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Fertilizing Wheat for Yield and Quality

By H. F. Murphy

OKLAHOMA AGRICULTURAL EXPERIMENT STATION
Oklahoma A. and M. College, Stillwater
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For Good Yields and High Protein . . .

The 20 years of research on wheat fertilization reported in this bulletin show that:

Phosphorus fertilization increases wheat yields but decreases the protein content of the grain.

Nitrogen fertilization increases the protein content.

Other experiments at the Oklahoma Station and elsewhere show definitely that *legumes increase the yields of succeeding crops.*

These facts are of great significance to Oklahoma wheat farmers and to the state's grain and milling industry. Many Oklahoma soils already need phosphorus fertilizer to increase yields, and more will need it in the future.* When phosphate is used to get better yields of wheat, the soil must have a good supply of nitrogen to keep up the percentage of protein in the grain. *This means that the use of legumes, organic matter and nitrogen fertilizers is becoming increasingly important in the management of Oklahoma wheat soils.* Since nitrogen fertilizer is expensive, and enough manure is not available, legume crops can be profitably grown on many Oklahoma wheat soils to add nitrogen for both higher yields and satisfactory protein content.

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* A simple chemical test will show whether a soil needs phosphorus. Your county agent can make this test for you.

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Fertilizing Wheat for Yield and Quality

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Yield is still the yardstick in wheat production, but both the grower and the industry are also definitely interested in quality. More and more importance is being attached to the chemical composition of the grain and how it is changed by climate, soil, fertilizers, and other factors.

This bulletin reports a group of experiments made to determine not only the effect of commercial fertilizers upon yield, but also their effect on the quality of grain, flour and bread. These tests were made at the Oklahoma Agricultural Experiment Station between 1924 and 1944. The group of experiments include:

1. A complete triangular fertilizer test extending from 1924 to 1937.
2. Related experiments:
   a. Residual effects of fertilizers.
   b. Fertilization at lighter rates.
   c. Different forms of nitrogen fertilizer.
   d. Different times of applying nitrogen fertilizer.

Observations were also made on suitability of the growing wheat for pasture. The Turkey variety of wheat was used in all tests.

Measures of Quality.—Yield is easily measured, but as yet no means of accurately defining and measuring wheat quality has been devised. Common measures of quality are test weight per bushel and protein content, but these criteria do not always agree with milling and baking results.

Soil Used for the Experiments.—The soil used for these experiments is typical of many Oklahoma wheat soils in profile, composition, and topography. It is classified as Kirkland loam to very fine sandy loam. The surface is dark brown in color. A lighter brown dense clay subsoil is encountered at a depth of about 14 inches; this limits moisture penetration and restricts root develpment: Small grains do well on this soil, but summer-growing crops may suffer because of a moisture deficiency as the season advances. The particular soil used for this investigation had a low supply of available phosphorus. It had a nitrogen content of 1420 pounds per acre in the approximate plow zone,* which is not unlike the nitrogen content of many wheat soils in Oklahoma.

* This is the nitrogen content of the surface 6⅔ inches of soil, or more accurately the nitrogen content of the surface 2,000,000 pounds of unfertilized soil at the end of the experiment.

TRIANGULAR EXPERIMENT, 1924-1937

The original experiment was started in 1924 to study the effect of fertilizers on yield. Beginning with the 1928 crop, data were also taken on grain and flour characteristics.

The fertilizer treatments used are given in Table I. The relative proportions of nitrogen, phosphorus and potassium applied to the several plots are shown graphically in Figure 1. The numbers in Figure 1 are the plot numbers as listed in Table I. The plots along the base line received no nitrogen, while the apex (plot 21) represents a treatment consisting of nitrogen alone. Plots shown between the base line and the apex received varying amounts of nitrogen, with the amount increasing toward the top of the triangle. The lower left-hand corner plot (plot 16) received potash only, while the plot represented at the lower right-hand corner (plot 2) received only superphosphate. Thus, nitrogen is the principal fertilizer for the plots shown in the upper one-third of the triangle, potash for those in the lower left-hand one-third, and phos-

TABLE I.—Fertilizer Treatments of Plots in Triangular Experiment.

Plot No.*	Annual Treatment
1	Unfertilized
2	300 pounds superphosphate
3	225 pounds superphosphate, 75 pounds kainit
4	225 pounds superphosphate, 75 pounds nitrate of soda
5	Unfertilized
6	150 pounds superphosphate, 150 pounds kainit
7	150 pounds superphosphate, 75 pounds nitrate of soda, 75 pounds kainit
8	150 pounds superphosphate, 150 pounds nitrate of soda
9	75 pounds superphosphate, 225 pounds kainit
10	Unfertilized
11	75 pounds superphosphate, 75 pounds of nitrate of soda, 150 pounds kainit
12	75 pounds superphosphate, 150 pounds nitrate of soda, 75 pounds kainit
15	Unfertilized
16	300 pounds kainit
17	75 pounds nitrate of soda, 225 pounds kainit
18	150 pounds nitrate of soda, 150 pounds kainit
19	Unfertilized
20	225 pounds nitrate of soda, 75 pounds kainit
21	300 pounds nitrate of soda
23	Unfertilized
27	75 pounds superphosphate, 225 pounds nitrate of soda

* The missing plots are fertilized with other materials not included in the triangular system.

phorus for those in the lower right-hand one-third. Plots in the center of the triangle received fertilizers containing nitrogen, phosphorus and potash.

The fertilizers were usually applied in the fall following the seeding of the wheat by broadcasting them on the surface of the ground. In some instances they were applied broadcast and worked into the soil in the final preparation of the seed-bed just before planting.

The data collected are summarized in Tables II and III (pages 9 and 14) and in Figures 2 to 15.

Effect on Yield and Growth

Grain Yield

All fertilizers containing phosphorus gave higher grain yields than other fertilizer combinations. Yet phosphorus alone was not sufficient to attain the highest yield. For both

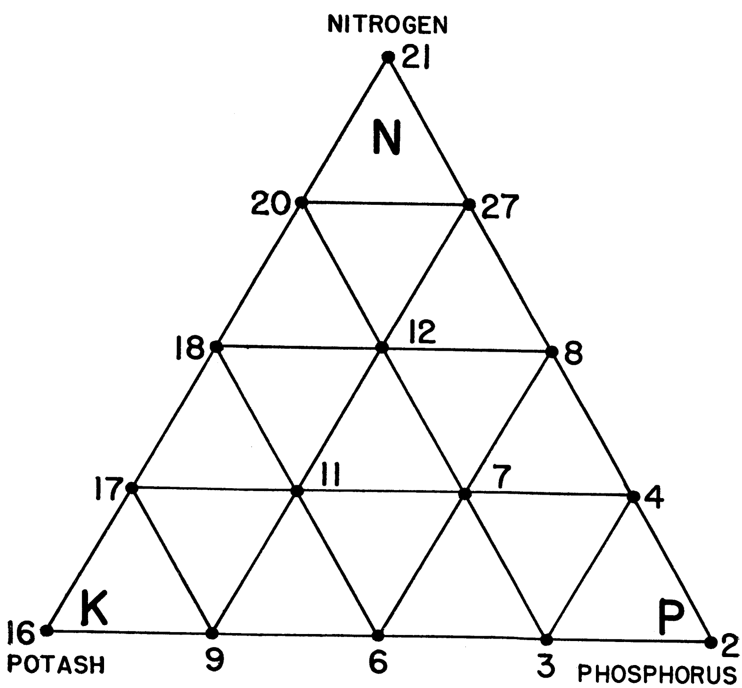


Fig. 1.—Plot numbers and relationship of the several treatments in triangular experiment. See Table I for treatments. (Unfertilized plots listed in Table I are not shown here.)

the 10-year and 13-year periods (Figures 2 and 3) the highest average yield per acre was secured when the fertilizer consisted of three-fourths superphosphate and one-fourth nitrate of soda (Plot 4.) A fertilizer consisting of one-half superphosphate and one-half kainit (Plot 6) was a close second.

Nitrogen and potash, either together or singly, were not effective in increasing the yield of wheat on this soil. In fact, the yield was less with the higher nitrogen supply.

MATURITY

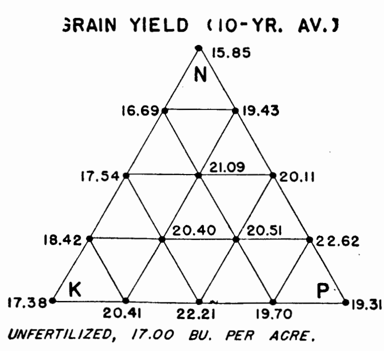
The reduced yields from plots receiving a larger proportion of nitrogen was related to the later maturity of such plots, which often produced shrivelled grain. Wheat that matures late often suffers yield decreases in Oklahoma because of the rapid temperature rise which usually occurs early in June.

Superphosphate and potash, or superphosphate alone, gave the earliest maturity (Plots 3, 9, 6, and 2, in that order). Potash alone had little effect on maturity.

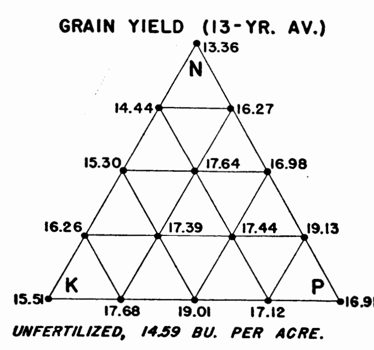
Plot 8, which received one-half superphosphate and one-half nitrate of soda, was the latest phosphate plot to mature. Wheat on this plot made a very vigorous growth, but the nitrogen tended to delay maturity slightly and, therefore, to reduce the yield. This was also reflected in lower test weight per bushel and in lower weight of 100 kernels (See page 10).

SEASONAL GROWTH

The phosphated plots always presented a more thrifty appearance during the growing season, although in some years



Grain Yield (10-yr. av.)
Fig. 2.—Ten-year average grain yield (1928-37) in bushels per acre.

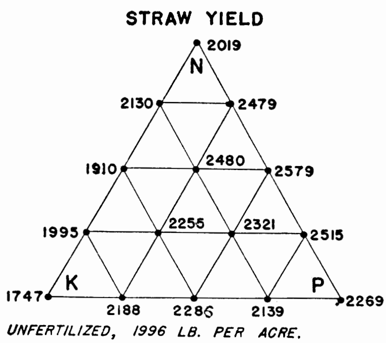


Grain Yield (13-yr. av.)
Fig. 3.—Thirteen-year average grain yield (1925-37) in bushels per acre.

TABLE II.—*Summary of Data on Yields and Grain Characteristics. (10-year average, 1928 to 1937, except as indicated.)*

Plot	Treatment[1] (Pounds per acre)	GRAIN YIELD (Bu. per A.) 13-yr. av.	GRAIN YIELD (Bu. per A.) 10-yr. av.	Straw Yield (Lbs. per acre)	Test Weight (Lbs. per bu.)	Weight of 100 kernels (grams) d	Phosphorus in grain (percent)	Protein in grain (percent)
2	300 SP	16.91	19.31	2269	58.39	2.568[b]	0.347[a]	11.38
3	225 SP, 75 K	17.12	19.70	2139	58.69	2.616	0.338	11.39
4	225 SP, 75 N	19.13	22.62	2515	57.81	2.405	0.325	12.66
6	150 SP, 150 K	19.01	22.21	2286	58.59	2.585	0.330	11.66
7	150 SP, 75 K, 75 N	17.44	20.51	2321	57.91	2.440	0.312	13.17
8	150 SP, 150 N	16.98	20.11	2579	56.81	2.301	0.331	14.33
9	75 SP, 225 K	17.68	20.41	2188	58.59	2.675	0.296	12.54
11	75 SP, 150 K, 75 N	17.39	20.40	2255	58.32	2.587	0.291	13.48
12	75 SP, 75 K, 150 N	17.64	21.09	2480	57.90	2.449	0.292	14.58
16	300 K	15.51	17.38	1747	58.04	2.489	0.310	12.77
17	225 K, 75 N	16.26	18.42	1995	57.99	2.583	0.285	13.15
18	150 K, 150 N	15.30	17.54	1910	57.80	2.458	0.271	14.53
20	75, K, 225 N	14.44	16.69	2130	57.41	2.431	0.254	14.75
21	300 N	13.36	15.85	2019	56.65	2.378[b]	0.254	15.53
27	75 SP, 225 N	16.27	19.43	2479	56.53[a]	2.271[b]	0.254[c]	14.74
	Unfertilized	14.59	17.00	1996	57.52	2.407	0.278	13.11

[1] SP=superphosphate; K=kainit; N=nitrate of soda. (See Table I.)
[2] a, 9-year average; b, 6-year average; c, 8-year average; d, 7-year average.



Straw Yield
Fig. 4.—Yield of straw in pounds per acre. (Ten-year average, 1928-37.)

superphosphate alone was not quite so good in this respect as a combination of 150 pounds or more of superphosphate with other nutrients. The phosphated plots showed a pronounced fall growth compared with the untreated plots. They made more vegetative growth and dfeinitely would have furnished more fall pasture.

During some seasons the wheat was somewhat pale green early in the spring where superphosphate was used alone. This evidently was due to a lack of available nitrogen since this color was not apparent where the fertilizer contained some nitrogen.

The wheat plants developed a better crown and root system during the fall on the phosphated plots than on the other plots. However, the wheat tended to lodge somewhat worse on the phosphated plots when adverse weather conditions, such as excessive rainfall and wind, prevailed during the later stages of growth. Plots 8 and 4, which received 150 and 75 pounds of nitrate of soda respectively in addition to superphosphate, were affected more than the others by lodging.

Straw Yield

The vigorous vegetative growth of wheat grown on plots receiving both nitrogen and phosphorus is reflected in the straw data (Figure 4). Phosphorus alone increased straw; nitrogen alone had practically no effect; and potash decreased straw yields to some extent.

Effect on Grain Quality

Test Weight and Kernel Plumpness

The plumpest kernels were produced on plots which received a mixture of superphosphate and potash. This is reflected in the weight of 100 kernels and also in test weight per bushel (Figures 5 and 6.) Plots which received considerable nitrogen produced wheat with lower kernel and test weights, and the kernels were often shrivelled.

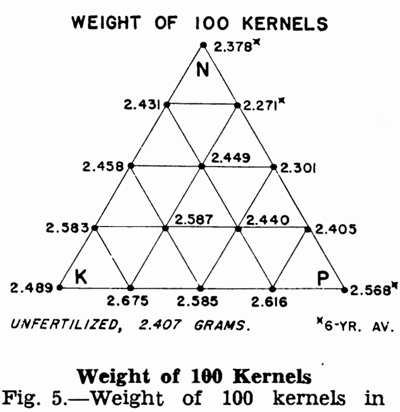
Phosphorus and Protein in Grain

An application of 150 pounds or more of superphosphate per acre increased the phosphorus content of the grain appreciably (Figure 7.) Seventy-five pounds of superphosphate per acre, except where the rest of the fertilizer was all nitrogen (Plot 27), increased the phosphorus content to some extent. Over 150 pounds of nitrate of soda per acre decreased the phosphorus content of the grain.

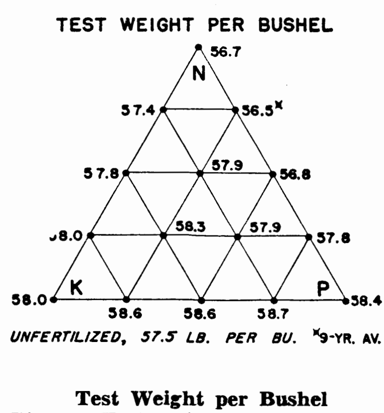
On the other hand the protein content of the wheat (Figure 8) was increased by nitrogen fertilization and was decreased by phosphorus fertilization. Potash fertilization had little effect.

Good Combinations for Yield and Protein

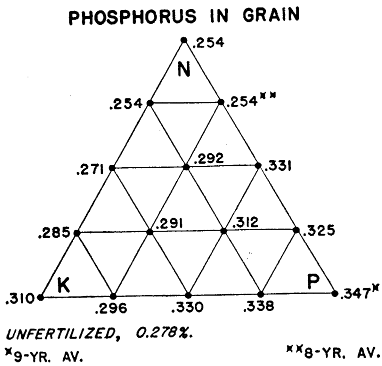
Considering both yield per acre and protein content, a fertilizer made by mixing two parts of nitrate of soda and one part of each of superphosphate and kainit (Plot 12) produced very good results. The yield was not quite as high (21.09 bushels) as when the fertilizer contained one part of nitrate of soda and three parts of superphosphate (Plot 4), but the protein content was considerably better (14.58 percent compared with 12.66 percent). The latter fertilizer mixture would be preferable, however, since the protein content (12.66 percent) is still within the range of wheat making good flour, the cost of the fertilizer is less, and the extra yield was 1.53 bushels per acre.



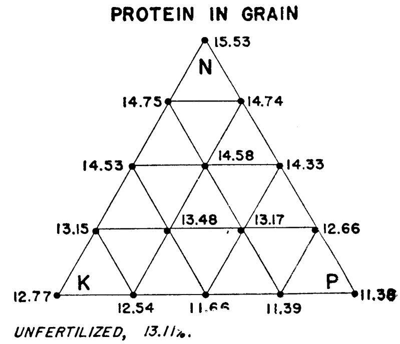
Weight of 100 Kernels
Fig. 5.—Weight of 100 kernels in grams. (Seven-year average, 1929-37. No data were collected in 1931 and 1933.)



Test Weight per Bushel
Fig. 6.—Test weight in pounds per bushel. (Ten-year average, 1928-37.)



Phosphorus in Grain
Fig. 7.—Phosphorus content as percent of whole wheat grain. (Ten-year average, 1928-37.)



Protein in Grain
Fig. 8.—Percentage of protein in grain. (Ten-year average, 1928-37.)

Effect on Flour

Yield

The yield of flour per 100 pounds of wheat (Figure 9) showed no outstanding differences among the several treatments nor between the treated and untreated plots, although there was a tendency for the yield of flour to increase slightly when potash was included in the fertilizer.* Superphosphate alone gave a slightly lower flour yield than when no fertilizer was used, but the difference was insignificant.

Ash Content

There were no significant differences in the ash content of the flours (Figure 10), although the fertilizers containing the higher phosphorus and potash contents produced flour with a very slightly higher ash content. Wheat from unfertilized soil produced a flour with 0.412 percent ash content, while the highest ash content for any of the treatments was 0.439 percent.

Protein

The protein in the wheat was reflected in the protein content of the flour (Figure 11), and the general discussion given for protein in wheat applies. It can be summed up in the statement that potash had little effect, phosphorus lowered the percentage of protein, and nitrogen increased the percentage of protein.

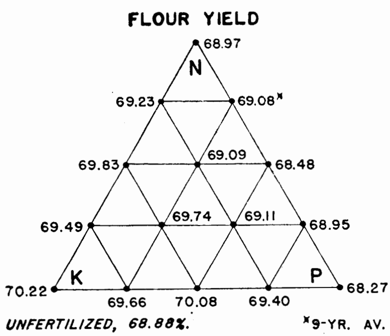
* With no potash the average flour yield was 68.75 percent; with one-fourth of the fertilizer a potash fertilizer, 69.21 percent; one-half, 69.88; three-fourths, 69.58 percent; and where all of the fertilizer was a potash carrier, 70.22 percent.

Water Absorption

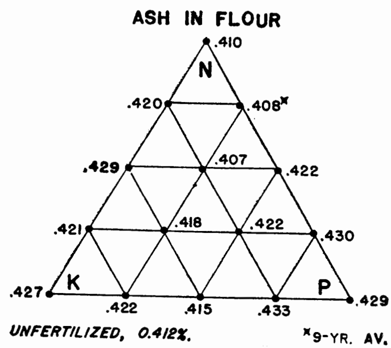
Little variation occurred in the percentage of water absorption by the several flours (Figure 12). The total range in absorption of water was 57.1 percent to 58.1 percent, with 58.0 percent for flour produced from unfertilized wheat.

Baking Characteristics

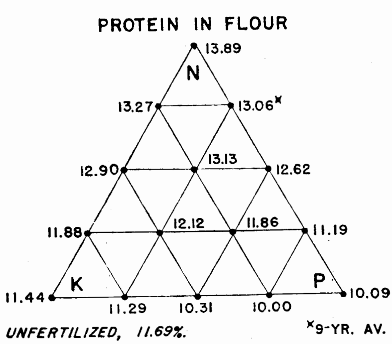
Loaf Volume.—All of the flours made nice test loaves. However, flour from plots treated with superphosphate alone or with superphosphate and potash (especially when superphos-



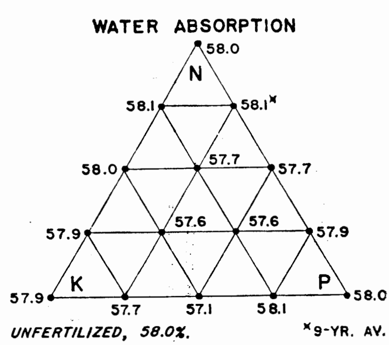
Flour Yield
Fig. 9.—Flour yield; pounds of flour per 100 pounds of wheat. (Ten-year average, 1928-37.)



Ash in Flour
Fig. 10.—Ash content of flour expressed in percent. (Ten-year average, 1928-37.)



Protein in Flour
Fig. 11.—Percentage of protein in flour, calculated on a 13.5 percent moisture basis. (Ten-year average, 1928-37.)

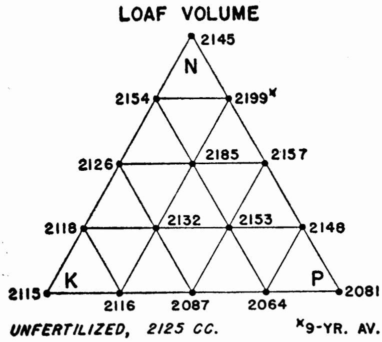


Water Absorption
Fig. 12.—Water absorption of flour (percent). (Ten-year average, 1928-37.)

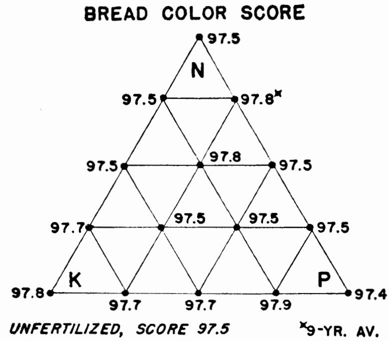
TABLE III.—Summary of Data on Flour and Bread Quality.
(10-year average, 1928 to 1937.)

Plot	Treatment[1] (Pounds per acre)	FLOUR CHARACTERISTICS				BREAD CHARACTERISTICS		
		Yield (Pct.)	Ash Content (Pct.)	Protein (Pct.)	Absorption (Pct.)	Loaf Volume (Cubic centimeters)	Texture Score	Color Score
2	300 SP	68.27	0.429	10.09	58.0	2081	97.3	97.4
3	225 SP, 75 K	69.40	0.433	10.00	58.1	2064	97.6	97.9
4	225 SP, 75 N	68.95	0.430	11.19	57.9	2148	97.5	97.5
6	150 SP, 150 K	70.08	0.415	10.31	57.1	2087	97.4	97.7
7	150 SP, 75 K, 75 N	69.11	0.422	11.86	57.6	2153	96.9	97.5
8	150 SP, 150 N	68.48	0.422	12.62	57.7	2157	97.5	97.5
9	75 SP, 225 K	69.66	0.422	11.29	57.7	2116	97.0	97.7
11	75 SP, 150 K, 75 N	69.74	0.418	12.12	57.6	2132	97.2	97.5
12	75 SP, 75 K, 150 N	69.09	0.407	13.13	57.7	2185	97.7	97.8
16	300 K	70.22	0.427	11.44	57.9	2115	97.7	97.8
17	225 K, 75 N	69.49	0.421	11.88	57.9	2118	97.5	97.7
18	150 K, 150 N	69.83	0.429	12.90	58.0	2126	97.3	97.5
20	75 K, 225 N.	69.23	0.420	13.27	58.1	2154	97.5	97.5
21	300 N	68.97	0.410	13.89	58.0	2145	97.1	97.5
27	75 SP, 225 N	69.08[a]	0.408[a]	13.06[a]	58.1[a]	2199[a]	98.1[a]	97.8[a]
	Unfertilized	68.88	0.412	11.69	58.0	2125	97.6	97.5

[1] SP=superphosphate; K=kainit; N=nitrate of soda. (See Table I.)
[2] a, 9-year average.



Loaf Volume
Fig. 13.—Test loaf volume in cubic centimeters. (Ten-year average, 1928-37.)

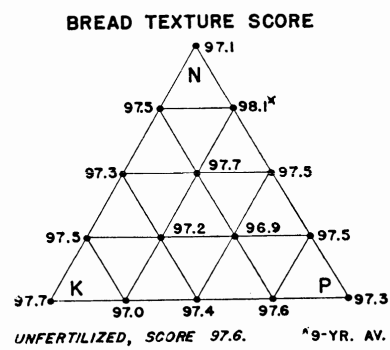


Bread Color Score
Fig. 14.—Color score of bread. (Ten-year average, 1928-37.)

phate made up one-half or more of the mixture) produced loaves of slightly less volume. Nitrogen raised the loaf volume somewhat.

The lowest loaf volume from any of the fertilized plots was 2064 cc., which is about 2.9 percent less than from unfertilized wheat (Figure 13.) This plot received 3 parts of superphosphate and 1 part of kainit.

The wheat from the highest yielding plot (Plot 4) made a very nice loaf of slightly greater volume than that from unfertilized wheat. This plot received 3 parts of superphosphate and 1 part of nitrate of soda.



Bread Texture Score
Fig. 15.—Texture score of bread. (Ten-year average, 1928-37.)

Color and Texture.—All of the breads had good color and texture scores, and variations were slight (Figures 14 and 15). Bread from unfertilized wheat averaged 97.6 in texture score and the range for the treated plots was 96.9 to 98.1. The color score of bread from unfertilized wheat averaged 97.5 while the range for the treated plots was 97.4 to 97.8.

RELATED EXPERIMENTS

Residual Effects of Fertilizers

The plots used in the triangular experiment were fertilized for the last time in the fall of 1936, for the 1937 crop. Growing of wheat on these plots was continued, however, to determine the residual effects of the previous fertilizer treatments.

PHOSPHORUS ACCUMULATION IN SOIL

In 1939, soil samples from all the plots were analyzed for easily soluble phosphorus. Those which had received phosphate were much higher in this fertilizer element than were the untreated plots (Table IV). Phosphorus in a rather soluble form had accumulated in the surface soil of the phosphate-treated plots, and to some extent in the subsurface.

GRAIN YIELD

The increase in soil phosphorus is reflected in the yields secured since the termination of fertilizer applications (Table V and Figure 16). The residual effects of superphosphate following 13 years of application have been pronounced in keep-

TABLE IV.—Easily Soluble Phosphorus in Soil After 13 Years' Treatment.*

Annual Application for 13 Years	EASILY SOLUBLE PHOSPHORUS (PARTS PER MILLION) 0-6 in.	7-12 in.	13-18 in.
225 to 300 pounds superphosphate	18+ (medium)	11	4
150 pounds superphosphate	18 (medium)	9	3
75 pounds superphosphate	15 (medium)	5	2.5
Nitrogen and potash only	8+ (low)	4	2—
Untreated	8 (low)	4	2—

* By fifth normal sulfuric acid method. See Okla. Exp. Sta. Bul. 205.

TABLE V.—Residual Effects of Fertilizers Applied in Triangular Experiments; Average 1938-44.

Previous Treatment	Yield (Bu. per A.)	GAIN OVER UNTREATED PLOTS Bushels	Percent
Unfertilized	13.31		
No superphosphate*	14.61	1.30	9.7
75 lbs. superphosphate	17.87	4.56	32.7
150 lbs. superphosphate	19.63	6.32	47.4
225 lbs. superphosphate	22.24	8.93	67.1
300 lbs. superphosphate	21.31	8.00	60.1

* Fertilized with nitrogen, potash, or combinations of these two.

ing up yields, while the effect of nitrogen and potash has been very much less.

On adjoining plots not included in this triangular experiment, a treatment of 150 pounds of superphosphate and 50 pounds of nitrate of soda per acre annually for the period 1925-37 inclusive resulted in an average residual yield (1938-44) of 19.82 bushels per acre, while untreated soil yielded only 10.57 bushels. This represents a gain of 87 percent.

Phosphorus-Nitrogen Relationship

There has been a tendency for the plots which had received the higher phosphate treatments to show considerable yellowing of the vegetation during the fall and spring, indicating a lack of sufficient nitrogen to take care of the vegetative growth. This is very pronounced some seasons.

In 1944 a light application of nitrogen to a portion of each of these plots quickly changed the color of the vegetation dark green. In this case the soil with the extra phosphorus needed the nitrogen in order to give a better balance for plant growth.

Similar color characteristics may be due to other causes. For example, on rather rich bottom land which was somewhat too cold and wet for good wheat growth in the spring of 1944, a treatment of 100 pounds of ammonium nitrate per acre was made. The wheat quickly turned dark green in color, grew off well, and yielded 18.47 bushels of grain and 2628 pounds of straw per acre. The yield on adjoining untreated soil was 14.37 bushels of grain and 1722 pounds of straw. This was a case where the cold, wet soil was retarding nitrogen availability.

Foot Rot

Dry foot rot was very serious on the plots in 1943. The yields on all plots were very low, and on some of the previously untreated plots the wheat was a complete failure. The disease was less severe on plots which had previously received prosphate fertilizers, indicating that wheat on soils well supplied with prosphorus is less liable to injury from this disease.

Test Using Lighter Fertilizer Applications

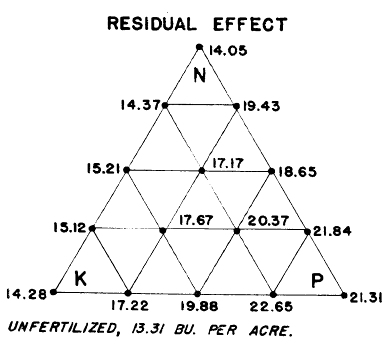
In 1936 a series of plots on Kirkland loam soil was laid off for a fertilizer test using a total of 150 pounds of fertilizer per acre. The fertilizer treatments are shown in Table VI and the results in Figure 17.

During eight years, the highest yield of grain has been secured using superphosphate alone. This has given an average annual increase of 4.45 bushels per acre at a fertilizer cost of $1.95, or 43.8 cents per bushel.*

During 1925-37 two plots of Kirkland very fine sandy loam were planted to wheat continuously. One plot was left untreated and the adjoining plot received an annual application of 150 pounds of superphosphate and 50 pounds of nitrate of

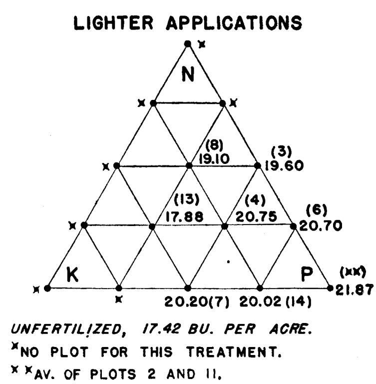
TABLE VI.—Fertilizer Treatments of Plots in Test of Lighter Applications.

Plot	Treatment
2	150 pounds superphosphate.
3	75 pounds superphosphate, 75 pounds nitrate of soda.
4	75 pounds superphosphate, 37.5 pounds kainit, 37.5 pounds nitrate of soda.
6	112.5 pounds superphosphate, 37.5 pounds nitrate of soda.
7	75 pounds superphosphate, 75 pounds kainit.
8	37.5 pounds superphosphate, 37.5 pounds kainit, 75 pounds nitrate of soda.
11	150 pounds superphosphate.
13	37.5 pounds superphosphate, 75 pounds kainit, 37.5 pounds nitrate of soda.
14	112.5 pounds superphosphate, 37.5 pounds kainit.
	Plots 1, 5, 9, 10, 12, 15—Untreated.



Residual Effect

Fig. 16.—Residual effect of fertilizers as shown by yield of wheat in bushels per acre. Average of seven years (1938-44) after application of fertilizer was terminated.



Lighter Applications

Fig. 17.—Yield in bushels per acre with total fertilizer application of 150 pounds per acre. (Eight-year average, 1937-44.) Numbers in parentheses indicate the plot numbers.

* The average cost of superphosphate has been approximately $1.30 per hundred pounds.

soda. The 13-year average yields were 13.06 and 16.74 bushels of wheat respectively.

Effect of Form of Nitrogen on Protein Content

An experiment conducted from 1928 to 1937 compared nitrate of soda and ammonium sulfate as nitrogen sources in relation to protein content of the flour. All applications were at the rate of 16 pounds of nitrogen per acre. The wheat treated with nitrate of soda milled a flour slightly higher in protein than that treated with ammonium sulfate (Table VII).

Effect of Time of Application on Protein Content

Fall vs. Spring Application

The comparison of nitrogen sources was arranged to also give a comparison of fall and spring applications. Fall applications were broadcast at seeding time. Spring applications were made when growth started, usually the first part of March. The general average of results (Table VII) shows little difference between fall and early spring treatments in the protein content of the flour.

Application at Different Stages of Spring Growth

In a four-year test on the 1929 to 1932 wheat crops, nitrate of soda was broadcast at the rate of 100 pounds per acre at different stages of spring growth. The results shown in Table VIII indicate that an available supply of nitrogen at the approximate boot stage of development had the greatest influence on protein content. Light applications of available nitrogen applied early in the spring were largely expended in vegetative growth.

An effect similar to that obtained in this experiment by applying nitrate of soda at boot stage in the spring could be obtained by a fall application of organic matter such as manure. The nitrogen contained in organic substances has a slower availability, therefore some of the organic nitrogen applied in the fall would be made available to the wheat plant during the later stages of its growth in the spring.

Nitrogen could also be supplied in the spring, as well as throughout the entire life of the wheat plant, by growing legume crops in a rotation and returning the legume residues to the soil.

TABLE VII.—Effect of Kind of Nitrogen Fertilizer and Time of Application Upon Protein Content of Flour.

Fertilizer* and time of application	Protein content of flour (percent)										
	1928	1929	1930	1931	1932	1933	1934	1935	1936	1937	Average
Nitrate of soda:											
Fall	12.70	13.85	13.30	13.40	14.50	13.70	12.40	11.40	14.40	14.30	13.40
Spring	13.32	14.20	12.70	14.20	13.20	13.10	12.20	11.90	15.10	15.20	13.51
Ammonium Sulfate:											
Fall	12.20	14.40	12.30	12.10	13.20	13.20	11.80	10.70	13.00	12.70	12.57
Spring	12.55	14.20	11.40	12.80	12.80	11.85	11.90	11.70	14.30	13.40	12.69

* Applications at rate of 16 pounds of nitrogen per acre..

TABLE VIII.—Protein Content of Wheat Fertilized at Different Stages of Growth.

Time of Application	Percent protein in wheat at harvest time				
	1929	1930	1931	1932	Average
Unfertilized	16.00	14.50	12.20	14.45	14.29
At start of Vegetative Growth	15.01	15.00	12.10	16.10	14.55
Jointing Stage	16.27	14.38	13.90	14.70	14.81
Boot Stage	17.19	16.27	15.20	14.80	15.87
Milk to dough stages	16.74	15.61	15.05	14.30*	15.43

* 200 pounds of nitrate of soda applied per acre.

CONCLUSIONS

The percentage of protein in both grain and flour was reduced by phosphorus fertilization and increased by nitrogen fertilization. Potash fertilizer had little effect.

All fertilizers containing phosphorus gave higher grain yields than other combinations. However, a mixture of three-fourths superphosphate and one-fourth nitrate of soda gave higher yields than superphosphate alone. This mixture was the best fertilizer combination tested, considering both yield and protein. Wheat from this plot also made a very nice loaf of bread having slightly greater volume than test loaves from unfertilized wheat.

Phosphate fertilization gave much greater fall growth, and phosphated plots would have furnished considerably more fall pasture.

Color and texture scores of bread were only slightly affected by the different fertilizer treatments.

The residual effect of superphosphate has been pronounced in keeping up yields, although high rates of application of this fertilizer with limited or no nitrogen have shown definite nitrogen deficiency in the wheat plant. The residual effects of nitrogen and potash have been much smaller.

Dry foot rot was less severe in 1943 on plots adequately supplied with phosphate.

Wheat treated with nitrate of soda milled a flour slightly higher in protein than that from plots treated with ammonium sulfate.

In a comparison of fall and spring applications of nitrogen, there was little difference in the protein content of the flours.

Among different times of spring application of nitrogen, protein content was most greatly influenced by available supply of nitrogen at the approximate boot stage of plant growth.

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