Utilization of Phosphorus From Various Fertilizer Materials By Sugar Beets in Colorado[1]

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Many questions remain unanswered regarding the relative availability of various phosphate fertilizers on calcareous soils. Results on acid soils are not necessarily applicable to the irrigated soils of the West. Although a number of experiments comparing source of phosphorus have been conducted on calcareous soils, the results obtained vary with location and are neither conclusive nor unanimous on the relative availability of the various fertilizers (3, 6, 9, 11, 12)[2]. The introduction of the radioactive tracer technique to field experimentation with phosphate fertilizers provides a more accurate method for comparing the availability of various fertilizer materials (1, 10, 13). In a single season, the radioactive method supplies considerably more information on the availability of the fertilizer than can be obtained by the usual yield measurements.

The effect of source of phosphorus, placement, rate, and time of application on the utilization of phosphorus by sugar beets and its movement in the soil are reported in this paper. A more comprehensive report including other crops may be found elsewhere (8).

MATERIALS AND METHODS

The radioactive fertilizers used in 1948 are described by Hill, et al. (2), and those used in 1949 were prepared in a similar manner[3]. These were applied with a four-row belt-type distributor mounted on a tractor specially designed for using radioactive materials. The activity of the fertilizers at the time of application was about 0.1 millcurie per gram of P_2O_5.

Plant assays[4] for P^{32} and P^{31} were made according to described procedures (4, 5).

Detailed descriptions of the two experiments conducted in 1948 were presented previously (7).

Three new materials were added in the 1949 experiments: ammonium phosphate (11-48-0), treble superphosphate, and liquid phosphoric acid. Both 1949 experiments were conducted on the Fort Collins loam (Agronomy Farm) described previously (7). Four materials were included in one ex-

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[2] Numbers in parentheses refer to literature cited.

[3] The preparation and distribution of the fertilizer materials containing P^{32} was accomplished by W. E. Hill, E. J. Fox, S. B. Hendricks, and L. A. Dean at the Plant Industry Station, Beltsville, Md. All radioactive phosphorus was supplied by the Atomic Energy Commission.

[4] Assays for P^{31} and P^{32} in 1948 were made in the laboratories of the North Carolina Agricultural Experiment Station under the supervision of N. S. Hall and A. J. MacKenzie.

periment. The materials were ammonium phosphate, superphosphate (20%), calcium metaphosphate, and alpha tricalcium phosphate. All were tested at two placements; and one, the superphosphate, at two rates. The placements were (a) phosphorus mixed with a rototiller in a band 4 inches wide and 4 inches deep, and (b) phosphorus placed in a single band 4 inches deep and 4 inches to one side of the row (the same as in 1948). Phosphorus was applied at the rate of 40 pounds of P_2O_5 per acre and nitrogen at 80 pounds N per acre. One superphosphate plot per replication received 80 pounds of P_2O_5 per acre. There were three replications for each placement. Each plot was 8 rows wide and 64 feet long. Three rows 32 feet long received radioactive fertilizer. These plots were irrigated July 5, August 5 and August 31.

Another experiment was conducted to compare treble superphosphate applied at planting time and on June 29 with liquid phosphoric acid applied June 29. Phosphorus was applied at the rate of 80 pounds of P_2O_5 per acre and nitrogen at 80 pounds N per acre. The dry fertilizer was placed in a band 4 inches deep and 4 inches to one side of the row at planting time and 4 to 5 inches deep and 6 inches to one side of the row on June 29.

The liquid phosphoric acid was applied in the irrigation water as follows: The acid was mixed with water in 10-gallon milk cans placed on a truck and applied to the furrow through a faucet and garden hose to 8-foot sections of the row. The water was applied at the rate of one inch per acre. The cans were filled with water by a hose from the municipal water supply. All plots received a normal irrigation the following day. Two rows 32 feet long received radioactive phosphate (3 furrows in the case of H_3PO_4), while the remaining rows received ordinary phosphate at the same rate. The radiophosphorus was added to each can as a solution of radioactive KH_2PO_4. There were 8 rows per plot 64 feet long and 6 replications. These plots were irrigated on June 30, July 28, and August 24.

Dates of field operations are shown in Table 1.

Table 1.—Dates of field operations.

Locations	Date of Planting	Sampling Date[1] 1	2	3	4	5
		Sugar beets (dry fertilizer)				
Agronomy Farm, 1948	April 21	May 28	June 24	Aug. 2	Sept. 13	.....
Agronomy Farm, 1949	April 22	June 10	July 1	Aug. 10	Sept. 8	.....
Hoffman Farm, 1948	April 27	May 29	June 30	Aug. 10	Sept. 14	.....
		Sugar beets (liquid vs. dry)				
Agronomy Farm, 1949	May 2	July 7	Aug. 1	Aug. 22	Sept. 14	Oct. 10

[1] The sampling dates correspond to the following stages of growth:
Sugar beets (dry fertilizer):
1. Thinning time.
2. Beginning of grand period of growth.
3. Middle of grand period of growth.
4. Near harvest time.
Sugar beets (liquid vs. dry):
1. One week after liquid H_3PO_4 was applied.
2, 3, 4. Intermediate stages.
5. Harvest time.

MOVEMENT OF APPLIED PHOSPHORUS

The movement of the radiophosphorus in the fertilizer can be followed readily by measuring the activity of the soil itself. Successive samples were taken July 23 from the bottom of the irrigation furrow to a depth of 18 inches on the sugar beet plots receiving liquid phosphoric acid.

Liquid phosphoric acid containing radiophosphorus was also applied at 80 pounds P_2O_5 per acre to fallow land in 8-foot sections of furrows similar

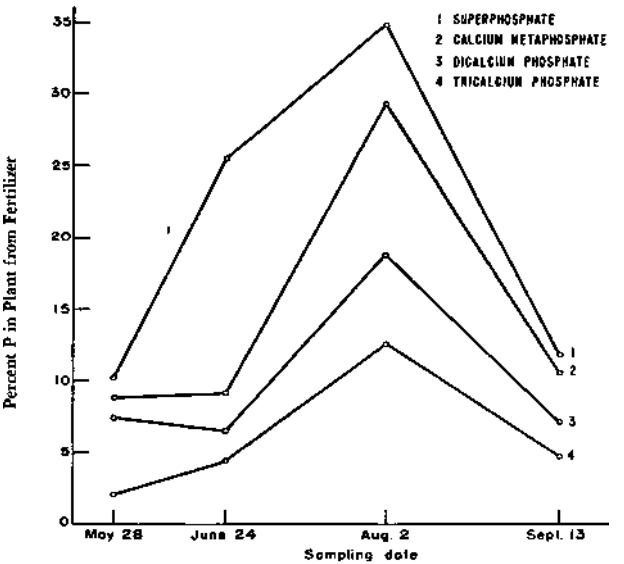


Figure 1. Percentage of Phosphorus Derived from Fertilizer as Affected by Source of Phosphorus on Fort Collins Loam (1948).

to those used on sugar beets. The fertilizer was mixed with a volume of water equal to irrigation rates of one-third, one, and three inches of water per acre to determine the effect of dilution on movement. This was followed

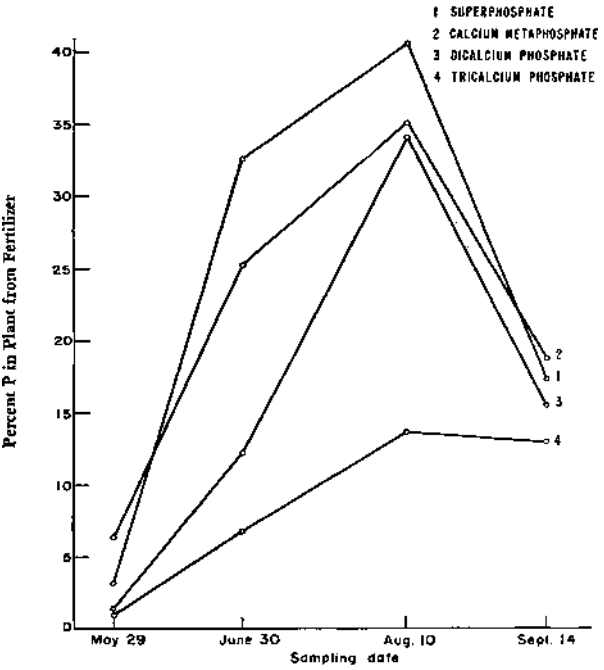
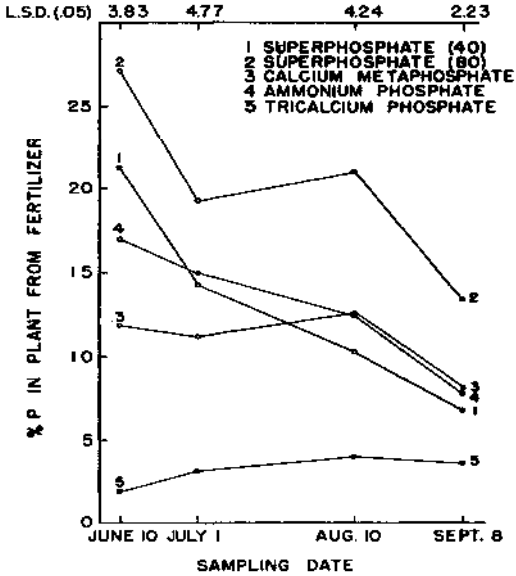


Figure 2. Percentage of Phosphorus in Sugar Beets Derived from Fertilizer as Affected by Source of Phosphorus on Cass Fine Sandy Loam (1948).

by the application of water necessary to give a total of three inches of water in each case. Horizontal as well as vertical movement was determined by measuring the activity in soil samples taken between the furrows.

Movement of phosphorus from the band-placed dry fertilizer was determined by measuring the activity from successive samples beneath the band. All samples were taken with a rectangular sampling tool 1 inch wide, 1 inch deep, and 3 inches long. The soil was sampled parallel to the band.



PERCENTAGE OF PHOSPHORUS DERIVED FROM FERTILIZER BY SUGAR BEETS AS AFFECTED BY SOURCE OF PHOSPHORUS ON FORT COLLINS LOAM

Figure 3.

The activity of all samples was determined as follows: Five grams of soil were spread evenly in a flat container 34 mm in diameter **and** 5 mm deep. The soil was tamped gently with a 100-gm. weight to give **uniform** geometry, and the activity determined with an end-window Geiger tube. Absolute amounts of fertilizer phosphorus in each sample were determined by making comparisons with the activity of a 5-gm. sample containing a known amount of radioactive phosphorus fertilizer.

RESULTS AND DISCUSSION

Percentage of Phosphorus in Plant Derived from the Fertilizer

The results for 1948 are shown in Figures 1 and 2 and for 1949 *in* Figure 3. At all locations and sampling dates, the absorption of phosphorus from alpha tricalcium phosphate was the least. Superphosphate supplied more phosphorus to the plants than calcium metaphosphate in the early stages of growth and more than dicalcium phosphate at all sampling periods.

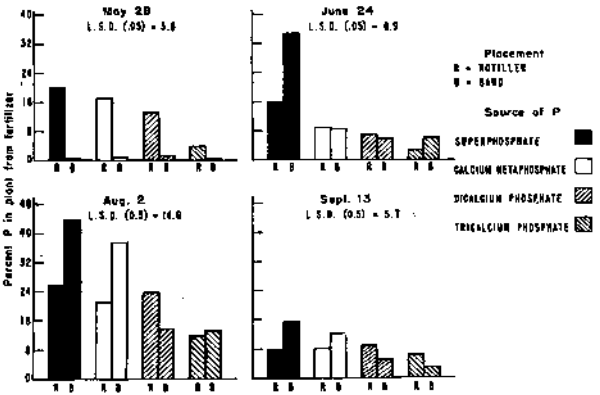


Figure 4. Effect of Placement and Source of Phosphorus on Percentage of Phosphorus in Sugar Beets Derived from Fertilizer on Fort Collins Loam (1948).

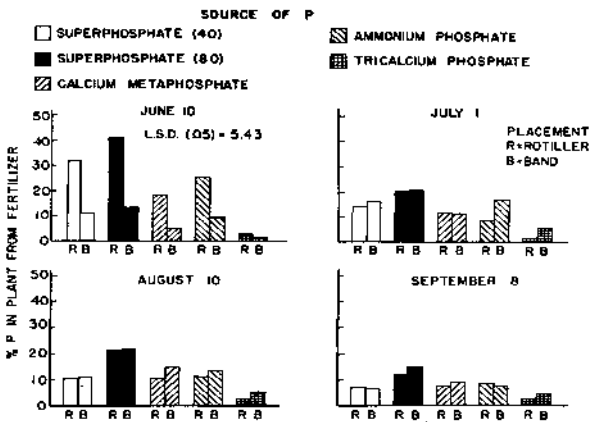
The plants absorbed less phosphorus from ammonium phosphate than from superphosphate the first sampling, but about equal amounts were absorbed from these two fertilizers thereafter.

The uptake of phosphorus from the 80-pound rate of superphosphate was approximately twice as much as from the 40-pound rate for the last two sampling periods. This difference, however, was not reflected in the final yield of beets.

Comparing the results for both years, there is a marked difference in the shape of the curves showing uptake of phosphorus, which is due probably to differences in the amount of rainfall each year. In 1948, only 4.04 inches of rain fell in May and June, whereas 9.31 inches occurred in 1949. Although the first sampling dates are not the same each year, the relative stages of growth are comparable. When the surface four inches of the soil were kept moist almost continuously by the high rainfall in 1949, the plants absorbed

considerably more phosphorus from the fertilizer than in 1948 when the surface soil was usually dry.

After irrigation in 1948, the root activity in the surface four inches of the soil probably was stimulated, causing a pronounced increase in the uptake of phosphorus from the fertilizer. The effect of irrigation in 1949 was not noticeable, since the plants had been well supplied with water all through the early stages of growth. The downward slope of the curves



EFFECT OF PLACEMENT AND SOURCE OF PHOSPHORUS ON PERCENTAGE OF PHOSPHORUS IN SUGAR BEETS DERIVED FROM FERTILIZER ON FORT COLLINS LOAM

Figure 5.

showing uptake of phosphorus with stage of growth (Figure 3) appears to be quite typical when the crop is well supplied with water. As the root system extends throughout the soil, the roots absorb relatively more phosphorus from the soil than from the fertilizers, although this effect probably is due, in part, also to the conversion of the water-soluble phosphorus in the fertilizer to less available forms.

Comparing the uptake of phosphorus from superphosphate and calcium metaphosphate (Figures 1, 2, and 3) , it appears that the latter is less available in the early stages of growth, but equal to superphosphate at later growth periods. Possibly the calcium metaphosphate must be hydrolyzed to the orthophosphate before it can be utilized by the plants. The rate of hydrolysis would probably be slower if the soil moisture content were low, i.e., after

Table 2.—Total uptake of phosphorus from the soil, from the fertilizers, and the percentage utilization of the applied phosphorus at the final sampling.

Fertilizer	P_2O_5 applied lbs./A.	P_2O_5 in plants from fertilizer, lbs./A. Sampling, days after planting				P_2O_5 in plants from soil, lbs./A. Sampling, days after planting				Percentage of fertilizer P_2O_5 used
		49	70	110	139	49	70	110	139	
None		.....	.....	.....	.....	0.18	2.60	25.7	45.2	.....
Superphosphate	40	0.059	0.45	3.02	3.90	0.23	2.83	26.7	44.9	9.75
Superphosphate	80	0.087	0.73	7.16	8.70	0.25	3.20	27.2	47.3	10.8
Calcium metaphosphate	40	0.030	0.35	3.61	4.87	0.24	2.89	25.5	45.2	12.2
Ammonium phosphate	40	0.043	0.48	3.65	4.85	0.20	2.77	26.5	45.5	12.1
Alpha tricalcium phosphate	40	0.005	0.10	1.11	2.08	0.26	3.35	28.8	46.7	5.20
L.S.D. (0.05)		0.010	0.15	1.18	1.88	0.06	N.S.[1]	N.S.	N.S.	.....
C.V.[2]		19.5	24.2	26.2	31.9	21.7	17.0	12.2	8.58	.....

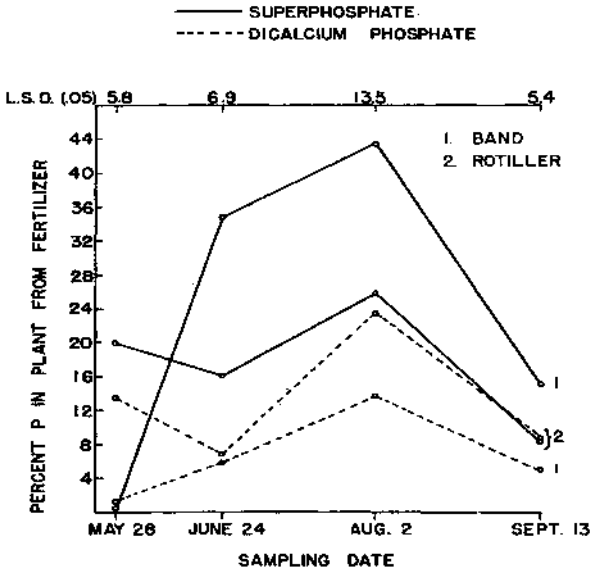
[1] N.S. = not significant.
[2] C.V. = coefficient of variation.

June 24 (Figure 1) the plots were irrigated and the uptake from calcium metaphosphate greatly increased.

Effect of Placement on the Uptake of Phosphorus from the Fertilizers

The uptake of phosphorus from each fertilizer and placement is shown in Figures 4 and 5. The seeds were planted in the rototiller band. Therefore, the roots could contact the fertilizer from the beginning of growth. At thinning time it appears that the roots had not penetrated to the locality of the concentrated band in 1948, although some uptake had occurred in 1949. This comparison of early uptake from the fertilizer may be important on soils low in available phosphorus when the need in early stages of growth is large. In such cases, these data suggest the advisability of placing at least part of the phosphate near the seed.

The effect of placement on uptake of phosphorus varies with the source of phosphorus and with season. In a dry year (1948), the absorption of phosphorus from superphosphate and calcium metaphosphate is much higher from the band than from the rototiller placement, whereas placement has little effect on either dicalcium phosphate or alpha tricalcium phosphate (Figure 6). In a wet year (1949), the effect of placement at thinning time was the same is in 1948, but afterward placement did not affect appreciably the uptake from any of the fertilizers. These results indicate that when comparisons of fertilizer materials or placement are being studied, the moisture status in the surface 4 to 5 inches of soil is a very important factor. It seems probable that when the fertilizer is placed in the top 4 to 5 inches of soil, the effect of moisture will be dependent for the most part upon the amount of rainfall, since in either year the plants were well supplied with irrigation water. These relationships between moisture and phosphorus uptake would be modified, however, by the frequency and manner of irrigation, and the depth of placement of the fertilizer.



PERCENTAGE OF PHOSPHORUS DERIVED FROM FERTILIZER BY SUGAR BEETS AS AFFECTED BY PLACEMENT AND SOURCE OF PHOSPHORUS

Figure 6.

Comparison of Liquid Phosphoric Acid and Treble Superphosphate

The percentage of phosphorus in sugar beets derived from the fertilizer as affected by source and time of application is shown in Figure 7. The late application of treble superphosphate supplied about one-half as much phosphorus to the plants as the early application. Except for the first sampling period, the liquid phosphoric acid furnished about the same amounts of phosphorus to the plant as the early application of treble superphosphate. These results indicate that, if late side-dressings of phosphate are to be made, liquid phosphoric acid would be a better source of phosphorus than band-placed treble superphosphate. Application of the phos-

phorus before or at planting time appeared to be the best method, particularly if the plants lacked phosphorus in the early stages of growth.

Yield increases of sugar beets were not significant; the yields ranged from 11.2 to 11.9 tons per acre. Yield of sugar per acre was not affected by the treatments.

Amount of P_2O_5 Absorbed **from** the Fertilizer and from the **Soil**

Total uptake of phosphorus from the soil and from the fertilizer and

Table 3.—Effect of source of phosphorus on yield of sugar beets in tons/acre (1948).

Treatment	Agronomy Farm		Hoffman Farm	
	August 2	October 12	August 10	October 9
None	8.74	19.9	9.48	13.2
Superphosphate	9.68[1]	20.7	9.58	16.7[2]
Calcium metaphosphate	9.83[1]	20.2	9.14	15.1[1]
Dicalcium phosphate	9.46[1]	20.3	8.05	14.9
Alpha tricalcium phosphate	9.17	20.6	8.80	14.1

[1] Significant increase at 5% level compared to check.
[2] Significant increase at 1% level compared to check.

the percentage utilization of the applied phosphorus is shown in Table 2. Except for alpha tricalcium phosphate, the utilization of the applied phosphorus was about the same for all other fertilizers. The crop absorbed 10 to 12 percent of the applied phosphorus. About 9 percent of the liquid phosphoric acid and treble superphosphate applied in a separate experiment was utilized by the sugar beets. At the first sampling date, the amount of phosphorus absorbed from the soil in the fertilized plots was higher than from the check plots.

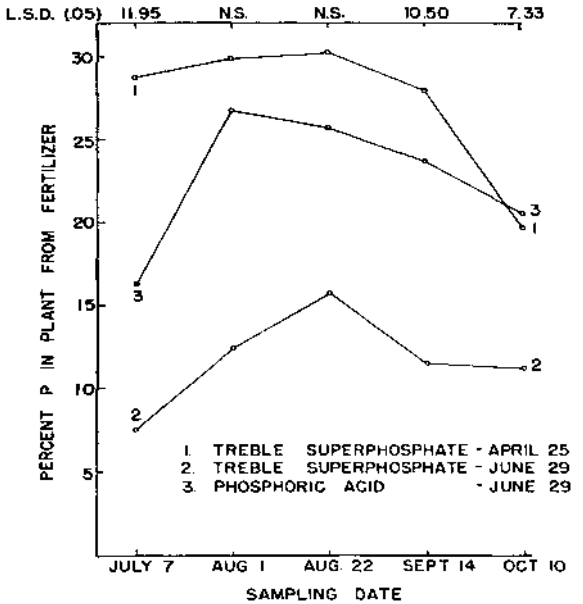
Yields

The differences in the uptake of phosphorus due to source of material and stage of growth should be reflected in yield, unless the plants can obtain their maximum needs for phosphorus from the soil, or if some other growth factor, i.e., moisture or nitrogen, becomes limiting. Moisture tension data were not obtained from these experiments, but each year on the Agronomy Farm a moisture-fertility experiment was conducted adjacent to the radioactive experiment. Irrigations on the radioactive plots were made to correspond with those plots in the moisture-fertility study which received the highest number of irrigations, and were presumably well supplied with

Table 4.—Yield of sugar beets at various stages of growth as affected by source of phosphorus (1949).

Treatment	Sampling Date				
	June 10[3] gms/96' row	June 30 gms/150' row	Aug. 10 Tons/A.	Sept. 8 Tons/A.	Oct. 11 Tons/A.
None	37.1	273	8.18	15.0	17.9
Superphosphate (40)	55.8[2]	334	9.73[2]	16.8	18.5
Superphosphate (80)	64.5[2]	408[2]	9.63[2]	16.8[1]	18.7
Calcium metaphosphate	53.4[1]	336	9.65[2]	16.1	18.4
Ammonium phosphate	47.6	345[1]	9.69[2]	17.0[1]	19.5
Alpha tricalcium phosphate	52.8[1]	389[2]	9.39[1]	15.9	18.8

[1] Significant increase at 5% level compared to check.
[2] Significant increase at 1% level compared to check.
[3] Whole plant sampled.



PERCENTAGE OF PHOSPHORUS DERIVED FROM FERTILIZER BY SUGAR BEETS AS AFFECTED BY SOURCE OF PHOSPHORUS ON FORT COLLINS LOAM

Figure 7.

moisture. Nitrogen was probably not a limiting growth factor on the radioactive plots, as indicated by nitrogen level studies in adjoining experiments and by the color of the leaves.

Yields of sugar beets as affected by source of phosphorus at various stages of growth are shown in Table 3 for 1948, and Table 4 for 1949. On August 2 (Figure 1), when the plants contained the largest amounts of phosphorus from the fertilizer, the yield was increased by those fertilizers furnishing the most phosphorus to the plants on the Agronomy Farm. At harvest time, however, the effect of phosphate fertilizer was not significant.

The yields on the Hoffman farm were affected some by variations in stand, but the final yields showed an increase due to superphosphate and calcium metaphosphate. These two fertilizers also supplied the most phosphorus to the plants.

In Table 4, the yields in 1949 tend to show an increase for all fertilizers in the early stages of growth and up to the middle of the growing season. The final yields, however, were not affected significantly by source of phosphorus. The data *in* Tables 3 and 4, and in Figures 1, 2, and 3 indicate that the same conclusions would be made regarding the availability of

Table 5.—Percentage of phosphoric acid found at various depths applied to surface of of soil (sugar beets).

Depth Inches	Proportion of total P added found at various depths[1]	Depth Inches	Proportion of total P added found at various depths[1]
	percent		percent
0-1	55.0	8-9	1.90
1-2	21.2	9-10	2.23
2-3	6.06	10-11	1.49
3-4	2.97	11-12	0.59
4-5	2.53	12-13	0.41
5-6	1.90	13-14	0.40
6-7	1.41	14-15	0.37
7-8	1.49	15-16	0.11

[1] Each value represents the average of four samples.

the various fertilizers whether or not a yield increase was obtained.

It has been observed commonly that phosphorus affects plant growth most markedly in the early stages of growth. If a soil is on the borderline of deficiency in available phosphorus, the early stimulation of growth may be overcome by the untreated plants after the root systems become well established.

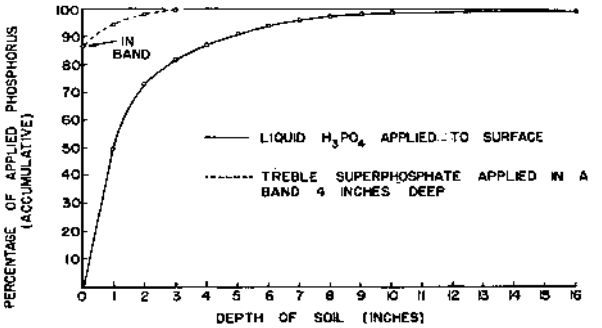
Table 6.—Percentage of total phosphoric acid added found at various depths applied with varying amounts of water (fallow land).

Depth Inches	Acre inches of water applied with H_3PO_4		
	three	one	one-third
	percent[1]	percent[1]	percent[1]
0-1	51.9	49.7	48.5
1-2	21.3	23.4	25.8
2-3	6.40	8.88	8.58
3-4	5.93	5.45	5.31
4-5	4.26	5.89	2.98
5-6	2.84	2.80	2.04
6-7	1.65	2.10	1.79
7-8	0.95	1.48	1.83
8-9	0.95	0.78	1.58
9-10	1.42	0.47	0.89
10-11	1.33	0.47	0.40
11-12	0.57	0.16	0.20
12-13	0.09	0.07	0.10
13-14	0.05	0.07	0.05
14-15	0.05	0.07	0.05
15-16	0.05	0.07	0.05

[1] Each value represents the average of four samples.

Phosphorus Content of Tops

Analysis of the leaves for total phosphorus showed that the phosphorus content was increased over the check plots by superphosphate and calcium metaphosphate at the last three sampling periods on both locations in 1948. The phosphorus content of the leaves varied somewhat with sampling date in 1949. Only the higher rate of superphosphate consistently increased the phosphorus content at all sampling periods. All fertilizers except alpha tricalcium phosphate increased the phosphorus content of the leaves over the check at the last sampling period (September 8) .



MOVEMENT OF PHOSPHORUS APPLIED AS LIQUID PHOSPHORIC ACID AND TREBLE SUPERPHOSPHATE

Figure 8.

The phosphorus content of the leaves was not affected significantly by the application of liquid phosphoric acid or treble superphosphate.

Movement of Phosphorus

The movement of liquid phosphoric acid applied to land in sugar beets and on fallow land is shown in Tables 5 and 6. Movement of phosphorus below twelve inches was very slight (Figure 8) . At least 85 percent of the applied phosphorus was found in the top four inches of the soil. The amount of water applied with the phosphoric acid had little effect on the movement of the phosphorus. The results on the fallow land were essentially the same as where the sugar beets were growing.

Tests were made under both conditions to eliminate possible contamination of the soil samples by the sugar beet roots, since radiophosphorus ab-

sorbed near the surface subsequently could be translocated downward to roots at lower depths. Ulrich, et al. (13) added phosphoric acid containing radiophosphorus to the Aiken loam. The phosphorus penetrated about 12 inches and 75 percent was found in the top four inches of the soil.

The movement of phosphorus from band-placed treble superphosphate (Table 7) was considerably less than from the liquid phosphoric acid. Very little of the treble superphosphate moved beyond three inches. The greater movement of phosphorus from the early application was caused probably by an additional 9.31 inches of rain which fell between May 2 and June 29. The soil samples were taken July 23.

There was no appreciable horizontal movement of the liquid phosphoric acid. Soil samples taken on top of the ridge between furrows, at the center of the ridge, or in the ridge at a position horizontal with the bottom of the furrows showed no radioactivity. The fertilizer would have to move from 4 to 7 inches in order to reach the center of the ridge. When the phosphorus was applied, the furrows were filled with water to about 50 percent of their capacity.

Table 7.—Percentage of total treble superphosphate added found at various depths applied in a band four inches deep.

Depth inches below band	Date of application	
	May 2	June 29
	percent[1]	percent[2]
in band	86.7	95.7
0-1	7.5	2.5
1-2	3.9	1.1
2-3	1.9	0.8

[1] Average of four samples
[2] Average of six samples.

SUMMARY

The effect of source of phosphorus, placement, rate, and time of application on its ultization by sugar beets was studied.

Calcium metaphosphate was less available than superphosphate in the early stages of growth, but about equal thereafter. Ammonium phosphate (11-48-0) and superphosphate were about equally available. Alpha tricalcium phosphate supplied the least amount of phosphorus to the crop at all stages of growth.

Liquid phosphoric applied June 29 was about equal to treble superphosphate applied May 2, but higher than treble superphosphate applied June 29.

Placement of the fertilizer near the seed increased markedly the uptake of phosphorus at thinning time compared to band placement. In later stages of growth, however, the band placement supplied more phosphorus than the rototiller placement in a dry year, and about equal amounts in a wet year.

The crop absorbed 10 to 12 percent of the applied phosphorus, except with alpha tricalcium phosphate.

Phosphorus applied in the irrigation water moved downward at least 12 inches, although 85 percent of the total applied was found in the top

four inches of soil. Phosphorus applied as treble superphosphate in a band four inches deep moved downward about three inches below the band.

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