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The Comparative Value of Commercial Phosphoric Acid as a Fertilizer

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THE COMPARATIVE VALUE OF COMMERCIAL PHOSPHORIC ACID AS A FERTILIZER

by

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For irrigated land

Introduction

The practice of applying fertilizers to the soil by adding the liquid form to the irrigation water is increasing in popularity. There are several advantages maintained for such a method of application. Some of the advantages are:

(A) Ease of application.

(B) No special equipment is required for application.

(C) The fertilizer can be applied at any stage of plant growth without physical disturbance of the plant.

(D) Penetration into the root zone may be greater than the dry fertilizers.

Considerable phosphate fertilizer is used on soils of irrigated regions. If the behavior of liquid phosphoric acid after its incorporation with soil is such that it penetrates into the root zone and is otherwise as efficient as dry phosphate fertilizers in inducing favorable plant response, then it would seem practical to utilize the other advantages offered by applying the fertilizer in irrigation water.

Commercial phosphoric acid (52% available P_2O_5) is produced by applying an excess of sulfuric acid to ground rock phosphate. This phosphoric acid is usually applied to an additional amount of phosphate rock to make concentrated superphosphate. A given quantity of phosphoric acid can yield more available phosphorus by applying it to rock phosphate than by using it directly as a fertilizer.

Because of its potential value in producing concentrated superphosphate commercial phosphoric acid has been used very little as a fertilizer. There is insufficient research in which the comparative value of the acid as a fertilizer has been investigated. The purposes of the studies reported in this paper are, to compare: (A) the value of commercial phosphoric acid and concentrated superphosphate as fertilizers when applied in equivalent amounts and, (B) the different methods of application and dilution of the phosphoric acid.

Review of Literature

The fixation and mobility of phosphorus in the soil have been studied extensively. Although the "dry" form of phosphate fertilizers was used in most of the studies, the results and principles involved should give an indication as to what might be expected from the use of liquid phosphoric acid.

The immobility of phosphorus in the soil is an important factor in fertilizer practices. This fact was well established as early as 1900. Crawley (3), in 1902, showed by analysis of drainage water taken at different depths in the soil that the phosphorus was not being moved by the percolating water. Many other researchers have since demonstrated the validity of this principle (7, 20).

Due to the immobility of phosphorus it is generally accepted (4, 16) that phosphorus fertilizer should be so placed as to be accessible to plant roots.

It has become a general practice to drill the phosphate fertilizers in bands. This practice is based upon the assumption that there is a marked reduction in the amount of fixation by placing phosphate fertilizers in concentrated bands.

The supposed advantages for such a practice are not universally accepted. Jones and Green (10) maintain that phosphate distribution throughout the root zone is preferred. They suggest that such a distribution is obtained by the use of commercial phosphoric acid in irrigation water. It is assumed that under these conditions the phosphorus is fixed in a slowly available (reverted) form throughout the root zone. Crawley (3) also maintains that the reverted phosphorus has practically the same availability as the more water soluble forms.

According to Harrison and Das (8) the movement of phosphorus compounds in calcareous soils is not in relation to their solubility, but is related to their reaction with calcium carbonate. These authors agree with others (12, 13) that the amount of phosphorus held in the soil solution depends upon the amount of calcium present.

Gilligan (7) concluded from a study with metaphosphates, which have a low water solubility, and superphosphate that the least soluble phosphate was also the least efficient as a fertilizer. The mobility and availability of superphosphate generally exceeded that of metaphosphate.

McGeorge and Breazeale (12) maintain that the important factor in nutrition of phosphorus is not the amount that is water soluble, but the ability of the soil to supply phosphate and carbon dioxide in the zone of the growing root. (The carbon dioxide aids in dissolving the phosphate.) They concluded that carbon dioxide must be present in amounts sufficient to reduce the pH to 6.4 or 6.2 before phosphorus solubility is materially affected. Carbon dioxide from organic matter did not measureably increase the phosphate solubility in the soils they studied. Rhoades (17) concluded that the increase of phosphorus in soil solution due to addition of organic matter was largely phosphorus released from the organic matter and was not brought about by an increase in the solubility of the native soil phosphorus.

MacIntire (13) gives the following explanation for the action between phosphorus and lime in soil: One unit of P_2O_5 in combination with one of lime gives a water-soluble phosphate, one unit of P_2O_5 with two units of lime gives an intermediate water-insoluble phosphate, and one unit of P_2O_5 with three units of lime gives a relatively insoluble tricalcium phosphate. McGeorge and Breazeale (12) maintain that the formation of complex compounds such as carbonate apatite ($3Ca_3(PO_4)_2 \cdot CaCO_3$) results in low solubility of phosphates in calcareous soils. Thus, on calcareous soils the phosphate is made unavailable by the formation of the insoluble phosphate.

In acid soils the continued incidence of the quickly formed dicalcium phosphate is considered to be an advantage. If the acid soil has been limed, the slowly available dicalcium phosphate is formed. On the other hand if the acid soils are deficient in lime the insoluble iron and aluminum phosphates are formed instead of the calcium phosphates.

Several workers have noted an increase in phosphorus uptake by plants by the use of lime on acid soils (15, 5).

If liquid phosphoric acid is more mobile than the dry forms of phosphate fertilizer now in general use, it may also be more available to the plant. Tiedjens and Schermerhorn (21) concluded that the application of dry fertilizers increases the quantity of plant nutrients in the soil which may or may not be available to the plant, but the nutrients supplied by the liquid fertilizers are available. The results of their experiments with mixed fertilizers indicate that in some instances the response in growth by using liquid fertilizer was greater than equivalent amounts of dry fertilizer. Sweet potatoes consistently showed a greater response to the liquid form of fertilizer. On the other hand, it has been reported that Rauterberg found very little or no advantage in the use of liquid fertilizers (2).

MacIntire (13) and associates concluded from results obtained in pot experiments, that phosphoric acid (C.P. 85% P_2O_5) was possibly less effective as a fertilizer than equivalent amounts of treble superphosphate. Their work also showed that dilution of the acid had no effect on the value of the phosphoric acid as a fertilizer.

Ensminger and Larsen (6) divided calcareous soils into three groups according to their effect on soluble phosphates. The division of the soils into groups on the bases of lime content was as follows: 0.5 to 1.0% lime, 1.0 to 2.0% lime, and greater than 2.0% lime. They found no increase in the effect of lime on phosphate availability as the lime content increased above 2%. They suggest that 2% lime in the soil may be just as effective as greater amounts in reducing the quanity of soluble phosphates.

The effect of lime on phosphorus availability is probably the most important single factor to be considered in the use of phosphatic fertilizers on calcareous soils. There are, however, many factors that effect fixation and mobility of phosphorus.

Soils that fix phosphorus as tricalcium phosphate are usually basic or very slightly acid and relatively low in active iron and aluminum. A low pH favors combination with iron and aluminum rather than calcium. It is not necessary for aluminum and iron to be in solution to react with and fix phosphate (9).

Methods of Procedure

Field Experiments

Description of fields

During the spring of 1947 several field plot experiments were conducted to determine the relative value of commercial liquid phosphoric acid as a fertilizer. Comparisons were made with treble superphosphate* (43% available P_2O_5) and liquid

*The treble superphosphate and the commercial liquid phosphoric acid used and referred to throughout this paper are the products manufactured by the Anaconda Copper Company. The treble superphosphate is sold under the trade name Treble Superphosphate. Double superphosphate, double acid phosphate, and treble superphosphate are all correctly used to describe this and comparable products.

phosphoric acid (52% available P_2O_5). The plots were placed on fields of several different types of soil. The fields were located at Price (Carbon County), Farmington (Davis County), Petersboro (Cache County), North Ogden (Weber County), North Logan (Cache County) and Garland (Box Elder County).

Various crops were produced at the different locations.

Established crops of alfalfa were being produced at Price, Petersboro, and Farmington. The North Ogden field was seeded to alfalfa in the spring of 1947; but due to the uneven stand was not harvested. The North Logan field was in perennial pasture on which rotation grazing is practiced. Sugar beets were produced at the Garland plot.

There was some variation in field conditions at the several locations. The soil at Petersboro was a clay loam high in organic matter and high in lime. There was a deficiency of phosphorus in this soil as indicated by the chemical analysis of the soil and the crop response to additions of phosphate fertilizer. Irrigation water was not applied to this field throughout the summer. The land is located at a level lower than most of the neighboring land. The underground water supplies sufficient moisture for crop production. It was necessary to dust the alfalfa with two applications of insecticide to control weevil. One application of grasshopper poison was also necessary.

The soil at Price was a clay loam, low in organic matter and very characteristic of the area (table 1). The salt

Table 1. Summary of soil analysis data

Use and source of the soil	Phosphorus (p.p.m. CO_2 soluble)	pH	Conductivity (millimohs per cm.)	Lime (pct.)	Organic matter (pct.)	Texture
<u>Soils for greenhouse</u>						
Price*	.5	-	.58	1.3	1.6	clay loam
Petersboro*	2.0	8.1	.72	28.5	5.2	clay loam
Farmington	7.0	7.6	-	1.0	1.8	loam
<u>Soils from field plots</u>						
Farmington	18.0	7.9	.56	1.3	2.0	loam
North Logan	-	7.7	.56	2.0	4.3	clay loam
Garland	.5	7.8	.47	3.0	2.7	loam

*The soils used in the greenhouse from Price and Petersboro were obtained from the same farm in proximity to the alfalfa plots.

content indicated by conductivity measurements, was not as high as many of the soils in this area. This field was flood irrigated with the aid of corrugations.

The soils at Farmington, Garland, and North Logan were generally in good agricultural condition. Flood irrigation was practiced at Farmington and North Logan.

Alfalfa

Each replication of the alfalfa plots consisted of seven randomized treatments. There were three replications at each location. Each plot was 12 feet wide x 50 feet in length and constituted about 1/72 of an acre. Fertilizer applications were made during the early spring of 1947.

The treatments consisted of three methods of application. The treble superphosphate was broadcast and drilled in bands. The commercial phosphoric acid was diluted and sprinkled on the soil surface. The fertilizers were applied at two rates for each method of application. One plot in each replication received no phosphate and was used as a control.

Treble superphosphate was applied at the rate of 200 pounds (86 pounds P_2O_5) and 600 pounds (258 pounds P_2O_5) per acre to the drilled and broadcast plots. The broadcast fertilizer was distributed by hand. The drilled fertilizer was applied in bands four to five inches deep and about fifteen inches apart. The bands were applied by means of a small experimental fertilizer drill.

The commercial phosphoric acid was applied at two rates which were equivalent to those of the treble superphosphate. The desired amount of phosphoric acid was diluted in fifteen to twenty parts of water. It was applied to the soil surface by the use of a hand sprinkling can. To prevent "burning" a sprinkling can full of water was used to remove the acid that may have remained on the green foliage.

The samples, for yield estimation and chemical analysis, were harvested just prior to the crop harvest made by the farm operator. An area of forty-five square feet (five quadrangles of nine square feet each) was harvested from each plot. The alfalfa was hand cut by the use of a sickle. The yield on a green weight basis was determined in the field and a sample taken to the laboratory for chemical analysis. Data were obtained for three crops at Petersboro and Farmington, and for two crops at Price.

Pasture

The treatment and harvest of the pasture plots were managed in a similar manner to that of the alfalfa plots. (Plots were 12 feet wide and 30 feet long). All treatments were surface applications and included nitrogen as well as phosphorus. Mixed fertilizers in the liquid and dry form were also used. Harvest was made with a mowing machine equipped with a catcher behind the cutter-bar. Each harvest took place just prior to periodic grazings. Thus a swath five feet wide and the length of the plot was harvested for each crop. This method of harvest was not different from the usual practices since it is customary to "clip" the pasture with a mowing maching after each periodic grazing. Green weight was determined and samples were taken to the laboratory for analysis.

Sugar beets

The sugar beets* were planted in rows that were alternately 12" and 24" apart with beets 12" apart in the row. An irrigation furrow was placed between the two rows 24" apart. The two rows with a common irrigation furrow made up one plot. The plots were thus each three feet wide and fifty feet in length.

There were eleven treatments and four replications of each treatment. Two hundred pounds of ammonium nitrate per acre was drilled on each plot except those receiving nitrogen from a liquid source. Some treatments of the liquid fertilizers were applied with an applicator mounted on a tractor. The applicator was so designed as to place the fertilizers in drilled concentrated bands comparable to drilled treble superphosphate. An application of liquid fertilizers was also made in the irrigation water. The water containing the liquid fertilizers was not allowed to run beyond the plot so treated. This was accomplished by turning the irrigation water out of the furrow as soon as it had reached the bottom. The stream was turned back into the furrow as soon as the water containing the fertilizer had soaked into the ground.

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* The sugar beet experiments were conducted in cooperation with Dr. J. L. Hadock of the United States Department of Agriculture, Bureau of Plant Industry, Soils and Agricultural Industry.

Samples of leaf petioles of the near mature beets were taken September 3, 1947, for chemical analysis. The total weight of the sugar beets and tops produced were determined for each plot when harvested October 18, 1947. Samples for sugar content were also taken. Due to a refrigeration mishap which damaged the samples the results for sugar content are not considered reliable.

Greenhouse Experiments

Soils used in the greenhouse

Greenhouse experiments were conducted during the winter of 1947-48 to determine the effect of dilution of the liquid phosphoric acid on its value as a fertilizer.

The soils used in the greenhouse were obtained from Price, Petersboro, Farmington, and North Ogden. The soils from Price and Petersboro were obtained from the same farm and a proximity of the alfalfa experiments described above. The soil from Farmington was obtained from the same farm but not in a proximity of the alfalfa experiment.

The four lots of soil used in the greenhouse were first allowed to dry on a cement floor after which they were screened. The screen was of a heavy wire mesh (four mesh per square inch) and did not break the soil into fine particles. After screening, the soil was placed in the pots in which the plants were to be grown. The same amount of soil was placed in each of the thirty-three pots containing any one soil.

The pots were arranged on tables in the greenhouse according to replications. All pots of number one replication of all four soils were placed on number one table. All the pots of number two replication were placed on the second table, and those of the third replication on a third table. The pots of any one soil were placed in a single row and randomized within the row. Thus, there were four rows, each of one soil on each table.

<u>Fertilizer treatments</u>

There were eleven treatments and three replications of these treatments for each separate soil lot. The treatments consisted of two different rates of liquid phosphoric acid and four different dilutions of each rate. Equivalent rates of treble superphosphate mixed with the top third of the soil in the pot were also used. The liquid fertilizer was applied to the surface of the soil. After application of the phosphoric acid in the various dilutions, enough water was applied to make the same total amount of water applied for all treatments of any one soil.

<u>Crops grown in the greenhouse</u>

After the fertilizer treatment, tomato seeds were planted in the pots and thinned to five or six plants per pot. The plants were watered as needed. After six to nine weeks of growth the plants were harvested. All pots of any one soil lot were treated alike in respect to the number of plants per pot and the length of time the plants were allowed to grow. The green and dry weights of the plant material harvested were determined.

After the harvest of the tomato plants the pots were replanted to alfalfa. There was no additional fertilizer added. The alfalfa plants were thinned to about twenty plants per pot. Although the number of plants for each pot was not uniform, it was necessary for the soil of each pot to supply nutrients to the plants at its maximum capability. The alfalfa crop was managed in a manner similar to that used in handling the tomato crop.

Laboratory Analyses

A sample of the alfalfa from each plot and one from each crop grown in the field was taken to the laboratory for chemical analysis. The samples were first dried in the oven, then ground in a mill and thoroughly mixed. A two gram sample was digested in nitric and perchloric acid and subsequently total phosphorus was determined. The phosphorus content was determined by the ammonium molybdate colormetric method. The procedure suggested by Allen (1), in which amydol (2,4-diaminophenol dihydrochloride) is used as the reducing agent, was followed in this determination.

A similar procedure was used for chemical analysis of the forage produced on the pasture. The percent moisture was also determined for the green pasture forage. This latter information was used to calculate the weight of dry plant material produced on the pasture plots.

The total phosphorus was not determined for the plant material grown in the greenhouse. Green and dry weights were determined.

Leaf petioles of the sugar beets were analyzed under the direction of Dr. J. L. Hadock (see foot note, page 11). A small sample of dried plant material was extracted with 0.1 N acetic acid. The extract was filtered and evaporated to dryness. The residue was taken up in distilled water. Phosphorus content was then determined colormetrically. This method is a modification of Ulrick (22).

Soil samples were taken from the field plots at a depth of 0 to 8 inches and also from the mixed soil used in the greenhouse. The results of soil analyses are reported in table 1.

Each of the laboratory determinations were made according to the standard procedures used by the Utah Soils Laboratory of the Soil Conservation Service. They are as follows:

(A) Salt content was determined by the conductivity of the water extract obtained from a saturated soil (18).

(B) Percent lime was determined by neutralizing the carbonates with an excess of standard sulfuric acid and back titrating with standard sodium hydroxide. The method is based on the assumption that the acid used reacted with carbonate in the soil (18, p. 93).

(C) The pH was determined on a paste of the soil using a glass electrode.

(D) Organic matter content was determined by oxidizing with sulfuric acid. The amount of chromate used was determined by adding an excess of standard ferrous ammonium sulfate and back titrating with standard potassium permanganate. This method is a modification of the dichromate-permanganate method of Smith and Weldon (19).

(E) Available phosphorus was determined by the amount of phosphorus present in water after bubbling carbon dioxide gas through a water suspension of a soil sample (11). The phosphorus content of the water extract was determined by the ammonium molybdate method. Stannous chloride was used as the reducing agent in developing color.

Results*

Field Experiments

Alfalfa

The application of phosphorus containing fertilizers gave an increase in the yield of alfalfa, at Petersboro and Price (table 2). The increase was particularly marked at Petersboro. There was also a measureable response in the yield of the plots according to the method and rate of application at these two locations. There was no response to the fertilizer applications at Farmington, although the total production was greater than at the other two locations.

At Petersboro, the first crop yield was benefited most by the broadcast treble superphosphate. The broadcast was only slightly better than the liquid, and no better than the drilled in increasing the yield of the second crop at this location. There was little difference in the yield from the

* The difference in crop response reported in this paper and the conclusions drawn are all based on the statistical analysis of the data collected.

.24 x green wt = cured hay.

Table 2. The influence of phosphoric acid and treble superphosphate on the green forage produced by field grown alfalfa* - 1947

Location and crop	Broadcast: Pounds P_2O_5 86	Broadcast: Pounds P_2O_5 258	Drilled: Pounds P_2O_5 86	Drilled: Pounds P_2O_5 258	Liquid: Pounds P_2O_5 86	Liquid: Pounds P_2O_5 258	Control
	Method of application and rate of P_2O_5 per acre						
Farmington							
First	11.2	11.6	10.4	13.2	10.8	10.6	11.1
Second	9.9	9.3	10.0	9.8	9.6	9.8	9.3
Third	6.7	7.3	6.7	7.0	6.6	6.7	7.0
Mean	9.2	9.4	9.0	10.0	9.0	9.0	9.1
Price							
First	13.8	13.9	11.9	11.9	12.2	10.8	11.4
Second	9.1	9.0	10.3	8.9	9.3	9.8	8.9
Mean	7.6	7.6	7.4	6.9	7.2	6.9	6.8
Petersboro							
First	4.8	4.5	1.9	1.6	2.5	3.0	.8
Second	5.7	5.6	5.4	6.9	4.3	5.9	1.3
Third	2.6	3.2	2.5	3.4	1.6	2.9	.4
Mean	4.4	4.4	3.3	4.0	2.8	3.9	.8
Petersboro							
First (1948)	5.3	5.8	4.9	6.0	4.6	5.9	1.5

? means.

Mean difference necessary for significance:	.05	.01
Farmington	n.s.	n.s.
Price	.9	1.4
Petersboro (1947)	.6	.9
Petersboro (1948)	.9	1.2

*The yield is expressed as ton per acre and is an average of three replications at each location.

Note
Red figures of no value

Analysis of variance for each location in table 2.

Farmington (1947)

Source	Degrees of Freedom	Mean Square
Treatments	6	.78
Replications	2	.34
Error (a)	12	.52
Crops	2	72.43**
Crops x treatment	12	.62
Errors (b)	28	.21
Total	62	2.74

Price (1947)

Source	Degrees of Freedom	Mean Square
Treatments	6	1.19*
Replications	2	3.58**
Error (a)	12	.36
Crops	1	63.10**
Crops x treatment	6	2.19**
Error (b)	13	.36
Total	40	2.49

Petersboro (1947)

Source	Degrees of Freedom	Mean Square
Treatments	6	6.29**
Replications	2	.63
Error (a)	12	.25
Crops	2	30.02**
Crops x treatment	12	1.90
Error (b)	28	.26
Total	62	2.49

Petersboro (1948)

Source	Degrees of Freedom	Mean Square
Treatments	6	4.98**
Replications	2	.25
Error	12	.13
Total	20	1.60

several plots receiving phosphorus in the third crop.

The plots at Price followed somewhat the same order of response as did those at Petersboro.

The response of yield to the several treatments at all locations may be summarized as follows: The total yield of comparable plots treated with liquid phosphoric acid was never greater and often less than those plots treated with treble superphosphate. Broadcast treble superphosphate induced a greater total yield than did drilled or the liquid form of fertilizer.

On those plots which showed a response to the form of fertilizer, the dry form always gave a higher percent of phosphorus in the plant than did the liquid (table 3). There was also a greater phosphorus percentage in the alfalfa grown on the plots receiving the highest rate of fertilizer.

At Petersboro the phosphorus content of alfalfa was higher on those plots which were drilled than on those which were broadcast. The analysis of the plant material produced at Farmington indicated that the phosphorus content was the highest on those plots which received broadcast fertilizer, lowest on those which received phosphoric acid, and intermediate on those which received drilled fertilizer. There were no differences attributed to method of fertilizer application, in the phosphorus content of the plant material produced at Price.

The total phosphorus uptake for all locations was greatest on those plots which were broadcast. This method of application

Table 3. The influence of phosphoric acid and treble superphosphate on the phosphorus content of field grown alfalfa - 1947*

Location and crop	Method of application and rate of P_2O_5 per acre						
	Broadcast		Drilled		Liquid		Control
	Pounds P_2O_5 86	258	Pounds P_2O_5 86	258	Pounds P_2O_5 86	258	
Farmington							
Second	.288	.286	.271	.285	.270	.271	.253
Third	.280	.288	.253	.265	.261	.238	.252
Mean	.284	.287	.263	.275	.265	.255	.253
Price							
First	.149	.167	.143	.163	.162	.183	.147
Second	.216	.213	.205	.213	.219	.220	.189
Mean	.182	.190	.174	.188	.191	.201	.168
Petersboro							
First	.218	.211	.215	.228	.200	.217	.150
Second	.174	.175	.191	.191	.172	.184	.118
Third	.138	.159	.177	.204	.137	.159	.125
Mean	.177	.182	.194	.208	.170	.187	.130
Petersboro							
First (1948)	.165	.192	.169	.157	.159	.176	.138

Mean difference necessary for significance:	.05	.01
Farmington	n.s.	n.s.
Price	.018	.025
Petersboro (1947)	.017	.024
Petersboro (1948)	.017	.026

*The phosphorus content is expressed as percent phosphorus and is an average of three replications at each location.

Analysis of variance for each location in table 3.

Farmington (1947)

Source	Degrees of Freedom	Mean Square
Treatments	6	.001102
Replications	2	.00015
Error (a)	12	.000583
Crops	1	.001511**
Crops x treatment	6	.000205
Error (b)	13	.000110
Total	41	.00044

Price (1947)

Source	Degrees of Freedom	Mean Square
Treatments	6	.000770*
Replications	2	.000739
Error (a)	12	.000205
Crops	1	.028184**
Crops x treatment	6	.000179
Error (b)	13	.000427
Total	40	.001084

Petersboro (1947)

Source	Degrees of Freedom	Mean Square
Treatments	6	.005359**
Replications	2	.000287
Error (a)	12	.000276
Crops	2	.012886**
Crops x treatment	12	.000435
Error (b)	28	.000308
Total	62	.001220

Petersboro (1948)

Source	Degrees of Freedom	Mean Square
Treatments	6	.001047**
Replications	2	.000096
Error	12	.000088
Total	20	.000376

gave a greater uptake or an uptake equal to the other methods of application on all soils. There was very little difference between the drilled treble superphosphate and the liquid form of fertilizer as far as total uptake was concerned.

Pasture

The perennial pasture at North Logan was treated with nitrogen fertilizer, and mixed fertilizer as well as the fertilizer containing phosphorus. The treatments and yield are given in table 4. The treble superphosphate induced greater yields for the three crops (total and also each crop individually) than equivalent amounts of phosphoric acid. This was also true when a nitrogen fertilizer was added to each form of phosphate fertilizer.

There were no measureable differences as indicated by the response in plant growth among the mixed fertilizers in the liquid or the dry form.

The phosphorus content of the plant material from the several plots did not differ materially, except that there was a greater percentage of phosphorus in the plant as the season progressed (table 5). It should be noted also that the second crop yielded the largest amount of forage and the third crop the least.

Sugar beet

Fertilizer treatment had no effect on the yield of tops and roots in the experiment with sugar beets (table 6). In general, the form of fertilizer, liquid or dry, had no effect on the

Table 4. The influence of liquid and dry fertilizers on the average yields of oven dry forage and phosphorus content on the pasture at North Logan - 1947

Treatment	Average* tons per acre of oven dry forage			
	1st crop	2nd crop	3rd crop	Mean
1. Control	.60	.99	.58	.72
2. Ammonium Nitrate 200 lbs. per acre (N_1)	1.07	1.14	.57	.93
3. Treble superphosphate (P_1) 200 lbs. per acre	.78	1.06	.55	.80
4. Phosphoric acid (A_1) 165 lbs. per acre	.55	.87	.56	.66
5. ~~Treatment No. 2 plus No. 3~~ $N_1 + P_1$	1.46	1.29	.57	1.11
6. ~~Treatment No. 2 plus No. 4~~ $N_1 + A_1$	1.05	1.22	.52	.93
7. Liquid fertilizer 15-8-4 12 gal./acre	.75	.99	.56	.77
8. Dry fertilizer Equiv. No. 7	.85	1.08	.56	.83
9. Liquid fertilizer 10-10-5 12 gal./acre	.70	1.05	.64	.80
10. Dry fertilizer Equiv. to No. 9	.64	.98	.60	.74
L. S. D. .05				.15
.01				.20

*Average of three replications.

Analysis of Variance

Source	Degrees of Freedom	Mean Square
Treatment	9	.3444**
Replication	2	.04859
Error (a)	18	.05220
Crops	2	4.2038**
Crop x treatment	18	.14690**
Error (b)	40	.05139
Total	89	.19373

Table 5. The influence of liquid and dry fertilizers on the phosphorus content of dry pasture forage at North Logan - 1947

Treatment	Average* percent phosphorus			
	1st crop	2nd crop	3rd crop	Mean
1. Control	.259	.252	.293	.268
2. Ammonium Nitrate 200 lbs. per acre	.245	.272	.330	.271
3. Treble superphosphate 200 lbs. per acre	.268	.298	.266	.277
4. Phosphoric acid 165 lbs. per acre	.269	.286	.313	.290
5. Treatment No. 2 plus No. 3	.248	.276	.299	.276
6. Treatment No. 2 plus No. 4	.258	.260	.291	.270
7. Liquid fertilizer 15-8-4 12 gal./acre	.260	.256	.297	.271
8. Dry fertilizer Equiv. to No. 7	.242	.238	.297	.260
9. Liquid fertilizer 10-10-5 12 gal./acre	.239	.272	.328	.280
10. Dry fertilizer Equiv. to No. 9	.246	.272	.307	.275

*Average of three replications. There was no statistical difference between treatments.

Analysis of Variance

Source	Degrees of Freedom	Mean Square
Treatment	9	.000819
Replication	2	.000954
Error (a)	18	.0002173
Crops	2	.018063**
Crop x treatment	18	.000845
Error (b)	40	.000553
Total	89	.00133

Table 6. The effect of type of fertilizer and method of application on sugar beets at Garland - ~~1947~~

Fertilizer and method of application*	Phosphorus in petiole (percent)	Tons per acre of green tops	Tons per acre of sugar beets
Applicator			
1. Phosphoric acid (165 lbs./acre)	.083	16	30
2. Phosphoric acid (495 lbs./acre)	.104	15	31
3. Liquid 10-10-5 (15 gal./acre)	.082	15	27
Drilled			
4. Treble superphosphate (200 lbs./acre)	.105	16	27
5. Treble superphosphate (600 lbs./acre)	.140	17	33
6. No. 4 plus potassium chloride (100 lbs./A.)	.109	18	28
7. No. 6 plus minor elements	.092	18	30
Irrigation Water			
8. Phosphoric acid (165 lbs./acre)	.104	15	30
9. Phosphoric acid (495 lbs./acre)	.147	16	32
10. Liquid 10-10-5 (15 gal./acre)	.060	15	27
11. Control	.076	16	29
L. S. D. .05	.033	N.S.	N.S.
.01	.044		

*Ammonium nitrate was applied at the rate of 200 lbs. per acre to all plots not receiving nitrogen from a liquid source.

phosphorus content of the leaf petiole. Chemical composition of sugar beet petioles was similar for all high application rates of treble superphosphate and liquid phosphoric acid in irrigation water. Both methods of phosphate application gave a greater phosphorus content than all other treatments including the high rate of phosphoric acid in the irrigation water. Both methods of phosphate application resulted in a greater phosphorus content of leaf petioles than all other treatments including the high rate of phosphoric acid applied by the applicator. The phosphorus content of the leaf petiole taken from beets on the upper part of the lower part of the plots was the same where the phosphoric acid was applied in the irrigation water.

Greenhouse Experiments

The yields of the tomato and alfalfa crops grown in the greenhouse responded similarly. The application of phosphorus to the soils resulted in a definite response in the growth of the plants. The response was greater for the tomatoe crop. The plants growing in the soil not receiving phosphorus could easily be detected by phosphorus deficiency symptons. The heavier rate of application of fertilizer consistently gave the largest plant yield.

In the greenhouse experiments, there was no discernible effect due to diluting the phosphoric acid. The treble superphosphate mixed with the soil gave a lower yield than equivalent amounts of liquid phosphoric acid. This effect was especially true with the Petersboro soil (see table 7).

Table 7. The effect of dilution of commercial phosphoric acid on its value as a fertilizer in pot experiments

Dilution - surface inches of water	Lbs. P_2O_5 per acre	North Ogden	Farm-ington	Price	Peters-boro	Mean
Alfalfa Crop*						
Concentrated	86	13.8	16.1	12.9	16.4	14.8
	258	16.9	16.8	13.8	18.8	16.6
1 inch	86	15.2	15.5	12.2	17.5	15.1
	258	17.9	18.0	14.8	21.5	18.0
3-5 inches	86	16.3	16.7	11.9	15.2	15.0
	258	17.1	15.0	15.2	19.6	16.7
Treble superphosphate (dry)	86	15.4	15.0	16.3	14.8	15.4
	258	17.7	16.8	13.5	15.9	16.0
Control		17.1	15.9	12.6	9.8	13.9
Mean difference necessary for significance:				.05		1.9
				.01		2.6
Tomatoe Crop*						
Concentrated	86	5.1	4.9	6.5	5.4	5.5
	258	6.2	5.4	5.8	5.8	6.1
1 inch	86	4.5	3.7	5.7	5.0	4.8
	258	5.4	4.3	5.8	7.7	5.8
2-3 inches	86	5.4	3.3	7.4	6.0	5.5
	258	5.8	4.2	5.6	6.9	5.6
3-5 inches	86	4.5	3.5	6.0	4.4	4.6
	258	4.5	5.9	9.6	5.8	6.7
Treble superphosphate (dry)	86	4.3	4.4	7.8	2.9	4.9
	258	4.6	5.0	6.2	4.4	5.1
Control		2.4	1.3	2.1	1.4	1.8
Mean difference necessary for significance:				.05		1.0
				.01		1.3

*Yield of dry plant material expressed as grams per pot.

Analysis of variance for table 7.

Alfalfa Crop

Source	Degrees of Freedom		Mean Square
Soils	3		52.25**
Replications	2		181.70
Error (a)	6		2.978
Treatments	10		18.481**
Rate		1	86.18**
Method		4	8.30
Rate x method		4	4.338
P_2O_5 vs. check		1	56.09**
Treatment x soils	30		8.43
Rate		3	4.31
Method		12	6.158
Rate x method		12	4.12
P_2O_5 vs. check		3	38.88**
Error (b)	80		5.615
Total	131		10.88

Tomato Crop

Source	Degrees of Freedom		Mean Square
Soils	3		18.91*
Replications	2		10.59
Error (a)	6		2.94
Treatments	10		19.73**
Rate		1	13.152**
Method		4	2.59
Rate x method		4	3.99*
P_2O_5 vs. check		1	147.60**
Treatment x soils	30		3.005**
Rate		3	3.75
Method		12	4.31**
Rate x method		12	1.76
P_2O_5 vs. check		3	1.88
Error (b)	80		1.472
Total	131		3.93

Discussion

Field Experiments

Phosphate fertilizers applied in concentrated bands beneath the soil surface are generally considered to give better response than those applied to the soil surface. According to the alfalfa field experiments reported in this paper band applications were never better than, although in some instances they did equal, broadcast applications. The advantage of the broadcast fertilizer is particularly marked in the first crop of the year.

The crop responses to the several treatments may be interpreted as follows. Root injury due to the mechanics of drilling "set back" the growth of the plants on the drilled plots. This resulted in a smaller yield in the first crop. Later in the year this set back was overcome, and the yield of the drilled plots equalled the yield of those plots which were broadcast. Such as interpretation may account for a portion, but not all, of the differences obtained in yield by the two methods of application.

The plots treated with liquid phosphoric acid very often gave yields which were smaller than those obtained by the use of treble superphosphate. There was visible evidence that high rate of liquid phosphoric acid slightly "burned" some of the alfalfa grown on the plots so treated at Price. But the decrease in yield, due to the slight burning, would have very little effect on total production. It is, therefore, concluded that the liquid phosphoric acid is no better than treble superphosphate in this experiment (and usually not as good).

The results obtained on the perennial pasture experiment indicates that the broadcast treble superphosphate is superior to phosphoric acid. The treble superphosphate resulted in a greater yield but there was very little difference in the phosphorus content of the forage. There was no such advantage of the dry form of mixed fertilizers in comparison with the liquid form. Although the experiment with mixed fertilizer is limited, it is evident that the liquid form does not have the advantage that some theories imply.

One of the major factors against the application of liquid fertilizers in irrigation water is distribution of the water bearing fertilizers. When irrigation water is applied to row crops distribution may not be much of a problem. It is indicated by the phosphorus content of leaf petioles in the sugar beet experiment that the liquid is distributed throughout the row. The information from this one experiment is very limited and is not sufficient to form a general conclusion.

The yield of sugar beets did not show a response to the fertilizer applications.

Greenhouse Experiments

According to the greenhouse experiments, dilution had no effect on the value of phosphoric acid. It may be pointed out that the dilutions used in the experiment reported in this paper, were greater than those used by MacIntire and associates (8). The greater dilution approximated dilution in an irrigation stream. Regardless of dilution, the conclusions are in agreement with those made by the above named authors.

The phosphoric acid applied to the soil surface was superior to equivalent amounts of treble superphosphate mixed with the soil in the greenhouse experiment. It is likely that complete mixing of the treble superphosphate with the soil in the pot increased the amount of fixation.

Summary

Studies were conducted during 1947 and 1948 on the comparative value of commercial phosphoric acid as a fertilizer. There is a lack of experimental evidence to support the advantages maintained for liquid fertilizers.

Commercial phosphoric acid (52 percent P_2O_5) is an intermediate product in the manufacture of treble superphosphate.

On fields producing forage crops diluted phosphoric acid applied to the soil surface was compared to equivalent amounts of broadcast and drilled treble superphosphate. On a field producing sugar beets a limited study was made on the application of phosphoric acid in "bands" and in irrigation water.

Greenhouse experiments were conducted to determine the effect of dilution on the value of the acid as a fertilizer. There were no measureable effects due to the dilution of the phosphoric acid.

The yield and phosphorus content of the plant material produced on the field plots treated with phosphoric acid were never greater, and very often less, than comparative plots treated with treble superphosphate.

From these experiments it is concluded that commercial phosphoric acid is no better and often inferior to treble superphosphate as a fertilizer. It is also concluded that dilution of the acid, such as applying in an irrigation stream, should not alter its fertilizer value. unless there be something in the water to ppt the phosphate.

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