A COMPARISON OF THE EFFECT OF CALCIUM METAPHOSPHATE AND OTHER PHOSPHATIC FERTILIZERS ON THE YIELD OF CERTAIN CROPS UNDER FIELD CONDITIONS

By

ROBERT O. WOODWARD

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1940

Submitted to the faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1955

A COMPARISON OF THE EFFECT OF CALCIUM METAPHOSPHATE

AND OTHER PHOSPHATIC FERTILIZERS ON

THE YIELD OF CERTAIN CROPS UNDER

FIELD CONDITIONS

Thesis Approved:

Lester V. Reed
Thesis Adviser

J. C. Lynd

Robert Maclean
Dean of the Graduate School

ACKNOWLEDGEMENTS

The author wishes to express his gratitude for the encouragement and constructive criticisms of Dr. Lester W. Reed, Dr. H. J. Harper, Dr. H. F. Murphy, and Mr. Wesley Chaffin in connection with this study and in the preparation of this thesis. Special credit is due Messrs. L. W. Osborn (deceased), Omy Price, LeRoy Hardy, and W. B. Edwards who permitted the study to be conducted on their farms and gave willingly their machinery, labor, and time throughout its course; and to my wife, Anna Lee Hilbert Woodward, for her constant encouragement and endless patience, and for proofreading the entire paper.

TABLE OF CONTENTS

LIST OF TABLES

List of Tables (Continued)

List of Tables (Continued)

LIST OF ILLUSTRATIONS

List of Illustrations (Continued)

List of Illustrations (Continued)

APPENDIX A

INTRODUCTION

One of the problems of paramount importance to the successful farmer of today, as was also true a half century ago, is cost of operation. The ratio of machinery cost to other investments now is about the same as it was at the turn of the century. Seed and labor costs are relative, and prices on most crops have been adjusted to parity through governmental agencies. One major change in this entire structure that has developed within the past fifteen years and one which may prove to be the difference between comfortable margins and below average income to the farmer is the general use of commercial fertilizers.

A substantial portion of the farmer's fertilizer dollar must be used to buy phosphate. The deficiency of phosphate in Oklahoma soils is continually emphasized. In a recent report, it was shown that of 60,000 soil samples tested, over 30 percent were deficient in phosphorus (6)[1]. This is dramatic evidence of the need for large quantities of phosphate fertilizer on Oklahoma farms.

Curtis (9) states that the cost per unit of available P_2O_5 in concentrated superphosphate is less than the cost per unit of available P_2O_5 in ordinary superphosphate, f.o.b. the farmer. Many farmers and agricultural workers, on receiving information regarding the production of this fertilizer, have asked questions pertinent to its

---

[1]Figure in parenthesis refer to literature cited.

merits as compared to ordinary superphosphate when used under varied climatic and soil conditions.

There are no published data on the relative value of calcium metaphosphate as compared with other phosphatic fertilizers under field conditions in Oklahoma. Information is also lacking on the response of certain crops to this material under varying conditions of climate and soil found in the fertilizer consuming area of the state. Calcium metaphosphate looks promising as a phosphatic fertilizer for Oklahoma farmers since its high concentration could result in a lower cost per pound of P_2O_5 delivered to the farm. Considering that the processes for the manufacture of calcium metaphosphate have been perfected, and large scale production is now possible, it is important that the value of this material be definitely established so that appropriate recommendations can be made concerning its use. The objective of this study was to evaluate crop response on phosphorus deficient soils to calcium metaphosphate and other phosphorus carriers.

REVIEW OF LITERATURE

Many experiments have been conducted to determine the relative value of calcium metaphosphate under both greenhouse and field conditions. In all but one of the tests reviewed, the fertilizer was supplied by the Tennessee Valley Authority (36). Calcium metaphosphate was developed at the Sheffield, Alabama, plant on a scale approaching commercial proportion in the late 1930's (10). The first large scale field testing of calcium metaphosphate was done on the basis of cooperative agreements between the Tennessee Valley Authority and several land-grant colleges. The tests were conducted to obtain information concerning the value of calcium metaphosphate under full scale farming operations. This was referred to as the Unit test-demonstration program.

In an agreement between the Oklahoma Agricultural and Mechanical College and the Tennessee Valley Authority, 150 tons of calcium metaphosphate was released through the Oklahoma Unit test-demonstration program to 66 farmers during 1947 for testing under field conditions (7). Working agreements were signed with selected farmers and the use of this material was limited to soil conserving and soil improving crops. A representative part of each field was left untreated for comparison. Response was very promising, and it appeared that calcium metaphosphate could occupy an important place in Oklahoma agriculture.

The original field tests of calcium metaphosphate in Oklahoma were established with standard fertilizer drills and distributors as

found on the farms. While every effort was made to get the fertilizer applied at prescribed rates, it was realized that variations occurred on many farms. Only a limited number of yield determinations was made and reports contained such meaningless phrases as "quite an increase", "half again as much", "40 percent more", and "a lot better" (45). It is obvious that proper evaluation of calcium metaphosphate cannot be made unless rates of application are controlled and yields are accurately determined.

Conditions under which the tests were conducted, in states other than Oklahoma, varied rather widely. Extremes ranged from low fertility soils of Southeastern United States to the very high fertility soils of Oregon, Idaho and New Mexico. The experiments were designed to compare calcium metaphosphate with other phosphatic fertilizers of known value. The crops were selected on the basis of their feeding habits, ranging from crops with low phosphate requirements such as oats, to sweet clover and alfalfa, which have high phosphate requirements. In all of the reports, response under field conditions was commensurate with that obtained in the greenhouse tests.

McGeorge (29) found that the phosphorus in calcium metaphosphate was nearly as available as that of triple superphosphate. Olsen et al (33), reported that calcium metaphosphate was not as effective as superphosphate on wheat, barley and sugar beets. In another report from Colorado (34), where radioactive phosphorus was used, alfalfa absorbed about equal amounts of phosphorus from calcium metaphosphate and superphosphate at all stages of growth; but wheat and barley obtained less phosphorus from calcium metaphosphate than from superphos-

phate when fertilizers were applied at planting time. Toeus et al (41), reported that calcium metaphosphate increased alfalfa production 16 percent over the check plot, but it was only 71 percent as effective as triple superphosphate. In a second test, they found calcium metaphosphate and fused tricalcium phosphate did not give an increase over the check plot while triple superphosphate increased alfalfa production 3.16 tons per acre. Idaho tests conducted during 1939, showed that triple superphosphate increased alfalfa production an average of 1.14 tons per acre, while calcium metaphosphate increased the yield only 0.59 ton per acre. In a study with radioactive phosphorus on calcareous soils, it was concluded that the uptake from calcium metaphosphate was consistantly below superphosphate (22). Baker (2), reported that unpublished data with greenhouse work gave similar results as those given by Toeus (41) where calcium metaphosphate was only 71 percent as effective as triple superphosphate.

Stanford (39) and others in Iowa, working with radioactive phosphates, found calcium metaphosphate less efficient than superphosphate as a source of phosphorus for oats, but there was no significant difference when the two materials were used on alfalfa. On all of the soils used in these experiments, the greatest recovery of phosphorus was from superphosphate, while the lowest recovery was from calcium metaphosphate. Calcium metaphosphate tended to supply less phosphorus on soils of pH 5.6 and 6.0 than did other carriers, while it was somewhat superior to other carriers on soils of pH 6.7. Cheney et al (8), found on three-fourths of their experiments superphosphate and calcium

metaphosphate gave equally good results, while on the other one-fourth the crop yields were significantly higher where superphosphate was used.

Karraker (26), and others in Kentucky, reported that calcium metaphosphate was practically equivalent to superphosphate as a source of phosphorus for alfalfa, corn, and white clover. In Maine, Brown (3) conducted experiments to determine the efficiency of calcium metaphosphate on soils with a pH range of 4.6 to 6.5. He reported that calcium metaphosphate was nearly 7% superior to either superphosphate or triple superphosphate as a source of phosphorus for German millet. In seven of twelve tests with oats, wheat, Hungarian millet and German millet, Brown et al (4), reported that calcium metaphosphate gave higher yields than superphosphate. Alway et al (1), in Minnesota, found that calcium metaphosphate was as effective as superphosphate on all except calcareous soils when incorporated into the soil prior to seeding the crop.

Hinkle (21) reported that in experiments conducted in New Mexico, annual sweet clover failed to produce as much dry weight or absorb as much phosphorus from calcium metaphosphate as from triple superphosphate. In another test (20), calcium metaphosphate was less effective than superphosphate for alfalfa. Dregne (12) states that in other New Mexico tests on calcareous soils, calcium metaphosphate increased alfalfa yields about 50 percent over the unfertilized plot while increases from superphosphate were considerably more than 50 percent. Blaser et al (5), found orchard grass and ladino clover did not absorb as much P_2O_5 from calcium metaphosphate as from superphosphate

under several conditions, including varied rates and methods of application.

In greenhouse experiments, Jacob et al (24) in Oregon found that calcium metaphosphate was not as effective as superphosphate on soils possessing an alkaline reaction. Gilbert et al (16) in Rhode Island, studied a number of phosphate carriers with several types of plants during 1936 and reported calcium metaphosphate gave very poor results. The phosphorus in calcium metaphosphate was determined to be less available than that in several other phosphates. Neilson (31) in Utah reports, "It appears from these tests that while calcium metaphosphate has value in this area, it is not as effective as superphosphate". In Virginia, O'Brien (32) reports the following percentage increases in alfalfa yields over the check: superphosphate, 35%; calcium metaphosphate, 29%; and fused rock phosphate, 23%. From this it was concluded that calcium metaphosphate was an effective fertilizer for a wide variety of crops grown in rotation.

Peterson et al (36), studied the results of fertilizer experiments on calcareous soils in the Western states and reported ordinary superphosphate was equal to concentrated superphosphate, ammonium phosphate and phosphoric acid but was superior to calcium metaphosphate, tricalcium phosphate and rock phosphate. In this same report, Oregon data indicated calcium metaphosphate was equal to superphosphate only on acid soils. In Colorado, calcium metaphosphate was equal to superphosphate under certain conditions and for some stages of crop growth. In Montana, calcium metaphosphate was not as effective as the superphosphates. In New Mexico, ammonium phosphate and

superphosphate were superior to calcium metaphosphate. He indicated that on Western soils, while calcium metaphosphate occasionally shows a fair response, generally there is a marked advantage of superphosphate over calcium metaphosphate.

Jones et al (25), in a summary of several hundred field experiments using calcium metaphosphate on legumes, corn, cotton, and wheat in seven states East of the Mississippi River reports that the average relative crop yield was 99% as compared with a value of 100% for superphosphate. In this same report, it was indicated that results from field experiments on alkaline soils in the Western states are conflicting. Placement of fertilizer, soil moisture, and rate of hydrolysis of metaphosphate to orthophosphate may be factors which affect the efficiency of calcium metaphosphate as a source of phosphorus.

MATERIALS AND METHODS

It was considered desirable to secure information concerning the relative value of calcium metaphosphate from several sections in Oklahoma where variations in soil and rainfall conditions occur. It was assumed that by wide distribution of experimental plots, a possible loss in one area from hail or insects would not necessarily result in a complete loss of the season's efforts. Early in 1948, an experiment was designed for four locations of varying soil and rainfall conditions to test the response of sweet clover, lespedeza, oats and irrigated alfalfa to calcium metaphosphate as a fertilizer under field conditions, as is shown in figure 23, Appendix "A". The objective of the study was to evaluate crop response to calcium metaphosphate and other phosphorus carriers on phosphorus deficient soils.

Locations were selected that would be comparable to several conditions in Oklahoma in which appreciable quantities of fertilizer would be used. Plots were established on soil of low fertility in a high rainfall area (40 inches per year); soil of low fertility in an area of medium rainfall (36 inches per year); soil of medium fertility in an area of medium rainfall (32 to 36 inches per year); and, under irrigated conditions. The three legumes and one non-legume were chosen as they represent not only the extremes in feeding habits, but also the crops of rather great importance in their respective areas. Three fertilizers of known value were chosen to provide an index with which to measure any yield differences that might be found. The three fertilizer materials used as an index were also used by many of the authors

cited in the review of literature; consequently, a closer correlation could be drawn between this study and other work on calcium metaphosphate.

Location of Plots

The following locations were selected for the study:

Muskogee County; L. W. Osborn farm, 1 1/2 miles north of Muskogee, Oklahoma. (See Table II, Appendix "A")

Pawnee County; Omy Price farm, 1 1/2 miles north and 3 miles east of Glencoe, Oklahoma. (See Table III, Appendix "A")

Noble County; LeRoy Hardy farm, 7 miles south and 2 miles east of Perry, Oklahoma. (See Table IV, Appendix "A")

Jackson County; W. B. Edwards farm, one mile east of Martha, Oklahoma. (See Table V, Appendix "A")

Table I. Soil Type, Soil Reaction and Available Phosphorus Level Found at the Four Locations.

Location	Soil Type (14)	Soil Reaction*	Available Phosphorus**
Muskogee County	Parsons very fine sandy loam	Strongly Acid pH 4.9	Very Low Less than 12 lbs. per acre.
Pawnee County	Renfrow silt loam	Strongly Acid pH 4.9	Very Low Less than 12 lbs. per acre.
Noble County	Renfrow clay loam	Slightly Acid pH 6.3	Low 16-20 lbs. per acre.

Table I. (continued)

Jackson County	Foard silt loam	Neutral pH 7.8	High 40-50 lbs. per acre

*Determined by the Modified Comber Test for Soil Acidity (13).
**Determined by the 1/50th Normal Sulphuric Acid Test for Phosphorus (13).

Fertilizers Used

The four different kinds of phosphate fertilizers used in this experiment together with the method of manufacturing of each material is given below.

1. Commercial superphosphate $CaH_4(PO_4)_2 + CaSO_4$: made by mixing finely ground rock phosphate with an equal weight of sulphuric acid.

2. TVA triple superphosphate $CaH_4(PO_4)_2$: made by mixing phosphoric acid and powdered rock phosphate. The phosphoric acid required in preparing this product is made by smelting rock phosphate with coke and silica in an electric furnace. The evolved gases are burned and the phosphorus pentoxide fumes are passed into water, thereby producing phosphoric acid. This acid is mixed with finely powdered rock phosphate in proper proportions. The mixture is permitted to cure and is then reground to the desired fineness.

3. Fused tricalcium phosphate $Ca_3(PO_4)_2$: made by passing dry steam for a period of 5 to 15 minutes through a molten mass of rock phosphate, which has been heated to at least 2732 degrees Fahrenheit.

4. TVA calcium metaphosphate $Ca(PO_3)_2$: made by passing gaseous phosphorus pentoxide prepared as for TVA triple superphosphate into a stream of dry air which then passes upward through a vertical column

of finely ground rock phosphate which has been heated from 2012 to 2224 degrees Fahrenheit. A liquid is produced which, upon cooling, becomes a semitransparent, glassy material. It is reground before marketing.

Chemical Analysis of Materials

Quantitative analyses were made on samples from the above materials with the following values obtained:

Fertilizer	Total P_2O_5 (percent)
Commercial Superphosphate	20.27
Triple Superphosphate	49.06
Fused Tricalcium Phosphate	29.09
Calcium Metaphosphate	62.71

The fused tricalcium phosphate was sifted through a 20-mesh seive to facilitate evaluation due to particle size. The portion passing through the seive is referred to as 20 minus and that remaining on the seive is referred to as 20 plus.

Establishing Plots and Measuring Effect of Fertilizer

The farmers' equipment and machinery was used for the preparation of the seedbed and other field operations necessary in connection with the project. Plots were measured off with a steel tape, laid out with a small garden plow, and stakes were set to identify each plot. Broadcast applications were made by hand and plots disced three times parallel to the length before seeding. Row applications were made by hand in a three-inch furrow, and one inch of soil was placed between the fertilizer and seed. Sweet clover, lespedeza, and oats were seeded with a Planet Junior number 3 hill and drill seeder.

Work was started in Muskogee and Pawnee Counties in 1948, and locations in Noble and Jackson Counties were established in 1949. Heavy rains in the Muskogee area destroyed the lespedeza plots and new plantings were made in 1949. Poor inoculation and dry weather in Pawnee County caused abandonment of the lespedeza plots in 1948. New plantings of lespedeza at Pawnee in 1949 were not harvested because of poor stands and adverse weather. Complete descriptions of these experiments are shown in Tables II, III and IV, Appendix "A".

After the plots were established in Muskogee, Pawnee and Noble Counties, three visitations were made at two-week intervals for observation and study. Subsequent visits were made as needed, but not in excess of six-week intervals at any time. Two randomized samples were cut from each plot for yield determinations. The sweet clover was harvested at approximately 2/10 bloom, and lespedeza was harvested at an estimated maximum growth. The oats were ripe when cut.

The Jackson County plots were visited regularly for observation and study. Two samples were taken at random from each of the blocks at each cutting. The time of sampling was governed by the farmer's plan for haying, and clippings were generally made within two days of harvest. A complete description of this experiment is shown in Table V, Appendix "A".

EXPERIMENTAL DESIGN

The Muskogee, Pawnee and Noble County plots consisted of three randomized replications of each series of treatments. Each series included four different phosphate fertilizer treatments and a check, or a total of five plots. Plot treatments included both row and broadcast applications. In order to compensate for any soil variations that might occur within the plot area, the row and broadcast application series were alternated. The experiment was essentially a randomized block split plot design.

Plot treatments within each series were as follows: calcium metaphosphate; fused tricalcium phosphate, less than 20-mesh; fused tricalcium phosphate, more than 20-mesh; commercial superphosphate; and a non-treated check plot. Applications of fertilizer were made at the rate of 40 pounds P_2O_5 per acre. Each plot was 10 feet wide and 36 feet long with rows running parallel to the length of the plot on 16-inch intervals.

The Jackson County experiment was a latin square which included four replications on an established stand of irrigated alfalfa. Water borders on 30-foot intervals were used as boundaries, running east and west. Three-foot alleyways on 50-foot intervals were used as boundaries running north and south. Broadcast applications of calcium metaphosphate, triple superphosphate, and commercial superphosphate were made at the rate of 120 pounds P_2O_5 per acre on each series.

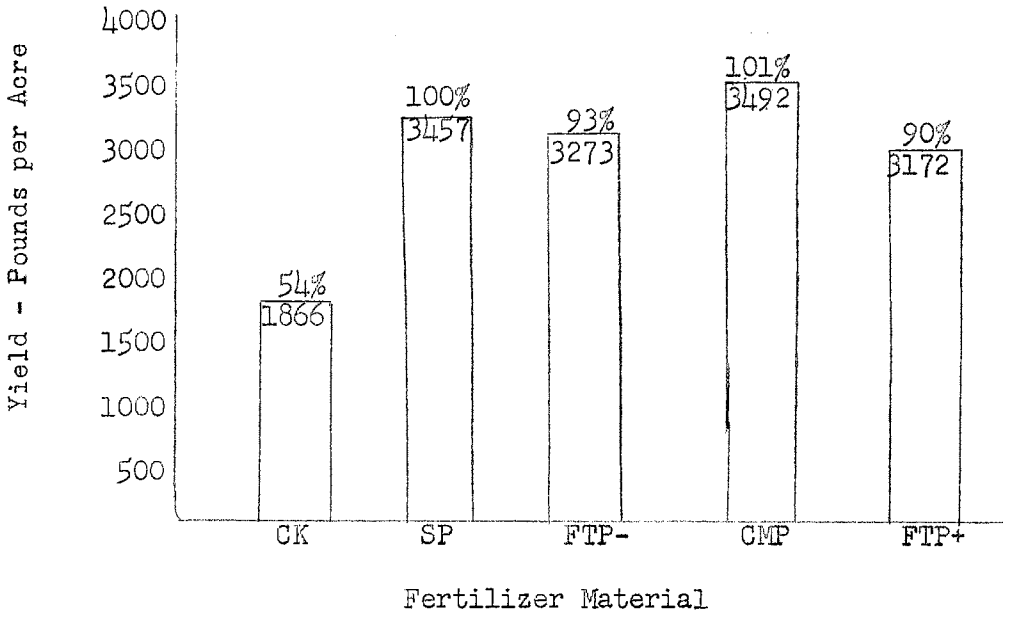
RESULTS AND DISCUSSION

In each of the locations commercial superphosphate was used as a measure of crop response to other types of phosphate fertilizers. The relative value of each phosphate source was determined by comparing the average crop yield on plots where it was applied with the yield on plots where superphosphate was applied, using a value of 100% for the latter.

Sweet Clover Response to Row Fertilization

In Muskogee County, the plots treated with calcium metaphosphate outyielded those treated with superphosphate an average of 36 pounds

Figure 1. Yield of sweet clover and relative value of several sources of phosphorus applied to the row in Muskogee County, 1949.



CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

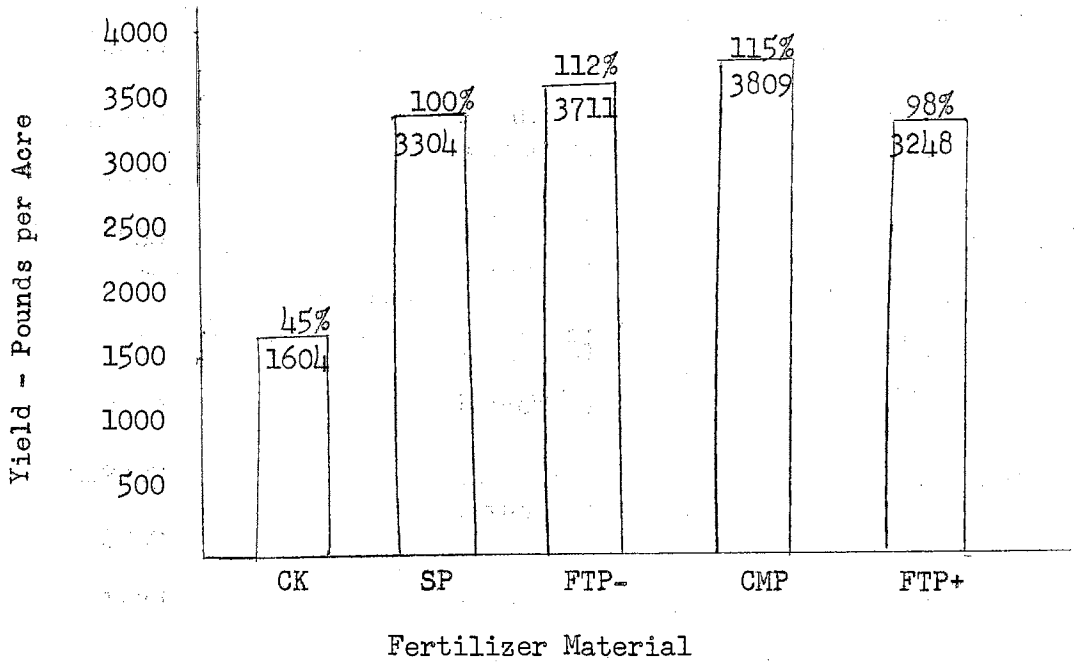
per acre, as shown in figure 1 and Table VI, Appendix "B". This is approximately 101% on the basis of 100% for superphosphate. Fine mesh fused phosphate was inferior to superphosphate by 184 pounds per acre and coarse mesh fused phosphate was inferior by 285 pounds per acre. These two materials rated 93% and 90% respectively. The check plot yielded 1,591 pounds per acre or 54% of the superphosphate yield.

The difference of only 36 pounds per acre in the production of sweet clover, between calcium metaphosphate and superphosphate should hardly be considered in evaluating these materials as this could easily result from variations in plant population, harvesting methods, or from other causes. In the statistical analysis of the variation in yield between treatments, the LSD value of 33.4 pounds per acre was obtained at the 5% point for 4 degrees of freedom, as shown in Table XVII, Appendix "C". Therefore, at Muskogee, the increase in the yield of sweet clover on the plots treated with superphosphate, calcium metaphosphate, and fused phosphate over the check plot is statistically significant.

In Pawnee County, the plots treated with calcium metaphosphate outyielded those treated with superphosphate an average of 505 pounds per acre as shown in figure 2 and Table VII, Appendix "B". This is equivalent to 115% on the basis of 100% for superphosphate. Fine mesh fused phosphate was 407 pounds per acre superior to superphosphate, and rated 112%. Coarse fused phosphate was 56 pounds per acre inferior to superphosphate and rated 98%. Superphosphate was superior to the check plot by 1,898 pounds or 55 percent.

Statistical analysis of the data on row application of the various phosphates on sweet clover in Pawnee County showed the LSD value to be 305.6 pounds per acre at the 5% point for 4 degrees of freedom, as shown in Table XVII, Appendix "C". Therefore, the increase in production due to the three sources of phosphate was significant at this location.

Figure 2. Yield of sweet clover and relative value of several sources of phosphorus applied to the row in Pawnee County, 1949.

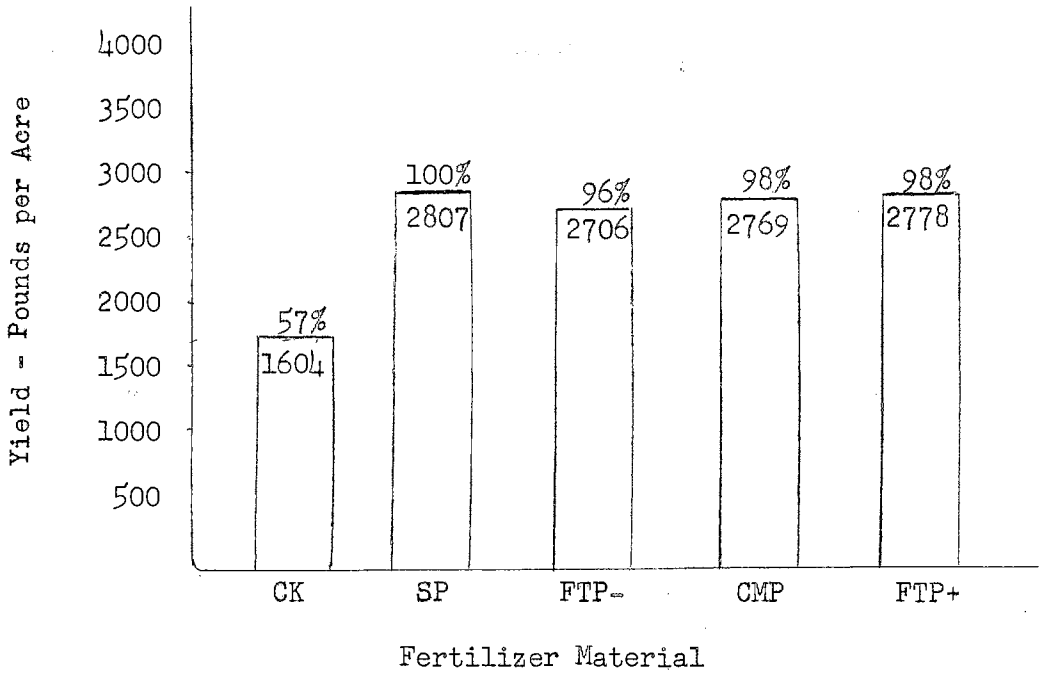


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

In Noble County, the plots treated with superphosphate outyielded those treated with coarse mesh fused phosphate an average of 29 pounds per acre, as shown in figure 3 and Table VIII, Appendix "B". This is

equivalent to 98% on the basis of 100% for superphosphate. Calcium metaphosphate was inferior to superphosphate by 38 pounds per acre, fine mesh fused phosphate was inferior by 101 pounds per acre, and the check plot was inferior by 1203 pounds per acre. On the basis of 100% for superphosphate these materials would rate 98%, 96% and 57% respectively. The LSD value of 168.6 pounds per acre was obtained at the 5% point with 4 degrees of freedom, as shown in Table XVII, Appendix "C", therefore, the increase in yield due to the source of phosphate is statistically significant at this location.

Figure 3. Yield of sweet clover and relative value of several sources of phosphorus applied to the row in Noble County, 1949.



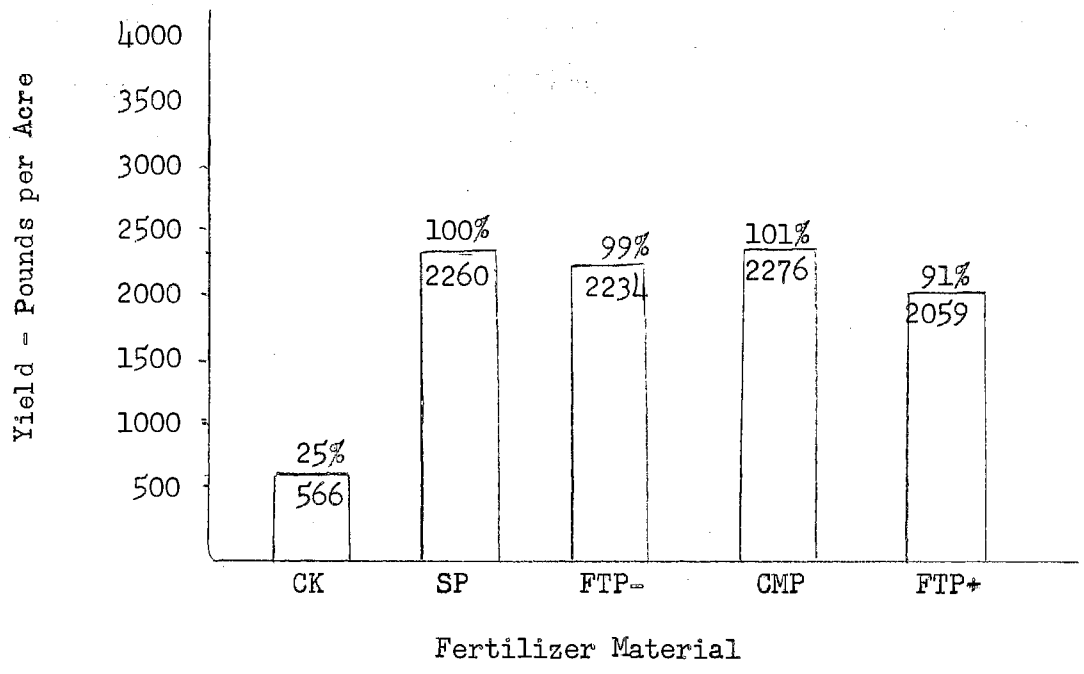
CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate.

Lespedeza Response to Row Fertilization

At Muskogee, calcium metaphosphate was superior to superphosphate as a fertilizer for lespedeza by an average of 16 pounds per acre. The ratio is 101%, as shown in figure 4 and Table IX, Appendix "B". Fine mesh fused phosphate and coarse mesh fused phosphate were both inferior to superphosphate by 26 pounds per acre and 201 pounds per acre, or 99% and 91%, respectively. Superphosphate was superior to the check plot by 1694 pounds per acre.

The computed LSD value of 102 pounds of hay per acre at the 5% point for 4 degrees of freedom is shown in Table XIX, Appendix "C". The increase in yield per acre of lespedeza over the check plot is statistically significant at this location.

Figure 4. Yield of lespedeza and relative value of several sources of phosphorus applied to the row in Muskogee County, 1949.

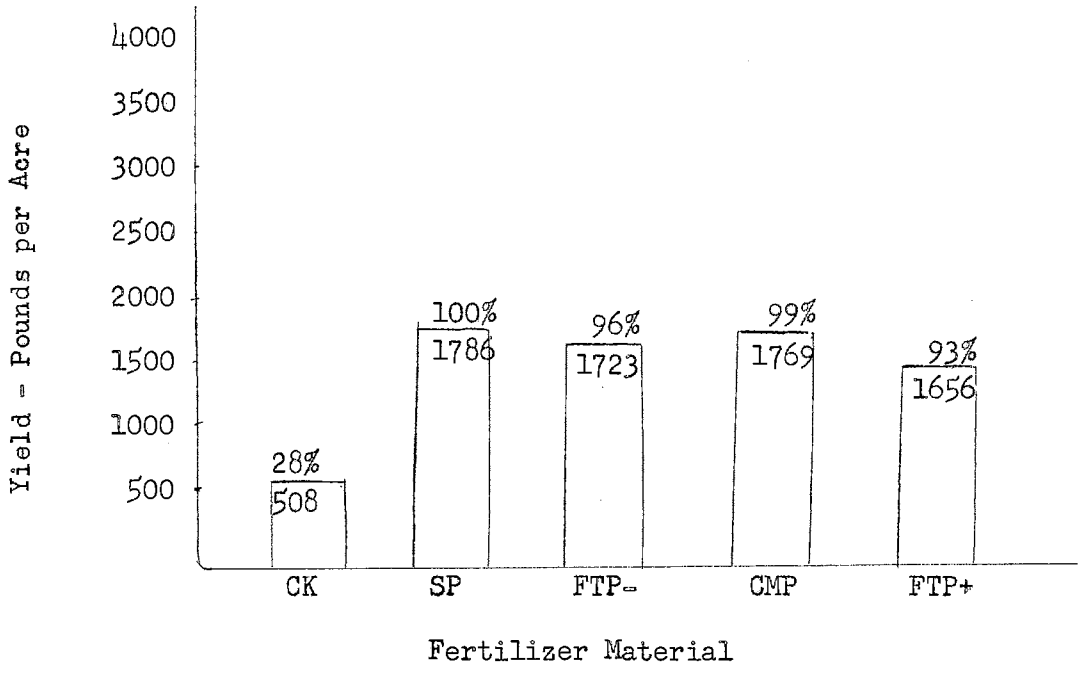


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

In the Noble County experiment in 1949, superphosphate was superior to calcium metaphosphate, fine mesh and coarse mesh fused phosphate, and the check plot by 17 pounds, 63 pounds, 130 pounds, and 1279 pounds per acre respectively, as shown in figure 5 and Table X, Appendix "B". On the basis of 100% for superphosphate this would rate each 99%, 96%, 93%, and 28%.

The computed LSD value of 70 pounds per acre at the 5% point for 4 degrees of freedom shows the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 5. Yield of lespedeza and relative value of several sources of phosphorus applied to the row in Noble County, 1949.

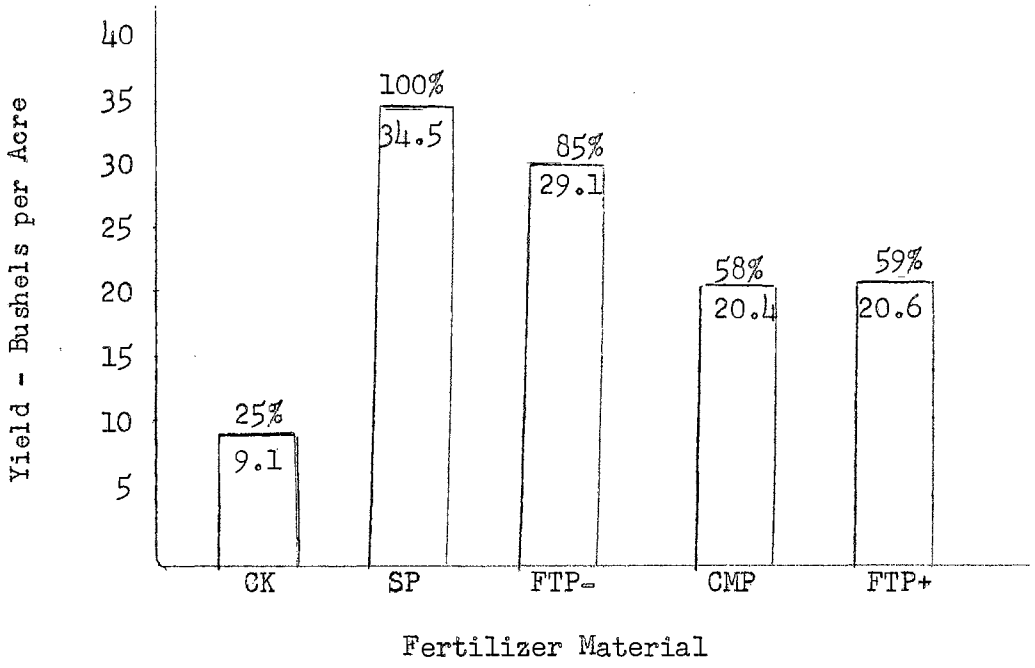


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

Oats Response to Row Fertilization

At the Muskogee County location in 1948, on oats, superphosphate was superior to fine mesh fused phosphate, coarse mesh fused phosphate, calcium metaphosphate and the check plot by 5.4 bushels, 13.9 bushels 14.1 bushels and 15.4 bushels per acre respectively, as shown in figure 6 and Table XI, Appendix "B". On the basis of 100% for superphosphate the yields rate 85%, 59%, 58% and 25% for each of the treatments.

Figure 6. Yield of oats and relative value of several sources of phosphorus applied to the row in Muskogee County, 1948.



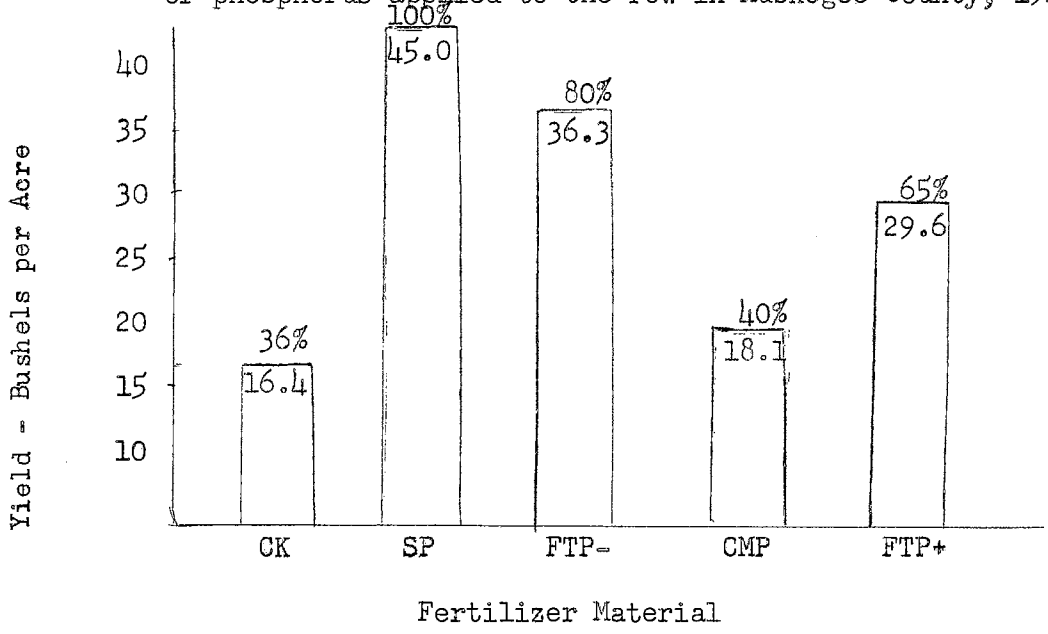
CK = Check. SP = Superphosphate. FTP = Fused tricalcium phosphate. CMP = Calcium metaphosphate

The computed LSD value of 1.9 bushels per acre at the 5% point for 4 degrees of freedom, as shown in Table XXIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Data on oats collected at Muskogee in 1949, figure 7 and Table XII, Appendix "B", indicates that superphosphate was superior to fine mesh fused phosphate by 8.7 bushels per acre; coarse mesh fused phosphate by 15.4 bushels per acre; calcium metaphosphate, 26.9 bushels per acre; and 28.6 bushels per acre over the check plot. On the basis of 100% for superphosphate, the other fertilizers would rate 80%, 65%, 40% and 36% respectively.

The computed LSD value of 1.4 bushels per acre at the 5% point for 4 degrees of freedom, as shown in Table XXVII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 7. Yield of oats and relative value of several sources of phosphorus applied to the row in Muskogee County, 1949.



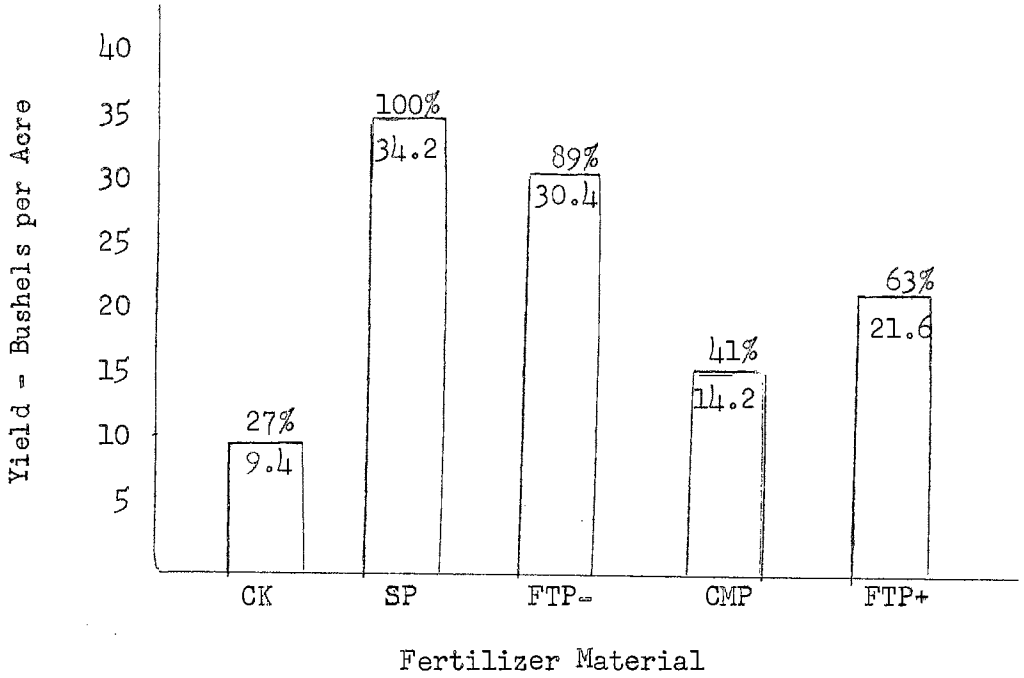
CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

The data collected at the Pawnee County location in 1948, indicated that superphosphate was superior to the other three types of phosphate fertilizer by 3.7, 12.6, 20.0 and 24.8 bushels per acre, as shown

in figure 8 and Table XIII, Appendix "B". On the basis of 100% for superphosphate, the yields would rate 89%, 63%, 41%, and 27% respectively.

The computed LSD value of 0.6 bushels per acre at the 5% point for 4 degrees of freedom as shown in Table XXIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 8. Yield of oats and relative value of several sources of phosphorus applied to the row in Pawnee County, 1948.



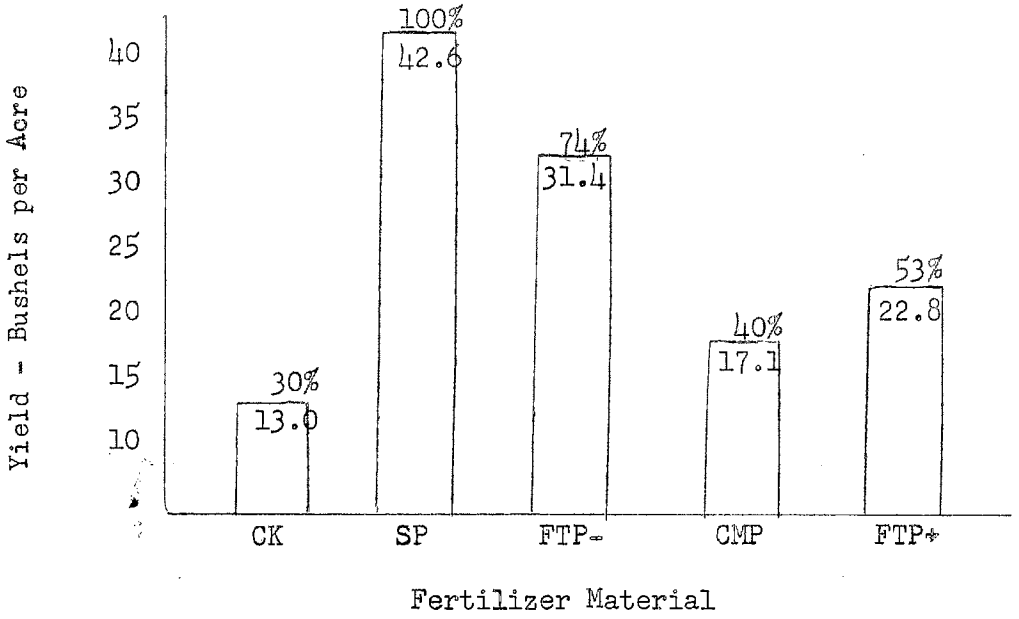
CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

Oat yields in 1949 at the Pawnee County location again indicated that superphosphate was superior to other forms of phosphate, as shown in figure 9 and Table XIV, Appendix "B". The increases in yields due to superphosphate over the other phosphates were as follows: fine mesh fused phosphate, 11.2 bushels; coarse mesh fused phosphate, 19.8 bushels; calcium metaphosphate, 25.5 bushels; and the check plot, 29.6 bushels

per acre. The relative value of all phosphates on the basis of 100% for superphosphate was 74%, 53%, 40% and 30% respectively.

The computed LSD value of 1.2 bushels per acre at the 5% point with 4 degrees of freedom as given in Table XXVII, Appendix "C", indicates the increase in production due to the phosphate fertilizer to be significant at this location.

Figure 9. Yield of oats and relative value of several sources of phosphorus applied to the row in Pawnee County, 1949.



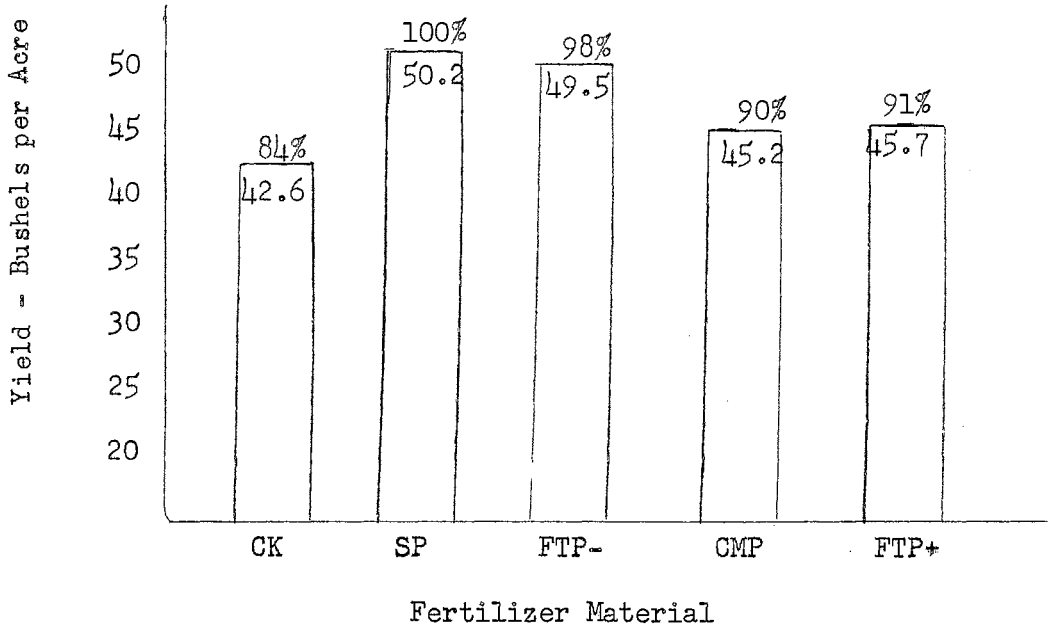
CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

In Noble County, superphosphate was superior to the other phosphate fertilizers on oats, as shown in figure 10 and Table XV, Appendix "B". The superphosphate treated plot outyielded the other treatments as follows: fine mesh fused phosphate, 0.7 bushels per acre; coarse mesh fused phosphate, 4.5 bushels per acre; calcium metaphosphate, 5.0 bushels per acre; and the check plot, 7.6 bushels per acre. The relative value as indicated by this data, on the basis of 100% for superphosphate

would be 98%, 91%, 90%, and 84% respectively.

The computed LSD value of 1.9 bushels per acre at the 5% level and 4 degrees of freedom as given in Table XXVII, Appendix "C" indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 10. Yield of oats and relative value of several sources of phosphorus applied to the row in Noble County, 1949

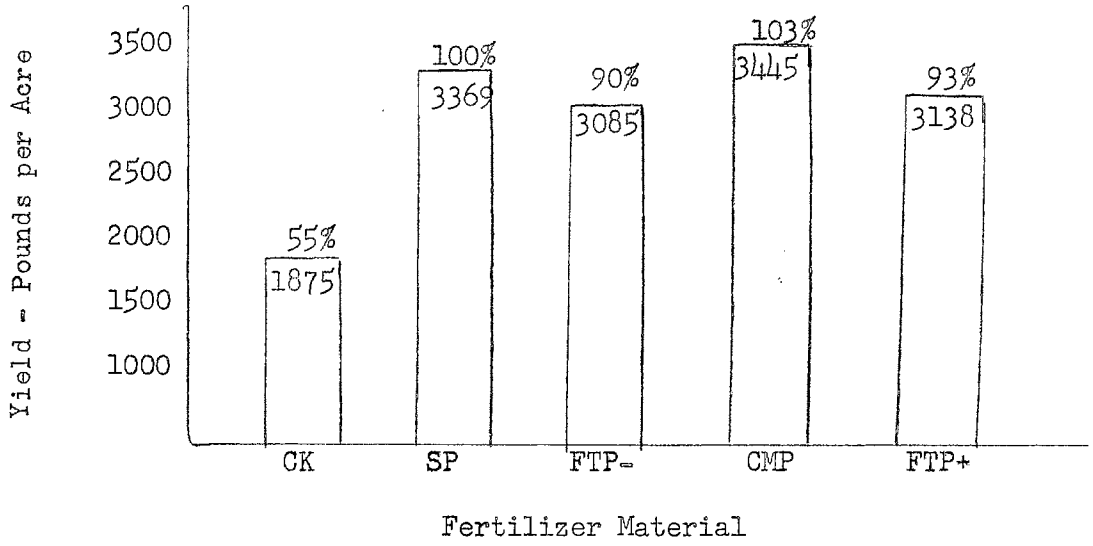


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

Sweet Clover Response to Broadcast Application

In Muskogee County, the response of sweet clover to the broadcast application of the four phosphate fertilizers was significantly greater than the check plot as shown in figure 11 and Table VI, Appendix "B". Calcium metaphosphate was 116 pounds per acre superior to superphosphate, 347 pounds per acre superior to coarse mesh fused phosphate, 400 pounds per acre superior to fine mesh fused phosphate and 1610 pounds per acre superior to the check plot. The computed LSD value of 149 pounds per acre at the 5% point with 4 degrees of freedom, as given in Table XVIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 11. Yield of sweet clover and relative value of several sources of phosphate, broadcast application, in Muskogee County, 1949.

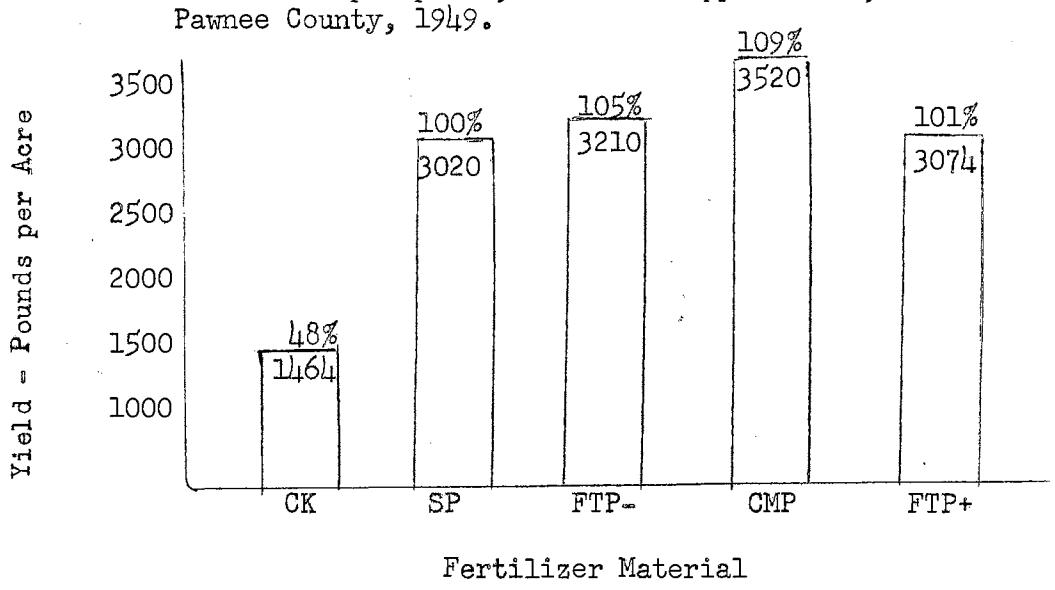


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate
CMP - Calcium metaphosphate

Sweet clover yields in Pawnee County showed broadcast applications of calcium metaphosphate to be significantly superior to the other three

forms of phosphate fertilizers, as shown in figure 12 and Table VII, Appendix "B". The plots treated with calcium metaphosphate yielded 310 pounds per acre more than fine mesh fused phosphate, 446 pounds per acre more than coarse mesh fused phosphate, 500 pounds per acre more than superphosphate and 2056 pounds per acre more than the check plot. The computed LSD value of 134.2 pounds per acre at the 5% point and 4 degrees of freedom, as given in Table XVIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 12. Yield of sweet clover and relative value of several sources of phosphate, broadcast application, in Pawnee County, 1949.

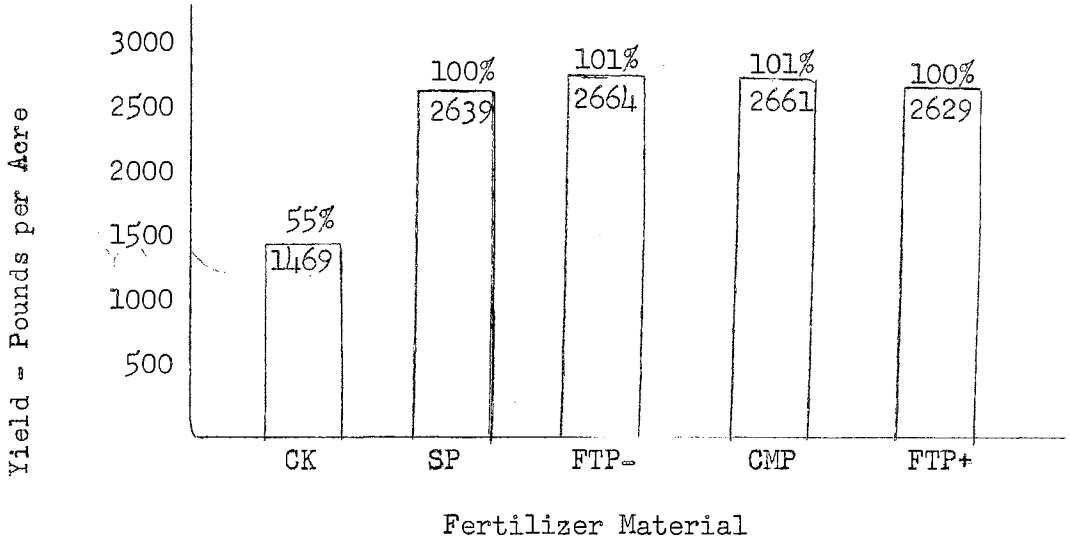


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

In Noble County, the difference in the yield of sweet clover on all of the phosphate fertilizer plots was of no significance when the application was broadcast as shown in figure 13 and Table VIII, Appendix "B". The increase of approximately 1200 pounds per acre of all treated plots over the check plot was highly significant with a computed LSD

value of 161 pounds per acre at the 5% point for 4 degrees of freedom, as shown in Table XVIII, Appendix "C".

Figure 13. Yield of sweet clover and relative value of several sources of phosphate, broadcast application, in Noble County, 1950.

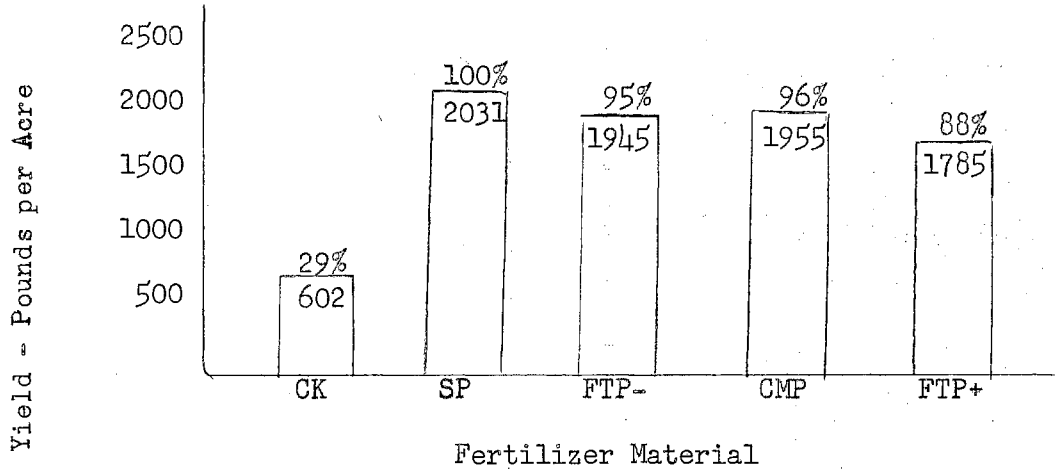


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

Lespedeza Response to Broadcast Application

Lespedeza responded very favorably to broadcast applications of superphosphate, calcium metaphosphate and fine mesh fused phosphate in Muskogee County, as shown in figure 14 and Table IX, Appendix "B". The response to coarse mesh fused phosphate was approximately 250 pounds per acre less than 0-20-0, however, it was 1183 pounds per acre superior to the check plot. The computed LSD value of 186 pounds per acre at the 5% point for 4 degrees of freedom, as given in Table XX, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

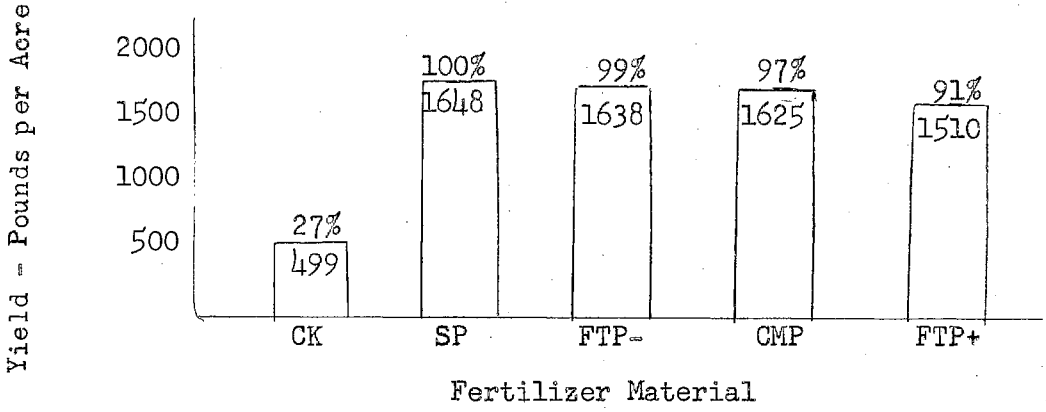
Figure 14. Yield of lespedeza and relative value of several sources of phosphate, broadcast application, in Muskogee County, 1949.



CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium Metaphosphate

At the Noble County location, lespedeza responded favorably to broadcast applications of the four phosphate fertilizers, as shown in figure 15 and Table X, Appendix "B". The computed LSD value of 74.2 pounds per acre at the 5% point for 4 degrees of freedom, as shown in Table XX, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be significant at this location.

Figure 15. Yield of lespedeza and relative value of several sources of phosphate, broadcast application, in Noble County, 1949.

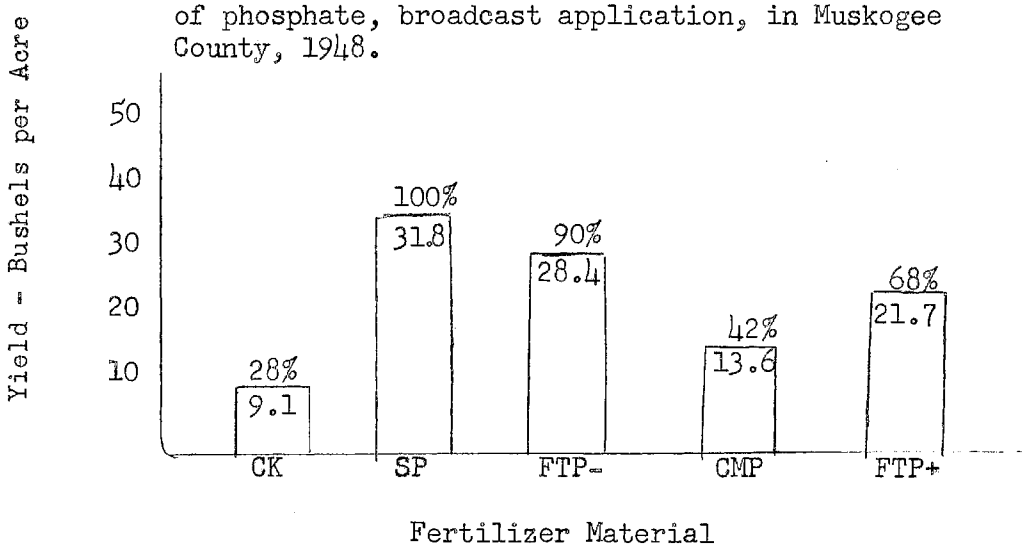


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

Oat Response to Broadcast Application

At Muskogee in 1948, the yield of oats on the superphosphate plot was superior to fine mesh fused phosphate, coarse mesh fused phosphate and calcium metaphosphate by 3.4, 10.1 and 18.2 bushels per acre respectively, and outyielded the check plot 22.7 bushels per acre, as shown in figure 16 and Table XI, Appendix "B". The computed LSD value of 2.2 bushels per acre at the 5% point for 4 degrees of freedom, as shown in Table XXIV, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be statistically significant at this location.

Figure 16. Yield of oats and relative value of several sources of phosphate, broadcast application, in Muskogee County, 1948.

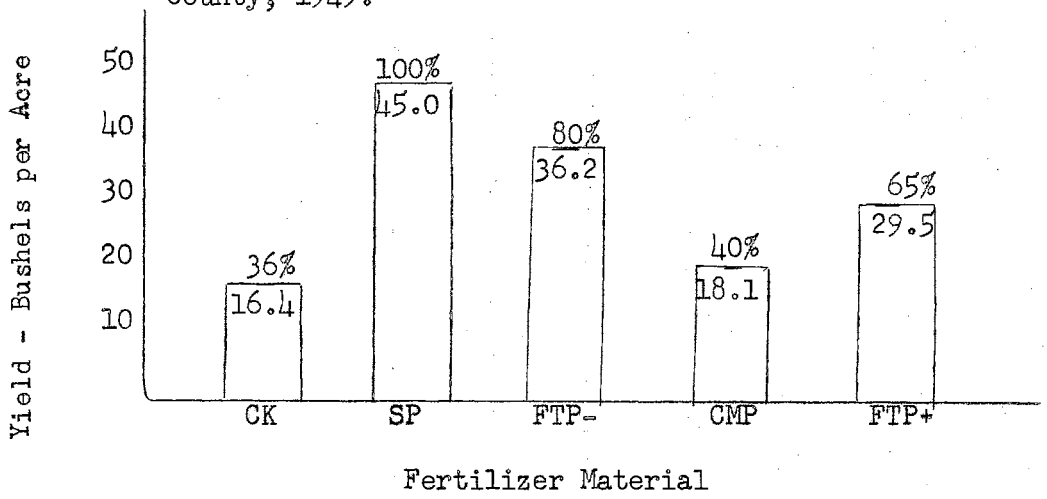


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

In Muskogee County the 1949 response on oats was in the same order as the 1948 response on oats; the broadcast application of superphosphate was superior to the other phosphate fertilizers, figure 17 and Table XII, Appendix "B". Superphosphate outyielded fine mesh fused

phosphate, calcium metaphosphate and the check plot by 8.8, 15.5, 26.9, and 28.6 bushels per acre respectively. The computed LSD value of 1.4 bushels per acre at the 5% point with 4 degrees of freedom, as shown in Table XXVIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be statistically significant at this location.

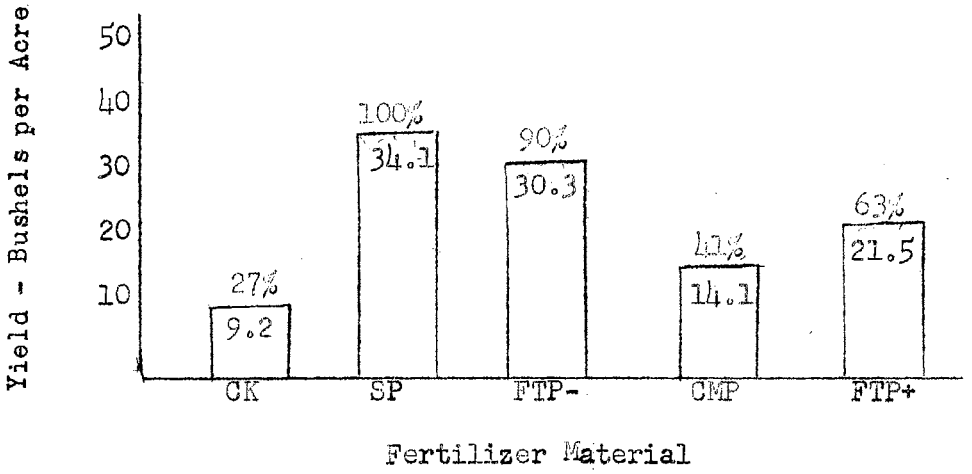
Figure 17. Yield of oats and relative value of several sources of phosphate, broadcast application, in Muskogee County, 1949.



CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

Calcium metaphosphate plots averaged 4.9 bushels per acre more oats than the check plot in Pawnee County in 1948; however, it was 20.0 bushels per acre inferior to the superphosphate treated plot, as shown in figure 18 and Table XIII, Appendix "B". Superphosphate produced 3.8 bushels per acre more than fine mesh fused phosphate. The computed LSD value of 1.8 bushels per acre at the 5% point and 4 degrees of freedom, as shown in Table XXIV, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be statistically significant at this location.

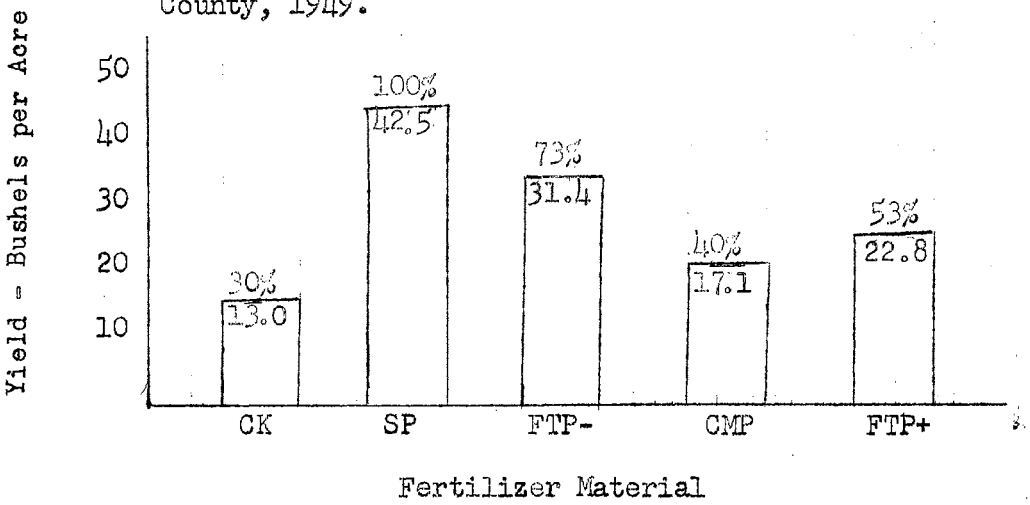
Figure 18. Yield of oats and relative value of several sources of phosphate, broadcast application, in Pawnee County, 1948.



CK = Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

In Pawnee County in 1949, significant increases in oat production due to the broadcast application of the various phosphates are shown in figure 19 and Table XIV, Appendix "B". Superphosphate

Figure 19. Yield of oats and relative value of several sources of phosphate, broadcast application, in Pawnee County, 1949.

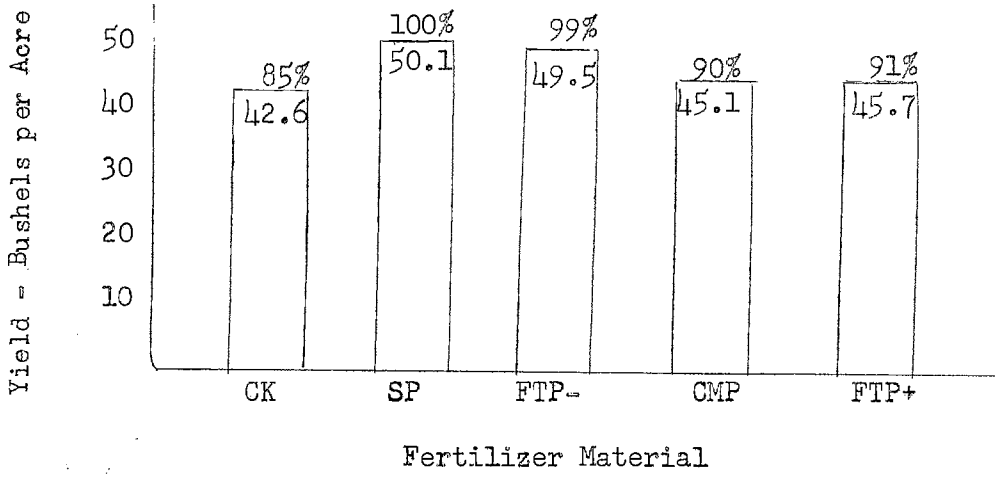


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

was again superior to fine mesh fused phosphate by 11.1 bushels, coarse mesh fused phosphate 19.7 bushels, calcium metaphosphate 25.4 bushels, and the check plot 29.5 bushels per acre. The computed LSD value of 1.1 bushels per acre at the 5% point and 4 degrees of freedom as shown in Table XXVIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be statistically significant at this location.

In the Noble County experiment in 1949, superphosphate was superior to the other phosphate fertilizers by only a small difference as is shown in figure 20 and Table XV, Appendix "B". Superphosphate was superior to fine mesh fused phosphate by 0.6 bushels per acre; coarse mesh fused phosphate, 4.4 bushels per acre; calcium metaphosphate, 5.0 bushels per acre; and the check plot, 7.5 bushels per acre.

Figure 20. Yield of oats and relative value of several sources of phosphate, broadcast application, Noble County, 1949.

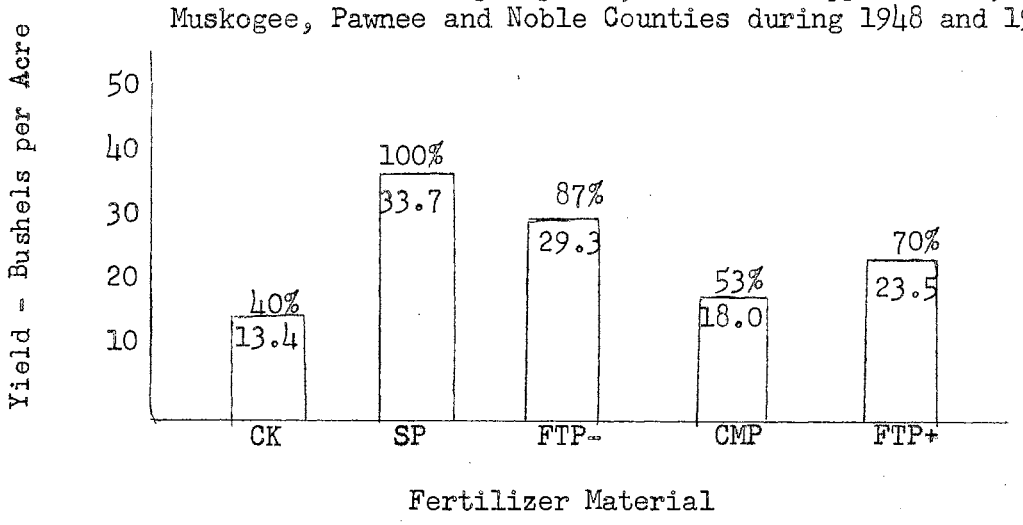


CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

The computed LSD value of 1.9 bushels per acre at the 5% point and 4 degrees of freedom, as shown in Table XXVIII, Appendix "C", indicates the increase in production due to the phosphate fertilizers to be statistically significant at this location.

In all three locations during 1948 and 1949 the average of each treatment shows superphosphate superior to fine mesh fused phosphate, coarse mesh fused phosphate, calcium metaphosphate and the check plot by 4.4 bushels, 10.2 bushels, 15.7 bushels and 20.3 bushels per acre, respectively, as is shown in figure 21. On the basis of 100% for

Figure 21. Combined average yield of oats and relative value of several sources of phosphate, broadcast application, in Muskogee, Pawnee and Noble Counties during 1948 and 1949.



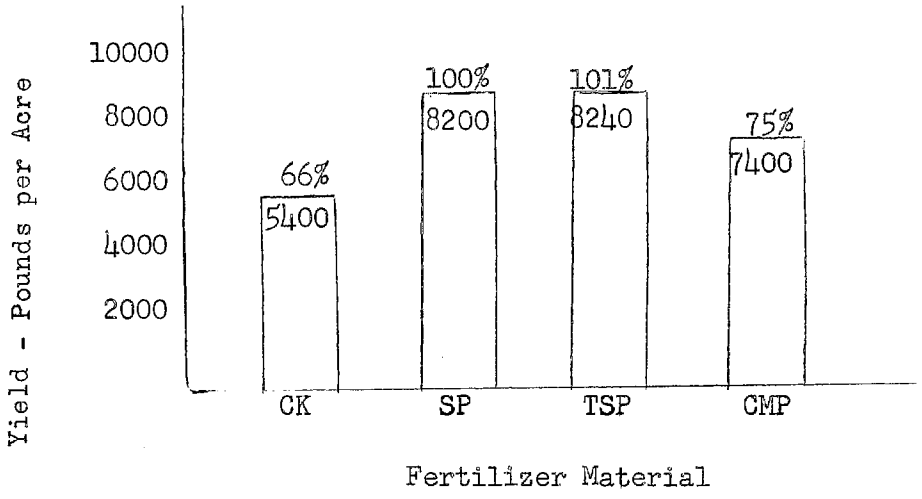
CK - Check. SP - Superphosphate. FTP - Fused tricalcium phosphate. CMP - Calcium metaphosphate

superphosphate the respective values are 87%, 70%, 53% and 40%. The computed LSD value at the 5% point for 29 degrees of freedom in 1948, Table XXVI, Appendix "C", and 44 degrees of freedom in 1949, Table XXX, Appendix "C", is 1.2 bushels per acre; therefore, the increase in production due to the phosphate fertilizers is statistically significant at Muskogee, Pawnee and Noble Counties in 1948 and 1949.

Alfalfa Response

The growth of irrigated alfalfa at the Jackson County location showed calcium metaphosphate to be inferior to 0-20-0 and 0-45-0 but superior to the check plot through the season as shown in figure 22 and Table XVI, Appendix "B". In this test, the difference in yield between 0-20-0 and 0-45-0 was considered insignificant. The calcium metaphosphate plots averaged 1.0 ton per acre more than the check plot for the season; however, they averaged 1.4 tons less than the superphosphate plots. On the basis of 100% for superphosphate the relationship for triple superphosphate, calcium metaphosphate, and the check plot would be 101%, 75% and 66% respectively.

Figure 22. Yield of alfalfa and relative value of several sources of phosphate in Jackson County, 1949.



CK - Check. SP - Superphosphate. TSP - Triple superphosphate. CMP - Calcium metaphosphate

The difference between superphosphate and calcium metaphosphate was significant at the 5% point with 3 degrees of freedom as shown in Tables XXXI through XXXVI, Appendix "C". The increase over the check plot due to the calcium metaphosphate treatment was significant at the 5% point.

SUMMARY

Studies were begun in 1948 in Muskogee and Pawnee Counties and the additional two locations in Jackson and Noble Counties were added the following year. This report is a compilation of the data comparing calcium metaphosphate with other phosphatic fertilizers by crops, location, and method of application. Significant increases in crop production due to the source of phosphate were found, and a slight difference in yield was noted with certain crops between locations.

The use of calcium metaphosphate as a phosphate fertilizer may be summed up in condensed review of the data. The yield of lespedeza on the plots treated with calcium metaphosphate in Muskogee County was 16 pounds per acre higher than it was on plots treated with 0-20-0, and 1710 pounds better than on the check plot. The yield of sweet clover was 36 pounds per acre higher than 0-20-0 and 1627 pounds per acre better than that obtained on the untreated area. It was inferior to the other materials tested on oats in 1948 and 1949. In Pawnee County, calcium metaphosphate was superior to the other phosphates tested on sweet clover. It ranked fourth on oats, yet showed a significant increase in production over the check plot. In Noble County, under lespedeza, calcium metaphosphate was inferior to 0-20-0 by 17 pounds per acre, but it was superior to the check plot by 1148 pounds per acre. Under sweet clover, calcium metaphosphate ranked third, the yield being nine pounds per acre less than the yield on plots treated with 0-20-0; however, it outyielded the check plot by 1165

pounds per acre. Under oats, calcium metaphosphate ranked lower than the other phosphates in the test, yet it outyielded the check plot by 2.6 bushels per acre which is significant.

These data indicate that calcium metaphosphate was not inferior to the other phosphorus carriers except on oats in Muskogee, Pawnee and Noble Counties; and on alfalfa in Jackson County. The main conclusion that can be drawn from this work is that calcium metaphosphate was found to be a reliable phosphorus fertilizer for legumes at the Muskogee, Pawnee and Noble County locations.

FERTILIZER ECONOMICS

During the period 1936-1940, the total sales of all fertilizers in Oklahoma amounted to 4,302 tons. During the period January 1, 1952, to December 31, 1952, over 172,000 tons of varying grades and materials were sold throughout the state (47). Calculated estimates of the quantities of fertilizers that could profitably be used in Oklahoma under conditions of proper soil management approximates 745,642 tons (6).

During 1952, more than 21 different grades of fertilizer materials were registered for sale with the Oklahoma State Department of Agriculture (47). The quantities of nutrient elements in these fertilizers ranged from 20 units to more than 60 units per 100 pounds. Superphosphate and rock phosphate constituted 86,609 tons or 50.2% of the total fertilizer consumption in the state (46), and 270 tons of calcium metaphosphate was used by 60 test-demonstration farmers in fourteen counties (45). Thus the use of commercial fertilizers in the farming operation creates another cost item to the farmer and one of his major concerns will be to obtain the most economical type of material to use.

Calcium metaphosphate could be the answer to this problem in many localities. Curtis (10) et al, reports calcium metaphosphate as 73.05 percent the cost of 16 2/3 percent superphosphate f.o.b., the farmer. Curtis reasons as follows:

Consider three plants located equally distant from a farmer who pays a freight charge of $4.50 per net ton on fertilizer purchased.

At one of the plants, bulk superphosphate averaging 16 2/3 percent available P_2O_5 is offered at $9.00 per ton in the stock pile; at another of the plants, bulk superphosphate averaging 50 percent available P_2O_5 is offered at $40.00 per ton in the stock pile. Assume that the following costs apply to all three:

Recovery from storage, crushing, screening, and bagging.	$1.00 per ton
Bags	1.75 per ton
State tax	.50 per ton
Freight	4.50 per ton
Dealer's profit	10 percent

The cost per ton of available P_2O_5 to the farmer is:

	Superphosphate 16 2/3% P_2O_5 Material	Triple Superphosphate 50% P_2O_5 Material	Calcium Metaphosphate 62% P_2O_5 Material
In stock pile	$ 54.00	$66.00	$61.50
Recovery, crushing, etc.	6.00	2.00	1.54
Bags	10.50	3.50	2.69
State tax	3.00	1.00	.77
Freight	27.00	9.00	6.92
Dealer's profit	10.05	8.15	7.34
Cost to farmer	$110.55	$89.65	$80.76

Due to Oklahoma's location in respect to phosphate deposits, calcium metaphosphate would be an economical source of phosphatic fertilizer according to Curtis' theory. Two apparent obstacles, however, jeopardize acceptance and maximum use of this material: reliable tests of calcium metaphosphate have not proven it to be sufficiently effective to offset the savings in initial cost; and, it is not yet available on the market.

With continued investigation by the Tennessee Valley Authority, the process of manufacturing might become commercially feasible, and

calcium metaphosphate could become a regular material on the fertilizer market. Sufficient information should be assembled to indicate its value under the various climatic, soil and crop conditions found in Oklahoma. In this study of several phosphates under field conditions, the writer attempted to assemble data that could be used in evaluating calcium metaphosphate when compared to commercial superphosphate and other phosphorus fertilizer materials.

LITERATURE CITED

1. Alway, F. J. and Nesom, G. H. "Effectiveness of Calcium Metaphosphate and Fused Rock Phosphate on Alfalfa." Journal of American Society of Agronomy 36, 1944, pp 73-88.

2. Baker, G. O., Soil Technologist. Personal Correspondence. Moscow: University of Idaho, 1952.

3. Brown, Bailey E. "An appraisal of Different Phosphatic Material as Sources of Phosphorus for Crop Plants." American Fertilizer, 98 (6), pp 10-11.

4. Brown, B. E. and Clark, K. G. "An Appraisal of Calcium and Potassium Metaphosphates as Sources of Phosphorus for Crop Plants." American Fertilizer, 98 (5), pp 10, 11, 24, 26.

5. Blaser, R. E. and McAuliff, Clayton. "Utilization of Phosphorus from Various Fertilizer Materials". Soil Science 68, pp 145-150.

6. Chaffin, Wesley, Extension Agronomist. Annual Report of Extension Agronomy Work. Extension Division, Oklahoma A. and M. College, 1952, p 33.

7. Chaffin, Wesley, Extension Agronomist. Annual Report of Extension Agronomy Work. Extension Division, Oklahoma A. and M. College, 1948, p 55.

8. Cheney, H. B. and Meldrum, H. R. Phosphate Fertilizers. Iowa: Agricultural Extension Service pamphlet 184. 1952, 8 pp illustration.

9. Curtis, H. A. "Metaphosphate Investigation Aims at Cheaper Fertilizers." Chemical and Metallurgical Engineering, 44. 1937, Illustration.

10. Curtis, H. A. et al. "Full-scale Production of Metaphosphate Achieved at Wilson Dam." Chemical and Metallurgical Engineering, 45. 1938, Illustration.

11. Curtis, H. A.; Miller, A. M. and Newton, R. H. "Process Developments at T.V.A. Phosphoric Acid Plant." Chemical and Metallurgical Engineering, 45. 1938. Illustration.

12. Dregne, H. E. Personal Correspondence. 1952.

13. Garman, Wm L. Personal Correspondence. 1949.

14. Galloway, Harry M. Personal Correspondence. 1955.

15. Fudge, J. F. and Fraps, G. S. Value of Different Phosphates for Various Texas Soils and Grasses, as indicated by pot experiments. Texas Agricultural Experiment Station Bulletin 627, 1945.

16. Gilbert, Basil E. and Pember, Frederick R. A Study of the Availability of Ammoniated Superphosphate and Various Unusual Phosphatic Carriers by Means of Vegetative Pot Tests. Rhode Island: Agricultural Experiment Station Bulletin 256, 1936.

17. Green, J. R. Phosphate Investigations on Irrigated Crops, Montana: Agricultural Experiment Station Bulletin 356, 1938.

18. Houghland, G. V. C.; Clark, K. G.; Hawkins, Arthur, and Campbell, John C. "Nutrient Value of Some New Phosphatic Materials Used on Potatoes." American Fertilizer 97 (7), pp 5, 8, 24, 26. 1942.

19. Hill, W. L. et al. "Phosphate Fertilizers by Calcination Process; Composition of Defluorinated Phosphate." Industry and Engineering Chemistry, 29 1937, pp 1299-1304, Illustrations.

20. Hinkle, D. A. "Efficiency of Various Phosphate Fertilizers on Calcareous Soils for Alfalfa and Sweet Clover." Journal of American Society of Agronomy, 34, pp 913-918.

21. Hinkle, D. A. Use of Phosphatic Fertilizers on Alfalfa. New Mexico: Agricultural Experiment Station Bulletin 289. 19 pp Illustration.

22. Idaho Agricultural Experiment Station. Comparative values of Various Phosphate Carriers Determined, Idaho Agricultural Experiment Station Bulletin 251, 1943. pp 9-10.

23. Idaho Agricultural Experiment Station. Relative Efficiency of Some Phosphate Fertilizers on Calcareous Soils. Idaho Agricultural Experiment Station Bulletin 270, 1948. pp. 16-19.

24. Jacob, K. D. and Ross, William H. "Nutrient Value of the Phosphorus in Defluorinated Phosphate, Calcium Metaphosphate, and other Phosphatic Materials as Determined by Growth of Plants in Pot Experiments." Journal of Agricultural Research 61, 1940, pp 539-560.

25. Jones, Randall J. and Rogers, Harold T. "New Fertilizers and Fertilizer Practices." Advances in Agronomy, Vol. 1, 1949.

26. Karraker, P. E.; Miller, Harold F; Boetner, C. E. and Todd, Jack R. Greenhouse Tests of the Availability of Phosphorus in Certain Phosphate Fertilizers. Kentucky Agricultural Experiment Station Bulletin 413, 1941.

27. Larson, H. W. E. and Baker, G. Orien. A Preliminary Report on the Relative Value of Various Phosphate Fertilizers for Southern Idaho Soil Conditions. Idaho: University Extension Division Bulletin 120, 16 pp Illustration. 1939.

28. MacIntire, W. H.; Hardin. L. J. and Oldham, F. D. Calcium Metaphosphate Fertilizers, Chemical Composition and Properties. Industrial and Engineering Chemistry, 29, 1937. pp 224-234, Illustrations.

29. McGeorge, W. T. Factors Influencing the Availability of Native Soil Phosphates and Phosphate Fertilizers in Arizona Soils. Arizona: Agricultural Experiment Station Technical Bulletin 82, 1939.

30. Nall, C. F. and Irwin, C. J. Field Tests of Phosphate Fertilizers. Pennsylvania: Agricultural Experiment Station Bulletin 423, 1942. 14 pp Illustrations.

31. Nielson, Rex F. Personal Correspondence, 1952. Utah State Agricultural College.

32. O'Brien, R. E. and Obenshain, S. S. The Effect of Different Phosphatic Fertilizers on the Yield, Plant Population, and Chemical Composition of Pasture Herbage on Dumare and Emory Soils. Virginia: Agricultural Experiment Station Tech. Bulletin 80, 1942, 37 pp Illustrations.

33. Olsen, Sterling R. and Gardner, Robert. "Utilization of Phosphorus from Various Fertilizer Materials: IV Sugar Beets, Wheat and Barley in Colorado." Soil Science 68, 1949, pp 163-169.

34. Olsen, Sterling R. et al. Utilization of Phosphorus by Various Crops as Affected by Source of Material and Placement. Colorado: Agricultural Experiment Station Bulletin 42, 1950, 43 pp Illustrations.

35. O'Brien, R. E. Field Experiments with Phosphatic Fertilizers. Virginia: Agricultural Experiment Station Bulletin 364, 1944, 26 pp Illustrations.

36. Peterson, H. B. and Paschal, J. L. "A Summary of Phosphate Fertilizer Experiments in the Fifteen Western States." Research Report No. 210, 1951.

37. Rich, C. I. and Lutz, J. A. Crop Response to Phosphate Fertilizer in Virginia. Virginia: Agricultural Experiment Station Tech. Bulletin 115, 14 pp Illustrations.

38. Roberts, George; Freeman, J. F. and Miller, Harold. Field Tests of the Relative Effectiveness of Different Phosphate Fertilizers. Kentucky: Experiment Station Bulletin 420, 1942.

39. Stanford, George and Nelson, L. B. "Utilization of Phosphorus from Various Fertilizer Materials, III Oats and Alfalfa in Iowa." Soil Science, 68, pp 157-161.

40. Termon, Gilbert L. "Effectiveness of Fused Phosphate of Different Particle Size." Soil Science Society American Proceedings, 9, pp 154-158.

41. Toeus, John L. and Baker, G. Orien Progress Report of Phosphate and Other Fertilizer Investigations at the Aberdeen Branch Experiment Station. Idaho: Agricultural Experiment Station Bulletin 230, 1939, 27 pp. Illustrations.

42. Weeks, M. E. and Miller, H. F. "Residual Effects of Phosphates Used on Longtime Field Experiments". Soil Science Society of American Proceedings, 13, pp 102-107, 1949.

43. Whittaker, C. W. et al "Influence of Placement on Response of Crops to Calcium Metaphosphates." Journal of American Society of Agronomy, 39, 1947, pp 859-868, Illustrations.

44. Woodhouse, W. W., Jr. Use of TVA Phosphates and Limestone on Permanent Pastures. North Carolina: Agricultural Experiment Station Agronomy Circular 140, 10 pp Illustrations.

45. Woodward, R. O. Assistant Extension Agronomist. Annual Report of TVA Program. Annual Report, Oklahoma A. and M. College, 1949.

46. Yeats, Parks, Fertilizer Consumption in Oklahoma for the Past 10 Years. Oklahoma State Department of Agriculture.

47. Yeats, Parks, Distribution of Fertilizer in Oklahoma Counties by Grades and Materials, 1952.

APPENDIX A

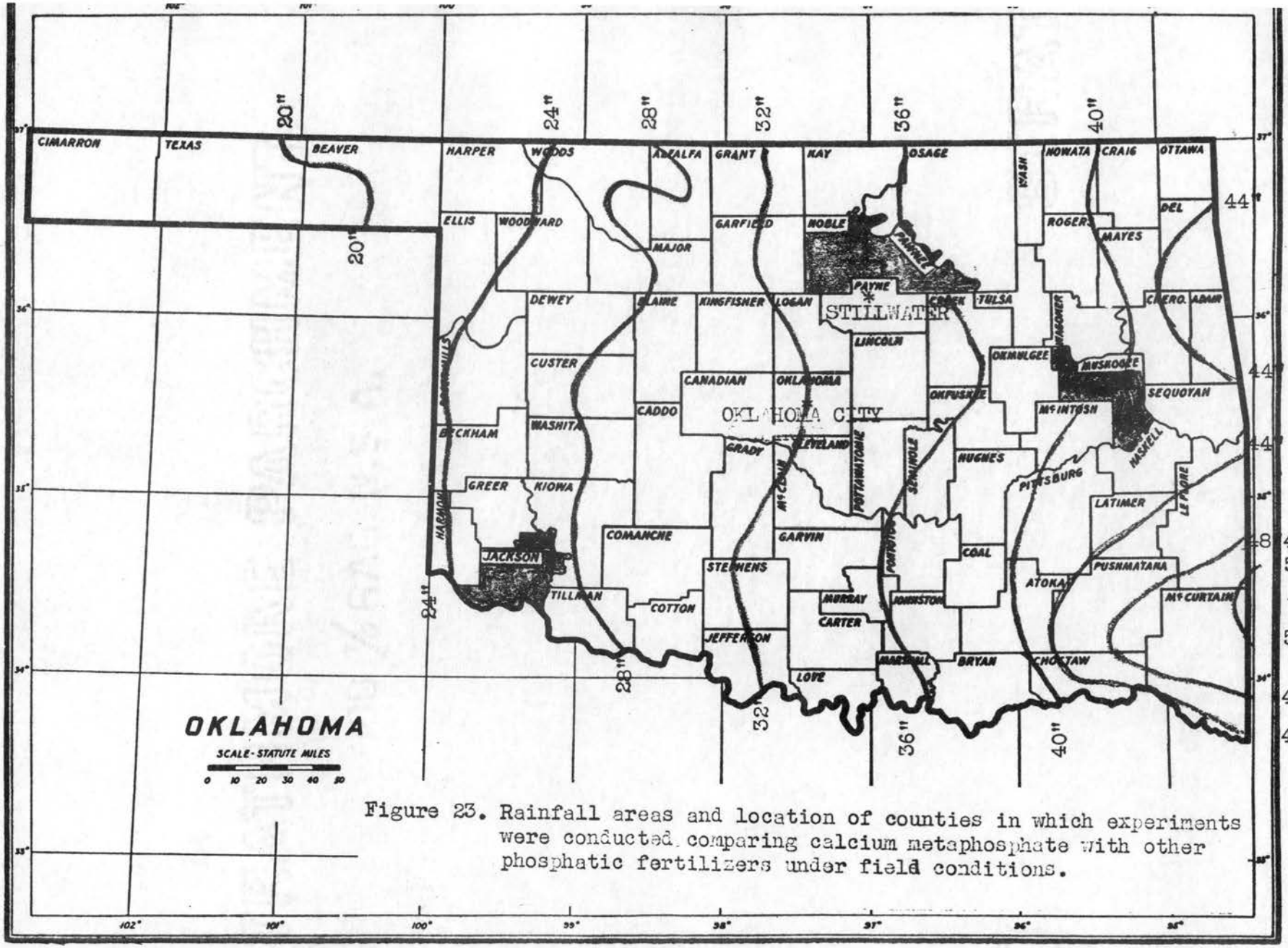


Figure 23. Rainfall areas and location of counties in which experiments were conducted comparing calcium metaphosphate with other phosphatic fertilizers under field conditions.

Table II. Location, Ownership, Soil Conditions and log of activities on the Muskogee County Experiment with several Phosphate Fertilizers on Oats, Sweet Clover and Korean Lespedeza.

Location:	1 1/2 miles north of Muskogee, Oklahoma.
Farmer:	L. W. Osborn, P. O. Box 724, Muskogee, Oklahoma.
Soil Type:	Parsons very fine sandy loam.
Soil Reaction:	Strongly acid (pH4.9).
Available Phosphorus:	Very low - less than 12 pounds per acre.
Crops:	New Nortex oats, Madrid Sweet clover, Korean lespedeza.

Activity during 1948:

Plots marked off, fertilized and seeded March 9, and March 10.

0-20-0	200 pounds per acre.
0-29-0	140 pounds per acre.
0-60-0	66 pounds per acre.

Oats harvested June 17.

Korean Lespedeza abandoned due to poor stand caused by washing on April 6.

Activity during 1949:

Plots marked off and seeded March 1.

Oats harvested June 23.

Sweet Clover harvested June 23.

Korean Lespedeza harvested August 18.

Table III. Location, Ownership, Soil Conditions and Log of activities on the Pawnee County Experiment with several Phosphate Fertilizers on Oats, Sweet Clover and Korean Lespedeza.

Location:	1 1/2 miles north, 3 miles east of Glencoe, Oklahoma.
Farmer:	Omy Price, Glencoe, Oklahoma.
Soil Type:	Renfrow silt loam.
Soil Reaction:	Strongly acid (pH 4.9)
Available Phosphorus:	Very low - less than 12 pounds per acre.
Crops:	New Nortex oats, Madrid Sweet clover, Korean lespedeza.

Activities during 1948:

Plots marked off and seeded March 27 and March 30.

0-20-0	200 pounds per acre.
0-29-0	140 pounds per acre.
0-60-0	66 pounds per acre.

Oats harvested June 19.

Korean Lespedeza abandoned due to poor stand and poor inoculation.

Activities during 1949:

Plots marked off, fertilized and seeded March 22.

Sweet Clover harvested June 15.

Oats harvested June 21.

Korean Lespedeza abandoned due to poor stand.

Table IV. Location, Ownership, Soil Conditions and Log of activities on the Noble County Experiment with several Phosphate Fertilizers on Oats, Sweet Clover and Korean Lespedeza.

Location:	7 miles south, 2 miles east of Perry, Oklahoma.
Farmer:	LeRoy Hardy, Marshall, Oklahoma.
Soil Type:	Renfrow clay loam.
Soil Reaction:	Slightly acid (pH 6.3)
Available Phosphorus:	Low - 16-20 pounds per acre.
Crops:	New Nortex oats, Madrid Sweet clover, Korean Lespedeza.

Activity during 1949:

Plots marked off, fertilized and seeded March 1.

0-20-0	200 pounds per acre.
0-29-0	140 pounds per acre.
0-60-0	66 pounds per acre.

Oats harvested June 23.

Lespedeza harvested August 23.

Activity during 1950:

Sweet Clover harvested June 22.

Table V. Location, Ownership, Soil Condition and Log of activities on the Jackson County Experiment with several Phosphate Fertilizers on Irrigated Alfalfa.

Location:	1 mile east of Martha, Oklahoma, or 10 miles north and 2 miles west of Altus, Oklahoma.
Farmer:	W. B. Edwards, Martha, Oklahoma
Soil Type:	Foard silt loam.
Soil Reaction:	Neutral (pH 7.8).
Available Phosphorus:	High - 40-50 pounds per acre.
Crop:	Irrigated alfalfa.

Activity during 1949:

Plots marked off and fertilizer applied January 24.

0-20-0	600 pounds per acre.
0-45-0	266 pounds per acre.
0-60-0	200 pounds per acre.

First cutting April 3,
Field was cut for hay April 13.

Second cutting June 6,
Field was cut for hay June 9.

Third cutting July 26,
Field was cut for hay July 26.

Fourth cutting September 5,
Field was cut for hay September 5.

Fifth cutting September 26,
Field was cut for hay September 26. (Crop was not watered between fourth and fifth cutting in an attempt to get a seed crop).

Sixth cutting October 30,
Field was cut for hay October 30.

APPENDIX B

TABLE VI

Individual Sample Weights
Muskogee County
Sweet Clover, Pounds Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	1795	1932	1843	1896	1902	1824
0-20-0	3402	3538	3390	3471	3481	3463
20m(1)	3318	3234	3243	3304	3276	3267
20p(2)	3265	3087	3240	3114	3171	3156
CMP(3)	3507	3475	3487	3493	3476	3514

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	1848	1911	1871	1896	1902	1824
0-20-0	3297	3433	3401	3382	3381	3324
20m(1)	3118	3066	3112	3071	3064	3082
20p(2)	2961	3328	3197	3137	3082	3124
CMP(3)	3318	3591	3576	3554	3421	3453

(1)20 minus fused phosphate
(2)20 plus fused phosphate
(3)Calcium metaphosphate

TABLE VII

Individual Sample Weights
Pawnee County
Sweet Clover, Pounds Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	1440	1286	1671	1691	1737	1802
0-20-0	2415	4305	2962	3604	3397	3142
20m(1)	2835	4830	2971	4641	3174	4320
20p(2)	2205	4226	3504	3012	3942	2609
CMP(3)	2730	4861	3972	3741	3246	4304

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	1680	1286	1293	1585	1476	1467
0-20-0	3202	2835	3011	3047	3037	2982
20m(1)	3045	3391	3247	3176	3187	3214
20p(2)	3255	2898	3147	3062	3024	3061
CMP(3)	3307	3675	3476	3579	3582	3504

(1) 20 minus fused phosphate
(2) 20 plus fused phosphate
(3) Calcium metaphosphate

TABLE VIII

Individual Sample Weights
Noble County
Sweet Clover, Pounds Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	1617	1577	1600	1642	1576	1617
0-20-0	2778	2817	2842	2791	2762	2853
20m(1)	2695	2812	2714	2681	2676	2654
20p(2)	2793	2866	2767	2740	2692	2789
CMP(3)	2704	2606	2787	2842	2821	2856

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	1492	1445	1497	1442	1432	1510
0-20-0	2597	2682	2602	2679	2587	2690
20m(1)	2548	2695	2742	2643	2692	2667
20p(2)	2704	2631	2542	2631	2604	2662
CMP(3)	2755	2606	2593	2701	2706	2610

---

(1)20 minus fused phosphate
(2)20 plus fused phosphate
(3)Calcium metaphosphate

TABLE IX

Individual Sample Weights
Muskogee County
Lespedeza, 1949, Pounds Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	565	535	607	521	492	676
0-20-0	2305	2210	2410	2267	2307	2102
20m(1)	2280	2200	2276	2212	2321	2114
CMP(2)	2260	2325	2421	2196	2343	2117
20p(3)	2200	2015	2176	1943	1991	2032

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	655	545	672	624	526	593
0-20-0	2065	1950	2036	1982	1962	2192
20m(1)	2005	1865	2013	1904	1923	1962
CMP(2)	1770	2150	1967	1992	1921	1943
20p(3)	1590	1900	1627	1976	2017	1602

(1) 20 minus fused phosphate
(2) Calcium metaphosphate
(3) 20 plus fused phosphate

TABLE X

Individual Sample Weights
Noble County
Lespedeza, 1949, Pounds Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	455	550	572	514	463	497
0-20-0	1860	1714	1763	1814	1792	1767
20m(1)	1720	1805	1821	1604	1596	1794
CMP(2)	1630	1900	1743	1794	1767	1782
20p(3)	1650	1635	1697	1702	1624	1631

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
Check	455	420	516	427	457	421
0-20-0	1715	1600	1673	1689	1570	1643
20m(1)	1700	1570	1697	1628	1595	1649
CMP(2)	1535	1705	1642	1630	1631	1611
20p(3)	1460	1560	1500	1547	1490	1504

---

(1) 20 minus fused phosphate
(2) Calcium metaphosphate
(3) 20 plus fused phosphate

TABLE XI

Individual Samples
Muskogee County
Oats 1948, Bushels Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	23.97	18.36	22.04	19.46	18.92	21.14
20m(2)	30.07	28.05	30.21	28.59	29.34	28.79
0-20-0	37.74	32.13	36.52	34.14	31.71	34.93
CMP(3)	19.38	21.17	19.72	20.91	20.75	20.69
Check	7.65	10.71	8.14	9.63	9.47	9.02

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	20.91	22.68	21.27	21.92	22.42	21.04
20m(2)	27.52	29.84	28.42	28.17	27.87	28.90
0-20-0	30.60	32.39	33.04	32.14	31.71	30.96
CMP(3)	12.75	15.04	12.97	13.84	13.19	13.72
Check	8.16	10.45	8.72	8.97	9.14	9.32

(1)20 plus fused phosphate
(2)20 minus fused phosphate
(3)Calcium metaphosphate

TABLE XII

Individual Samples
Muskogee County
Oats 1949, Bushels Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	32.39	34.91	32.61	33.47	33.92	33.60
20m(2)	38.00	35.96	37.82	36.01	36.71	37.42
0-20-0	50.24	46.16	49.17	51.01	50.16	49.52
CMP(3)	24.48	23.72	24.06	24.41	23.87	24.62
Check	18.87	18.10	18.72	18.36	18.24	18.61

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	29.58	29.84	29.43	29.81	28.96	29.91
20m(2)	38.00	35.19	37.84	36.04	35.23	35.41
0-20-0	46.42	43.61	43.91	45.87	44.62	45.74
CMP(3)	17.84	18.36	18.42	17.86	18.01	18.36
Check	15.55	17.59	15.62	15.87	16.92	16.73

---

(1)20 plus fused phosphate
(2)20 minus fused phosphate
(3)Calcium metaphosphate

TABLE XIII

Individual Samples
Pawnee County
Oats 1948, Bushels Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	28.56	28.82	28.91	28.24	27.93	28.98
20m(2)	29.58	30.60	30.68	30.09	29.43	29.96
0-20-0	41.57	40.30	42.04	40.71	39.96	41.72
CMP(3)	21.42	21.68	20.89	22.43	21.37	21.79
Check	9.18	9.69	8.90	9.70	9.34	9.86

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	22.19	20.66	22.04	21.09	21.93	21.47
20m(2)	29.84	31.37	29.71	30.04	31.76	29.44
0-20-0	33.41	34.94	34.86	34.11	33.43	34.19
CMP(3)	13.00	15.04	14.73	14.24	14.31	13.64
Check	8.67	9.94	9.47	9.03	9.16	8.96

---

(1)20 plus fused phosphate
(2)20 minus fused phosphate
(3)Calcium metaphosphate

TABLE XIV

Individual Samples
Pawnee County
Oats 1949, Bushels Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	32.90	35.96	35.16	33.72	34.47	34.72
20m(2)	34.68	32.64	32.97	33.89	33.04	33.82
0-20-0	48.20	42.59	47.89	44.50	43.64	45.21
CMP(3)	25.25	26.27	26.16	25.62	24.97	27.00
Check	11.98	11.22	11.64	11.97	12.01	11.42

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	25.25	20.91	22.24	23.84	21.76	23.04
20m(2)	29.07	34.68	30.06	31.19	31.76	31.92
0-20-0	41.83	43.87	42.14	42.76	41.92	43.04
CMP(3)	16.06	18.10	17.36	16.42	17.14	17.61
Check	12.49	13.51	13.14	12.79	12.91	13.42

(1)20 plus fused phosphate
(2)20 minus fused phosphate
(3)Calcium metaphosphate

TABLE XV

Individual Samples
Noble County
Oats 1949, Bushels Per Acre

Row Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	42.84	46.57	44.81	44.67	46.24	43.00
20m(2)	51.25	56.04	46.02	47.14	46.49	46.98
0-20-0	46.28	47.62	55.87	52.00	54.73	52.91
CMP(3)	50.01	44.85	49.86	49.92	48.24	48.16
Check	41.12	40.83	39.90	41.06	39.87	40.92

Broadcast Application

Treatment	Series "A"		Series "B"		Series "C"	
20p(1)	44.85	46.57	45.14	45.82	46.26	45.72
20m(2)	48.86	50.30	49.78	49.86	48.96	49.42
0-20-0	50.30	49.44	51.42	50.04	49.89	50.17
CMP(3)	45.13	44.85	45.00	45.34	44.81	46.04
Check	42.33	43.99	41.00	43.18	42.74	42.38

(1)20 plus fused phosphate
(2)20 minus fused phosphate
(3)Calcium metaphosphate

TABLE XVI

Individual Samples
Alfalfa 1949, Pounds Per Acre - Dry Weight

Date	Check	Commercial Superphosphate	Triple Superphosphate	Calcium Metaphosphate
April 3	543	725	730	584
	500	761	733	617
	572	717	721	636
	410	713	785	593
June 6	1173	1215	1265	1155
	1175	1207	1230	1131
	1133	1250	1327	1127
	1133	1219	1295	1161
July 26	1475	2270	2125	1541
	1502	2315	2160	1501
	1370	2035	2143	1555
	1425	2241	2367	1645
September 5	1088	1393	1336	1046
	1030	1390	1327	1107
	1044	1416	1347	1134
	1071	1322	1199	1118
September 26[1]	280	542	577	276
	264	553	580	386
	278	533	557	403
	253	540	565	393
October 30	1071	2033	2166	1473
	907	2016	2150	1307
	927	2021	2097	1346
	917	2033	2119	1327
Tons Per Acre	2.7	4.1	4.1	3.7
Relative Yield	66%	100%	101%	75%

[1]Small samples due to the farmer not applying water in an attempt to get a seed crop. After realizing the lateness of date he cut a short crop in order to get an additional full cutting before frost.

APPENDIX C

For brevity in the following tables two degrees of freedom of replications were not included.

Each replication represents the mean of two samples.

TABLE XVII

Analysis of Variance
Sweet Clover, Row Application

Muskogee County

Means	Treatment	A	B	C	
3,730.67	Check	3727	3739	3726	11192
6,915.00	0-20-0	6940	6861	6944	20745
6,547.33	20m	6552	6547	6543	19642
6,344.33	20p	6352	6354	6327	19033
6,984.00	CMP	6982	6980	6990	20952
		30553	30481	30530	91564

Source	df	Ms	F	PrL
Total	14			
Treatment	4	2,489,352	9769.62	.0005**(2)
Error	8	561.88		
SE	13.69		LSD @ 5%	66.9(1)

Pawnee County

Means	Treatment	A	B	C	
3,209.00	Check	2726	3362	3539	9627
6,608.33	0-20-0	6720	6566	6539	19825
7,590.33	20m	7665	7612	7494	22771
6,499.33	20p	6431	6516	6551	19498
7,618.00	CMP	7591	7713	7550	22854
		31133	31769	31673	94575

Source	df	Ms	F	PrL
Total	14			
Treatment	4	9,818,283	209.47	.0005**(2)
Error	8	46,871		
SE	125.00		LSD @ 5%	611.2(1)

Table XVII (Continued)

Noble County

Means	Treatment	A	B	C	
3,209.67	Check	3194	3242	3193	9629
5,614.33	0-20-0	5595	5633	5615	16843
5,410.67	20m	5507	5395	5330	16232
5,549.00	20p	5659	5507	5481	16647
5,538.67	CMP	5310	5629	5677	16616
		25265	25406	25296	75967

Source	df	Ms	F	PrL
Total	14			
Treatment	4	3,241,597	227.08	.0005**(2)
Error	8	14,275		
SE	68.98			LSD @ 5% 337.3(1)

(1) For significance, yield difference between treatments must be 66.9, 611.2 or 337.3 pounds per acre. See Table V, VI and VIII.

(2) Results significant 9,995 times per 10,000 times.

TABLE XVIII

Analysis of Variance
Sweet Clover, Broadcast Application

Muskogee County

Means	Treatment	A	B	C	
3,750.67	Check	3759	3767	3726	11252
6,739.33	0-20-0	6730	6783	6705	20218
6,171.00	20m	6184	6183	6146	18513
6,276.33	20p	6289	6334	6206	18829
6,971.00	CMP	6909	7130	6874	20913
		29871	30197	29657	89725

Source	df	Ms	F	PrL
Total	14			
Varieties	4	4,989,657	1778.53	.0005**(2)
Error	8	2,805.50		
SE	30.58°			LSD @ 5% 149.8(1)

Pawnee County

Means	Treatment	A	B	C	
2,929.00	Check	2966	2878	2943	8787
6,040.00	0-20-0	6037	6058	6025	18120
6,420.00	20m	6436	6423	6401	19260
6,149.00	20p	6153	6209	6085	18447
7,041.00	CMP	6982	7055	7086	21123
		28574	28623	28540	85737

Source	df	Ms	F	PrL
Total	14			
Varieties	4	7,733,306.25	3424.27	.0005**(2)
Error	8			
SE	27.44°			LSD @ 5% 134.2(1)

Table XVIII (Continued)

Noble County

Means	Treatment	A	B	C	
2,939.33	Check	2937	2939	2942	8818
4,279.00	0-20-0	5279	5281	5277	15837
5,329.00	20m	5243	5385	5359	15987
5,258.00	20p	5335	5173	5266	15774
5,323.67	CMP	5361	5294	5316	15971
		24155	24072	24160	72387

Source	df	Ms	F	PrL
Total	14			
Varieties	4	3,339,018.75	1026.32	.0005**(2)
Error	8	3,253.38		
SE	32.93°		LSD @ 5%	161.0(1)

(1)For significance, yield difference between treatments must be 149.8, 134.2 or 161.0 pounds per acre. See Table VI, VII and VIII.

(2)Results significant 9,995 times per 10,000 times.

TABLE XIX

Analysis of Variance
Lespedeza 1949, Row Application

Muskogee County

Treatment	A	B	C	
Check	1100	1128	1168	3396
0-20-0	4515	4677	4409	13601
20m	4480	4488	4435	13403
CMP	4585	4617	4460	13662
20p	4215	4119	4023	12357
	18895	19029	18495	56419

Source	df	Ms	F	PrL
Total	14			
Treatment	4	6573784.	1260.31	.0005**(2)
Error	8	5216.		
SE	41.70		LSD @ 5%	102.0(1)

Noble County

Treatment	A	B	C	
Check	1005	1086	960	3051
0-20-0	3575	3577	3559	10711
20m	3525	3425	3390	10340
CMP	3530	3537	3549	10616
20p	3285	3399	3255	9939
	14920	15024	14713	44657

Source	df	Ms	F	PrL
Total	14			
Treatment	4	363.19	1462.7	.0005**(2)
Error	8	2.48		
SE	28.74		LSD @ 5%	70.0(1)

(1) For significance, yield difference between treatments must be 102 or 70 pounds per acre, see Table IX and X.

(2) Results significant 9995 times per 10,000 times.

TABLE XX

Analysis of Variance
Lespedeza 1949, Broadcast Application

Muskogee County

Treatment	A	B	C	
Check	1200	1296	1119	3615
0-20-0	4015	4018	4154	12187
20m	3870	3917	3885	11672
CMP	3920	3959	3864	11743
20p	3490	3603	3619	10712
	16495	16793	16641	

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1729.69	987.72	.0005**(2)
Error	8	4.378		
SE	38.20		LSD @ 5% 186.8	

Noble County

Treatment	A	B	C	
Check	875	943	878	2696
0-20-0	3315	3362	3213	9890
20m	3270	3325	3244	9829
CMP	3240	3272	3242	9154
20p	3020	3047	2994	9061
	13720	13949	13571	41240

Source	df	Ms	F	PrL
Total	14			
Treatment	4	3248.71	4707.86	.0005**(2)
Error	8	690.00		
SE	15.17		LSD @ 5% 74.2(1)	

---

(1) For significance, yield difference between treatments must be 186.8 or 74.2 pounds per acre. See Table IX and X.

(2) Results significant 9,995 times per 10,000 times.

TABLE XXI

Combined Analysis of Variance
Lespedeza 1949, Row Application

Source		df	Ms	F	PrL
Total		29			
Blocks w/Locations		4			
Treatment w/Locations		8			
Treatment		4	9984522.75	2593.55	.0005**(1)
Treatment X Locations		4	221208.50	57.46	.0005**
Locations		1	4611488.00	1197.87	.0005**
Error (Within)		16	3849.75		
SE Treatment	25.33		LSD @ 5%	109.9	
SE Locations	16.02		LSD @ 5%	48.1	

TABLE XXII

Combined Analysis of Variance
Lespedeza 1949, Broadcast Application

Source		df	Ms	F	PrL
Total		29			
Blocks w/Locations		4			
Treatment w/Locations		8			
Treatment		4	7228374.75	2970.21	.0005**(1)
Treatment X Locations		4	44285.00	17.47	.0005**
Locations		1	2516624.00	992.90	.0005**
Error (Within)		16	2534.63		
SE Treatment	20.55		LSD @ 5%	89.2	
SE Locations	13.00		LSD @ 5%	39.0	

(1) Results significant 9995 times per 10,000 times.

TABLE XXIII

Analysis of Variance
Oats 1948, Row Application

Muskogee County

Means	Treatment	A	B	C	
41.26	20p	42.33	41.50	40.06	123.89
58.29	20m	58.12	58.80	58.13	175.05
68.99	0-20-0	69.87	70.66	66.64	207.17
40.83	CMP	40.55	40.63	41.44	122.62
18.19	Check	18.36	17.77	18.49	54.62
		229.23	229.36	224.76	683.35

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,128.01	898.00	.0005**(2)
Error	8	1.256		
SE	.6471		LSD @ 5% 1.9(1)	

Pawnee County

Means	Treatment	A	B	C	
57.09	20p	47.38	57.15	56.91	171.44
60.05	20m	60.18	60.77	59.39	180.34
82.02	0-20-0	81.87	82.75	81.68	246.30
43.15	CMP	43.10	43.32	43.16	129.58
18.87	Check	18.87	18.60	19.20	56.67
		261.40	262.59	260.34	784.33

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,628.80	9171.2	.0005**(2)
Error	8	.1776		
SE	.2433		LSD @ 5% 0.6(1)	

---

(1) For significance, yield difference between treatments must be 1.9 or 0.6 bushels per acre. See Table XI and XII.

(2) Results significant 9,995 times per 10,000 times.

TABLE XXIV

Analysis of Variance
Oats 1948, Broadcast Application

Muskogee County

Means	Treatment	A	B	C	
43.37	20p	43.59	43.19	43.46	130.24
56.85	20m	57.36	56.59	56.77	170.72
63.55	0-20-0	62.99	65.18	62.67	190.84
27.14	CMP	27.79	26.81	26.91	81.51
18.24	Check	18.61	17.69	18.46	54.87
		210.34	209.46	208.27	628.07

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,106.32	1851.58	.0005**(2)
Error	8	.5975		
SE	.4463		LSD @ 5% 2.18(1)	

Pawnee County

Means	Treatment	A	B	C	
43.08	20p	42.85	43.13	43.40	129.38
60.66	20m	61.21	59.75	61.20	182.16
68.25	0-20-0	68.35	68.97	67.62	204.94
28.29	CMP	28.04	28.97	27.95	84.96
18.39	Check	18.61	18.50	18.12	55.23
		219.06	219.32	218.29	656.67

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,328.94	3385.83	.0005**(2)
Error	8	.3925		
SE	.3617		LSD @ 5% 1.77(1)	

---

(1) For significance, yield difference between treatments must be 2.18 and 1.77 bushels per acre. See Table XI and XIII.

(2) Results significant 9995 times per 10,000 times.

TABLE XXV

Combined Analysis of Variance
Oats 1948, Row Application

Source	df	Ms	F	PrL
Total	29			
Block w/Locations	4			
Treatment w/Locations	8			
Treatment	4	2680.43	3738.92	.0005**(1)
Treatment X Locations	4	76.39	106.56	.0005**
Locations	1	339.90	474.12	.0005**
Error (Within)	16	0.7169		
SE Treatment	.3457	LSD @ 5%	1.50	
SE Location	.2186	LSD @ 5%	0.66	

TABLE XXVI

Combined Analysis of Variance
Oats 1948, Broadcast Application

Source	df	Ms	F	PrL
Total	29			
Block w/Locations	4			
Treatment w/Locations	8			
Treatment	4	2427.80	4906.64	.0005**(1)
Treatment X Locations	4	7.46	115.07	.0005**
Locations	1	27.26	15.10	.0005**
Error (Within)	16	.4948		
SE Treatment	.2872	LSD @ 5%	1.25	
SE Location	.1817	LSD @ 5%	0.55	

Means

	In Rows	Broadcast
20p	49.32	43.36
20m	59.23	58.93
0-20-0	75.73	66.10
CMP	42.12	27.80
Check	18.58	18.37

(1) Results significant 9,995 times per 10,000 times.

TABLE XXVII

Analysis of Variance
Oats 1949, Row Application

Muskogee County

Means	Treatment	A	B	C	
66.90	20p	67.30	66.08	67.52	200.90
73.90	20m	73.96	73.83	74.13	221.92
98.65	0-20-0	96.40	100.18	99.68	296.26
48.34	CMP	48.20	48.47	48.49	145.16
36.93	Check	36.97	37.08	36.85	110.90
		322.83	325.64	326.67	975.14

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,714.16	1676.44	.0005**(2)
Error	8	1.0225		
SE	.5838		LSD @ 5% 2.8(1)	

Pawnee County

Means	Treatment	A	B	C	
68.24	20p	68.86	68.88	67.19	204.93
66.95	20m	67.32	66.86	66.86	201.04
90.59	0-20-0	90.79	92.39	88.85	272.03
51.70	CMP	51.52	51.78	51.97	155.27
23.39	Check	23.20	23.61	23.43	70.24
		301.69	303.52	298.30	903.51

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,849.17	2600.44	.0005**(2)
Error	8	5.6885		
SE	.4868		LSD @ 5% 1.2(1)	

Table XXVII (Continued)

Noble County

Means	Treatment	A	B	C	
89.29	20p	89.41	89.48	89.24	268.13
97.88	20m	107.29	93.16	93.47	293.92
103.03	0-20-0	93.90	107.87	107.64	309.41
96.92	CMP	94.86	99.78	96.40	291.04
81.15	Check	81.95	80.96	80.79	243.70
		467.41	471.25	467.54	1406.20

Source	df	Ms	F	PrL
Total	14			
Treatment	4	219.29	6.50	.025**(3)
Error	8	33.7288		
SE	3.3531		LSD @ 5% 1.9(1)	

(1)For significance, yield difference between treatments must be 2.8, 1.2 or 1.9 bushels per acre. See Table XII, XIV and XV.

(2)Results significant 9,995 times per 10,000 times.

(3)Results significant 975 times per 10,000 times.

TABLE XXVIII

Analysis of Variance
Oats 1949, Broadcast Application

Muskogee County

Means	Treatment	A	B	C	
59.12	20p	59.42	59.24	58.87	177.53
72.50	20m	73.19	73.88	70.64	217.71
89.97	0-20-0	90.03	89.78	90.36	270.17
36.25	CMP	36.20	36.28	36.37	108.85
32.73	Check	33.14	31.49	33.65	98.28
		291.98	290.67	289.89	872.54

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,762.37	1704.91	.0005**(2)
Error	8	1.0337		
SE	.5870		LSD @ 5% 1.43(1)	

Pawnee County

Means	Treatment	A	B	C	
45.63	20p	56.16	56.08	44.80	137.04
62.83	20m	63.75	61.25	63.68	188.68
85.10	0-20-0	85.70	84.90	84.96	255.56
34.20	CMP	34.16	33.78	34.75	102.69
26.06	Check	26.00	25.93	26.33	78.26
		255.77	251.94	254.52	762.23

Source	df	Ms	F	PrL
Total	14			
Treatment	4	1,680.16	2885.39	.0005**(2)
Error	8	.5823		
SE	.4406		LSD @ 5% 1.1(1)	

Table XXVIII (Continued)

Noble County

Means	Treatment	A	B	C	
91.36	20p	91.42	90.96	91.98	274.36
98.96	20m	99.16	99.64	98.38	297.18
100.32	0-20-0	99.74	101.46	100.06	301.26
90.30	CMP	89.98	90.34	90.85	271.17
85.12	Check	86.32	84.18	85.12	255.62
		466.62	466.58	466.39	1399.59

Source	df	Ms	F	PrL
Total	14			
Treatment	4	120.94	170.29	.0005**(2)
Error	8	.7102		
SE	.4865		LSD @ 5%	1.9(1)

(1) For significance, yield difference between treatments must be 1.4, 1.1 or 1.9 bushels per acre. See Table XII, XIV and XV.

(2) Results significant 9,995 times per 10,000 times.

TABLE XXIX

Combined Analysis of Variance
Oats 1949, Row Application

Source	df	Ms	F	PrL
Total	44			
Block w/Location	6			
Treatment w/Locations	12			
Treatment	4	3077.2431	260.3090	.0005**(1)
Treatment X Locations	8	352.7815	29.8441	.0005**
Locations	2	4929.3424	417.00	.0005**
Error (Within)	24	11.8208		
SE Treatment	1.1460	LSD @ 5%	4.78	
SE Location	.8878	LSD @ 5%	3.13	

TABLE XXX

Combined Analysis of Variance
Oats 1949, Broadcast Application

Source	df	Ms	F	PrL
Total	44			
Block w/Location	6			
Treatment w/Locations	12			
Treatment	4	2890.6899	3727.9983	.0005**(1)
Treatment X Locations	8	336.3917	433.8299	.0005**
Locations	2	7735.3086	9975.8945	.0005**
Error (Within)	24			
SE Treatment	.2936	LSD @ 5%	1.22	
SE Location	.2274	LSD @ 5%	0.80	

(1) Results significant 9995 times per 10,000 times.

TABLE XXXI

Analysis of Variance
Alfalfa, April 3, 1949

Sample	Plot	Sample	Plot	Sample	Plot	Sample	Plot
1630	1[3]	1853	4	2162	3	2150	2
2187	2	1500	1	1910	4	2357	3
2190	3	2285	2	1717	1	1780	4
1752	4	2200	3	2152	2	1230	1
7759		7838		7941		7517	

Source	df	Ms	F	PrL
Total	15			
Rows	3	22,102		
Columns	3	8,153		
Treatment	3	444,754.6	28.3	.001**[2]
Error	6	15,874.9		
SE treatment		63.00	LSD @ 5% 308.7[1]	

Means; (1) 1519.2, (2) 2193.5, (3) 2227.2, (4) 1823.7

---

[1]For significance, yield difference between treatments must be 308.7 pounds per acre. See Table XVI, Appendix "B".

[2]Results significant 999 times per 1000 times.

[3]Plot 1 - Check. Plot 2 - Superphosphate. Plot 3 - Triple superphosphate. Plot 4 - Calcium metaphosphate.

TABLE XXXII

Analysis of Variance
Alfalfa, June 6, 1949

Sample	Plot	Sample	Plot	Sample	Plot	Sample	Plot
3520	1[3]	3392	4	3972	3	3657	2
3647	2	3525	1	3382	4	3707	3
3795	3	3620	2	3400	1	3482	4
3465	4	3690	3	3750	2	3400	1
14427		14227		15164		13721	

Source	df	Ms	F	PrL
Total	15			
Rows	3	4,102.7		
Columns	3	4,632.2		
Treatments	3	118,186.2	12.64	.01**[2]
Error	6	9,352.3		
SE treatment		45.35	LSD @ 5%	236.92[1]

Means; (1) 3,461, (2) 3,668, (3) 3,791, (4) 3,430

---

[1] For significance, yield difference between treatments must be 236.9 pounds per acre. See Table XVI, Appendix "B".

[2] Results significant 99 times per 100 times.

[3] Plot 1 - Check. Plot 2 - Superphosphate. Plot 3 - Triple superphosphate. Plot 4 - Calcium metaphosphate.

TABLE XXXIII

Analysis of Variance
Alfalfa, July 26

Sample	Plot	Sample	Plot	Sample	Plot	Sample	Plot
4425	1[3]	4507	4	6430	3	6722	2
6810	2	4507	1	4667	4	7102	3
6375	3	6949	2	4112	1	4935	4
4625	4	6780	3	6105	2	4275	1
22235		22743		21314		23034	

Source	df	Ms	F	PrL
Total	15			
Row	3	77,562.42		
Column	3	142,288.08		
Treatment	3	6,261,526.08	129.57	.0005**[2]
Error	6	48,324.67		
SE treatment		109.92	LSD @ 5% 538.61[1]	

Means; (1) 4329.75 (2) 6646.50 (3) 6671.75 (4) 5683.50

---

[1]For significance, yield difference between treatments must be 538.6 pounds per acre. See Table XVI, Appendix "B".

[2]Results significant 9,995 times per 10,000 times.

[3]Plot 1 - Check. Plot 2 - Superphosphate. Plot 3 - Triple superphosphate. Plot 4 - Calcium metaphosphate.

TABLE XXXIV

Analysis of Variance
Alfalfa, September 5

Sample	Plot	Sample	Plot	Sample	Plot	Sample	Plot
3885	1[3]	3955	4	4810	3	4722	2
4977	2	3680	1	4050	4	4282	3
4772	3	4967	2	3732	1	3995	4
3737	4	4740	3	5057	2	3825	1
17371		17342		17649		16824	

Source	df	Ms	F	PrL
Total	15			
Rows	3	11,074.41		
Columns	3	29,594.41		
Treatments	3	1,229,829.08	35.69	.0005**[2]
Error	6			

SE treatment 92.81 LSD @ 5% 454.77[1]

Means; (1) 3,780.50 (2) 4,930.75 (3) 4,651.00 (4) 3,934.25

---

[1]For significance, yield difference between treatments must be 454.8 pounds per acre. See Table XVI, Appendix "B".

[2]Results significant 9,995 times per 10,000 times.

[3]Plot 1 - Check. Plot 2 - Superphosphate. Plot 3 - Triple superphosphate. Plot 4 - Calcium metaphosphate.

TABLE XXXV

Analysis of Variance
Alfalfa, September 26

Sample	Plot	Sample	Plot	Sample	Plot	Sample	Plot
1000	1[3]	1380	4	1990	3	1930	2
1937	2	945	1	1442	4	2017	3
2062	3	1977	2	992	1	1405	4
987	4	2072	3	1907	2	905	1
5986		6374		6331		6257	

Source	df	Ms	F	PrL
Total	15			
Rows	3	15,695.17		
Columns	3	7,583.83		
Treatment	3	1,058.330.50	80.85	.0005**[2]
Error	6	13,089.75		
SE treatment		57.21	LSD @ 5% 280.33[1]	

Means; (1) 960.50 (2) 1937.75 (3) 2035.25 (4) 1303.50

---

[1]For significance, yield differences between treatments must be 280.3 pounds per acre. See Table XVI, Appendix "B".

[2]Results significant 9,999 times per 10,000 times.

[3]Plot 1 - Check. Plot 2 - Superphosphate. Plot 3 - Triple superphosphate. Plot 4 - Calcium metaphosphate.

TABLE XXXVI

Analysis of Variance
Alfalfa, October 30

Sample	Plot	Sample	Plot	Sample	Plot	Sample	Plot
3828	1[3]	4667	4	7490	3	7260	2
7262	2	3240	1	4807	4	7567	3
7737	3	7202	2	3310	1	4740	4
5260	4	7680	3	7217	2	3275	1
24087		22789		22824		22842	

Source	df	Ms	F	PrL
Total	15			
Rows	3	15,725.42		
Columns	3	100,715.75		
Treatments	3	15,906,816.75	699.67	.0005**[2]
Error	6	22,734.71		
SE treatment		75.39	LSD @ 5% 369.41[1]	

Means; (1) 3413.24 (2) 7235.25 (3) 7618.50 (4) 4,868.50

---

[1] For significance, yield difference between treatments must be 369.4 pounds per acre. See Table XVI, Appendix "B".

[2] Results significant 9,999 times per 10,000 times.

[3] Plot 1 - Check. Plot 2 - Superphosphate. Plot 3 - Triple superphosphate. Plot 4 - Calcium metaphosphate.

VITA

ROBERT O. WOODWARD
candidate for the degree of
Master of Science

Thesis: A COMPARISON OF THE EFFECT OF CALCIUM METAPHOSPHATE AND OTHER PHOSPHATIC FERTILIZERS ON THE YIELD OF CERTAIN CROPS UNDER FIELD CONDITIONS

Major: Soils

Biographical and other Items:

Born: June 17, 1917 at Lawton, Oklahoma

Undergraduate Study: Cameron State Agricultural College, Lawton, Oklahoma, 1936-1938; Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, 1938-1940

Graduate Study: Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, 1940-1955

Experience: Reared on a farm; Comptroller, Agricultural Adjustment Administration, Stillwater, Oklahoma, 1940-1941; United States Air Force, 1941-1946; Agronomy Section, Extension Division, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, 1946-1955.

Member of the American Society of Agronomy

Date of Final Examination: May, 1955

THESIS TITLE: A COMPARISON OF THE EFFECT OF CALCIUM METAPHOSPHATE AND OTHER PHOSPHATIC FERTILIZERS ON THE YIELD OF CERTAIN CROPS UNDER FIELD CONDITIONS

AUTHOR: Robert O. Woodward

THESIS ADVISER: Dr. Lester W. Reed

The content and form have been checked and approved by the author and thesis adviser. The Graduate School Office assumes no responsibility for errors either in form or content. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

TYPIST: Dorothy E. Kizer