EFFECT OF ENVIRONMENT ON YIELD AND PROTEIN CONTENT OF WHEAT IN KANSAS

by

BYRD COLLINS CURTIS

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TABLE OF CONTENTS

INTRODUCTION

Yield and protein content are the most important characters of winter wheat, the former because of its direct value to the farmers and the latter because of its relation to quality. The complex of factors included in environment importantly affect the growth and yield of plants as well as the composition of the plant. Probably the most important and yet the most complex phase of the environment of plants is climate which is generally recognized to affect both yield and protein content of wheat. The factors of climate that most affect winter wheat are precipitation, relative humidity, and temperature. High temperatures are usually associated with low rainfall, and high rainfall in spring and early summer are usually accompanied by low temperatures. High evaporation is an effect of low humidity and low humidity is a result of low rainfall.

Climate may also affect yield and protein content of winter wheat indirectly in that it is an important factor in disease development, particularly the rusts. During warm wet springs rust may become a limiting factor in the production of wheat.

Hildreth et al. (13) reports that in one way or another, temperature influences every chemical and physical process connected with plants; solubility of minerals; absorption of water, gasses, and other mineral nutrients; diffusion; synthesis - as well as the vital processes such as growth and development. The effects of high temperatures on plants are difficult to separate from the usually accompanying factors of high light intensity and rapid transpiration. Most crops make their growth during the portion of the year that the temperature remains within certain limits, maturing, dying, or becoming dormant when the temperature falls too low or rises too high.

Investigators are generally agreed that most data now available are inadequate for deductions concerning the influence of factors of environment on crop growth and yield. Most forms of meterological data are quite complete for certain studies but for studies relating to crop production they are not.

The present study is concerned with marked deviations of protein content and yield of winter wheat from year to year and in some cases marked deviations among several varieties during the same year. The interrelationship between protein content and yield of the crop and the incidence of temperature, moisture, and other factors are too complex to warrant very accurate predictions relative to these two characters even when knowledge of weather conditions are available. However, certain instances can be pointed out where specific factors of environment are responsible for deviations of yield or protein content of winter wheat and some general associations can be shown.

REVIEW OF LITERATURE

The literature on the correlation between weather and wheat production is too voluminous to review in detail. A selected bibliography of the influence of weather on crops was published by Hannay (11) in 1931. A review of the literature indicates that in general the climatological data used in past investigations were inadequate for a thorough understanding of the problems studied. For certain studies not related to crop production the present methods of recording climatological data are quite suitable. However, in order that the effects of weather on crop production be fully apprehended a more critical examination of the daily weather variants is essential. There is a need for basic knowledge concerning the influence of weather factors on plant growth.

Sando (33) found a significant negative correlation between rainfall and yields of wheat grown at the Maryland Agricultural Experiment Station. He noted that in general, yields above normal were associated with subnormal rainfall for the months of March and May. No definite relation appeared to exist between yields of the varieties studied and other climatic factors such as snowfall, temperature, and sunshine. Welton and Morris (43) studied the effect of rainfall on wheat yields in Ohio and concluded that subnormal rainfall induced higher yields of wheat. They found that November and April are the two individual months in which the subnormal rainfall appears to be the most beneficial. They concluded that the exceptionally high yields, which were occasionally obtained, represented what wheat could and probably would do every year, barring the interference of other factors, providing the rainfall were a little less.

Dunham (8) studied the effect of environment on wheat, oats, and flax grown at Crookston, Minnesota during a period of four years, 1934 to 1937. He found an apparent association between yield and precipitation for wheat, oats, and flax in 1935 and 1936, but not in 1937 and 1934 unless the precipitation during the preceding year of fallow was disregarded. In summation of a 30 year study of the influence of rainfall on wheat yields in South Australia (Victoria), Richardson (31) reported that yield of wheat is very largely determined by rainfall. Throughout the entire 30 year period the wheat growers of Victoria secured on the average 0.89 bushels of wheat for every inch of winter rainfall. Call and Hallsted (6) reported that moisture is the limiting factor in wheat production in western Kansas. According to Howard (15), the distribution of rainfall during the growing season is more important than the total amount.

In a statistical study of data covering a total of 387 crop years at 19 field stations in the Great Plains, Cole (17) found that spring wheat yields were positively associated with annual rainfall. He obtained coefficients of correlation between precipitation and average yield ranging from 0.61 to 0.90 at the several stations.

The effect of environment on protein content of wheat has been the object of many correlation studies. Most investigators are agreed that climate exhibits greater influence on protein content of wheat grain than any other one factor of environment (3, 9, 12, 13, 33, 34, 35, 37, 40).

Waldron, Harris, Stoa, and Sibbitt (42) state that protein content of wheat grown in moist climates is generally less in quantity than in wheats grown in regions of less rainfall with relatively high temperatures at certain periods in the cycle of growth. Waldron (40) made a statistical study on 25 varieties of spring wheat grown under conditions of high temperature and low moisture. He found that when wheat was grown under those conditions, high protein content was gained at the expense of other characters such as yield and test weight. Shaw (34) shows that the protein content of wheat is influenced by the percentage of sunshine which the grain receives during its period of growth and to an even greater extent by the rainfall during the latter growing period of the crop. He stipulates that the protein content of the wheat is largely influenced by the water content of the soil, and the effect of either irrigation or rainfall is to lower its protein content. Hopkins (14) reported that the greatest effect on nitrogen content of wheat is caused by the rainfall in the early part of the growing season.

Thatcher (39) pointed out that a study of the wheat belt of Washington indicated that "under conditions of uniform soil, growing season, distribution of annual rainfall, elevation, etc., with the total annual rainfall the only variable, the average protein content of wheat varies inversely with the total rainfall received." After a 28 year investigation of seasonal effects on wheat quality, Shutt (35) concluded that the production of soft, low protein wheat was associated with comparatively low temperature and a high soil moisture content during the latter weeks of the season, and conversely that high protein grain would follow from high maximum temperatures and a comparatively dry soil during the same period. Shutt and Hamilton (36) made somewhat the same conclusions in an earlier publication. Bayfield (3) studied the effect of climate directly from 5 day averages for mean daily temperatures and precipitation during the 50 day period preceding harvesting. He found that temperature apparently acted only as a modifying factor upon precipitation, for during the 50 day period studied, it produced much less effect on protein content than rainfall. Rainfall was found to influence the amount of protein in wheat when it occurred during a 10-15 day interval during and just preceding the heading period. Precipitation at this time was associated with a decrease in protein.

Many investigators agree that diseases may affect the protein content of the grain, especially leaf and stem rusts when they are present in epiphytotic conditions. Waldron (41) found that leaf rust reduced the protein content of two hard red spring wheats that were rust susceptible. Peturson, Newton, and Whiteside (29) noted similar effects of leaf rusts on protein content of grain.

Johnston and Miller (18) found that leaf rust reduced the average yield of susceptible varieties from 42.4 to 93.8 percent depending upon the length of the infection period. Reductions in grain yields were due primarily to the production of fewer kernels by rusted plants and secondarily to reduced kernel weight.

MATERIALS AND METHODS

Variety tests of hard red winter wheat grown in 1/50th acre plots on the Agronomy Farm at Manhattan and on the Fort Hays Branch Experiment Station provided information for this study. The author collected data on the crop at Manhattan in 1950.

Similar data collected in previous years by Laude (21) and others at Manhattan and by Swanson (37) at Hays were used to supplement the data collected in 1950. Data at Manhattan were available back to 1911, and at Hays back to 1925 except 1929, '35, '37, '38, and '40. Since not all of the varieties were grown throughout the entire period the data used included those from Turkey and Kanred at Manhattan and from Turkey at Hays.

Additional data were obtained from reports of the Kansas State Board of Agriculture and Bureau of Agricultural Economics cooperating on wheat yields in different sections of Kansas.

Test weight data was taken on all samples in the ordinary manner by using an official Boerner weight per bushel apparatus.

Data on protein content of the wheat were obtained in cooperation with the Kansas State College Milling Department. Samples were sent to the Milling Department each year for protein analysis. The data were reported as percent of protein in the grain.

Leaf and stem rust data were collected at Manhattan in cooperation with C. O. Johnston, U. S. D. A. Plant Pathologist, Kansas State College. Similar data were collected at Hays by A. F. Swanson.

Yield data were collected in 1950 and other recent years by harvesting the entire test plot with the combine. In earlier years, the crop was cut and bound with a grain binder and threshed with a plot thresher.

DISCUSSION OF RESULTS

Relation Between Rainfall and Wheat Yield

At Manhattan. Predicting yields of wheat from rainfall data is hazardous even though it is known that rainfall is of foremost importance in the production of wheat, in areas of low precipitation. Rainfall interacts with the other factors of climate in producing its ultimate effect on yield. Dunham (8) reports that there is a tendency for the association of yield and precipitation to be more apparent than real since the temperature factor is important. Rainfall may influence yield of wheat both directly and indirectly; directly by supplying adequate amounts of water for normal physiological processes of the plant; indirectly by modifying disease development and lodging. Salmon (32) states that high rainfall, especially when accompanied by high temperatures, is unfavorable for wheat, chiefly because these conditions favor development of wheat diseases. High rainfall also promotes lodging and interferes with harvesting and threshing of the crop.

The frequency as well as the amount of rainfall may be of consequence in wheat production. Table 1 shows the frequency of rainfall, amount of rainfall, and a rainfall-frequency index for the spring growing season and the average yield of wheat for each year from 1911 to and including 1950 at Manhattan, Kansas. The rainfall frequency data were obtained by counting the number of days in which there was .01 inch or more of rainfall from March 1, the arbitrary starting date for the spring growing season for wheat at Manhattan, to the ripening date of the grain. The yield data were obtained by averaging together the yields of Kanred and Turkey wheat, two similar varieties that were grown throughout the entire period.

In general the data in Table 1 indicate that as the frequency of rainfall increases the yield of wheat decreases. Figure 1 shows the relation between frequency of rainfall and yield. The diagram is divided into four quadrants by drawing the axes intersecting the scales at the mean values of their respective factors. These quadrants have been numbered I to IV in clockwise sequence, beginning with the upper right quartile. Quadrants II and IV contain 15 dots each while quadrants I and III contain only 6 and 4 dots, respectively. Thus, all except 10 of the 40 dots lie in the second and fourth quadrants indicating that there is a negative correlation between frequency of rainfall and yield. A high frequency of rainfall is somewhat associated with low yields and low rainfall frequency with high yields.

There is a general tendency for the frequency of rainfall to be directly associated with the amount of rainfall during the spring growing season at Manhattan. The association is reported in Table 1 and shown graphically in Fig. 2 for the 40 year period, 1911 to 1950. The correlation between frequency and amount of rainfall from March 1 to ripening date of the grain was +0.616. The average increase in rainfall for each additional rain was 0.428 inches.

Figure 3 reveals that the total amount of rainfall during the spring growing season is associated with yield in somewhat the

Table 1. Data on rainfall during the spring growing season, March 1 to ripening date of grain, and average yield of Kanred and Turkey wheat grown at Manhattan from 1911 to 1950.

Year	Rainfall			Yield
	Frequency	Amount inches	Rainfall-frequency index	bu.
1911	13	4.92	17.92	32.9
1912	33	13.35	46.35	16.5
1913	26	11.32	37.32	35.4
1914	29	8.01	37.01	35.7
1915	36	20.34	56.34	24.5
1916	38	17.42	55.42	27.9
1917	36	14.13	50.13	14.9
1918	27	10.68	37.68	19.0
1919	38	16.14	54.14	20.8
1920	34	7.87	41.87	30.3
1921	25	7.69	34.69	32.2
1922	35	12.79	47.79	31.1
1923	37	13.09	50.09	36.0
1924	31	8.09	39.09	33.4
1925	29	10.09	39.09	36.8
1926	31	5.76	36.76	35.5
1927	32	18.62	50.62	34.0
1928	26	9.11	35.11	45.6
1929	30	17.74	47.74	13.8
1930	24	18.79	42.79	33.0
1931	28	10.51	38.51	46.6
1932	28	9.09	37.09	46.7
1933	18	6.25	24.25	34.3
1934	13	5.68	18.68	30.6
1935	42	15.67	57.67	26.9
1936	21	8.12	29.12	33.2
1937	35	8.08	43.08	42.4
1938	36	14.89	50.89	13.8
1939	29	14.04	43.07	17.6
1940	32	11.89	43.89	25.0
1941	33	9.93	42.20	20.2
1942	37	12.11	49.11	19.9
1943	35	16.02	51.78	21.7
1944	43	17.61	62.83	20.7
1945	36	22.21	60.47	27.4
1946	29	7.92	36.92	25.5
1947	52	17.95	71.23	25.7
1948	37	21.56	58.56	30.8
1949	41	12.51	53.51	24.2
1950	28	9.43	37.95	39.2
Total	1263	497.42	1768.76	1167.7

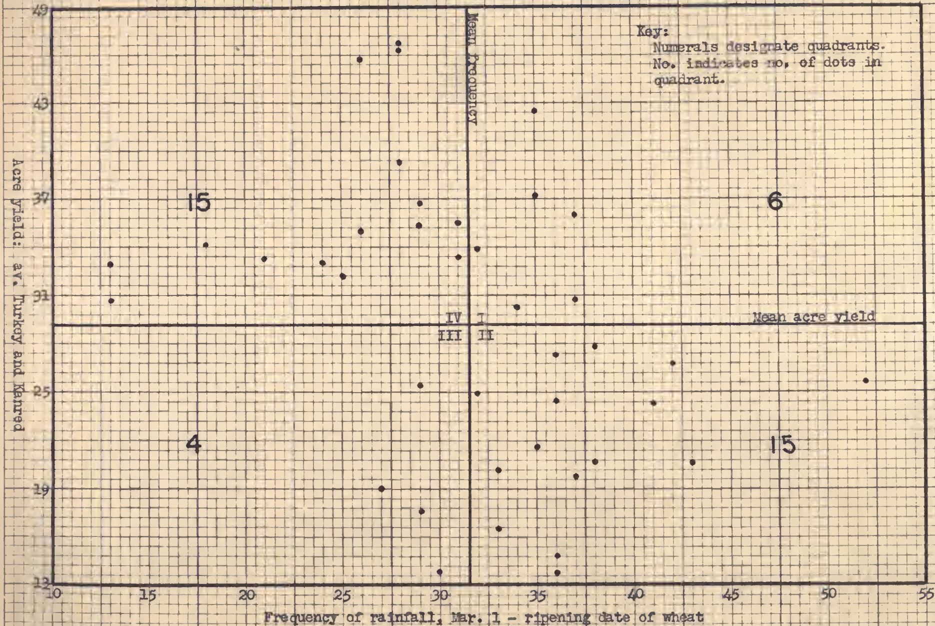

Fig. 1. Relation between frequency of rainfall during the spring growing season and yield of wheat grown at Manhattan from 1911 to 1950.

same manner as the frequency of rainfall although the relationship is not as close. Since both rainfall frequency and amount are similar in their effect on yield it appears logical that they may be combined to form a single rainfall factor for use in determining wheat yields. A rainfall-frequency index was obtained by adding together the total amount of rainfall and the number of rains which occurred during the spring growing season. These data are shown in Table 1. Figure 4 pictures the rainfall-frequency index factor as it is related to yields. All except 9 of the 40 dots fall into quadrants II and IV, signifying an inverse relation of yield on the rainfall-frequency index. The association does not appear as close as that of the frequency of rainfall on yield since the scatter of dots is more widespread in Fig. 4 than in Fig. 2, but it does point out that both the frequency and amount of rainfall do conspire in partial determination of yields of wheat.

In the Western One-third of Kansas. The western one-third of Kansas is characterized by relatively high daily maximum temperatures in late spring and summer months, low rainfall, high winds in the winter and spring months, and low humidity. Flora (9) reports that the wind velocities in the south central and western counties are approximately a third greater than in eastern counties. The low relative humidity of the western part of the state coupled with the high winds account for a rapid rate of evaporation.

In general, soils in western Kansas are fertile and well drained which is conducive to wheat production if soil moisture

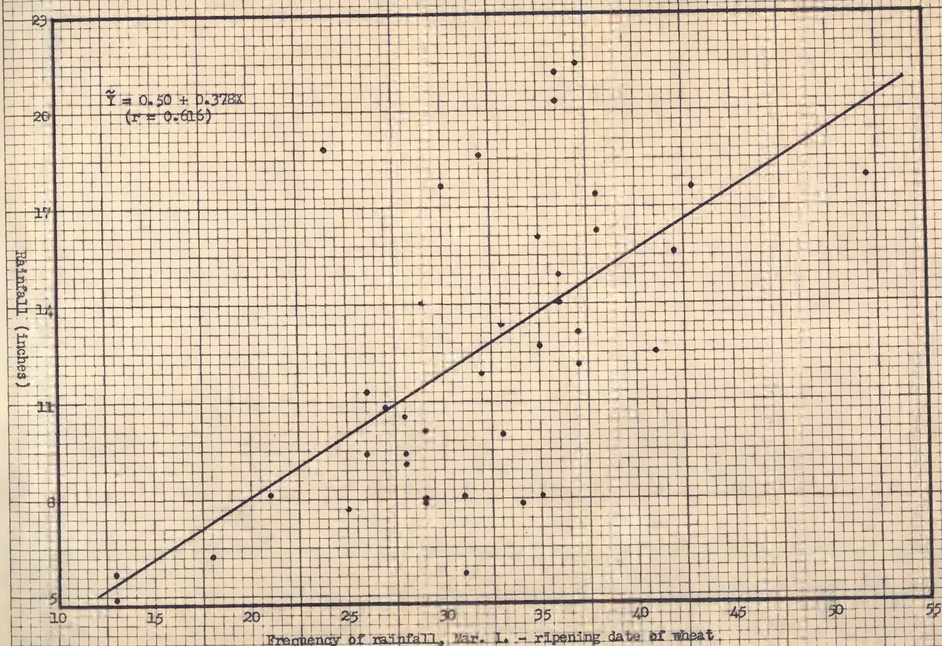

Fig. 2. Relation between amount and frequency of rainfall during the spring growing season at Manhattan from 1911 to 1950.

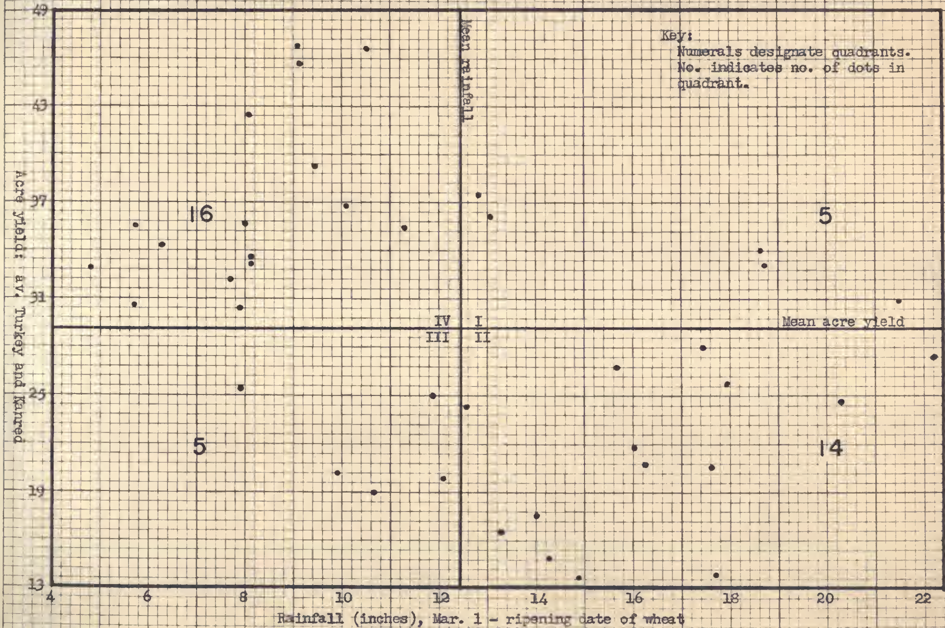

Fig. 3. Relation between rainfall during the spring growing season and yield of wheat grown at Manhattan from 1911 to 1950.

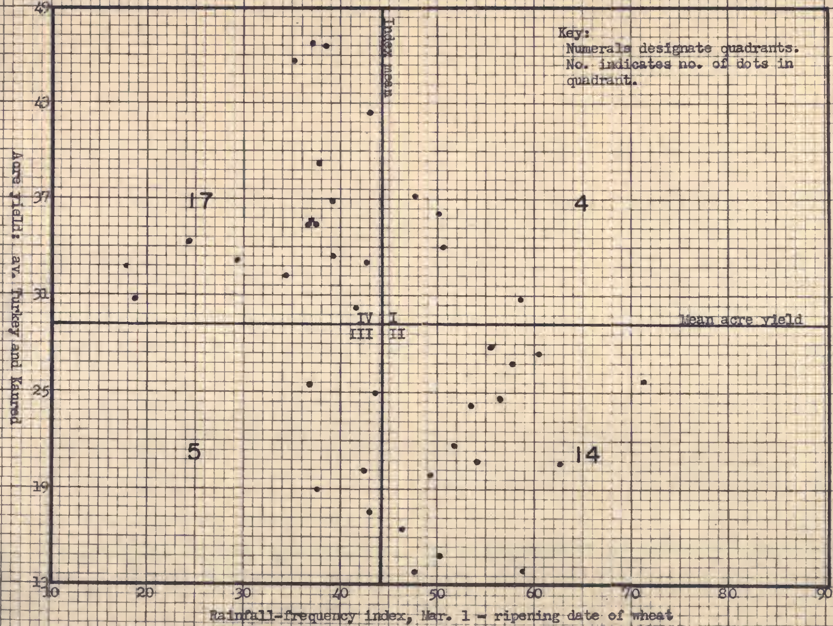

Fig. 4. Relation between a rainfall-frequency index and yield of wheat grown at Manhattan from 1911 to 1950.

is available (6). The average acre yield of wheat and the amount of rainfall for the western one-third of the state are shown in Table 2 for each year from 1926 to and including 1950. The average annual yield was computed by dividing the total yield in bushels by the total number of acres harvested. The amount of rainfall recorded is that which occurred during the wheat season, July 1 to May 31. With very few exceptions, the larger portion of the Kansas wheat crop is harvested during the month of June.

The relation between amount of rainfall and yield is shown in Fig. 5. The correlation coefficient between rainfall from July 1 and May 31 and acre yield of wheat was +0.817. The average increase in yield for each one inch increase in rainfall was 1.18 bushels per acre.

The association between yield and rainfall in western Kansas then is the reverse of that at Manhattan. The reason probably lies in the differences in humidity since the difference in the average temperatures at the respective places is very small. Temperature data reported by Flora (9) show that for any one month the differences in average temperature at Manhattan and the western one-third of Kansas are less than 3 degrees. His data also show that the average annual temperature for the western one-third of the state during the period, 1887 to 1945, was 53.7° F. and for Manhattan during the period, 1857 to 1946, was 55.3° F. The relative humidity during the spring months is from 4 to 15 percent higher in the eastern than in the western part of the state.

As already pointed out, in years of high rainfall at Manhattan, a humid condition exists which is unsuitable for producing a high

Table 2. Seasonal rainfall, July 1 to May 31, and wheat yield data for the western one-third and the eastern one-third of Kansas.

Year	Rainfall inches	Yield bushels	Year	Rainfall inches	Yield bushels
Western One-third			Eastern One-third		
1926	16.01	12.2	1926	25.48	18.5
1927	13.03	4.6	1927	39.62	14.1
1928	18.82	17.1	1928	31.31	16.5
1929	17.43	14.2	1929	39.26	10.2
1930	16.92	13.5	1930	25.18	15.7
1931	20.72	17.0	1931	25.90	21.1
1932	13.55	9.3	1932	32.32	13.9
1933	11.98	6.2	1933	26.94	15.0
1934	14.24	5.5	1934	25.05	15.4
1935	11.17	4.6	1935	31.55	13.4
1936	12.95	6.9	1936	26.86	15.3
1937	9.49	4.7	1937	25.89	16.6
1938	15.10	9.4	1938	30.36	14.1
1939	12.69	5.2	1939	23.39	16.5
1940	11.45	7.7	1940	22.34	19.4
1941	18.80	14.6	1941	29.36	11.6
1942	21.41	21.1	1942	40.40	14.3
1943	15.73	14.1	1943	34.65	13.0
1944	21.54	17.7	1944	32.18	16.1
1945	17.86	19.0	1945	42.72	13.7
1946	14.68	15.8	1946	29.93	16.6
1947	24.46	22.3	1947	33.01	19.1
1948	13.40	17.7	1948	26.10	20.8
1949	20.28	11.4	1949	35.68	16.5
1950	13.62	12.7	1950	27.14	23.3
Total	397.33	304.5		762.62	400.7
Average	15.89	12.18		30.50	16.03

r= −0.536 Eastern One-third   r=+0.817 Western One-third
Significant at the .01 level.

yield of wheat. Infectuous diseases are less likely to occur in the western part of the state than in the more humid environment at Manhattan. For example, in 1944 and 1948, a considerable amount of leaf and stem rust was reported at Manhattan while at Colby and Garden City, located in western Kansas, no rust was

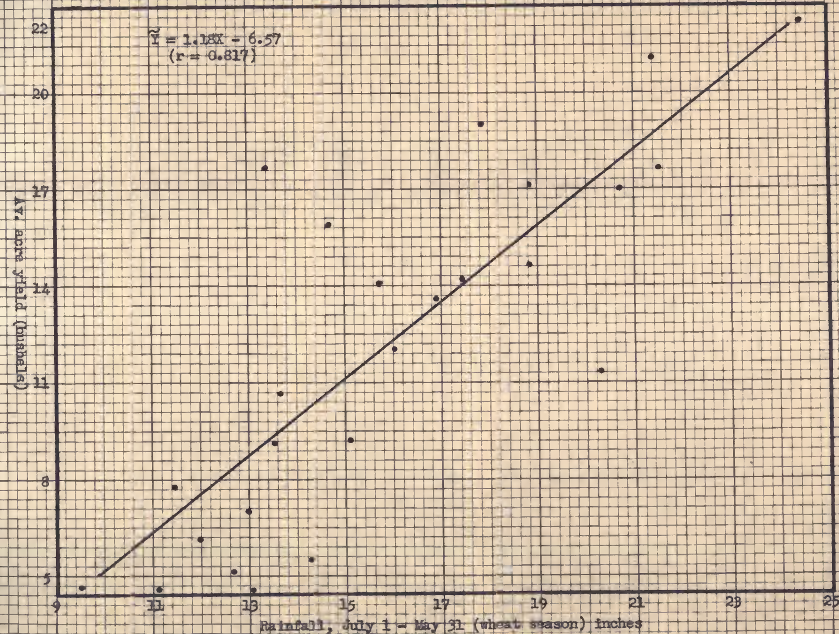

Fig. 5. Yield of wheat in the western one-third of Kansas in relation to rainfall.

reported (21).

Different fertility levels of the soil at Manhattan and Hays may be of some consequence in causing a difference in the relation between rainfall and yield at the two places. In general, soils in the western area of Kansas are more fertile than soils at Manhattan. In years of high rainfall, wheat grown on soils in western Kansas should theoritically outyield wheat grown on soils at Manhattan. However, the soil often is not the limiting factor in wheat production at either location.

__In the Eastern One-third of Kansas__. The eastarn one-third of the state is characterized by relatively high daily maximum temperatures in late spring and summer, high rainfall, and a rather high relative humidity.

The soils in eastern Kansas are generally less fertile than soils in the western part of the state, however, the soil in the eastern part of the state will produce good yields of wheat if other environmental factors are favorable.

The average acre yield of wheat in the eastern one-third of Kansas from 1926 to 1950 was 16.0 bushels compared with 12.2 bushels for the western one-third of the state for the same period. These data are shown in Table 2. The average amount of rainfall in the eastern one-third of the state during the period, July 1 to May 31, was 30.50 inches compared with 15.89 inches for the same period in the western one-third of the state. A highly significant correlation coefficient of -0.536 was found between rainfall and yield of wheat in the eastern one-third of the state. This relation is the reverse of the rainfall yield in the western one-third of the state. Apparently, then, wheat requires subnormal rainfall in producing maximum yields.

Relation Between Weather and Protein Content of Wheat

Protein content of wheat is a factor of quality in that protein has been found to be directly correlated with strength of dough and loaf volume of bread. There has been some controversy regarding the environmental causes of annual fluctuations of the protein content of wheat, however, most investigators agree that climate is of utmost importance in regulating the protein content. Le Clerc (22) reports that climate is such a dominant factor in influencing the composition of wheat that soil and seed play only a small part. The soil although not as important as climate, undoubtedly, does exert an influence on the protein content of wheat. The soil must contain a considerable amount of available nitrogen in order to produce wheat containing a high percent of protein.

The present study is concerned with marked deviations in protein content from year to year at Hays, Kansas and Manhattan, Kansas. The data were studied independently at each station in order to reach a concept of the effects of climate at each locality. Data regarding yield, test weight, and protein content were collected on the variety Turkey which was grown at Hays during the period, 1925 to 1950. Protein data, however were unavailable for years 1929, '35, '37, '38, and '40. Similar data were obtained at Manhattan on wheat varieties, Kanred and Turkey, grown during the period, 1912 to 1950. These data are shown in Tables 3 and 4,

Table 3. Data on rainfall and summation of daily maximum temperatures exceeding 80°F. for different periods of growth of Turkey wheat grown at Hays from 1925 to 1950, excluding years 1929, '35, '37, '38, and '40. The table also includes agronomic data on Turkey wheat for the same years.

Year	Period of growth										Test weight	Protein percent	Yield
	10 day prehead		First half: fruiting		Last half: fruiting		Fruiting period		10 day prehead + fruiting				
	rain	temp	rain	temp	rain	temp	rain	temp	rain	temp			
1925	0.60	7	0.05	77	0.52	119	0.57	196	1.17	201	55.5	16.8	12.9
1926	1.10	13	0.00	100	1.49	121	1.49	221	2.59	234	56.5	20.3	14.9
1927	1.03	33	3.62	58	4.47	97	8.09	155	9.12	188	60.5	14.5	9.3
1928	2.05	0	3.71	48	5.54	35	9.25	83	11.30	83	62.0	14.3	36.3
1930	1.83	0	1.67	55	2.05	115	3.72	170	5.55	170	63.5	11.9	37.3
1931	2.05	28	0.65	87	5.42	128	6.07	215	8.12	243	60.0	11.7	24.0
1932	0.17	36	3.84	51	7.20	83	11.04	134	11.21	170	63.0	11.1	34.8
1933	0.09	49	0.58	89	0.33	221	0.91	310	1.00	359	55.0	19.2	15.4
1934	0.68	56	0.84	112	0.52	233	1.36	345	2.04	401	61.0	18.5	7.9
1936	0.06	30	3.11	32	0.34	191	3.45	223	3.51	253	60.0	15.1	25.1
1939	0.15	47	1.03	133	1.95	128	2.98	261	3.13	308	60.0	17.6	11.7
1941	1.42	23	5.97	24	1.26	115	7.23	139	8.65	162	60.0	13.9	21.8
1942	0.00	71	5.84	86	4.86	47	10.70	133	10.70	204	59.0	16.7	18.7
1943	0.31	0	0.62	96	0.90	232	1.52	328	1.83	328	60.0	16.7	7.1
1944	1.15	22	1.22	30	0.04	177	1.26	207	2.41	229	58.4	15.1	28.2
1945	2.49	46	2.15	43	3.91	93	6.06	136	8.55	182	53.5	14.0	11.6
1946	1.42	8	3.50	23	2.53	247	6.03	270	7.45	278	60.4	12.8	19.6
1947	2.46	7	5.98	42	3.02	73	9.00	115	11.46	122	63.8	11.2	37.5
1948	0.00	49	4.27	72	3.17	57	7.44	129	7.44	178	57.0	14.0	34.0
1949	0.61	10	6.32	28	2.00	138	8.32	166	8.93	176	53.5	14.0	7.0
1950	0.87	36	1.76	24	0.33	212	2.09	236	2.96	272	57.0	13.9	6.9
Total	20.54	535	56.73	1310	51.85	3862	108.58	4172	129.12	4741	123.96	313.3	422.0
Av.	0.98	25.5	2.70	62.4	2.47	136.3	5.17	198.7	6.15	225.76	59.0	14.9	20.1

Table 4. Data on rainfall and summation of daily maximum temperatures exceeding 80°F. for different periods of growth of Kanred and Turkey wheat grown at Agronomy farm, Manhattan from 1911 to 1950. The table also includes agronomic data on Kanred and Turkey for the same years.

Year	Period of growth										Test weight	Protein percent	Yield
	10 day prehead		First half fruiting		Last half fruiting		Fruiting period		10 day prehead + fruiting				
	rain	temp	rain	temp	rain	temp	rain	temp	rain	temp			
1911	0.24	56	1.44	111	0.00	233	1.44	344	1.68	400	61.5	13.4	32.9
1912	0.00	97	3.19	70	0.00	95	3.19	165	3.19	262	59.4	15.1	16.5
1913	4.30	18	0.93	99	0.62	99	1.55	198	5.85	216	58.5	12.3	35.4
1914	0.85	15	0.68	123	2.36	141	3.04	264	3.89	279	59.5	12.8	35.7
1915	5.00	18	6.67	49	4.07	76	10.74	125	15.74	143	56.0	17.6	24.5
1916	1.75	16	4.58	54	3.86	94	8.44	148	10.19	164	60.0	12.0	27.9
1917	1.89	35	6.56	18	0.00	77	6.56	95	8.45	130	55.0	14.8	14.9
1918	5.05	61	0.15	66	0.00	232	0.15	298	5.20	359	60.0	14.5	19.0
1919	1.19	8	3.72	50	1.61	150	5.33	200	6.52	208	51.8	12.6	20.8
1920	0.68	23	0.42	115	0.92	127	1.34	242	2.02	265	58.1	14.5	30.3
1921	0.34	92	0.55	67	2.89	65	3.44	132	3.78	224	56.0	14.0	32.2
1922	1.99	2	0.14	38	0.00	168	0.14	206	2.13	208	58.5	11.2	37.1
1923	1.74	2	5.30	27	1.38	102	6.68	129	8.42	131	57.6	10.7	36.0
1924	0.10	19	3.14	19	1.77	150	4.91	169	5.01	188	61.6	13.3	33.4
1925	0.81	14	1.44	75	2.09	125	3.53	200	4.34	214	60.5	12.3	36.8
1926	0.55	21	0.02	148	1.34	95	1.36	243	1.91	264	55.1	13.2	35.5
1927	0.46	19	2.02	33	5.68	71	7.70	104	8.16	123	59.3	12.6	34.0
1928	0.03	31	1.92	41	1.23	48	3.15	89	3.18	120	61.8	15.5	45.6
1929	0.46	29	5.08	43	3.76	93	8.84	136	9.30	165	51.7	13.8	13.8
1930	0.95	12	2.78	37	3.54	96	6.32	133	7.27	145	61.3	10.9	33.0

Table 4. (concl.)

Year	Period of growth										Test weight	Protein percent	Yield
	10 day prehead		First half fruiting		Last half fruiting		Fruiting period		10 day prehead + fruiting				
	rain	temp	rain	temp	rain	temp	rain	temp	rain	temp			
1931	0.87	28	0.66	60	2.67	130	3.33	190	4.20	218	60.6	11.6	46.6
1932	0.05	31	2.11	89	3.38	101	5.49	190	5.54	221	60.0	13.0	46.7
1933	0.10	50	0.74	118	0.00	278	0.74	396	.84	446	55.1	14.6	34.3
1934	0.91	45	3.26	73	0.68	291	3.94	364	4.85	409	58.7	11.7	30.6
1935	3.19	0	5.55	23	5.56	123	11.11	146	14.30	146	59.5	13.1	26.9
1936	0.17	24	3.52	71	0.18	268	3.70	339	3.87	363	59.3	13.1	33.2
1937	0.35	31	2.55	70	2.30	204	4.85	274	5.20	305	61.2	10.1	42.4
1938	3.53	11	2.82	57	2.88	114	5.70	171	9.23	183	50.1	13.3	13.8
1939	0.92	18	1.94	85	6.11	133	8.05	218	8.97	236	55.8	14.8	17.6
1940	1.04	13	1.29	66	3.95	98	5.24	164	6.28	177	60.4	11.9	25.0
1941	0.79	37	1.11	76	3.61	57	4.72	133	5.51	170	54.5	13.2	20.2
1942	2.19	0	4.11	118	8.42	65	12.53	183	14.72	183	53.1	12.9	19.9
1943	1.60	0	3.02	54	9.94	135	12.96	189	14.56	189	58.9	12.8	21.7
1944	2.10	47	1.85	73	1.17	163	2.99	236	5.09	283	54.5	12.9	20.7
1945	1.41	24	1.84	63	8.29	49	10.13	112	11.54	136	57.6	11.7	27.4
1946	1.69	1	0.33	100	1.84	155	2.17	255	3.86	256	55.7	9.4	25.5
1947	2.19	0	4.09	74	3.23	98	7.32	172	9.51	172	56.6	14.4	25.7
1948	1.59	29	1.04	87	11.62	66	12.66	153	14.25	182	56.9	10.6	30.8
1949	2.66	3	2.94	33	0.57	113	3.51	146	6.17	149	57.9	12.7	24.2
1950	0.62	16	3.62	44	2.36	188	5.98	232	6.60	248	60.2	12.5	39.2
Total	56.35	996	99.12	2717	115.88	5166	215.00	7883	271.35	8879	2309.8	517.4	1167.7
Av.	1.41	24.9	2.48	67.9	2.90	129.2	5.38	197.07	6.78	222.0	57.7	12.9	29.2

respectively, for the two stations.

Since there seemed to be little relation of annual rainfall and temperature to protein content, shorter periods of the year were considered. Three periods were taken: the 10 day preheading period, the first half of the fruiting period, and the second half of the same. Rainfall and temperature data were collected for each period at both stations. Table 3 shows these data collected from the Hays station and Table 4 shows similar data collected from the Manhattan station. The rainfall data are expressed as the number of inches that fell during each period. The temperature data are expressed as the sum of maximum daily temperatures exceeding 80° F. for each period. This manner of stating temperatures was adopted since it is suspected that the high daily extremes of temperature are more closely related to protein content than the daily averages of temperature. The base of 80° F. was used for the purpose of recording only the warm temperatures.

These data show a considerable amount of variation from one year to the next. At Hays, the amount of rain that fell during the period, 10 days prior to heading to the ripening date of the grain, ranged from 1.00 inch in 1933 to 11.46 inches in 1947. The average for this period for all years was 6.15 inches. Rainfall exceeded 10 inches during the same period in years, 1928, '32, '42, and '47, and was below 2 inches in years, 1925, '33, '43, and '50.

The amount of accumulated temperature varied somewhat inversely with the rainfall. Years which had a high amount of rainfall in the periods studied usually had a low amount of accumulated temperature during the same periods. The reverse situation existed when the rainfall was scarce.

Temperature and Protein Content of Wheat Grown at Hays. There appeared to be little association between the amount of accumulated temperature during the 10 day period preceding heading and protein percent of the grain. During the first half of the heading period, however, there seemed to be a positive association of the amount of accumulated temperature and high protein content of the grain as depicted in Fig. 6. All except 4 of the 21 dots lie in quadrants I and III. With one exception, grain produced in years when the accumulated temperature during the first half of the fruiting period exceeded 75 day degrees contained a higher than average protein percent. The association of temperature on protein content may be somewhat apparent since it has been pointed out that rainfall is associated with temperature; i.e., high temperatures are usually associated with low rainfall and low temperatures are associated with high rainfall. In general it will be noted that in years when the protein percent of the grain was high the test weight was low. In years when the protein content of the grain was higher than average, the test weight averaged 58.1 pounds per bushel while in years when the protein content of the grain was lower than average the test weight averaged 59.5 pounds per bushel. Although the difference between the two average test weights may not be significant there does appear to be some general association of test weight and protein content. Lamb and Bayfield (19) found that weight per bushel and wheat protein were in some cases definitely associated and in other cases there was very little association. Bailey and Hendel (2)

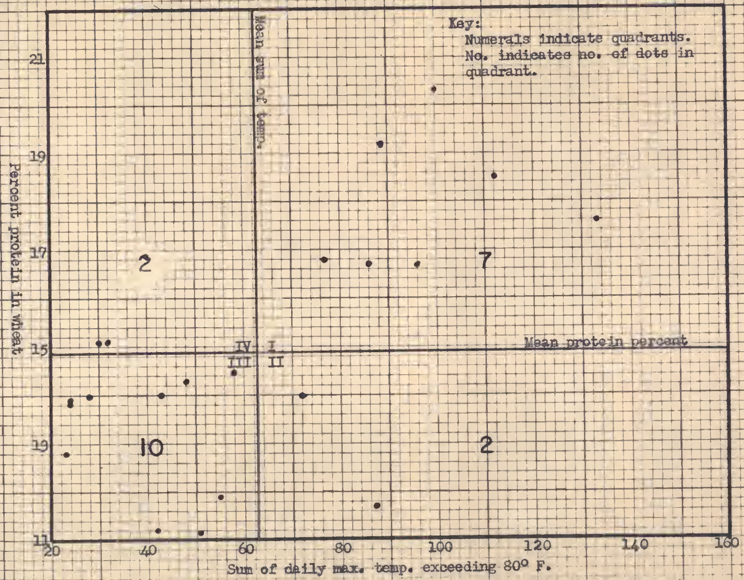

Fig. 6. Relation between temperature during first half of fruiting period and percent protein in wheat grown at Hays from 1925 to 1950 except 1929, '35, '37, '38, and '40.

found no association between the amount of crude protein and test weight.

The manner in which temperature affects the protein content is not clear. It seems logical to assume that temperatures either instigate a rapid movement of nitrogenous material into the kernel or inhibit carbohydrate formation or both. The data are inadequate to determine which of these processes predominates. Further examination in controlled laboratory experiments would be necessary in order to correctly answer such a question. Larmour (20) reports that higher temperatures might be expected to effect the ratio of nitrogenous to carbonaceous material in the developing grain by increasing the rate of respiration. Respiration is undoubtedly a factor in decreasing the amount of carbonaceous material, especially in the period just previous to the time the grain is ripe when carbohydrate formation has ceased. McGinnis and Taylor (23) report that the protein composition of wheat, oats, and barley is influenced to a marked degree by the loss of carbohydrate material during the ripening period, however, factors other than respiration or in connection with the process contribute largely to the formation of high protein grains. Woodman and Engledow (44) noted a slight increase in the percentage of nitrogen during the last week of ripening and concluded that it was caused by the loss of nonnitrogenous material in the grain by respiration rather than by the actual gain of nitrogenous material by transport. Miller (27) found that the amount of nitrogen began to increase in the heads at about the same time as it began to decrease in the stems and leaves. The amount of nitrogen in the heads increased continuously from the time of emergence of the heads until the grain was ripe. It is fairly well established that the products of photosynthesis are partially used in providing carbon skeletons for the formation of amino acids which in turn are combined into protein substances. It is also generally known that high temperatures tend to lessen the rate of photosynthesis and to increase respiration, especially if they persist for a considerable length of time. Meyer and Anderson (26) state that high temperatures may decrease the rate of photosynthesis by: destroying the chlorophyll, inactivating essential enzymes, and lessening the rate of diffusion of carbondioxide into the cells. If the amount of photosynthate is reduced by a slower rate of photosynthesis and a higher rate of respiration, and if at the same time nitrogen absorption or translocation and protein synthesis are not restricted it appears logical that the protein carbohydrate ratio would be high. Miller (27) shows evidence that nitrogen is still being absorbed by the wheat plant up until only a few days prior to date when the grain is fully ripe. Evidently then protein metabolism occurs throughout most of the fruiting period and is not affected by high temperatures in the same manner as carbohydrate metabolism.

The accumulated temperatures during the last half of the fruiting period and corresponding percentage of protein are given in Table 3. It appears that during the latter part of the fruiting period high amounts of accumulated temperature affect the protein content no differently than small amounts. This suggests that high temperatures during the latter part of the fruiting period are of less importance in determining the protein content than high temperatures during the first half of the fruiting period.

Temperature and Protein Content of Wheat Grown at Manhattan. At Manhattan, accumulated temperatures during each of the periods studied reported in Table 4 apparently were of little importance in determining the protein content of grain. Evidently the interaction of temperature with other environmental factors becomes more complex in affecting the quantity of protein in wheat grown at Manhattan than in that grown at Hays.

The average amount of accumulated temperature for the period 10 days prior to heading to the ripening date of the grain was 222.0 day degrees at Manhattan and 225.7 at Hays. The difference between the two averages is relatively small indicating that the average daily maximum temperature at both locations is approximately the same. It appears than, since Manhattan is located in a more humid area than Hays, that in humid areas temperature has a less apparent effect on protein content than in drier localities. This phenomenon could possibly be explained by the fact that in humid areas, disease is more prevalent, especially leaf rust, and in general the soils are less fertile than in the drier areas. Any one factor, climatic or otherwise, was not found to be positively or negatively associated with protein content of wheat grown at Manhattan.

Rainfall and Protein Content of Wheat Grown at Hays. Protein content is probably influenced more by rainfall than any other factor of environment. Rainfall exerts an influence on the soil moisture, relative humidity, temperature, and evaporation, all of which in some unpredictable manner help to determine the amount of protein in grain. Bailey (1) reports that the ratio of protein to starch in the wheat kernel is largely determined by moisture at the blossom and post floral period, by temperature, and by available nitrates in the soil. He relates that when the weather is cool, and the rainfall and atmospheric humidity are fairly high, and there is sufficient available soil moisture for the plant, the fruiting period tends to be prolonged. Relatively a large amount of starch tends to be deposited and a plump kernel of low protein results.

Figure 7 shows the relation of rainfall during the 10 day preheading period and percent protein of the grain. All but 5 of the 21 dots lie in quadrants II and IV indicating that there is a negative association between the amount of rainfall and protein content. In all years when the rainfall exceeded 1.15 inches for the 10 day preheading period the protein content remained below 14.5 percent which is 0.4 percent below average. With one exception the high protein grains were produced when there was less than an inch of rainfall. The one exception was the year 1926 which had 1.10 inches of rain or 0.12 inch above average during the 10 day preheading period. Grain produced in 1932 contained only 11.1 percent protein and yet the 10 day preheading period received only 0.17 inch of rain. In this particular year only a small amount of rain fell even during the 20 day preheading period. However, during the 5 day period following the heading date a total of 2.28 inches of precipitation occurred, and during the entire fruiting period a total of 11.04 inches of rain was recorded. This amount was 5.87 inches above normal for the fruiting period. Conditions during the fruiting period evidently were conducive to a high rate of carbohydrate formation thus causing a relative decrease in the protein percent. It is also interesting to note that the wheat yielded 34.8 bushels per acre in 1932 compared to much lower yields secured in 1926 and 1933 when the protein content of the grain was extremely high.

The relation of rainfall during the first half of the fruiting period and protein content of the grain is shown in Fig. 8. Although there is some inverse correlation of rainfall during this period and protein content, the association is not as close as that obtained during the 10 day preheading period. In this instance, quadrants I and III contain 2 and 4 dots respectively while quadrants II and IV contain 8 and 7 dots respectively. Thus, 6 dots lie outside of quadrants II and IV indicating an inverse relation. It should be noted that only when the amount of rainfall during this period was less than 1.05 inches did the protein content of the grain exceed 17 percent.

There was very little relation if any between rainfall during the last half of the fruiting period and protein content. However, it is shown in Fig. 9 that the amount of rainfall during the period, 10 days prior to heading to ripening date of the grain, does exert a profound influence on the protein content. An inverse relation exists since only 3 of the 21 dots lie outside quadrants II and IV. Rainfall less than 5 inches during this period is generally associated with a high percentage of protein and rainfall exceeding 5 inches is generally associated with a low percentage of protein. Olson (28) found that the percentage of nitrogen in the kernel

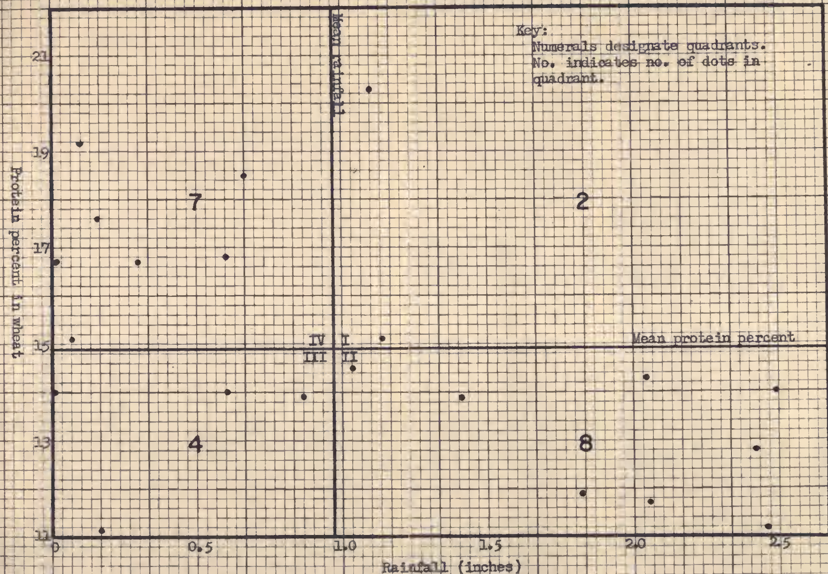

Fig. 7. Relation between rainfall during the 10 day preheading period and percent of protein in wheat grown at Hays from 1925 to 1950 except 1929, '35, '37, '38, and '40.

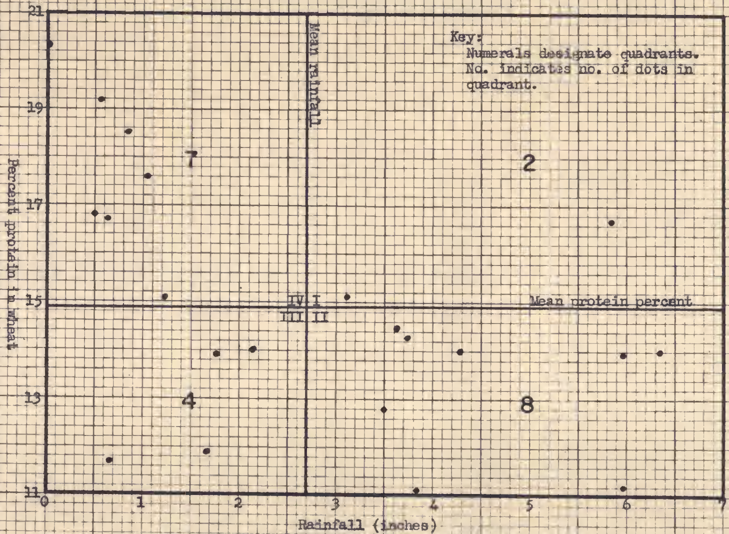

Fig. 8. Relation between rainfall during the first half of fruiting period and percent protein in wheat grown at Hays from 1925 to 1950 except 1929, '35, '37, '38, and '40.

decreased as the grain matured. Also wheat kernels showed little increase in weight due to starch being laid down after the moisture of the kernel declined to 40 percent.

In general the weather conditions at Hays during the six-week period preceding date of ripening of the grain is very important in influencing the ratio of nitrogenous to nonnitrogenous material in the grain.

No association was found to exist between rainfall in any period studied and protein content of grain produced at Manhattan.

Rainfall-temperature Index and Protein Content of Wheat Grown at Hays. It has been shown (Fig. 6) that there is a direct relation between accumulated temperature during the first half of the fruiting period and protein content at the Hays station. Also it was shown that an inverse association exists between rainfall during the same period and protein content. It appeared logical then that an index could be formulated including both temperature and rainfall for the first half of the fruiting period. Such an index was formed by subtracting the amount of rainfall from 7 and multiplying by 14.7, then adding together the product of this computation and the accumulated temperature. The amount of rainfall was subtracted from 7 in order to change the inverse relationship of rainfall on protein content to a direct relationship, and to avoid working with negative values. Multiplying the remainder (7 minus rainfall) in each case by 14.7 caused the means of these remainders and temperature summation to be approximately the same; i.e., the range of rainfall values appeared to be little different than the range of temperature values.

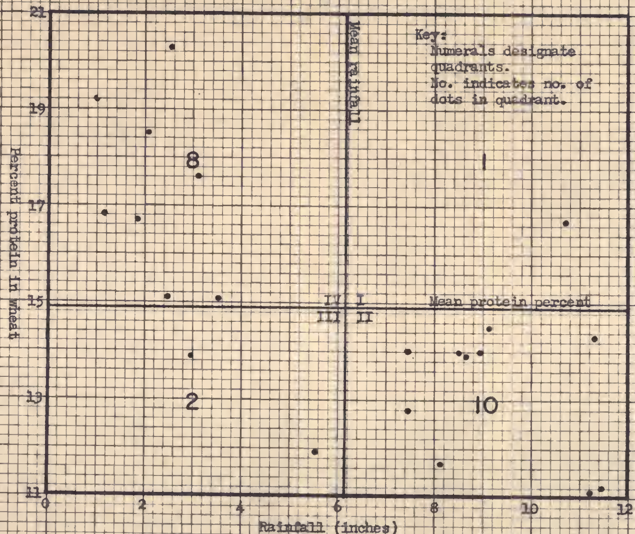

Fig. 9. Relation between rainfall during the period, 10 days prior to heading to ripening date of wheat, and percent protein in wheat grown at Hays from 1925 to 1950 except 1929, '35, '37, '38, and '40.

The relation between the rainfall-temperature index and protein content is illustrated in Fig. 10. As would be expected, a direct association exists and all but 5 of the 21 dots lie inside quadrants I and III. It is noted that the highest protein percentages occurred when the index exceeded 180. High amount of accumulated temperature combined with low amounts of rainfall evidently provide conditions that are suitable for forming a high protein-carbohydrate ratio in the wheat grain.

Yield and Protein Content of Wheat Grown at Hays and Manhattan

The association between yield and percent protein is somewhat irregular at both Manhattan and Hays as indicated by Tables 3 and 4, respectively. The relationship would appear to be essentially negative. The absolute amount of protein in the grain from a plot depends on the amount of nitrogen taken up and the proportion translocated to the kernel, and in considerable degree may be independent of the photosynthetic activity. It is possible that wheat was grown in some seasons on poor soils that were especially low in total available nitrogen. On these soils it is highly probable that wheat produced may be low in protein content and in yield. On the very rich soils, protein may be high in spite of high yields. Thus, depending upon season, there may or may not be a good correlation between yield and protein content. Malloch and Newton (25) found that when wheat is grown under conditions favoring a high yield, the protein content is usually low. In his study of wheat grown in the western United States, Fifield (10) found that yield of grain and protein content of the grain were negatively correlated. Spring wheats showed a higher negative correlation than winter wheats. Harris, Sibbitt, Waldron, and Stoa (12) stated that yields of wheat grown in North Dakota were not associated to any extent with the protein content of the grain.

Figures 11 and 12 show that there is a positive association between yield and pounds of protein produced per acre at Hays and Manhattan. High yields produced larger amounts of protein per acre than low yields. It should be noted that the scatter of points on the two diagrams is caused mainly by the differences in protein percent of the grain. Some of the difference, however, may be attributed to experimental errors in technique of harvesting the grain and determining the protein content.

Wheat may contain a high percent of protein, yet if the yield is low the total protein per acre is low and thus the crop is of small economic importance. Swanson (38) reports that the quantity of protein produced per acre is of greater importance than the quantity of protein per bushel.

Effect of Leaf Rust on Protein Content of Wheat Grown at Hays and Manhattan

Table 5 shows the protein percent of grain produced at Hays and Manhattan when leaf rust or stem rust or both were present. The table also includes the percentage of infection of the rusts and the amount of rainfall that occurred during the period, 10 days prior to heading to the ripening date of the grain, for the years

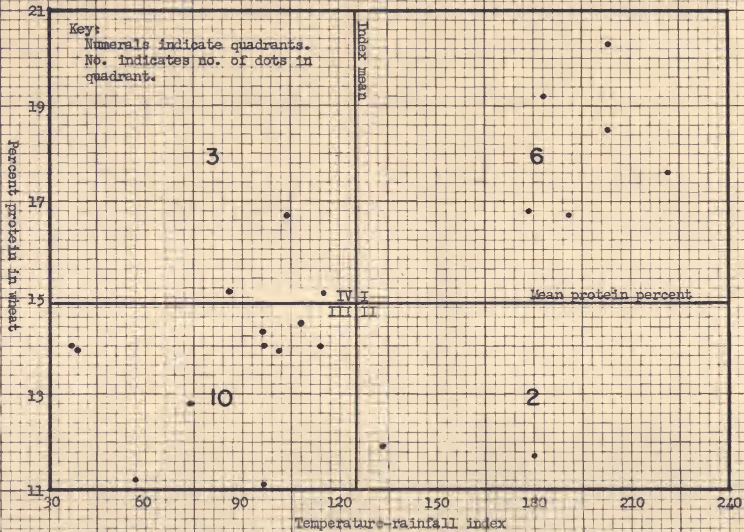

Fig. 10. Relation between a temperature-rainfall index for the first half of the fruiting period and percent protein of wheat grown at Hays from 1925 to 1950 except 1929, '35, '37, '38, and '40.

that rust was present at each location. No stem rust was reported at Hays.

The protein content of wheat grown at Hays furing years when rust occurred there was in general considerably lower than in years when rust was absent. The average protein content for years when leaf rust developed was 13.3 as compared to 15.9 percent for years when leaf rust did not develop. It happened that leaf rust occurred only when the rainfall exceeded 8 inches during the period, 10 days prior to heading to the ripening date of the grain, and only in the year 1944, when the rainfall was 10.70 inches during this period did leaf rust fail to develop. However, in this particular year, the entire 10.70 inches of rain fell during the fruiting period with the greatest amount occurring in the latter part of the fruiting period, consequently, the leaf rust had very little time in which to develop since it requires moist conditions for development.

The question whether leaf rust was actually a factor in reducing the protein content is a difficult one to answer. The lowest percentage of protein recorded at Hays was in the year 1932 when the amount of leaf rust infection was only 10 percent. In 1941 and 1949 the percentages of leaf rust infection were 85 and 80, respectively, and the protein content was 13.9 and 14.0 percent, respectively, which was about one percent below the average percent of protein. It has been pointed out earlier that excessive rainfall occurring during the period, 10 days prior to heading date to ripening date of the grain, tended to reduce the protein content of the grain. It may be possible then that higher amounts

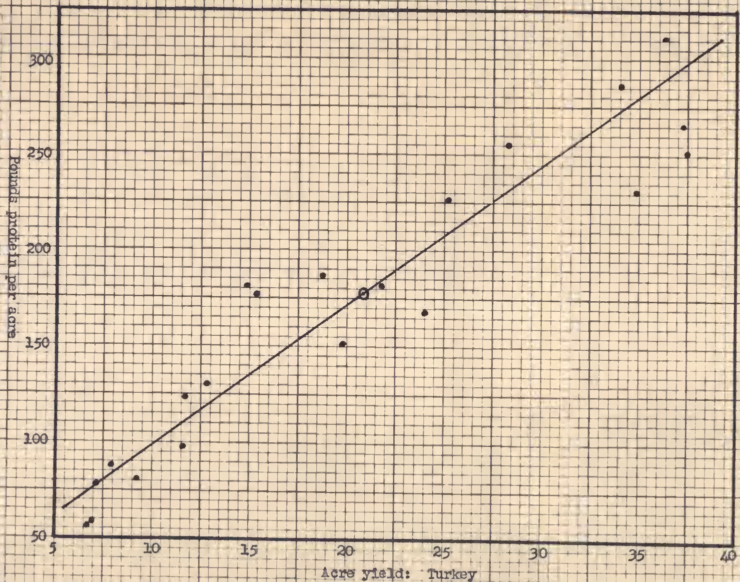

Fig. 11. Pounds of protein produced per acre in relation to yield of wheat grown at Hays from 1925 to 1950 except 1929, '35, '37, '38, and '40.

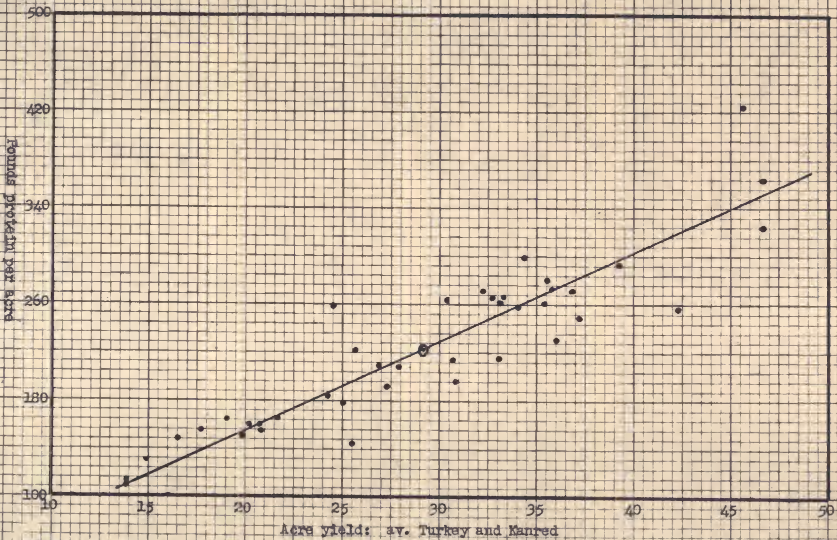

Fig. 12. Pounds of protein produced per acre in relation to yield of wheat grown at Manhattan from 1911 to 1950.

Table 5. Data on rainfall, 10 days prior to heading to ripen-date of grain, and percent rust infection and percent protein content of wheat grown at Manhattan and Hays.

	Year	Rainfall inches	Percent rust Leaf	Percent rust Stem	Percent protein
Manhattan	1927	8.16	80		12.6
	1928	3.18	50		15.5
	1929	9.30	81		13.8
	1930	7.27	42		10.9
	1932	5.54	65		13.0
	1935	14.30	38	25	13.1
	1936	3.87		19	13.1
	1938	9.23	90	36	13.3
	1939	8.97	91		14.8
	1941	5.51	71	12	13.2
	1942	14.72	74		12.9
	1943	14.56	78		12.8
	1944	5.09	59	44	12.9
	1945	11.54	56		11.7
	1946	3.86	24		9.4
	1947	9.51	42		14.4
	1948	14.25	45		10.6
	1949	6.17	60		12.7
	1950	6.60	16		12.5
Total		161.63			243.2
Average		8.50			12.8
Hays	1927	9.12	30		14.5
	1928	11.30	65		14.3
	1932	11.21	10		11.1
	1941	8.65	85		13.9
	1945	8.55	31		14.0
	1947	11.46	30		11.2
	1949	8.93	80		14.0
Total		69.22			93.0
Average		9.9			13.3

of rainfall during the latter part of the growing period of the plant may reduce the protein content of the grain by stimulating disease development. Caldwell, Kraybill, Sullivan, and Compton (5) reported that the percentage of protein in the grain of susceptible varieties of both hard and soft winter wheat was very significantly reduced by severe rust infection. Caldwell and Compton (4) found leaf rust associated with protein reduction up to 11.5 percent, Johnston (17) up to 13.1 percent, and Phipps (30) about 8 percent. Leaf rust evidently partially inhibits the movement of nitrogenous material into the kernel. Since the same moisture conditions that favor rust development also favor a higher rate of carbohydrate formation in the wheat kernel it seems logical to assume that both factors are of consequence in reducing protein content of wheat.

At Manhattan, rusts develop to some degree in almost every year. No relation appeared to exist between the amount of rust infection and protein content of the wheat produced at Manhattan. It has already been stated that the interaction of factors of the environment at Manhattan are quite complex in their effect on yield and protein content of wheat. Rusts are likely to produce some effect on the protein content of the wheat grown at Manhattan but their effect is probably overshadowed by other factors or complex of factors.

Effect of Leaf and Stem Rust on Yield of Wheat Grown at Manhattan

The season of 1943-44 was a favorable one for the development of both leaf rust and stem rust at Manhattan, although stem rust came rather late and affected only the late susceptible varieties.

Table 6 shows the average yields and rust percentages of 27 varieties of winter wheat grown at Manhattan in 1944. Figure 13 shows the relation of yield and a rust index calculated by adding together the percent of leaf rust and the percent of stem rust for the same year. Only the C.I. numbers of the varieties are shown in Fig. 13. This graphic picture illustrates generally that as the rust percent increases the yield of wheat decreases. A complete inverse correlation of rust and yield is virtually impossible because some varieties although highly infected with rust tend to retain their yielding ability. Figure 14 points out that the variety, Wichita, carried a high percentage infection of rust over a seven year period, yet its yield was only slightly lower than Pawnee, the highest yielder. Mains (24) reports that a resistant plant may show as much infection as a susceptible one but the effects are much less pronounced. Caldwell, Kraybill, Sullivan, and Compton (5) in their study of leaf rust effects on wheat found that in very susceptible varieties, with one exception, reductions in yield of grain ranging from 14.8 to 28.4 percent were associated with heavy infections of leaf rust. The one exception was that the yield of the variety Fulhard was not reduced even though this variety was severely rusted. These investigators agree with Mains (24) and Johnston (16) that most of the grain losses caused by leaf rust result from a reduction in the number of kernels per head, and the remainder from a reduction in weight per kernel.

Rust and yield data collected on 10 varieties of winter wheat grown at Manhattan from 1941 to 1948, excluding 1946, are shown

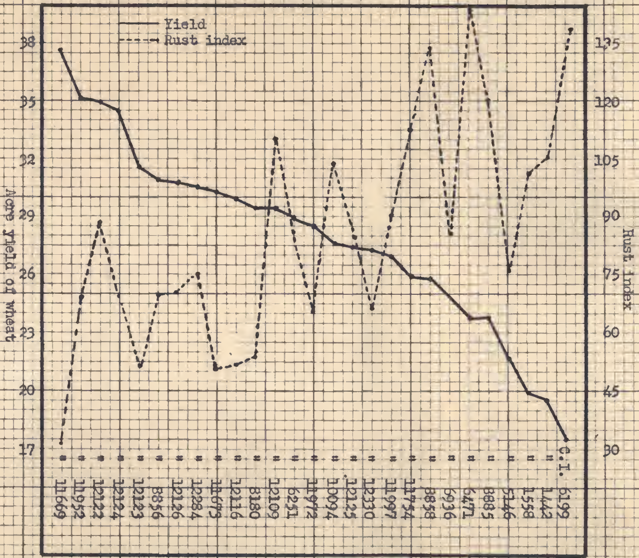

Fig. 13. Yield of winter wheat in relation to rust index for the year 1944 at Manhattan. Rust index calculated by adding the percentages of leaf and stem rust.

Table 6. Data on yield and percent rust infection of 27 varieties of winter wheat grown at Manhattan in 1944.

Variety	C. I. No.	Yield bushels	Percent rust Leaf	Percent rust Stem
Pawnee	11669	37.6	15	15
Wichita	11952	35.1	63	5
Cheyenne x E Blkhull	12122	34.9	63	25
E.Blkhull x Tenq	12124	34.4	63	5
Cheyenne x Tenq	12123	31.4	15	45
Early Blackhull	8856	30.8	63	5
Tenmarq x Blkhull	12126	30.7	45	25
Harvest Queen x Kaw	12284	30.4	35	40
Comanche	11673	30.1	25	25
Quivira x Tenq	12116	29.9	23	28
Kawvale	8180	29.4	23	30
Red Chief	12109	29.3	65	45
Blackhull	6251	28.9	60	23
Chey. x Tenq	11972	28.6	20	45
Nebred	10094	27.5	70	33
Tenq. Selection	12125	27.4	43	43
Kaw-Marq. x Tenq	12330	27.2	T	65
Inbred Selection	11997	26.9	40	50
Chiefkan	11754	25.9	43	25
Clarkan	8858	25.8	70	63
Tenmarq	6936	24.7	45	40
Fulcaster	6471	23.7	80	63
Cheyenne	8885	23.7	58	60
Kanred	5146	21.5	35	40
Turkey	1558	19.8	63	38
Kharkof	1442	19.3	55	50
Harvest Queen	6199	17.4	80	58

in Table 7. In general, those years were characterized by wet humid springs and early summers which are contributing factors to leaf and stem rust development. Leaf rust was prevalent in all years while stem rust occurred only in 1941, 1944, and 1948. Pawnee produced the highest yields during this period while Khardof and Turkey produced the lowest yields. In general, with the exception of Wichita, high yields were associated with low percentages of rust infection and low yields were associated with high

Fig. 14. Av. yield of winter wheat varieties grown at Manhattan from 1941 to 1948 except 1946 in relation to the average rust index for each variety. Rust index was calculated by adding the percentages of leaf and stem rust.

Table 7. Percentage of leaf and stem rust infection for 10 varieties of hard red winter wheat grown at Manhattan from 1941 to 1948 except 1946.

Variety	1941 Yield bushels	1941 % Rust Leaf	1941 % Rust Stem	1942 Yield bu.	1942 % Rust Leaf	1942 % Rust Stem	1943 Yield bu.	1943 % Rust Leaf	1943 % Rust Stem	1944 Yield bu.	1944 % Rust Leaf	1944 % Rust Stem
Pawnee	31.4	30	4	34.4	22		32.6	28		37.6	15	15
Wichita	27.9	78		36.2	72		26.3	77		35.1	65	5
Comanche	29.6	15	3	30.9	10		28.2	27		30.1	25	25
Tenmarq	23.9	45	3	27.1	40		29.8	42		24.7	45	40
Red Chief	25.3	63	20	25.7	52		21.7	70		29.3	65	45
Clarkan	17.6	58	63	31.0	57		28.7	77		25.8	70	63
Cheyenne	28.1	83	4	26.2	82		32.5	82		23.7	58	60
Kanred	20.8	53	T	21.0	62		20.9	63		21.5	35	40
Kharkof	18.7	73	15	20.7	77		27.7	77		19.3	55	50
Turkey	19.6	70	10	18.8	70		22.4	78		19.8	63	38

Table 7. (concl.)

Variety	1945 Yield bu.	1945 % Rust Leaf	1945 % Rust Stem	1947 Yield bu.	1947 % Rust Leaf	1947 % Rust Stem	1948 Yield bu.	1948 % Rust Leaf	1948 % Rust Stem
Pawnee	47.3	63		42.1	25		48.6	25	
Wichita	35.7	100		37.9	68		53.2	25	
Comanche	40.5	57		35.0	43		47.2	15	1
Tenmarq	34.4	77		30.9	43		45.9	25	18
Red Chief	34.3	82		30.8	45		43.7	40	27
Clarkan	34.2	80		31.8	48		39.1	50	50
Cheyenne	35.0	65		30.3	52		27.1	60	67
Kanred	27.7	53		25.3	35		32.3	20	50
Kharkof	31.9	70		26.2	47		24.5	50	73
Turkey	27.0	43		26.0	37		29.3	40	70

percentages of rust infection as depicted by Fig. 14. It is apparent then that high rainfall not only causes lowered yields by inducing certain deteriorating chemical processes in the plant but provides conditions which stimulates the development of destructive diseases which also reduce yields.

SUMMARY AND CONCLUSIONS

The present study was concerned with the effect of environment on yield and protein content of hard red winter wheat. Variety tests of hard red winter wheat grown in 1/50th acre plots on the Agronomy Farm at Manhattan and on the Fort Hays Branch Experiment Station provided information for this study. The author collected data on the crop grown at Manhattan in 1950.

Similar data collected by Laude (21) and others at Manhattan and by Swanson (37) at Hays were used to supplement the data collected in 1950. Data were available on varieties Kanred and Turkey back to 1911 at Manhattan and on the variety Turkey back to 1925 at Hays except years 1929, '35, '37, '38, and '40. Additional data were obtained from reports of the Kansas State Board of Agriculture and Bureau of Agricultural Economics cooperating on wheat yields in different sections of Kansas.

Weather data were taken from monthly summaries of Climatological Data of Kansas, and from data reported by Flora (9).

At Manhattan both the frequency and the amount of rainfall during the spring growing season, March 1 to ripening date of the grain, were found to be somewhat inversely related to yield of wheat although the relation between the amount of rainfall and yield was somewhat less than that between frequency of rainfall and yield.

A correlation coefficient of +0.616 was found between frequency and amount of rainfall during the spring growing season at Manhattan.

A rainfall-frequency index computed by adding together the total amount of rainfall during the spring growing season and the frequency of rainfall was found to be negatively related to wheat yield at Manhattan.

A correlation coefficient of +0.817 was found between rainfall during the wheat season, July 1 to May 31, and average yield of wheat in the western one-third of Kansas. The correlation coefficient between rainfall and wheat yield for the same period in the eastern one-third of the state was -0.536.

At Hays the sum of daily maximum temperatures exceeding 80° F. during the first half of the fruiting period were found to be positively associated with protein percent of the grain. No such relation was found in a corresponding period at Manhattan.

At Hays the amount of rainfall during the period, 10 days prior to heading to ripening date of the grain, was found to be negatively associated with protein percent of the grain. A positive relation was found between a rainfall-temperature index and protein percent of the wheat. Apparently when the weather is cool and there is sufficient soil moisture, a large amount of starch tends to be deposited and a plump kernel of low protein results.

Yield of wheat was found to be positively associated with pounds of protein produced per acre at Manhattan and Hays.

Wheat yields at Manhattan were materially reduced in years when there were epiphytotic outbreaks of rust. It was shown that in 1944 those varieties exhibiting rust resistance generally produced higher yields than susceptible varieties. The same relation held true for a number of varieties grown at Manhattan from 1941 to 1948 except 1946.

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EFFECT OF ENVIRONMENT ON YIELD AND PROTEIN CONTENT OF WHEAT IN KANSAS

by

BYRD COLLINS CURTIS

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