THE AVAILABILITY OF PHOSPHORUS IN CERTAIN PHOSPHATIC FERTILIZERS

by

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INTRODUCTION AND REVIEW OF LITERATURE

The phosphorus content of American agricultural soil varies considerably. Some soils are very deficient, others contain more phosphorus than the parent materials from which they were derived. It is believed that the majority of the cultivated soils of that portion of the United States east of the Mississippi River would be forced out of cultivation within a few years if phosphatic fertilizers were withheld. It even has been estimated that mid-western United States will soon need 4,000,000 tons of phosphatic fertilizers per year. Only a small part of this 4,000,000 tons will be available to the plants needing it. Proper application of this large amount of phosphatic fertilizer is the concern of farmers and commercial fertilizer men.

Various workers have reported relative to the availability of different forms of phosphatic fertilizers. Hendricks, et al. (10) reported that fluorine is a part of the raw mineral phosphate in all the phosphate deposits in the U. S. and that rock phosphate is primarily a mixture of fluorapatite and hydroxyapatite. Furthermore, these apatitic bonds must be broken in order to improve their usefulness. Bartholomew (2) found that the natural phosphates containing the least fluorine produced the highest yields.

The degree of fineness of raw phosphate and less-soluble processed phosphates influences the availability of phosphorus to plants to a certain degree. Most of the rock phosphate that is sold for commercial use is ground so that 90 percent or more will pass a 100-mesh sieve. Some is even ground so that 80 percent will pass a 200-mesh sieve. Salter and Barnes (18) have shown that in some cases finer particles than are found in the commercial product provide greater availability of the phosphorus to plants. However, the increased cost of grinding usually does not justify such procedure.

Salter and Barnes (18) also observed that liming may decrease the availability of rock phosphate. Numerous experiments have shown that rock phosphate is of little or no value when applied to calcareous soils.

Truog (20) noted that plants varied in their ability to utilize the phosphorus in rock phosphate. In general, most of the cereals were poor feeders, whereas buckwheat and legumes, such as sweet clover and alfalfa, were heavy feeders.

It has been suggested that decomposing organic matter exerts a solvent action upon raw phosphate. Bauer (3) studied the effects of fermenting residues of such plants as sweet clover, alfalfa, and buckwheat on the availability of phosphorus in rock phosphate. The results failed to prove any solvent action. Bray (4) believed that the extra beneficial effect of adding organic matter with rock phosphate came from a solvent action on the rock phosphate.

The Indiana Agricultural Experiment Station conducted a number of field tests in which superphosphate and finely ground rock phosphate were compared. A summary of the results reported by Wiancko and Conner (22) is presented in Table 1. As a result of the 82 tests, it was concluded that it paid to use superphosphate on the average Indiana soil under average conditions. Raw phosphate also showed a profit but it was smaller than that from the use of superphosphate.

Bauer, (3) in working with mono, di, and tricalcium phosphates, concluded that crops responded to these three forms of phosphate carriers in the order listed. In comparison with superphosphate, Green (8) reported that for alfalfa, oats, and wheat in Montana, monocalcium phosphate produced lower

Table 1. Summary of Indiana experiments in which superphosphate and raw phosphate were compared.@

Crop and number of location-year tests	Kind of phosphate	Pounds material applied per acre per year	Average yield per acre	Yield increase
Corn (36 tests)	Superphosphate	190	43.04 bu.	5.49 bu.
	Raw rock	532	42.20 bu.	4.65 bu.
	None		37.65 bu.	
Wheat (33 tests)	Superphosphate	190	15.28 bu.	4.31 bu.
	Raw rock	532	12.08 bu.	1.91 bu.
	None		10.97 bu.	
Legume hay (9 tests)	Superphosphate	190	2998 lb.	320 lb.
	Raw rock	532	2773 lb.	95 lb.
	None		2678 lb.	
Potatoes (4 tests)	Superphosphate	500	112.0 bu.	29.4 bu.
	Raw rock	1000	94.2 bu.	11.6 bu.
	None		82.6 bu.	

@ Data from Wiancko and Conner (22).

yields than concentrated superphosphate. Dicalcium phosphate was inferior to either concentrated superphosphate or monocalcium phosphate.

Tests conducted in North Carolina by Hall, et al. (9) found no difference in yields of seed cotton produced by use of dicalcium phosphate and concentrated superphosphate. In general, tricalcium phosphate was less effective than either monocalcium phosphate or dicalcium phosphate.

Data from field tests conducted by the agricultural experiment stations of Alabama, Georgia, Kentucky, Mississippi, North Carolina, Tennessee and Virginia and summarized by Long and Winters (11) indicated that fused tricalcium phosphate, when ground to pass through a 40-mesh sieve, compared favorably with superphosphate when applied to white clover grass mixtures on acid soils. However, small grains, corn and cotton crops did not respond as well to application of fused tricalcium phosphate as with application of superphosphate. Green (8) reported that in contrast to the relatively favorable reports for fused tricalcium phosphate on acid soils, tests on alkaline or calcareous soils showed that fused tricalcium phosphate was not a satisfactory source of phosphorus under these conditions.

Bauer (3) reported that, in general, calcined phosphates have performed very similarly to fused tricalcium phosphates.

Various testings of calcium metaphosphate by Alway and Nesom (1), showed that crops responded as well to this carrier of phosphate as to application of superphosphate provided the soil had a pH value of 6.5 or less. In an experiment on calcareous Ida silt loam, calcium metaphosphate was less effective in increasing corn yields than was superphosphate, but when applied to slightly acid Monona silt loam (pH 6.5), this phosphate compared favorably with superphosphate. Rogers, et al. (16) cited Tisdale comparing potassium metaphosphate with concentrated superphosphate showed a mean relative yield value of 101 for potassium metaphosphate. In these same tests the control plots (no phosphate applied) had a mean value of 67.

As a result of studies by Ensminger (6), basic slag was found to be less effective than superphosphate. From tests conducted in Alabama with cotton as the test crop, a relative increase of 85-90 was reported. From this and other tests, basic slag was found to be more effective on corn, winter legumes, and pastures than with cotton.

After completing 26-30 tests in Virginia on corn, wheat, hay and pastures, Rich and Lutz (14) reported relative yield for basic slag ranging from 91 to 95. Salter and Barnes (18) reported basic slag to have an efficiency of about 85 per cent for cereals grown on unlimed land, but under the same conditions it was 40 per cent superior to superphosphate when applied to clover.

The phosphorus in monoammonium phosphate and diammonium phosphates are available to plants. The importance of neutralizing the acidity of these forms of phosphorus was shown by a sixteen year test conducted by Ensminger and Cope (7). When lime was omitted, monoammonium phosphate produced less cotton than the control plots. Salter and Barnes (18) and Weiser (21) also showed that the relative efficiency of this phosphate was increased markedly by liming the soil.

Ammonium phosphates appear unusually well adapted for use on alkaline or calcareous soils because of their high solubility, the combination of nitrogen and phosphorus contained therein and residual acidity.

Ensminger (6) concluded from 199 location-year tests in Alabama that when dolomite was added to neutralize the acidity and ammonium sulphate was added to supply needed sulfur, both mono and diammonium phosphates were about as effective for cotton as was superphosphate. Diammonium phosphate appeared to be unstable in nature, especially under humid conditions.

The process of treating rock phosphate with nitric acid yields a product called "nitric phosphate". Rogers (15) summarized data from ten state agricultural experiment stations relative to the efficiency of the NP and NPK products made by the nitric-phosphoric and nitric-sulfuric acidulation of rock phosphate. It was observed that the phosphorus in the nitric phosphates was as available as it was in concentrated superphosphate for corn, cotton, and small grain grown on acid soils.

There was no evidence that water-solubility greater than about 10 percent was required in the nitric phosphates for small grain, corn, and cotton on the soils of the Southeast. A few tests suggested that nitric phosphates of low water-solubility may be less effective on alkaline soils than the more soluble superphosphate. There appeared to be a beneficial effect on crops by having N, P, K and S present in a multiple-nutrient particle.

The process of treating superphosphate with ammonia to form ammoniated superphosphate has the disadvantage of forming less soluble compounds of phosphorus. Parker (13) prepared a critical review of all experimental work pertaining to the avability of the precipitated phosphates and of ammoniated superphosphate. These data indicated that the phosphorus in ammoniated superphosphate was from 75 to 100 percent as effective as that in superphosphate.

Williamson (23) published extensive investigations relative to the influence of ammoniation of superphosphate upon the availability of phosphorus. The data showed that superphosphate, ammoniated to the extent of containing two percent of ammonia gave a relative increase of 100, but when it was ammoniated to the extent of four percent of ammonia the relative increase dropped to 85 compared to 100 as the increase from superphosphate. When the mixture was ammoniated to an extent of more than three percent of ammonia, the degree of reversion of phosphorus was increased. The addition of six percent of ammonia resulted in the formation of about 30 percent of tricalcium phosphate.

Work by Ross, et al. (17) indicated that long-season crops were better able to utilize the phosphorus in highly ammoniated mixtures than were short-season crops.

General conclusions concerning ammoniation of superphosphate can be made. Ammoniation of ordinary superphosphate to the extent of two percent NH_3 does not affect availability of phosphorus to plants. Addition of ammonia beyond that point results in a relatively small, though consistant, decrease in effectiveness as the percentage of ammonia is increased. The ammoniation of concentrated superphosphate to a given level results in much less reversion to unavailable forms of the phosphorus.

Radiophosphorus field experiments conducted by a number of state experiment stations and the United States Department of Agriculture were begun in 1948. The tagged phosphates that were produced and tested included ordinary and concentrated superphosphate, superphosphate ammoniated to different levels of nitrogen, tricalcium phosphate, dicalcium phosphate, calcium metaphosphate, ammonium phosphate, and nitric phosphates. Results from these tests show that as much or more phosphorus is absorbed from applied superphosphate as from any other source tested. Calcium metaphosphate tended to furnish more phosphorus to the plants than either di or tricalcium phosphate, but in most cases somewhat less than superphosphate. On neutral to alkaline soils Dion, et al. (5) found that monoammonium phosphate supplied significantly larger amounts of phosphorus to wheat and barley than did monocalcium phosphate and that dicalcium phosphate was inferior to either of those sources. Olsen, et al. (12) also found that dicalcium phosphate furnished less phosphorus to wheat, barley, and sugar beets on calcareous soils than did superphosphate. Their results further showed that alfalfa and potatoes absorbed about equal amounts of phosphorus from calcium metaphosphate and from superphosphate. Tricalcium phosphate generally furnished less phosphorus to plants than did the other sources, although occasionally it furnished more than dicalcium. These phosphate carriers have been rated according to their absorption rate as follows: Superphosphate ammonium phosphate > calcium metaphosphate > dicalcium phosphate > tricalcium phosphate.

Over the past several decades, numerous trials have been conducted in Kansas in which ordinary superphosphate has been compared with concentrated superphosphate. Generally speaking, these sources of phosphorus have been about equal in effectiveness when used at such rates as to compare comparable amounts of available P_2O_5. Rock phosphate has been compared with superphosphate in a rotation experiment at the Columbus Experiment Field since 1923. These results were reported by Smith, et al. (19). Calcium metaphosphate has been compared with superphosphate on certain test demonstration farms in southeastern Kansas. Calcium metaphosphate has proved satisfactory as a source of phosphorus for alfalfa. Little had been done prior to 1954 insofar as the evaluations of nitric phosphates and diammonium phosphate were concerned.

The experiment reported herein was designed to pursue the following objectives:

(1) To compare ammoniated superphosphate, ammonium phosphates, nitric phosphate and concentrated superphosphate as sources of phosphate for wheat.

(2) To compare the beneficial effects of various ratios of nitrogen: available phosphoric anhydride contained in mixed fertilizers made from the above materials.

(3) To compare broadcasting of the various phosphatic sources with banding in the drill row as methods of placement of fertilizers for wheat.

(4) To evaluate, insofar as possible, the general response of wheat to fertilization.

EXPERIMENTAL METHODS

Description of Soils

Experimental plots were established in Riley County, Kansas upon the Ashland Agronomy Farm of Kansas State College. This experimental location is in NE¼ of Section 34, Township 10S, Range 7E. The soil at this location is fine sandy loam derived from Kansas River alluvium. It is well drained and quite productive of wheat, oats, corn and alfalfa when supplied with adequate moisture and fertilizer nutrients. The area involved in this experiment had been used by the Soil Conservation Service for the production of grasses prior to 1954. In 1954, oats was grown on this land. It was prepared for wheat seeding in the fall of 1954.

Experimental plots also were established in Morris County, Kansas upon the farm of Otto Frey, located four miles south of Council Grove, Kansas. This experimental location is in SE¼ of Section 3, Township 17S, Range 8 E. The soil at this location is Verdigris dark variant. It is fairly well drained and quite productive of wheat, oats, corn, and alfalfa when supplied with adequate moisture and fertilizer nutrients. The area involved in this experiment had been used for the production of wheat for several years prior to the establishment of these experimental plots.

Chemical Properties of Soils

Soil samples were collected from each of the experimental locations. These samples were analyzed in the State Soil Testing Laboratory of the Department of Agronomy at Kansas State College, Manhattan. The results of these analyses are presented in Table 2.

Table 2. Chemical properties of soils used in wheat fertilizer trials, 1954-55.

Experimental location	pH	Organic matter %	Available phosphorus (lbs./A)	Exchangeable potassium (lbs./A)
Ashland Agronomy Farm, Manhattan	6.4	2.07	43	720
Otto Frey Farm, Council Grove	6.2	2.0	64	550 +

The soil site at the Ashland Agronomy Farm is of such pH value as to indicate no need for addition of liming material. It is only medium in its content of organic matter. This would suggest a lack of available nitrogen inasmuch as the reserve supply is rather low. Phosphorus availability, which was medium, might limit wheat yields under certain circumstances. Potassium availability was very high.

The same general fertility pattern existed at the Frey farm site near Council Grove. This latter soil was slightly more acid in reaction, suggesting a limited need for addition of lime. The actual measured lime requirement amounted to one ton per acre. Phosphorus availability which was higher than that on the Ashland Agronomy Farm, usually would not be expected to limit wheat yields. Again potassium availability was quite adequate.

Description of Fertilizer Materials

Fertilizer materials used for these experiments included the following:

1. Diammonium Phosphate. This material was furnished by the Colorado Fuel and Iron Corporation of Denver, Colorado. It had a guaranteed analysis of 21-52-0. Thus it had a ratio of $N:P_2O_5$ of 1:2.47. On this account, certain other fertilizers were adjusted to this ratio so as to provide a basis for comparison. This material contains phosphorus which is entirely in a water soluble form. This was used for treatments two to five, inclusive at both experimental locations.

2. Commercial Mono-ammonium Phosphate-sulfate and Ammonium Nitrate Mixture. The mono-ammonium phosphate-sulfate was furnished by the Olin Mathieson Chemical Corporation of Pasadena, Texas. It had a guaranteed analysis of 13-39-0. This material was mixed with ammonium nitrate (33.5-0-0) supplied by the Spencer Chemical Company of Kansas City, Missouri, to produce a fertilizer having an analysis of 14.5-36-0. The 13-39-0 fertilizer was made from fertilizer grade mono-ammonium phosphate. The 13-39-0 originally contains a small amount of ammonium sulfate since it was made by using a combination of phosphoric acid and sulfuric acid in the neutralization process.

The 14.5-36-0 grade was made by using 92.35 pounds of 13-39-0 fertilizer, which furnished 12 pounds of N and 36 pounds of P_2O_5. To this amount, 7.65 pounds of 33.5-0-0 fertilizer was added which furnished 2.5 pounds of N. Therefore, each 100 pounds of the fertilizer mixture contained 14.5 pounds of N and 36 pounds of P_2O_5 to provide an analysis of 14.5-36-0 and having a ratio of N:P_2O_5 of 1:2.47. This was used for treatments 6 to 9, inclusive, at both experimental locations.

3. Ammoniated Triple Superphosphate and Ammonium Nitrate Mixture. The ammoniated triple superphosphate was supplied by the Snyder Chemical Company, Topeka, Kansas. It had a guaranteed analysis of 8-32-0. The ammonium nitrate (33.5-0-0) was furnished by the Spencer Chemical Company. The 8-32-0 was made by ammoniating triple superphosphate. An 11.2-28-0 grade of fertilizer was made by using 87.5 pounds of 8-32-0 fertilizer which furnished 7 pounds of N and 28 pounds of P_2O_5. To this was added 12.5 pounds of 33.5-0-0 which furnished 4.2 pounds of N. Therefore, each 100 pounds of this fertilizer mixture contained 11.2 pounds of N and 28 pounds of P_2O_5 to form an analysis of 11.2-28-0 having a ratio of N:P_2O_5 of 1:2.47. This was used on treatments 10-13, inclusive, at both experimental locations.

4. Nitric Phosphate. This experimental fertilizer was furnished by the Allied Chemical and Dye Corporation from its plant located at South Point, Ohio. This fertilizer had a guaranteed analysis of 15-15-0, thus a N:P_2O_5 ratio of 1:1. This was used for treatments 14-17, inclusive, at only the Ashland location.

5. Ammoniated Triple Superphosphate. This material was manufactured by the Kansas Agricultural Chemical Company of Junction City, Kansas. This commercial grade was made by a process which utilized an ammoniating solution and triple superphosphate. It had a guaranteed analysis of 15-15-0 with the N:P_2O_5 ratio thus being 1:1. This was used for treatments 18-21, inclusive, at both experimental locations.

6. Triple Superphosphate and Ammonium Nitrate Mixture. This mixture of fertilizers had an analysis of 19-19-0. The triple superphosphate was furnished by Armour Fertilizer Company located at North Kansas City, Missouri, having a guaranteed analysis of 0-43-0. The ammonium nitrate (33.5-0-0) was supplied by Spencer Chemical Company. The 19-19-0 analysis was made by using 44 pounds of Armour's triple superphosphate, which furnished 19 pounds of P_2O_5 and adding to this 56 pounds of ammonium nitrate which furnished 19 pounds of N. This mixture yielded a ratio of $N:P_2O_5$ of 1:1. This was used for treatments 22-25, inclusive, at both experimental locations.

7. Triple Superphosphate. This material was furnished by Armour Fertilizer Company. It had a guaranteed analysis of 0-43-0. This was used for treatments 26-29, inclusive, at the Ashland location and treatments 14-17, inclusive, at the Council Grove location.

8. Unfertilized. Cultures 1 and 30 were used as control plots and thus did not receive fertilizer at the Ashland experimental location. The Council Grove experimental location had culture 1 as check plots and to this fertilizer was not added.

Solubility Characteristics of Fertilizers

Fertilizers used in these trials varied considerably in degrees of water solubility of the phosphorus contained therein (Table 3). For example in the $N:P_2O_5$ ratio group of 1:2.47, the solubility of phosphorus varied from 100 percent of the guaranteed amount to as low as 66.7 percent of the guaranteed P_2O_5 content. Ordinarily each of the materials in this ratio would be regarded as being well supplied with soluble phosphorus. Fertilizers in the $N:P_2O_5$ ratio group of 1:1 were even more variable in this respect. The mechanical mixture, prepared by blending ammonium nitrate and triple superphosphate, contained 99 percent of water soluble phosphorus. The 15-15-0 grade of nitric phosphate had the lowest solubility of any material used, that being only 12 percent of the guaranteed analysis. Ammoniation of the triple superphosphate used in manufacturing the 15-15-0 grade of fertilizer furnished by the Kansas Agricultural Chemical Company apparently had lowered its water solubility. Presumably the triple superphosphate used in preparing this grade was originally quite high but it had been lowered to 50 percent as a result of the manufacturing processes.

Planting Methods

Wheat was planted in a conventional manner at each experimental location. An International-Harvester combination grain and fertilizer drill was used. This implement was equipped with nine drill spouts, each of which was spaced seven inches from the adjoining spout. Concho wheat was planted on the Ashland Agronomy Farm on October 31, 1954. Pawnee Wheat was planted on the Frey Farm on November 11, 1954. Each location was seeded at a rated five pecks per acre of seed as established by drill measure. Good emergence and excellent stands were observed the following spring despite these rather late plantings which were made at the two locations.

Placement of Fertilizer

Fertilizer was distributed by means of the combination grain and fertilizer drill. In those instances where the fertilizer was broadcast ahead of the planting, this was done by removing the flexible spouts from the drill shoes and allowing it to be dropped and spread upon the soil as a preliminary operation. Some incorporation of this into the soil was accomplished by the action of the drill disks upon the soil.

Table 3. Solubility characteristics of fertilizers used in wheat fertilizer trials, 1954-55.

Fertilizer grade, $N-P_2O_5-K_2O$	Water Soluble P_2O_5 (%)	$\frac{\text{Water soluble } P_2O_5}{\text{Available } P_2O_5} \times 100$ (%)	Used for treatments: Ashland Agronomy Farm	Frey Farm
1. 21-52-0	52.0	100.0	2 to 5, incl.	2 to 5, incl.
2. 14.5-36-0	33.6	93.1	6 to 9, incl.	6 to 9, incl.
3. 11.2-28-0	18.7	66.7	10 to 13, incl.	10 to 13, incl.
4. 15-15-0 (Allied)	1.8	12.0	14 to 17, incl.	none used
5. 15-15-0 (Kan Gro)	7.5	50.0	18 to 21, incl.	18 to 21, incl.
6. 19-19-0	18.8	99.0	22 to 25, incl.	22 to 25, incl.
7. 0-43-0	42.6	99.0	26 to 29, incl.	14 to 17, incl.

In the other cases, fertilizer and seed were dispersed simultaneously from the drill through the flexible spouts and deposited in the furrow in rather intimate contact with each other.

Plot Layout

The basic plot design included randomized complete blocks of treatments and check cultures. In the case of the Ashland experimental trial, three randomized complete blocks were used. Included in each of these blocks were two sets of control cultures. Thus six replications of the controls were utilized whereas only three replications of each fertilized plot were included. The Council Grove location utilized four randomized complete blocks. Thus each fertilized, and each control culture appeared a total of four times in the experimental design. Each plot was 5.25 feet wide x 100 feet in length.

Harvesting Technique

Individual plots were harvested, one at a time, by means of a small Allis-Chalmers combine. The machine utilized at each location was designed to cut a strip 60 inches wide. It was possible to harvest a single drill strip with each passage of this combine. Sufficient time was allowed to lapse between plots so as to effect rather complete cleaning of the machine. Grain from each plot was collected in a burlap bag. It was weighed, the weight per acre was ascertained and then converted to bushels per acre, assuming a weight of 60 pounds per bushel.

Test Weight Measurements

A sample of grain from each harvested plot was collected at the time of harvesting. This sample was later used in the measurement of the "test weight" of each. The standard apparatus for determining "weight per measured bushel" was employed for this purpose.

EXPERIMENTAL RESULTS

Yield Data

Ashland Agronomy Farm. As may be seen in Table 4, any treatment involving concentrated superphosphate (0-43-0) yielded less than the control plots. However, only one of these four treatments actually yielded significantly less than the control. This significant reduction occurred where the equivalent of 25 pounds per acre of P_2O_5 was drilled with the seed. Two other fertilizer materials, 14.5-36-0 and 19-19-0, behaved in a similar fashion inasmuch as each treatment within these two groups yielded less than the control. No individual treatment actually yielded significantly less than the control in either case, however.

In addition to the reduction caused by the low rate of concentrated superphosphate drilled with the seed. Three other treatments reduced grain yields significantly. Specifically these treatments included diammonium phosphate (21-52-0) broadcast at such rate as to furnish 50 pounds of available P_2O_5, the experimental nitric phosphate (15-15-0) broadcast at such rate as to furnish only 25 pounds of available P_2O_5 and the ammoniated superphosphate (15-15-0) drilled with the seed at such rate as to furnish 25 pounds per acre of available P_2O_5.

Two treatments yielded significantly more than the control plots. These involved an ammoniated superphosphate type of fertilizer (11.2-28-0) broadcast at such rate as to furnish 50 pounds per acre of available P_2O_5 and another ammoniated superphosphate (15-15-0) drilled with the seed at the same rate. These two treatments produced yields that were significantly higher than any other treatment with the exception of ammoniated superphosphate type of fertilizer (11.2-28-0) drilled with seed at such rate as to furnish 50 pounds per acre of available P_2O_5 and nitric phosphate type of fertilizer (15-15-0)

Table 4. Summary of wheat grain yields, Ashland Agronomy Farm, Manhattan, Kansas - 1955.

Rate of P_2O_5 (lbs./A)	Method of application	Yields[1] for various fertilizer grades, bushels per acre: 21-52-0	14.5-36-0	11.2-28-0	15-15-0[2]	15-15-0[3]	19-19-0	0-43-0	Average for rates and methods of application
25	Broadcast	42.8	40.5	36.1	34.3	39.9	38.3	37.1	38.4
25	Drilled with seed	42.7	35.9	41.3	42.1	35.1	41.5	32.7	38.8
50	Broadcast	34.5	42.5	54.2	47.0	39.3	36.9	36.9	41.6
50	Drilled with seed	42.9	35.5	48.8	38.9	51.4	39.1	36.9	41.9
Average for grades		40.7	38.6	45.1	40.6	41.4	39.0	35.9	

No treatment = 42.6 bushels per acre, an average of 6 replications

[1]Yield data represent averages of 3 replications

[2]15-15-0 grade was an experimental nitric phosphate supplied by Allied Chemical and Dye Corporation.

[3]15-15-0 grade was commercial ammoniated superphosphate supplied by Kansas Agricultural Chemical Co. (Kan Gro).

Difference required for significance = 7.2 bushels per acre at .05 level.

broadcast at such rate as to furnish 50 pounds per acre of available P_2O_5.

The treatment involving only concentrated superphosphate (0-43-0) drilled with seed at such rate as to furnish 25 pounds per acre of available P_2O_5 produced the lowest yield. There were numerous treatments which produced significantly more than this. These were diammonium phosphate (21-52-0) broadcast at such rate as to furnish 25 pounds per acre of available P_2O_5 and drilled with seed at such rate as to furnish both 25 and 50 pounds per acre of available P_2O_5; commercial monoammonium phosphate-sulfate and ammonium nitrate mixture (14.5-36-0) broadcast at such rates as to furnish both 25 and 50 pounds per acre of available P_2O_5; ammoniated triple superphosphate and ammonium nitrate mixture (11.2-28-0) drilled with the seed at such rates as to furnish both 25 and 50 pounds per acre of available P_2O_5 and broadcast at such rates as to furnish 50 pounds per acre of available P_2O_5; nitric phosphate (15-15-0) both drilled with seed and broadcast at such rates as to furnish 25 and 50 pounds per acre of available P_2O_5, respectively; ammoniated superphosphate (15-15-0) broadcast and drilled with the seed at such rates as to furnish 25 and 50 pounds per acre of available P_2O_5, respectively; and triple superphosphate and ammonium nitrate mixture (19-19-0) drilled with the seed at such rates as to furnish 25 pounds per acre of available P_2O_5.

Of the broadcast treatments, nitric phosphate (15-15-0) when used at such rate as to provide 25 pounds per acre of available P_2O_5 yielded the least. Any broadcast treatment yielding 41.5 bushels per acre or more produced significantly more than this. Therefore, diammonium phosphate (21-52-0) broadcast at such rate as to furnish 25 pounds per acre of available P_2O_5, ammoniated triple superphosphate and ammonium nitrate mixture (11.2-28-0) broadcast at such rate as to furnish 50 pounds per acre of available P_2O_5, nitric phosphate (15-15-0) broadcast at such rate as to produce 50 pounds per acre of available P_2O_5, and commercial mono-ammonium phosphate-sulfate and ammonium nitrate mixture (14.5-36-0) broadcast at such rates as to furnish 50 pounds per acre of available P_2O_5 were superior to the low rate of nitric phosphate which was broadcast ahead of planting.

Of the treatments drilled with the seed, concentrated superphosphate (0-43-0) when used at such rate as to provide 25 pounds per acre of available P_2O_5 yielded the least. Any treatment drilled with the seed, yielding 39.9 bushels per acre or more produced significantly more than this. Therefore, diammonium phosphate (21-52-0) drilled with the seed at such rate as to furnish both 25 and 50 pounds per acre of available P_2O_5, ammoniated triple superphosphate and ammonium nitrate mixture (11.2-28-0) drilled with the seed at such rate as to furnish both 25 and 50 pounds per acre of available P_2O_5, nitric phosphate (15-15-0) drilled with the seed at such rate as to furnish 25 pounds per acre of available P_2O_5, ammoniated superphosphate (15-15-0) drilled with the seed at such rate as to furnish 50 pounds per acre of available P_2O_5, and triple superphosphate and ammonium nitrate mixture (19-19-0) drilled with the seed at such rate as to furnish 25 pounds per acre of available P_2O_5 were superior to the lower rate of concentrated superphosphate which was drilled with the seed.

The average yield of grain per acre on the treatment receiving 25 pounds per acre of available P_2O_5 was 3.15 bushels per acre less than the treatments receiving available P_2O_5 at the rate of 50 pounds per acre.

Broadcasting 25 pounds per acre of available P_2O_5 gave an average yield of wheat which was 3.2 bushels per acre less than that for broadcasting 50 pounds per acre of available P_2O_5. Similarly, drilling 25 pounds per acre of available P_2O_5 yielded an average of 3.1 bushels per acre less than did drilling 50 pounds per acre.

Of the seven different grades of fertilizer used, (0-43-0) produced the lowest average yield, 35.9 bushels per acre. The (11.2-28-0) grade produced the greatest yield, 45.1 bushels per acre. The average yield of these seven fertilizers was 40.2 bushels per acre compared with 42.6 for the check yield. As a general rule, fertilizer was not especially beneficial upon this particular farm.

Frey Farm. Table 5 shows that there was a greater response to fertilizers at the Frey Farm than at the Ashland Agronomy Farm location (Table 4). The average yield for these treatments involving the six fertilizers used was 46.3 bushels per acre whereas the control plots yielded an average of 41.0 bushels per acre.

The lowest yielding treatment, fertilizer grade (21-52-0) drilled with the seed at the higher rate, produced 34.2 bushels per acre. All other treatments produced a significantly greater yield than did this treatment. On the other hand, fertilizer grade (14.5-36-0) both broadcast and drilled with the seed at the lower rate and fertilizer grade (0-43-0) both drilled with the seed at the lower rate and broadcast at the higher rate produced significantly greater yields than any other treatment yielding 44.9 bushels per acre or less. The fertilizer treatments acting in this manner were (21-52-0) drilled with the seed at the higher rate, (14.5-36-0) broadcast at the higher rate, (11.2-28-0) broadcast at the higher rate, (0-43-0) both broadcast and drilled with the seed at lower and heavier rates respectively, (15-14-0) ammoniated superphosphate both broadcast and drilled with the seed at lower and higher rates respectively, and (19-19-0) broadcast at both the low and high rate.

Any treatment shown on Table 5 and having an average yield greater than 47.3 bushels per acre produced significantly more than the control which

Table 5. Summary of wheat grain yields, Frey Farm, Council Grove, Kansas - 1955.

Rate of P_2O_5 (lbs./A)	Method of application	Yields[1] for various fertilizer grades, bushels per acre						Average for rates and methods of application
		21-52-0	14.5-36-0	11.2-28-0	0-43-0	15-15-0[2]	19-19-0	
25	Broadcast	48.2	51.2	49.6	44.3	42.6	42.0	46.3
25	Drilled with seed	48.3	53.3	47.8	51.4	47.5	48.9	49.5
50	Broadcast	47.8	43.7	44.7	51.9	46.2	40.8	45.8
50	Drilled with seed	34.2	46.6	47.1	42.0	42.6	48.0	43.4
Average for grades		44.6	48.7	47.3	47.4	44.7	44.9	

No treatment = 41.0 bushels per acre, an average of 4 replications

[1] Yield data represent averages of 4 replications

[2] 15-15-0 grade was commercial ammoniated superphosphate supplied by Kansas Agricultural Chemical Co. (Kan Gro).

Difference required for significance = 6.3 bushels per acre at .05 level.

yielded 41.0 bushels per acre. On the contrary, treatments yielding less than 34.7 bushels per acre were significantly less than the control. The only treatment acting in this manner was the grade of 21-52-0 drilled with the seed at the higher rate. It should be noted at this point that diammonium phosphate (21-52-0) when drilled with the seed at such rate as to furnish 50 pounds per acre of available P_2O_5 caused severe lodging of the wheat. This effect was noticeable only in this particular case.

The lowest yielding broadcast treatment was 19-19-0 grade used at the high rate of available P_2O_5 per acre. Any treatment yielding 47.1 bushels per acre or more, yielded significantly more than did this treatment. Treatments 21-52-0 broadcast at both the low and high rates, 14.5-36-0 and 11.2-28-0 broadcast at the higher rate, and 0-43-0 broadcast at the lower rate acted in this manner.

The lowest yielding treatment drilled with the seed was 21-52-0 applied at the low rate of available P_2O_5 per acre. It yielded 34.2 bushels per acre. All other treatments drilled with the seed yielded 40.5 bushels per acre or more and were thus significantly greater than this treatment.

Treatments receiving available P_2O_5 at the rate of 25 pounds per acre averaged 3.3 bushels per acre more than treatments receiving 50 pounds of available P_2O_5 per acre.

Broadcasting 25 pounds per acre of available P_2O_5 gave an average yield of wheat which was 0.5 bushels per acre more than that for broadcasting 50 pounds per acre of available P_2O_5. Similarly, drilling 25 pounds per acre of available P_2O_5 yielded an average of 6.1 bushels per acre more than did drilling 50 pounds per acre.

Of the six different grades of fertilizer used, the average yields of grain were on two levels. 21-52-0 averaged 44.6 bushels per acre, (15-15-0) ammoniated superphosphate averaged 44.7 bushels per acre and 19-19-0 averaged 44.9 bushels per acre. These three represented the low level of response, whereas 11.2-28-0 averaged 47.3 bushels per acre, 0-43-0 averaged 47.4 bushels per acre and 14.5-36-0 averaged 48.7 bushels per acre to represent the high level of response.

Test Weight Data

Ashland Agronomy Farm. As shown in Table 6, little variation in the wheat test weights was obtained as a result of fertilizer treatments. The over all test weight average for the treatments was 61.9, whereas that of the control was 62.2 pounds per bushel. The highest test weight was shared by treatments (21-52-0) broadcast at the lower level and (11.2-28-0) broadcast at the higher level. The lowest test weight was 61.0 from treatment (19-19-0) broadcast at the higher level. The broadcast treatments had an average test weight of 61.9 and the treatments drilled with the seed had a test weight of 62.0. Treatments receiving 25 pounds of available P_2O_5 per acre and those receiving 50 pounds of available P_2O_5 per acre averaged the same test weight of 61.9.

The seven different grades of fertilizers yielded wheat that had test weights on two levels. Treatments 21-52-0 and 11.2-28-0 produced wheat averaging test weights of 62.3 and 62.4 respectively. Treatments of 14.5-36-0, nitric phosphate, ammoniated superphosphate, 19-19-0, and 0-43-0 produced wheat averaging test weights on a lower level of 61.7, 61.8, 61.8, 61.6 and 61.8 respectively.

Table 6. Summary of wheat test weights, Ashland Agronomy Farm, Manhattan, Kansas - 1955.

Rate of P_2O_5 (lbs./A)	Method of application	Wheat test weights[1] for various fertilizer grades, pounds per measured bu.							
		21-52-0	14.5-36-0	11.2-28-0	15-15-0[2]	15-15-0[3]	19-19-0	0-43-0	Average for rates and methods of application
25	Broadcast	62.8	61.3	62.1	61.2	61.5	61.8	62.1	61.8
25	Drilled with seed	62.4	62.1	62.2	62.3	61.7	61.8	61.9	62.0
50	Broadcast	61.7	62.1	62.8	62.4	61.6	61.0	61.5	61.9
50	Drilled with seed	62.2	61.2	62.4	61.4	62.5	61.8	61.8	61.9
Average for grades		62.3	61.7	62.4	61.8	61.8	61.6	61.8	

No treatment = 62.2 pounds per measured bushel, an average of 6 replications

[1]Test Weight data represent average of 3 replications

[2]15-15-0 grade was an experimental nitric phosphate supplied by Allied Chemical and Dye Corporation.

[3]15-15-0 grade was commercial ammoniated superphosphate supplied by Kansas Agricultural Chemical Co. (Kan Gro).

Frey Farm. Table 7 shows wheat test weights of the treatments on the Frey farm also reflected very little variation. The highest test weight was for the ammoniated superphosphate treatment drilled with the seed at the higher rate. It had a test weight of 61.2. In contrast, the lowest test weight from treatment 21-52-0 drilled with the seed at the higher level was 60.2. The test weight average for all the treatments was 60.5 in comparison to 60.8 for the control. Broadcast treatments produced an average test weight of 60.6 whereas treatments drilled with the seed produced an average test weight of 60. Treatments receiving 25 pounds of available P_2O_5 per acre and those receiving 50 pounds of available P_2O_5 per acre produced identical average test weights of 60 pounds per bushel.

Wheat grown on plots treated with 21-52-0, 11.2-28-0, 0-43-0 had an average test weight of 60.5 while that grown on plots receiving 14.5-36-0, ammoniated superphosphate and 19-19-0 had average test weights of 60.6 pounds per bushel.

DISCUSSION OF RESULTS

Ashland Agronomy Farm

The results obtained at the Ashland Agronomy Farm were undoubtedly influenced by the fertility and texture of the soil. The treatments containing nitrogen yielded more than did the treatments containing only superphosphate. Since the soil tests indicated a possible deficiency in available nitrogen, the nitrogen supplied the plants by means of the treatments appeared to have been beneficial. Therefore, one might assume that the ammoniation of phosphates was beneficial to wheat plants since the ammoniated triple superphosphate and ammonium nitrate mixture was superior to the other treatments. The fine sandy loam texture should be an inducement for leaching and removal by rainwater of the water soluble nitrates of the treatments. This possibility could

Table 7. Summary of wheat test weights, Frey Farm, Council Grove, Kansas - 1955.

Rate of P_2O_5 (lbs./A)	Method of application	Wheat test weight[1] for various fertilizer grades, pounds per measured bu.						
		21-52-0	14.5-36-0	11.2-28-0	0-43-0	15-15-0[2]	19-19-0	Average for rates and methods of application
25	Broadcast	60.4	60.5	60.3	60.5	60.5	60.9	60.5
25	Drilled with seed	60.9	60.8	60.7	60.5	60.7	61.0	60.8
50	Broadcast	60.6	60.3	60.4	60.7	60.8	60.7	60.6
50	Drilled with seed	60.2	60.6	60.7	60.4	61.2	60.9	60.7
Average for grades		60.5	60.6	60.5	60.5	60.6	60.6	

No treatment = 60.8 pounds per measured bushel, an average of 4 replications

[1] Test weight data represent average of 4 replications

[2] 15-15-0 grade was commercial ammoniated superphosphate supplied by Kansas Agricultural Chemical Co. (Kan Gro).

account for some of the variation noted insofar as yield effects were concerned.

The treatments receiving application of 50 pounds of available P_2O_5 per acre averaged a greater yield than did the treatments receiving 25 pounds of available P_2O_5 per acre. Therefore, the phosphates supplied by the treatments seemed to be effective in most cases. However, it should also be noted at this point that as the level of P_2O_5 was increased, so was the level of added nitrogen. It may have been that the effect of increased fertilizer applications was largely a nitrogen effect.

The broadcast treatments averaged a slightly lower yield than did the treatments drilled with the seed. Therefore, one might assume the available P_2O_5 that was placed with the seed, was more available to the plants because of its location.

The experimental nitric phosphate with its content of 1.8% water soluble P_2O_5, was equal to the other fertilizers insofar as average yields of grain was concerned except for the ammoniated triple superphosphate and ammonium nitrate mixture which yielded 4.5 bushels per acre more. This would lead one to believe that the less water soluble P_2O_5 was as available to plants as was that of much higher water solubility.

The cultures receiving fertilizers having a $N:P_2O_5$ ratio of 1:2.47 yielded very little more grain on the average than did the cultures receiving fertilizers having a ratio of 1:1.

Diammonium phosphate and ammoniated triple superphosphate and ammonium nitrate mixture were superior to the other fertilizers in increasing the test weight of the grain. These two fertilizers had the lowest $N:P_2O_5$ ratio. There was very little difference in the yields of cultures whether the fertilizer was drilled with the seed or whether it was broadcast ahead of planting.

The control culture involving six replications was superior to all fertilizer treatments except ammoniated triple superphosphate and ammonium nitrate mixture. Poor germination of the seed and injury of the wheat plants are possibilities to be considered in evaluating the results. Symptoms usually suggesting such interferences were not observed, however. Apparently unfertilized soil at this location was in a relatively high state of fertility when it produced the 1954-55 wheat crop.

Frey Farm

The results of the Frey Farm location suggest that each of the six fertilizer treatments were definitely helpful, causing the yield of wheat to be improved over that obtained on unfertilized soil. The soil tests indicated a slight need for lime and a medium organic matter content. The phosphorus availability was of an amount which usually would not be expected to limit wheat yields. The added commercial fertilizer elements supplemented the original soil fertility to provide a more balanced and abundant supply of food for the growing wheat plants, thus an increase in the yield of wheat.

The water holding capacity of the Frey Farm location was greater than the Ashland Agronomy Farm. This probably was a very important factor in causing yields produced to be higher at the Frey Farm. This effect was undoubtedly very important under the drought conditions which prevailed during a part of the growing season, especially during the spring portion when the wheat at the Ashland Farm was observed to be suffering from lack of soil water upon occasion.

Treatments having a $N:P_2O_5$ ratio of 1:2.47 were superior in increasing yields of grain to those having a $N:P_2O_5$ ratio of 1:1 except for diammonium phosphate which yielded nearly the same as the fertilizers with a 1:1 ratio. The superphosphate treatment increased yields of grain more than the treatments having a $N:P_2O_5$ ratio of 1:1. These effects would suggest nitrogen unavailability was not especially important in limiting yields at the Frey Farm.

Treatments involving applications of 25 pounds of available P_2O_5 per acre produced greater yields of grain than did treatments involving 50 pounds of available P_2O_5 per acre. Possibly the heavier soil at the Frey Farm was more capable of supplying and retaining phosphatic fertilizers for the plants than was the sandy soil at the Ashland Farm. This may have accounted for the apparent greater efficiency at the Frey location.

The broadcast treatments and treatments drilled with the seed responded similarly to the Ashland Agronomy Farm location, therefore, the same general assumption could be made.

Diammonium phosphate, with its completely water soluble P_2O_5 produced the lowest average yield of grain except for the control cultures. These results would tend to confirm the assumption that slight water solubility of the P_2O_5 was as satisfactory for wheat plants as was complete water solubility of the P_2O_5. However, an important factor involved in the rather poor behavior of the diammonium phosphate was its poor performance when drilled at the higher rate with the seed. Reasons for this poor performance were not readily apparent. Variations of test weight values of the cultures were within such a small range that an accurate interpretation of the results was not feasible.

SUMMARY AND CONCLUSION

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

Phosphatic fertilizers, in general, caused greater results on the heavier clay type soils than on the fine sandy loam soils.

When ammonia was incorporated with superphosphate to form a mixed commercial fertilizer, the results were often significantly greater than when superphosphate fertilizer was used alone.

Ammoniated triple superphosphate and ammonium nitrate mixture generally was superior to the other mixed fertilizers in increasing the yield of grain, whereas triple superphosphate and ammonium nitrate mixture had the least effect.

Nitric phosphate was equal to other fertilizers insofar as stimulation of yield of grain was concerned. Phosphatic fertilizers that had a relatively low percent of water soluble P_2O_5 were equal to those having a higher percent of water soluble P_2O_5.

Mixed fertilizers, having a $N:P_2O_5$ ratio of 1:2.47, caused greater yields of grain than those mixed fertilizers having a $N:P_2O_5$ ratio of 1:1. This was especially so on heavier clay type soils. This behavior indicated that nitrogen unavailability was not a problem on the heavy soil.

Broadcast treatments yielded slightly less grain than did the treatments drilled with the seed. Differences were not great, however. Apparently phosphate unavailability was not a big factor with either soil.

The fine sandy loam soil apparently responded more to an application of 50 pounds of available P_2O_5 per acre whereas the heavier clay type soil responded more to the 25 pounds of available P_2O_5 per acre. Somewhat greater efficiency of phosphate utilization was suggested for the heavy soil.

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THE AVAILABILITY OF PHOSPHORUS
IN CERTAIN PHOSPHATIC
FERTILIZERS

by

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

In order to evaluate the efficiency of certain phosphatic fertilizers, two locations were selected and customary fertilizer experimental procedures followed on them. The Ashland Agronomy Farm in Riley County was one location and the other was on the Frey Farm four miles south of Council Grove in Morris County.

The soil at the Ashland Farm was fine sandy loam, medium in organic matter and available phosphorus, whereas the Frey Farm had heavier soil of the Verdigris dark variant type and contained greater amounts of available phosphorus. Both soils were well drained.

The following phosphatic fertilizers were made up to have a $N:P_2O_5$ ratio of 1:2.47: diammonium phosphate (21-52-0), monoammonium phosphate-sulfate (13-39-0) and ammonium nitrate mixture, ammoniated triple superphosphate (8-32-0) and ammonium nitrate mixture, whereas, the remaining listed fertilizers had a $N:P_2O_5$ ratio of 1:1: nitric phosphate (15-15-0), ammoniated triple superphosphate (15-15-0) and triple superphosphate and ammonium nitrate mixture (19-19-0). Triple superphosphate (0-43-0) was also used. These fertilizers were applied to wheat at seeding time by the methods of being drilled with the seed and broadcast ahead of planting. They were applied at two different rates, the higher rate which was 50 pounds of available P_2O_5 per acre and the lower rate which was 25 pounds of available P_2O_5 per acre. Check plots were maintained.

The water solubility of the phosphorus fertilizers used varied from 100 percent to as low as 12 percent.

Pawnee and Concho were the varieties of wheat planted at the Frey Farm and

Ashland Farm, respectively.

The plots were harvested individually, the grain weighed, and these weights converted to bushels per acre. A small sample of the grain was then collected and its "test weight" determined.

The results from the Ashland Farm indicated that ammoniation of phosphates was beneficial to the plants, but as a whole, fertilization of the plots did not stimulate the plants to produce greater yields. In fact, the control was superior in average yields of grain to all of the fertilizer treatments except ammoniated triple superphosphate and ammonium nitrate mixture. The plots at the Frey Farm, on the other hand, generally responded significantly to all of the fertilizers applied to them.

Cultures receiving 50 pounds of available P_2O_5 per acre at the Ashland Farm, averaged a greater yield than the cultures receiving 25 pounds of available P_2O_5 per acre. This was just the opposite of the results obtained from the Frey Farm.

The treatments at both farms which were drilled with the seed, averaged a slightly higher yield than the treatments broadcast before planting.

The cultures receiving fertilizers having a $N:P_2O_5$ ratio of 1:2.47 yielded more grain than those receiving fertilizers having a $N:P_2O_5$ ratio of 1:1. This was especially true at the Frey Farm.

The experimental nitric phosphate with its content of 1.8% water soluble P_2O_5, was equal to the other fertilizers at the Ashland Farm insofar as average yields of grain were concerned except for the ammoniated triple superphosphate and ammonium nitrate mixture. On the other hand, at the Frey Farm the diammonium phosphate with its completely water soluble P_2O_5, produced the lowest average yield of grain except for the control cultures at the Frey Farm.

One could assume from these results that the less water soluble P_2O_5 was as available to plants as was that of the much higher water solubility.

The test weight values of the grain from the Ashland Farm cultures were fairly consistant except for the grain influenced by the diammonium phosphate and ammoniated triple superphosphate and ammonium nitrate mixture. These two fertilizers had the lowest $N:P_2O$ ratio. The test weight values at the Frey Farm were within such a small range that an accurate interpretation of the results was not feasible.

It may be concluded that under the conditions of this experiment, the use of phosphatic fertilizers, in general, caused greater results on the heavier clay type soils than on the fine sandy loam soils. However, results indicated the ammoniated phosphates usually gave greater response to plants than phosphatic fertilizers alone. Thus the nitrogen may have been responsible for these results to a degree. Also, phosphatic fertilizers that had a relatively low per cent of water soluble P_2O_5 were equal to those having a higher percent of water soluble P_2O_5; and mixed fertilizers, having a $N:P_2O_5$ ratio of 1:2.47, caused greater yields of grain than those fertilizers having a $N:P_2O_5$ ratio of 1:1.