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BY

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IRRIGATION AND THE PROTEIN CONTENT OF WHEAT*

By J. S. JONES, C. W. COLVER, and H. P. FISHBURN

With the development of irrigation projects in intermoutain areas of the Rocky Mountain states has come an enormous increase in the amount of wheat produced annually with irrigation. The crop commands the attention and consideration of millers and grain men generally in intermountain sections and will continue to do so because there is in cultivation at present a small fraction only of the acreage that can be successfully farmed with irrigation. The general run of irrigated wheat regardless of the class to which the varieties may belong is plump and relatively heavy. It is unfortunately at the same time soft and starchy and because of its relatively low protein content is almost invariably sold on markets that do not stress strength in wheat flour. The irrigation farmer has no particular reason for dissatisfaction with the money return for his crop; yields are good and the demand for wheat so great that any and all grades are quickly absorbed by home and foreign markets. The United States Grain Standards Act, however, makes it plain to him that an equal number of bushels of hard wheat, or of wheat substantially richer in protein, would net him yearly a handsome sum over that which he now receives. Wheat is so generally fundamental in the human diet, that, economically speaking, quality of grain for milling purposes is a matter of national importance; the richer our wheats in protein the greater their value as food, and, in times of shortage, the greater can be the dilution of flours made from them in the making of light bread. Perhaps no other food stuff varies so widely in its content of protein because of favorable or unfavorable conditions of growth for its elaboration. There is unfortunately in the minds of wheat growers and millers generally the notion that irrigation and pronounced starchiness of kernel are inseparably linked. The unreasonableness of that view, the scarcity of evidence in support of it, and the growing importance of irrigated wheats in this State suggested as far back as 1908 the present investigation. It now seems certain that there is nothing fundamentally incompatible with irrigation, as it may be practiced in southern Idaho at least, and the notion always held by a few that wheats of high protein content are possible with it, and under conditions of growth, too, that make for maximum yields.

Incidentally this investigation contributes very substantially to a better understanding of the factors which control in protein elaboration by the wheat plant under any conditions of growth.

THE LITERATURE REVIEWED

The literature is not particularly rich in reports of investigations which sought to establish relationships between irrigation practice and the composition of plant parts. It is much richer in reports of investigations and observations which bear somewhat indirectly upon the ques-

* The manuscript for this publication was prepared during the early months of 1918 by J. S. Jones, then director and chemist of the Agricultural Experiment Station.

tions involved. Many investigators, for example, have attached great importance to the influence of certain factors of climate, as rainfall, humidity, sunshine, and temperature, upon the elaboration of protein by the wheat plant and are very positive in their conclusions that the environment imposed by climate determines between wheat-growing sections the relative richness of their wheats in protein. In our judgment a great deal of the evidence submitted in support of this view is based far too largely upon general observations and is for that reason not convincing. The extensive development of semi-arid lands within recent years and their splendid adaptability under irrigation to the growth of the small grains make all questions relative to quality of grain important economic ones in the intermountain states. We have assumed that it would serve no useful purpose in this connection to review any other than the more recent investigations.

Widtsoe (14) in 1901 grew a variety of wheat called New Zealand in Cache Valley, Utah, with varying amounts of irrigation water ranging from 4.63 to 40 inches. The soil used is a shallow one, varying in depth between 9 and 59 inches. It is underlaid with coarse gravel to a depth of 300 feet. Widtsoe noted differences in the protein content of the harvested wheat kernels ranging from 26.72 per cent to 15.26 per cent, and, notwithstanding pronounced irregularities, attributed these differences to variations in amounts of water applied. With increase of water there was a decrease in the protein content of the harvested grain.

Humphries (5) cites the fact that the 1903 season in England was one of abnormal rainfall and sunshine and that the season of 1904 was much drier with more than the usual amount of sunshine. He states that the 1903 crop of English wheat was fully as good if not better than that of 1904 for flour-making purposes. He does not cite any analytical data in support of his observations. He rejects the notion that rainfall is the determining factor where quality in milling wheat is concerned and points out the fact that the rainfall at St. Paul, Minnesota, during the growing months is greater than it is in England, and still the Minnesota-grown wheat is generally recognized as far superior to the English-grown wheat.

LeClerc (9) reports the growth of Kubanka in 1904 in seven localities with 15 inches or less of rainfall and in six localities with more than 15 inches of rain fall, or with irrigation. He found by analysis a difference of .47 per cent of nitrogen in favor of the wheat grown in the drier regions. He notes also a difference of 3.3 per cent in the average protein content of seven samples from irrigated sections when compared with seven samples of the same variety grown in as many different localities in the western states without irrigation; the non-irrigated samples were richer in protein. A still greater difference was noted by him when irrigated and non-irrigated Durum wheats grown in Mexico were compared. Again LeClerc found that between samples of Kubanka wheat grown in Idaho and Colorado, with and without irrigation, there was an average difference of .73 per cent of nitrogen in favor of the dry-farmed samples.

Shutt (11) concluded from his work with Red Fife and Kharkof grown at Lethbridge, Alberta, in 1908 on dry-farmed and irrigated land that irrigation lowers the protein content. From this work and earlier determinations of protein in wheat grown on new and old lands, Shutt reached the conclusion that soil moisture is a factor of great importance in determining the protein content of wheat.

In 1908 Jones and Nelson (6) of the Idaho Experiment Station grew on the Caldwell Substation in the Snake River valley of southern Idaho, Palouse Bluestem and Little Club each in seven plats with varying amounts of irrigation water ranging by differences of 3 inches and 6 inches from no inches to 24 inches. The rainfall in that section of the State is practically negligible for crop-growing purposes. The badly shrunken samples from the plats to which no water had been given in all cases but one were highest in protein. The analytical data on all *normally* matured samples furnish inconclusive evidence on the influence of irrigation water on the storage of protein in the wheat kernel. In no instance did the application of least water produce wheat of the highest protein content. The work was repeated in 1909. The high percentages of protein for the normally matured samples of both varieties that year are worthy of special comment as indicative of the possibilities of high-protein wheat on irrigated lands.

Shaw (10) conducted experiments with six different types of wheat on the University Farm at Davis, California, during the season of 1908-9. For each type, plat A received no irrigation; plat B received one irrigation just after the plants were out of the boot; and plat C received two irrigations, one as given to plat B and one after the grain was set. The amount of irrigation water applied is not mentioned, neither is the amount of rainfall which, however, we find from Weather Bureau reports to have been 12.36 inches for the time intervening between sowing and harvesting. A part of each plat was cut early, June 24; the other part one week later. From his tabulated analytical data Shaw concludes that with an increase in irrigation water the protein content of wheat is lowered. For the early-cut crop the average percentages of protein for the six types from plats A, B and C were 14.56, 13.11 and 12.77 per cent respectively, (all presumably reduced to the dry basis). For the late-cut crops the corresponding figures are 14.83 per cent, 14.44 per cent, and 14.04 per cent.

In very close connection with his work with irrigation, Shaw mentions the fertilization of wheat plats for several years with sodium nitrate and other fertilizers. From his analytical data he concludes that the application of nitrates or other nitrogen-containing fertilizers is without effect in increasing the protein content of wheat.

Stewart and Hirst (12) grew ten varieties of wheat on the Greenville farm in Cache Valley, Utah, with the application of no inches, 15 inches and 25 inches of irrigation water. The averages for the protein content of the harvested grain were 15.45, 14.35, and 14.00 per cent respectively. Corresponding averages for the flours resulting from the grinding of the wheat samples were 13.62, 12.92, and 12.63 per cent.

Howard (4) and his coworkers, from work conducted at several stations in India between 1907 and 1912, at some with irrigation and at others with normal rainfall only, conclude that irrigation and high quality of grain may go together when the cultivation is suitable and the amount of irrigation water regulated.

The Department of Agriculture, * New South Wales, reports the exhibition of samples of Bobs, Comeback, and Florence wheats at the Royal Agricultural Society's show in Sidney during the years 1912 to 1916, inclusive. The samples were grown in the several wheat-growing districts of the State with rainfall during the growing season ranging from 4.5 to 15.22 inches. The wheats had their percentages of flour determined and the flours their percentage content of gluten and baking strength. With the analytical data for any variety arranged for correlation with data for rainfall, there does not appear to be for any of the varieties or for any district a direct connection between gluten content and rainfall.

Thatcher (13) in a summary of wheat investigations conducted in Washington from 1906 to 1912 inclusive correlated the rainfall of eastern Washington between 1905 and 1909 with the average content of protein in wheat samples secured during the same years. He reached the conclusion that the protein content of wheat in eastern Washington decreases with increase of rainfall.

Bailey (1) in a similar manner correlated data on the rainfall of the different wheat-growing sections of Minnesota from April to September, 1911, with the average protein content of wheat samples analyzed by him as representative of the products of the several sections the same year. His conclusions are that on the whole increased rainfall in Minnesota is accompanied by relatively lowered protein content in the harvested grain.

Harris (2) from his investigations of wheat conducted in pots under greenhouse conditions at Cornell states that the kernels from the plants grown in wet soils were soft and starchy. He found the percentage of nitrogen in both straw and grain to be highest in plants grown on the driest soils. With an increase of soil moisture up to 37½ per cent there was a gradual decrease in the percentage of nitrogen. Harris is careful to state that the grain of highest protein content was plump and apparently of normal maturity. He observed that the protein content of both wheat and straw was influenced by the period of growth at which high or low soil moisture conditions prevailed. Highest protein content was secured with a low soil moisture content up to the booting stage of the plant and a high soil moisture content from then on to maturity. Harris further notes that fertilizers high in nitrogen increased the nitrogen content of his crops.

Jones and Colver (7) from observations in the field and from analytical work performed on samples of dry-farmed and irrigated wheats collected over a term of three years in representative dry-farmed and irrigated sections of southern Idaho conclude that some varieties are more affected by irrigation than others.

Headden (3) in speaking of wheats grown in 1913 and 1914 in Colorado with one and two acre-feet of irrigation water states that no results were secured that show conclusively that differences in amounts of water used made any difference in weights of wheat per bushel and composition of grain. In 1913 he secured and analyzed a large number

* Private correspondence.

of samples of Dicklow wheat grown in southern Idaho in 1913 in duty-of-water investigations. The amounts of water used in growing the grain from which Headden secured samples ranged from .66 acre-feet to 3.28 acre-feet. The protein in the samples ranged from 7.18 per cent to 9.48 per cent. The sample highest in protein was grown with the next to the least amount of irrigation water. The sample next highest in protein, 9.16 per cent, was grown with the maximum application of water. The samples next highest in protein, 8.97 per cent and 8.94 per cent, were grown with 1.62 acre-feet and 2.34 acre-feet of water respectively. Turkey Red grown the same year in the same line of investigation with .47, .89, and .93 acre-feet of water produced grain containing 10.56, 10.57, and 10.65 per cent of protein respectively.

In 1914 Headden again secured samples of wheat grown in southern Idaho in duty-of-water investigations. This time the samples were of the Marquis variety, grown on 6 one-tenth acre plats with 1, 2, and 3 acre-feet of irrigation water with barnyard manure amounting to 15.7 loads per acre, and without manure. The irrigation season for the different plats was between June 2 and July 16 for those given 1 acre-foot, between May 21 and July 15 for those given 2 acre-feet, and between May 11 and July 15 for those given 3 acre-feet of water. The number of irrigations for the 1, 2, and 3 acre-feet applications was 3, 5, and 7 respectively. The grain ripened July 24 and 25, 114 days from the time of planting. Without exception the development of the grain was good in so far as could be determined by weight of kernel. Yields of both straw and grain were increased with the 2 and 3 acre-feet applications and still further increased by the application of manure. The protein percentages of the harvested grain for the unmanured and the manured plats were 10.42 and 10.55, 10.52 and 10.81, and 10.52 and 11.93 from plats given 1, 2, and 3 acre-feet of water respectively. In summation of his work with irrigation, Headden concluded that neither the amounts nor the distribution of irrigation water makes any material difference in the composition of the grain.

From extensive experimental work and a large number of analyses, Headden is strongly of the opinion that the soil's content of available nitrogen is the determining factor in the elaboration of protein by the wheat plant.

Widtsoe and Stewart (15) in extensive experiments conducted on the Greenville farm in Cache Valley, Utah, to determine the effects of variations in amounts of irrigation water upon the composition of grains and forage crops grew wheat with as little as 5 and as much as 50 inches of irrigation water in addition to the normal rainfall of 15 inches. From their analytical data they conclude that the protein content of wheat is lowered as the amount of irrigation water is increased.

Jones and Colver (8) from work conducted with hard wheats under irrigation on the Gooding and Aberdeen stations in southern Idaho conclude that under conditions which make for rapid nitrification of soil organic matter rich in nitrogen hard wheats of the very highest quality are possible with irrigation. Some remarkably high percentages of protein are recorded for the years 1914, 1915, and 1916 for Minnesota Bluestem and Glyndon Fife grown with normal irrigation.

From this review of the literature it is perfectly apparent that very divergent views are held by the various investigators in this field regarding the influence of irrigation water upon the composition of wheat.

EXPERIMENTAL

The lease of a forty-acre tract of raw sagebrush land two miles south of Gooding by the Experiment Station in 1909 for the conduct of experimental work in the irrigation of farm crops provided splendid opportunities and the necessary facilities for the conduct of this particular piece of work. Most fortunately, too, the conditions under which the work was commenced are essentially identical with those which confront the man who takes up raw land in the semi-arid regions of the intermountain states for conversion into farm land. Moreover the conditions prevailing on the Gooding farm at the close of our experimental work were precisely those which prevail after a similar length of time on the average irrigated farm in southern Idaho whose owner brings to his task of development a keen appreciation of the needs of these lands for enrichment with nitrogen-containing organic matter. The investigation is directly applicable to irrigation practice.

The tract of land on which our experimental work was conducted was known between 1909 and 1917 as the Gooding Substation. It lies at an elevation of approximately 3600 feet in the Snake River valley a little nearer the western than the eastern border of the State. The surface soil is a medium clay loam. It has a fairly heavy clay subsoil and is underlaid at a depth of 10 or 12 feet by the basaltic lava rock that is characteristic of southern Idaho. The farm is fairly representative of the Snake River plains area on which wheat and other small grains are extensively grown mostly with irrigation. The average annual rainfall between 1910 and 1916 inclusive was 9.2 inches. From 1911 on, the farm was under the superintendency of Mr. John S. Welch to whom credit is due for cordial cooperation in planning and executing the field work. The work was commenced in 1910 and was continued without interruption or serious mishap thru 1916. The objective points at the beginning of the investigation were: (1) Additional data in support of or against the commonly held opinion that low-protein wheat invariably results from the practice of irrigation, (2) fundamental reasons for the influence of soil water on protein formation, and (3) the determination of cumulative effects on protein content from the application of varying amounts of irrigation water. As will be noted later, our ideas regarding the fundamental problems involved underwent some revision with the progress of the work. Its completion put us in possession of a somewhat different kind of information than we anticipated at the start.

Plan of Work.

The plan of work was comparatively simple. It involved (1) the growing of three varieties of wheat side by side in several plats one-fifth and one-tenth acre each in such manner that varying amounts of irrigation water could be applied from no inches to as much as the soil could be made to absorb conveniently; (2) the quantitative estimation of soil nitrates at frequent intervals in the plats of one series to determine besides relative amounts of nitrates their possible concentration under the influence of irrigation water in zones beyond the feeding range of the plant roots; (3) harvesting and threshing; (4) milling and analytical work on representative samples from each plat.

Figure 1 illustrates the planting plan in 1910. A similar arrangement of plats was followed in 1911, 1912, and 1913, but in 1913 fallow plats were introduced in the Bluestem Series adjacent to plats 1, 7, 13 and 19. In 1914, as will be noted later, the number of plats was reduced.

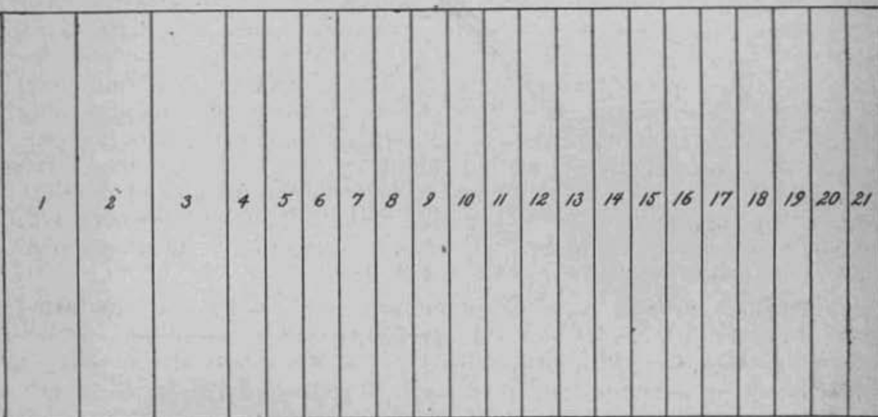


FIG. 1. Plan of planting followed in 1910, 1911, 1912, and 1913.

Figure 2 shows the planting plan for 1914, 1915, and 1916. The original seed of the Sonora, grown for the entire seven years, and of the

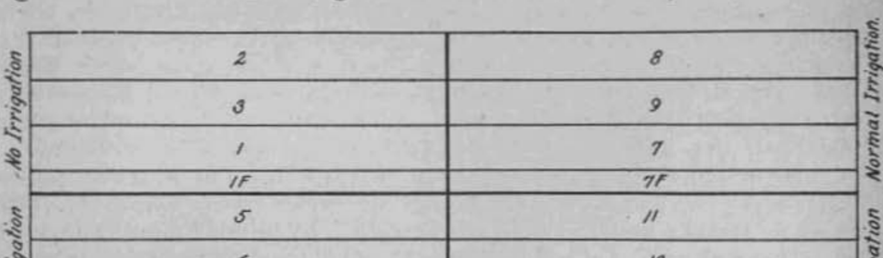


FIG. 2. Plan of planting followed in 1914, 1915, and 1916.

Palouse Bluestem and Little Club, grown for the first four years, was purchased from the Caldwell Milling & Elevator Company. Seed for the Minnesota Bluestem and Glyndon Fife, which were substituted for Palouse Bluestem and Little Club in 1914 and succeeding years, was sent from the central station at Moscow where those varieties had been grown for several years from seed originally secured at University Farm, Minnesota. The seed was sown each year at the rate of 90 pounds per acre with a common grain drill. All irrigation water was applied by flooding between borders and was very carefully measured. For nitrate determinations ,soil samples were taken with a King soil tube. The nitrates were determined colorimetrically in an especially fitted-up laboratory in the basement of one of the Gooding public school buildings. At threshing time samples from each plat were retained for analytical and milling work as was seed for sowing on a corresponding plat the following season. In the analytical work the greatest emphasis was placed upon protein determinations in the wheat and flour and the greatest importance is now attached to those determinations. The total ash content and the percentage of phosphorous as P_2O_5 and potassium as K_2O were made each year to determine any possible relationships that might exist between irrigation and relative amounts of these constituents of the grain. The total ash was determined on each flour sample mostly as a check on the closeness of the milling operations.

The field observations, analytical data and comments upon the same follow.

The Crop of 1910.

The crop of 1910 was grown on raw sagebrush land well prepared of course for irrigation and planting. Nitrate determinations were not made but the concentration of that very essential soil component must have been low, probably not so low, however, as in 1911 and 1912 for there is on the surface of these semi-arid lands some decayed organic matter that owes its origin to the very thin growth of native grasses among the sagebrush. If this organic matter is not covered too deeply in the operations involved in clearing and leveling, its nitrification during the first year of cultivation must be rapid and of distinct benefit to the first crop. It is the common experience of farmers on semi-arid lands that yields of grain decline sharply from the first crop until the soil has been enriched with some form of organic matter. The reason unquestionally is the depletion of the small amount of available nitrogen originally present. The plats were sown on April 20. The least amount of water was given in two, and the largest amount in nine applications. The ripening period for the Sonora ranged from July 20, for the plat on which no water was applied, to July 29 for the plat on which most water was applied. The ripening period for the Bluestem and Little Club ranged from July 24, for plats given no water, to August 2 for plats given the most water. The analytical data for the 1910 crop are presented in Table 1.

From the increase in weights per 1000 kernels with increase in amounts of irrigation water up to at least one foot it would seem that a normally matured grain in any of the three series was not secured in 1910 with less than one foot of water. If the product of all plats except No. 2 Sonora is considered, there was a fairly consistent decrease in protein with an increase of irrigation water. If the comparison is limited to *normally* matured grain, however, the decrease in protein with increase in water was relatively small. As nearly as one might reasonably expect on the basis of crude protein and wet and dry gluten, the flours took the

Table 1. Field and Analytical Data on Wheat and Flour, Crop of 1910.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grains	Per bu., lbs.	Moisture, per cent	per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	211	Bluestem*	....	.....	....	38.30	....	8.39	11.81	12.89	1.54	.94	.63	.....	...	.....	.....	.....
1	292	Bluestem	.000	7.02	.33	22.62	51½	9.00	13.08	14.37	1.90	.98	.60	10.07	.57	11.08	43.54	13.73
4	293	Bluestem	.533	18.70	.84	25.14	52½	9.25	12.11	13.34	2.04	....	...	10.11	.55	10.64	40.42	13.27
7	294	Bluestem	.713	23.26	.99	27.14	53½	10.25	12.07	13.45	2.08	1.05	.62	9.94	.59	9.84	37.59	11.95
10	295	Bluestem	.842	30.40	1.29	31.18	55	10.45	11.80	13.18	2.00	....	...	10.17	.50	9.85	38.41	12.56
13	296	Bluestem	1.210	33.33	1.20	35.74	57	10.35	11.09	12.37	1.94	.99	.57	9.90	...	9.16	35.10	11.24
16	297	Bluestem	1.435	33.50	1.60	35.84	56½	10.30	10.83	12.07	1.99	....	...	9.98	.52	8.80	33.75	10.80
19	298	Bluestem	2.486	33.00	1.19	36.40	57	9.85	10.44	11.58	1.94	1.02	.59	9.86	.54	9.20	31.54	10.02
..	212	Little Club*	.....	.....	....	.....	....	.....	13.03	14.40	1.50	.92	.63	.....	...	.....	.....	.....
3	301	Little Club	.000	8.07	.34	19.74	53	10.20	12.94	14.41	2.27	....	...	8.68	.64	11.32	47.17	15.22
6	302	Little Club	.434	20.45	.89	21.74	54	10.20	12.59	14.02	2.16	1.06	.67	8.62	.57	11.28	42.57	14.25
9	303	Little Club	.594	22.65	.86	27.90	58	10.40	12.40	13.84	2.07	1.03	.58	8.90	.54	10.92	43.80	14.42
12	304	Little Club	.907	30.40	1.07	28.46	57	10.30	12.02	13.40	2.02	....	...	8.84	.55	10.48	40.18	12.50
15	305	Little Club	1.091	35.00	1.22	30.44	58½	10.35	11.09	12.37	1.95	1.03	.60	8.91	.53	9.62	36.76	11.40
18	306	Little Club	1.786	37.63	1.29	31.02	59	10.90	10.53	11.82	1.97	....	...	8.94	52	9.56	36.49	11.77
21	307	Little Club	3.010	43.91	1.45	31.56	58	11.05	11.09	12.47	1.94	1.00	.59	8.96	.52	9.36	34.13	11.00
..	213	Sonora*	.....	.....	....	37.94	....	8.50	10.24	11.19	1.80	.96	.50	.....	...	.....	.....	.....
2	283	Sonora	.000	10.08	.31	27.12	58	9.90	9.40	10.43	1.57	.95	.52	9.11	.52	10.04	34.43	10.86
5	284	Sonora	.352	20.45	.41	28.00	59½	9.30	11.40	12.57	1.82	....	...	9.17	.54	9.72	35.18	11.21
8	285	Sonora	.533	20.63	.63	31.78	60½	9.45	11.14	12.30	1.94	.95	.50	8.55	.57	9.84	35.73	11.67
11	286	Sonora	.945	23.86	.74	32.14	60½	10.20	11.40	12.70	1.90	....	...	8.68	.49	9.24	33.07	10.68
14	287	Sonora	1.100	32.20	1.06	35.52	60	9.80	11.32	12.55	1.88	.96	.48	8.81	.49	9.64	33.58	11.22
17	288	Sonora	1.601	34.50	1.33	34.28	58	9.90	10.44	11.59	1.87	....	...	8.91	.56	8.80	30.79	10.88
20	289	Sonora	2.355	35.00	1.14	35.20	61	9.05	10.65	11.71	1.98	1.00	.50	8.72	.59	8.72	30.60	10.32

* Original Seed.

Table 2. NO_3 in parts per million on dry soil, 1911.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*					
				May	June		July		August
				16-31 a	1-15 b	16-30 c	1-15 d	16-31 e	1-16 f
....	....	....	1	....	2.9	2.0	1.6	2.0	1.8
....	....	....	2	....	2.8	1.8	1.3	.9	1.1
1	0	.000	3	....	5.5	2.9	2.9	1.9	2.1
....	....	....	4	....	6.3	1.9	2.4	2.2	1.6
....	....	....	5	....	5.3	2.1	2.7	1.5	2.1
....	....	....	6	....	2.7	1.7	2.1	1.8	2.3
....	....	....	1	....	3.7	1.6	1.8	1.7	1.3
....	....	....	2	....	3.1	1.5	1.4	1.0	.8
4	1	.479	3	....	5.0	2.8	2.5	1.3	2.1
....	....	....	4	....	5.8	3.1	3.2	2.4	3.8
....	....	....	5	....	6.5	3.6	4.7	4.5	4.7
....	....	....	6	....	6.9	5.8	5.1	5.7	4.7
....	....	....	1	....	3.0	1.8	1.4	2.3	1.7
....	....	....	2	....	4.5	1.2	1.3	1.1	1.1
7	3	1.285	3	....	6.4	2.7	2.3	2.1	2.7
....	....	....	4	....	8.3	4.5	3.1	3.6	3.7
....	....	....	5	....	9.2	4.8	3.1	7.2	3.7
....	....	....	6	....	12.1	5.4	4.0	13.2	2.1
....	....	....	1	....	2.5	2.3	1.7	2.4	4.2
....	....	....	2	....	1.8	1.5	2.1	0.9	1.4
10	5	1.516	3	....	7.3	4.5	2.2	1.8	2.1
....	....	....	4	....	5.6	4.8	2.5	2.5	3.1
....	....	....	5	....	8.6	8.3	4.7	2.7	3.9
....	....	....	6	....	11.3	9.3	5.2	4.4	3.8
....	....	....	1	....	3.0	1.5	1.3	1.6	1.5
....	....	....	2	....	3.0	1.2	1.2	1.7	0.9
13	4	1.737	3	....	5.9	1.7	1.3	1.3	1.3
....	....	....	4	....	8.1	2.4	2.8	1.6	2.6
....	....	....	5	....	6.7	4.3	4.6	3.6	2.9
....	....	....	6	....	6.6	5.8	9.1	2.9	5.5
....	....	....	1	....	2.6	1.3	1.3	2.1	5.5
....	....	....	2	....	3.0	1.1	1.2	0.9	1.5
16	7	2.558	3	....	7.3	2.0	1.4	1.2	1.9
....	....	....	4	....	7.4	3.8	2.4	1.3	2.6
....	....	....	5	....	5.6	5.3	2.2	3.1	2.9
....	....	....	6	....	6.6	7.2	3.0	4.0	3.3
....	....	....	1	....	2.2	1.4	1.4	1.7	4.0
....	....	....	2	....	1.9	1.2	1.1	0.9	1.4
19	10	2.820	3	....	2.1	1.0	1.0	1.8	0.4
....	....	....	4	....	2.3	0.8	1.0	1.8	0.4
....	....	....	5	....	2.9	1.4	1.1	2.0	0.8
....	....	....	6	....	1.8	1.9	2.0	3.9	1.0

* Samples were taken for the determination of their nitrate content on the following dates: June 1, 3, 6, 9, 12, 15, 20, 22, 26, and 28; July 6, 10, 12, 17, 20, 24, and 27; and August 1, 8, and 15.

same relative position as the wheats from which they were grown. A maximum yield was possibly not obtained for the Little Club.

The Crop of 1911.

The crop of 1911 was grown on land that had been cleared of sagebrush in 1909 and used for barley and oat plats in 1910. It was plowed in the fall of 1910 and prepared for the wheat plats in the spring of 1911 by thoro disking. All plats were sown on March 25. The first irrigation was given June 1, the last July 27. The number of irrigations ranged from one to ten. There was a range of four days in the dates of ripening. Nitrates were determined in foot cores to a depth of six feet in all Bluestem plats; the data averaged for arbitrarily chosen periods of 15 and 16 days appear in Table 2.

It will be noted that the supply of nitrates was low even at the beginning of the season. So low indeed was the supply that it is doubtful if the plants at any time had an adequate amount for maximum growth. The barley and oat crop of the preceding year of course drew heavily on the small stock of nitrogen originally present. The field and analytical data are given in Table 3.

With the exception of 3 plats, No. 19 in the Bluestem series and Nos. 2 and 20 in the Sonora series, the product of each plat in 1911 was lower in protein than the seed from which it was grown. A lower yield of both and grain and straw was also noticeable on most of the plats.

The Crop of 1912.

The crop of 1912 was grown on the same land that grew the crop of 1911. The ground was plowed in the spring, disked, harrowed, and floated in preparation for planting and irrigation. The borders of each plat were identical with those of the corresponding one of the preceding season. The sowing was made April 1. The first irrigation was given June 3, the last July 25. As in 1911 the number of irrigations ranged from 1 to 10 and again there was a range of 4 days in the dates of ripening. The nitrate data are presented by periods in Table 4.

The concentration of nitrates was again very low.

The field and analytical data are given in Table 5.

The yield of grain on most of the plats was heavier than on corresponding plats of the preceding season, but as a general rule the yield of straw was lighter. For the major portion of the plats the yields of both grain and straw were lower, however, in 1912 than in 1910. With the exception of plat 4 in the Bluestem series and plats 3 and 6 of the Little Club series, the product of each plat appeared to be normally developed. In general there was a still further decline in the protein content of the grain from each plat, but variations in the protein content of the grain were not strictly in keeping with variations in the amounts of irigation water used.

For reasons that will become perfectly obvious in the discussion of 1913 and succeeding years' work, the field and analytical data for 1910, 1911, and 1912 have been summarized for presentation in Table 6.

In studying this table it is well to remember that thus far the soils on which these wheats were grown had undergone no treatment looking toward their enrichment with organic matter over their original very low

Table 3. Field and analytical data on wheat and flour samples, crop of 1911.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	462	Bluestem	0.000	15.87	.70	32.46	56½	8.90	11.41	12.53	1.99	1.08	.57	10.30	.43	9.27	33.03	12.59
4	463	Bluestem	.479	18.47	.78	30.38	53	9.68	10.96	12.14	2.01	....	...	10.48	.45	9.59	28.83	11.22
7	464	Bluestem	1.285	22.05	1.00	35.10	57½	9.00	10.96	12.05	2.02	1.06	.57	10.51	.40	9.59	30.58	11.88
10	465	Bluestem	1.516	22.85	.92	34.82	57½	9.14	10.53	11.59	1.99	....	...	10.35	.40	8.57	30.67	12.97
13	466	Bluestem	1.737	26.08	1.00	32.96	58½	8.72	10.35	11.34	1.98	1.06	.57	9.99	.40	8.29	30.91	12.65
16	467	Bluestem	2.558	24.54	1.16	33.80	57	8.77	10.27	11.26	2.05	....	...	10.73	.45	8.05	29.51	11.79
19	468	Bluestem	2.820	17.03	.58	34.86	58	8.73	11.23	12.30	2.00	1.06	.59	10.24	.46	9.22	35.87	14.04
3	471	Little Club	0.000	17.72	.72	23.38	57	8.88	11.23	12.33	1.99	1.07	.59	10.10	.51	8.98	28.24	10.23
6	472	Little Club	.417	21.42	.76	25.96	58	8.14	10.88	11.84	2.02	....	...	10.08	.50	8.66	27.02	10.27
9	473	Little Club	1.148	28.49	1.05	29.40	57½	8.81	10.62	11.65	1.96	1.02	.61	10.34	.46	8.66	25.69	9.95
12	474	Little Club	1.451	30.55	1.05	28.98	57½	8.43	10.35	11.30	2.09	....	...	10.31	.47	8.82	25.52	10.02
15	475	Little Club	1.842	26.06	.95	29.18	58	9.32	10.09	11.13	2.04	1.06	.58	10.34	.50	8.64	26.46	10.37
18	476	Little Club	2.161	18.99	.64	28.90	57½	9.48	10.18	11.25	2.10	....	...	10.35	.48	8.82	26.29	9.79
21	477	Little Club	2.834	16.14	.56	29.72	58	9.27	10.96	12.08	2.07	1.09	.56	9.98	.45	8.80	29.92	11.50
2	453	Sonora	0.000	16.22	.58	32.00	61	8.55	10.69	11.69	1.89	1.05	.52	10.99	.36	8.59	28.31	11.91
5	454	Sonora	.379	18.26	.57	31.40	60	8.45	10.35	11.33	1.95	....	...	11.33	.38	8.11	27.98	10.82
8	455	Sonora	1.184	19.89	.78	34.88	59	9.45	10.18	11.24	1.97	1.03	.52	10.69	.46	8.11	27.71	10.52
11	456	Sonora	1.374	23.15	.96	35.50	60	9.12	10.44	11.49	1.96	....	...	10.49	.50	8.31	27.18	10.50
14	457	Sonora	1.861	18.86	.79	34.50	59½	9.27	10.18	11.22	2.03	1.06	.55	10.42	.49	8.15	27.91	11.16
17	458	Sonora	2.853	22.51	.92	34.50	60	9.38	9.92	10.95	1.97	....	...	10.59	.46	7.87	26.82	10.29
20	459	Sonora	3.156	13.29	.53	34.28	60	9.20	11.76	12.95	2.09	1.12	.55	10.18	.47	9.16	26.30	10.43

Table 4. NO_3 in parts per million on dry soil, 1912.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Period for which nitrate data were averaged*					
				May	June		July		August
				16-31 a	1-15 b	16-30 c	1-15 d	16-31 e	1-12 f
....	....	....	1	....	2.4	2.7	1.7	1.0	1.5
....	....	....	2	....	1.9	1.8	.6	.5	.4
1	0	.000	3	....	3.1	1.8	.9	1.1	.8
....	....	....	4	....	3.8	2.0	2.6	1.6	.9
....	....	....	5	....	5.9	3.7	2.6	1.8	1.3
....	....	....	6	....	5.3	4.6	4.9	2.8	2.0
....	....	....	1	....	3.1	2.6	1.6	1.3	1.3
....	....	....	2	....	1.8	2.0	.7	.8	.9
4	1	.589	3	....	1.7	1.5	.6	.6	.6
....	....	....	4	....	2.3	1.8	1.4	1.2	3.1
....	....	....	5	....	6.4	2.4	2.3	1.7	4.5
....	....	....	6	....	6.7	2.8	2.1	4.0	4.1
....	....	....	1	....	2.5	2.7	1.6	1.4	2.5
....	....	....	2	....	1.2	2.1	.6	.7	.7
7	3	1.244	3	....	3.1	2.9	.8	.5	.9
....	....	....	4	....	4.4	3.3	1.5	1.3	2.2
....	....	....	5	....	6.3	5.9	3.0	2.9	3.2
....	....	....	6	....	6.5	9.4	5.5	3.1	4.0
....	....	....	1	....	2.6	3.0	1.6	1.3	1.5
....	....	....	2	....	2.0	2.0	.7	.4	.6
10	4	1.275	3	....	2.2	1.7	.9	7.	.4
....	....	....	4	....	2.2	2.0	.8	1.2	.5
....	....	....	5	....	2.9	2.5	1.2	1.5	1.5
....	....	....	6	....	4.7	3.6	2.8	4.0	2.9
....	....	....	1	....	3.2	2.6	1.2	1.5	1.1
....	....	....	2	....	1.8	1.7	.5	.3	.7
13	6	1.806	3	....	2.0	1.7	.6	.2	.6
....	....	....	4	....	2.0	1.4	1.1	.5	.4
....	....	....	5	....	2.5	2.3	1.3	2.0	.7
....	....	....	6	....	4.0	4.1	2.5	5.1	1.8
....	....	....	1	....	4.8	2.4	1.5	1.3	2.2
....	....	....	2	....	2.3	1.8	.7	.4	.7
16	7	2.381	3	....	2.6	1.6	.7	.5	.8
....	....	....	4	....	2.7	1.6	1.2	1.1	.9
....	....	....	5	....	3.6	1.9	1.8	7.6	2.1
....	....	....	6	....	4.0	2.7	4.7	2.8	2.3
....	....	....	1	....	3.1	2.7	1.1	1.3	1.4
....	....	....	2	....	1.8	1.7	.4	.2	.2
19	10	2.638	3	....	2.3	1.5	.4	.2	.3
....	....	....	4	....	2.3	1.7	.7	.5	.4
....	....	....	5	....	2.1	2.7	1.1	.9	.4
....	....	....	6	....	3.1	3.2	1.5	1.0	.5

* Samples were taken for the determination of their nitrate content on the following dates: June 3, 6, 10, 14, 20, 24, 26, and 29; July 2, 5, 9, 11, 15, 18, 23, 26, and 30; and August 5 and 12.

Table 5. Field and Analytical data on wheat and flour samples, crop of 1912.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	Per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	498	Bluestem	.000	18.13	.54	34.70	56½	10.41	9.21	10.28	1.90	.93	.54	13.19	.44	7.36	26.82	8.86
4	499	Bluestem	.589	18.40	63	31.30	56	9.81	9.12	10.11	1.91	....	...	13.14	.43	7.12	24.47	8.16
7	500	Bluestem	1.244	25.51	.99	37.90	56	9.13	9.82	10.81	1.97	1.03	.56	13.16	.49	7.92	29.23	9.55
10	501	Bluestem	1.275	25.42	.99	37.80	58½	9.66	9.48	10.49	1.91	....	...	13.00	.49	7.44	26.68	8.78
13	502	Bluestem	1.806	24.07	.91	38.56	58	10.55	10.18	11.38	1.91	1.01	.57	13.13	.56	8.40	30.20	10.11
16	503	Bluestem	2.381	27.54	1.00	38.16	59	10.49	10.18	11.37	1.92	....	...	13.05	.50	8.16	30.05	9.95
19	504	Bluestem	2.638	33.71	1.18	41.14	....	10.11	9.82	10.93	1.94	1.02	.58	13.20	.51	7.76	28.12	9.37
3	512	Little Club	.000	17.37	.50	25.90	55½	9.60	9.04	10.00	1.88	.93	.56	13.37	.48	7.04	22.60	7.45
6	513	Little Club	.481	18.71	.60	28.88	57	9.00	9.21	10.12	1.96	....	...	13.21	.45	7.36	27.53	8.95
9	514	Little Club	1.273	23.46	.75	31.26	58	9.83	9.74	10.80	1.99	1.01	.60	13.70	.53	7.84	31.34	10.51
12	515	Little Club	1.272	24.46	81	31.40	58½	10.00	9.48	10.53	2.02	....	...	13.90	.51	7.52	30.90	10.58
15	516	Little Club	1.815	26.48	.92	32.30	58½	9.67	10.18	11.27	2.01	1.01	.61	13.55	.57	8.16	34.04	11.40
18	517	Little Club	2.146	25.60	.92	31.60	58½	9.36	9.65	10.65	2.00	....	...	13.44	.48	7.68	30.34	9.98
21	518	Little Club	2.436	30.76	1.08	31.98	57½	9.24	10.09	11.12	2.07	1.04	.61	13.48	.51	7.60	31.20	10.18
2	505	Sonora	.000	15.21	.41	33.94	58	10.04	8.86	9.85	1.78	.94	.50	13.49	.44	7.68	24.00	8.43
5	506	Sonora	.343	20.12	.55	34.44	58	9.73	9.12	10.10	1.87	....	...	13.64	.52	7.60	25.57	8.66
8	507	Sonora	1.190	20.13	.56	36.84	60	9.04	9.56	10.51	1.92	1.03	.54	13.32	.50	7.84	28.35	9.34
11	508	Sonora	1.179	29.59	.64	37.16	60	9.31	9.39	10.35	1.96	....	...	13.49	.50	7.44	25.63	8.36
14	509	Sonora	2.125	24.73	.82	37.44	61	9.81	9.92	11.00	1.95	1.03	.54	13.19	.53	8.00	28.21	9.10
17	510	Sonora	2.216	29.51	1.06	38.20	60	10.15	9.82	10.93	1.93	....	...	13.03	.66	8.48	29.18	9.18
20	511	Sonora	2.798	29.67	1.00	37.04	60	9.51	9.65	10.66	1.94	1.00	.54	13.22	.59	7.68	27.49	8.38

Table 6. Averages for fiield and analytical data on wheat and flour samples, crops of 1910, 1911, and 1912.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	Per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
..	211	Bluestem	.....	.....	....	38.30	....	8.39	11.81	12.89	1.54	.94	.63	.....	...	.....	.....	.....
1	...	Bluestem	.000	13.67	.52	29.93	54.8	9.44	11.23	12.39	1.93	1.00	.57	11.19	.48	9.24	34.46	11.73
4	...	Bluestem	.533	18.52	.75	28.94	53.8	9.58	10.73	11.86	1.99	....	...	11.24	.48	9.12	31.24	10.88
7	...	Bluestem	1.081	23.61	.99	33.38	55.7	9.46	10.95	12.10	2.02	1.05	.58	11.20	.49	9.12	32.46	11.13
10	...	Bluestem	1.211	26.23	1.07	34.60	57.0	9.75	10.60	11.75	1.97	....	...	11.17	.46	8.62	31.92	11.44
13	...	Bluestem	1.585	27.83	1.04	35.75	57.8	9.87	10.54	11.69	1.94	1.02	.57	11.01	.48	8.62	32.07	11.33
16	...	Bluestem	2.124	28.53	1.25	35.93	57.5	9.85	10.43	11.57	1.99	....	...	11.25	.49	8.34	31.10	10.85
19	...	Bluestem	2.648	27.91	.98	37.50	57.5	9.56	10.49	11.60	1.96	1.03	.59	11.10	.50	8.73	31.84	11.14
..	212	Little Club	.....	.....	....	28.44	....	9.50	13.03	14.40	1.50	.92	.63	.....	...	.....	.....	.....
3	...	Little Club	.000	14.39	.52	23.01	55.2	9.56	11.07	12.25	2.05	1.00	.57	10.72	.54	9.11	32.67	10.99
6	...	Little Club	.444	20.19	.75	25.53	56.3	9.11	10.89	11.99	2.05	....	...	10.64	.51	9.10	32.37	11.16
12	...	Little Club	1.005	24.86	.89	29.52	57.8	9.68	10.92	12.10	2.01	1.02	.60	10.98	.51	9.14	33.61	11.63
9	...	Little Club	1.210	28.47	.98	29.61	57.7	9.57	10.62	11.74	2.04	....	...	11.02	.51	8.94	32.20	11.03
15	...	Little Club	1.583	29.18	1.03	30.64	58.3	9.78	10.78	11.59	2.00	1.03	.60	10.93	.51	8.81	32.42	11.06
18	...	Little Club	2.031	27.41	.95	30.51	58.3	9.91	10.12	11.24	2.02	....	...	10.91	.49	8.69	31.04	10.51
21	...	Little Club	2.760	30.20	1.03	31.09	57.8	9.85	10.71	11.89	2.03	1.04	.59	10.81	.49	8.59	31.75	10.89
..	213	Sonora	.....	.....	....	37.94	....	8.50	10.24	11.19	1.80	.96	.50	.....	...	.....	.....	.....
2	...	Sonora	.000	13.83	.43	31.02	59.	9.49	9.65	10.66	1.75	.98	.51	11.19	.44	8.77	28.91	10.40
5	...	Sonora	.358	19.61	.51	31.28	59.2	9.16	10.29	11.33	1.88	....	...	11.38	.48	8.47	29.58	10.23
8	...	Sonora	.969	20.22	.66	34.50	59.8	9.31	10.29	11.35	1.94	1.00	.52	10.85	.51	8.59	30.59	10.51
11	...	Sonora	1.166	25.53	.78	34.93	60.2	9.54	10.41	11.51	1.94	....	...	10.88	.49	8.33	28.63	9.85
14	...	Sonora	1.695	25.26	.89	35.82	60.2	9.63	10.47	11.59	1.95	1.02	.52	10.81	.51	8.59	29.90	10.49
17	...	Sonora	2.223	28.84	1.10	35.66	59.3	9.81	10.06	11.16	1.92	....	...	10.84	.56	8.38	28.93	10.12
20	...	Sonora	2.769	25.98	.89	35.50	60.3	9.25	10.68	11.77	2.00	1.04	.53	10.71	.55	8.52	28.13	9.71

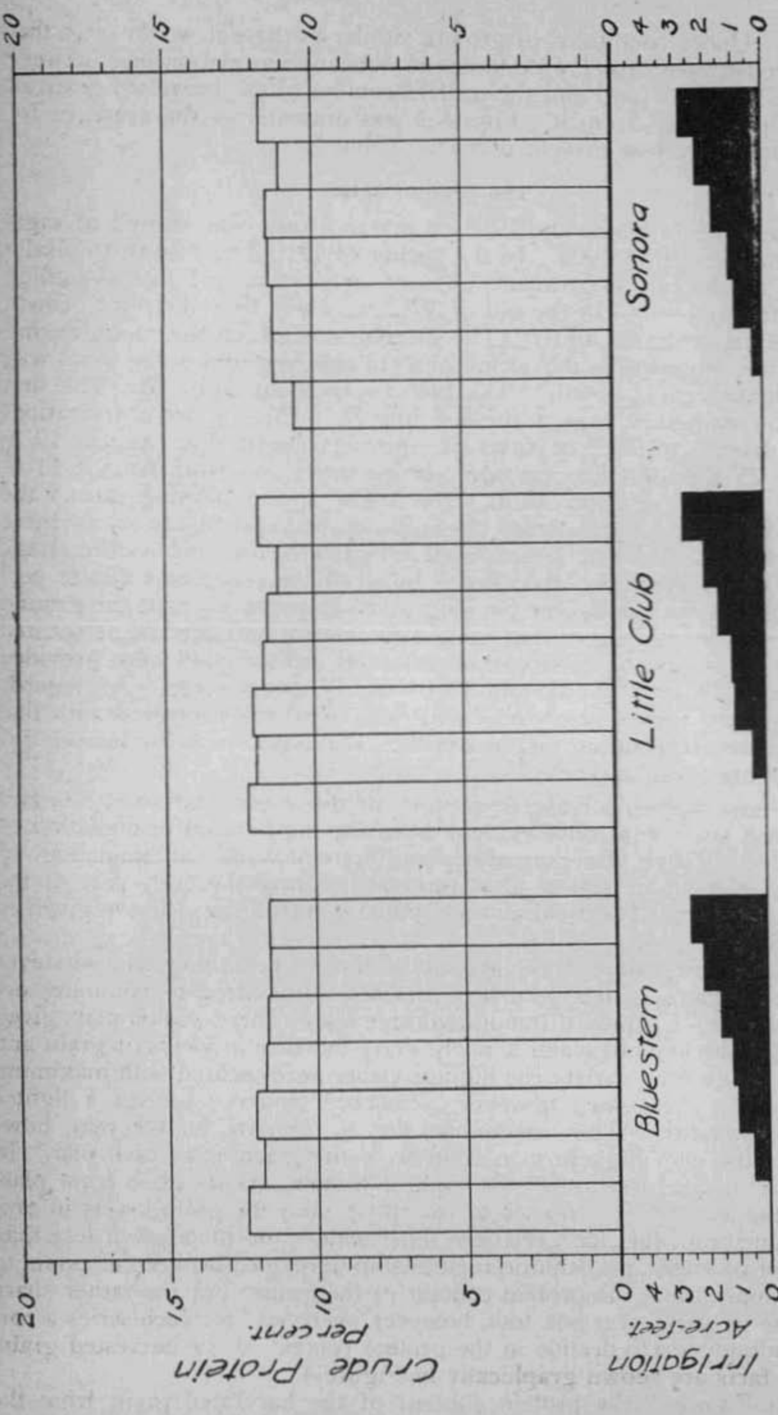


FIG. 3. Crude protein of wheats grown for three years with varying amounts of irrigation water. Drawn from data presented in Table 6.

content. Under conditions of growth similar to these it would seem that there are between rather wide limits no outstanding relationships between amounts of water used and the protein content of the harvested grain or of the flour milled from it. Figure 3 was drawn from the averages for irrigation and wheat protein given in Table 6.

The Crop of 1913.

The land on which the 1913 crop was grown was cleared of sagebrush and leveled in 1909. In the spring of 1910 it was sown to alfalfa for the conduct of experiments in seed production and rate-of-seeding tests. It was plowed in the fall of 1912, at which time the third growth of alfalfa was turned under. The ground was left in the rough during the winter, replowed in the spring of 1913 and prepared in the usual way for irrigation and sowing. The plats were sown April 28. The first irrigation was given June 3, the last July 28. The number of irrigations ranged from 1 to 9. The dates of ripening ranged from August 19 to August 25 for the Bluestem and Sonora series and from August 11 to August 24 for the Little Club series. The spring plowing caused the loss of so much of the stored precipitation that the plants on all three plats which received no water made no growth after the booting stage and of course were not harvested. In all of the plats some alfalfa persisted in spite of the double plowing given in preparation of the ground for sowing. In the belief that some definite information could be secured from them regarding nitrification processes, fallow plats were provided adjacent to Nos. 1, 7, 13, and 19 of the Bluestem series. As regards irrigation, the treatment of these plats was in all ways identical with that given the corresponding cropped plats. The nitrate data by periods for the year are given in Table 7.

A remarkable increase in nitrates in the wheat plats over the two preceding years is at once evident from the most casual examination of this table. There was noticeable, too, a remarkable accumulation of nitrates in the four fallow plats especially during the early part of the growing season. The field and analytical data for the year are given in Table 8.

For the first time in the growth of these wheats they had whatever advantage there is in a seed bed enriched with nitrogen-containing organic matter. In spite of the unfavorable season there was on plats given the larger amounts of water a fairly sharp increase in yields of grain and straw. With each variety the highest yields were secured with maximum irrigation. There was, however, a marked tendency toward a lighter weight of kernel. The outstanding fact in the data for the year, however, is the very high protein content of the grain from each plat. In two out of the three series the highest protein wheats came from plats given the least water. In each of the three series the grain lowest in protein came from the plat given the most water. On plats given less than one foot of water, no defiinite relationship developed between amounts of water applied and the protein content of the grain. For the rather sharp increase in water over one foot, however, there was for each series a correspondingly sharp decline in the protein content of the harvested grain. These facts are shown graphically in Figure 4.

In Figure 5 the protein content of the harvested grain from the

Table 7. NO_3 in parts per million on dry soil, 1913.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	May 16-31 a	June 1-15 b	June 16-30 c	July 1-15 d	July 16-31 e	August 1- f
....	....	....	1	....	71.7	84.1	47.0	75.3	64.0
....	....	....	2	....	25.0	12.0	2.9	8.0	4.8
1	0	.000	3	....	3.2	1.2	0.0	1.6	0.0
....	....	....	4	....	0.8	0.2	0.0	0.0	0.0
....	....	....	5	....	0.4	0.0	0.0	0.0	0.0
....	....	....	6	....	0.0	0.0	0.0	0.0	0.0
....	....	....	1	....	119.8	49.0	79.0	103.3	95.0
....	....	....	2	....	17.8	15.3	6.3	11.7	12.0
1-F	0	.000	3	....	2.1	1.2	1.6	0.9	0.0
....	....	....	4	....	0.6	0.0	0.0	0.0	0.0
....	....	....	5	....	0.5	0.6	0.0	0.0	0.0
....	....	....	6	....	0.0	0.0	0.0	0.0	0.0
....	....	....	1	....	87.2	27.3	16.0	26.0	22.0
....	....	....	2	....	61.0	45.0	21.0	31.3	20.0
4	1	.299	3	....	8.1	12.6	4.4	15.8	8.7
....	....	....	4	....	1.3	1.8	0.5	5.7	0.0
....	....	....	5	....	0.5	1.3	1.4	0.0	0.0
....	....	....	6	....	0.0	0.6	0.0	0.0	0.0
....	....	....	1	....	61.5	50.3	21.0	29.2	20.0
....	....	....	2	....	29.2	21.0	21.0	4.9	8.0
7	2	.515	3	....	5.1	4.0	0.7	2.8	0.0
....	....	....	4	....	1.5	2.0	0.0	0.6	0.0
....	....	....	5	....	0.9	0.9	0.0	0.4	0.0
....	....	....	6	....	1.0	0.0	0.0	0.0	0.0
....	....	....	1	....	90.0	71.3	97.0	26.0	24.0
....	....	....	2	....	53.0	55.3	29.0	35.0	6.9
7-F	2	.515	3	....	9.5	19.6	11.6	6.5	11.0
....	....	....	4	....	1.7	0.9	2.8	1.2	0.0
....	....	....	5	....	1.4	0.9	2.4	0.0	0.0
....	....	....	6	....	1.5	0.3	0.0	0.0	0.0
....	....	....	1	....	54.0	38.1	2.7	3.5	3.9
....	....	....	2	....	27.0	14.5	1.5	1.7	0.0
10	3	.541	3	....	4.7	5.2	0.0	0.0	1.7
....	....	....	4	....	1.8	0.3	0.0	0.0	0.0
....	....	....	5	....	0.7	0.7	0.0	0.0	0.0
....	....	....	6	....	0.0	0.3	0.0	0.0	0.0
....	....	....	1	....	38.5	6.1	2.6	3.0	2.4
....	....	....	2	....	30.5	14.7	0.3	0.5	1.6
13	4	.978	3	....	5.0	6.6	1.8	0.0	4.1
....	....	....	4	....	1.9	1.0	2.0	0.0	0.0
....	....	....	5	....	1.1	0.3	0 8	0.0	0.0
....	....	....	6	....	0.4	0.0	0.0	0.0	0.0
....	....	....	1	....	53.3	65.0	12.9	23.3	23.0
....	....	....	2	....	25.8	50.6	27.5	22.4	18.0
13-F	4	.978	3	....	5.5	2.4	3.3	4.2	1.7
....	....	....	4	....	0.6	0.4	0.0	0.3	0.0
....	....	....	5	....	1.1	0.0	0 0	0.0	0.0
....	....	....	6	....	0.7	0.0	0.0	0.0	0.0

(Periods for which nitrate data were averaged*)

TABLE NO. 7—(Concluded)

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*					
				May	June		July		August
				16-31 a	1-15 b	16-30 c	1-15 d	16-31 e	1- f
....	....	....	1	....	65.5	62.3	4.1	5.4	1.0
....	....	....	2	....	40.5	53.3	3.6	4.6	1.3
16	5	1.182	3	....	6.2	1.5	15.0	5.5	2.6
....	....	....	4	....	1.5	0.3	0.0	0.0	8.6
....	....	....	5	....	1.2	0.0	0.0	0.0	0.0
....	....	....	6	....	0.5	0.0	0.0	0.0	0.0
....	....	....	1	....	69.3	12.4	1.6	1.4	1.8
....	....	....	2	....	39.7	56.3	2.1	0.8	1.8
19	9	1.863	3	....	15.5	27.0	34.5	17.0	26.0
....	....	....	4	....	2.7	0.9	15.5	9.6	7.9
....	....	....	5	....	1.8	0.0	0.8	1.4	0.0
....	....	....	6	....	1.4	0.0	2.0	0.6	0.0
....	....	....	1	....	46.3	33.5	7.9	12.4	8.2
....	....	....	2	....	32.0	71.0	7.0	4.3	8.2
19-F	9	1.863	3	....	16.8	60.7	16.5	18.2	19.0
....	....	....	4	....	3.5	7.8	22.7	29.9	27.0
....	....	....	5	....	1.3	0.0	31.5	4.8	9.0
....	....	....	6	....	1.2	0.0	25.0	16.3	40.0

* Samples were taken for the determination of their nitrate content on the following dates: June 3 7, 10, 14, 17, 24, and 30; July 7, 11, 16, 21, and 28, and August 1.

Bluestem plats given normal irrigation in 1911, 1912, and 1913 and the average soil nitrate content by periods to a depth of three feet are shown for ease of correlation.

The nitrate data used in the graphs were secured by averaging the nitrate data for the first 3 feet of soil for periods of 15 and 16 days during June and July and for all determinations made in August. Plat 7 was taken as representative of normal irrigation in 1911 and 1912. Plat 13 was taken for normal irrigation in 1913 during which season all plats were given less water than in preceding years. In Figures 6 are shown the corresponding data for plats of Bluestem given maximum irrigation the same years. A very substantial difference between the soil's content of nitrates in June, 1911 and 1912, and that of June, 1913, cannot escape notice. To us it suggests very strongly a definite relationship between available soil nitrogen during the early growing period and the ability and readiness of the wheat plant to elaborate it into protein for storage later in the seed. The relative amounts of soil nitrates to the same depth of soil and for the same periods in plats given no irrigation and those given minimum irrigation in 1911, 1912, and 1913 might have been shown graphically with even more striking effect. Great activity on the part of nitrifying organisms during the early part of the growing season in 1913 is believed to be very clearly shown from the nitrate data of the fallow plats shown in Table 7.

Table 8. Field and analytical data on wheat and flour samples, crop of 1913.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	Per cent,	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	...	Bluestem	.000	lost	....	.....	....	.....	.....	.....	....	....	...	.....	...	.....	.....	.....
4	570	Bluestem	.299	17.16	.57	30.58	57	8.31	18.21	19.86	1.82	....	...	11.96	.51	14.41	61.73	20.64
7	571	Bluestem	.515	25.96	1.05	26.99	55½	8.85	17.86	19.59	1.97	1.03	.59	11.79	.50	14.10	61.05	20.82
10	572	Bluestem	.541	27.68	1.40	26.40	55	8.58	17.95	19.64	2.10	....	...	11.80	.50	13.66	59.73	19.52
13	573	Bluestem	.978	28.40	1.38	36.36	58½	8.59	16.57	18.13	1.97	1.08	.57	11.70	.49	13.14	53.91	17.62
16	574	Bluestem	1.182	25.85	1.55	32.96	57	7.86	18.26	19.82	2.14	....	...	11.41	.53	14.28	60.25	20.47
19	575	Bluestem	1.863	41.08	2.07	31.34	56½	9.26	15.21	16.74	1.92	1.02	.59	12.24	.47	12.16	49.18	15.47
3	...	Little Club	.000	lost	....	.....	....	.....	.....	.....	....	....	...	.....	...	.....	.....	.....
6	584	Little Club	.258	22.31	.71	23.19	55	8.12	19.35	21.06	2.04	....	...	11.84	.58	16.04	62.15	23.60
9	585	Little Club	.500	32.02	1.19	21.99	56	8.84	17.95	19.74	2.16	1.13	.65	12.34	.68	15.12	58.94	20.01
12	586	Little Club	.690	22.96	1.21	23.96	56½	8.10	18.10	19.70	2.19	....	...	12.29	.59	14.45	57.09	21.01
15	587	Little Club	.930	22.01	1.14	29.98	59½	8.86	19.53	21.43	2.13	1.16	.56	12.33	.58	15.53	60.40	22.31
18	588	Little Club	1.097	42.23	2.19	21.98	56	8.36	17.91	19.54	2.17	....	...	12.32	.58	15.01	60.90	22.62
21	598	Little Club	1.836	59.03	2.61	28.74	58	9.07	15.72	17.10	2.00	1.05	.60	12.51	.54	11.98	46.17	15.80
2	...	Sonora	.000	lost	....	.....	....	.....	.....	.....	....	....	...	.....	...	.....	.....	.....
5	577	Sonora	.264	18.48	.53	26.22	60	8.73	17.32	18.98	1.90	1.02	.52	11.69	.56	12.92	49.18	17.26
8	578	Sonora	.475	30.65	.92	31.32	58½	8.71	16.24	17.79	1.83	.98	.49	11.85	.56	13.30	51.61	17.42
11	579	Sonora	.691	37.71	1.58	31.02	59	8.45	15.78	17.24	1.87	1.00	.49	11.67	.57	12.35	45.35	15.33
14	580	Sonora	1.185	31.31	1.02	34.20	59½	8.41	17.05	18.62	1.98	1.09	.50	11.41	.62	14.26	51.87	17.38
17	581	Sonora	1.255	31.47	1.20	29.61	59½	8.52	16.59	18.14	2.13	....	...	11.93	.63	13.52	51.23	17.37
20	582	Sonora	2.198	60.52	1.97	34.90	60½	8.83	13.03	14.29	1.94	1.06	.54	12.17	.54	10.56	42.05	13.64

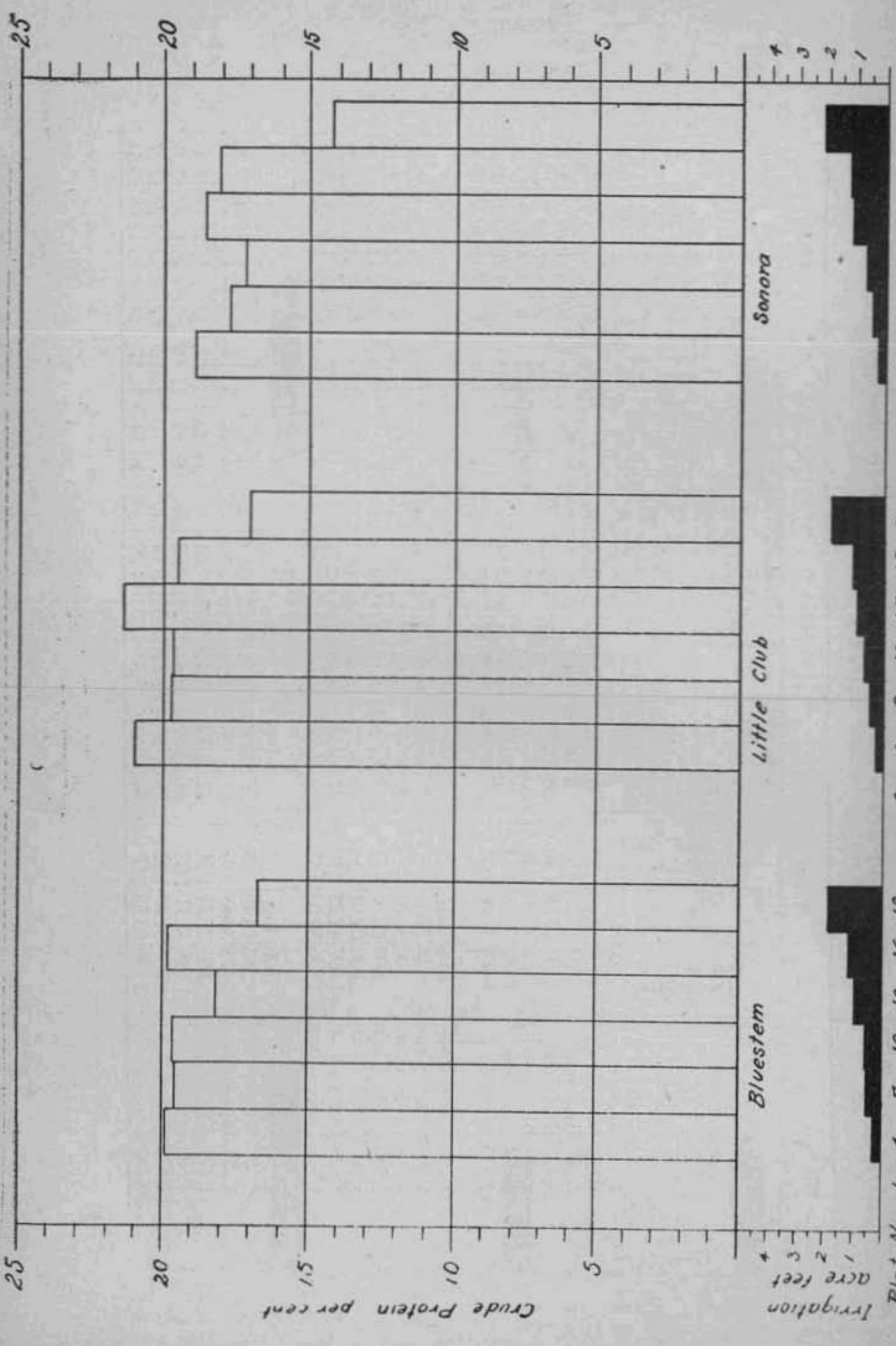


FIG. 4. Crude protein of wheats grown with varying amounts of irrigation water in 1913. Drawn from data presented in Table 8.

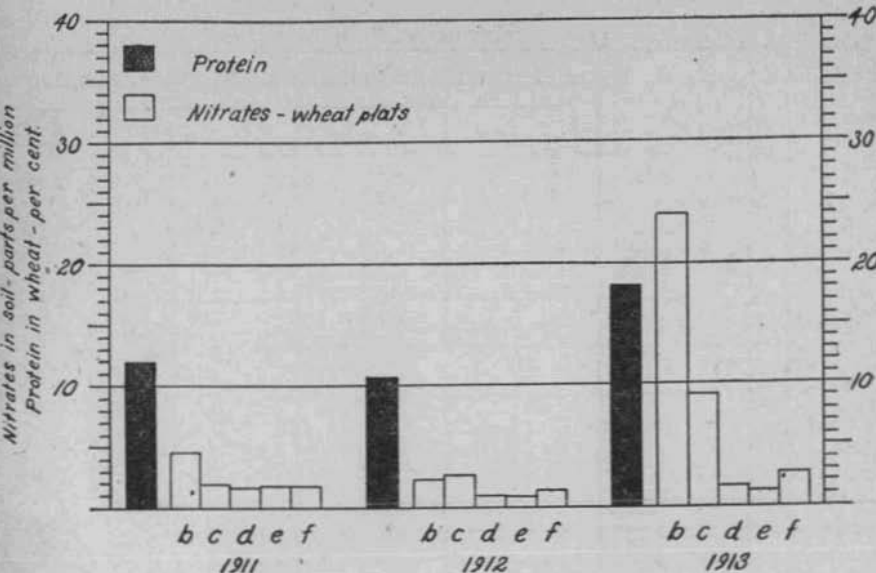


FIG. 5. Protein in Bluestem wheat from plats given normal irrigation in 1911, 1912 and 1913 and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same years. b period, June 1 to 15, inclusive; c period, June 16 to 30, inclusive; d period, July 1 to 15, inclusive; e period, July 16 to July 31, inclusive; and f period, August 1 to 16, inclusive.

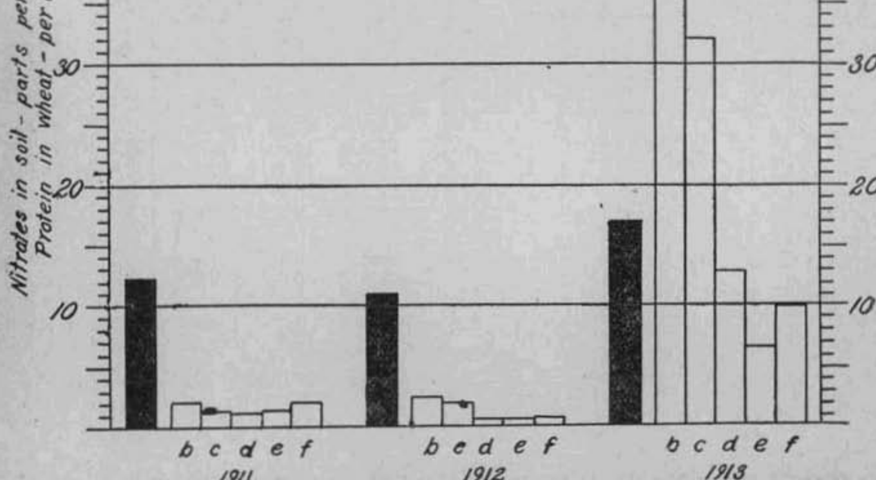


FIG. 6. Protein in Bluestem wheat from plats given maximum irrigation in 1911, 1912, and 1913 and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same years.

Table 9. NO_3 in parts per million on dry soil, 1914.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Period for which nitrate data were averaged*					
				May	June		July		August
				16-31 a	1-15 b	16-30 c	1-15 d	16-31 e	1-19 f
....	....	....	1	....	12.7	18.0	13.0	9.6	7.5
....	....	....	2	....	5.3	3.6	1.2	8.8	0.4
1	0	.000	3	....	11.1	7.4	4.0	3.7	1.2
....	....	....	4	....	5.7	4.3	2.3	4.1	1.1
....	....	....	5	....	5.7	3.6	2.6	3.6	0.6
....	....	....	6	....	7.8	4.7	1.9	6.2	1.9
....	....	....	1	....	23.6	51.4	58.3	50.1	48.5
....	....	....	2	....	11.4	6.5	7.5	11.1	9.0
1-F	0	.000	3	....	8.2	5.0	12.0	11.6	10.7
....	....	....	4	....	13.5	6.5	11.3	9.7	7.8
....	....	....	5	....	5.6	7.7	2.5	6.2	2.8
....	....	....	6	....	4.2	5.9	0.9	7.6	2.4
....	....	....	1	....	5.6	11.1	3.3	3.2	3.6
....	....	....	2	....	3.7	4.4	1.1	3.7	2.4
4	1	.519	3	....	10.4	23.3	3.1	12.3	21.2
....	....	....	4	....	23.5	16.7	6.5	6.9	4.8
....	....	....	5	....	25.5	10.6	5.4	5.8	1.6
....	....	....	6	....	10.2	9.9	8.3	6.5	2.6
....	....	....	1	....	39.4	29.1	65.9	38.0	19.7
....	....	....	2	....	30.5	29.6	16.4	19.9	4.4
4-F	1	.519	3	....	21.3	15.5	9.7	17.0	3.8
....	....	....	4	....	16.5	16.4	13.8	18.9	3.1
....	....	....	5	....	15.3	16.5	13.3	18.7	2.6
....	....	....	6	....	5.3	9.1	11.9	12.2	3.3
....	....	....	1	....	9.4	9.7	5.1	4.8	7.2
....	....	....	2	....	16.5	2.7	4.6	6.2	61.6
7	3	1.012	3	....	44.7	19.0	37.4	8.9	31.1
....	....	....	4	....	28.6	7.0	21.4	7.7	3.9
....	....	....	5	....	17.1	6.2	10.5	3.1	1.1
....	....	....	6	....	6.9	3.6	6.3	3.7	1.4
....	....	....	1	....	46.6	23.4	20.2	22.9	10.1
....	....	....	2	....	15.9	22.4	20.5	21.3	12.8
7-F	3	1.012	3	....	13.7	14.0	15.9	27.4	15.6
....	....	....	4	....	19.1	10.4	14.5	32.9	16.6
....	....	....	5	....	11.2	16.0	11.5	13.4	11.6
....	....	....	6	....	3.6	8.7	7.6	8.2	8.0
....	....	....	1	....	6.3	2.3	1.4	6.2	1.9
....	....	....	2	....	7.1	0.9	0.3	1.6	0.8
10	11	2.341	3	....	3.9	0.6	0.4	0.9	2.8
....	....	....	4	....	4.3	9.1	4.8	5.7	3.8
....	....	....	5	....	5.1	10.7	11.9	6.2	2.6

The Crop of 1914.

In 1914 Minnesota Bluestem, Minnesota, No. 169, and Glyndon Fife, Minnesota, No. 163, were substituted for Palouse Bluestem and Little Club. The seed, as stated before, was sent from the central station where it had been grown from seed originally secured from University Farm, Minnesota. We wished to ascertain the behavior of these hard spring wheats under irrigation. It was considered unnecessary to continue the use of so large a number of plats. The planting and irrigation scheme for 1914 and subsequent years called for plats of no irrigation, plats of minimum irrigation, plats of normal irrigation and plats of maximum irrigation for each variety and for fallow plats adjacent to each one in the Blustem series. Figure 2 shows a typical arrangement of the plats during 1914, 1915, and 1916.

The crop history of the land on which the 1914 crop was grown up to the fall of 1912 was identical with that of the land used for the crop of 1913. In 1913 it was planted to potatoes and produced a heavy crop. It was spring-plowed in 1914 and prepared as usual for sowing and irrigation. A cultivated crop thus intervened between one which makes decidedly for soil enrichment and the growing of this wheat crop. The plats were sown April 3. The first irigation was given June 6, the last, July 29. The number of irrigations ranged from 1 to 11. There was a range in dates of ripening of 10 days, the last to ripen being the plats given maximum irrigation, harvested August 14.

Nitrate data for all Bluestem plats and corresponding fallow plats are given in Table 9.

Again from the concentration of nitrates in the fallow plats, it would seem that there was great activity on the part of nitrifying organisms. The concentration of nitrates in the wheat plats of course for corresponding periods was much lower. The rather low initial content of the Bluestem plat given maximum irrigation and the sharp drop from that for the next two periods is noticeable.

The field and analytical data appear in Table 10.

Plats 1 and 2 were unfortunately too close to the supply ditches and received some water by seepage that was not intended for them. The yields on them were unquestionably higher than one could reasonably expect in that section from no irrigation. The Sonora plat given maximum irrigation rusted badly and for that reason was low in yield. The yield of Plat 11 was cut to some extent by the presence of an adobe spot. There was an unmistakable tendency toward lightness in weight. All samples of grain and flour were high in protein—those from plats given normal irrigation and less, extremely so. A close study of the data, however, gives no ground for assigning high protein content to lightness of kernel for the heavy-weight kernels were in the high-protein class. A close relationship between the supply of available nitrogen in the soil during the early period of growth and the protein content of the harvested grain again suggests itself. Plats given most water in each of the three series produced wheat of lowest protein content but again there was no *gradual* decreases of protein with increase of water in any series.

The Crop of 1915.

....	....	....	6	....	3.7	0.0	8.5	2.8	75.5

* Samples were taken for the det ermination of their nitrate content on the following dates: June 10, 14, 19, 24, and 29; July 2, 5, 12, 19, 23, 26, and 29; and August 4 and 10.

Table 10. Field and analytical data on wheat and flour samples, crop of 1914.

Variety	Total Irrigation, A.-feet	Yield: Grain per A., bu.	Yield: Straw per A., tons	WHEAT: Weight: Per 1000 kernels, grams	WHEAT: Weight: Per bu., lbs.	WHEAT: Moisture, per cent	WHEAT: Crude protein N x 6¼: Per cent	WHEAT: Crude protein N x 6¼: On dry basis, per cent	WHEAT: Ash, per cent	WHEAT: P_2O_5 in grain, per cent	WHEAT: K_2O in grain, per cent	FLOUR: Moisture, per cent	FLOUR: Ash, per cent	FLOUR: Crude Protein Nx5.7, per cent	FLOUR: Gluten: Wet, per cent	FLOUR: Gluten: Dry, per cent
ı. Bluestem, Minn. No. 169	.000	20.58	1.20	25.10	55	9.39	17.75	19.59	1.92	1.05	.57	13.38	.57	13.58	44.60	14.45
ı. Bluestem, Minn. No. 169	.519	26.45	1.60	25.90	55	10.59	17.08	19.10	1.94	1.08	.58	13.28	.54	14.02	50.20	16.27
ı. Bluestem, Minn. No. 169	1.012	32.23	1.90	32.30	57	10.17	17.67	19.64	1.93	1.09	.51	12.36	.58	14.45	49.50	15.03
n. Bluestem, Minn. No. 169	2.341	27.07	2.67	28.68	57½	9.98	14.03	15.59	1.94	1.08	.54	12.82	.55	11.58	38.25	12.02
don Fife, Minn. No. 163	.000	26.33	1.35	24.99	57	9.35	18.06	19.92	1.78	.95	.54	12.[illegible]	.57	13.86	52.50	16.65
ıdon Fife, Minn. No. 163	.466	35.01	1.92	26.26	57	9.95	17.36	19.28	2.02	1.08	.55	12.46	.53	13.84	51.10	16.65
ıdon Fife, Minn. No. 163	1.006	30.01	1.74	29.10	58	9.40	17.91	19.77	2.08	1.14	.53	12.67	.51	14.47	52.40	16.93
ıdon Fife, Minn. No. 163	2.544	32.90	2.47	30.16	57	9.66	13.11	14.51	1.96	1.09	.63	12.59	.50	10.88	35.00	11.52
ora	.000	11.10	.86	27.08	59½	9.92	17.32	19.23	1.93	1.08	.48	12.24	.57	14.26	49.35	16.78
ora	.420	23.03	1.58	22.86	55	10.50	16.00	17.88	1.96	1.03	.52	12.74	.43	10.58	32.90	12.62
ora	.870	20.78	1.50	20.21	55	10.77	15.44	17.30	2.08	1.04	.59	12.41	.56	12.08	42.90	16.26
ora	4.415	12.35	2.09	17.44	55	10.89	11.08	12.15	2.20	1.10	.65	12.84	.43	10.74	34.45	12.60

Table 11. NO_3 in parts per million on dry soil, 1915.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Period for which nitrate data were averaged*					
				May	June		July		August
				16-31 a	1-15 b	16-30 c	1-15 d	16-31 e	1-10 f
1	....	....	1	....	13.8	11.8	13.4	13.2	23.1
....	....	....	2	....	7.4	3.8	6.1	8.1	7.0
1	1	.206	3	....	5.0	4.8	3.8	2.4	12.7
....	....	....	4	....	0.0	5.5	1.0	0.7	3.8
....	....	....	5	....	0.0	....	....	....	2.6
....	....	....	6	....	2.4	....	....	....	....
....	....	....	1	....	144.0	114.0	194.0	157.0	262.0
....	....	....	2	....	27.2	23.0	36.0	31.5	45.0
1-F	1	.206	3	....	17.5	14.6	14.8	13.2	26.3
....	....	....	4	....	6.0	5.7	4.6	5.2	13.0
....	....	....	5	....	0.9	....	....	....	4.6
....	....	....	6	....	5.3	....	....	....	3.8
....	....	....	1	....	3.6	10.7	6.8	4.7	14.7
....	....	....	2	....	7.5	5.4	2.6	1.3	6.4
4	2	.729	3	....	5.6	2.6	2.4	1.2	2.1
....	....	....	4	....	0.0	0.6	1.5	0.5	2.1
....	....	....	5	....	....	....	....	....	....
....	....	....	6	....	....	....	....	....	....
....	....	....	1	....	88.0	72.0	119.3	56.5	130.0
....	....	....	2	....	15.9	27.3	36.8	14.4	35.0
4-F	2	.729	3	....	4.4	11.9	11.7	14.5	18.6
....	....	....	4	....	4.8	6.7	3.3	9.8	6.6
....	....	....	5	....	....	....	....	....	3.6
....	....	....	6	....	....	....	....	....	3.7
....	....	....	1	....	11.3	4.7	5.8	4.5	6.3
....	....	....	2	....	2.1	4.2	3.3	2.2	2.9
7	4	1.176	3	....	2.2	1.4	2.5	2.2	2.5
....	....	....	4	....	0.8	0.0	0.7	0.4	2.2
....	....	....	5	....	1.2	....	....	....	1.7
....	....	....	6	....	....	....	....	....	1.9
....	....	....	1	....	62.5	73.0	77.0	48.0	54.2
....	....	....	2	....	21.0	30.3	59.0	45.2	52.4
7-F	4	1.176	3	....	3.7	16.8	17.9	52.5	31.2
....	....	....	4	....	2.4	5.5	4.7	23.8	13.0
....	....	....	5	....	1.9	0.0	0.0	0.0	10.9
....	....	....	6	....	2.8	0.0	0.0	0.0	3.7
....	....	....	1	....	4.3	4.5	3.2	2.1	3.9
....	....	....	2	....	3.4	2.1	1.8	1.1	3.1
10	7	2.185	3	....	5.4	4.5	2.3	1.6	2.2
....	....	....	4	....	2.4	2.8	5.4	0.3	2.7
....	....	....	5	....	0.9	0.3	2.5	1.2	2.8
....	....	....	6	....	0.0	0.0	0.8	2.4	11.4
....	....	....	1	....	101.9	84.3	41.2	33.4	10.3
....	....	....	2	....	70.3	45.3	46.6	29.7	38.7
10-F	7	2.185	3	....	24.9	23.8	58.3	24.2	49.1
....	....	....	4	....	3.8	24.7	36.6	9.6	43.0
....	....	....	5	....	2.8	0.9	20.0	[illegible]	[illegible]

Table 12. Field and analytical data on wheat and flour samples, crop of 1915.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	Per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	803	Minn. Bluestem, Minn. No. 169	.206	19.82	1.34	26.72	52½	10.99	17.69	19.87	1.82	1.03	.55	12.60	.53	13.89	48.05	16.11
4	804	Minn. Bluestem, Minn. No. 169	.729	29.10	1.82	26.96	51	9.78	17.40	19.29	2.03	1.05	.60	13.30	.53	13.32	49.85	16.79
7	806	Minn. Bluestem, Minn. No. 169	1.176	57.08	2.49	36.08	58	10.25	14.84	16.54	1.88	1.00	.53	13.15	.51	11.16	37.25	13.19
10	805	Minn. Bluestem, Minn. No. 169	2.185	59.36	3.54	35.35	55½	10.83	13.20	14.80	1.87	1.00	.52	13.18	.53	10.52	32.00	11.53
2	807	Glyndon Fife, Minn. No. 163..	.164	22.10	1.56	23.72	56	10.41	17.95	20.04	1.86	.96	.56	12.87	.50	13.22	47.85	16.06
5	808	Glyndon Fife, Minn. No. 163..	.675	39.70	1.67	24.79	55	10.72	16.81	18.83	1.82	.98	.56	13.15	.54	13.38	47.75	16.23
8	810	Glyndon Fife, Minn. No. 163..	1.413	64.83	2.78	34.22	58	11.77	14.05	15.92	1.84	1.04	.51	12.81	.45	11.76	35.30	12.69
11	809	Glyndon Fife, Minn. No. 163..	2.660	56.20	3.42	33.77	55	11.38	12.78	14.42	1.85	1.04	.50	12.83	.46	11.24	31.65	11.83
3	811	Sonora	.173	24.02	1.47	25.63	57	12.18	17.21	19.60	1.76	.94	.53	13.16	.48	12.34	38.50	14.93
6	812	Sonora	.773	36.16	1.71	33.92	55	9.86	14.56	16.15	1.69	.95	.48	12.79	.45	12.36	36.60	13.98
9	814	Sonora	1.400	42.85	2.23	38.72	57	10.46	13.99	15.62	1.95	1.04	.48	12.84	.46	10.86	36.90	14.28
12	813	Sonora	2.222	59.36	2.53	37.82	60	10.55	10.95	12.24	1.70	1.01	.51	12.71	.42	8.76	25.98	10.56

as follows: It was cleared of sagebrush in 1909, given over to the growth of barley in 1910 and to wheat in 1911 and 1912. In 1913 it was sown to red clover with barley as a nurse crop. Two crops were cut for hay in 1914. A heavy late growth was turned under with the plow in the fall. This land was prepared with the disk and harrow in the spring of 1915 for the wheat plats. This procedure again gave a soil considerably enriched over its native condition with nitrogen-containing organic matter.

The plats were sown April 5. The very dry spring necessitated the irrigation of *all* plats 10 days later to insure a stand. The seventh and last irigation was given July 26. There was a total range of 12 days in dates of ripening altho most plats were harvested within a range of 9 days. The nitrate data for the year will be found in Table 11.

There was perhaps a lower concentration of nitrates during the early-growing period than one might with good reason have anticipated. An exceptionally great activity on the part of nitrifying organisms during the entire season, however, is indicated by the nitrate data for the fallow plats. A fair conclusion is that even tho the nitrate concentration in the soil of the wheat plats was low, nitrification processes were going on with sufficient rapidity to supply the maximum requirements of the wheat plants.

There was a sharp increase in yields of grain and straw with increase of irrigation water. A plump, heavy kernel was produced with both normal and maximum irrigation. In each series the protein of the wheat for the first time gradually and consistently declined with the increase of irrigation water. With the exception of Sonora from Plat 12, however, the protein of the wheat from each plat was high.

The Crop of 1916.

The crop history of the land which grew the crop of 1916 is practically identical with that used for the 1915 crop up to the spring of 1915. Wheat instead of barley was grown in 1910 and the red clover was sown in 1913 with oats as a nurse crop. A heavy late growth of red clover was turned under in the fall of 1914 and potatoes were planted on it in the spring of 1915, for duty-of-water work. A cultivated crop, therefore, again intervened between one which makes for soil enrichment with nitrogen-containing organic matter and the grain crop. Immediately following the harvesting of the potato crop the ground was plowed and left in the rough over winter. In the spring it was worked down with a disk and harrowed in preparation for planting and irrigation.

The seed was sown April 24. The first irrigation was given June 7 and the last July 25. The minimum amount of water was given in one irrigation; the maximum amount in eight irrigations. The plats ripened between August 2 and August 15. Soil sampling for nitrate determinations began approximately two weeks earlier than in any preceding year. The nitrate data for the year are given in Table 13.

A substantial nitrate concentration during the early periods of growth is noticeable for all of the wheat plats. The concentration of nitrates in the fallow plats was far less than for corresponding periods in 1915 but it was sufficient to indicate great activity on the part of the nitrifying organisms. The wheat plants had whatever advantage there is in an

Table 13. NO_3 in parts per million on dry soil, 1916.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*					
				May	June		July		August
				16-31 a	1-15 b	16-30 c	1-15 d	16-31 e	1-8 f
....	....	....	1	31.2	34.4	11.2	14.7	25.5	27.4
....	....	....	2	17.0	8.4	25.5	22.7	13.6	12.9
1	0	.000	3	9.6	20.1	33.1	13.5	8.8	28.3
....	....	....	4	19.4	23.8	19.8	12.5	8.2	13.3
....	....	....	5	11.4	16.2	19.8	13.7	7.5	11.1
....	....	....	6	5.9	2.7	11.6	5.7	3.9	4.6
....	....	....	1	49.0	55.1	38.8	67.1	57.3	26.0
....	....	....	2	18.1	14.0	30.2	68.2	27.5	19.7
1-F	0	.000	3	30.1	19.7	38.7	73.4	19.6	17.7
....	....	....	4	26.0	24.3	26.1	29.0	21.6	8.1
....	....	....	5	20.2	23.5	18.0	23.1	13.1	10.3
....	....	....	6	0.0	8.9	17.7	5.3	9.4	6.9
....	....	....	1	47.5	29.5	28.9	6.3	15.1	20.0
....	....	....	2	25.6	53.4	80.8	21.4	15.0	15.0
4	1	.355	3	38.8	62.8	58.2	27.6	32.7	5.4
....	....	....	4	9.0	24.0	27.3	17.1	9.7	2.2
....	....	....	5	5.9	19.9	23.9	9.2	10.1	4.4
....	....	....	6	0.0	3.1	9.9	4.7	8.5	2.2
....	....	....	1	38.2	46.5	21.3	50.1	29.5	15.1
....	....	....	2	23.9	24.2	29.5	51.1	12.3	11.4
4-F	1	.355	3	26.9	40.5	50.3	32.7	22.9	23.3
....	....	....	4	19.3	28.9	33.3	35.6	25.9	25.6
....	....	....	5	8.3	9.8	29.8	35.0	16.3	11.4
....	....	....	6	3.5	8.9	18.5	18.7	12.2	4.6
....	....	....	1	46.9	8.5	6.4	10.2	4.4	6.3
....	....	....	2	8.1	20.1	14.2	6.8	6.6	4.3
7	3	.900	3	11.8	19.4	39.9	28.5	10.9	6.5
....	....	....	4	20.2	17.9	24.8	34.6	12.9	11.4
....	....	....	5	9.8	15.8	17.5	18.6	13.6	4.4
....	....	....	6	8.3	9.7	11.2	13.8	8.1	4.9
....	....	....	1	47.9	58.9	21.4	49.7	33.3	26.8
....	....	....	2	13.3	34.7	51.8	33.8	17.9	15.9
7-F	3	.900	3	12.3	25.9	40.1	32.9	37.1	19.9
....	....	....	4	4.1	36.3	24.6	22.6	24.7	15.4
....	....	....	5	3.5	15.4	30.5	23.3	29.6	12.8
....	....	....	6	7.1	11.0	12.9	22.5	14.1	9.4
....	....	....	1	30.0	18.9	21.9	8.0	3.0	4.4
....	....	....	2	6.9	9.3	14.0	8.1	4.9	2.3
10	8	1.879	3	10.1	14.5	16.1	10.7	5.5	4.7
			[illegible]	[illegible]	15.5	16.9	22.8	7.1	2.3

Table 14. Field and analytical data on wheat and flour, crop of 1916.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	Per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	930	Minn. Bluestem, Minn. No. 169	.000	22.60	1.03	28.91	54	9.98	17.64	19.60	1.87	1.00	.52	11.69	.62	14.46	56.90	17.17
4	931	Minn. Bluestem, Minn. No. 169	.355	26.73	1.61	29.51	55	8.78	18.72	20.52	1.96	1.08	.54	12.09	.64	15.39	53.05	16.86
7	932	Minn. Bluestem, Minn. No. 169	.900	35.92	1.92	37.07	60	8.88	16.88	18.53	1.96	1.05	.48	12.32	.64	12.90	44.25	13.46
10	933	Minn. Bluestem, Minn. No. 169	1.879	33.02	1.97	36.39	56	9.92	14.19	15.76	1.89	1.03	.49	12.28	.59	11.50	40.05	16.98
2	934	Glyndon Fife, Minn. No. 163..	.000	28.10	1.12	27.93	55	9.79	18.21	20.19	1.83	.93	.50	11.73	.51	15.49	55.05	17.35
5	935	Glyndon Fife, Minn. No. 163..	.339	31.00	1.55	26.71	55	10.04	18.83	20.93	2.01	1.08	.52	12.26	.52	15.69	61.15	18.80
8	936	Glyndon Fife, Minn. No. 163..	.943	44.88	2.12	34.73	60	10.09	17.47	19.43	1.97	1.08	.48	12.09	.56	14.16	52.10	15.83
1	937	Glyndon Fife, Minn. No. 163..	1.659	42.30	2.20	36.77	57	10.73	14.71	16.48	1.99	1.05	.47	11.79	.49	12.38	45.10	14.10
3	926	Sonora	.000	24.72	.82	28.21	58½	10.23	16.21	18.06	1.82	.92	.50	11.07	.49	12.71	48.15	16.31
6	927	Sonora	.354	33.92	1.37	29.05	55½	9.36	15.63	17.24	1.99	.98	.54	11.47	.54	12.78	50.65	17.27
9	928	Sonora	.887	48.57	1.48	38.64	61	9.96	14.93	16.58	1.75	.97	.47	12.02	.54	12.30	46.90	16.05
2	929	Sonora	1.567	44.25	1.47	39.94	60½	10.00	12.44	14.06	1.94	1.00	.51	11.69	.51	10.26	33.25	11.20

Table 15. Averages for field and analytical data, crops of 1914, 1915, and 1916.

No.				Yield		WHEAT								FLOUR				
						Weight			Crude protein Nx6¼								Gluten	
Plat	Laboratory	Variety	Total Irrigation, A.-feet	Grain per A., bu.	Straw per A., tons	Per 1000 kernels, grams	Per bu., lbs.	Moisture, per cent	Per cent	On dry basis, per cent	Ash, per cent	P_2O_5 in grain, per cent	K_2O in grain, per cent	Moisture, per cent	Ash, per cent	Crude Protein Nx5.7, per cent	Wet, per cent	Dry, per cent
1	...	Minn. Bluestem, Minn. No. 169	.206	21.00	1.19	26.91	53.8	10.12	17.69	19.69	1.87	1.03	.55	12.56	.57	13.97	49.85	15.91
4	...	Minn. Bluestem, Minn. No. 169	.534	27.43	1.67	27.46	53.7	9.72	17.73	19.64	1.97	1.07	.57	12.89	.57	14.24	51.03	16.64
7	...	Minn. Bluestem, Minn. No. 169	1.029	41.74	2.10	35.15	58.3	9.76	16.46	18.24	1.92	1.05	.53	12.61	.57	12.84	43.66	13.89
10	...	Minn. Bluestem, Minn. No. 169	2.135	39.82	2.73	33.47	56.3	10.24	13.81	15.38	1.90	1.04	.52	12.76	.56	11.20	36.76	13.51
2	...	Glyndon Fife, Minn. No. 163..	.164	25.51	1.34	25.55	56.0	9.85	18.07	20.05	1.82	.95	.53	12.23	.53	14.19	51.80	16.69
5	...	Glyndon Fife, Minn. No. 163..	.493	35.24	1.71	25.92	55.7	10.23	17.67	19.68	1.95	1.05	.54	12.62	.53	14.30	53.33	17.23
8	...	Glyndon Fife, Minn. No. 163..	1.121	46.57	2.21	32.68	58.7	10.42	16.48	18.37	1.96	1.05	.51	12.52	.51	13.46	46.60	15.15
11	...	Glyndon Fife, Minn. No. 163..	2.287	43.80	2.69	33.57	56.3	10.59	13.53	15.14	1.93	1.06	.53	12.40	.48	11.50	37.25	12.48
3	...	Sonora	.173	19.95	1.05	26.97	58.3	10.78	16.91	18.96	1.84	.98	.50	12.15	.51	13.10	45.33	16.01
6	...	Sonora	.516	31.04	1.55	28.61	55.3	9.91	15.39	17.09	1.88	.98	.51	12.33	.47	11.91	40.05	14.62
12	...	Sonora	1.052	37.40	1.74	32.52	57.7	10.39	14.78	16.50	1.93	1.02	.51	12.42	.52	11.75	42.23	15.53
9	...	Sonora	2.735	38.65	2.03	31.73	58.5	10.48	11.49	12.82	1.95	1.04	.56	12.41	.45	9.92	31.23	11.45

protein content fell off very sharply. The protein content of all samples grown with normal amounts of irrigation water and less, was remarkably high. That of samples from the plats given maximum irrigation was sufficient to give them unquestioned standing among high-protein wheats.

In Table 15 are presented the averaged field and analytical data for the years 1914, 1915, and 1916.

In connection with the study of this table, the conditions of growth for the three-year period should be clearly in mind. The soils which grew these crops, like that which grew the crop of 1913, had been substantially enriched with nitrogen-containing organic matter and thru the activity of nitrifying organisms soil nitrogen had been put in available form in substantial amounts for the wheat plants.

Large increases of water over normal amounts increased the average yield of straw in each series but not the average yield of grain. In the increased yield of Sonora for this period over the first three years with corresponding amounts of water, there is substantial additional proof for the claim made elsewhere by Superintendent Welch that the duty of water is increased substantially with an increase in the soil's content of organic matter. The maximum weight of grain was reached in each series with

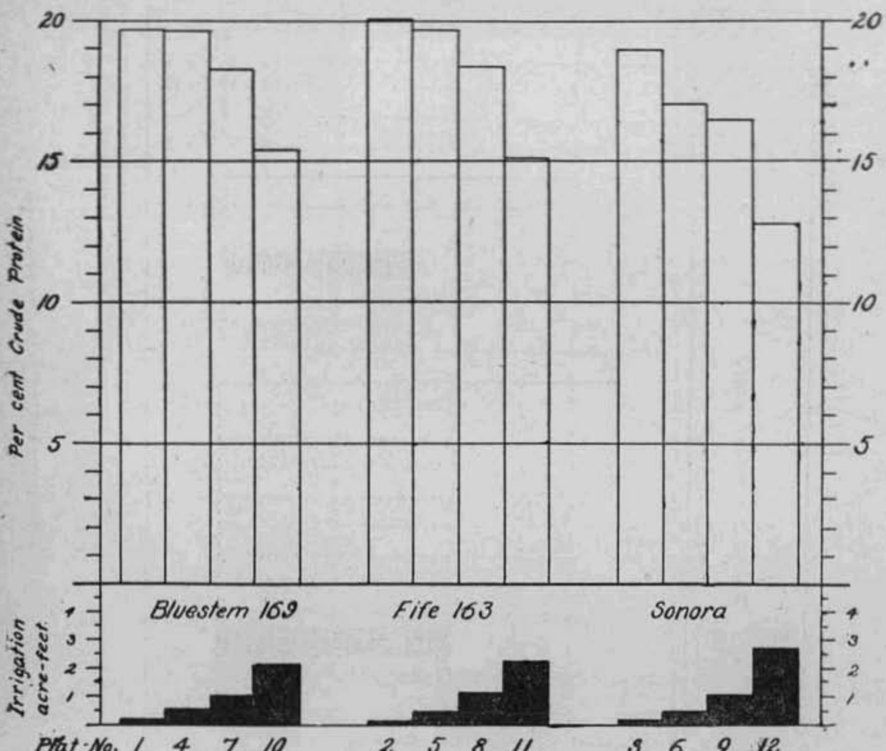


FIG. 7. Crude protein of wheats grown for three years with varying amounts of irrigation water. Drawn from data presented in Table 15.

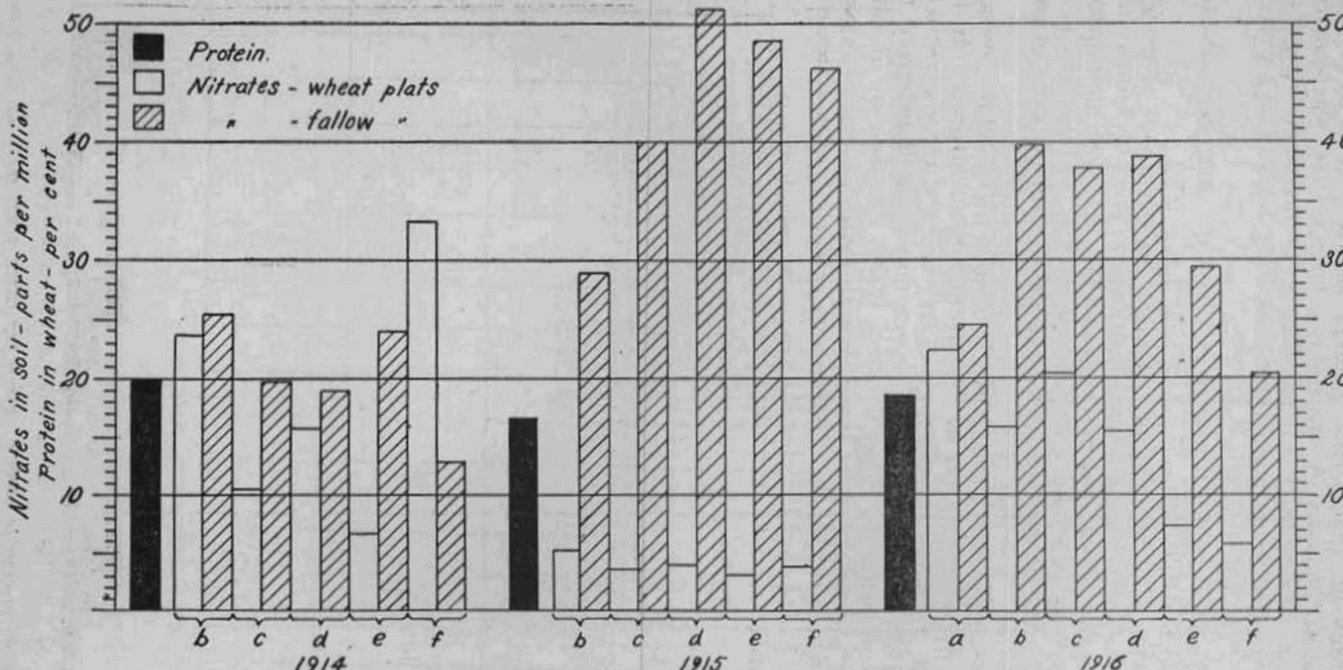


FIG. 8. Protein in Minnesota Bluestem (Minn. 169) from plats given normal irrigation in 1914, 1915, and 1916, and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same years; a period, May 16 to 31, inclusive; b period, June 1 to 15, inclusive; c period, June 16 to 30, inclusive; d period, July 1 to 15, inclusive; e period, July 16 to 31, inclusive; and f period, August 1 to 19, inclusive.

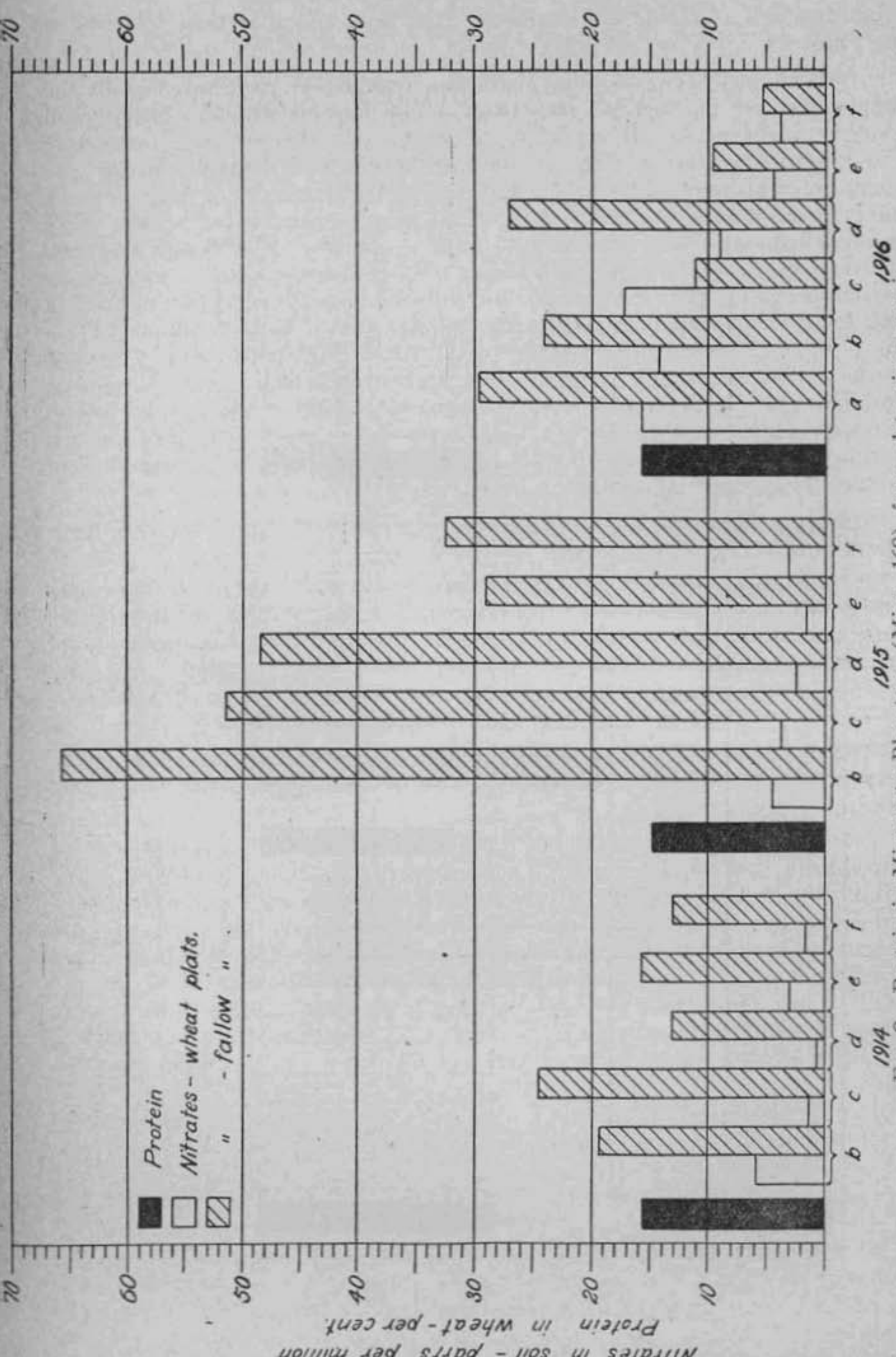


FIG. 9. Protein in Minnesota Bluestem, (Minn. 169) from plats given maximum irrigation in 1914, 1915, and 1916 and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same year.

abundance of available soil nitrogen. The field and analytical data follow in Table 14.

Maximum production in 1916 was reached in each series with the application of the normal irrigation. The kernels attained exceptional weight with the larger amounts of water. With increase in amounts of irrigation water over the minimum, there was a decrease in the percentage of protein in the wheat and flour. With maximum irrigation the normal irrigation. In each of the three series grain of remarkably high protein content was produced with normal applications of water and less. Protein in the grain from each series fell off sharply with an increase in irrigation water over the normal, but with the possible exception of Sonora not to an extent sufficient to rule the samples grown with maximum irrigation out of the high-protein class. With the possible exception of Sonora grown with maximum irrigation, the high protein and gluten content of the flours would insure for them a high place in the estimation of bakers who are accustomed to the handling of strong wheat flours. The mineral requirements of the wheat plants in so far as the grain is concerned seem to have been satisfied with the minimum application of water.

Figure 7 presents graphically the correlation of irrigation and protein data for these three years.

In Figures 8 and 9 the nitrate data averaged for the first three feet from determinations made during 15 and 16-day periods in May, June, July and in August and the protein data for the plats given normal and maximum irrigation are shown for correlation.

THE SEVEN YEARS' WORK IN REVIEW

The outstanding facts in the field and analytical data covered by the entire time of this investigation may now be summarized for correlation wherever possible.

Climate, of course, imposed certain uncontrollable conditions of growth thruout the investigation. The more outstanding ones were a low humidity, high percentage of sunshine and comparatively low temperatures during the growing seasons. These conditions, however, were so nearly uniform year after year as to merit no further consideration in this connection. The controllable conditions of growth were those of the soil. The conditions imposed during the first three years' work were those of a soil rich in the essential mineral elements of plant food but low in nitrogen and varied between rather wide limits in its content of moisture.

From seed fairly high in protein at the beginning of the work in 1910, the harvested grain from all plats in each series reached a very low level of protein in the crop of 1912. Substantial variations in amounts of irrigation water were without marked effect in producing variations in the protein content of the harvested grain and flour ground from it. The irrigation data for 1911 and 1912, averaged from determinations made during 15 and 16-day periods in June and July and from those made in early August, graphically presented in Figure 10, lend little support to the notion that there was a concentration of nitrates in zones beyond the feeding range of the wheat plants. The only tenable explanation of the

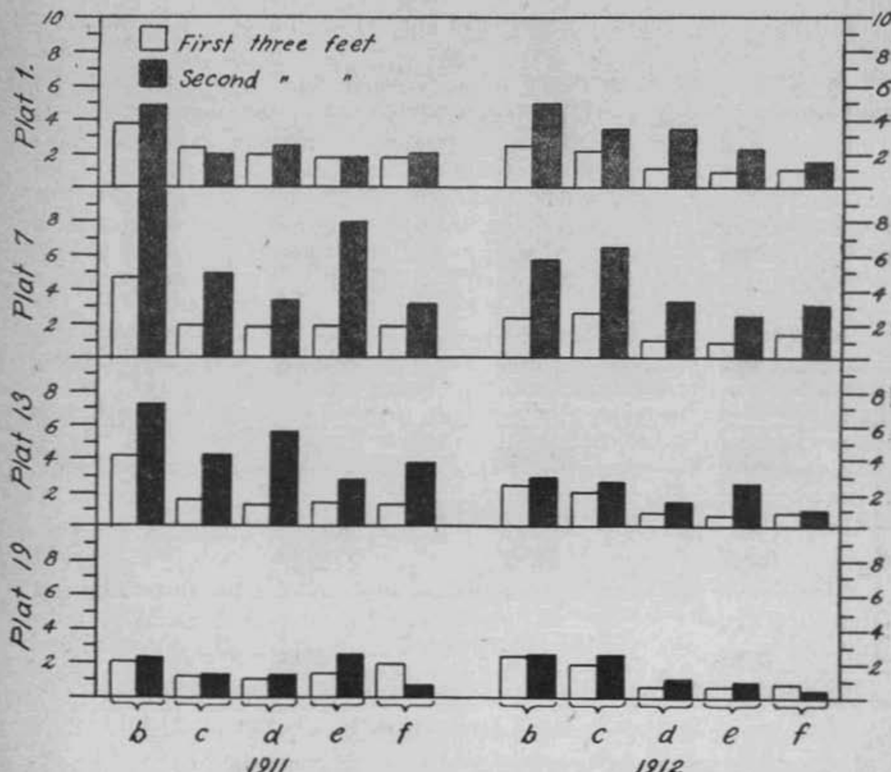
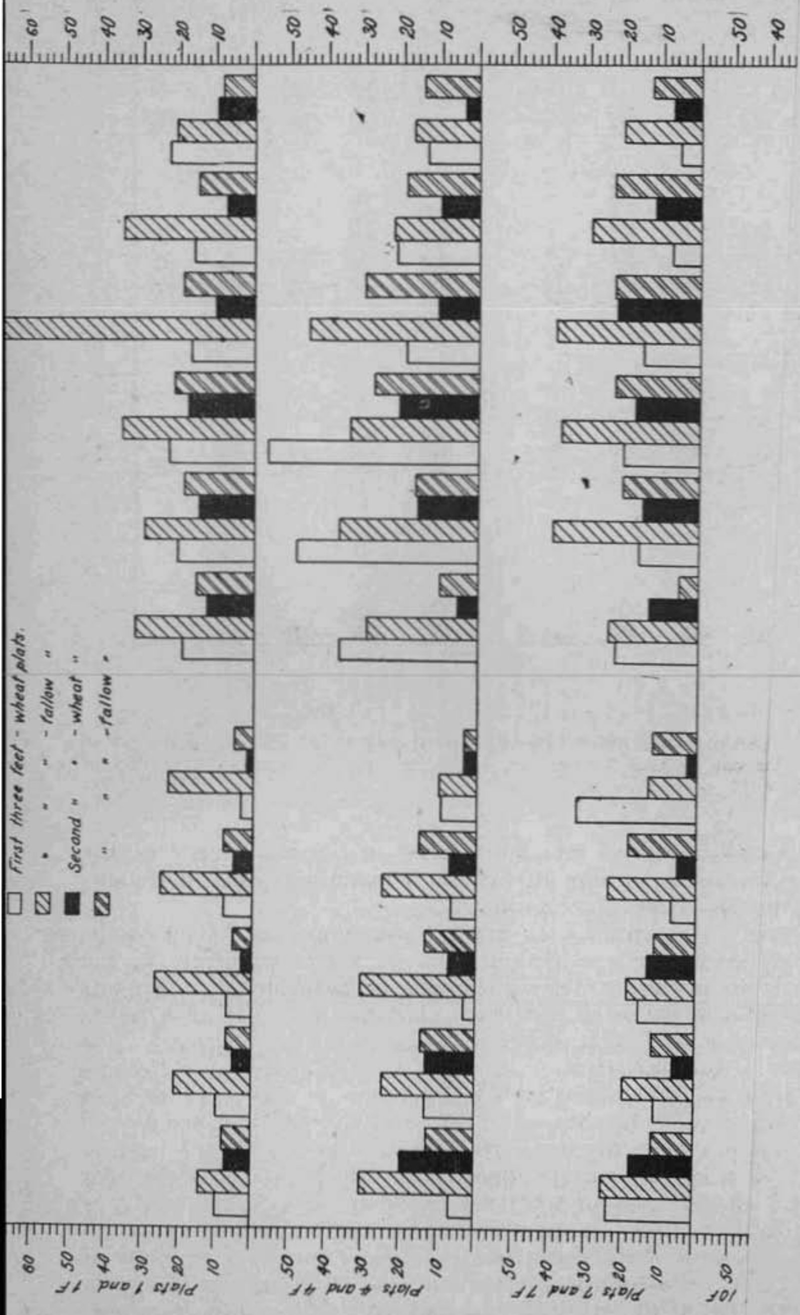


FIG. 10. NO_3 in parts per million on dry soil averaged for periods of 15 and 16 days in June, July and August for the first three feet and the second three feet of plats 1, 7, 13, and 19, years 1911 and 1912.

low level of protein reached lies, we believe, in the inadequacy of the soil's content of available nitrogen to permit of maximum yields and maximum elaboration and storage of protein.

In 1913 the soil conditions for growth were modified. The conditions that year made for a superabundance of available nitrate in the wheat plats and the wheat profited accordingly, as shown by the enormous increase in protein in the product of each plat that year. In each series the plat given maximum irrigation produced grain lowest in protein. For an explanation of this occurrence one might with reason look for a lessened activity on the part of nitrifying organisms in the presence of a greater amount of soil moisture or in the leaching effect of the larger applications of water operating to remove the nitrates beyond the feeding range of the plant roots. An examination of the nitrate data for that year, however, lends no support whatever to the first hypothesis and very little, if any, to the second. It may be that the explanation lies in a decreased transpiration of the wheat plants because of excessive amounts of soil moisture. The substantially greater amounts of protein in the grain of all plats over that of the original seed and over that grown from cor-



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esponding plats of the preceding year answer in the negative the ques-ion raised at the beginning of the work relative to cumulative and perm-nent effects of large amounts of water on the protein content of wheat. t is perfectly apparent that however low wheat may go in its content of rotein because of adverse conditions of growth or because of conditions hich do not favor the elaboration of protein, it responds immediately to avorable conditions of growth by the elaboration and storage of max-num quantities of protein when given access to substantial amounts of vailable soil nitrogen.

In 1914 Minnesota Bluestem and Glyndon Fife were substituted for alouse Bluestem and Little Club. For that year and the next two years, we may judge from the nitrate data for those years, conditions of rowth were such as to insure for the growing wheat plants a liberal sup-y of available soil nitrogen, at least during the early growing periods. ith normal irrigation and less, remarkably high percentages of protein the harvested grain were shown each year. In each series maximum rigation produced grain of lowest protein content but always grain suf-iently rich in protein to insure for it a high standing. In a final attempt establish a definite and fundamental reason for this decline in protein om the application of the maximum amounts of water in soils rich in trate nitrogen, the nitrate data for the three years were very critcally amined. The data for 1914 and 1916 support, to some extent, the no-n that heavy applications of water tend to remove nitrate nitrogen from e feeding range of plant roots. Figure 11 is based upon the nitrate ta for these two years averaged for the first three and the second three et for whatever determinations were made in 15 and 16-day periods in ay, June, July and in early August. Unmistakable proof, however, of e leaching effect of the irrigation water upon the nitrates in the surface t of soil to the detriment of the growing plant is not in our judgment parent. A fundamental reason for the falling away of protein when ex-sive applications of water are given under the conditions noted has not been established.

At the end of seven years of growth with an average annual applica-n of irrigation water exceeding 2¾ acre-feet, the Sonora was decidedly her in protein than the original seed. Minnesota Bluestem and Glyn-n Fife with normal irrigation developed greater weight and at the same e substantially greater amounts of protein than were contained in the ginal Minnesota-grown seed. Moreover, the maximum irrigation given se two varieties failed to lower the protein content below that of original seed and to reduce the average protein for the three years w the average for the same varieties grown the same years at Uni-sity Farm, Minnesota. *

Bulletin No. 103, Idaho Experiment Station.

CONCLUSIONS

Since this investigation was conducted under field conditions that are identical with those which confront the settler on the raw lands of our irrigation projects on the Snake River plains, the results secured and our field observations in connection with them warrant several very definite conclusions regarding the possibility of growing a better quality of wheat for milling purposes with irrigation.

1. The general run of wheat grown with irrigation in that part of the intermountain section represented by the snake River plains is soft and starchy and unquestionably low in protein, therefore, of relatively low value for flour-making purposes.

2. Growers and millers are not right, however, in assuming that low-protein wheat necessarily results from the practice of irrigation. As a matter of fact irrigation is not the controlling factor in determining what shall be the protein content of the harvested grain.

3. In the course of their development irrigation projects produce and market large amounts of wheat from practically raw sagebrush soils—soils whose content of available nitrogen is always low. Regardless of the amount of irrigation water used, wheats from soils of that kind are invariably low in protein.

4. A much better quality of grain is possible as soon as grain is brought into rotation with alfalfa or red clover. The sod of these legumes turned under and the activity of nitrifying organisms provide for the growing wheat plants a substantitally greater supply of available nitrogen. Protein elaboration is stimulated somewhat in proportion. Carelessness in the use of irrigation water may offset to some extent, however, the advantage of otherwise favorable soil conditions for maximum protein elaboration. The climate of the irrigated sections is favorable. The essential soil conditions for high protein wheat are easily within the control of the irrigation farmer. Fortunately soil conditions which favor maximum protein elaboration are also those which favor maximum production.

5. However, "deteriorated" in quality a really good variety of milling wheat may be from growth with irrigation on soils depleted of available nitrogen, seed from it will respond with the production of maximum amounts of protein for the variety if given the favorable conditions of growth indicated in the preceding paragraph. There is nothing to be gained by the irrigation farmer by importing seed of that variety from distant localities.

6. There is much to be gained, however, by irrigation farmers from the more rigid selection of varieties on the basis of well recognized milling value. The notion that low-protein wheat and irrigation practice are inseparably linked is largely responsible for the carelessness so frequently shown by irrigation farmers in the selection of varieties. Bushel for bushel the hard red spring wheats at their best command a somewhat higher price, and when used properly, can be made to go much further than the soft starchy varieties in feeding a hungry world. In the light of this investigation we would not question the ability of the careful irrigation farmer to grow the highest quality of the hard red spring wheats. In the absence

of positive proof that the hard red spring varieties will hold their own from the standpoint of production in comparison with the better classes of white wheats, always popular with the irrigation farmer, we do not wish at this time to urge their introduction and growth except for trial. In this connection it is well to emphasize the fact that the white wheats will also respond to favorable conditions for protein elaboration. White wheats rich in protein, we venture, will command a premium among millers in the intermountain states if grown in sufficiently large quantities to command their attention.

7. Unquestionably there are large amounts of high-protein wheats being grown now on the older irrigation projects under conditions we have outlined above. It is doubtful if the growers realize on them as they should because they are lost in the larger amounts of low-protein wheats grown on soils not yet brought into rotation with alfalfa, red clover, or other legumes. When the requirements for high-protein wheats are more generally understood, and the irrigation projects reach that point in their development where there is no more raw sagebrush land given over to wheat production, and undesirable milling varieties have been eliminated, this matter will right itself. In the meantime growers on any project who really desire to grow high-protein wheat might with profit to themselves form an organization that would force the attention of millers to their product.

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