THE EFFECT OF VARIOUS RATES, TIMES OF APPLICATION AND COMBINATIONS OF FERTILIZERS ON THE YIELD, QUALITY AND PLANT CHARACTERISTICS OF PAWNEE WHEAT AT VARIOUS LOCATIONS IN KANSAS, 1947-48

by

CHARLES ABRAHAM SIMKINS

B. S., Kansas State College
of Agriculture and Applied Science, 1948

A THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1950

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INTRODUCTION

Wheat is the most important cultivated crop in Kansas. It is grown on approximately half of the cultivated acreage of the state. Wheat usually has a relatively high market value, therefore, a small increase in yield may result in a profit from the proper use of fertilizers.

Numerous investigations have demonstrated that wheat will respond to large amounts of available plant nutrients.

The use of phosphatic fertilizers at the time of seeding wheat has been a well established practice on many farms in eastern Kansas. Recently, however, the production of large quantities of nitrogenous fertilizers in the state has stimulated a great deal of interest in the possibility of increasing the yields of wheat by the use of such fertilizers.

The purpose of this experiment was to obtain information concerning the best time, rate and method of applying nitrogenous fertilizers to wheat, both alone and in combination with phosphatic and potassic fertilizers, under various Kansas conditions. Additionally this experiment was designed to indicate some of the effects of added fertilizer elements on plant growth characteristics and the quality of product harvested.

Only limited research work has been conducted in the central portion of Kansas relative to the effect of fertilizer elements on wheat production and only limited information is available relative to the effect of high rates of fertilization on wheat quality.

It is generally agreed that the efficiency with which fertilizers are utilized by winter wheat depends primarily on the native fertility of the soil, previous cropping history, time of application of fertilizer materials and weather conditions prevailing during the various growth periods.

REVIEW OF LITERATURE

Early investigations by Davidson and Le Clerc (10,11) indicated that when sodium nitrate was applied at the first stage of wheat growth, at a time when the crop was about two inches high, it greatly stimulated the vegetative growth of the crop and gave increased yields. The presence of sodium nitrate in the soil at the time of heading resulted in a better quality of grain with reference to color and protein content. The vegetative growth was not affected by the application of sodium nitrate at this time. Sodium nitrate applied at the milk stage had no effect on yield, quality, or protein content of the grain.

Woods (30) found an apparent increase in protein content of both grain and straw with increased application of nitrogen fertilizer on oats.

Bracken (4, 5), of Utah, collected data at the Nephi-Dry Land Station from 1928 to 1933, inclusive, relative to the effect of soil treatment on the yield of winter wheat. It was concluded that the reduction of available nitrate nitrogen significantly reduced the yield of winter wheat. Treatments with manure, because of the content of considerable available nitrogen, gave yields 16 per cent higher than treatments which included no manure. Significant increases in protein content also resulted from the application of barnyard manure.

In the Palouse area of eastern Washington, Doneen (12) secured large increases in the yield of wheat by the application of nitrogen fertilizers. Where there was only limited quantities of available nitrogen in the soil, the addition of nitrogen fertilizer stimulated plant growth and caused an increased yield and increased protein content of the grain. On soils containing sufficient quantities of available nitrogen for large yields of grain, the addition of sodium nitrate as a fertilizer caused a retardation of growth during the vegetative period of the plant and did not materially increase the yield or nitrogen content of the grain.

Experiments carried on by Neidig and Snyder (21), and Vandecaveye and Baker (29) have shown that for every 100 pounds of sodium nitrate fertilizer employed, the yield was increased by three to four bushels.

Studies made by Murphy (20) at the Oklahoma Agricultural Experiment Station indicated that neither nitrogen nor potash would increase the yield of wheat on sandy loam soils of that section. The introduction of phosphorus, whether with nitrogen or potassium or a combination of all three elements, greatly increased yields. The highest yielding combination was found to be a combination of phosphorus and potassium fertilizers. In the same experiment the protein content of the wheat increased as the amount of nitrogen in the fertilizer was increased. One hundred and fifty pounds of sodium nitrate gave the highest increase in protein content per unit of nitrogen supplied. Phosphorus when included in the fertilizer, whether alone or with nitrogen or with potash, decreased the protein content of the wheat.

Gainey, Sewell and Myers (14) of Kansas reported that the small, well defined areas of the taller and darker green plants in grain fields of the eastern two-thirds of Kansas were the direct result of the soil supplying the wheat plants with more available nitrogen. This nitrogen addition results from the urine deposits of livestock being winter pastured on the fields. The wheat plants from such spots made 2.6 times the total growth, contained 1.8 times as much nitrogen per unit weight, and had actually assimulated 4.68 times as much nitrogen per plant as those from the field at large.

The results obtained by the use of fertilizers over a wide range of soils in Saskatchewan, by Mitchell (19) indicated a remarkably good response of wheat to both nitrogenous and phosphatic fertilizers. Phosphatic fertilizers appeared to be more effective in increasing yields than nitrogenous materials. Fertilization had no definite effect on protein content or bushel weight of the wheat.

Recent experiments on wheat in England confirm the view that additional nitrogen is an important requirement of the crop.

Cowie (9) found that phosphate and potash were economical supplements for only definitely deficient soils. Spring top dressings appeared to have an advantage over the use of nitrogen in the fall. There appeared to be no clear advantage in dividing the nitrogen treatment,--applying one-half in the autumn and one-half in the spring. The yield of grain per acre varied little between March, April or May applications of nitrogen fertilizers. The application of 200 pounds of ammonium sulfate resulted in an additional increase almost equal to the increase received from the application of 100 pounds of the material.

Miller and Bauer (18) of Illinois collected much data relative to the effect of soil treatments on winter wheat. Tests with different carriers of nitrogen applied in the spring showed that sodium nitrate was slightly more effective than ammonium sulfate or calcium cyanamid in increasing wheat yields. Nitrogen carrying fertilizers were found to be most effective when broadcast early in the spring. Phosphatic fertilizers resulted in increased yields whether used alone or in combination with nitrogenous materials. The best response to phosphate treatments was obtained by drilling superphosphate near the seed. Potassium, where needed as indicated by soil test, was most beneficial when applied at seeding time.

Pendleton (23), working with nitrate fertilizers on wheat in Iowa, concluded that late applications of nitrogen were somewhat more efficient in increasing the protein content of wheat and gave approximately equal increases in yield when compared to early treatments. The use of superphosphate had little effect in increasing the yield of wheat.

A study of the effect of time, rate and method of application of fertilizer on the yield and quality of hard red winter wheat has been made by Smith (25) and Smith and Simkins (26) in Kansas. Highly significant increases in yield were obtained from the use of nitrogen and phosphatic fertilizers. Significant increases were obtained when either both of these materials were placed with the seed or when the phosphorus was placed with the seed and the nitrogen applied as a spring top dressing. The use of potassium fertilizer in addition to nitrogen and phosphorous did not cause an additional increase in the yield of wheat. The protein content of wheat, as produced under conditions of this experiment, was not significantly influenced by the application of the fertilizers.

Hanway, Olson, Pumphrey, Ehlers, Luebs (16) indicate that winter wheat grown on many soils in Nebraska will respond to additional amounts of available nitrogen. Certain soils will also respond to additional amounts of available phosphorous. Time of application of nitrogen fertilizer had little effect on the yield of wheat under the conditions existing in their experiments. Applications of nitrogen fertilizer increased the protein content of wheat grain considerably. Applications of phosphorous and potassium fertilizers had no appreciable effect on the protein content of the wheat.

Other investigators (7), (9), (16), (24) and (27), have related that response of wheat to additions of nitrogen fertilizers is greatly influenced by the varietal characteristics, seasonal variations and other environmental factors.

METHODS OF STUDY

Location and Description of Plots

Experimental plots were established in Neosho County, near Thayer, Kansas, on the Gerald Umbarger farm; in Sedgwick County, near Goddard, Kansas, on the William Stewart farm; and in Republic County near Belleville, Kansas, on the Lloyd Lowell farm.

The soil type in Neosho County is Parsons silt loam. This area was very typical of much of the upland soils for that particular area. This soil consists of a moderately deep silt loam surface soil with a clay pan subsoil. Wheat and lespedeza had been grown on the field two years previous to the study, and wheat had again occupied the field the year previous to the study. The wheat yield the previous year was about 35 bushels per acre.

At the Sedgwick County location the soil is a deep, dark reddish silt loam soil very typical of the upland of this area. This soil is probably a member of the Polo soil series. The field had been cropped continuously with wheat for the last several years.

The area selected in Republic County is probably a Crete silt loam soil, deep and very dark with moderately light clay subsoil. The topography is very uniform and the area is typical upland soil for this locality. Corn, oats, and wheat were the dominant crops grown on this land during the previous 18 years.

Plan of Experiment

The experimental plan was the same for all locations. The experiment consisted of 40 different treatments. These treatments were included in the experiment as a part of a randomized block. Each treatment was replicated three times. Therefore, a total of three blocks or 120 plots was used at each location. The various treatments with the time, rate and method of application are indicated in Table 1.

The plots were 140 feet in length and 5 feet 4 inches in width. An alley way of 16 inches was present between each plot. At harvest time 137 feet and 5 inches were harvested from the 140 feet plots which was equal to 1/60 of an acre. Dead furrows which existed as a result of previous plowing were not seeded to wheat as part of the experiment. The alley-ways between blocks were 30 feet in length.

Table 1. Treatments employed at each of the three locations for wheat fertilizer tests, 1947-1948.

Plot	Treatments Rate per acre N - P_2O_5 - K_2O	Method of N application*	
1.	100 - 50 - 25	N broadcast	
2.	50 - 50 - 25	"	
3.	25 - 50 - 25	"	
4.	100 - 0 - 0	"	
5.	50 - 0 - 0	"	
6.	25 - 0 - 0	"	
7.	100 - 50 - 0	"	
8.	50 - 50 - 0	"	
9.	25 - 50 - 0	"	
10.	100 - 50 - 25	N seeding	
11.	50 - 50 - 25	"	
12.	25 - 50 - 25	"	
13.	100 - 0 - 0	"	
14.	50 - 0 - 0	"	
15.	25 - 0 - 0	"	
16.	100 - 50 - 0	"	
17.	50 - 50 - 0	"	
18.	25 - 50 - 0	"	
19.	0 - 50 - 0	"	
20.	0 - 0 - 0	(No treatment)	
21.	50 - 50 - 25	N Top dressing,	December 20
22.	50 - 50 - 25	"	February 20
23.	50 - 50 - 25	"	March 10
24.	50 - 50 - 25	"	March 30
25.	50 - 0 - 0	"	December 20
26.	50 - 0 - 0	"	February 20
27.	50 - 0 - 0	"	March 10
28.	50 - 0 - 0	"	March 30
29.	50 - 50 - 0	"	December 20
30.	50 - 50 - 0	"	February 20
31.	50 - 50 - 0	"	March 10
32.	50 - 50 - 0	"	March 30
33.	25N- 50 - 25 25N	N half at seeding + top dressing,	December 20
34.	25N- 50 - 25 25N	"	February 20
35.	25N- 50 - 25 25N	"	March 10
36.	25N- 50 - 25 25N	"	March 30
37.	50 - 50 - 25	N-top dressing ($CaCN_2$)	December 20
38.	50 - 50 - 25	"	February 20
39.	50 - 50 - 25	"	March 10
40.	50 - 50 - 25	"	March 30

*All phosphorus and potassium were applied at planting time by means of fertilizer attachment on grain drill.

Experimental Procedure

All broadcast applications of nitrogen fertilizer were made on the stubble just prior to plowing. Applications of nitrogen fertilizer at the time of seeding were made by means of the fertilizer attachment on the grain drill. Winter and spring top dressings of nitrogen fertilizer were broadcast either by hand or by means of the fertilizer attachment on the grain drill.

Fertilizer materials used in these tests included ammonium nitrate as the source of nitrogen in all instances except where calcium cyanamid is indicated. Treble superphosphate (45% P_2O_5) was used as the source of phosphorous and muriate of potash (60% K_2O) as the source of potassium.

Pawnee wheat was drilled at all locations at the rate of 75 pounds per acre.

At all locations the seed bed has been prepared by plowing with a mold-board plow during the month of July and then by harrowing and disking the ground several times prior to seeding. The dates of seeding are shown in Table 2.

Table 2. Dates of seeding Pawnee wheat at various locations in wheat fertilizer experiments, 1947-48.

Location	Date of seeding
Thayer, Kansas	October 10, 1947
Goddard, Kansas	October 9, 1947
Belleville, Kansas	October 31, 1947

Chemical Analyses of Soils

Organic carbon determinations were made according to the procedure as given by Allison (1). Analyses for available phosphorus were conducted by the method as given by Bray and Kurtz (6). Total phosphorus determinations were conducted according to the method as given by Association of Official Agricultural Chemists (3). To determine the exchangeable potassium, a solution of 1N ammonium acetate was added to 20 grams of soil. After shaking for two minutes, the suspension was filtered. Five milliliters of an aqueous solution of 1N ammonium acetate containing 1,100 ppm of lithium were added to the extract and the final determinations were made on the flame photometer. A 1:1 mixture of soil and water was used for the pH determination. The pH measurements were made by the use of the Leeds and Northrup glass electrode pH meter.

Protein Analyses of Grain Samples

Total nitrogen determinations were made according to the procedure given by the Association of Official Agricultural Chemists (3). All nitrogen values were multiplied by the factor 6.25 to obtain the protein content of the grain.

Test Weight Data

Test weight data were secured by use of the standard apparatus for determining the test weight per bushel of grain. The samples of wheat used for this purpose were collected at the time of threshing and were also used in making the protein determinations.

Plant Growth Characteristics

In order to obtain an indication of the effect of various fertilizer treatments on the growth of Pawnee wheat, measurements were taken of the height of the wheat plants and length of the spikes.

Ten wheat height measurements were taken at random from each plot in one of the replications at the Thayer location. Twenty measurements were taken of the spike lengths from the same corresponding plots at the Thayer location.

RESULTS

Rainfall Data

The precipitation received at Thayer was such as to provide an abundance of soil moisture at all times during the growing season. At the Belleville location there was an insufficient supply of moisture at the time of planting and throughout the winter period. Moisture supplies at Goddard, both in the soil and as a result of precipitation during the entire growing period, were well below average.

Table 3. Precipitation record in inches by months from July 1, 1947 to June 30, 1948 for various locations of fertilizer experiments on wheat.

Month	Thayer	Goddard	Belleville
July 1947	3.62	.67	.35
August 1947	3.81	2.46	.83
September 1947	5.75	.52	.65
October 1947	2.29	2.32	.88
November 1947	1.69	.83	1.37
December 1947	1.32	2.30	2.06
January 1948	.56	.58	.41
February 1948	.50	1.17	2.95
March 1948	3.28	1.89	2.13
April 1948	3.37	.63	1.11
May 1948	3.46	1.00	2.70
June 1948	8.82	4.14	4.89
Total for year	38.47	18.51	20.33

Plant Growth Characteristics

Table 4. A summary of average plant height and average spike length, wheat fertilizer experiment, Thayer, Kansas, 1947-48.

Treatment number	Av. plant height in.*	Av. spike length in.**
1	28.8	2.36
2	27.9	2.37
3	31.7	2.07
4	33.7	2.32
5	29.2	1.98
6	29.6	1.99
7	33.3	2.18
8	30.6	2.40
9	28.1	2.30
10	33.0	2.35
11	33.5	2.44
12	33.0	2.40
13	33.1	2.32
14	32.6	2.18
15	33.3	2.11
16	33.2	2.46
17	32.6	2.33
18	35.1	2.14
19	28.5	2.03
20	29.0	2.08
21	36.3	2.26
22	31.0	2.45
23	30.7	2.35
24	31.7	2.36
25	27.9	2.30
26	30.3	2.04
27	33.0	2.28
28	28.5	2.94
29	34.3	2.23
30	32.7	2.37
31	35.3	2.25
32	29.6	2.38
33	35.2	2.48
34	35.2	2.34
35	33.7	2.16
36	33.8	2.35
37	29.6	2.50
38	32.1	2.47
39	34.2	2.54
40	32.0	2.24

* Plant height data are means of 10 measurements for each treatment.
** Spike length data are means of 20 measurements for each treatment.

Chemical Analyses of Soils

Table 5. Chemical characteristics of the soils used in wheat fertilizer experiments, 1947-48.

Location	Profile depth	pH	Total phosphorus percent	Available phosphorus lbs / acre	Organic carbon percent	Exchangeable potassium lbs/acre
Thayer	0-6"	5.05	.0962	22	1.44	118
Thayer	7-12"	5.51	.0920	15	1.09	180
Goddard	0-6"	5.72	.141	28	1.32	440
Goddard	7-12"	6.00	.125	23	1.14	460
Belleville	0-6"	5.85	.119	77	1.41	840
Belleville	7-12"	5.98	.103	70	1.11	750

Yield Data

Table 6. Summary of yields for Thayer, Goddard, Belleville, wheat fertilizer experiments, 1947-48.*

Treatment number	Thayer Bu/acre	Goddard Bu/acre	Belleville Bu/acre
1	54.8	24.4	43.0
2	48.8	25.5	33.6
3	45.8	19.6	35.7
4	37.7	19.1	44.1
5	31.4	18.0	39.2
6	30.2	16.4	36.8
7	57.2	26.1	45.5
8	43.6	22.2	39.5
9	45.8	20.4	37.1
10	60.5	23.3	44.5
11	59.3	21.3	43.5
12	52.7	20.8	37.9
13	37.8	17.9	43.1
14	35.9	18.6	40.2
15	40.5	17.7	36.9
16	56.3	26.1	47.2
17	56.3	23.8	38.0
18	52.1	22.9	36.1
19	40.7	17.8	27.1
20	28.0	13.8	31.3
21	57.3	21.6	41.1
22	57.3	21.5	36.7
23	52.0	24.2	41.3
24	48.2	19.0	42.9
25	36.0	15.0	42.5
26	38.1	15.5	39.8
27	34.7	16.7	39.8
28	34.1	17.3	40.5
29	60.0	20.7	41.3
30	57.6	22.1	42.8
31	53.4	22.3	38.9
32	49.7	21.8	39.3
33	62.2	25.1	41.9
34	64.0	22.8	41.7
35	54.5	22.7	40.0
36	57.8	20.1	39.7
37	50.3	20.3	33.6
38	53.5	18.0	40.3
39	53.2	21.3	29.7
40	46.4	18.3	35.3

*These yields are means of 3 replications for each location.

Test Weight

Table 7. Summary of test weights for Thayer, Goddard, Belleville, wheat fertilizer experiments, 1947-48.*

Treatment number	Thayer Lbs./acre	Goddard Lbs./acre	Belleville Lbs./acre
1	59.7	58.7	59.7
2	58.2	58.9	59.4
3	58.7	58.9	60.3
4	58.2	59.1	60.2
5	57.8	59.1	59.7
6	59.2	58.8	60.1
7	57.9	58.4	59.9
8	59.0	58.2	60.2
9	60.0	58.8	60.3
10	60.6	58.8	60.2
11	60.1	58.1	60.9
12	59.8	58.8	60.1
13	58.8	58.9	59.8
14	58.8	59.4	60.2
15	58.8	59.3	59.8
16	57.9	58.3	60.9
17	57.6	58.9	60.2
18	57.7	59.3	59.8
19	57.9	58.8	59.7
20	59.2	58.9	60.6
21	58.7	58.9	59.6
22	59.7	59.2	60.0
23	60.4	59.2	60.6
24	59.1	58.2	60.5
25	59.1	58.9	59.6
26	57.8	59.2	59.8
27	58.2	59.2	60.3
28	57.7	59.3	60.4
29	58.3	59.2	60.6
30	57.9	59.3	59.7
31	57.7	58.9	60.5
32	58.7	58.9	59.9
33	57.9	58.5	60.6
34	58.8	58.9	60.3
35	58.1	58.8	60.0
36	57.7	58.9	60.0
37	59.8	59.1	60.6
38	59.6	58.9	60.5
39	58.1	59.3	60.1
40	57.6	58.8	60.2

*These test weight data represent means of 3 replications at each location.

Protein Data

Table 8. Summary of protein data for Thayer, Goddard, Belleville, wheat fertilizer experiments, 1947-48.*

Treatment number	Thayer percent	Goddard percent	Belleville percent
1	11.25	15.20	13.18
2	10.05	14.66	12.04
3	9.11	13.20	11.45
4	12.24	16.22	13.34
5	11.40	15.35	11.98
6	10.34	14.48	11.31
7	10.66	15.72	13.29
8	10.41	14.10	11.42
9	9.64	13.21	11.10
10	10.92	14.40	13.55
11	10.09	14.03	11.89
12	9.78	12.92	11.80
13	12.45	15.18	14.63
14	11.70	14.78	13.53
15	12.11	14.44	12.29
16	10.89	14.46	13.39
17	10.55	13.45	12.10
18	9.94	13.41	11.74
19	9.86	13.22	11.71
20	10.41	13.62	11.46
21	11.06	13.85	12.39
22	10.94	14.08	12.90
23	10.47	13.96	12.22
24	10.26	13.79	12.92
25	11.88	15.14	14.48
26	11.49	14.32	12.71
27	12.03	14.89	12.98
28	12.09	14.80	11.97
29	11.61	13.87	12.79
30	11.38	13.85	12.25
31	10.94	13.98	12.05
32	10.74	14.57	12.65
33	11.76	13.70	12.07
34	11.13	13.76	12.29
35	10.41	14.40	12.84
36	10.58	13.78	12.43
37	10.34	13.49	11.99
38	9.89	13.38	12.08
39	10.91	12.80	12.58
40	10.28	13.17	12.12

*These protein data represent means of 3 replicates for each location.

Statistical Analyses

Table 9. Analysis of variance for wheat yield data at Thayer wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	119	13331.15				
Between treatments	39	11220.48	287.70	11.64	1.54	1.84
Between blocks	2	179.46	89.73			
Error	78	1931.21	24.75			

L. S. D. at .05 = 7.92 bu./acre
L. S. D. at .01 = 10.43 bu./acre

Table 10. Analysis of variance for protein content of wheat at Thayer, wheat fertilizer experiment, 1947-48.

	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	119	141.20				
Between treatments	39	75.20	1.928	2.368	1.54	1.84
Between blocks	2	2.49	1.249	1.534		
Error	78	63.51	0.814			

L. S. D. at .05 = 1.43 percent protein
L. S. D. at .01 = 1.89 percent protein

Table 11. Analysis of variance for test weight of wheat at Thayer, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	119	258.37				
Between treatments	39	42.99	1.102	0.552*	1.54	1.84
Between blocks	2	59.65	29.825	14.940		
Error	78	155.73	1.996			

*Nonsignificant

Table 12. Analysis of variance for wheat height at Thayer, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	399	3039				
Between treatments	39	2163	55.46	22.79	1.43	1.65
Within treatments	360	876	2.43			

L. S. D. at .05 = 1.39 inches.
L. S. D. at .01 = 1.87 inches.

Table 13. Analysis of variance for spike length at Thayer, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	799	48.84				
Between treatments	39	20.37	.5223	13.94	1.41	1.61
Within treatments	760	28.47	.0374			

L. S. D. at .05 = .122 inch
L. S. D. at .01 = .165 inch

Table 14. Correlation coefficient for yield and height of wheat at Thayer, wheat fertilizer experiment, 1947-48.

	Total	Mean	S. S.	Sum of products	D.F.	rxy	Significance .05	.01
Yield	1861	46.52	91495.00	60088.0	38	-.687**	-.313	-.408
Height	1276.9	31.92	40954.54					

**Denotes highly significant

Table 15. Correlation coefficient for yield and spike length of wheat at Thayer, wheat fertilizer experiment, 1947-48.

	Total	Mean	S. S.	Sum of products	D.F.	rxy	Significance .05	.01
Yield	1861	46.52	91495.00	4341.21	38	-.171*	-.313	-.408
Height	93	2.33	217.80					

*Not significant

Table 16. Analysis of variance for yield at Goddard, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F"	
Total	119	1822.13				
Between treatments	39	1213.13	31.11	5.07	1.54	1.84
Between blocks	2	130.02	65.01			
Error	78	478.98	6.14			

L. S. D. at .05 = 3.94 bu./acre
L. S. D. at .01 = 5.19 bu./acre

Table 17. Analysis of variance for protein content of wheat at Goddard, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	119	95.60				
Between treatments	39	71.06	1.82	7.99	1.54	1.84
Between blocks	2	6.73	3.37	14.78		
Error	78	17.81	.228			

L. S. D. at .05 = .76 percent
L. S. D. at .01 = 1.00 percent

Table 18. Analysis of variance for test weight of wheat at Goddard, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	Tabled "F" .01
Total	119	46.86				
Between treatments	39	13.22	0.339	1.21*	1.54	1.84
Between blocks	2	11.97	5.986	21.53		
Error	78	21.67	0.278			

*Nonsignificant

Table 19. Analysis of variance for wheat yield at Belleville, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	Tabled "F" .01
Total	119	4050.67				
Between treatments	39	2514.33	64.47	6.73	1.54	1.84
Between blocks	2	789.32	394.66			
Error	78	747.02	9.57			

L. S. D. at .05 level = 4.93 bu./acre
L. S. D. at .01 level = 6.50 bu./acre

Table 20. Analysis of variance for protein content of wheat at Belleville, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	119	127.45				
Between treatments	39	74.01	1.90	5.39	1.54	1.84
Between blocks	2	25.95	12.98	36.57		
Error	78	27.49	0.352			

L. S. D. at .05 level = 0.94 percent protein
L. S. D. at .01 level = 1.24 percent protein

Table 21. Analysis of variance for test weight of wheat at Belleville, wheat fertilizer experiment, 1947-48.

Factor	D.F.	S. S.	Variance	Calculated "F" value	Tabled "F" .05	.01
Total	119	68.64				
Between treatments	39	14.22	0.365	0.629*	1.54	1.84
Between blocks	2	9.11	4.56			
Error	78	45.31	0.580			

*Nonsignificant

DISCUSSION OF RESULTS

The results of this investigation are presented in Tables 4, 6, 7, and 8. Included are the data relative to the yield of wheat, protein content of wheat and test weight of wheat. Statistical interpretation of these results are presented in succeeding tables of data.

Yield Data at Thayer

Significant increases in yield were obtained as a result of fertilizer treatments at Thayer.

The application of phosphorus fertilizer at seeding time resulted in highly significant increases in yield. Phosphorus, whether applied alone or in combination with nitrogen and potash fertilizers, produced yields which were significantly above those yields where this element was omitted.

The use of nitrogen as a fertilizer constituent consistently produced significant increases in yields when applied either in combination with phosphorus or in combination with phosphorus and potash fertilizers. Increases in yield from the use of nitrogen alone were not statistically significant when less than 100 pounds of N per acre were applied to the stubble prior to planting. Nitrogen topdressed at the rate of 50 pounds of N per acre resulted in significant increases in yields, except where it was applied without the benefit of previous phosphatic or phosphatic and potassic fertilization and the application was delayed as late as

March 10. The application of nitrogen as a topdressing produced highest yields when applied at the December 20 or February 20 dates.

Nitrogen furnished in split applications did not produce significant increases over the nitrogen applied at one operation; however, many of the yields obtained by this split application method were somewhat higher than the yields recorded as a result of other methods of application.

The topdressing of nitrogen did not prove to be significantly superior to applying the nitrogen at seeding time. The use of rates of nitrogenous fertilizers equivalent to 100 pounds per acre of nitrogen and 50 pounds per acre of nitrogen did not significantly increase the yield over that obtained by the use of only 25 pounds of nitrogen per acre.

Calcium cyanamid, as a nitrogen carrier, produced yields which were statistically no different than those obtained by use of ammonium nitrate.

The use of potassium-bearing fertilizer in combination with nitrogenous and phosphatic fertilizer resulted in no significant increase in yield when compared to those treatments where similar amounts of nitrogen and phosphoric acid were used.

Protein Data at Thayer

Significant increases in protein content were obtained as a result of six fertilizer treatments. It is of interest to note that all of these significant increases were the result of the application of nitrogen alone.

Nitrogen applied at the rate of 100 pounds of N per acre produced highly significant increases in protein content when applied on the stubble and at seeding time. The topdressing of 50 pounds of nitrogen alone resulted in significant increases in protein content of wheat in three instances. The use of 25 pounds of nitrogen per acre resulted in a significant increase in protein content in only one trial at the Thayer location.

Test Weight Data at Thayer

The fertilizer treatments produced no significant increase or decrease in the test weight of the wheat as indicated by analysis of variance.

Plant Characteristics at Thayer

A highly significant positive correlation was found to exist between the yield of wheat and the height of the wheat plants at harvest time. Most fertilizer treatments produced wheat which was significantly taller than did the no treatment plots.

The application of phosphorus alone failed to produce a significant increase in wheat height. All plots receiving an application of nitrogen at seeding time produced wheat which was significantly greater in height than that of the untreated plots. Several plots which received only a topdressing of nitrogen did not produce wheat which was significantly taller than the untreated wheat. Plots receiving both nitrogen and phosphorus or nitrogen, phosphorus and potash produced wheat of the greatest height.

A significant correlation between wheat yields and the length of the wheat spikes was not found. Twenty-nine different treatments, however, produced wheat spikes which were significantly greater in length than the no treatment plots. All plots receiving $CaCN_2$ as a topdressing produced wheat spikes significantly greater in length than the spikes of untreated wheat. The only treatments which did not result in significant increases in spike length over no treatment were those in which either nitrogen or phosphorus was applied alone.

Yield Data at Belleville

The response of wheat to fertilizer applications at the Belleville location apparently was closely related to the results provided by chemical analyses of the soil. The amount of available phosphorus, as shown by soil tests, was quite high and the use of 50 pounds of P_2O_5 per acre as a soil treatment resulted in no significant increase in yield of wheat.

Exchangeable potassium tests also indicated that the level of potassium was sufficient. The use of potassium fertilizer in combination with nitrogenous and phosphatic fertilizer apparently resulted in no increase in the yield of the wheat when compared to treatments which included similar amounts of nitrogen and phosphoric acid.

All plots receiving an equivalent of 100 pounds of N per acre, whether alone or in combination with phosphorus or phosphorus and potash, produced yield increases which were significantly greater than the yields from untreated plots.

The application of 50 pounds of N per acre resulted in highly significant increases in yield in 21 of 25 treatments. These treatments included nitrogen alone and nitrogen in combination with phosphorus and potash. It is interesting to note that, although the application of 100 pounds of nitrogen per acre did not give consistently significant increases over the 50 pound rate, the yields in every comparison are higher and are significant in 4 of 6 comparisons. There seemingly was little difference in the effectiveness of the time or method of nitrogen application.

Protein Data at Belleville

One-half of the fertilizer treatments produced significant increases in protein content of the wheat at the Belleville location. The application of 100 pounds of nitrogen either alone or in combination with other fertilizers resulted in highly significant increases in all instances. Nitrogen alone resulted in the greatest increase in protein. Nitrogen at the rates of 25 pounds per acre and 50 pounds per acre did not consistently increase the protein content of the wheat. As shown by analysis of variance, the time or method of application of the nitrogen had little influence on the protein content. Nitrogen applied alone at seeding time did, however, result in highly significant increases on all such plots.

Test Weight Data at Belleville

No significant increases or decreases in the test weight of the grain were produced by fertilizer treatments. The difference between the highest test weight and lowest test weight recorded was only 1.5 pounds per bushel.

Yield at Goddard

Chemical analysis of the soil at the Goddard location showed that there was considérable total phosphorus present in the soil. The supply of available phosphorus, as shown by this analysis, however, was deficient. This apparent deficiency, as shown by the soil analysis, was verified inasmuch as an application of 50 pounds of P_2O_5 per acre in the form of superphosphate produced significant increases in the yield of wheat.

Nitrogen alone applied at the rate of 25 pounds of N per acre failed to produce significant increases in yield. Nitrogen applied as a topdressing on plots which had received no additional treatment did not significantly increase the yield. A combination of 25 pounds of nitrogen per acre plus 50 pounds of P_2O_5 per acre increased the yield of wheat significantly over phosphorus alone or nitrogen alone. In most cases a combination of nitrogen and phosphorus produced the greatest yield. The yields on plots receiving more than 25 pounds of nitrogen per acre plus 50 pounds of P_2O_5 were not great enough to be significantly above those of the lower rate.

Although no significant differences were obtained by different times and methods of application of nitrogen, applications later than March 10 had the tendency to produce yields somewhat below those of the earlier applications.

Potash in combination with nitrogen and phosphorus fertilizer materials failed to increase yields significantly over nitrogen and phosphorus combination where similar amounts of N and P_2O_5 were provided.

Protein Data at Goddard

Protein data for the wheat from the various fertilizer treatments at the Goddard location provided results similar to those of the Belleville and Thayer locations inasmuch as all plots which received the equivalent of 100 pounds of nitrogen per acre produced significant increases in the protein content of the grain. Nitrogen alone applied at the rates of 25 and 50 pounds of N per acre significantly increased the protein content of the grain on all plots except one. All plots which received topdressings of $CaCN_2$ plus phosphorus and potash at seeding time failed to significantly increase the protein content. The time of application of the nitrogen apparently influenced very little the protein content of the grain under conditions experienced in this experiment.

Test Weight Data at Goddard

None of the fertilizer treatments produced a significant increase in the test weight of wheat over that of no treatment. No significant decreases in test weight were produced by any of the treatments used in this investigation.

Table 22. A comparison of nitrogen broadcast on stubble and nitrogen at seeding, wheat fertilizer experiments, 1947-48.*

Location	N Broadcast	N at seeding
	Bushels per acre	
Thayer	43.9	50.2
Belleville	39.9	40.8
Goddard	21.3	21.4

*Average of 3 replications and 9 treatments.

Table 23. A comparison of various rates of nitrogen fertilizer with 50# P_2O_5 and No P_2O_5, wheat fertilizer experiments, 1947-48.*

Location	Lbs. of nitrogen No P_2O_5				Lbs. of nitrogen with P_2O_5			
	0	25	50	100	0	25	50	100
	Bushels per acre							
Thayer	28.0	40.5	35.9	37.8	40.7	52.1	56.3	56.3
Belleville	31.3	36.9	40.2	43.1	27.1	36.1	38.0	47.2
Goddard	13.8	17.7	18.6	17.9	17.8	22.9	23.8	26.1

*Average of 3 replications at each location.

Table 24. Increase from various treatments over no treatment plots, wheat fertilizer experiments, 1947-48.*

Location	Treatments						
	0-50-0	25-0-0	50-0-0	100-0-0	25-50-0	50-50-0	100-50-0
	Bushels per acre						
Thayer	12.7	12.5	7.9	9.8	24.1	28.3	28.3
Belleville	-4.2	5.6	8.9	11.8	4.8	6.7	15.9
Goddard	4.0	3.9	4.8	4.1	9.1	10.0	12.3

*Average increase from 3 replications at each location.

Table 25. A comparison of ammonium nitrate and calcium cyanamid, wheat fertilizer experiments, 1947-48.*

Location	Source of nitrogen	
	NH_4NO_3	$CaCN_2$
	Bushels per acre	
Thayer	53.0	50.7
Belleville	40.5	34.7
Goddard	21.8	19.5

*Average of applications on Dec. 20, Feb. 20, March 10, and March 30.
Rate of fertilizer 50-50-25# per acre.

Table 26. Wheat yields with and without potassium, wheat fertilizer experiments, 1947-48.*

Location	25# K_2O	No K_2O
	Bushels per acre	
Thayer	53.7	53.2
Belleville	40.0	40.6
Goddard	22.1	22.8

*Average of 3 replications and 10 treatments.

Table 27. A comparison of time of application of 50 pounds of nitrogen per acre, wheat fertilizer experiment, 1947-48.*

Location	Time of application				
	Seeding	Dec. 20	Feb. 20	Mar. 10	Mar. 30
	Bushels per acre				
Thayer	50.5	51.1	51.0	46.7	44.0
Belleville	40.6	41.6	39.8	40.0	40.9
Goddard	21.2	19.1	19.7	21.1	19.4

*Average of 3 replications and 3 treatments (50-50-25
(50-50-0
(50-0-0

Supplemental Discussion

In order that comparisons could be made between the different treatments at the various locations, simple averages were calculated for the different treatments. These comparisons are shown in Tables 22 to 27, inclusive.

A comparison of the use of ammonium nitrate and calcium cyanamid as a source of nitrogen fertilizer is shown in Table 25. Very little difference in yield resulted from the use of these two nitrogen carriers at the Thayer and Goddard locations. At the Belleville location, however, ammonium nitrate produced average yields which were 5.8 bushels higher than those produced by the use of calcium cyanamid. This difference was probably due to the toxic effect which existed as a result of the application of the calcium cyanamid. Many of the wheat plants showed symptoms of being burned after the calcium cyanamid was applied as a top-dressing.

As shown by Table 26, the use of 25 pounds of potash per acre did not result in consistent increases in yield at the three locations. A slight increase was obtained only at the Thayer location and it was not statistically significant.

At the Thayer location the application of 50 pounds of nitrogen gave highest average yields when applied before the March 10 date. Little difference existed between the yields obtained by the various dates of application of nitrogen at the Belleville and Goddard locations.

Nitrogen applied at seeding time produced higher average yields than nitrogen broadcast on the stubble at all locations. The difference between the average yields was very slight at the Belleville and Goddard locations. It amounted to less than one bushel per acre in both cases. The difference was much greater at the Thayer location with a 6.3 bushel per acre greater average yield obtained by applying the nitrogen at seeding time.

Table 23 presents the average yields obtained by the use of various rates of nitrogen applied with and without the addition of phosphorus. The equivalent of 25 pounds of nitrogen per acre at the Thayer location, 100 pounds at the Belleville location and 50 pounds at the Goddard location resulted in the highest average yields where P_2O_5 was not applied. However, the only rate of nitrogen which produced statistically significant increases over the 25 pound rate was the 100 pound application at Belleville.

When 50 pounds of P_2O_5 were applied to the soil, the average yields at all the locations increased as the rates of nitrogen were increased. There apparently was little advantage in applying more than 25 pounds of nitrogen per acre except at the Belleville location since this was the only location where more than 25 pounds of N produced significant increases in yield.

A combination of nitrogen and phosphorus at the rates of 25 pounds of N and 50 pounds of P_2O_5, respectively, resulted in the highest significant increases at Thayer and Goddard. At the Belleville location a combination of 100 pounds of N plus 50 pounds of P_2O_5 gave the highest significant increase over no treatment plots.

SUMMARY AND CONCLUSION

The data obtained in this experiment suggest the following conclusions:

1. Highly significant increases in yield were produced at the Thayer, Goddard and Belleville locations by the application of commercial fertilizers.

2. A combination of nitrogen and phosphorus fertilizer materials gave the greatest increases in yield at all locations.

3. The use of potassium-bearing fertilizer in addition to nitrogen and phosphorus did not result in a statistically significant increase in yield at any of the locations.

4. The use of superphosphate alone so as to provide 50 pounds of P_2O_5 per acre gave significant increases in yield at the Thayer and Goddard locations but failed to significantly increase the yields at Belleville.

5. The application of nitrogenous fertilizer so as to provide 50 or 100 pounds per acre of nitrogen did not significantly increase the yields over those yields received from the use of 25 pounds of nitrogen per acre.

6. Apparently there was a greater increase in yield resulting from the use of the 50 and 100 pound rates of nitrogen at the Belleville location than at either Thayer or Goddard.

7. The time of application of nitrogen fertilizer influenced very little the increase of wheat yields as produced under conditions in this experiment.

8. There were no significant differences between the increase

in yield produced by the use of calcium cyanamid and that produced by the use of ammonium nitrate.

9. The application of nitrogen fertilizer at the rate of 100 pounds of nitrogen per acre whether alone or in combination with phosphatic or potassic fertilizers significantly increased the protein content of the grain at all locations.

10. Nitrogen applied alone produced the greatest increases in protein content of the wheat.

11. The test weight of wheat, as produced under conditions of these experiments, was not significantly influenced by fertilizer applications.

12. Both the wheat height and the length of the wheat spikes were increased by the use of fertilizers at the Thayer location.

13. A significant correlation was found to exist between the yield of wheat and its height at the Thayer location.

14. No significant correlation existed between the yield of wheat and the length of the wheat spikes as indicated by the data obtained in this investigation.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Dr. Floyd W. Smith, Major Instructor, for his interest and valuable guidance in the research work and preparation of this thesis.

Acknowledgment is also due Dr. H. E. Myers, Head, Department of Agronomy, for his suggestive criticisms.

The author desires to acknowledge the financial support provided by the Spencer Chemical Company and the cooperation provided by the farmers on whose land these experiments were conducted.

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