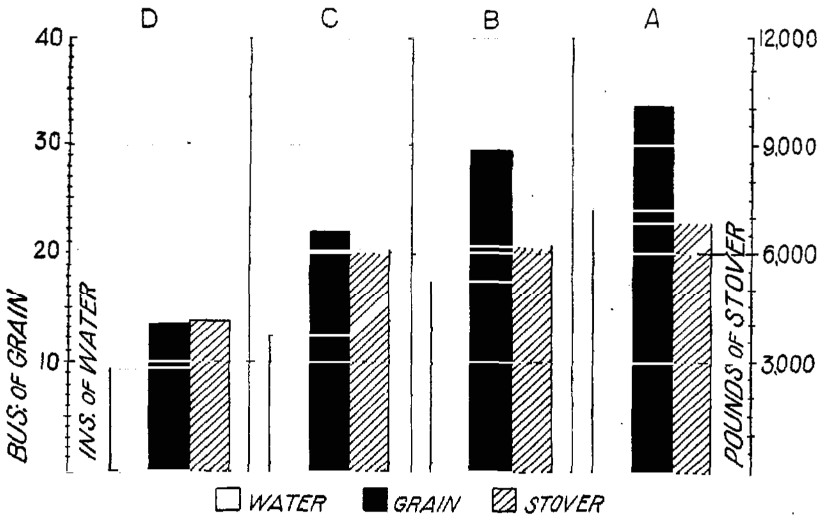

FIG. 6.—Graphs showing the effect of different quantities of irrigation water on yield of kafir; average for four seasons, 1915 to 1918

productive a crop as milo to raise under irrigation in the Garden City district, and should not be grown unless stover or forage as well as grain is a consideration. The yields of stover from the two crops are practically the same. Kafir stover, however, is more valuable, which may in some instances justify the growing of kafir at some sacrifice in yield of grain.

RESULTS WITH SUMAC

The amounts of water applied to sumac and the time of application were much the same as for milo and kafir, indicating that the sumac used water in about the same way and at about the same rate. However, the general characteristics of sumac are quite different from those of milo or kafir. It is primarily a forage crop and in this experiment is considered from that standpoint. The results are given in Table V and shown graphically in figure 7.

TABLE V.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF SUMAC

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Seed	Stover		Seed	Stover		Seed	Stover		Seed	Stover
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915............	11.5	15.0	21,600	11.5	12.8	21,600	14.9	13.2	19,800	21.1	17.4	17,400
1916............	5.2	.0	9,200	8.6	9.9	15,800	14.3	26.2	18,600	21.3	39.2	20,200
1917............	8.2	.0	10,000	13.8	4.8	18,000	21.6	12.6	21,000	29.7	9.8	19,200
1918............	....	....	....	12.7	17.0	9,000	19.5	24.8	13,800	22.6	26.8	13,600
1919............	....	....	....	.0	27.6	9,400	2.5	31.6	10,400	7.3	36.7	12,000
Av., 1915 to 1917,	8.3	5.0	13,600	11.3	9.2	18,470	16.9	17.3	19,800	24.0	22.1	18,933
Av., 1915 to 1919,	....	....	....	9.3	14.4	14,760	14.6	21.7	16,720	20.4	26.0	16,480

In general, the response of sumac to water was about the same as for milo and kafir, but the practical conclusions to be derived from the experiment are quite different because the crop is used primarily for forage rather than for grain. The yields of forage, it will be noted, gradually increased with the application of water in the "C" and "B" series. There appeared to be practically no differ-

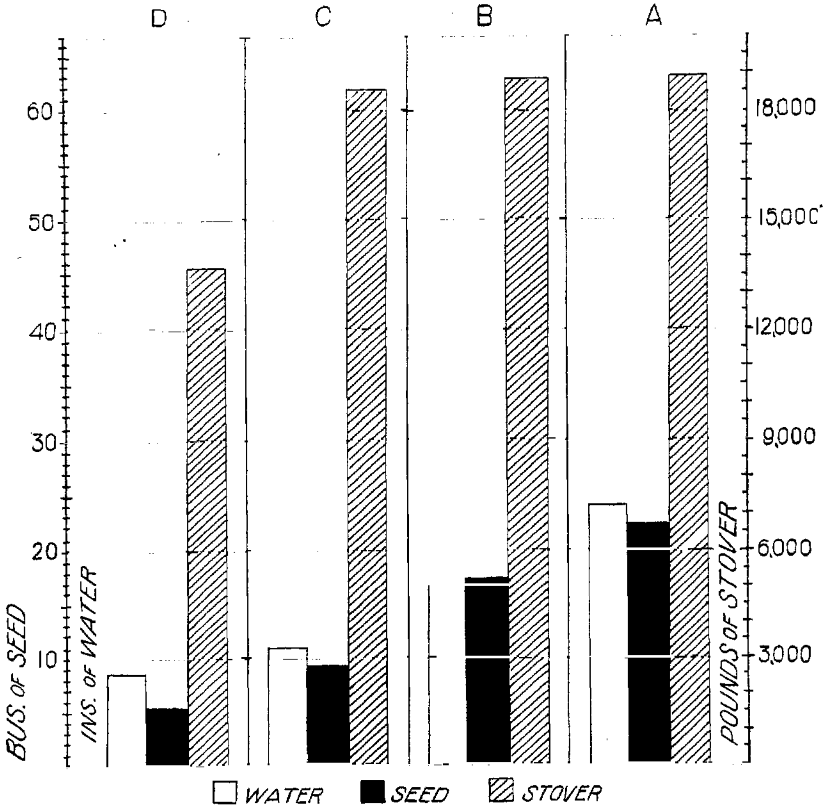

FIG. 7.—Graphs showing the effect of different quantities of irrigation water on yield of sumac; average for three seasons, 1915 to 1917

ence, however, between the "B" and the "A" series. It will be noted also that the difference in yield between the "D" and the "C" series and between the "C" and the "B" series was rather small considering the rather large yield secured with winter irrigation alone. The variation in yields from year to year is of interest. In 1915, when the summer rainfall was unusually large, the highest yield was from the "D" and the "C" plots, and the yield decreased progressively as the amounts of water increased. Notwithstanding this, the soil moisture was exhausted, apparently by the crop, so that it was necessary to apply water to maintain the soil moisture at the required amounts. In only two seasons did the highest rate of watering produce the greatest yield. In one of these, 1916, there was a consistent increase with an increase in the amount of water applied.

It is of interest to note that even though there was practically no difference in the average yield of stover between the "A" and the "B" plots, the average yield of seed was greatest for the "A" plots. In fact, there was a uniform increase in seed production from the lowest to the highest rate of watering. Evidently higher rates of watering might have 'produced still more seed, although it is doubtful if the yield of stover would have been increased. Sumac is a late-maturing crop at Garden City and often the seed fails to ripen before frost. Throughout the course of the experiment it was observed that the sorghum crops most plentifully supplied with water invariably matured earlier than those which experienced a shortage of water. This appeared to be due to the crop's entering a dormant state whenever moisture was deficient. When moisture was added the crop resumed its growth. On the other hand, those crops having sufficient moisture were not retarded in their growth and as a result matured earlier. Seed from the "A" plots of sumac was large, plump, and usually well matured, but from those plots receiving less water with few exceptions was small, immature, and shriveled.

The results show a marked failure of sumac to make efficient use of large amounts of water when grown for forage. It seems safe to conclude that in the Garden City district the most economical use of water for this crop will be secured by the application of a generous winter irrigation only.

RESULTS WITH SUDAN GRASS

The results with Sudan grass are given in Table VI and shown graphically in figure 8. No data are available for 1919 on account of a failure to secure a stand.

One of the most striking results of this experiment was the failure of Sudan grass to respond uniformly and significantly to increased quantities of water, either as regards the yield of seed or stover. There was a slight increase in the yield of stover, but the increase was very small compared with the amount of water used. It might be supposed that because of these low yields the water requirements of the crop were also low, but an examination of the

TABLE VI.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF SUDAN GRASS

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Seed	Stover		Seed	Stover		Seed	Stover		Seed	Stover
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915	11.5	11.8	6,200	11.5	11.0	6,600	14.9	9.2	6,800	21.1	8.5	7,000
1916	5.2	1.5	2,600	8.6	2.0	4,000	14.3	1.0	4,600	21.3	1.6	6,800
1917	8.2	4.7	2,000	13.8	2.2	4,000	21.6	3.5	4,000	29.7	4.2	4,600
1918	12.7	4.2	2,800	12.7	8.2	3,200	21.6	6.7	3,800	26.2	6.2	2,400
Average	9.4	5.6	3,400	11.7	5.9	4,450	18.1	5.1	4,800	24.6	5.1	5,200

averages at the bottom of Table VI shows that more water was used than for any other sorghum crop in the experiment. Since water was added only as necessary, as indicated by the moisture content of the soil, it seems that water must have been used more rapidly by the Sudan grass than by the other sorghums. It will be noted that on none of the plots were the yields either of seed or stover high. This result, as far as production of hay is concerned, was no doubt to some extent due to planting the crop in rows primarily for seed. In experiments with Sudan grass on unirrigated land, where the seed has been drilled for a hay crop, it has produced from two to four crops of hay each year, averaging about a

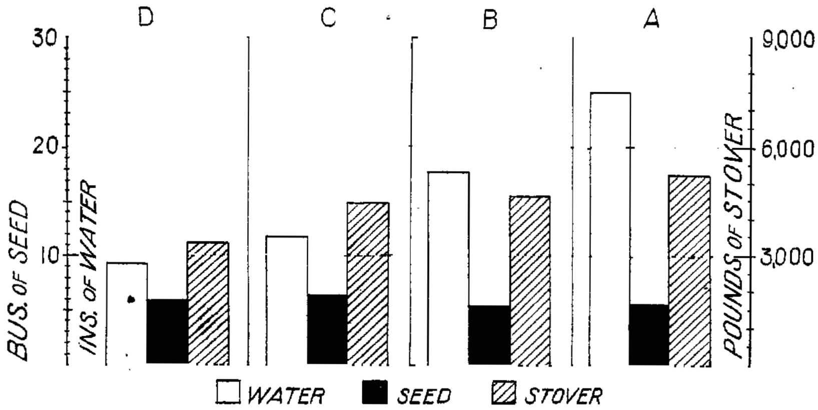

FIG. 8.—Graphs showing the effect of different quantities of irrigation water on yield of Sudan grass; average for four seasons, 1915 to 1918

ton of hay per acre for each crop. It therefore seems probable that had the Sudan grass in this experiment been drilled and harvested as a hay crop, the yields of hay would have been much larger and there probably would have been a greater range in yield with the different amounts of water.

Attention is also called to the fact that the average seed yield was highest on the "C" plots. This was not because the higher rates of watering did not increase the yield of seed, so much as it was a secondary result of the maturity of the seed. Sudan grass is a plant which, under favorable conditions, stools or suckers profusely. Increasing the amount of water increased the number of suckers, and seed on the suckers as a rule matured much later than on the main stalks. As a result there were at harvest time large amounts of overripe and of immature seed on the plots which received the most water. The amount decreased with the decrease in the amount of water and hence the loss from shattering also decreased in like ratio. The conclusion seems justified that a large amount of water should not be applied to Sudan grass grown for seed.

RESULTS WITH WHEAT

The amount of water used by the wheat was practically the same as that used by the sorghum crops. It will be seen that more than an average amount was applied in 1916, In that year there was less than an average rainfall and the crop on the land was much heavier than in the two other dry years. Crop records show that the last irrigation was applied to the "C" and "B" series on June 6, and to the "A" series on June 27. The crop was harvested that year on July 5. At harvest time thesoil moisture was 13.3 percent, 14.9 percent, and 17.6 percent in the "C," "B," and "A" series, respectively, showing that with the exception of a small amount in the "C" series, no more water was applied than was necessary to keep the soil moisture at the required amount.

The results are given in Table VII and shown graphically in figure 9.

It will be noted that in general the yields increased somewhat with the application of water but that the increase secured from the "C" to the "A" plots was too small to justify the extra expense.

Examination of the data shows considerable variation in the results from year to year. This seems to be as great with high rates of watering as with the lower rates, from which it appears that adverse climatic conditions affected all plots alike almost without regard to soil moisture conditions.

The unusually low yields obtained in 1917 and 1918 may be accounted for partly by the failure of the winter wheat to survive the winters, and the substitution of spring wheat for it.

Straw is of little value and in this experiment straw yields would not be considered except for the information they give regarding the general characteristics of the crop as influenced by different amounts of water. It will be seen that there was an almost uniform increase of straw with increase of water, showing a tendency of the crop to produce relatively larger amounts of straw than grain as the available water was increased.

It is evident from the results that wheat yields are influenced nearly as much by general climatic conditions as by soil moisture; that no amount of water will insure good yields in unfavorable years; and that increasing the amount of water has little effect on

TABLE VII.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF WHEAT

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Seed	Straw		Seed	Straw		Seed	Straw		Seed	Straw
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915.............	4.1	25.3	3,000	9.1	32.1	3,270	11.0	26.0	2,740	14.3	28.8	2,950
1916.............	8.9	15.6	1,300	13.5	20.3	1,705	20.6	26.9	2,585	34.5	29.1	2,660
1917.............	8.8	.0	0	8.8	.1	117	15.8	1.4	715	19.3	1.2	875
1918.............	8.0	3.3	1,100	8.0	11.0	1,170	16.6	12.2	1,940	22.2	16.8	1,790
1919.............	11.8	23.0	2,560	11.8	33.0	3,120	14.5	29.0	2,860	18.5	34.5	3,780
Average..........	8.3	13.4	1,592	10.2	19.3	1,876	15.7	19.1	2,168	21.8	22.1	2,411

yields and very little will be gained by the applicatio of more than about 10 inches of irrigation water.

RESULTS WITH OATS

Table VIII gives the results obtained from the experiments with oats. These results are shown graphically in figure 10. The average results indicate about the same phenomena as in the wheat experiment. Although the average shows a consistent increase in yield with increasing amounts of water up to and including the "B" series, the results for single years show little or no regularity and seem to have but little relation to the amounts of water applied. Thus in 1915 the amounts of water ranged from 4.1 inches on the "D" series

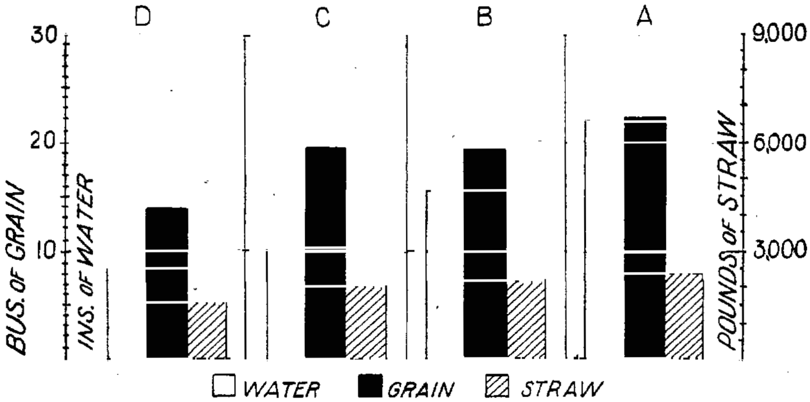

FIG. 9.—Graphs showing the effect of different quantities of irrigation water on yield of wheat; average for five seasons, 1915 to 1919

to 16.2 inches on the "A" series, but the extreme range of the crop yield was but 2.8 bushels per acre, the highest yield being on the lowest rate of watering. This was a year of relatively high rainfall. In 1919, another year of more than normal rainfall, the range of yield again was small, being but 4.1 bushels per acre. That year, however, the highest yield was on the "B" series and the lowest on the "A" series. In 1916, when the rainfall was below normal, there was a range in yield of from 15 bushels per acre on the "D" plots to 49.6 bushels per acre on the "A" plots, although here was, but little increase above the "B" plots. In 1917 climatic conditions were so unfavorable that almost no grain was produced, irrespective of the amount of water applied.

These results seem to show that oats are dependent upon general weather conditions to at least as great an extent as is wheat, and

TABLE VIII.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF OATS

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Grain	Straw		Grain	Straw		Grain	Straw		Grain	Straw
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915.............	4.1	51.8	1,800	9.1	49.0	1,530	11.6	49.0	1,570	16.2	50.6	2,560
1916.............	7.6	15.0	620	12.2	33.9	1,315	18.3	40.3	1,310	31.7	40.6	1,550
1917.............	7.1	.0	000	7.1	.7	127	14.1	6.7	685	17.6	5.9	710
1918.............	8.2	9.0	1,010	8.2	15.6	900	16.8	24.9	1,300	16.8	20.3	1,250
1919.............	7.6	38.1	1,430	7.6	38.4	970	15.3	42.2	1,200	23.0	36.6	930
Average..........	6.9	22.8	972	8.8	27.5	968	15.2	32.6	1,213	21.1	30.8	1,400

that climatic conditions exert a greater influence upon yields than soil moisture conditions or amounts of water. Thus, with the very adverse conditions of 1916 to 1918, inclusive, the crop showed a very small response to increasing amounts of water, the highest yields even in those years scarcely exceeding the minimum yields of more favorable seasons; and in 1915 and 1919, when climatic conditions were more favorable, good yields were obtained on all the plots irrespective of the amounts of water used.

RESULTS WITH BARLEY

The results with barley are given in Table IX and shown graphically in figure 11.

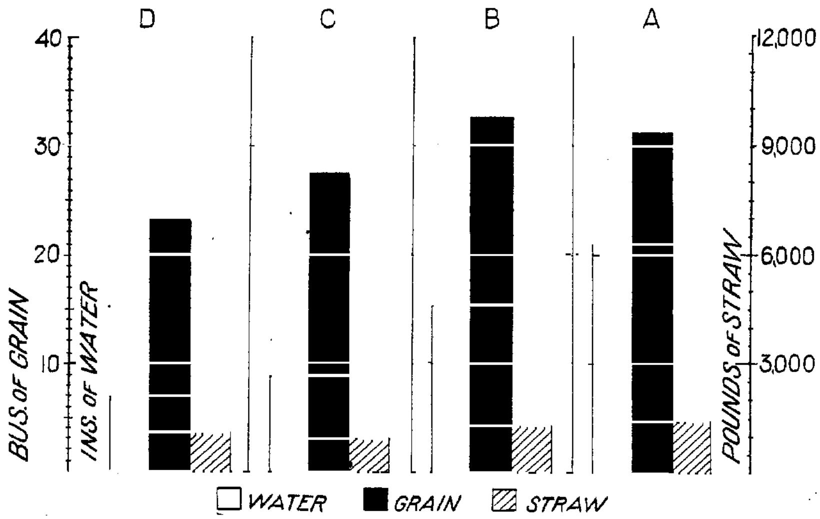

FIG. 10.—Graphs showing the effect of different quantities of irrigation water on yield of oats; average for five seasons, 1915 to 1919

The conclusions regarding the effect of climatic conditions on the yield of oats appear to apply equally well to barley. The data show that climatic conditions evidently had a greater effect upon the production of grain than differences in the amounts of water. The average yield for the five years, however, differed from oats in that there was very little difference in yield between the "D" and "C" plots, and the yield continued to increase from the "B" to the "A" plots. Unlike the cases of most of the crops studied, the greatest increase in yield was between the "C" and "B" plots, but the greatest yield per inch of water was in the "D" plots, indicating

TABLE IX.—EFFECT OF QUANTITY OF IRRIGATION WATER ON YIELD OF BARLEY

YEAR	"D" Series			"C" Series			"B" Series			"A" Series		
	Water applied	Yield		Water applied	Yield		Water applied	Yield		Water applied	Yield	
		Grain	Straw		Grain	Straw		Grain	Straw		Grain	Straw
	Ins.	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*	*Ins.*	*Bus.*	*Lbs.*
1915	4.1	43.3	1,520	8.1	39.6	2,400	10.1	53.2	2,960	14.7	63.1	3,490
1916	6.1	14.5	1,400	12.8	18.1	1,730	17.4	27.3	2,190	33.9	29.6	2,715
1917	7.2	.4	230	7.2	.6	120	9.2	3.0	455	10.2	2.7	470
1918	8.3	3.4	740	17.3	6.2	700	17.3	8.3	750	27.1	10.6	840
1919	6.9	20.3	1,325	6.9	22.0	1,395	14.6	28.9	1,365	22.3	26.3	1,440
Average	6.5	16.4	1,043	10.5	17.3	1,269	13.7	24.1	1,544	21.6	26.5	1,791

that barley utilized small amounts of water more economically than the other grains.

The results make it seem probable that, in the Garden City area, such crops as oats and barley are unable to utilize more than a small amount of water, and that ordinarily irrigation can be limited to the amount required to put the soil in good condition at seeding time.

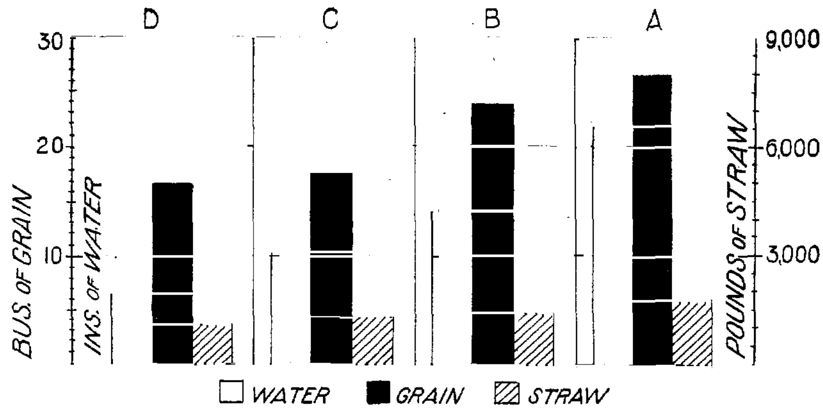

FIG. 11.—Graphs showing the effect of different quantities of irrigation water on yield of barley; average for five seasons, 1915 to 1919

CONCLUSIONS

The following conclusions are drawn from the data presented in this bulletin:

1. The amount of water required to keep the soil moisture content at a given percent of saturation varies somewhat with the kind of crops grown.

2. Crops differ greatly in the amounts of water which they can profitably use, and in the range of yield which can be effected by applying various amounts of water.

3. Milo shows a marked ability to increase in yield of grain as additional amounts of water are applied, and where the crop receives sufficient irrigation water it is affected less by unfavorable climatic conditions than the other crops included in this experiment. The yield of stover was not greatly influenced by increasing the amount of water.

4. Kafir exhibits much the same characteristics as milo, but is unable to respond to the application of water to the same extent as milo, so far as this is measured by the yield of grain.

5. Sumac sorgo was not able to use economically large amounts of water, and showed a slight falling off in yield of stover when more than about 15 inches was applied.

6. Sudan grass grown in rows for seed is not a profitable irrigation crop, and when it is so grown it should not be irrigated heavily.

7. The yields of small grain crops such as wheat, oats, and barley are controlled to a greater extent by prevailing climatic conditions than by available amounts of water, and no amount of water has sufficed to insure good yields in years of adverse climatic conditions.