THE COMPARATIVE AVAILABILITY OF PHOSPHATE IN TRIPLE SUPERPHOSPHATE, MONOAMMONIUM PHOSPHATE, AND ROCK PHOSPHATE.

by

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INTRODUCTION

Use of commercial fertilizers has become increasingly important in Kansas agriculture. Both commercial and farmer interests have suggested the necessity of evaluating the comparative availability to plants of phosphate contained in various fertilizers. An attempt to compare these availabilities under unfavorable conditions as brought about by presence of excess $CaCO_3$ was made. Unfavorable soil conditions as caused by marked acidity also was investigated.

Various workers have reported findings dealing with comparative availability to plants of phosphorus in different sources. Salter and Barnes (7) reported that raw rock phosphate was about 40 percent as efficient as superphosphate for supplying phosphorus to common grain and hay crops upon the unlimed Wooster and Canfield soils of Ohio. The reaction of these soils ranged from about pH 5 to 5.5. Liming the soil to the range of pH 7.0 to 7.5 reduced the efficiency of rock phosphate to about zero for these crops.

Salter and Barnes also reported efficiency ratings for monoammonium phosphate as compared to superphosphate. This material was only 69 percent as efficient at pH 5.5, 73 percent as efficient at pH 6.0, and 112 percent as efficient at pH 7.0.

Bennett, et. al., (1) compared the efficiency of various phosphatic fertilizers on alkaline (pH - 8.3) Houston Black clay. It was found that only phosphate materials with a high percentage of water soluble phosphorus were of much value in increasing crop yields. Sodium pyrophosphate and monoammonium phosphate were the two most outstanding sources of phosphorus. These sources were not significantly superior to superphosphate, however. Such materials as colloidal phosphate, defluorinated rock phosphate and tricalcium phosphate were of little or no value in increasing yields on this soil type.

Ensminger (3) concluded that both monoammonium and diammonium phosphate were about as effective for cotton as was superphosphate provided dolomite was used to neutralize acidity and ammonium sulfate was used to supply needed sulfur.

Rogers, et. al. (6) concluded that ammonium phosphates are well adapted to alkaline soils and are good sources of phosphorus on acid soils when their residual acidity is neutralized with limestone. Upon the basis of results obtained with tracer techniques they rated several of the phosphates as follows: Superphosphate = ammonium phosphate > calcium metaphosphate > dicalcium phosphate > tricalcium phosphate. Marked differences in the availability of superphosphate and dicalcium phosphate in percentage of fertilizer phosphorus absorbed by plants have not been reflected in crop yields. They also showed that liming decreased the effectiveness of raw phosphates, especially for crops that are not strong feeders on rock phosphate. For legumes only enough lime should be used to give optimum yield. Raw phosphates are of little or no value when applied to calcareous soils.

Hinkle (4) compared various phosphatic materials as sources of phosphorus for alfalfa and also as sources of phosphorus for annual yellow sweetclover. He reported somewhat better results for monoammonium phosphate (11-48-0) than for calcium metaphosphate with alfalfa. Two sources of triple superphosphate and one source of ordinary superphosphate were not inferior to monoammonium phosphate. No nitrogen was added to the superphosphates to offset that included in monoammonium phosphate. With annual yellow sweet clover, triple superphosphate (0-44-0) which was reinforced with ammonium sulfate to supply the same amount of nitrogen as contained in monoammonium phosphate actually yielded more than the latter material.

Olsen, et. al. (5) found that alpha tricalcium phosphate consistently furnished less phosphorus to plants grown in calcareous soils than did such sources as superphosphate (0-20-0), concentrated superphosphate (0-43-0), ammonium phosphate (11-48-0), calcium metaphosphate, dicalcium phosphate and liquid phosphoric acid. Superphosphate and ammonium phosphate supplied about equal amounts of phosphorus to all crops tested, except alfalfa in Arizona. In the case of alfalfa in Arizona, superphosphate was superior to ammonium phosphate.

Weiser (8) showed that the efficiency of monoammonium phosphate was increased markedly by liming of the soil.

The objectives of this study were: (1) to evaluate by means of plant growth response the comparative availability of phosphorus supplied in the form of superphosphate, monoammonium phosphate, and rock phosphate to soils of varying $CaCO_3$ content; (2) to evaluate by means of chemical extraction the comparative availability of phosphorus supplied in the form of superphosphate, monoammonium phosphate, and rock phosphate to soils of varying $CaCO_3$ content.

METHODS OF STUDY

Description of soils

Four soil materials were used for this study. Reactions of the soils ranged from acid to alkaline. The two naturally alkaline soil samples were obtained from near Garden City, Kansas on the William Mai farm. One sample was from the surface layer and one was from the subsoil. These samples are identified by the farmer's name in this thesis.

One sample of soil material was obtained from the Kansas State College Agronomy Farm near Manhattan, Kansas. This sample of Geary silt loam soil was neutral in reaction.

The fourth soil sample was obtained from southeastern Kansas near Columbus. This sample of Cherokee subsoil was very acid and required 7,000 pounds per acre of limestone for neutralization.

One series each of the Geary silt loam and the Cherokee silt loam subsoil received an application of $CaCO_3$ equivalent to an excess of 3.0 percent. Thus a total of six series of cultures was included in the greenhouse study with phosphatic fertilizers.

Greenhouse Techniques

The greenhouse study was conducted to measure response in yield of wheat to application of various phosphatic fertilizers. Fertilizer was mixed with the soil on February 27, 1954, wheat was planted on March 3, 1954 and it was harvested on June 3, 1954. Phosphate was applied at rates indicated in table 1.

Table 1. Phosphate treatments employed in greenhouse experiment with wheat.

Treat. No.	Fertilizer Material	Amount of P furnished (ppm)
1	No treatment	
2	Triple superphosphate (0-42-0)	40
3	Triple superphosphate (0-42-0)	160
4	Monoammonium phosphate (11-48-0)	40
5	Monoammonium phosphate (11-48-0)	160
6	Rock phosphate (32% total P_2O_5)	320

Each culture received the equivalent of 0.17 gram of nitrogen either in the form of ammonium nitrate, as a constituent of 11-48-0, or as a combination of these two forms depending upon the treatment concerned. An addition of 0.5 gram KCl was made to each culture involving Cherokee subsoil. An additional 0.17 gram of nitrogen was added on April 11, 1954 to each culture involving Mai surface soil, Mai subsoil, Cherokee subsoil, and Cherokee subsoil plus 3.0 percent excess $CaCO_3$.

Conventional greenhouse procedures using earthenware pots containing 2500 grams of soil each were employed. Four replications of each culture were used. Arrangement of pots was changed in random fashion every three days until after heading so as to avoid any differences due to location in the greenhouse.

Laboratory Analyses

Laboratory determinations of pH, lime requirement and available phosphorus were made on each soil material before application of fertilizers.

The pH was determined by the standard glass electrode method. Lime requirement was determined by the standard procedure of the state soil testing laboratory.

Available phosphorus was determined by the colorimetric method of Bray and Kurtz (2).

Table 2. Chemical properties of untreated soils used in greenhouse experiment at Manhattan, Kansas, 1954.

Soil Material	Soil pH 1:1	Soil pH 1:50	Available P[1] (lbs./A)	Lime Status $CaCO_3$ Equiv.(%)	Lime Status $CaCO_3$ Req.(lb./A)
1. Mai Surface	8.0	8.4	29	3.0	none
2. Mai Subsoil	7.7	8.1	4	20.7	none
3. Geary Silt Loam	7.0	-	29	none	none
4. Cherokee Subsoil	5.3	-	9	none	7,000

[1]Using 0.03 N NH_4F in 0.025 N HCl at a soil:solution ratio of 1:50

After harvest cultures of the soil again were sampled and analyzed for available phosphorus. A solution of 0.03 N NH_4F in 0.025 N HCl was used for extraction. A soil:solution ratio of 1:50 was employed. Soil and solution were shaken for one minute and then filtered. The filtrate was adjusted to neutrality, made to volume and ammonium molybdate (PB) and organic reducing agent (PC) were added, mixed and allowed to stand fifteen minutes. Transmittance was determined in an Evelyn photoelectric colorimeter at wave length of 660 mu.

Phosphorus content of straw and grain also was determined. A weighed sample was transferred to a porcelin crucible. To this a solution of alcohol and magnesium nitrate $Mg(NO_3)_2 \cdot 6H_2O$ was added. The crucibles were placed on the hot plate, ignited and allowed to oxidize to dryness. The crucibles then were transferred to the muffle furnace and brought to a temperature of 550° C for two hours. The ash was cooled and dissolved in HCl. This solution then was treated with PB and PC solutions. Phosphorus determination was accomplished on these as it was on the soil material.

INTERPRETATION OF RESULTS

Upon the basis of determination of available phosphorus (Table 2), it appeared that growth response to added phosphate could be expected on each soil. Two soils, the Mai surface and the Geary soil, were only medium in available phosphorus content. The other two were quite low in available phosphorus content.

Yield Results

Grain Yields. As seen in Appendix Table 3, no phosphatic fertilizer treatment gave outstanding grain yield increases with the Mai surface soil. Statistical analyses showed no significant effects of the treatments.

With the Mai subsoil, statistical analyses revealed a highly significant increase for treatment 3 over check. Treatments 2 and 5 produced significant increases over check. Comparable rates of application of phosphorus from triple superphosphate were significantly better than applications of phosphorus from monoammonium phosphate at both the high and low rates of application. High rates of either triple superphosphate or monoammonium phosphate gave significant increases in yield over the lower rates of application. Rock phosphate was ineffective when compared to either of the other forms of phosphate.

With the unlimed Geary soil significant increases in grain yield were obtained from both rates of application of superphosphate and monoammonium phosphate. The high rate of application of monoammonium phosphate was significantly poorer than either the low rate of this fertilizer or comparable rate of application of triple superphosphate. Rock phosphate treatment was significantly inferior to some of the other phosphate treatments.

Geary soil with an excess of 3 percent $CaCO_3$ produced significant increases in yield of grain for each phosphate treatment, including rock phosphate. Here comparable additions of monoammonium phosphate and triple superphosphate gave somewhat higher yields than the lower rates of application, but the added effects were not statistically significant.

With unlimed Cherokee subsoil significant increases in yield were obtained with each treatment. The high rates of application of triple superphosphate and monoammonium phosphate were significantly better than the lower rates of application. Rock phosphate was significantly superior to the low rates of application of either triple superphosphate or monoammonium phosphate.

On Cherokee subsoil with 3 percent excess $CaCO_3$, all phosphate treatments except that involving rock phosphate gave significantly greater yields. Again the higher rates of application of the more soluble carriers of phosphorus were significantly better than the low rates of application.

Straw Yields. As seen in Appendix Table 4, significant increases in yield of straw occurred where either triple superphosphate or monoammonium phosphate was added to the Mai surface soil. Differences between the high and low rates of application of the more soluble forms of phosphatic fertilizers were not significant. Rock phosphate was ineffective in increasing straw yield on this soil.

With the Mai subsoil significant increases in straw yield were obtained where triple superphosphate and monoammonium phosphate were employed. Here the high rates were significantly better than the low rates of application. At this low rate of application superphosphate was significantly better than monoammonium phosphate. Rock phosphate was ineffective in increasing the straw yield.

Yields of straw on the unlimed Geary soil were increased significantly over the check for every phosphatic treatment. Comparable rates of application of triple superphosphate and monoammonium phosphate were about equal. Treatment with rock phosphate was significantly better than the check, but significantly lower than either rate of application of superphosphate. With limed Geary soil highly significant increases in yield of straw were obtained with every phosphatic treatment.

High rates of application of either triple superphosphate or monoammonium phosphate were superior to rock phosphate application. However, use of rock phosphate on this limed soil was just as effective as the use of the other carriers at low rates of application.

Also with the unlimed Cherokee subsoil highly significant increases were obtained with every application of phosphatic fertilizers. The high rates of application of triple superphosphate was significantly better than a comparable rate of monoammonium phosphate. Rock phosphate treatment was comparable to treatment with either the low rate of triple superphosphate or the high rate of monoammonium phosphate.

Highly significant increases in yield of straw resulted on the limed Cherokee subsoil where triple superphosphate and monoammonium phosphate treatments were employed. Yield from monoammonium phosphate treatment was somewhat lower than yield from triple superphosphate treatment, but not significantly so. Rock phosphate treatment was significantly lower than other phosphate treatments and comparable to the check.

Total Yield of Grain and Straw. Highly significant increases in total yield of plant material were obtained with the low rates of application of triple superphosphate and monoammonium phosphate on the Mai surface soil. The high rates of application of these carriers gave lower yields than the low rates of application but these were not significantly lower. Rock phosphate produced no response in total yield of wheat plant material.

On the Mai subsoil highly significant increases in total yield of plant material resulted from treatment with either triple superphosphate or monoammonium phosphate. Triple superphosphate was better than monoammonium phosphate at comparable rates of application. High rates of application of either of these carriers were significantly better than low rates. Rock phosphate was ineffective on this soil.

Treatments involving either triple superphosphate or monoammonium phosphate gave highly significant increases in total yields of plant material on unlimed Geary soil. Triple superphosphate was significantly better than the comparable rate of application of monoammonium phosphate on this soil. Triple superphosphate at the low rate of application produced more yield than at the high rate. Rock phosphate was ineffective on unlimed Geary soil.

Significant increases in total yield of plant material occurred with every treatment on limed Geary soil. Yields from triple superphosphate and monoammonium phosphate were comparable. Rock phosphate treatment was significantly better than no treatment, but significantly lower than either high or low rates of application of the more soluble phosphatic fertilizers.

Phosphate treatment on unlimed Cherokee subsoil gave highly significant increases in total yield in every case. Low rates of application of either triple superphosphate or monoammonium phosphate gave comparable results. High rates of application of these same carriers gave greater total yields. Triple superphosphate was better than monoammonium phosphate at the high rates of application. Rock phosphate produced results comparable to the high rate of application of monoammonium phosphate.

On limed Cherokee subsoil highly significant increases were obtained from use of the more soluble phosphate fertilizers, but no increase resulted from the use of rock phosphate. Similar rates of triple superphosphate and monoammonium phosphate gave comparable results. High rates of application of these soluble fertilizers were better than low rates of application. Treatment with rock phosphate did not affect total yield of plant material.

Analyses of Plant Material

Percentage of Phosphorus in Grain. The percentage of phosphorus in grain varied little as a result of phosphate treatments which were applied to the soil. Rates of application of phosphorus had little effect on percentage of phosphorus in grain. In some instances the percentage of phosphorus was actually lower for the high rates of application of phosphorus than it was for the low rates of application. Percentage of phosphorus in grain from treatments where rock phosphate was employed compared very favorably with percentage of phosphorus in grain from those treatments where more soluble phosphatic carriers were used.

Percentage of Phosphorus in Straw. The percentage of phosphorus in the straw behaved somewhat like that in the grain. Probably there was a greater increase in percentage of phosphorus in the straw as a result of high rates of application of phosphate (Appendix Table 7) than there was in the case of grain (Appendix Table 6). In many instances the percentage of phosphorus in the straw was lower as a result of low rate of phosphate application than for no treatment with phosphate. Where the high rates were employed the percentage of phosphorus in most cases compared favorable with no treatment. Rock phosphate seemed somewhat variable in its ability either to raise or to lower the percentage of phosphorus in the grain or in the straw.

Phosphorus Uptake in Grain. Phosphorus uptake in grain from the Mai surface soil (Appendix Table 8) showed no significant increase or decrease as a result of treatment of the soil with phosphatic fertilizers.

In the Mai subsoil a highly significant increase in phosphorus uptake in grain resulted where either triple superphosphate or the high rate of monoammonium phosphate was employed. Use of monoammonium phosphate resulted in significantly lower phosphorus uptake than did comparable amounts of triple superphosphate. Both the low rate of application of monoammonium phosphate and rock phosphate compared closely with no treatment.

The unlimed Geary soil reflected significant increases from the use of triple superphosphate and from the use of the low rate of monoammonium phosphate. Low rates of the more soluble forms of phosphate gave slightly higher phosphorus uptake than the high rates. Rock phosphate was not effective in increasing phosphorus uptake and was significantly lower than either treatment with triple superphosphate or treatment with low rates of monoammonium phosphate.

With the limed Geary soil, significant increases in phosphorus uptake of grain were obtained with either monoammonium phosphate treatment or treatment with the high rate of triple superphosphate. Phosphorus uptake from triple superphosphate treatment at the low rate was significantly lower than for treatment with a comparable rate of monoammonium phosphate. Low rate of application of triple superphosphate was significantly less effective than the high rate. Rock phosphate treatment was significantly better than no treatment, but significantly lower than the high rate of triple superphosphate in this regard.

Phosphorus uptake in the grain from unlimed Cherokee subsoil was significantly increased only where high rates of triple superphosphate and monoammonium phosphate were employed. Low rates of application of triple superphosphate and monoammonium phosphate were somewhat less effective than high rates of application of these materials. Rock phosphate treatment compared closely to no treatment in this regard.

Phosphorus uptake in the grain from the limed Cherokee subsoil reflected highly significant increases in phosphorus uptake from either triple superphosphate or monoammonium phosphate treatment. Phosphorus uptake in the grain was increased significantly more by treatment with triple superphosphate than it was by treatment with comparable low rates of application of monoammonium phosphate.

However, the reverse was true for high rates of application of these materials. Treatment with rock phosphate produced a highly significant decrease in phosphorus uptake. Actually no grain was produced by this treatment.

Phosphorus Uptake in Straw. Phosphorus uptake in the straw produced on the Mai surface soil, (Appendix Table 9) was increased by all treatments except that involving rock phosphate. Triple superphosphate and monoammonium phosphate gave comparable results at low level of application. High rates of application of the more soluble phosphatic fertilizers were significantly superior to low rates of application in this respect. The high rate of application of triple superphosphate was significantly more effective than the comparable rate of monoammonium phosphate. Rock phosphate was ineffective in increasing phosphorus uptake in the straw. Phosphorus uptake in straw produced in the Mai subsoil was not greatly affected by phosphate treatment. Only treatment with the high rate of monoammonium phosphate significantly increased the phosphorus uptake.

Phosphorus uptake in the straw produced on the unlimed Geary soil showed significant increases only where high rates of triple superphosphate and monoammonium phosphate were applied. No treatment, low rates of application of either triple superphosphate or monoammonium phosphate, and application of rock phosphate all gave about the same results.

Phosphorus uptake on the limed Geary soil was significantly greater only where the high rate of triple superphosphate was employed. Low rate of application of monoammonium phosphate was somewhat less effective than low rate of application of triple superphosphate. Treatment with rock phosphate was much less effective than no treatment at all.

Phosphorus uptake in the straw from the unlimed Cherokee subsoil was increased by all rates of application of triple superphosphate and monoammonium phosphate and by treatment with rock phosphate. Triple superphosphate and monoammonium phosphate gave comparable results. Uptake of phosphorus in the straw was greater for the high rates of application of either triple superphosphate or monoammonium phosphate than for the low rates of application of the same fertilizers. Rock phosphate treatment was significantly more effective than either of the low rates of application of more soluble phosphate.

On the limed Cherokee subsoil highly significant increases in phosphorus uptake were obtained from both rates of application of triple superphosphate and from the high rate of application of monoammonium phosphate. Triple superphosphate was more effective than monoammonium phosphate. Treatment with rock phosphate gave results which were significantly inferior to all other treatments and comparable to no treatment.

<u>Total Uptake of Phosphorus in Wheat Plants.</u> Total uptake of phosphorus (Appendix Table 10) for the Mai surface soil indicated a highly significant increase from the use of monoammonium phosphate and the high rate of triple superphosphate. Low rate of application of triple superphosphate and treatment with rock phosphate were comparable to no treatment insofar as total phosphorus uptake was concerned. High rate of application of triple superphosphate was significantly better than low rate of application. Low rate of application of monoammonium phosphate was significantly more effective than a comparable rate of application of triple superphosphate.

Total uptake of phosphorus from the Mai subsoil was significantly increased by every phosphate treatment except that involving rock phosphate. Treatments involving triple superphosphate were significantly more effective than comparable treatments of monoammonium phosphate. Rock phosphate was somewhat less effective than no treatment.

Total phosphorus uptake in plants produced on the unlimed Geary soil was significantly greater for every phosphate treatment except where rock phosphate was employed. Triple superphosphate gave results comparable to monoammonium phosphate. Rock phosphate, of course, was ineffective in increasing phosphorus uptake.

Total phosphorus uptake in plants produced on the limed Geary soil was significantly increased only by treatment with the high rate of monoammonium phosphate. Triple superphosphate and monoammonium phosphate were comparable in effectiveness. Rock phosphate treatment compared favorable with both triple superphosphate treatments and with the low rate of application of monoammonium phosphate.

Total phosphorus uptake in plants produced on unlimed Cherokee subsoil was significantly increased only by the high rates of application of triple superphosphate and monoammonium phosphate. Effects of triple superphosphate and of monoammonium phosphate were comparable in this regard. Effects of low rates of application of triple superphosphate and monoammonium phosphate were not pronounced. Effect of rock phosphate treatment was significantly greater than the low rate of application of triple superphosphate.

Highly significant differences in phosphorus uptake were obtained on limed Cherokee subsoil from treatment with either triple superphosphate or with monoammonium phosphate. Low rate of application of triple superphosphate was significantly more effective in this regard than was comparable rate of application of monoammonium phosphate. Rock phosphate actually was less effective than no treatment.

Chemically Available Phosphorus in Soils after Harvest

All treatments involving the soluble phosphates produced increases in the amount of chemically available phosphorus remaining in the Mai surface soil after plants had been harvested. Highly significant increases in available phosphorus content of soil was produced as a result of application of high and low rates of triple superphosphate and monoammonium phosphate. Greater increases in available phosphorus content of soil were obtained where triple superphosphate was employed than were obtained for comparable rates of application of monoammonium phosphate. Rock phosphate treatment resulted in significantly lower available phosphorus content in the soil than did other phosphate treatments.

Highly significant increases in available phosphorus content of the soil were obtained from all phosphate treatments applied to the Mai subsoil except for the low rate of application of monoammonium phosphate. Triple superphosphate treatment resulted in significantly greater amounts of available phosphorus in the soil than did comparable monoammonium phosphate treatments. Rock phosphate was significantly more effective than low rate of application of monoammonium phosphate and no treatment, but significantly less effective than other phosphate treatments.

Triple superphosphate and monoammonium phosphate were very effective in increasing available phosphorus content of unlimed Ceary soil. Treatments with triple superphosphate was significantly more effective than treatment with comparable amounts of monoammonium phosphate. Rock phosphate was ineffective in this regard. Increases in available phosphorus content were highly significant on the limed Ceary soil as a result of treatments with either triple superphosphate of monoammonium phosphate. At the high level of application triple superphosphate was significantly more effective than a comparable amount of monoammonium phosphate. Rock phosphate was significantly less effective than other phosphate treatments.

On the unlimed Cherokee subsoil highly significant increases in available phosphorus content were obtained with every phosphate treatment. Comparable rates of monoammonium phosphate were significantly more effective than triple superphosphate treatments. Rock phosphate treatment was significantly more effective than the low rates of the more soluble phosphatic carriers, but significantly less effective than high rates of application of the same materials.

Treatments involving application of either triple superphosphate or monoammonium phosphate on the limed Cherokee subsoil were significantly effective in increasing available phosphorus content. Triple superphosphate and monoammonium phosphate were comparable in this regard. Rock phosphate was ineffective insofar as increasing the available phosphorus content of the Cherokee subsoil was concerned.

SUMMARY AND CONCLUSIONS

The effects of the different carriers of phosphorus may be summarized as follows:

Triple superphosphate increased the yield of grain on all soils except Mai surface soil. Monoammonium phosphate increased the yield of grain on all soils except at the high rate of application on the Mai surface soil. Grain yield on the limed Geary soil was greater from treatments involving monoammonium phosphate than a comparable application of superphosphate. Rock phosphate was ineffective except on the limed Geary soil and on the acid Cherokee subsoil.

Triple superphosphate generally was superior to monoammonium phosphate in increasing yield of straw except on the limed Geary soil where treatment with monoammonium phosphate was somewhat more effective though not significantly so. Rock phosphate increased straw yield appreciably only on limed Geary soil and on acid Cherokee subsoil

Triple superphosphate was equal to monoammonium phosphate insofar as yields of total plant material were concerned. Rock phosphate significantly increased total yield of plant material only on limed Geary soil and on acid Cherokee subsoil.

Percentage of phosphorus in grain varied little as a result of application of any phosphatic fertilizers.

High rates of application of either triple superphosphate or monoammonium phosphate increased the percentage of phosphorus in the straw in most cases. Low rates of applications of these materials on the Geary soils actually reduced the percentage of phosphorus in the straw. The effect of rock phosphate was somewhat variable.

Triple superphosphate was superior to monoammonium phosphate insofar as uptake of phosphorus was concerned on the Mai subsoil. With the other soils triple superphosphate was equal to monoammonium phosphate. Rock phosphate caused no increase in uptake of phosphorus by the grain.

Triple superphosphate was equal to, if not superior to, monoammonium phosphate insofar as causing an increase in phosphorus uptake in the straw. Rock phosphate was ineffective in increasing phosphorus uptake in the straw.

Triple superphosphate was superior to monoammonium phosphate in increasing total phosphorus uptake by wheat plants on Mai subsoil and unlimed Geary soil. It also was superior in the case of the high rate of application on unlimed Cherokee soil and in the case of the low rate of application on limed Cherokee soil. Monoammonium phosphate was equal to or superior to triple superphosphate on Mai surface soil, limed Geary soil: in the case of low rate of application on unlimed Cherokee soil: and at the high rate of application on the limed Cherokee subsoil. Rock phosphate was ineffective in increasing total phosphorus uptake by wheat plants. Treatment with rock phosphate actually decreased total uptake of phosphorus on limed Cherokee subsoil

In general a larger quantity of chemically available phosphorus remained in the various soils after harvest of the wheat where triple superphosphate was used than where monoammonium phosphate was used. Rock phosphate was effective in increasing the amount of chemically available phosphorus only on unlimed Cherokee subsoil.

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APPENDIX

EXPLANATION OF PLATE I

Fig. 1. The influence of various phosphatic fertilizer treatments on growth of wheat, Mai surface soil. (May 5, 1954)

Fig. 2. The influence of lime and various phosphatic fertilizer treatments on growth of wheat, Mai subsoil. (May 5, 1954)

Phosphate treatments as follows:

1-No treatment
2-40ppm P-triple superphosphate
3-160 ppm P-triple superphosphate
4-40 ppm P-monoammonium phosphate
5-160 ppm P-monoammonium phosphate
6-320 ppm P-rock phosphate

PLATE I

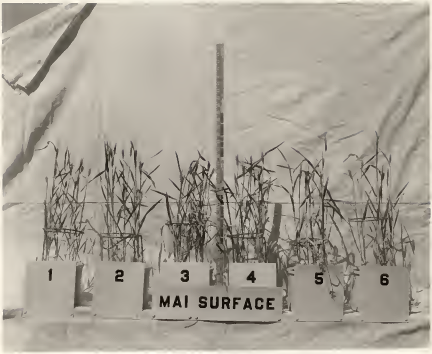


Fig. 1

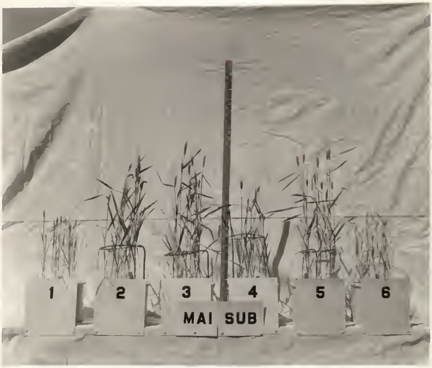


Fig. 2

EXPLANATION OF PLATE II

Fig. 1. The influence of various phosphatic fertilizer treatments on growth of wheat, Geary soil, (May 5, 1954)

Fig. 2. The influence of lime and various phosphatic fertilizers on growth of wheat, Geary soil. (May 5, 1954)

Phosphate treatments as follows:

1-No treatment
2-40 ppm P-triple superphosphate
3-160 ppm P-triple superphosphate
4-40 ppm P-monoammonium phosphate
5-160 ppm P-monoammonium phosphate
6-320 ppm P-rock phosphate

PLATE II

Fig. 1

Fig. 2

EXPLANATION OF PLATE III

Fig. 1. The influence of various phosphatic fertilizer treatments on growth of wheat, Cherokee subsoil. (May 5, 1954)

Fig. 2. The influence of lime and various phosphatic fertilizer treatments on growth of wheat, Cherokee subsoil. (May 5, 1954)

Phosphate treatments as follows:

1-No treatment
2-40 ppm P-triple superphosphate
3-160 ppm P-triple superphosphate
4-40 ppm P-monoammonium phosphate
5-160 ppm P-monoammonium phosphate
6-320 ppm P-rock phosphate

PLATE III

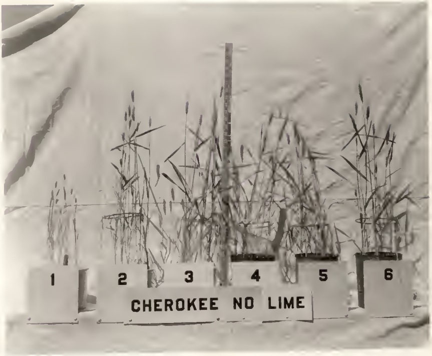


Fig. 1

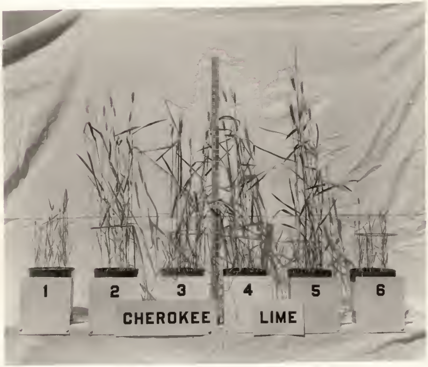


Fig. 2

EXPLANATION OF PLATE IV

Fig. 1. The influence of phosphatic fertilizer treatment on growth of wheat, Mai surface soil, Mai subsoil. (May 10, 1954)
1-No treatment
2-40 ppm P-triple superphosphate

Fig. 2. The influence of phosphatic fertilizer treatment on growth of wheat, Mai surface soil, Mai subsoil. (May 10, 1954)
1- No treatment
3-160 ppm P-triple superphosphate

PLATE IV

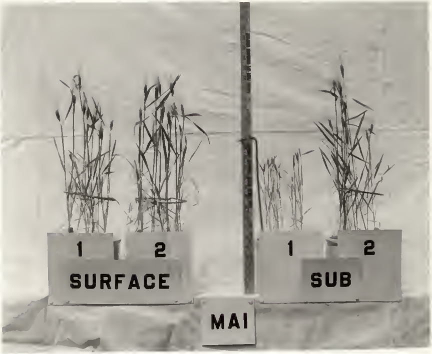


Fig. 1

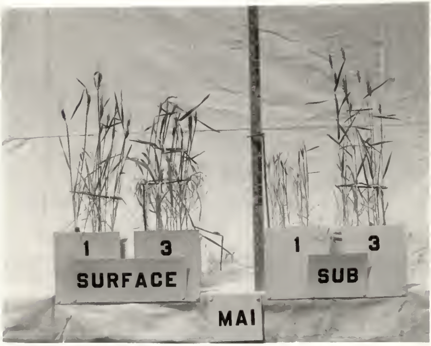


Fig. 2

EXPLANATION OF PLATE V

Fig. 1. The influence of phosphatic fertilizer treatment on growth of wheat, Mai surface soil, Mai subsoil. (May 10, 1954)
1-No treatment
4-40 ppm P-monoammonium phosphate

Fig. 2. The influence of phosphatic fertilizer treatment on growth of wheat, Mai surface soil, Mai subsoil. (May 10, 1954)
1-No treatment
5-160 ppm P-monoammonium phosphate

PLATE V

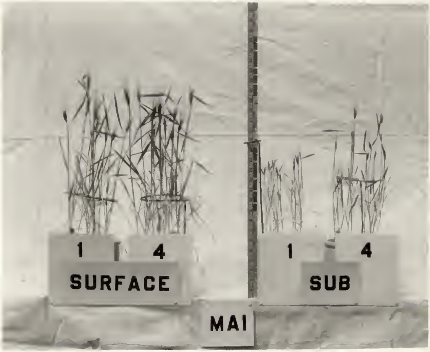


Fig. 1

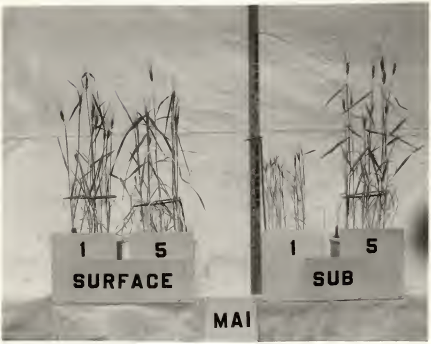


Fig. 2

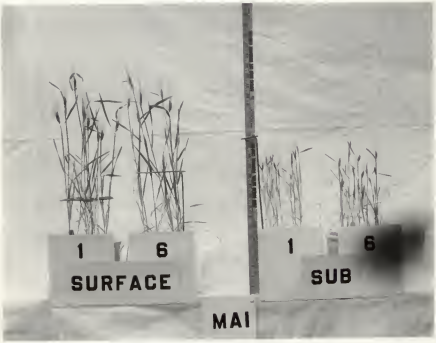
EXPLANATION OF PLATE VI

The influence of phosphatic fertilizer treatment on growth of wheat, Mai surface soil, Mai subsoil. (May 10, 1954)

1-No treatment

6-320 ppm P-rock phosphate

PLATE VI



EXPLANATION OF PLATE VII

Fig. 1. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Geary surface soil. (May 10, 1954)
1-No treatment
2-40 ppm P-triple superphosphate

Fig. 2. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Geary surface soil. (May 10, 1954)
1-No treatment
3-160 ppm P-triple superphosphate

PLATE VII

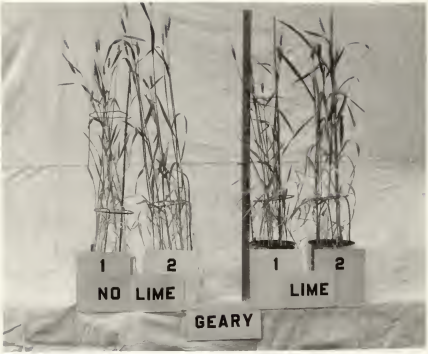


Fig. 1

Fig. 2

EXPLANATION OF PLATE VIII

Fig. 1. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Geary surface soil. (May 10, 1954)
1-No treatment
4-40 ppm P-monoammonium phosphate

Fig. 2. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Geary surface soil. (May 10, 1954)
1-No treatment
5-160 ppm P-monoammonium phosphate

PLATE VIII

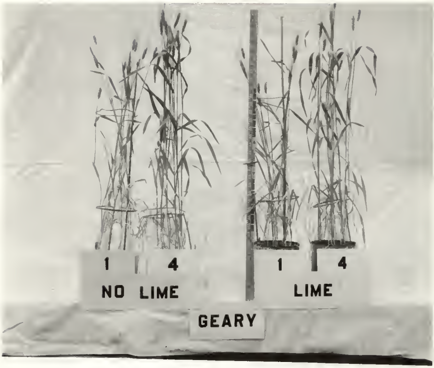


Fig. 1

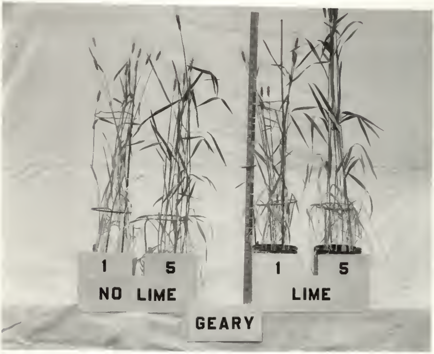


Fig. 2

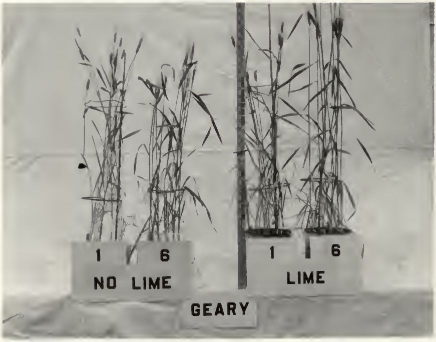
EXPLANATION OF PLATE IX

The influence of lime and phosphatic fertilizer treatment on growth of wheat, Geary surface soil. (May 10, 1954)

1-No treatment

6-320 ppm P-rock phosphate

PLATE IX



EXPLANATION OF PLATE X

Fig. 1. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Cherokee subsoil. (May 10, 1954)
1-No treatment
2-40 ppm P-triple superphosphate

Fig. 2. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Cherokee subsoil. (May 10, 1954)
1-No treatment
3-160 ppm P-triple superphosphate

PLATE X

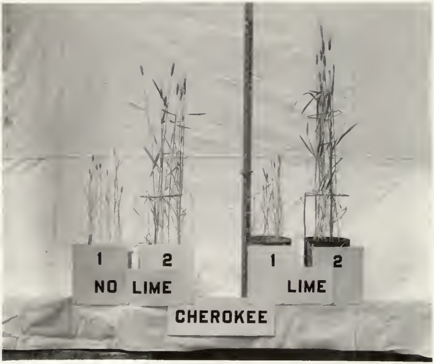


Fig. 1

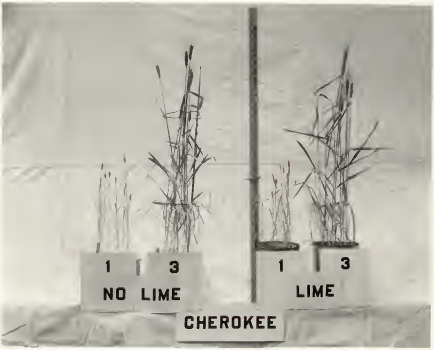


Fig. 2

EXPLANATION OF PLATE XI

Fig. 1. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Cherokee subsoil. (May 10, 1954)
1-No treatment
4-40 ppm P-monoammonium phosphate

Fig. 2. The influence of lime and phosphatic fertilizer treatment on growth of wheat, Cherokee subsoil. (May 10, 1954)
1-No treatment
5-160 ppm P-monoammonium phosphate

PLATE XI

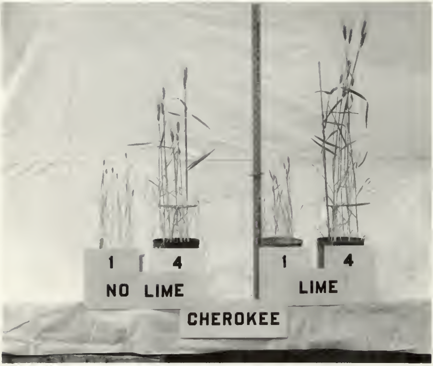


Fig. 1

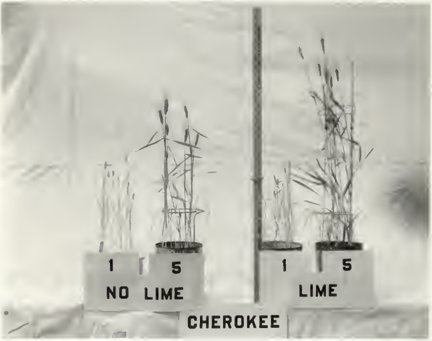


Fig. 2

EXPLANATION OF PLATE XII

The influence of lime and phosphatic fertilizer treatment on growth of wheat, Cherokee subsoil. (May 10, 1954)

1-No treatment

6-320 ppm P-rock phosphate

PLATE XII

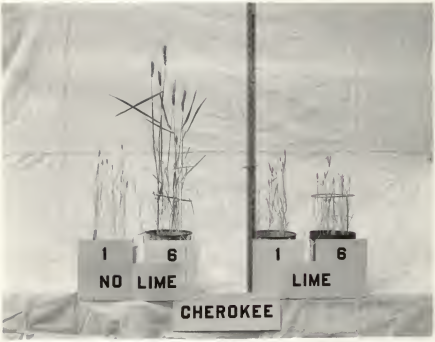


Table 3. Influence of various phosphatic treatments upon yield of wheat grain obtained with various Kansas soils in greenhouse experiment, 1954.

Treatment			Average[1] yield of wheat grain (grams/pot)				
		Mai Surface Soil	Mai Subsoil	Geary soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil, Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment		1.95	.06	3.88	3.93	.37	.11
2. Superphosphate, 40 ppm P		1.31	1.83	5.77	5.60	2.15	2.58
3. Superphosphate, 160 ppm P		1.57	2.56	5.17	5.95	4.70	3.22
4. Monoammonium phosphate, 40 ppm P		2.18	.80	5.51	6.22	2.38	2.68
5. Monoammonium phosphate, 160 ppm P		1.35	1.82	4.33	6.33	3.35	3.92
6. Rock phosphate, 320 ppm P		1.53	.06	3.58	5.70	2.84	0.00
Least significant difference	(.01)	N.S.	1.89	1.52	1.67	.62	1.19
	(.05)	N.S.	1.39	1.10	1.21	.45	.86

[1]Average of four replications.

Table 4. Influence of various phosphatic treatments upon yield of wheat straw obtained with various Kansas soils in greenhouse experiment, 1954.

Treatment		Average[1] yield of wheat straw (grams/pot)					
		Mai Surface Soil	Mai Subsoil	Geary soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil, Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment		3.62	1.33	6.27	7.41	1.61	1.44
2. Superphosphate 40 ppm P		5.93	3.97	10.30	11.13	5.20	6.29
3. Superphosphate 160 ppm P		5.10	4.32	9.28	11.66	7.10	7.00
4. Monoammonium phosphate 40 ppm P		5.02	2.48	7.98	11.46	4.84	5.75
5. Monoammonium phosphate 160 ppm P		5.24	3.85	8.34	11.99	5.13	6.78
6. Rock phosphate 320 ppm P		3.48	1.30	7.48	10.22	5.85	1.54
Least significant difference	(.01)	1.06	.72	1.59	1.74	.77	1.09
	(.05)	.77	.52	1.15	1.26	.56	.79

[1] Average of four replications.

Table 5. Influence of various phosphatic treatments upon total yield of wheat plant material obtained with various Kansas soils in greenhouse experiment, 1954.

Treatment		Mai Surface Soil	Average[1] total yield of wheat plant material (grams/pot)				
			Mai Subsoil	Geary Soil, Unlimed	Geary Soil Plus 3.0% Excess $CaCO_3$	Cherokee Subsoil Unlimed	Cherokee Subsoil plus 3.0% Excess $CaCO_3$
1. No treatment		5.57	1.39	10.15	11.34	1.99	1.55
2. Superphosphate 40 ppm P		7.24	5.80	16.07	16.73	7.35	8.87
3. Superphosphate 160 ppm P		6.67	6.88	14.45	17.61	11.80	10.22
4. Monoammonium phosphate 40 ppm P		7.20	3.28	13.49	17.68	7.22	8.43
5. Monoammonium phosphate 160 ppm P		6.59	5.67	12.67	18.32	8.48	10.70
6. Rock phosphate 320 ppm P		5.01	1.36	11.06	15.92	8.69	1.54
Least significant difference	(.01)	1.51	.95	2.13	.88	1.97	2.13
	(.05)	1.09	.69	1.54	.64	1.41	1.54

[1] Average of four replications.

Table 6. Influence of various phosphatic treatments upon percentage phosphorus in wheat grain obtained with various Kansas soils in greenhouse experiment, 1954.

Treatment	Average[1] Percent P in Grain					
	Mai Surface Soil	Mai Subsoil	Geary Soil, Unlimed	Geary Soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment	.352	.267	.329	.353	.173	.232
2. Superphosphate 40 ppm P	.354	.355	.377	.301	.214	.335
3. Superphosphate 160 ppm P	.396	.273	.401	.226	.268	.295
4. Monoammonium phosphate 40 ppm P	.365	.284	.412	.323	.237	.223
5. Monoammonium phosphate 160 ppm P	.410	.274	.399	.361	.291	.317
6. Rock phosphate 320 ppm P	.334	.184	.395	.346	.244	.000

[1] Average of duplicate determinations made on each of four replications used as greenhouse cultures.

Table 7. Influence of various phosphatic treatments upon percentage phosphorus in straw obtained with various Kansas soils in greenhouse experiment, 1954.

Treatment	Mai Surface Soil	Average[1] Percent P in Straw: Mai Subsoil	Geary Soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment	.031	.018	.071	.062	.015	.019
2. Superphosphate 40 ppm P	.047	.025	.033	.054	.015	.020
3. Superphosphate 160 ppm P	.156	.025	.100	.060	.019	.036
4. Monoammonium phosphate 40 ppm P	.059	.035	.029	.027	.020	.015
5. Monoammonium phosphate 160 ppm P	.192	.051	.081	.051	.022	.023
6. Rock phosphate 320 ppm P	.051	.045	.035	.017	.021	.019

[1] Average of duplicate determinations made on each of four replications used as greenhouse cultures.

Table 8. Influence of various phosphatic treatments upon phosphorus uptake of wheat grain obtained with various Kansas soils in greenhouse experiment, 1954.

Treatment		Mei Surface Soil	Average[1] uptake of phosphorus in grain (mg./pot)				
			Mei Subsoil	Geary Soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment		7.38	2.25	12.78	13.90	6.34	3.19
2. Superphosphate 40 ppm P		4.56	6.45	21.67	16.00	4.46	8.63
3. Superphosphate 160 ppm P		6.30	6.94	20.64	26.82	12.55	9.33
4. Monoammonium phosphate 40 ppm P		7.95	2.26	22.70	20.12	5.66	5.83
5. Monoammonium phosphate 160 ppm P		5.41	4.95	17.21	22.85	9.78	12.42
6. Rock phosphate 320 ppm P		5.10	1.96	14.15	19.70	6.86	0.00
Least significant difference	(.01)	N.S.	2.03	8.30	6.90	2.53	1.08
	(.05)	N.S.	1.47	5.90	5.00	1.83	.78

[1] Average of four replications.

Table 9. Influence of various phosphatic treatments upon phosphorus uptake in wheat straw obtained with various Kansas soils in greenhouse experiments, 1954.

Treatment		Mai Surface Soil	Mai Subsoil	Geary soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil, Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
		Average[1] uptake of phosphorus in straw (mg./pot)					
1. No treatment		1.06	.24	3.70	4.60	.24	.27
2. Superphosphate 40 ppm P		2.77	.98	3.35	6.00	.83	1.24
3. Superphosphate 160 ppm P		8.06	1.05	9.20	6.96	1.34	2.56
4. Monoammonium phosphate 40 ppm P		2.99	.86	2.12	3.03	.97	.87
5. Monoammonium phosphate 160 ppm P		6.93	2.00	6.69	6.18	1.12	1.51
6. Rock phosphate 320 ppm P		1.74	.59	2.68	1.68	1.22	.30
Least significant difference	(.01)	.82	1.40	2.01	2.78	.74	.88
	(.05)	.59	1.01	1.46	2.02	.54	.64

[1] Average of four replications.

Table 10. Influence of various phosphatic treatments upon total uptake of phosphorus with wheat obtained on various Kansas soils in greenhouse experiment, 1954.

Treatment		Mai Surface Soil	Average[1] total uptake of phosphorus (mg./pot)				
			Mai Subsoil	Geary soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil, Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment		8.44	1.93	16.49	18.50	6.59	2.41
2. Superphosphate 40 ppm P		7.29	7.43	25.02	22.25	5.29	9.85
3. Superphosphate 160 ppm P		14.36	7.99	27.35	20.37	13.89	11.39
4. Monoammonium phosphate 40 ppm P		11.94	3.12	24.82	2[illegible].16	6.62	6.70
5. Monoammonium phosphate 160 ppm P		12.34	6.95	2[illegible].90	29.03	10.65	13.93
6. Rock phosphate 320 ppm P		6.93	1.42	14.33	21.38	7.57	.30
Least significant difference	(.01)	3.27	.85	14.93	12.99	2.71	3.15
	(.05)	2.37	.62	6.27	5.80	1.96	2.28

[1] Average of four replications.

Table 11. Chemically available phosphorus[1] contained in soils used in greenhouse experiment after harvest of wheat, 1954.

Treatment		Mai Surface Soil	Average[2] available phosphorus content of soils lb/acre: Mai Subsoil	Geary soil, Unlimed	Geary soil plus 3.0% excess $CaCO_3$	Cherokee Subsoil, Unlimed	Cherokee Subsoil plus 3.0% excess $CaCO_3$
1. No treatment		44.6	14.7	30.8	13.4	6.3	12.3
2. Superphosphate 40 ppm P		86.3	20.7	53.7	37.9	17.2	24.4
3. Superphosphate 160 ppm P		210.4	23.5	176.7	121.8	55.6	71.0
4. Monoammonium phosphate 40 ppm P		65.3	15.4	42.6	34.9	20.8	23.9
5. Monoammonium phosphate 160 ppm P		164.6	21.5	140.7	99.8	60.6	62.7
6. Rock phosphate 320 ppm P		41.9	17.6	30.8	18.8	41.6	12.6
Least significant difference	(.01)	7.52	2.77	13.94	16.38	1.93	13.41
	(.05)	5.43	2.00	10.08	11.85	1.41	9.70

[1]Measured by using 0.03 N NH_4F in 0.025 N HCl at a soil:solution ratio of 1:50.

[2]Average of duplicate determinations made on each of four replications of soil samples.

THE COMPARATIVE AVAILABILITY OF PHOSPHATE
IN TRIPLE SUPERPHOSPHATE, MONOAMMONIUM
PHOSPHATE, AND ROCK PHOSPHATE.

by

CLARENCE WILLIAM SWALLOW, JR.

B. S., Kansas State College
of Agriculture and Applied Science, 1951

AN ABSTRACT OF 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

1955

THE COMPARATIVE AVAILABILITY OF PHOSPHATE IN TRIPLE SUPERPHOSPHATE, MONOAMMONIUM PHOSPHATE, AND ROCK PHOSPHATE.

Both commercial and farmer interest have suggested the necessity of evaluating the availability of phosphorus contained in certain fertilizers.

A greenhouse evaluation of the efficiency of triple superphosphate, monoammonium phosphate and rock phosphate was made. The comparative availabilities of phosphorus in these fertilizers in the presence of excess $CaCO_3$ was studied. Unfavorable soil conditions as caused by marked acidity also were investigated.

The four soil materials used ranged in pH values from acid to alkaline. In addition, at the beginning of the experiment cultures of the two more acid soils were treated with excess $CaCO_3$. Measured amounts of each fertilizer were added to each soil along with uniform applications of nitrogen on all soils and applications of potassium on the Cherokee subsoil. Wheat was planted, allowed to grow to maturity, harvested and weighed. The soils then were analyzed for available phosphorus content. Plant material was analyzed for its content of phosphorus.

Application of the more soluble forms of phosphate produced some increase in yields of plant material in all cases. In general, triple superphosphate was slightly more effective in this regard than was monoammonium phosphate. Triple superphosphate produced substantially greater yields of wheat plants of the Mei subsoil which had a great excess of $CaCO_3$. Monoammonium phosphate gave greater yields of wheat plants than did triple superphosphate in only one instance, that being with the high rate of application of phosphorus on the limed Geary soil. Rock phosphate was completely ineffective on naturally calcareous soils. It also was not effective on naturally acid Cherokee subsoil after addition of 3 percent excess of $CaCO_3$. It was most effective on the very acid Cherokee subsoil.

Phosphorus content of the straw was increased by high rates of application of either triple superphosphate or monoammonium phosphate. Low rates of application of either of these materials generally were not effective in increasing phosphorus content of straw. The effect of rock phosphate was somewhat variable. The percentage of phosphorus contained in grain varied little as a result of application of any phosphatic fertilizer.

Triple superphosphate was superior to monoammonium phosphate in increasing total phosphorus uptake by wheat plants on the highly calcareous Mai subsoil. It also was superior in the case of the high rate of application on unlimed Cherokee subsoil and the case of the low rate of application on limed Cherokee subsoil. Monoammonium phosphate was equal to or superior to triple superphosphate on Mai surface soil, limed Geary soil, in the cases of low rate of application on unlimed Cherokee soil, and at the high rate of application on the limed Cherokee subsoil. Rock phosphate was ineffective in causing an increase in total phosphorus uptake by wheat plants. This treatment actually decreased total uptake of phosphorus on limed Cherokee subsoil.

In general, a larger quantity of chemically available phosphorus remained in the various soils after harvest of the wheat where triple superphosphate was used than where monoammonium phosphate was used. Rock phosphate was effective in increasing the amount of chemically available phosphorus only on unlimed Cherokee subsoil.

It may be concluded that under the conditions of this experiment the use of triple superphosphate was always fully as effective as the use of moncammonium phosphate. On the other hand, there were some instances where use of monoammonium phosphate gave poorer results than did use of triple superphosphate. Rock phosphate was much less effective than either of the other fertilizer materials.