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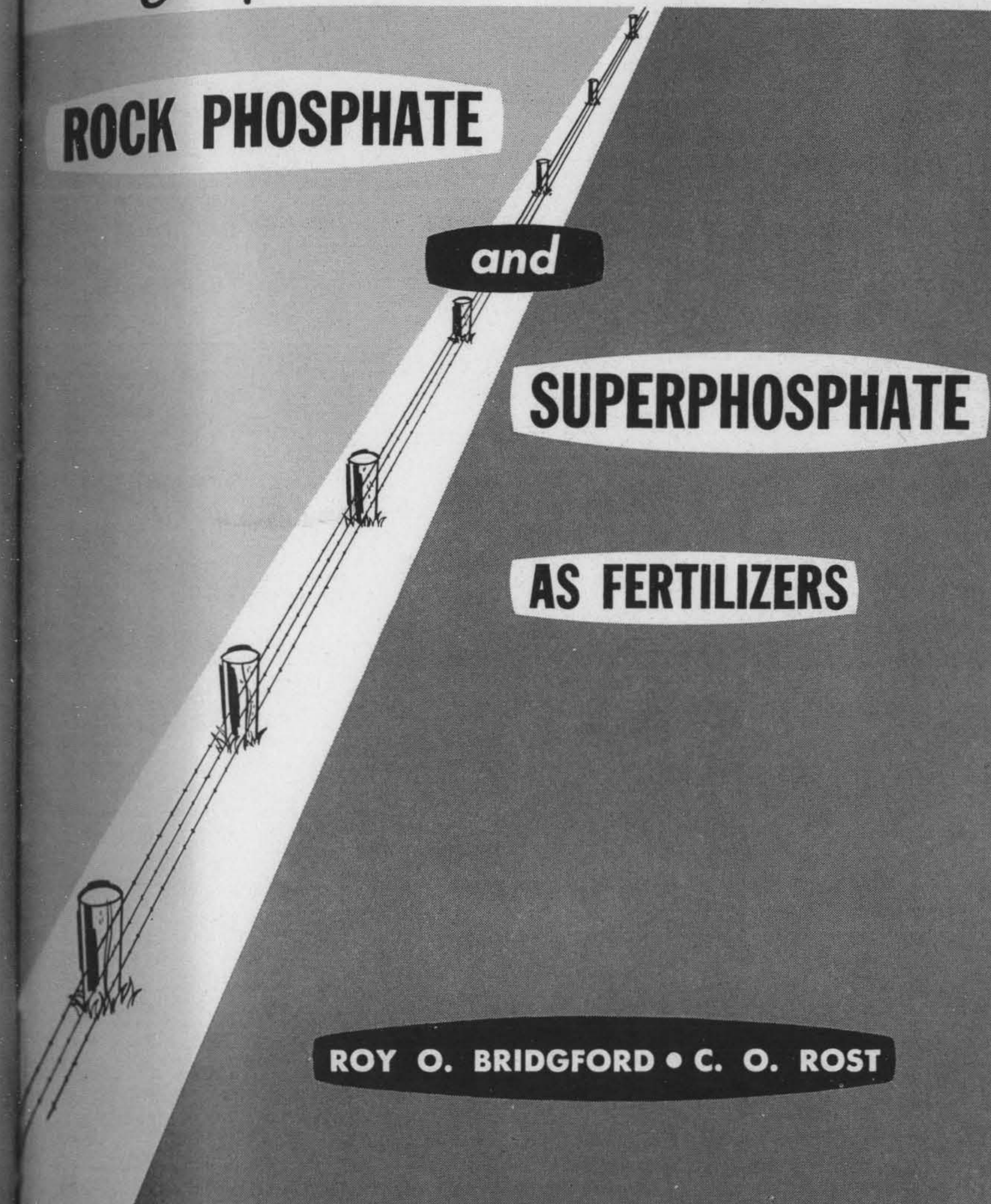

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CONTENTS

ACKNOWLEDGMENTS—Since this bulletin reports the results of experimental work covering 40 years, 1914-54, it is obvious that many investigators made important contributions. However, the authors feel that special mention is due the contributions of the following: F. J. Alway, professor emeritus, head of the Department of Soils, 1914-42; George H. Nesom, assistant professor emeritus, Extension Soils Specialist, 1916-42; the late Paul E. Miller (1888-1954), superintendent of the West Central School and Experiment Station, Morris, 1917-38, and Director of the Agricultural Service, 1938-54; and H. W. Kramer, senior experimental plot supervisor for the Department of Soils.

Comparative Value of Rock Phosphate and Superphosphate as Fertilizers

Roy O. Bridgford and C. O. Rost[1]

WHAT IS THE MOST efficient phosphorus fertilizer? The question is not as simply answered as it could have been a few years ago. Modern technology has produced many different fertilizers containing phosphorus, but superphosphate is still the backbone of the fertilizer industry.

All fertilizer phosphorus comes from phosphate rock-tricalcium phosphate. The phosphorus in the rock is not readily available to crop plants because the natural rock contains 1 to 3 percent of fluorine, and this makes the phosphorus soluble with difficulty. Nevertheless, it has been and still is the practice to grind the rock very finely and use it for fertilizer, since some of the phosphorus becomes available with time. In the fertilizer trade, this finely ground rock is called by various names such as "rock phosphate," "ground rock phosphate," and "raw rock phosphate."

It was found by treating the phosphate rock with an acid, that the phosphorus could be changed to a soluble form and thus be readily available to the growing crop. The acid-treated product is designated as a "superphosphate." The amount or percentage of phosphorus in superphosphate is dependent on the amount of phosphorus in the original rock and the kind of acid used in acidulation.

By treating a high grade of rock with sulfuric acid, a 20 percent P_2O_5 material is produced. In the trade this is presently known as single-superphosphate. When the rock is treated with phosphoric acid, a fertilizer containing 45 to 47 percent phosphate (P_2O_5) is obtained. This is called double-superphosphate or triple-superphosphate. The latter comes from the fact that the original superphosphate contained only 16 percent P_2O_5.

While early practice was to use rock phosphate as a fertilizer because of its low cost and the scarcity of acidulating facilities, the superiority of superphosphate was soon recognized. This gave rise to one school of thought which felt that the extra cost for acidulation was well worth-while. A second school held that even though rock phosphate was a somewhat slower acting material it was more economical to use, applying it at a heavier rate.

The merits of rock phosphate and superphosphate have been studied over a long period of years. Experiments conducted at the Ohio, Indiana, and Illinois Agricultural Experiment Stations are noteworthy. In these states, superphosphate was found to give somewhat greater increases in crop yields than rock phosphate. This was especially true in Ohio and Indiana. Because of the price differential between the two

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fertilizers at that time, Illinois investigators considered the use of rock phosphate more economical. Those at the Ohio Experiment Station felt that superphosphate was enough superior to recommend its use over rock phosphate. The history of the experiments in eastern states along with those obtained in Ohio and Illinois has been reviewed and discussed by Hopkins.[2] Lang[3] reviewed the results obtained in Illinois since Hopkins' time. Recently Collings[4] (p. 225) discussed the comparative value of the two fertilizers.

A pound of P_2O_5 in rock phosphate is lower in cost than a pound in the form of superphosphate. However, since the phosphorus in rock phosphate is not readily soluble it is usually applied at a much heavier rate than superphosphate. This tends to equalize or increase costs. The question then arises as to which form gives the better returns in the form of increased crop yields. This bulletin is concerned with the yield increases obtained in a 40-year experiment comparing the two forms as they affect crops grown in a 4-year and a 3-year rotation.

PLAN OF THE EXPERIMENT

In the spring of 1914 four series (or sets) of plots numbered I to IV were laid out at the West Central Experiment Station at Morris, Minnesota, each set consisting of 18 plots of 6 treatments in triplicate. (See figure 1.)

The treatments and plot numbers on each series were as follows:

Plots 1, 6, 13—No treatment (checks)
Plots 2, 7, 14—Rock phosphate
Plots 3, 8, 15—Rock phosphate and manure
Plots 4, 9, 16—Manure
Plots 5, 10, 17—Superphosphate and manure
Plots 6, 11, 18—Superphosphate

Each series was planted to either corn, wheat, oats (with legume), or hay, and this sequence was followed from 1915 to 1936, inclusive. Thus each crop appeared each year on one of the four series of plots. Five rotations would have normally been completed in 1934. Because of severe drouth, no crops were harvested in 1933 and 1934 so the period was extended to include 1936.

Finely ground Tennessee rock phosphate, 33 percent P_2O_5, was applied at the rate of 1 ton per acre. The first application was made in 1914 and repeated at the same rate in 1926, 1932, 1943, and 1953. Thus plots on which the rock phosphate was applied received 5 tons per acre during the 40-year period. This was equivalent to 3,300 pounds of P_2O_5. The rock phosphate was broadcast in the spring on all series and worked into the soil.

When the experiment was initiated in 1914, superphosphate was applied as 16 percent material at the rate of 480 pounds of fertilizer (76.8 pounds of P_2O_5) per acre every 4 years. As the experiment progressed, 20 percent and then 45 percent superphosphate was used—but the rate of application of 76.8 pounds of P_2O_5 every 4 years was maintained. The total amount of P_2O_5 applied in the 40-year period was 768 pounds per acre. The superphosphate was broadcast in the spring for corn and was worked in when the seedbed was prepared.

Manure was applied at 8 tons per acre preceding the corn crop. This rate is equivalent to 2 tons per acre per year. When the experiments were started in 1914, proportional amounts of manure were applied on the plots to receive manure on each of the series.

One year was required to seed the hay crop and for seeding of a green manure crop to serve as a substitute for the hay crop which preceded corn.

[2] Hopkins, Cyril G. 1910. *Soil Fertility and Permanent Agriculture*. Ginn and Company.
[3] Lang, A. L. 1950. "The use of rock phosphate in Illinois during and since the time of Hopkins." *Proc. Soil Science of Florida*. 10, 47, 1950.
[4] Collings, Gilbreath H. 1955. *Commercial Fertilizers*. McGraw-Hill, New York.

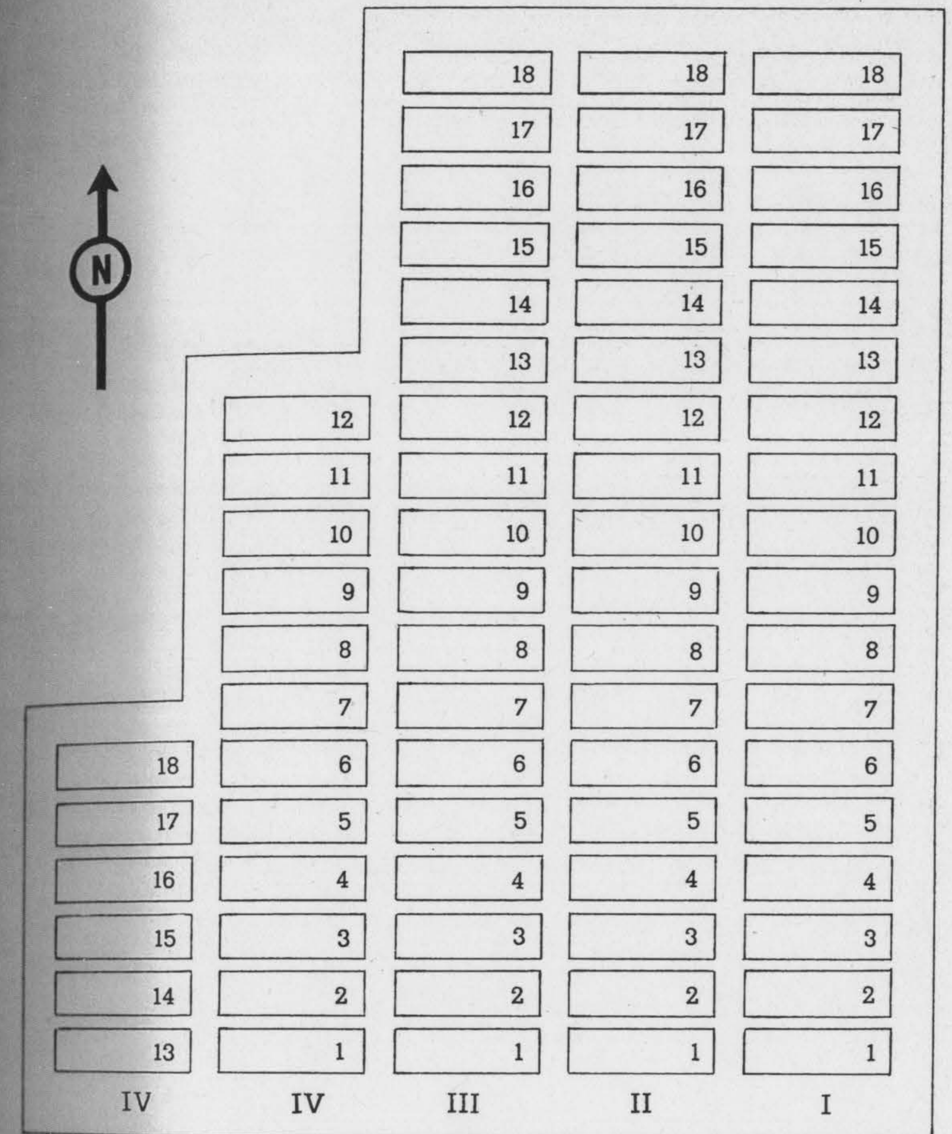

Fig. 1. Diagram of the plots used in the experimental work, 1914 through 1954, at the West Central Experiment Station, Morris, Minn. Six treatments were carried out in triplicate on each series of 18 plots, Series I to IV. The plan of the experiment is described in detail in the text (pages 6 and 8).

For these reasons the first crops of the rotation were harvested in 1915.

In 1937 after the growing of twenty crops, six plots of Series IV were needed for other purposes, leaving only three of the series of plots intact. The cropping system was then reduced to a 3-year rotation of corn, wheat, and hay, and cropping was confined to Series I, II, and III. The treatments, however, remained the same except that the rate of application of manure was reduced to 6 tons per acre and superphosphate to 57.6 pounds of P_2O_5 per acre. The rate of application of rock phosphate continued the same.

In the first period of twenty years (1915-36) there were some interruptions. In 1918, during World War I, all series were seeded to wheat and in 1933 and 1934, years of severe drought, all crops failed completely. The 3-year rotation (1937-1954) was uninterrupted.

SOIL CONDITIONS

The soil upon which the plots were located is Barnes silt loam. The Barnes soils were developed on calcareous glacial till and are neutral to slightly acid in reaction. Moderately low precipitation (22-23 inches), an abundance of tall-grass vegetation, and good drainage combined to furnish ideal conditions for the development of the dark color of these soils. Accordingly, the organic matter content is high and the productive capacity under adequate rainfall equally high.

These prairie soils usually carry large amounts of available potash, but the supply of available phosphate is often inadequate for maximum crop yields. They were originally well supplied with nitrogen, but in many instances this has been reduced by heavy cropping to corn and wheat.

WEATHER CONDITIONS

At the end of 1915, the normal mean rainfall at the West Central Experiment Station was 23.31 inches and the normal mean temperature was 41.3° F. Weather records had been kept since 1885, or for a 30-year period prior to 1915. The normal mean precipitation and normal mean temperature were determined by averaging the annual precipitation and annual temperatures of the 30-year period.

By the end of 1954, the normal mean precipitation was 23.49 inches and the normal mean temperature 42.2° F. This means that on the average 0.18 inch more water, in the form of rain and snow, fell annually in the 40-year period ending in 1954 than fell between 1885 and 1915. The annual mean temperature had increased by 0.9 of a degree, indicating a slightly warming tendency for the period as a whole.

Table 1. Variation in precipitation and temperature at West Central Experiment Station, Morris, 1915-54

Period	Precipitation			Temperature		
	Number of years			Number of years		
	Above normal	Normal	Below normal	Above normal	Normal	Below normal
1915-18	2	1	1	1	1	2
1919-22	1	1	2	2	2	0
1923-26	1	0	3	1	3	0
1927-30	1	2	1	2	2	0
1931-36	1	0	5	3	3	0
1937-39	1	1	1	2	1	0
1940-42	2	1	0	1	2	0
1943-45	1	1	1	1	2	0
1946-48	1	0	2	1	2	0
1949-51	1	0	2	0	1	2
1952-54	1	1	1	1	2	0
Total	13	8	19	15	21	4

Shorter periods of years may show quite wide variations in annual precipitation and average annual temperature. Weather records for the 40-year period were examined and the number of years in which the annual precipitation varied 1.0 inch from normal, and annual temperature by 2.0 degrees F. from normal, were recorded for each crop rotation. These data are shown in table 1.

Precipitation was below normal in 19 or nearly half of the 40 years; it was normal in 8 years and above normal in 13 years. The tendency, therefore, was for precipitation to be close to normal.

Temperatures were normal in 21 years, above normal in 15 years, and below normal in only 4 years. Thus, the period tended to be warmer than normal as well as slightly more moist.

A severe drought occurred during the 1931-36 period. During these 6 years, precipitation was below normal in 5 years and temperatures above normal in 3 years (table 1). Drought conditions were so severe that crops failed completely in 1933 and 1934. Because of this, the rotation period which would have normally ended in 1934 was extended to 1936.

EXPERIMENTAL RESULTS

A large amount of data was accumulated during the 40-year period. For the present purpose these data are presented on the basis of complete rotations. Thus between 1915 and 1936 (omitting 1933 and 1934, when crops failed) there were five 4-year rotation periods. From 1937 to 1954, inclusive, when a 3-year rotation was employed, there were six rotation periods. This made a total of eleven rotation periods.

In each period, each crop was grown once on each series of plots. The yield data for each period were subjected to statistical analysis. Average yields and increases required for significance are reported in subsequent tables. This procedure was followed for all crops. In this manner the effectiveness of the different treatments for each rotation period and for the entire 40-year period may be observed. Increases in yield which are significant at the 5 percent level are marked with an asterisk (*) and those significant at the 1 percent level with a double asterisk (**).

(If significant at the 5 percent level, the chances are 19 to 1 that the increase is a real or a valid one. For those significant at the 1 percent level, the chances are 99 to 1 that the increase is real or valid. When the analysis showed that yields were too variable to obtain a measure of significance, they are indicated by N. S.—"not significant.")

Corn

The effect of the six treatments on the yield of corn during the eleven rotation periods is shown in table 2. When compared with the check or untreated plots, rock phosphate failed to produce a significant increase in the yield of corn in any of the eleven rotation periods. But since there was some increase in most rotation periods, the accumulative effect on 36 crops over the 40-year period was enough to make the average increase of 2.9 bushels per acre significant, when the entire period is considered.

In no period did rock phosphate and manure produce a significant increase in the yield of corn over that obtained with manure alone. The average yield over the entire period was only 0.1 bushel greater for rock phosphate and manure combined than for manure alone.

Superphosphate used alone gave significant increases in the yield of corn over the untreated plots in four of the eleven periods. The average increase for the entire 40-year period was 4.7 bushels. Thus the overall effect was considerably greater than for rock phosphate.

When superphosphate was combined with manure, it was not significantly more effective than manure alone. The effectiveness of manure on the yield of corn is worthy of note.

Table 2. Yield of CORN and increases in yield (in bushels per acre) from five fertilizer treatments. West Central Experiment Station, Morris, 1915-54

Rotation period	Years	Untreated plots	Increase resulting from treatment: Rock phosphate	Manure and Rock phosphate	Manure	Manure and Super-phosphate	Super-phosphate	L.S.D. 5 percent level	L.S.D. 1 percent level
1	1915-18	36.8	0.9	5.7**	4.1*	4.0*	3.9*	3.2	4.5
2	1919-22	46.3	0.1	10.8*	9.5*	11.2*	3.6	8.4	11.6
3	1923-26	36.7	1.3	7.9**	8.1**	8.0**	4.4	5.1	6.3
4	1927-30	47.2	0.1	4.8*	3.5	6.6**	2.9	3.8	5.3
5	1931-36	27.1	3.8	1.4	0.7	—0.5	0.0	N.S.	N.S.
6	1937-39	48.4	—0.6	1.1	3.0	2.2	1.6	N.S.	N.S.
7	1940-42	56.4	4.0	3.9	3.5	3.6	3.0	N.S	N.S.
8	1943-45	63.9	6.8	9.9	8.6	7.2	4.6	N.S	N.S.
9	1946-48	58.7	4.2	10.5**	10.6**	11.9**	8.5*	6.3	9.0
10	1949-51	60.2	6.4	8.5*	11.2**	14.3**	10.3**	7.0	10.0
11	1952-54	76.9	4.8	9.2**	11.1**	8.9**	8.6**	5.1	7.3
Average	1915-54	50.8	2.9**	6.8**	6.7**	6.9**	4.7**	1.9	2.5

Table 3. Yield of WHEAT and increases in yield (in bushels per acre) from five fertilizer treatments. West Central Experiment Station, Morris, 1915-54

Rotation period	Years	Untreated plots	Increase resulting from treatment: Rock phosphate	Manure and Rock phosphate	Manure	Manure and Super-phosphate	Super-phosphate	L.S.D. 5 percent level	L.S.D. 1 percent level
1	1915-18	24.7	1.3	3.2	1.9	4.8	5.4	N.S.	N.S.
2	1919-22	17.7	0.8	2.8	2.6	4.4	3.6	N.S.	N.S.
3	1923-26	23.0	—0.4	2.5*	4.0**	5.0**	2.9**	2.0	2.7
4	1927-30	25.5	0.9	9.5**	10.9**	12.2**	7.7**	1.8	2.4
5	1931-36	21.7	1.0	4.6**	3.8**	4.2**	2.8*	2.1	2.9
6	1937-39	24.0	1.5	3.8*	5.9**	5.7**	4.6**	2.8	4.0
7	1940-42	31.1	1.6	6.2**	6.5**	6.4**	2.3	3.0	4.3
8	1943-45	23.2	0.7	5.5*	9.5**	9.5**	7.2**	4.4	5.9
9	1946-48	21.2	0.3	8.6**	6.9**	11.8**	6.8**	3.1	4.1
10	1949-51	25.7	1.2	9.6**	10.6**	11.3**	6.8*	5.3	7.1
11	1952-54	18.5	2.4	10.3**	9.1**	11.5**	6.8**	5.0	6.6
Average	1915-54	23.2	1.1	6.2**	6.7**	8.0**	5.3**	1.2	1.9

Wheat

The data for wheat are shown in table 3. Rock phosphate alone did not produce a significant increase in the yield of wheat in any of the eleven rotation periods. Moreover, the average increase of 1.1 bushels for the 40-year period (38 crops) was not great enough to be significant—although it closely approached significance. Where rock phosphate was combined with manure, the increase in yield of wheat was generally no greater than that from manure—and the 40-year average was less.

Superphosphate when used alone increased the yield of wheat significantly in eight of the eleven rotation periods. The average increase for the 40-year period was 5.3 bushels per acre. When superphosphate was combined with manure, the yields were generally higher than those secured with manure alone—but were significantly higher in only the 1946-48 rotation period. The average increase of 8.0 bushels for the entire period was significantly higher than for manure alone.

Oats

Oats were included in five rotation periods between 1915 and 1936, inclusive. Nineteen crops were grown. Rock phosphate alone was not effecive in producing a significant increase in any one of the five rotation periods or for the entire period in which oats were grown (table 4). When rock phosphate was accompanied by an application of manure, it was less effective than manure alone.

Superphosphate used alone gave highly significant increases in the yield of oats in three of five rotation periods, and the overall increase of 8.6 bushels was highly significant.

When superphosphate and manure were combined, the increases were somewhat greater than with manure alone—but were significantly higher in only the 1923-26 period.

The oat crop appears to be little benefited by rock phosphate but definitely improved by superphosphate.

Red Clover-Timothy

During the first 20 years of the experiment, red clover and timothy were seeded with oats; in the second 20, with wheat. A seeding mixture of 8 pounds of medium red clover and 6 pounds of timothy was sown for the hay crop.

In only two of the eleven rotations did rock phosphate used alone significantly increase the yield of hay (table 5). An average increase for the 40-year period of 0.24 tons per acre was highly significant. When used with manure it was little better than manure alone, the 40-year average increases being 0.63 and 0.59 tons per acre, respectively.

Superphosphate used alone significantly increased the yields of hay in eight of the eleven rotation periods, and the average increase for the entire period was 0.54 tons per acre. This increase was slightly more than double that obtained from the use of rock phosphate alone.

Yields obtained when superphosphate and manure were combined were not significantly higher than those obtained with manure alone. The average for the eleven rotation periods, however, was significantly higher than the average for manure alone.

Residual Effect of Rock Phosphate and Superphosphate

Beginning in 1937, Series IV was discontinued and a 3-year rotation established on Series I, II, and III. From 1937 to 1944 inclusive, plots 1 to 12 inclusive of Series IV (see figure 1) were used for growing bulk crops of alfalfa hay, corn, and grain. During that period no fertilizer or manure was applied.

In 1945, these 12 plots were divided into three strips or sub-series and a 3-year rotation of corn, wheat, and hay established and continued for 9 successive years. No fertilizer or manure was applied during the 9-year period. Since the original plots were 2 rods wide and 8 rods long, the divided plots were 2 rods wide by 2⅔ rods long.

The residual effects of phosphate fertilizers may be measured in several

Table 4. Yield of OATS and increases in yield (in bushels per acre) from five fertilizer treatments. West Central Experiment Station, Morris, 1915-36

Rotation period	Years	Untreated plots	Increase resulting from treatment					L.S.D.	
			Rock phosphate	Manure and Rock phosphate	Manure	Manure and Super-phosphate	Super-phosphate	5 percent level	1 percent level
1	1915-18	65.5	3.3	5.9	5.9	6.2	5.3	N.S.	N.S.
2	1919-22	53.5	1.9	7.3	6.4	8.3*	11.2**	7.4	10.3
3	1923-26	59.1	—1.1	10.6**	10.2**	16.9**	8.8**	7.7	10.6
4	1927-30	58.2	1.7	13.1**	15.2**	20.7**	10.9**	5.3	7.4
5	1931-36	46.9	4.0	6.5	7.6	10.4	6.5	N.S.	N.S.
Average	1931-36	56.6	2.0	8.7**	9.1**	12.1**	8.6**	4.0	5.9

Table 5. Yield of CLOVER-TIMOTHY HAY and in creases in yield (in tons per acre) from five fertilizer treatments. West Central Experiment Station, Morris, 1915-54

Rotation period	Years	Untreated plots	Increase resulting from treatment					L.S.D.	
			Rock phosphate	Manure and Rock phosphate	Manure	Manure and Super-phosphate	Super-phosphate	5 percent level	1 percent level
1	1915-18	2.04	0.61**	0.74**	0.51**	0.71**	0.54**	0.35	0.49
2	1919-22	3.03	0.13	0.65*	0.60*	1.01**	0.68*	0.58	0.91
3	1923-26	1.51	0.34*	0.57**	0.41**	0.55**	0.35*	0.29	0.40
4	1927-30	2.37	0.02	0.25	0.28	0.37	0.19	N.S	N.S.
5	1931-36	1.37	0.14	0.39*	0.47*	0.50*	0.43*	0.37	0.52
6	1937-39	2.71	0.13	0.53	0.52	0.53	0.28	N.S.	N.S.
7	1940-42	2.53	—0.04	0.17	0.39	0.30	0.14	N.S.	N.S.
8	1943-45	2.85	0.00	0.71*	0.49*	0.91**	0.53*	0.52	0.74
9	1946-48	2.49	0.36	0.87*	0.93**	1.09**	0.87*	0.66	0.93
10	1949-51	1.99	0.44	0.96**	0.89*	0.94**	0.95**	0.63	0.90
11	1952-54	1.29	0.48	1.04**	0.94*	1.13**	0.90*	0.70	1.00
Average	1915-54	2.19	0.24**	0.63**	0.59**	0.74**	0.54**	0.12	0.17

ways. They may be shown by a continuing increase in yield over untreated land, by the analysis of crops using radiophosphorus,[5] and by the chemical analysis of the soil using suitable methods.[6] All three methods were used on plots 1 to 12 inclusive of Series IV.

The average yields of the three crops for the 9-year period are shown in table 7. The residual effect from rock phosphate was not great enough to be significant in the case of any of the crops. The residual effects from a combination of manure and rock phosphate were great enough to be significant on all crops. However, when the residual effects of manure alone are considered, it is seen that the increases obtained were greater than those obtained with the rock phosphate-manure combination.

The residual effect from superphosphate was highly significant on all of the three crops when compared to yields on the untreated or control plots. Superphosphate and manure produced increases greater than those obtained with manure alone, although these increases were not significant. The residual effect of superphosphate alone was greater than manure alone on the yield of corn, but it did not equal the increases obtained on wheat and hay.

Caldwell[7] has recently studied these same 12 plots using chemical methods. Table 6 gives the results obtained. The "A" values represent the residual effect as obtained with red clover using the radiophosphorus technique. The second column represents the pounds per acre obtained by an analysis of the soil.

It is to be noted that the use of rock phosphate alone over the 40-year period did not appreciably increase the phosphorus uptake by red clover or in the soil. When combined with manure, the increase was no greater than obtained with manure alone.

Superphosphate on the other hand greatly increased the uptake by red clover, but the amount in the soil was no greater than where manure only was applied. When combined with manure, superphosphate produced a greater uptake by clover than the manure treatment alone and greatly increased the soil phosphorus.

Table 6. Residual effect of rock phosphate, manure, and superphosphate on the available phosphorus in the soil, as indicated by "A" values and Bray's adsorbed test.

Treatment	"A" values red clover	Bray's adsorbed phosphorus
None	69	6
Rock phosphate	70	7
Rock phosphate and manure	73	12
Manure	112	12
Superphosphate and manure	135	19
Superphosphate	160	12

DISCUSSION

The results obtained with the four crops over the 40-year period are summarized in table 8. The average yield increases from superphosphate used alone were much higher than those obtained by the use of rock phosphate only. Combining rock phosphate with manure did not significantly increase its effectiveness since the increases were no greater than obtained with manure alone.

When superphosphate was combined with manure, the average increases in all cases were greater than were obtained with manure alone. These increases were significantly higher for wheat and clover-timothy hay but not for corn and oats.

The value of manure in a crop rotation system is fully demonstrated in this

[5] Fried, Maurice and Dean, L. A. "A concept concerning the measurement of available soil nutrients." *Soil Science*, 73:263, 1952.

[6] Bray, R. H. and Krutz, L. T. "Determination of total, organic and available forms of phosphorus in soils." *Soil Science*, 59:39-45. 1945.

[7] Caldwell, A. C. *Studies on Phosphate Fertilizers in Minnesota*. Soil Series No. 44. University of Minnesota, Institute of Agriculture, Department of Soils.

Table 7. Residual effect of rock phosphate, superphosphate, and manure on the 9-year average yield of CORN, WHEAT, and HAY. (No fertilizer or manure applied in the 10 years preceding or during the 9 years of cropping)

Crop	Yield on unfertilized plots	Increase in yield from					L.S.D.	
		Rock phosphate	Manure and Rock phosphate	Manure	Manure and Super-phosphate	Super-phosphate	5 percent level	1 percent level
Corn (bushels per acre)	47.5	3.6	7.7*	8.2*	10.1*	9.5**	7.3	8.7
Wheat (bushels per acre)	18.3	0.9	4.9**	5.5**	6.5**	4.7**	2.2	2.6
Clover-timothy Hay (tons per acre)	1.38	0.12	0.80**	0.83**	0.88**	0.38**	0.31	0.37

Table 8. Average increases in yield of four crops from five fertilizer treatments over a 40-year period, 1915-54. West Central Experiment Station, Morris

Crop	Number of rotation periods	Number of crops	Average increase in yield from treatment				
			Rock phosphate	Manure and Rock phosphate	Manure	Manure and Super-phosphate	Super-phosphate
Wheat (bushels per acre)	11	38	1.1	6.2**	6.7**	8.0**	5.3**
Oats (bushels per acre)	5	19	2.0	8.7**	9.1**	12.1**	8.6**
Clover-timothy Hay (tons per acre)	11	35	0.24**	0.63**	0.59**	0.74**	0.54**
Corn (bushels per acre)	11	36	2.9**	6.8**	6.7**	6.9**	4.7**

** Increase statistically significant at the 1 percent level.

40-year experiment. When manure was used alone, substantial yield increases of the four crops were obtained, as shown by the data in tables 2 to 7 inclusive.

The nutrient lowest in supply in manure is phosphorus and supplementing it with a supply of readily available phosphate is generally considered to be a good practice. In the case of these experiments, the addition of superphosphate to manured land significantly increased the yields of wheat and clover-timothy hay but not of oats and corn.

One advantage claimed for rock phosphate has been its residual effect. Results obtained in this study show that applications of superphosphate were far superior to rock phosphate in carry-over or residual effect.

SUMMARY AND CONCLUSIONS

The experiment reported here tested the effect of rock phosphate and superphosphate as fertilizers on the yield of crops in a 3-year and 4-year rotation over a 40-year period, 1915-1954. The materials were used singly and in combination with barnyard manure. The 3-year rotation was corn, wheat, and hay; the 4-year rotation, corn, wheat, oats and hay.

The following conclusions may be drawn:

1. Rock phosphate used singly did not significantly increase the yields of corn or wheat in any of the eleven rotation periods, although the average increase of 2.9 bushels in the yield of corn over the eleven periods was significant.
2. Rock phosphate produced no significant increase in the yield of oats over five rotation periods.
3. Rock phosphate increased the yield of hay significantly in two of the eleven rotation periods. The average increase over the 40-year period was 0.24 tons, which was highly significant.
4. Combining rock phosphate with manure did not significantly increase the yield of any of the four crops over yields obtained with manure alone. In a number of cases the yields were slightly higher than obtained with manure but not significantly so. Yields with manure alone frequently exceeded those obtained with the combination.
5. Superphosphate used alone significantly increased the yield of corn in four, wheat in eight, and hay in seven of the eleven rotation periods. Oats were significantly increased in yield in three of the five periods. It was much more effective than rock phosphate.
6. In two instances, superphosphate and manure produced significantly higher yields than manure alone. In all other cases, however, the combination was no better than manure alone.
7. Average increases in yields of all crops for the 40-year period were much greater from superphosphate than from rock phosphate.
8. Manure used alone increased yields of all crops. It significantly increased the yield of corn in six, wheat in nine, and hay in eight of the eleven rotation periods. Oats yields were increased in two of the five periods in which oats were grown.
9. A study of the residual effects of the fertilizers—begining 9 years after the application of the phosphates and manure had ceased — showed that superphosphate was much superior to rock phosphate in its ability to supply residual phosphate.