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ABSTRACT

INTERACTION OF RATE AND METHOD OF FERTILIZER APPLICATION AND SOIL PHOSPHORUS WITH YIELD AND CHEMICAL COMPOSITION OF SUGAR BEETS

by Donald LeRoy Thurlow

Field and greenhouse experiments were conducted over a three year period to study the effect of time and method of application of fertilizer on the growth and chemical composition of sugar beets and to evaluate the change in chemically extractable and available phosphorus on a Kawkawlin-Wisner silty clay loam soil complex. The inorganic phosphorus in ten Michigan soils of the type now in sugar beet production was characterized by the procedure of Chang and Jackson.

The use of four levels of phosphorus plowed down in field studies; 1) increased phosphorus content, phosphorus and calcium uptake, and growth of young sugar beets, 2) increased yield of roots, 3) decreased the calcium content of sugar beet tops and petioles, and 4) had no effect on the sucrose content or apparent purity of extractable sucrose of sugar beets.

The use of three rates of a complete planting time fertilizer at two placements increased phosphorus content and uptake by young sugar beet plants at all plow down phosphorus levels and increased phosphorus content of petioles at low levels of plow down phosphorus. The greatest uptake of phosphorus, calcium and potassium at blocking time and the greatest yield of roots were obtained when the planting time fertilizer was placed three inches directly under the seed.

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The uptake of phosphorus by sugar beets as measured by petiole analysis was influenced by plow down phosphorus and by seasonal variations. These data indicate that the easily extractable phosphorus content should not drop below 0.15 percent phosphorus on the dry weight basis at any time during the growing season. Short-time uptake of phosphorus in the greenhouse by sugar beets was highly correlated with water soluble phosphorus. For longer periods Bray 1 extractable phosphorus, aluminum phosphate, A-values, and water soluble phosphorus were all highly correlated with phosphorus uptake. The Bray 1 extractable phosphorus (26, 44, 73, and 117 pounds per acre) and A-values (28, 57, 176, and 240 pounds per acre) were highly correlated with phosphorus plow down levels (0, 87, 174, and 348, respectively).

The forms of inorganic phosphorus in the ten Michigan soil profiles varied considerably, both within a soil type and between soil types. Bray 1 extractable phosphorus correlated highest with aluminum phosphate, but also correlated with water soluble and iron phosphate. Calcium phosphate showed a negative correlation to Bray 1 extractable phosphorus, aluminum phosphate and iron phosphate.

INTERACTION OF RATE AND METHOD OF FERTILIZER APPLICATION AND SOIL PHOSPHORUS WITH YIELD AND CHEMICAL COMPOSITION OF SUGAR BEETS

By

Donald LeRoy Thurlow

A THESIS

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TO BOBBIE

This thesis is affectionately dedicated to my wife for her constant interest, encouragement and willing sacrifices throughout the duration of these studies.

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CHAPTER I

INTRODUCTION

Yield and quality of agronomic crops result from an integration of basic plant growth factors; namely, light, carbon dioxide, temperature, genetics, water, soil aeration and plant nutrients. As native soil fertility levels are lowered and yield goals are raised, farmers become more dependent upon the fertilizer industry to supply nutrients for plant growth. Nevertheless, only a small percentage of fertilizer-phosphorus applied to the soil is removed by a crop the first year after application.

Sugar beets grown under Michigan climatic and soil conditions have been shown to respond markedly to fertilization. In 1958 there were approximately 77, 300 acres of sugar beets planted in Michigan (14). Approximately 60 percent of these beets received 500 pounds or more of fertilizer per acre as a planting time application.

In addition to causing increases in yield of roots, fertilizers have a marked stimulating effect on the early growth of the young plant. This latter effect appears to be largely from the nutrient element phosphorus. By stimulating the early growth of seedlings, the beets can be blocked and thinned earlier, resulting in a more economical use of labor. However, the use of large amounts of fertilizer at planting time may increase the length of time necessary for planting. Because of seasonal rainfall in Michigan, this may result in considerable delay in planting and subsequent lowering of beet yields.

The objectives of this study were to:

1. determine the interaction of rate and method of phosphorus application on composition and yield of sugar beets, and
2. characterize chemically and biologically the residual effect of heavy soil phosphorus applications.

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CHAPTER II

PLANT GROWTH RELATIONS OF SUGAR BEETS AS AFFECTED BY TIME AND METHOD OF APPLICATION OF PHOSPHATE FERTILIZERS

Review of Literature

Fried and Shapiro (18) stated that phosphorus uptake by plants from a soil system may be divided into four stages: 1) release of phosphorus from solid phase into soil solution, 2) movement of phosphorus as an anion to the root, 3) absorption of the ion by the root, and 4) translocation of phosphorus to the top of the plant. Diagrammatically this may be shown as:

$$\begin{array}{l} \text{P (minerals)} \\ \quad\downarrow\uparrow \\ \text{P (solution)} \rightleftharpoons \text{P (vicinity of root)} \rightarrow \text{P (absorbed)} \rightarrow \text{P (plant top)} \\ \quad\uparrow\downarrow \\ \text{P (absorbed)} \end{array}$$

Many different methods have been devised using a number of solutions to try to characterize the phosphate ion and its mineral character as found under different soil conditions.

Constant renewal of phosphorus in solution at the vicinity of the root hair is an important factor if maximum growth rate is to be maintained. Many workers have studied the effect of fertilizer phosphorus on the yield of sugar beets with varying conclusions. Nelson (35) conducted experiments on the yield of sugar beets at four locations in Colorado in 1947-1948 and found that greater yield and total sugar were produced when fertilizer was broadcast and plowed under as compared with broadcast or band placement at planting time.

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Olsen _et_ _al_. (37) and Schmehl (41), using radioactive phosphorus fertilizer to study the utilization of phosphorus from various fertilizer materials by sugar beets, concluded that mixing the fertilizer in a four inch square band with a rotatiller was a more effective placement in terms of fertilizer usage early in the season than placing the fertilizer in a band four inches to the side and four inches below the seed. They concluded that placement may be important for crops which need a rapid uptake of phosphorus for early growth. They also found that calcium metaphosphate was less available than monocalcium phosphate in the early stages of growth, but about equal thereafter. Monoammonium phosphate and superphosphate were about equally available. They found that only 10 to 12 per cent of the applied phosphorus was used by the plant when phosphorus was supplied as monoammonium phosphate, superphosphate or calcium metaphosphate. According to Schmehl, the availability of calcium metaphosphate to sugar beets increased as particle size of fertilizer decreased from minus 10 mesh to minus 100 mesh.

Jensen (26) in 1942, using six methods of application of fertilizer on sugar beets on field experiments, concluded that the phosphate applied with the seed in excess of 75 pounds per acre does not give a response conparable to equivalent amounts applied by the other methods used. The optimum application was found to include 50 pounds per acre with the seed and between 100 and 150 pounds per acre either side-dressed or broadcast. It was also found that quantities in excess of 200 pounds did not seem warranted economically, regardless of manner of application.

Tolman _et_ _al_. (48) found that the yield of sugar beets was increased approximately three tons per acre in Utah, Idaho, Washington, Montana and South Dakota by the application of 400 to 600 pounds per acre of a mixed fertilizer such as 16-20-0, 15-10-0, 13-15-0, or 14-14-0. They also found that broadcast application of fertilizer which was worked into the soil was not as effective as banding six inches to side and four inches below seed at planting time.

Larson (27) reported that in a two year trial on a silty clay soil double superphosphate at rates of 49 and 80 pounds of P_2O_5 per acre produced yield increases of three tons per acre of sugar beets.

Many workers (47, 6, 22) have concluded that the response of sugar beets to fertilization varies with soil type and growing conditions.

Olsen and Dreier (36) reported that nitrogen was a key factor in efficient use of phosphorus. From data obtained by using wheat and oats as indicator crops in field and greenhouse experiments, it was concluded that fertilizer nitrogen stimulated plant use of fertilizer phosphorus throughout a wide range of soil conditions. The ammonium ion apparently exceeded the nitrate ion in this capacity, especially during early stages of plant growth.

Lawton et al. (29), using radioactive phosphorus, conducted field experiments on Brookston clay loam soil to study the effect of placement on phosphate utilization by sugar beets. They found that 56 to 70 per cent of the phosphorus in young sugar beet tops was derived from fertilizer phosphorus where it was banded three inches below and 1$\frac{1}{4}$ inches to the side of seed. Two weeks later it decreased to between 44 and 57 per cent. This is in contrast to a very low percentage of fertilizer phosphorus in the top where fertilizer was drilled in bands seven inches apart and three inches deep prior to planting. Two weeks later the percentage of phosphorus in the beet tops from fertilizer increased to between 23 and 30 per cent where drilled placement was used. These authors explain this by characterization of root development of sugar beets. The tap root goes down first and is well-developed early t

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prior to secondary lateral root development; consequently, the percentage of fertilizer utilized from the band decreases as the secondary roots develop. However, the percentage of phosphorus in the top from the drilled application increases as secondary roots grow into the region of the fertilizer. They found significant yield response with all applications of fertilizer, but the greatest yield was obtained by a split application.

Afanasiev et al. (2), studying the physiology of growth, sugar accumulation and mineral content of tops and roots of sugar beets, showed that size of tops early in the season correlated closely with ultimate performance of the crop. They suggested that if beets emerge approximately May 15th, their tops should weigh on an average at least one-half pound each by the middle of July and one pound by the middle of August in order to produce good yields.

According to the sequence of reactions for path of phosphorus in soil to plant, given earlier by Fried and Shapiro (18), it may be possible to follow the availability of phosphorus in the soil by measuring it in the tissue at any given time in the growing season. This should be possible assuming that the rate limiting reaction is dissolution of mineral phosphorus and not movement to the root or intake into the plant.

Mellor et al. (33) reported in 1948 that phosphorus in the sugar beet tissue was highest early in the spring indicating a higher availability of phosphorus during the early part of the season. In their experiment, the fertilizer was plowed under prior to planting.

Fullmer (19) reported in 1952 that during the preceding 25 years, plant analysis had become increasingly important in the study of nutritional problems; however, the modern approach to plant analysis is concerned with the nutritional status of the plant itself.

Most investigators are not in agreement as to which part of the plant should be tested, nor as to how tests should be made. One school favors tests on conducting tissues for non-assimilated plant nutrients, while another uses leaf tissues and analysis for total nutrient content.

Baird (6) reported that growth of sugar beets correlated well with soil and petiole analysis in four out of six experiments. On the other hand, Robertson (39) was unable to obtain a significant correlation between plant tissue phosphorus and response of sugar beets to side-dressing.

Haddock (21) stated that a fair estimate of the nutritional status of sugar beets can be obtained by chemical analysis of either dry plant tissue or green tissue. He reported that the phosphorus content of sugar beet petioles was relatively high early in the season irrespective of moderate variability in soil moisture conditions, plant population or fertilizer treatment. It decreased rapidly from June to the last of July, after which it declined slowly reaching a minimum in October.

Ulrich (51) discussed the critical nutrient level and defined it as that range of concentrations at which the growth of the plant is restricted in comparison to those plants at a higher nutrient level. He pointed out that the critical levels for nitrogen, phosphorus, and potassium fluctuated over a relatively narrow range of values in comparison to the nutrient concentration of beets reported in literature above this level.

Ulrich (50) reporting on plant nutrient surveys made in 1943 and 1944 in 70 fields of the Salinas, San Joaquin, and Sacramento Valleys of California, found that during the two year period, 70 per cent of the fields were below the critical level for nitrogen, 28 per cent for phosphorus and 6 per cent for potassium. The critical levels of these nutrients as given were: 1000 ppm of NO_3- nitrogen, 1000 ppm of PO_4-phosphorus soluble in 2 per cent acetic acid, and 2 per cent total potassium.

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Brown (10) studied the effect of age of sugar beet petiole and number of petioles collected on variability of NO_3-nitrogen and P_2O_5-phosphorus content at different sampling dates and fertility levels. It was concluded that the proper petiole to be chosen to enter the composite representing the plot is defined as the petiole of the youngest mature leaf. Also, from the results of tests of carefully selected individual petioles and small composites taken from randomly chosen sugar beets, it was estimated that about 400 petioles would be required to yield a sample, from fields of the type investigated, with a 10 per cent error limit at the 19 to 1 probability ratio. A 75 petiole sample was sufficient to give a 20 per cent error limit at the 9 to 1 probability ratio.

Brown (11) reported results from experiments conducted in the Great Western Sugar Company area during 1940-1945 on sugar beet petiole analysis as an indicator of the supply of available nutrients. Nutrients were reported as parts per million of nitrate (NO_3) nitrogen and phosphorus on original petiole matter. It was concluded that if petiole samples are taken from various plots on the same field, differences in fertility will be reflected by differences in results of tests, but if a simple petiole sample is taken from a field, interpretation of the results of the tests is questionable, unless the results are high. They also concluded that while on the average a phosphorus test of 100 ppm phosphorus or more is required to produce a sufficiency, it did not follow that application of phosphate to a crop showing less than 100 ppm will produce a response.

Experimental Procedure

An experimental area was established in 1959 near Bay City, Michigan, on a Kawkawlin-Wisner silty clay loam soil complex.

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Certain chemical properties of this soil are given in Table 1. The area was divided into three sections (A, B, and C) each 792 by 112 feet, an area wide enough to contain 48 rows, 28 inches wide. A three year rotation of sugar beets, pea beans (commonly called navy beans) and winter wheat was begun in the Spring of 1959. Sugar beets were planted in section A in 1959, section B in 1960, and section C in 1961. Application rates of 0, 87, 174 and 348 pounds of phosphorus per acre were made on each section just prior to planting sugar beets. The phosphorus was applied as 0-46-0 on strips 66 feet wide across each section and plowed down. Each phosphorus level was replicated three times in each section. The entire area received a broadcast application of 200 pounds per acre of muriate of potash (0-0-60) immediately after broadcasting the phosphorus. An application of 60 pounds per acre of nitrogen was made in July as a sidedressing for sugar beets. Planting time fertilizer for sugar beets was 0, 150 or 300 pounds per acre of 5-20-10 in 1959 and 1960. In 1961 the above rates of 6-24-12 were used. All planting time fertilizer for sugar beets contained two per cent manganese and $1\frac{1}{2}$ per cent boron. Planting time fertilizer applications were replicated four times on each of the subsections of plow down phosphorus.

Additional fertilizer was supplied to the pea beans and wheat in the rotation in the amount of 150 pounds per acre of 5-20-10 applied at planting time.

The placement of the planting time fertilizer for sugar beets in 1959 was approximately 3/4 of an inch to the side of and two inches below the seed level. The planting time rates were the sub-plot treatments, each consisting of four (28 inch) rows, 66 feet long. In 1960-1961, the planting time fertilizer was applied in two ways: 1960--1) in a band 3/4 of an inch to the side and two inches below the seed; 2) in a band $1\frac{1}{2}$ inches to the side and two inches below the seed; 1961--1) in a band

Table 1. The chemical properties of a profile sample of Kawkawlin-Wisner silty clay loam.[a]

Depth of sample (Inches)	Horizon	Soil reaction (pH)	Extractable Nutrients[b] P (Lbs./A.)	K (Lbs./A.)	Ca (Lbs./A.)	Mg (Lbs./A.)
0-9	Ap	7.6	12	112	6,200	390
9-11	A_2	7.0	1	48	3,100	260
11-17	B_{12}	7.8	0	64	5,200	300
17-26	B_{2t2}	7.4	0	72	7,700	340
26-31	C_g	7.7	0	72	8,400	320
31-36	C_g	7.8	0	80	9,200	370

[a] Sample obtained from a check plot, November 7, 1961.

[b] Phosphorus was determined by Bray 1 solution with a 1:8 soil to solution ratio and potassium, calcium, and magnesium were extracted with 1 N NH_4OAc, pH 7.0 solution.

$1\frac{1}{2}$ inches to the side and three inches below the seed; 2) in a band three inches under the seed.

Monogerm beet seed, variety SL108XSP5481, and SL122XSP5460 was planted May 7, 1959, and April 13, 1961, respectively. The exact monogerm variety planted May 6, 1960, was not recorded.

Samples of aerial portion of 100 beet plants were made on June 12, 1959, June 2, 1960, and June 2, 1961. The method of selecting these samples in 1959 was to pull, cut off and discard the root portion of the plants from each of 2 rows of four replications of planting time treatments and to composite them so there were 100 plants in each sample. Thus, there were three replications of three planting time levels at each of four plowed down phosphorus treatments making 36 composited samples. The same method as above was used in 1961 except that the composite of 100 plants was from replications of the planting time treatments and there were two placements for each of the 150 and 300 pound levels of planting time fertilizer, thus, making composites of 20 treatments replicated 3 times. In 1960, there were four replications of the 20 treatments taken. The plants were dried at 65° C and dry weight determined. They were wet digested with nitric and perchloric acid, as described by Jackson (24).

Calcium and potassium were determined by use of a Beckman DU flame photometer using 422.7 and 767 mμ wavelength, respectively. Phosphorus in solution was determined by the ammonium molybdate-colorimetric procedure as outlined by Jackson (24) using 660 mμ wavelength light and a Coleman colorimeter.

Petiole samples were taken July 15, and September 1, 1959; July 11, and August 8, 1960; and July 11, August 3, and September 11, 1961. In selecting the sample, five beets were selected at random from each 66 foot row of the two row sub-sub-plot and a composite was made of two replications so that each sample analyzed contained 20 petioles.

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Three composite samples of each treatment were obtained. The petiole selected from each beet sampled was done by taking what appeared to be one of the youngest matured leaves. These petiole samples were quick frozen and analyzed for phosphorus by using a ten per cent sodium acetate extraction in three per cent acetic acid (pH 7.0) with a 1:20 tissue to solution ratio. In addition, total phosphorus was determined using wet perchloric acid analysis as described by Jackson (24). Calcium in the petiole was determined in 1959 and 1961, and total potassium was determined in 1961.

The beets were harvested on November 10, 1959; October 19 and 20, 1960; and October 10, 1961. The following data was determined at harvest time: number of beets of harvestable size, tons of beets per acre, per cent sucrose and per cent purity. Per cent sucrose and per cent purity were determined from a sample of six beets selected from two replications of each treatment.

The data was analyzed on the control data processing 3600 computer as a split or split-split plot by using the existing programs in the computer library of Michigan State University.

Results and Discussion

The yields of roots in tons per acre are given in Tables 2, 3, and 4 for 1959, 1960, and 1961, respectively. In 1959, the yield was increased from 14.7 to 16.8 to 18.9 by the addition of 0, 87, and 174 pounds of plowed down phosphorus. No further increase was obtained when an additional 174 pounds was used. The planting time fertilizer increased the yield from 16.6 to 17.5 by the 150 pound application. The addition of another 150 pounds did not give a significant increase over the first 150 pounds when all plow down rates were included; however, when no "plow down" phosphorus was used, yield increases

Table 2. The effect of time and method of application of fertilizer on early growth and yield of sugar beets, 1959.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	(Tons roots/A.)[a]				(Gms./100 plants)[b]			
0	13.0	15.0	16.0	14.7	34.0	68.6	78.1	60.2
87	16.7	16.8	16.8	16.8	56.4	78.6	91.2	75.4
174	18.7	19.1	19.0	18.9	67.7	85.0	95.1	82.6
348	18.0	19.2	19.1	18.8	79.1	99.3	102.1	93.5
Avg.	16.6	17.5	17.8		59.3	82.9	91.6	
LSD(0.05)								
Phosphorus levels				1.02**				11.53*
Planting time levels				.61**				4.40**
Phosphorus x planting time				N.S.				8.79*

[a] Averages of 12 replications.
[b] Averages of three replications sampled June 12th.
* Significant at five per cent level.
** Significant at one per cent level.

Table 3. The effect of time and method of application of fertilizer on yield of sugar beets,[a] 1960.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Tons roots/A.)						
0	8.8	9.5	9.8	10.0	10.2	9.2	9.9
87	10.8	10.6	10.6	11.2	11.4	10.7	11.0
174	11.2	11.2	11.0	12.0	11.4	11.3	11.3
348	12.4	12.1	12.3	13.4	12.6	12.5	12.5
Avg.	10.8	10.8	10.9	11.7	11.4		
LSD (0.05)							
Phosphorus levels						1.12**	1.24**
Planting time levels						.52**	N.S.
Placement						N.S.	

[a]Average of 12 replications.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and two inches below seed.
U-Planting time fertilizer placed 3/4 inch to side and two inches below the seed.
**Significant at one per cent level.

Table 4. The effect of time and method of application of fertilizer on yield[a] of sugar beets, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time								
	0	150		300		Avg.		Interaction Avg.[c]	
		S[b]	U[b]	S	U	S	U	S	U
(Lbs./A.)	(Tons roots/A.)								
0	13.2	14.3	18.0	15.3	17.3	13.9	16.5	14.8	17.6
87	15.0	15.4	17.1	16.0	16.5	15.2	16.5	15.7	16.8
174	14.8	16.6	18.0	16.7	18.4	15.8	17.3	16.7	18.2
348	17.9	19.2	20.0	19.3	20.6	18.6	19.7	19.2	20.4
Avg.	15.1	16.3	18.3	16.8	18.2			16.5	18.2
LSD (0.05)									
Phosphorus levels						1.31**	1.25**		
Planting time levels						.77**	.69**		
Placement								.40**	
Phosphorus x planting time								.81**	

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to the side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not contain the zero planting time values.
** Significant at one per cent level.

of 2.0 and 3.0 tons of sugar beets per acre were obtained by the use of 150 and 300 pounds of starter fertilizer, respectively. Maximum yield was obtained by using a combination of 150 and 174 pounds of planting time fertilizer and plow down phosphorus, respectively.

In 1960, fertilizer placement had no effect on yield. Again as in 1959, the yield was increased by the plow down phosphorus. The maximum yield response due to plow down application of phosphorus was 2.7 tons and was obtained by using the 348 pound application. The response in yield due to the planting time fertilizer was not as great as in 1959. The yield of roots where 300 pounds of fertilizer was applied was higher than where 150 pounds was used when all plow down levels were combined for a given planting time level. The maximum yield in 1960 was 13.4 tons per acre and was obtained from a plot which had a combination of 348 pounds of phosphorus per acre plowed down and 300 pounds of planting time fertilizer side-placed.

In 1961, 348 pounds of phosphorus per acre plowed down gave significantly better yields than lower rates. The yield was increased by the 150 and 300 pound planting time levels; however, the yield from the 300 pound level areas was not superior to areas where 150 pounds was applied. Table 4 shows that when planting time fertilizer was placed $1\frac{1}{2}$ inches to the side and three inches below the seed as compared to three inches under the seed it was less effective; also, there was significant interaction between placement of planting time fertilizer and plow down level of phosphorus. It was found that the yield response to plow down phosphorus was 4.4 tons per acre when planting time fertilizer was placed $1\frac{1}{2}$ inches to the side of the seed. However, there was 2.8 tons per acre average increase in yield due to plow down phosphorus when the planting time fertilizer was placed under the seed. The maximum yield in 1961 was 20.6 tons per acre and was a result of the combination of 348 pounds per acre of phosphorus plowed down and 150 pounds per acre planting time fertilizer placed three inches under the seed.

The interaction of phosphorus plowed down and starter fertilizer placement is given in the final two columns of Table 4. Yield increases of 2.8, 1.1, 1.5 and 1.2 tons of the 0, 84, 174, and 348 pounds per acre phosphorus levels, respectively, were obtained when the planting time fertilizer was moved from $1\frac{1}{2}$ inches to the side to directly below the seed. This increased yield may be related to an increase in early growth due to stimulating early root development by starter fertilizer under the seed so that the sugar beets can utilize the plow down phosphorus earlier and more efficiently.

The yield in tons of sugar beets per acre in 1959 reached a maximum at lower plow down levels of phosphorus than in 1960 and 1961. This may be due to the time of plow down application since in 1959 it was applied in May before plowing and planting, whereas in 1960 and 1961 it was applied in the fall preceding planting of sugar beets the following spring, thus allowing more time for phosphorus fixation in 1960 and 1961.

The early growth of the sugar beets is reported in Tables 2, 5, and 6 as grams dry weight per 100 plants. The samples were taken 26, 27, and 50 days after planting in 1959, 1960, and 1961, respectively. In 1959 the early growth was increased by all levels of plow down phosphorus and planting time fertilizer. There was an increase of 55 and 54 per cent by the highest levels of plow down and planting time fertilizer, respectively. There was an observed interaction between levels of plow down phosphorus and planting time levels. When comparing the early growth response due to planting time fertilizer, there was a per cent increase in early growth of 130, 62, 40, and 30 due to highest level of planting time fertilizer at 0, 87, 174, and 348 pounds of phosphorus per acre plowed down. There was a per cent increase of 133, 45, and 31 in early growth due to 348 pounds plow down phosphorus at 0, 150,

Table 5. The effect of time and method of application of fertilizer on early growth of sugar beet plants,[a] 1960.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Gms./100 plants)						
0	29.7	73.3	67.0	61.5	97.8	54.2	65.4
87	43.9	71.8	86.3	69.8	102.3	61.7	77.6
174	48.2	78.5	92.8	84.3	114.8	70.5	85.0
348	52.8	90.0	102.3	81.0	127.3	73.1	95.6
Avg.	43.6	78.4	87.1	74.1	110.5	76.2[c]	98.7[c]
LSD (0.05)							
Phosphorus levels						6.83**	12.43**
Planting time levels						13.67**	16.35**
Placement							8.54**
Placement x planting time							12.08**

[a] Average of three replications sampled June 12.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and two inches below seed.
U-Planting time fertilizer placed 3/4 inch to side and two inches below seed.
[c] These averages do not include the zero planting time values.
** Significant at one per cent level.

Table 6. The effect of time and method of application of fertilizer on early growth of sugar beet plants,[a] 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time								
	0	150		300		Avg.		Interaction Avg.[c]	
		S[b]	U[b]	S	U	S	U	S	U
(Lbs./A.)	(Gms./100 plants)								
0	10.2	16.8	39.6	20.4	52.5	15.8	34.1	18.6	46.1
87	17.3	28.8	44.2	29.5	61.7	25.2	41.1	29.1	52.9
174	20.2	32.0	45.8	34.4	57.5	28.9	41.2	33.2	51.7
348	25.4	35.9	56.0	40.7	66.5	34.0	49.3	38.3	61.3
Avg.	18.3	28.4	46.4	31.3	59.6			29.8	53.0
LSD (0.05)									
Phosphorus levels								5.68**	6.73**
Planting time levels								3.29**	4.80**
Placement								2.07**	
Placement x planting time								2.94**	
Placement x phosphorus								4.16**	

[a] Average of three replications sampled June 2nd.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to the side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not include the zero planting time values.
** Significant at one per cent level.

and 300 pounds per acre planting time levels, respectively. However, no further early growth response was obtained by addition of plow down phosphorus above the 87 pound level where 300 pounds of planting time fertilizer was used. The maximum early growth in 1959 was obtained by either of two combinations of plow down phosphorus and planting time fertilizers; namely, a combination of 348 with 150 pounds per acre or 87 with 300 pounds per acre plow down phosphorus and planting time fertilizer, respectively.

In 1960 and 1961 the planting time fertilizer was applied at two separate placements each year as given earlier. The movement of the planting time fertilizer to a placement closer to the seed caused a percentage increase of 30 and 81 percent for 1960 and 1961, respectively. Some of the difference between the two years may be because in 1960 the closest fertilizer placement was approximately 3/4 inches to the side as compared to under the seed in 1961. This is brought out by the planting time placement interaction for these years and implies that as the fertilizer was moved closer to a position under the seed, the planting time fertilizer was more effective in stimulating an increase in early growth. Lawton et al. (29) pointed out that the uptake of fertilizer by sugar beets was increased as the fertilizer was placed closer to a position directly below the seed.

There was an interaction of plow down phosphorus with placement of planting time fertilizer in 1961. This is shown by the percentage increases of 48, 82, 56, and 60 in early growth at the 0, 87, 174, and 348 plow down phosphorus level, respectively, due to the more effective planting time fertilizer placement. The low response to planting time placement at the lowest plow down phosphorus level can be explained by the low availability of phosphorus in the soil where no phosphorus was plowed down. However, where 87 pounds of phosphorus per acre were plowed down, the movement of the planting time fertilizer closer to under the seed gave a large response in early growth. This is probably due to the stimulating of early top and root growth and thus making it possible for the plant to obtain the braodcast fertilizer because of more soil-root contact. At the higher plow down phosphorus levels there is less response to placement of planting time fertilizer because of the greater amount of available phosphorus in the soil which makes it possible for the young plants to obtain the necessary phosphorus prior to the development of an extensive root system. In this respect it should be noted that maximum growth was not obtained with a side placement of starter fertilizer even where the heaviest application of plow down phosphorus was made.

The higher the level of plow down phosphorus or planting time fertilizer used in 1960 and 1961, the greater was the increase in early growth if the planting time fertilizer was placed at the closest position to under the seed.

The effect of fertilizers on the weight of petioles sampled at three different times in 1961 are shown in Tables 7, 8, and 9. The weight of petiole samples in 1959 and 1960 were not recorded.

Table 7 shows that the weight of 20 petioles at the July sampling date was still showing an increase in growth from the plow down phosphorus. Also, the planting time fertilizer was showing a response in growth when placement was under the seed. The average of all plots at each placement shows that the position under the seed had produced larger petioles at this stage of sampling. By the August sampling date (Table 8) there appeared to be little difference in the weights of 20 petioles sampled with the exception that the weight was less where the planting time fertilizer was increased at the placement under the seed. By the September sampling (Table 9) the weight of 20 petioles was greater where the planting time fertilizer placement was to the side of the seed. The change in weight of petioles at different fertilizer

Table 7. The effect of time and method of application of fertilizer on dry weight of sugar beet petioles,[a] 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Gms./100 plants)						
0	22.0	28.6	26.9	26.4	29.2	25.7	26.0
87	29.6	28.3	29.3	31.6	33.5	29.8	30.8
174	28.8	26.2	32.3	30.9	31.7	28.6	30.9
348	31.9	31.0	33.4	31.5	33.6	31.5	33.0
Avg.	28.1	28.6	30.5	30.1	32.0	29.3[c]	31.2[c]
LSD (0.05)							
Phosphorus levels						3.12*	2.40**
Planting time levels						N.S.	1.98**
Placement						1.50*	

[a] Average of three replications sampled July 11th.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not include the zero planting time values.
* Significant at five per cent level.
** Significant at one per cent level.

Table 8. The effect of time and method of application of fertilizer on dry weight of sugar beet petioles,[a] 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Gms./20 petioles)						
0	36.1	32.9	32.4	32.8	30.8	33.9	33.1
87	36.7	32.6	30.5	33.1	33.1	34.2	33.4
174	37.0	36.0	31.5	34.4	31.7	35.8	33.4
348	35.7	34.7	37.7	33.7	32.1	34.7	35.2
Avg.	36.4	34.1	33.0	33.5	31.9		
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						N.S.	2.97*
Placement						N.S.	

[a] Average of three replications sampled August 3rd.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$-inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
* Significant at five per cent level.

Table 9. The effect of time and method of application of fertilizer on dry weight of sugar beet petioles,[a] 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Gms./20 petioles)						
0	28.9	28.3	26.4	30.9	25.4	29.4	26.9
87	27.7	30.0	23.3	30.2	27.4	29.3	26.1
174	28.0	30.3	22.8	26.8	22.9	28.4	24.6
348	30.3	29.3	24.2	29.4	24.4	29.7	26.3
Avg.	28.7	29.5	24.2	29.3	25.0	29.4[c]	24.6[c]
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						N.S.	2.48**
Placement						2.19**	

[a]Average of three replications sampled September 11th.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below seed.
U-Planting time fertilizer placed three inches under seed.
[c]These averages do not include the zero planting time values.
**Significant at one per cent level.

treatments may be explained in part by the lack of adequate soil moisture. It appeared that extended dry periods in July and August more severely hindered growth of large plants. Therefore, plants that had shown a large response to quantity and placement of fertilizer produced smaller petioles by later sampling dates. However, in the side placement and lower fertilizer levels the rate of growth of the sugar beets was more constant throughout the season.

Per cent of sucrose, and purity of sugar beets for 1959, 1960, and 1961 are reported in Tables 10, 11, and 12, respectively. No significant effect due to treatment was found.

The effect of treatments on gross sugar production is shown in Tables 13 and 14 and reflects mostly the increase in final yield as there was no difference due to sucrose content or purity. The gross sugar values were obtained by multiplying tons of sugar beets per acre times sucrose content and per cent purity and converting them to hundred weights per acre.

The effect of time and method application of fertilizer on the number of harvestable size beets are given in Tables 15, 16, and 17 for the years 1959, 1960, and 1961, respectively. The number of beets harvested per 100 feet of row was not affected by fertilizer treatment in 1959; however, in 1960 the plow down phosphorus increased the number of beets at harvest time as did the heaviest application of planting time fertilizer when it was $1\frac{1}{2}$ to the side and two inches below the seed. When the planting time fertilizer was placed 3/4 inch to the side and two inches below the seed the plow down phosphorus did not effect the number of beets by harvest time. When all data where planting time fertilizer was applied is used, it can be seen that the application of plow down phosphorus again increased the number of beets at harvest. There was also an interaction with planting time levels and placement of planting time fertilizer. The number of beets at harvest was increased by

Table 10. The effect of time and method of application of fertilizer on per cent sucrose and purity of sugar beets,[a] 1959.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	% Sucrose[b]				% Purity[b]			
0	16.1	16.2	16.7	16.3	91.7	91.1	90.1	91.0
87	16.8	16.8	16.4	16.7	90.2	89.9	88.3	89.5
174	17.3	17.0	17.1	17.2	89.2	88.5	89.7	89.2
348	16.8	16.9	17.0	16.9	88.5	90.0	89.3	89.3
Avg.	16.8	16.7	16.8		90.2	89.6	89.4	

[a]Average of three replications.
[b]Data not significant at five per cent level.

Table 11. The effect of time and method of application of fertilizer on per cent sucrose and purity of sugar beets,[a] 1960.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	% Sucrose[b]				% Purity[b]			
0	18.7	19.0	18.1	18.6	89.5	90.8	89.9	90.1
87	18.7	19.0	17.9	18.5	89.9	89.9	85.6	88.4
174	17.9	18.1	18.1	18.0	89.6	89.7	90.1	89.8
348	18.1	18.8	18.7	18.5	89.8	90.8	91.0	90.6
Avg.	18.4	18.7	18.2		89.7	90.3	89.2	

[a]Average of three replications.
[b]Data not significant at five per cent level.

Table 12. The effect of time and method of application of fertilizer on per cent sucrose and purity of sugar beets,[a] 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time							
	0	150	300		0	150	300	
			S[b]	U[b]			S[b]	U[b]
(Lbs./A.)	% Sucrose[c]				% Purity[c]			
0	14.5	15.0	15.4	14.7	87.7	89.4	89.0	88.9
87	15.2	15.3	14.3	15.7	90.7	91.1	87.7	91.2
174	15.4	14.8	15.1	15.2	90.6	85.3	87.4	89.2
348	15.6	15.5	15.2	15.1	86.4	89.2	88.1	86.9
Avg.	15.2	15.2	15.0	15.2	88.9	88.8	88.1	89.1

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below seed.
U-Planting time fertilizer placed three inches under seed.
[c] Data not significant at five per cent level.

Table 13. The effect of time and method of application of fertilizer on gross sugar production of sugar beets[a] in 1959 and 1960.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time 1959 (Cwt./A.): 0	150	300	Avg.	1960: 0	150	300	Avg.
0	38.9	44.5	48.5	43.9	31.7	33.7	35.0	33.5
87	51.0	50.3	50.0	50.4	36.9	36.1	35.0	36.0
174	57.7	57.6	58.6	58.0	37.0	35.5	37.1	36.5
348	53.8	58.4	58.4	56.9	41.4	41.9	43.1	42.1
Avg.	50.3	52.7	53.9		36.8	36.8	37.5	
LSD (0.05)								
Phosphorus levels				5.91**				5.75*
Planting time levels				2.54**				N.S.

[a] Average of three replications.
*Significant at five per cent level.
**Significant at one per cent level.

Table 14. The effect of time and method of application of fertilizer on gross sugar production of sugar beets[a] in 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Cwt./A.)						
0	32.1	----	47.8	41.9	45.2	----	41.7
87	41.5	----	47.5	40.1	47.3	----	45.4
174	41.1	----	45.5	44.3	49.7	----	45.4
348	48.6	----	55.4	58.7	53.8	----	52.6
Avg.	40.8	----	49.0	46.3	49.0	----	
LSD (0.05)							
Phosphorus levels							N.S.
Planting time levels							3.47**

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
** Significant at one per cent level.

Table 15. The effect of time and method of application of fertilizer on the number of sugar beets harvested,[a] 1959.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time			
	0	150	300	Avg.
	(Number of beets per 100 feet of row)			
0	70	76	74	73
87	74	72	79	75
174	75	76	77	76
348	75	75	74	75
Avg.	74	76	76	
LSD (0.05)				
Phosphorus levels				N.S.
Planting time levels				N.S.

[a]Average of 12 replications.

Table 16. The effect of time and method of application of fertilizer on the number of sugar beets harvested,[a] 1960.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150		300		Avg.		Avg.[c]
		S[b]	U[b]	S	U	S	U	
(Lbs./A.)	(Number of beets per 100 feet of row)							
0	76	72	82	79	79	75	79	78
87	80	79	87	88	83	83	83	84
174	81	83	84	88	82	83	83	84
348	87	84	90	93	89	88	88	89
Avg.	81	79	86	87	83			
LSD (0.05)								
Phosphorus levels						5.9**	N.S.	6.6**
Planting time levels						3.5**	3.2*	2.7*
Placement						N.S.		
Placement x planting time						3.1**		

[a] Average of 12 replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and two inches below the seed.
U-Planting time fertilizer placed 3/4 inches to side and two inches below the seed.
[c] These averages do not contain the zero planting time values.
* Significant at five per cent level.
** Significant at one per cent level.

Table 17. The effect of time and method of application of fertilizer on the number of beets harvested,[a] 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Number of beets per 100 feet of row)						
0	82	91	98	92	98	87	93
87	88	95	99	95	98	92	97
174	92	98	95	96	97	94	96
348	96	98	94	95	100	95	98
Avg.	90	95	97	94	99	95[c]	98[c]
LSD (0.05)							
Phosphorus levels						4.9*	3.4*
Planting time levels						3.7**	3.0**
Phosphorus x planting time						N.S.	5.9**
Placement						2.1**	

[a]Average of nine replications.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c]These averages do not contain the zero planting time values.
*Significant at five per cent level.
**Significant at one per cent level.

use of 300 over the 150 pounds of planting time fertilizer at $1\frac{1}{2}$ by two inch placing. However, at the 3/4 by two inch placement the 300 pound level was not different from that of the 150 pound level.

In 1961 the number of beets at harvest was increased by all levels of plow down phosphorus or by all planting time fertilizer levels as compared to no plow down phosphorus or planting time fertilizer, respectively. However, there was no significant difference in the 87, 174, and 348 or 150 and 300 pound levels of plow down phosphorus and planting time fertilizer levels, respectively. The placement of planting time fertilizer three inches under the seed as compared to $1\frac{1}{2}$ inches to side and three inches under the seed showed an increase in the number of beets harvested.

There was an interaction between plow down phosphorus and planting time fertilizer levels of application, in regard to the number of beets harvested per 100 feet of row where planting time fertilizer was placed under the seed. The interaction shows that planting time levels caused greatest increase in the number of beets at low levels of plow down phosphorus and as the plow down phosphorus levels were increased, the influence of planting time fertilizer was less. This influence of fertilizer shown above on the number of beets at harvest might be due to more vigorous beets due to more adequate nutrient supply and to increased resistance to diseases such as black root (1).

The phosphorus content of sugar beet tops at an early stage of growth is shown in Tables 18, 19, and 21 for the years 1959, 1960, and 1961, respectively. The phosphorus content in the tops of young plants varied from .356 to .625; .423 to .600, and .377 to .645 percents in 1959, 1960, and 1961, respectively. The phosphorus content was increased by each succeeding level of plow down phosphorus in 1959 and 1960; however, in 1961 the phosphorus content was increased by 87 pounds per acre of plow down phosphorus, but the two heavier rates

Table 18. The effect of time and method of application of fertilizer on phosphorus content[a] and uptake of young sugar beets, June 12, 1959.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Phosphorus content				Phosphorus uptake			
(Lbs./A.)	% P				Gms. P/100 plants			
0	.356	.430	.459	.415	.121	.295	.360	.259
87	.490	.522	.528	.513	.276	.407	.481	.388
174	.514	.577	.585	.558	.350	.493	.558	.467
348	.588	.617	.625	.610	.465	.612	.635	.570
Avg.	.487	.536	.549		.303	.452	.508	
LSD (0.05)								
Phosphorus levels				.076**				.119**
Planting time levels				.029**				.039**

[a]Average of three replications and reported on dry weight basis.

**Significant at one per cent level.

Table 19. The effect of time and method of application of fertilizer on phosphorus content[a] of young sugar beet tops, June 12, 1960.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	% P						
0	.423	.517	.508	.479	.483	.461	.483
87	.538	.551	.543	.519	.510	.529	.537
174	.570	.566	.568	.587	.546	.578	.557
348	.581	.598	.600	.577	.580	.590	.582
Avg.	.528	.558	.555	.540	.529		
LSD (0.05)							
Phosphorus levels						.041**	.022**
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a] Average of four replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and two inches below the seed.
U-Planting time fertilizer placed 3/4 inch to side and two inches below the seed.
** Significant at one per cent level.

Table 20. The effect of time and method of application of fertilizer on the uptake of phosphorus by young sugar beets,[a] 1960.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Gms. P/100 plants)						
0	.124	.375	.340	.286	.471	.254	.317
87	.236	.395	.466	.362	.521	.378	.411
174	.274	.449	.541	.476	.627	.403	.477
348	.303	.541	.620	.467	.733	.431	.558
Avg.	.234	.440	.492	.398	.588	.419[c]	.540[c]
LSD (0.05)							
Phosphorus levels						.046**	.081**
Planting time levels						.071**	.097**
Placement						.044**	
Planting time x placement						.062**	

[a]Average of three replications.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side of seed and two inches below the seed.
U-Planting time fertilizer placed 3/4 inch to side of seed and two inches below the seed.
[c]These averages do not contain the zero planting time values.
**Significant at one per cent level.

Table 21. The effect of time and method of application of fertilizer on phosphorus content[a] of sugar beet tops, June 2, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
	% P						
0	.377	.535	.527	.537	.575	.483	.493
87	.583	.618	.578	.631	.587	.611	.583
174	.624	.615	.603	.657	.617	.632	.615
348	.633	.642	.603	.622	.595	.632	.611
Avg.	.554	.603	.578	.612	.594	.607[c]	.586[c]
LSD (0.05)							
Phosphorus levels						.046**	.041**
Planting time levels						.027**	.020**
Placement						.015**	
Phosphorus x planting time						.040**	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not contain the zero planting time values.
** Significant at one per cent level.

were not significantly different from 87 pound level as was the case in 1959 and 1960. The phosphorus content was increased by application of planting time fertilizer in 1959 and 1961; however, the two heavier applications showed no difference in phosphorus content. In 1961 there was an increase in phosphorus content when the planting time fertilizer was placed under the seed. Also in 1961 there was an interaction between the plow down phosphorus and planting time fertilizer levels on the phosphorus content of young sugar beet tops. The planting time fertilizer levels increased phosphorus content of beet top where no plow down phosphorus was used, but it had a decreasing effect at higher plow down phosphorus levels. This was probably due to the dilution effect because of the increased growth at the higher application levels. This may indicate that something in addition to phosphorus was influencing early growth.

Total phosphorus uptake per 100 young sugar beet plants is given in Tables 18, 20, and 22 for 1959, 1960, and 1961, respectively. The uptake, reported as grams of phosphorus per 100 plants, was lowest when no fertilizer was applied. It varied from .121 to .635; .124 to .733; and .030 to .394 grams phosphorus uptake per 100 plants for 1959, 1960, and 1961, respectively. The phosphorus uptake was increased by all levels of plow down phosphorus; however, each level was not significantly different from the other levels. The uptake was increased from .493 to .540 and .183 to .311 grams per 100 plants in 1960 and 1961, respectively, by moving the planting time fertilizer closer to a position under the seed. It can be seen from this that the most effective placement was under the seed. It should also be pointed out that this fertilizer was placed two and three inches below the seed in 1960 and 1961, respectively. All levels of planting time fertilizer caused an increased phosphorus uptake in each of the three years with the exception of the side fertilizer placement in 1960. In this case the

Table 22. The effect of time and method of application of fertilizer of phosphorus uptake[a] by early growth of sugar beets, June 2, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time								
	0	150		300		Avg.		Interaction Avg.[c]	
		S[b]	U[b]	S	U	S	U	S	U
(Lbs./A.)	(Gms. P/100 plants)								
0	.038	.909	.209	.109	.302	.079	.183	.100	.255
87	.102	.175	.255	.187	.361	.155	.239	.181	.308
174	.127	.197	.277	.227	.354	.183	.253	.212	.315
348	.162	.229	.337	.249	.394	.213	.298	.239	.366
Avg.	.107	.173	.270	.193	.353			.183	.311
LSD (0.05)									
Phosphorus levels						.034**	.037**		
Planting time levels						.020**	.027**		
Phosphorus x planting time									N.S.
Placement									.012**
Placement x phosphorus									.023*
Placement x planting time									.016**

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to the side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not include the zero planting time values.
[*] Significant at five per cent level.
[**] Significant at one per cent level.

300 pound rate was no better than the 150 pound rate. It was also observed in 1961 that the placement of the planting time fertilizer under the seed, as compared to $1\frac{1}{2}$-inches to the side, had a much greater influence on the phosphorus uptake at lower plow down phosphorus levels than at higher levels. It appeared that the phosphorus uptake by young sugar beets was more of a function of the size of the sugar beet at sampling than of the phosphorus content since the phosphorus content reached a level that did not change as more fertilizer was applied; however, the total growth of the young plants continued to increase as the amount of fertilizer (Table 6) was increased or the placement of planting time fertilizer was moved closer to the seed. Since the phosphorus content did not change as the planting time levels increased at the higher plow down phosphorus levels, then the increase in growth could have been influenced by the increase in nitrogen as the planting time fertilizer levels were increased.

The phosphorus content of the sugar beet petioles sampled during the three year period are reported as per cent phosphorus on a dry weight basis. An attempt was made to determine the inorganic phosphorus, total phosphorus, and the ratio of inorganic to total phosphorus in the conducting tissue. These data are reported in Tables 23 through 32.

It has been reported that the amount of phosphorus in the conducting tissue is a measure of the amount available in the soil. In 1959 and 1960 the phosphorus in the green tissue extract was greatly influenced by the plow down phosphorus levels at all dates of sampling. In these two years the planting time fertilizer showed no influence on the phosphorus in green tissue by July or later in the season. The same general influence of plow down phosphorus was found to exist with the total phosphorus in the petioles of samples taken in 1959 and 1960.

Table 23. The effect of time and method of application of fertilizer on phosphorus content[a] of sugar beet petioles, July 15, 1959.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Phosphorus in green tissue				Total phosphorus			
(Lbs./A.)	% P				% P			
0	.124	.109	.168	.133	.180	.163	.195	.179
87	.173	.195	.184	.184	.220	.236	.224	.227
174	.193	.204	.191	.195	.237	.249	.240	.242
348	.216	.219	.202	.212	.245	.260	.267	.258
Avg.	.176	.182	.186		.221	.227	.232	
LSD (0.05)								
Phosphorus levels				.027**				.028**
Planting time levels				N.S.				N.S.

[a]Average of three replications and reported on dry weight basis.
**Significant at one per cent level.

Table 24. The effect of time and method of application of fertilizer on phosphorus content[a] of sugar beet petioles, September 1, 1959.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Phosphorus in green tissue % P				Total phosphorus % P			
0	.089	.079	.104	.091	.176	.154	.181	.170
87	.215	.189	.168	.190	.235	.217	.210	.220
174	.224	.229	.205	.219	.281	.265	.250	.265
348	.236	.223	.230	.230	.261	.283	.266	.270
Avg.	.191	.180	.177		.238	.230	.227	
LSD (0.05)								
Phosphorus levels				.034**				.020**
Planting time levels				N.S.				N.S.

[a] Average of three replications and reported on dry weight basis.

** Significant at one per cent level.

Table 25. The effect of time and method of application of fertilizer on phosphorus content[a] of sugar beet petioles, July 15, 1960.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Phosphorus in green tissue				Total phosphorus			
(Lbs./A.)	% P				% P			
0	.069	.081	.107	.085	.165	.166	.179	.170
87	.141	.180	.133	.151	.280	.281	.236	.266
174	.151	.155	.149	.152	.276	.273	.287	.278
348	.167	.168	.185	.174	.283	.309	.274	.288
Avg.	.132	.146	.143		.251	.257	.244	
LSD (0.05)								
Phosphorus levels				.018**				.051**
Planting time levels				N.S.				N.S.

[a] Average of three replications and reported on dry weight basis.

** Significant at one per cent level.

Table 26. The effect of time and method of application of fertilizer on phosphorus content[a] of sugar beet petioles, August 8, 1960.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Phosphorus in green tissue				Total phosphorus			
(Lbs./A.)	% P				% P			
0	.050	.059	.078	.062	.108	.118	.142	.123
87	.090	.115	.095	.100	.147	.160	.172	.160
174	.133	.138	.123	.131	.199	.191	.191	.194
348	.161	.163	.158	.161	.213	.209	.203	.208
Avg.	.108	.119	.113		.167	.170	.177	
LSD (0.05)								
Phosphorus levels				.020**				.019**
Planting time levels				N.S.				N.S.

[a] Averages of three replications and reported on dry weight basis.
** Significant at one per cent level.

Table 27. The effect of time and method of application of fertilizer on phosphorus content in green tissue[a] of sugar beet petioles, July 11, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	% P						
0	.111	.097	.111	.112	.114	.106	.112
87	.222	.225	.212	.218	.200	.222	.211
174	.245	.236	.228	.220	.209	.234	.228
348	.250	.244	.226	.205	.234	.233	.237
Avg.	.207	.201	.195	.189	.189		
LSD (0.05)							
Phosphorus levels						.033**	.034**
Planting time levels						.013*	N.S.
Placement						N.S.	

[a]Average of three replications and reported on dry weight basis.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
*Significant at five per cent level.
**Significant at one per cent level.

Table 28. The effect of time and method of application of fertilizer on total phosphorus content[a] of sugar beet petioles, July 11, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
	% P						
0	.182	.145	.170	.165	.168	.164	.173
87	.292	.285	.277	.272	.268	.283	.279
174	.315	.303	.298	.283	.272	.300	.295
348	.313	.303	.300	.286	.298	.301	.304
Avg.	.275	.259	.261	.252	.252		
LSD (0.05)							
Phosphorus levels						.032**	.023**
Planting time levels						.012**	.012**
Placement						N.S.	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
** Significant at one per cent level.

Table 29. The effect of time and method of application of fertilizer on phosphorus content[a] in green tissue of sugar beet petioles, August 3, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	% P						
0	.051	.063	.059	.040	.056	.051	.056
87	.096	.116	.090	.103	.112	.104	.100
174	.122	.105	.126	.109	.125	.112	.125
348	.147	.155	.136	.141	.150	.148	.144
Avg.	.104	.109	.103	.098	.111		
LSD (0.05)							
Phosphorus levels						.016**	.017**
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
** Significant at one per cent level.

Table 30. The effect of time and method of application of fertilizer on total phosphorus content[a] of sugar beet petioles, August 3, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
	% P						
0	.143	.123	.152	.123	.162	.130	.152
87	.204	.248	.224	.232	.233	.228	.221
174	.260	.250	.245	.253	.295	.254	.266
348	.262	.292	.285	.275	.279	.276	.276
Avg.	.217	.228	.226	.221	.242		
LSD (0.05)							
Phosphorus levels						.024**	.033**
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
** Significant at one per cent level.

Table 31. The effect of time and method of application of fertilizer on phosphorus content[a] in green tissue of sugar beet petioles, September 11, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	% P						
0	.102	.121	.114	.123	.110	.116	.109
87	.250	.198	.228	.213	.213	.220	.230
174	.284	.236	.264	.263	.231	.261	.260
348	.255	.235	.253	.251	.243	.247	.250
Avg.	.222	.198	.215	.213	.200		
LSD (0.05)							
Phosphorus levels						.046**	.041**
Planting time levels						.016*	N.S.
Placement						N.S.	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
* Significant at five per cent level.
** Significant at one per cent level.

Table 32. The effect of time and method of application of fertilizer on total phosphorus content[a] of sugar beet petioles, September 11, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
	% P						
0	.198	.187	.188	.212	.213	.199	.200
87	.307	.247	.298	.295	.285	.283	.297
174	.315	.270	.323	.298	.288	.294	.309
348	.306	.290	.305	.307	.317	.301	.310
Avg.	.282	.248	.279	.278	.276	.264[c]	.277[c]
LSD (0.05)							
Phosphorus levels						.032**	.035**
Planting time levels						.021**	N.S.
Placement						N.S.	
Planting time x placement						.021*	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not contain the zero planting time fertilizer values.
* Significant at five per cent level.
** Significant at one per cent level.

The phosphorus content of the petioles in 1961 showed the greatest influence from the plow down phosphorus when sampled on August 3rd, as compared to July 11th or September 11th sampling date. The correlation of final yield with the total and green tissue phosphorus was the greatest on the August 3rd sampling date. There appeared to be a decrease in phosphorus content of the petioles in 1961 when the planting time fertilizer was placed $1\frac{1}{2}$ inches to the side of the seed. This could be explained by the more mobile ions, nitrogen and potassium, in the planting time fertilizers which may have been causing an increase in growth of the sugar beet which caused a dilution of the phosphorus in the petioles.

This is also indicated because planting time fertilizer had an influence on the total phosphorus in the petioles. At each placement during the July sampling date there was a decrease in phosphorus content as higher levels of planting time fertilizer were used. This influence of planting time fertilizer is also seen late in the season (September 11th). However, the influence at this time was an increase in total phosphorus content as the 150 pound rate was placed closer to the seed and as the rate of planting time fertilizer was increased at the side placement.

Both the green tissue phosphorus and the total phosphorus content in the petiole were highly correlated with final yield at all sampling dates in 1959 and 1960 and the August sampling date in 1961. This indicates that a tissue test taken from mid-July to late August could be used in determining if phosphorus is limiting the final yield of sugar beets. Ulrich (51) indicated that the critical level of inorganic phosphorus in the petiole is approximately 1000 parts PO_4 per million. Data in this thesis show many petiole samples below this critical level. The data also shows that final yield was increased by additional phosphorus when the petiole samples showed values that were above this critical level.

The per cent of the total phosphorus in the petioles in the inorganic form was relatively high for the no fertilizer plot in the July sampling dates in all years and thus did not appear to be influenced by the rate of phosphorus applied. These data are reported in Tables 33 through 37.

At later sampling dates, however, the ratio of inorganic to total phosphorus at lower phosphorus levels appeared to decrease. The ratio tended to increase with increasing phosphorus level. The lower ratio is probably due to the more rapid rate of growth of petioles during the mid-season, consequently, requiring a greater supply of phosphorus. By the September sampling dates the ratio again increased due to luxury consumption and slow growth of the sugar beet tops at this stage in growth.

The calcium uptake and content of young sugar beets are given in Tables 38 through 40. The calcium content in young sugar beet tops in 1959 and 1961 was decreased as the planting time fertilizer rates were increased. The calcium content in 1961 was also decreased by placing the planting time fertilizer under the seed. This decrease in calcium content in young sugar beet plants is probably due to a dilution effect since the increase in fertilizer application caused an increase in growth.

The calcium uptake as given in grams per 100 plants in 1959 and 1961 was increased by the application of plow down phosphorus and planting time fertilizer.

The calcium content of the petiole samples in 1959 is shown in Table 41. At the early sampling date, application of 150 pounds of planting time fertilizer appeared to decrease the calcium content. However, when the 300 pound application was used the calcium content appeared to increase to or above the level where no planting time fertilizer was applied. At the later sampling date in 1959 the plow down levels of phosphorus caused the calcium content in the petiole to decrease.

Table 33. The effect of time and method of application of fertilizer on the ratio of inorganic to total phosphorus in the green tissue of sugar beet petioles[a] at two dates in 1959.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time: 0	150	300	Avg.	0	150	300	Avg.
	Beet samples taken July 15th. Inorganic P/Total P(%)				Beet samples taken Sept. 1st. Inorganic P/Total P (%)			
0	68.9	67.5	86.1	75.2	50.4	51.1	58.2	53.2
87	78.0	83.4	81.9	81.1	91.5	86.7	79.4	85.9
174	81.8	82.0	79.1	81.0	81.1	86.4	82.3	83.3
348	88.2	84.6	75.5	82.8	90.5	79.1	86.5	85.4
Avg.	79.2	79.4	80.6		78.4	75.8	76.6	
LSD (0.05)								
Phosphorus levels				N.S.				11.0**
Planting time levels				N.S.				N.S.

[a]Average of three replications.
**Significant at one per cent level.

Table 34. The effect of time and method of application of fertilizer on the ratio of inorganic to total phosphorus in the green tissue of sugar beet petioles[a] at two dates in 1960.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Beet sample taken July 15th				Beet sample taken August 8th			
(Lbs./A.)	Inorganic P/Total P (%)				Inorganic P/Total P (%)			
0	45.0	48.8	60.2	51.3	46.3	50.7	55.7	50.9
87	51.0	63.8	56.4	57.0	60.9	71.5	55.7	62.7
174	54.9	56.8	52.2	54.6	66.1	72.1	64.1	67.4
348	60.2	54.8	68.6	61.2	75.4	78.0	78.2	77.2
Avg.	52.7	56.0	59.3		62.2	68.1	63.4	
LSD (0.05)								
Phosphorus levels				N.S.				13.0*
Planting time levels				N.S.				N.S.

[a] Average of three replications.
* Significant at five per cent level.

Table 35. The effect of time and method of application of fertilizer on the ratio of inorganic to total phosphorus in the green tissue of sugar beet petioles,[a] July 11, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	Inorganic P/total P (%)						
0	60.8	65.8	65.5	68.0	67.4	64.9	64.6
87	75.0	79.0	76.9	80.4	74.5	78.5	75.8
174	77.8	78.1	76.6	77.5	77.0	77.8	77.1
348	79.9	80.6	75.4	71.5	78.8	77.3	78.0
Avg.	73.6	75.9	73.6	74.4	74.4		
LSD (0.05)							
Phosphorus levels						8.8*	N.S.
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
* Significant at five per cent level.

Table 26. The effect of time and method of application of fertilizer on the ratio of inorganic to total phosphorus in the green tissue of sugar beet petioles,[a] August 3, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	Inorganic P/total P (%)						
0	36.1	52.4	38.9	31.6	34.9	40.0	36.7
87	46.7	46.5	39.6	44.1	48.5	45.8	44.9
174	47.0	42.0	51.9	43.1	42.6	44.1	47.2
348	56.6	53.2	48.7	51.1	55.6	53.6	53.7
Avg.	46.6	48.5	44.8	42.5	45.4		
LSD (0.05)							
Phosphorus levels						.068*	.088*
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a]Average of three replications.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
*Significant at five per cent level.

Table 37. The effect of time and method of application of fertilizer on the ratio of inorganic to total phosphorus in the green tissue of sugar beet petioles,[a] September 11, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	Inorganic P/total P (%)						
0	50.8	65.1	59.9	58.9	51.6	58.3	54.1
87	81.7	80.1	76.3	72.0	74.1	77.9	77.4
174	90.3	86.9	80.6	88.4	79.6	88.6	83.5
348	84.3	80.6	82.5	81.8	77.0	82.2	81.2
Avg.	76.8	78.2	74.8	75.3	70.6		
LSD (0.05)							
Phosphorus levels						3.1**	7.8**
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a] Average of three replications.

[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.

U-Planting time fertilizer placed three inches under the seed.

** Significant at one per cent level.

Table 38. The effect of time and method of application of fertilizer on calcium content and uptake of young sugar beets, June 12, 1959.

Phosphorus plowed down	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Calcium content[a]				Calcium uptake			
(Lbs./A.)	% Ca				Gms. Ca/100 plants			
0	.81	.94	.93	.89	.28	.65	.73	.55
87	.87	.97	.97	.94	.49	.77	.88	.71
174	1.01	1.00	.94	.98	.68	.85	.89	.81
348	.87	.91	.90	.89	.69	.90	.92	.84
Avg.	.89	.96	.94		.53	.79	.86	
LSD (0.05)								
Phosphorus levels				N.S.				.20*
Planting time levels				.05*				.07**

[a]Average of three replications reported on a dry weight basis.
*Significant at five per cent level.
**Significant at one per cent level.

Table 39. The effect of time and method of application of fertilizer on calcium content[a] of sugar beet tops, June 2, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time								
	0	150		300		Avg.		Interaction Avg.[c]	
		S[b]	U[b]	S	U	S	U	S	U
(Lbs./A.)	(% Ca)								
0	2.42	2.13	1.99	2.14	1.83	2.23	2.08	2.14	1.91
87	2.12	2.05	1.99	2.13	1.88	2.10	2.00	2.09	1.94
174	2.08	2.04	2.00	1.93	2.00	2.02	2.02	1.99	1.99
348	1.97	2.04	2.00	1.95	1.84	1.94	1.94	1.99	1.92
Avg.	2.15	2.07	1.99	2.04	1.88			2.05[c]	1.94[c]
LSD (0.05)									
Phosphorus levels						N.S.	N.S.		
Planting time levels						N.S.	.07*		
Phosphorus x planting time						N.S.	.13*		
Placement								.06**	
Placement x phosphorus								.11*	

[a]Average of three replications and reported on dry weight basis.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to the side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c]These averages do not include the zero planting time levels.
*Significant at five per cent level.
**Significant at one per cent level.

Table 40. The effect of time and method of application of fertilizer on calcium uptake[a] by early growth of sugar beets, June 2, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time: 0	150: S[b]	150: U[b]	300: S	300: U	Avg.: S	Avg.: U
	(Gms. Ca/100 plants)						
0	.246	.360	.790	.430	.956	.345	.664
87	.361	.573	.872	.619	1.134	.518	.789
174	.421	.645	.911	.669	1.137	.578	.823
348	.497	.726	1.108	.784	1.221	.669	.942
Avg.	.381	.576	.920	.626	1.112	.601[c]	1.016[c]
LSD (0.05)							
Phosphorus levels						.123**	.125**
Planting time levels						.069**	.079**
Placement						.038**	
Placement x planting time						.054**	

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not contain the zero planting time values.
** Significant at one per cent level.

Table 41. The effect of time and method of application of fertilizer on calcium content[a] of sugar beet petioles at two dates in 1959.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 5-20-10 applied at planting time							
	0	150	300	Avg.	0	150	300	Avg.
	Beet sample taken July 15th				Beet sample taken Sept. 1st			
	% Ca				% Ca			
0	.97	.90	1.00	.95	1.15	1.41	1.20	1.25
87	.98	.88	1.02	.96	.97	1.10	1.17	1.08
174	.93	.83	.96	.91	.93	1.01	.91	.95
348	.95	.80	1.05	.93	.88	.91	.93	.90
Avg.	.96	.85	1.01		.98	1.11	1.05	
LSD (0.05)								
Phosphorus levels				N.S.				.17**
Planting time levels				.06**				N.S.

[a] Average of three replications and reported on dry weight basis.

** Significant at one per cent level.

This again is probably due to the larger petiole and thus causing a dilution effect where phosphorus was applied.

The calcium content of the petiole samples taken in 1961 are given in Tables 42 through 44. As in 1959, the calcium content in the petioles appears to decrease where there is an increased growth of sugar beet petioles due to fertilizer application.

The potassium content and uptake by early growth of sugar beets in 1961 are given in Tables 45 and 46. The potassium content was increased when the fertilizer was placed three inches under the seed as compared with $1\frac{1}{2}$ inches to the side and three inches below the seed. There appeared to be an interaction in the potassium content by placement and rate of planting time fertilizer. At the 150 pound level of planting time fertilizer, the placement had no effect on the potassium content of the sugar beets. However, the potassium content was increased at either placement when the planting time fertilizer was increased. At the three hundred pound level the potassium content was increased by placing the fertilizer under the seed.

The potassium content in the sugar beet petioles in 1961 is shown in Tables 47 through 49. In July the potassium content was decreased from approximately 4.86 to 4.07 per cent by the application of 348 pounds of phosphorus as a plow down application. The petioles from the August sampling date show an interaction between the planting time rates and placement of planting time fertilizer on the potassium content. When the 150 pound rate of fertilizer was placed under the seed the potassium content of the petiole decreased. However, at the 300 pound rate, the potassium content appeared to increase when the fertilizer was placed under the seed but this was not a significant increase. The potassium content of the petioles taken in September were still being influenced by the rate and placement of planting time fertilizer.

Table 42. The effect of time and method of application of fertilizer on calcium content[a] of sugar beet petioles, July 11, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time							
	0	150		300		Avg.		Avg.[c]
		S[b]	U[b]	S	U	S	U	
	(% Ca)							
0	1.29	1.66	1.29	1.28	1.32	1.41	1.30	1.39
87	1.12	1.13	1.14	1.20	1.18	1.15	1.15	1.16
174	1.27	1.21	1.29	1.18	1.18	1.22	1.25	1.22
348	1.14	1.14	1.10	1.05	1.02	1.11	1.09	1.08
Avg.	1.20	1.28	1.20	1.18	1.18			
LSD (0.05)								
Phosphorus levels						N.S.	N.S.	1.52*
Planting time levels						.21*	N.S.	
Placement						N.S.		

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not include the zero planting time values.
* Significant at five per cent level.

Table 43. The effect of time and method of application of fertilizer on calcium content[a] of sugar beet petioles, August 3, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(% Ca)						
0	1.53	1.36	1.44	1.59	1.57	1.49	1.51
87	1.21	1.42	1.43	1.36	1.29	1.33	1.31
174	1.24	1.24	1.43	1.41	1.28	1.30	1.32
348	1.16	1.25	1.15	1.24	1.24	1.22	1.19
Avg.	1.28	1.32	1.36	1.40	1.35		
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.

Table 44. The effect of time and method of application of fertilizer on calcium content[a] of sugar beet petioles, September 11, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(% Ca)						
0	1.03	1.13	.91	1.18	.99	1.11	.98
87	.86	.99	.87	1.01	1.05	.96	.93
174	.93	1.00	.91	1.04	.91	.99	.92
348	.86	.90	.84	.87	.93	.87	.88
Avg.	.92	1.00	.88	1.03	.97	1.02[c]	.93[c]
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						N.S.	N.S.
Placement						.08*	

[a] Average of three replications and reported on dry weight basis.
[b] S-Planting time fertilizer placed 1½ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These average values do not contain the zero planting time values.

Table 45. The effect of time and method of application of fertilizer on potassium content[a] of sugar beet tops, June 2, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(% K)						
0	5.14	5.55	5.07	6.23	6.75	5.64	5.65
87	4.97	5.65	5.27	5.95	7.13	5.52	5.79
174	4.95	5.27	5.05	5.93	6.92	5.38	5.64
348	4.59	4.98	5.47	5.44	6.97	5.00	5.67
Avg.	4.91	5.36	5.22	5.89	6.94	5.63[c]	6.08[c]
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						.31**	.49**
Placement						.23**	
Placement x planting time						.44**	

[a]Average of three replications and reported on dry weight basis.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c]These average values do not contain the zero planting time values.
**Significant at one per cent level.

Table 46. The effect of time and method of application of fertilizer on potassium uptake[a] by early growth of sugar beets, June 2, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(Gms. K/100 plants)						
0	.53	.95	2.02	1.28	3.61	.91	2.05
87	.86	1.63	2.35	1.77	4.40	1.41	2.54
174	1.00	1.69	2.33	2.05	3.97	1.57	2.43
348	1.16	1.81	3.08	2.20	4.66	1.72	2.96
Avg.	.88	1.52	2.45	1.83	4.16	1.67[c]	3.30[c]
LSD (0.05)							
Phosphorus levels						.34**	.41*
Planting time levels						.23**	.44**
Placement						.22**	
Placement x planting time						.31**	

[a] Average of three replications.
[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
[c] These averages do not contain the zero planting time values.
* Significant at five per cent level.
** Significant at one per cent level.

Table 47. The effect of time and method of application of fertilizer on potassium content[a] of sugar beet petioles, July 11, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(% K)						
0	5.15	4.75	4.77	4.86	4.49	4.92	4.80
87	4.35	4.22	4.27	4.32	4.17	4.30	4.27
174	4.35	4.14	4.00	4.19	3.99	4.23	4.11
348	3.91	4.20	4.03	4.15	4.20	4.09	4.05
Avg.	4.44	4.33	4.27	4.38	4.22		
LSD (0.05)							
Phosphorus levels						.52*	.41*
Planting time levels						N.S.	N.S.
Placement						N.S.	

[a]Average of three replications and reported on dry weight basis.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
*Significant at five per cent level.

Table 48. The effect of time and method of application of fertilizer on potassium content[a] of sugar beet petioles, August 3, 1961.

Phosphorus plowed down	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
(Lbs./A.)	(% K)						
0	4.33	4.14	3.82	3.95	4.18	4.14	4.11
87	3.58	4.15	3.87	3.93	3.92	3.88	3.79
174	3.66	3.72	3.91	3.74	3.88	3.71	3.82
348	4.03	4.29	3.89	4.04	4.10	4.12	4.00
Avg.	3.90	4.07	3.87	3.91	4.02		
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						N.S.	N.S.
Placement						N.S.	
Placement x planting time						.20*	

[a]Average of three replications and reported on dry weight basis.
[b]S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.
*Significant at five per cent level.

Table 49. The effect of time and method of application of fertilizer on potassium content[a] of sugar beet petioles, September 11, 1961.

Phosphorus plowed down (Lbs./A.)	Lbs./A. 6-24-12 applied at planting time						
	0	150		300		Avg.	
		S[b]	U[b]	S	U	S	U
	(% K)						
0	3.98	3.87	3.59	4.12	4.39	3.99	3.99
87	4.10	3.51	4.12	4.09	4.33	3.90	4.18
174	3.78	3.79	4.22	4.24	4.07	3.94	4.02
348	3.79	3.37	4.00	3.97	4.15	3.71	3.98
Avg.	3.91	3.63	3.98	4.11	4.24	3.88[c]	4.11[c]
LSD (0.05)							
Phosphorus levels						N.S.	N.S.
Planting time levels						.23**	N.S.
Placement						.20*	

[a] Average of three replications and reported on dry weight basis.

[b] S-Planting time fertilizer placed $1\frac{1}{2}$ inches to side and three inches below the seed.
U-Planting time fertilizer placed three inches under the seed.

[c] These averages do not include the zero planting time values.

* Significant at five per cent level.

** Significant at one per cent level.

CHAPTER III

THE RELATIONSHIP OF APPLIED PHOSPHORUS IN THE FIELD AND GREENHOUSE WITH PLANT GROWTH, PHOSPHORUS UPTAKE AND CHEMICALLY EXTRACTABLE PHOSPHORUS FROM THE SOIL

The aim of many research workers has been to determine measurable parameters that are well correlated with plant growth. Early workers searched for the one factor that was limiting growth. Since the very early work many elements have been found to be essential for plant growth. Present day research has been directed in part to measuring the amount and state of essential plant nutrients in different plant parts at different stages of growth and/or in the soil and soil solution, and correlating both with plant growth.

Review of Literature

A detailed discussion of phosphorus in the sugar beet plant is presented in Chapter II. The use of tissue analysis as a parameter for predicting final yield of the plant is desirable from the standpoint that it gives the actual content in the plant at time of sampling which in turn reflects the nutrient supply available to that particular crop. However, it is limited in predicting the quantity of fertilizer to be used for the crop because by the time a deficiency is determined by tissue test the plant has reached a stage of growth where final yield has already been adversely affected. A measure of available nutrients in the soil by soil test as a parameter for correlating yield could have an advantage over tissue testing. With the development of a suitable method of measuring the rate of phosphorus released from the soil during a given length of time, it would be possible to determine the amount of fertilizer that might be needed for optimum plant growth. This could be done prior to planting time and the plant could be assured of a sufficient quantity of the plant nutrient for optimum growth. One disadvantage of the soil test is that it is difficult to distinguish between the many chemical states of a particular nutrient as it appears in the soil and its rate of release from the heterogeneous soil complex. It has been found that the plant absorbs phosphorus from the soil solution (5, 15); thus, at any instant during the growth of the plant the phosphorus content in the soil solution must be replenished. The concentration of phosphorus in solution is a function of the solid phase phosphate since the soil solution is essentially in equilibrium with the solid phase. The nature of the solid phase has been described in two different ways (18): first, in terms of the minerological composition; and, second, in terms of the relationship between the amount of phosphorus in the soil solution and the amount of phosphorus on the surface of the solid.

Early chemists first turned their attention to complete soil analysis. It was found that the total nutrient content of the soil showed little relation to total plant growth. It wasn't until much later that attention was focused to different forms of the nutrients as they exist in different soils.

Truog (49) in 1930 used a solution of 0.002 N H_2SO_4 buffered to pH 3 with $(NH_4)_2\ SO_4$ to remove the greater portion of the readily available phosphorus from the soil. This readily available phosphorus was considered to exist as calcium and possibly magnesium phosphate. However, other investigators found that the solution was not as specific to the kinds of phosphate dissolved, and it was not as effective as certain other extractants in removing phosphorus from soil.

The use of HCl and NH_4F was proposed by Bray and Kurtz (9) for the purpose of extracting more than one form of phosphorus and at the same time removing those forms used most by plants. The two extrantants proposed were solutions of 0.025N HCl and 0.03N NH_4F for removing "absorbed" phosphorus and 0.1N HCl and 0.03N NH_4F for removing both acid soluble and "absorbed" phosphorus. The acid in these solutions was to dissolve a certain quantity of the more readily soluble phosphates and the fluorinewas introduced to replace the absorbed phosphorus in the soil. These two solutions will be designated as Bray 1 and Bray 2, respectively, when they appear in later discussions.

Spurway (44) suggested a soil test that used 0.135N HCl as the extracting agent for the removal of the so-called "reserve" portion of soil phosphorus.

Chang and Jackson (13) developed a method using a series of extractions on one sample of soil that was to separate out the following discrete chemical forms: water soluble phosphorus with 1.0N NH_4Cl, aluminum phosphate with 0.5N NH_4F pH 7.0, iron phosphate with 0.1N NaOH, calcium phosphate with 0.5N H_2SO_4, and reductant soluble iron phosphate.

Many workers have used other chemical solutions and methods of extraction to determine the amount of available phosphorus that is found in the soil under different conditions.

Other methods may also be used aside from chemical soil extraction, for example by the utilization of radioactive atoms. Fried and Dean (17) theorized that the amount of available nutrients in the soil could be found by relating the nutrient uptake by a plant from the soil to that of an added nutrient in an available form. They used the radioactive phosphorus isotope (P^{32}) in the added fertilizer to distinguish between the soil and added phosphorus. The available phosphorus in the soil was

computed by the following equation:

$$A = \frac{B\ (1-Y)}{Y}$$

Where A is the amount of available phosphorus in the soil, B is the amount of fertilizer in labelled form; and Y is the portion of the total phosphorus content in the plant which is labelled. Murdock and Seav (34) show that the amount of added fertilizer may alter the A values because high rate of phosphorus may affect the equilibrium of the soil nutrient. It has been found that at low rates of application this is not a problem.

Many investigators have tried to find a mathematical expression which would relate the quantity of plant nutrient present in the soil or plant tissue to growth and final yield. Two approaches to this problem are possible (40): first, a previous hypothesis is set up in the form of an equation that seems to fit the facts and then the experimental data is used to test the hypothesis; and, second, the experimental data are studied by statistical methods and an empirical equation or regression formula is fitted with no assumptions to the underlying causes.

Liebig in his "Law of the Minimum" was the first to express the relationship of plant nutrient to growth. He stated that plant growth is regulated by the factor present in minimum amounts and rises and falls accordingly as the quantity of this factor is increased or decreased. Thus, Liebig suggested a linear relationship between nutrient supply and growth. It has been found that the relationship of plant growth to the supply of certain essential nutrients is usually not linear but many times a sigmoid function. That is the change in plant growth with a change in nutrient supply is first increasing at an increasing rate, then it increases at a decreasing rate and then finally decreases. This final decrease is probably due to toxic quantities of plant nutrients present.

Mitscherlich was among the first to apply smooth curves to experimental data by use of the following equation: $\frac{dy}{dx} = (A-Y)\,C$; where Y is yield, x is the growth factor studied, A is the maximum yield obtainable if the growth factor was present in excess, and C a rate constant. Upon integration and assuming that y = 0 when x = 0: the following equation is obtained: $Y = A\,(1-e^{-Cx})$ or more commonly expressed as $\text{Log}\,(A-Y) = \text{Log}\,A - Cx$.

The majority of recent work with different methods for soil testing and correlating of data to plant growth has been through the use of statistic methods and empirical equations such as a quadratic. The difficulty of this is that the equation used may not be the correct one, but because it does a good job of explaining the data in a particular experiment it may be accepted; however, under different conditions it may not work at all.

Olsen et al. (38), using three calcareous soils found that the availability of residual phosphates in the soil as measured by the A-value of Fried and Dean was highly correlated to the total phosphorus uptake by oats. They also found that the phosphorus extracted by solutions of Bray 1, $NaHCO_3$ or pure water and surface phosphorus was highly correlated with the A-value. It was reported that the relative efficiency of the phosphate residues compared to a freshly added resin-phosphate varied from 26 to 56 per cent depending on the soil. They stated that the availability of the resin-phosphate was similar to that of a superphosphate. The difference in relative efficiency of the residue phosphate was assumed to be related more to the initial level of available phosphorus than to soil type.

Welch et al. (54) used three Alabama soils in an experiment to correlate the relative yield response to the log of soil test values for phosphorus. The solutions used for the measure of soil test values were 0.05N HCl + 0.025N H_2SO_4, 0.5M $NaHCO_3$, and 0.03N NH_3F + 0.1N HCl.

The regression equation computed was in the following form:

$$Y = b \log x - a$$

where Y is the relative yield of Ladino clover, **x** is the soil test values, and a and b are regression coefficients for a particular soil. It was found that all extractant solutions used were highly correlated to relative yield.

Bray (8) concluded from correlation studies of phosphorus soil test with the response of wheat through a modified Mitscherlich equation that variations in soil, season and variety did not change the relative response of wheat to a soluble phosphate fertilizer. The soil test solutions used were the Bray 1, Bray 2, and 0.5N NH_4F solutions. The final equation for relative yield of wheat was given as:

$$\log (A-Y) = \log A - .0184 b - 0.25 \log X$$

where b is pounds of sorbed phosphorus per two million pounds of soil determined by Bray 1 test and **x** is in terms of pounds of soluble P_2O_5 per acre applied in a broadcast and double-disced distribution pattern. It was found in this study that the value of A did vary from field to field but the two constants did not vary over a wide range of soil and season conditions.

Vajragupta *et al*. (52) found that by using Bray's 2 soil test and Bray's modification of the Micherlich equation (8) he could correlate rice soils of Thailand with fertilizer response of rice.

Smith *et al*. (43) using Bray 1 soil test showed a soil to solution ratio of 1:50 to be superior to 1:7 for estimating available P in calcareous soils.

Blanchar and Caldwell (7), using seven calcareous soils, found a high correlation between phosphorus uptake by peas and Bray 1 (1:50 soil to solution ratio) but not to Bray 1 (1:8 soil to solution ratio).

They also found a good correlation to Morgan solution P (extracted by NaOAC pH 7.0), exchange extractable resin-phosphorus or sodium bicarbonate extractable phosphorus.

Thomas (46) using a calcareous soil found that the uptake of phosphorus by plants was significantly related to phosphorus extractable by $NaHCO_3$ or Bray 1 solutions. He found that the amount of extractable and total phosphorus in the soil after 5 years of cropping were significantly correlated to prior fertilizer additions. He found a changing relationship between $NaHCO_3$ and Bray 1 extractable phosphorus with cropping which may reflect a conversion of phosphorus more readily absorbed by plants than Bray 1 forms and that some fractions of the dilute acid NH_3F soluble phosphorus replenishes the supply of $NaHCO_3$ extractable phosphorus.

Smith and Pesek (42) used Bray 1 as a soil test solution for predicting biological response to residual fertilizer phosphorus on several Iowa soils which were acid to calcareous. Significant correlations were obtained with various measurements in the field and greenhouse, including grain, total dry matter, yield of phosphorus on radioactivity determined A-values. They found that soil test phosphorus was highly correlated with greenhouse A-values and the relationship was essentially linear over the range of levels of residual phosphorus. One regression line describes this relationship for all neutral and acid soil tested but was different from that for a calcareous (pH 8.0) soil. The soil test was correlated with the A-values regardless of whether the phosphorus had been applied 1, 2, or 3 years previously.

Amer et al. (3), using 16 soils found that the Fried and Dean A-value for soil phosphorus was highly correlated with labelled inorganic phosphorus extracted by either Bray 1 solution or resin exchangeable phosphorus.

Van Diest *et al.* (53), using 70 soils which varied in pH from 5.4 to 8.3 reported that either phosphorus measured by Bray 1 solution or anion exchange resin as suggested by Amer *et al.* (3) correlated with the yield of phosphorus in plants grown on the soils in the greenhouse; however, the latter was the better of the two. The regression coefficients were smaller for alkali than acid soils; however, they suggested that no distinction of soil acidity was necessary when the $H_2PO_4^-$ and the $HPO_4^=$ taken up by the resin were correlated with phosphorus uptake.

Susuki *et al.* (45), using 17 Michigan soils which ranged in pH from 4.8 to 7.8 determined the extractable phosphorus by .002N H_2SO_4 solution, Bray 1 solution, 0.5M $NaHCO_3$ solution, resin P by exchange resin, and surface phosphorus by isotopic exchange. The A-value and uptake by cropping were also determined. In addition, they extracted these soils according to Chang and Jackson's (13) soil fractionation procedure. It was found that the soil extracts of Bray 1, $NaHCO_3$, resin phosphate, surface exchange and A-value all were highly correlated to the aluminum phosphate as extracted by the NH_4F solution in Jackson's fractionation procedure.

Al-Abbas (4) using 24 soils which ranged in pH from 6.0 to 7.0 following much the Jackson fractionation procedure and found that the iron phosphate fraction correlated best with phosphorus uptake in plants. It was found that the short term uptake of phosphorus by barley in the greenhouse was highly correlated with Truog P (extracted by 0.002N H_2SO_4). They found that the A-value, which may be more indicative of seasonal availability, was highly correlated with NaH_2SO_4, Bray 1 and resin phosphate. It should also be pointed out that the resin phosphate correlated well with both the short term uptake and the A-values.

Experimental Procedure

Soil samples were obtained from the field experimental area described in Chapter II for chemical analysis and greenhouse studies. A sample consisting of 20 soil cores taken to a depth of nine inches was obtained from each of the 12 replications of each plow down phosphorus level. The samples were obtained on the following dates: Section A--July 30, 1959, and August 16, 1961; Section B--July 8, 1960, and August 16, 1961; and Section C--August 16, 1961.

Each soil sample was analyzed for available phosphorus by extraction with Bray 1 solution (0.025N HCl plus 0.03N NH_4F) with a one to eight soil to solution ratio on a volume basis. Phosphorus in solution was determined by use of the molybdenum blue reduction method with 1-amino-2-naphthol-4-sulfonic acid as the reducing agent.

In addition, samples from Section A sampled July 30, 1959, were extracted with Bray 1 solution with one to 50 soil to solution ratio on a volume basis, and with Spurway (44) reserve solution (0.135N HCl).

Bulk soil samples were taken from Section A in the Fall of 1959 after application of broadcast phosphorus was made in the Spring. These samples were taken from one replication of each of the plow down phosphorus treatments (0, 87, 174 and 348 pounds of phosphorus applied per acre). These samples were air dried in the greenhouse, screened through a 1/4 inch screen and seven kilograms of each field treatment placed in each of 18 two gallon glazed clay pots. One-half of these crocks had one liter of water added and were kept moist in the greenhouse at approximately 25^{o} C. for 59 days and then air dried. Treatments consisting of 0, 16.7, and 33.4 ppm phosphorus were supplied as P^{32} labelled ammonium-dihydrogen-phosphate (12-62.2-0). Twenty-five ppm nitrogen as ammonium-dihydrogen-phosphate and ammonium nitrate and 88 ppm

potassium as potassium chloride were added to all pots and all fertilizer treatments mixed thoroughly with the soil prior to planting sugar beets. Approximately 40 sugar beet seeds were planted in each pot and thinned to 16 plants per pot 29 days after planting. The plants removed by thinning from all replications of a treatment were composited into one sample. Forty days after planting all but six beet plants were harvested from each pot. All the remaining beets were harvested 51 days after planting. The beet tops were dried, weighed, ground and pressed into pellets using a hydraulic press. Specific activity measurements of the pellets were made using a NMC decade scaler and a Geiger-Mueller counting tube. After counting, pellets were analyzed for phosphorus by wet perchloric digestion as described by Jackson (24).

After cropping the soil in each pot was sampled and available phosphorus determined with Bray 1 solution with a one to eight soil to solution ratio on a weight basis. In addition each sample was extracted by the modified phosphorus fractionation procedure of Chang and Jackson (13) as given in Chapter IV.

Results and Discussion

Each chemical extractant used to evaluate soil phosphorus reflected an increase in extractable soil phosphorus with each increasing level of plow down phosphorus (see Table 50). The quantity of phosphorus applied was highly correlated with each of the different extraction methods used as shown in Tables 51 and 52. This correlation was higher for samples taken two or three years after application of phosphorus than for samples obtained the same year. The higher degree of correlation may be due to a more complete mixing of the applied phosphorus during tillage for each succeeding crop; thus, a more representative sample was obtained.

Table 50. The effect of phosphorus application on extractable phosphorus in a Kawkawlin-Wisner silty clay loam soil.[a]

Phosphorus plowed down	Sampling area: Section A				Section B		Section C
	Sampling dates				Sampling dates		Sampling dates
	July, '59			Aug. '61	July, '60	Aug. '61	Aug. '61
	Bray 1-8[b]	Bray 1-50[b]	Reserve 1-8[b]	Bray 1 1-8[b]	Bray 1 1-8[b]	Bray 1 1-8[b]	Bray 1 1-8[b]
(Lbs./A.)	(Lbs. P./A)						
0	24	102	116	27	23	29	26
87	40	122	136	40	50	49	48
174	70	175	188	64	89	63	79
348	120	285	305	111	130	98	117
LSD (0.05)	17**	38**	39**	7**	13**	6**	10**
C V (%)	32	27	25	13	22	12	19

[a]Averages of 12 replications.
[b]Soil to extraction ratio.
**Significant at one per cent level.

Table 51. Correlation of yield, applied phosphorus and chemically extractable phosphorus, Section A.

		Linear Correlation Coefficients[a]					
		July 1959			Aug. '61	Yield	
		Reserve 1-8	Bray 1 1-8	Bray 1 1-50	Bray 1 1-8	Tons/A	Phosphorus plowed down
July 1959	Reserve[b] 1:8[c]	----	.91	.94	.79	.53	.83
July 1959	Bray 1[d] 1:8		----	.93	.82	.61	.84
July 1959	Bray 1 1:50			----	.79	.54	.82
Aug. 1961	Bray 1 1:8				----	.47	.95
Yield	Tons/A					----	.58
Phosphorus plowed down							----

[a] All correlations are significant at one per cent level.
[b] Spurway Reserves phosphorus soil test (44).
[c] Soil to extractant ratio.
[d] Bray 1 phosphorus soil test (9).

Table 52. Correlation of yield, applied phosphorus and chemically extractable phosphorus, Sections B and C.

	Linear Correlations Coefficients[a]					
	Section B			Section C		
	July, '60 Bray 1 1-8	Aug. '61 Bray 1-8	Yield Tons/A.	Aug. '61 Bray 1-8	Yield Tons/A.	Phosphorus plowed down
Section B						
July 1960 Bray 1[b] 1:8[c]	----	.88	.68			.91
Aug. 1961 Bray 1 1:8		----	.64			.95
Yield Tons/A 1960			----			.63
Section C						
Aug. 1961 Bray 1 1:8				----	.67	.92
Yield Tons/A. 1961					----	.66
Phosphorus plowed down						----

[a] All correlations are significant at one per cent level.

[b] Bray 1 phosphorus soil test (9)

[c] Soil to extractant ratio.

Yield was highly correlated with phosphorus extracted by each extracting solution as shown in Tables 51 and 52. The highest correlation was found with the Bray 1 (1:8 soil to solution ratio) data and yield of sugar beet roots in 1959. The linear forms of a regression equation and quadratic form of a multiple regression equation using yield (Y) in tons per acre as a function of soil test phosphorus (X) in pounds per acre are shown in Table 53.

In 1959 the correlation of yield with soil test phosphorus was improved by the use of a quadratic form of a multiple regression equation. In 1960 and 1961 the quadratic form of the multiple regression equation did not account for more variability than did the linear regression equation.

The yield, phosphorus content, and phosphorus uptake of sugar beets grown in the greenhouse as affected by field and greenhouse applications of phosphorus are shown in Tables 54, 55, and 56, respectively. Incubation of the soils at a moisture content approximating field capacity for 59 days in the greenhouse prior to fertilizer addition resulted in an increased early plant growth as indicated by the first two harvest periods. There was no difference in plant growth at final harvest due to incubation of the soils. The incubation had no effect on the phosphorus content of the sugar beet plants, but the uptake of phosphorus was increased. The influence of incubation on phosphorus uptake was greatest in the early stage of growth and was less marked at later stages. Thus, the incubation of the soil in a moist state prior to planting beets may have mineralized considerable phosphorus or other plant nutrients to an available form causing an increased growth and uptake of phosphorus.

The plant growth, phosphorus content, and phosphorus uptake were all influenced by the amount of phosphorus applied in the field. The phosphorus uptake by plants harvested 40 days after planting was greatest at the highest level of phosphorus applied in the field; however, plants

Table 53. Correlation of yield and extractable soil phosphorus.

Comparison		Regression equation	r	R
Yield	Phosphorus soil test			
Y	X			
Yield in 1959	Spurway reserve	$Y = 13.3 + 0.0178X$	0.53**	
		$Y = 8.0 + 0.070X - 0.0001X^2$		0.61**
Yield in 1959	Bray 1 (1:50)	$Y = 13.5 + 0.018X$	0.54**	
		$Y = 10.1 + 0.056X - 0.00001X^2$		0.58**
Yield in 1959	Bray 1 (1:8)	$Y = 14.0 + 0.040X$	0.61**	
		$Y = 11.8 + 0.117X - 0.00045X^2$		0.67**
Yield in 1960	Bray 1 (1:8)	$Y = 8.6 + 0.029X$	0.68**	
Yield in 1961	Bray 1 (1:8)	$Y = 12.27 + 0.043X$	0.67**	

**Significant at one per cent level.

Table 54. The effect of phosphorus application and incubation of soil on early growth of sugar beets in the greenhouse, 1960.

Phosphorus applied: Field (Lbs./A.)	Phosphorus applied: Greenhouse (Lbs./A.)	Days from planting time to harvest: 29[a] (Gms/pot)	40[b] (Gms/pot)	51[b] (Gms/pot)	Total Yield
0	0	.6	1.3	3.6	5.2
	33	.7	2.3	5.5	8.5
	66	.6	2.5	5.0	8.1
	0[c]	.7	2.6	4.7	8.0
	33[c]	.9	3.3	6.1	10.3
	66[c]	1.1	3.1	5.3	9.5
87	0	.3	2.2	5.0	7.5
	33	.3	2.0	5.5	7.8
	66	.3	1.8	6.5	8.6
	0[c]	.7	2.1	6.4	9.2
	33[c]	1.0	2.5	6.3	9.8
	66[c]	.5	2.8	5.9	9.2
174	0	.3	1.9	7.6	9.8
	33	.5	1.9	7.7	10.1
	66	.5	2.1	6.9	9.5
	0[c]	.9	4.1	7.5	12.5
	33[c]	1.1	4.2	6.8	12.1
	66[c]	1.0	4.0	5.9	10.9
348	0	.3	2.0	6.1	8.4
	33	.2	1.1	6.6	7.9
	66	.3	1.3	6.1	7.7
	0[c]	.8	3.5	7.2	11.5
	33[c]	1.5	4.8	7.2	13.5
	66[c]	1.2	4.4	6.5	12.1
LSD (0.05)					
Field phosphorus levels			.50*	.43**	
Greenhouse phosphorus levels			N.S.	N.S.	
Incubation			.32**	N.S.	
Field phosphorus x incubation			.78**	N.S.	

[a] Values obtained from a single sample for each treatment by compositing all replications at this harvest period.

[b] Average of three replications.

[c] Pots incubated in the greenhouse at field capacity for 59 days prior to addition of greenhouse phosphorus.

* Significant at five per cent level.

** Significant at one per cent level.

Table 55. The effect of phosphorus application and incubation of soil on the phosphorus content of sugar beets in the greenhouse, 1960.

Phosphorus applied Field (Lbs./A.)	Greenhouse (Lbs./A.)	Days from planting time to harvest 29[a] (% P)	40[b] (% P)	51[b] (% P)
0	0	.133	.151	.133
	33	.267	.244	.225
	66	.330	.266	.254
	0[c]	.197	.132	.114
	33[c]	.370	.220	.228
	66[c]	.381	.273	.291
87	0	.386	.232	.176
	33	----	.265	.239
	66	.247	.269	.290
	0[c]	.230	.206	.152
	33[c]	.347	.233	.245
	66[c]	.355	.277	.304
174	0	.324	.234	.253
	33	.390	.296	.277
	66	.410	.300	.322
	0[c]	.437	.241	.256
	33[c]	.446	.241	.272
	66[c]	.392	.270	.306
348	0	.507	.284	.285
	33	.330	.288	.280
	66	.446	.472	.345
	0[c]	.460	.357	.270
	33[c]	.460	.283	.309
	66[c]	.521	.365	.378
LSD (0.05)				
Field phosphorus levels			.018**	.022**
Greenhouse phosphorus levels			.016**	.013**
Incubation			N.S.	N.S.
Field x greenhouse phosphorus			.031**	.027**
Field x greenhouse phosphorus x incubation			.044**	N.S.

[a] Values obtained from a single sample for each treatment by compositing all replications at this harvest period.
[b] Average of three replications.
[c] Pots incubated in the greenhouse at field capacity for 59 days prior to addition of greenhouse phosphorus.
* Significant at five per cent level.
** Significant at one per cent level.

Table 56. The effect of phosphorus application and incubation of soil on phosphorus uptake by sugar beets in the greenhouse, 1960.

Phosphorus applied Field (Lbs./A.)	Greenhouse	Days from planting time to harvest 29[a]	40[b] (Mg./pot)	51[b]	Total uptake
0	0	.7	2.0	4.7	7.4
	33	1.9	5.5	12.3	19.7
	66	1.9	6.7	12.6	21.2
	0[c]	1.4	3.4	5.4	10.2
	33[c]	3.2	7.2	13.7	24.1
	66[c]	4.1	8.5	15.5	28.1
87	0	1.1	5.1	8.9	15.1
	33	.5	5.2	13.1	18.8
	66	.6	4.8	19.0	24.4
	0[c]	1.6	4.2	10.8	16.6
	33[c]	3.3	5.9	15.5	24.7
	66[c]	1.8	7.7	17.5	27.0
174	0	.9	4.5	19.2	24.6
	33	2.1	5.6	21.6	29.3
	66	2.1	6.3	22.1	30.5
	0[c]	3.9	9.6	19.1	32.6
	33[c]	5.1	9.9	18.7	33.7
	66[c]	3.9	10.9	17.7	32.5
348	0	1.7	5.6	17.2	24.5
	33	1.7	3.3	18.5	21.5
	66	1.2	5.9	20.6	27.7
	0[c]	3.5	12.5	19.9	35.1
	33[c]	7.0	13.6	22.2	42.8
	66[c]	6.1	16.5	24.7	47.3
LSD (0.05)					
Field phosphorus levels			1.1**	1.8**	
Greenhouse phosphorus levels			1.2**	1.4**	
Incubation			.8**	N.S.	
Field x greenhouse phosphorus			N.S.	2.9**	
Field phosphorus x incubation			1.5**	2.3*	

[a] Values obtained from a single sample for each treatment by compositing all replications at this harvest period.
[b] Average of three replications.
[c] Pots incubated in the greenhouse at field capacity for 59 days prior to addition of greenhouse phosphorus.
* Significant at five per cent level.
** Significant at one per cent level.

harvested 51 days after planting showed no significant difference between the 174 and 348 pounds per acre of phosphorus levels. This indicates that the sugar beet plant needs a high amount of readily available phosphorus for early growth, but at later stages of growth and with extensive root systems it can obtain sufficient phosphorus from soils lower in readily available phosphorus. This may also be seen in Table 50 which shows extractable phosphorus; Tables 2, 3, and 4 which show the final yield of sugar beets; and Tables 2, 5, and 6 which show the early growth of sugar beet plants in the field. These data indicate that the early growth is influenced much more than final yield by higher amounts of extractable phosphorus. It can also be concluded from this that response of sugar beets to phosphate fertilizers in Michigan should be much greater on soils with less than 70 pounds per acre of extractable phosphorus by Bray 1 soil test (1:8 soil to solution ratio) as compared to those having soil tests higher than 70 pounds per acre.

The A-value as defined by Fried and Dean (17) is a measure of the available phosphorus in the soil. The A-values for the Kawkawlin-Wisner soil are shown in Table 57 as computed from three harvest periods. The A-values from the first harvest were computed from single values and are variable, particularly where there was no phosphorus applied in the field. The average A-values for all harvest periods are 28, 57, 176, and 240 pounds per acre available phosphorus where 0, 87, 714 and 348 pounds of phosphorus per acre, respectively, were applied in the field. Incubation of the soils in the greenhouse for 59 days prior to planting appeared to lower the available phosphorus as measured by A-values. The A-values as determined from the 40 day harvest were highly correlated with those from the 51 day harvested material (see Table 59). Both were highly correlated to Bray 1, water soluble, and aluminum phosphate phosphorus indicating that these forms are available for plant growth. There was no linear correlation between greenhouse

Table 57. The effect of phosphorus application and incubation of soil on A-values computed using sugar beets in the greenhouse, 1960.

Phosphorus applied in field	Days from planting time to harvest			
	29[a]	40[b]	51[b]	
			L[d]	H[d]
(Lbs./A.)	(A-values Lbs./A.)			
0	15	29	32	19
0[c]	58	31	35	18
87	--	61	60	45
87[c]	64	57	54	47
174	173	204	174	185
174[c]	170	167	183	144
348	228	249	279	259
348[c]	246	217	225	239
LSD (0.05)				
Field phosphorus levels		27**	12**	
Incubation		11*	8*	
Greenhouse phosphorus levels		N.S.	9*	

[a] Values obtained from a single sample for each treatment by compositing all replications at this harvest period.
[b] Average of six replications.
[c] Pots incubated in the greenhouse at field capacity for 59 days prior to addition of greenhouse phosphorus.
[d] L-Low level of greenhouse phosphorus, 33 pounds per acre.
H-High level of greenhouse phosphorus, 66 pounds per acre.
* Significant at five per cent level.
** Significant at one per cent level.

Table 58. The effect of phosphorus application and incubation of soil on the extractable phosphorus after growing sugar beets in the greenhouse,[a] 1960.

Phosphorus applied Field	Greenhouse	Bray 1 (1:8)[b]	Water[c] soluble	Aluminum[c] phosphate	Iron[c] phosphate	Calcium[c] phosphate
(Lbs./A.)		(ppm P)				
0	0	10	2	16	22	94
	33	15	5	38	27	101
	66	20	-	56	46	86
	0[d]	11	4	18	22	94
	33[d]	16	4	36	27	96
	66[d]	20	-	47	34	102
87	0	13	4	37	33	105
	33	22	9	43	27	86
	66	24	6	47	28	83
	0[d]	15	4	37	28	96
	33[d]	22	6	44	36	89
	66[d]	24	16	51	24	95
174	0	28	10	40	30	107
	33	35	13	60	31	98
	66	41	20	70	35	95
	0[d]	29	15	47	32	99
	33[d]	34	25	56	33	97
	66[d]	42	21	66	32	109
348	0	38	20	61	29	111
	33	46	21	64	34	93
	66	51	34	82	33	87
	0[d]	34	20	54	30	99
	33[d]	46	27	61	35	96
	66[d]	52	38	78	32	95
LSD (0.05)						
Field phosphorus		5.6**	5.7**	2.8**	2.2*	N.S.
Greenhouse phosphorus		1.5**	2.7**	4.2**	3.0*	N.S.
Incubation		N.S.	2.5*	N.S.	N.S.	N.S.

[a]Average of three replications.
[b]Soil to solution ratio.
[c]Chang and Jackson phosphorus fractionation procedure (13).
[d]Pots incubated in the greenhouse at field capacity for 59 days prior to addition of greenhouse phosphorus.
*Significant at five per cent level.
**Significant at one per cent level.

Table 59. The correlation of applied phosphorus, phosphorus uptake, plant growth, and chemically and biologically determined phosphorus.

	Linear correlation coefficients					
	A-values 40 days	A-values 51 days	Phosphorus uptake 40 days	Phosphorus uptake 51 days	Total phosphorus uptake	Total growth
A-values[a] 40 day growth	----					
A-values[a] 51 day growth	.94**	----				
Phosphorus uptake 40 days	.26	.25	----			
Phosphorus uptake 51 days	.71**	.71**		----		
Phosphorus plowed down	.89**	.95**	.43**	.68**	.65**	.41**
Greenhouse applied phosphorus	-.01	-.06	.28*	.43**	.41**	.06
Bray 1 1:8[b]	.87**	.90**	.47**	.79**	.74**	.42**
Water soluble[c] phosphorus	.79**	.81**	.60**	.67**	.72**	.37**
Aluminum-phosphorus[c]	.80**	.75**	.46**	.76**	.71**	.35**
Iron-phosphorus[c]	.13	.12	.14	.29*	.26	.19
Calcium-phosphorus[c]	-.18	-.17	-.10	-.07	.05	-.01

[a] A-values as determined by Fried and Dean (17).
[b] Bray Soil Test (9) 1:8 soil to solution ratio.
[c] Chang and Jackson's (13) phosphorus fractionation.
* Significant at five per cent level.
** Significant at one per cent level.

phosphorus application and A-values for the 40 day harvest; however, at the 51 day harvest greenhouse application of phosphorus lowered the A-values. A-values were not correlated with the phosphorus uptake at the 40 day harvest, but they were highly correlated to the phosphorus uptake at 51 day harvest. Iron and calcium phosphate contents were not correlated to A-values.

The early phosphorus uptake by sugar beets in the greenhouse was more highly correlated to water soluble phosphorus than other extractable forms, but the latest harvest indicated that phosphorus uptake is correlated more with Bray 1 and aluminum phosphate and A-values than other forms of extracted phosphorus. Phosphorus uptake by sugar beets in the greenhouse was not correlated with the amount of extractable calcium phosphate in the soil.

Bray 1, water soluble and aluminum phosphate phosphorus were reflecting the field and greenhouse applications of phosphorus (see Tables 58 and 60). The iron-phosphate and calcium-phosphate fractions showed no linear correlation with applied phosphorus, but the iron-phosphate fraction was increased by field and greenhouse phosphorus application when comparing zero phosphorus levels to higher application levels of field or greenhouse phosphorus.

Table 60. The correlation of phosphorus application and chemically extractable phosphorus.

	Linear correlation coefficients		
	Phosphorus plowed down field	Phosphorus applied in greenhouse	Bray 1 1:8
Bray 1 1:8[a]	.85**	.37**	----
Water soluble phosphorus[b]	.45**	.45**	.83**
Aluminum-phosphorus[b]	.70**	.56**	.86**
Iron-phosphate[b]	.15	.16	.34**
Calcium-phosphate[b]	-.01	.01	-.02

[a] Bray 1 Soil Test (9) 1:8 soil to solution ratio.

[b] Chang and Jackson phosphorus fractionation (13).

** Significant at one per cent level.

CHAPTER IV

THE RELATION OF CHEMICALLY EXTRACTABLE PHOSPHORUS TO OTHER PHYSICAL AND CHEMICAL PROPERTIES OF TEN MICHIGAN SOILS

There are many soil types in Michigan similar to the Kawkawlin-Wisner silty clay loam soil that have a potential for sugar beet production. The quantity and forms of phosphorus found in these soils are very important in growth of sugar beets. A laboratory experiment was conducted to characterize the inorganic phosphorus in ten Michigan soil profiles by the use of a modification of Chang and Jackson's phosphorus fractionation procedure (13) and to correlate the extractable phosphorus with other physical and chemical properties of the soil profile.

Review of Literature

In general, phosphorus fertilizers consist of chemical compounds that are too soluble to persist in soils; consequently, they disappear with the formation of products that are more stable in the soil environment. The solubility product principle has been used by many investigators to explain this behavior of soil phosphorus. Because the soil-solution is a heterogeneous system, soil phosphorus reactions cannot be adequately explained in terms of the reaction properties which exist where the fertilizer or its solution phase contacts the soil.

When water soluble salts such as monocalcium phosphate (MCP) dissolve in a deficiency of water in the soil, solutions which are nearly saturated are produced (23).

Monocalcium phosphate, $Ca(H_2PO_4)_2$, is one of the most widely used forms of water-soluble phosphorus in fertilizers. Brown and Lehr (12) used the phase rule in explaining the chemical behavior of MCP in soils by conducting experiments using a system of $CaO-P_2O_5-H_2O$ and obtaining the phosphorus solubility isotherm for the system. By shaking a water system with excess MCP for periods of one minute to 17 days they found that after one minute the solution was saturated with respect to dicalcium phosphate dihydrate, $CaHPO_4 \cdot 2H_2O$, (DCPD). The solution also had molar concentration of 3.5 and 1.4 for phosphorus and calcium, respectively. By one hour the solution had reached the metastable triple point (MTPS) equilibrium of a system of MCP and DCPD. This MTPS persisted for 24 hours after which anhydrous dicalcium phosphate was found to exist and then the solution composition changed to that of the stable triple point solution (TPS) of a system of MCP and DCP. The pH of this solution is 1.01 at the TPS and 1.48 at the MTPS. It was concluded that the dissolution of MCP in soils should yield solutions of composition similar to that of MTPS and possibly of TSP. By use of the solubility isotherms for the system of MCP and water they predicted the amount of MCP that would be left at the sight of the granule as DCP or DCPD. The equilibrium data that these authors (12) reported taken from the literature suggested that a residue of DCP will contain approximately 28 per cent of the phosphorus added. Brown and Behr found from experimental data using five soils at two moisture levels, 0.5 and 1.0 times moisture equivalent, that the observed values for the amount of phosphorus precipitated as DCP were higher than those predicted at the moisture equivalent of soils by nine per cent, and showed excellent agreement at the 0.5 moisture equivalent level.

Since the vapor pressure of the saturated solution is only about 0.9 that of the soil water, vapor transfer accounts for much of the movement of moisture into the pellet (23). Lehr et al.(30) using fertilizer tablets containing monocalcium phosphate monohydrate, $Ca(H_2PO_4)_2 \cdot H_2O$, which were placed in several soils concluded that capillary flow was the principle mechanism of movement of phosphate solution away from the tablet. Vapor-phase transport controlled the rate of dissolution and when phosphate from the tablet solution reacts with constituents of the soil, vapor from the depleted solution could recycle to the tablet, thereby hastening dissolution, as was the case with the Webster soil. It was also found that as MCP dissolved a coarsely porous residue of DCP was formed from which the soil particles readily blotted the phosphorus solution. When this soil phosphorus solution which dissolved from the MCP granule moves through the soil, other ions present may influence the solubility of the phosphate ion and its precipitation products. Ferric iron, Al^{+++}, Ca^{++}, Mg^{++}, K^+, NH_4^+, H^+, OH^-, and F^-, must be considered as potential reactants with the phosphate ions in solution and their activity may largely determine the fate of the phosphate ion.

Weathering of soils may release iron and aluminum and form crystalline or amorphous iron or aluminum hydrous oxides (25). The iron activity would most likely be governed by freshly precipitated amorphous hydrous iron oxide and it is not likely that it will be less than that in equilibrium with goethite (FeOOH) (32). Of the hydrous aluminum oxides identified in soil, gibbsite is considered to be the most stable (28). Thus, the aluminum activity would be expected to be governed by the amorphous oxide or that in equilibrium with gibbsite.

Calcium and magnesium activities may be governed by the solubility of their carbonates and partial pressure of CO_2. The exact compound that governs the activity of these two ions in acid and neutral soils is not known. But Lindsay and Moreno (32) assumed that calcium and magnesium activity in solution were governed by the exchange complex of the soils. Potassium activity is governed by minerals such as

orthoclase, feldspar, muscovite, illite or other potassium silicates.

Ammonium ion may be similar to that of potassium or its activity may be controlled by microorganism. Both hydrogen and hydroxyl ions are involved in all soil phosphate reactions and many other reactions of the soil.

Fluorine is also present in the soil and it may be present as alumino-fluorosilicates in acid soils or CaF_2 in neutral or alkaline soils.

Lindsay and Moreno (32) used the activity isotherms for $AlPO_4 \cdot 2H_2O$ (variscite), $FePO_4 \cdot 2H_2O$ (strengite), $Ca_{10}(PO_4)_6F_6$ (fluoroapatite), $Ca_{10}(HPO_4)_6(OH)_2$ (hydroxyapatite), $Ca_4H(PO_4)_3 \cdot 3H_2O$ (Octocalcium phosphate) and $CaHPO_4 \cdot 2H_2O$ (dicalcium phosphate dihydrate) to represent a single solubility diagram in which the function of the phosphate activity in solution was plotted against pH. This plot of the pH_2PO_4 as a linear function of pH in the presence of soil and soil solutions can be used for determining the relative solubility of these phosphate compounds and for predicting their transformation in soils upon the application of fertilizer or lime.

Lindsay et al. (31), by the use of X-ray, petrographic and chemical analysis, identified approximately 30 crystalline phosphate compounds and colloidal precipitates that were formed when fertilizers were allowed to dissolve in a soil. Two of the soils used were a Webster silty clay loam, pH 8.3 and Gila loam, pH 8.5. When MCP was reacted with Webster soils the MTPS with pH 1.48 was formed. As the reaction time was increased from 15 minutes to three days the pH increased and phosphorus precipitated from solution. During this period aluminum continued to dissolve from the soils in contact with the MTPS; whereas, soluble iron at first increased, then decreased. Filtrates obtained during the three day reaction period yielded precipitates upon standing which were identified as colloidal ferri-aluminum phosphates, (FeAlX)

$PO_4 \cdot nH_2O$ of indefinite composition (X indicating the presence of cations other than iron and aluminum and n indicating a variable content of water.

By adding such compounds as $Fe_2O_3 \cdot H_2O$, $Al(OH)_3$, NH_4^+ or K^+ salts other phosphates precipitated which included these added elements. If sufficient $Al(OH)_3$ is added to raise pH above two, $CaHPO_4 \cdot 2H_2O$ or $CaHPO_4$ was formed. An accompanying study was also made with dilute MTPS in order to simulate conditions near fertilizer bands as the initial fertilizer solution is later diluted by incoming moisture. When soil was reacted with diluted MTPS the reactions proceeded more slowly; nevertheless, colloidal $(FeAlX)PO_4 \cdot nH_2O$ did form in the filtrate. Small additions of $Fe_2O_3 \cdot H_2O$ to dilute MTPS formed a finely divided crystalline phase identified by X-ray as $FePO_4 \cdot 2H_2O$ coated on particles of the undissolved oxide. Gradual increase in pH during the two month reaction period was interpreted as indicating a continuation of the reactions. The following are some of the phosphate compounds that were identified as reaction products of MCP fertilizer in soil and soil components:

$HCaAl(PO_4)_2 \cdot 6H_2O$, Amorphous $(Fe, Al)PO_4 \cdot nH_2O$, $FePO_4 \cdot H_2O$ (Strengite), $FePO_4 \cdot 2H_2O$ (metastrengite) $H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$ (Taranakite).

Huffman (23) reports that soil pH is a very important consideration when selecting a source of phosphorus for plant growth. He reports on work done by Lindsay and Taylor who compared plant response to the amorphous and crystalline iron and aluminum phosphates and the monocalcium phosphate monohydrate on soils which varied in pH from 5.5 to 8.8. They reported that monocalcium phosphate was by far the superior source of phosphorus in the acid soil, with strengite and variscite virtually inert and the amorphous materials intermediate in value.

In the calcareous soil, however, the amorphous phosphates and the variscite were superior to the monocalcium phosphate and even the uptake from strengite was 17 per cent greater than that from the calcium phosphate.

As seen from the previous review, inorganic phosphate in the soil may be classified into four main groups: calcium phosphate, aluminum phosphate, iron phosphate and occluded or reductant soluble phosphate (13).

A procedure for fractionating the above forms from soils and soil profiles that have not had recent application of fertilizers was proposed by Chang and Jackson (13) and modified by Fife (16) and Glenn et al. (20). In the original procedure by Chang and Jackson one gram of soil was used which was extracted by a series of solutions. The first solution used was 1N NH_4Cl to remove the water soluble and loosely bound phosphorus and the exchangeable calcium. It was concluded that there would be very little phosphorus naturally occurring in the soil found in this form in most soils. The second solution used was 0.5N NH_4F, pH 7.0 to remove the aluminum phosphate from a pure aluminum phosphate mineral, variscite. It was also found that this solution removed considerable iron phosphorus. Fife (16) suggested raising the pH of the NH_4F solution to eight or above so that there would be a minimum of fluoroferrate complex formed. With this change it was found by Glenn et al. (20) that there was a very negligible amount of iron phosphate removed by the NH_4F solution. M. L. Jackson[1] agreed that dicalcium as well as monocalcium will be dissolved to a major extent, if present in the soil, by ammonium fluoride. The third solution used was 0.1N NaOH to remove the iron phosphate mineral, strengite. It was found that this extract removed 100 per cent of both strengite and variscite present in the pure

[1]Personal communication.

state, but did not remove more than a trace from pure apatite. Thus, this solution must follow the NH_4F solution to separate iron from aluminum phosphate.

Originally Chang and Jackson used a 0.5N H_2SO_4 solution next in sequence to remove calcium phosphate but it was pointed out by Glenn et al. (20) that this solution removed a considerable quantity of reductant soluble and occluded phosphate, and it was found (13) that the occluded phosphate procedure removed little calcium phosphate. The procedure was changed to remove reductant soluble and occluded phosphate before using H_2SO_4 to remove calcium phosphate. This was done by using one gram of $Na_2S_2O_4$ citrate in 40 ml of 0.3 M sodium citrate to reduce the iron present in the soil and bring it into solution. After the extraction of reductant soluble iron phosphate, then the 0.1N NaOH solution was used to remove occluded iron and aluminum phosphates.

Experimental Procedure

Soil profiles were selected for study that had a high clay content and a pH of subsoil horizons near or above seven. Selections were made from profile samples collected under Michigan Agricultural Experiment Station Project 413.

Soil type, location and a brief description of the soils used are given in Table 61. The following data were obtained from Project 413:[1]

1) clay content as determined by the pipet method,
2) pH of a one to one soil to distilled water ratio measured by a glass electrode,
3) ammonium acetate extractable calcium measured by use of a Beckman DU flame photometer at 422.7 mμ wavelength.

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[1]Data supplied by A. E. Erickson.

Table 61. Soil type, location, and drainage of the ten soil profiles studied.

Soil Type	Location	Physiographic position
Hoytville clay I	NW$\frac{1}{4}$ of SW$\frac{1}{4}$ Sec. 15, T8S, R3E	Shallow depression till plain
Hoytville clay loam II	Sec. 12, T8S, R5E	Lake bed
Paulding clay	Sec. 25, T4N, R13E	Lake bed
Pickford silty clay I	NE$\frac{1}{4}$ of NE$\frac{1}{4}$ of NE$\frac{1}{4}$ Sec. 25, T46N, R1W	Lake bed
Pickford clay II	SE$\frac{1}{4}$ of NE$\frac{1}{4}$ of NE$\frac{1}{4}$ Sec. 17, T20N, R6E	Lake bed
Pickford clay III	NE$\frac{1}{4}$ of SW$\frac{1}{4}$ of NE$\frac{1}{4}$ Sec. 20, T48N, R40W	Till plain
Selkirk silty clay loam I	NW$\frac{1}{4}$ of NW$\frac{1}{4}$ of NW$\frac{1}{4}$ Sec. 25, T31N, R4E	Till plain
Selkirk loam II	SW$\frac{1}{4}$ of SW$\frac{1}{4}$ of SW$\frac{1}{4}$ Sec. 9, T20N, R6E	Till plain
Sims loam I	NW$\frac{1}{4}$ of NW$\frac{1}{4}$ Sec. 33, T9N, R3E	Till plain
Sims loam II	SE$\frac{1}{4}$ of NE$\frac{1}{4}$ Sec. 28, T13N, R8E	Humic Gley

4) Spurway reserve phosphorus (44) colorimetrically determined by the molybdenum blue reduction method, and

5) Bray 1 (9) extractable phosphorus which was extracted with a one to eight soil to solution ratio and determined colorimetrically by the molybdenum blue reduction method.

All soil horizons were fractionated by a modification of Chang and Jackson's fractionation procedure (13). The following modifications were used: 1) the pH of the NH_4F solution was adjusted to 8.2, and 2) the order of extraction was changed so that the NaS_2O_3 solutions and second solution of NaOH were used before the H_2SO_4 solution.

The phosphorus in the reductant soluble iron fraction is not recorded because of the difficulty encountered in determining phosphorus. However, in all cases the sodium dithionite extraction was used ahead of the H_2SO_4 solution.

The iron content of the NaS_2O_3 extract was determined according to Jackson (24). All determinations were made in duplicate.

The data were analyzed on the control data processing 3600 computer as a simple correlation problem by using the existing programs in the computer library of Michigan State University.

Results and Discussion

Chemical and physical data and correlations for ten Michigan soil profiles are shown in Tables 62 and 63. In general, the water soluble phosphorus of these soils was very low. It showed a slight correlation to the Bray 1 soil test which could be expected as the Bray test removes all this phosphorus fraction. The water soluble fraction showed a high negative correlation to calcium content, soil pH and clay content. Since calcium content is related to pH, these two relations should be expected to affect the water soluble phosphorus in a similar manner.

Table 62. Some of the physical and chemical characteristics of ten soils of Michigan.

Horizon	Depth of horizon (inches)	Clay content (%)	Texture[a]	pH of soil	NH_4OAc extrac. Ca (Lbs./A.)	Fe (ppm)	Reserve P^b	Bray 1 P^c	Water soluble P^d (Lbs./A.)	Al-P^d	Fe-P^d	Ca-P^d
Sims loam I												
Ap	0-7	25.8	l	6.2	7392	2475	54	42	19.6	30.6	45.0	90.8
B_1G	7-22	29.1	c	6.8	4872	4084	66	13	5.9	12.0	23.2	124.0
B_2G	22-25	30.7	c	7.4	4023	5692	108	7	7.4	1.5	13.1	149.2
B_3G	26-29	32.8	c	7.2	4023	5866	120	7	14.8	0.0	20.5	151.0
C	37-40	40.0	c	7.4	4368	7252	156	4	5.7	2.0	27.2	215.0
Sims clay loam II												
Ap	0-7	26.3	cl	7.4	7392	1732	144	32	-	35.8	26.3	118.0
B_{1g}	7-10	25.0	cl	7.6	7728	1485	114	21	-	34.4	22.3	113.6
B_{2g}	10-16	27.0	cl	7.8	5544	2104	120	9	-	18.2	11.6	132.6
C	16+	28.8	cl	7.8	4872	2822	144	8	-	15.3	7.2	167.0
Selkirk silty clay loam I												
Ap	0-8	34.3	sicl	7.4	6216	3391	70	17	-	19.8	39.6	78.2
B_2G	8-16	48.3	c	7.4	7392	4034	170	15	-	16.0	34.2	186.6
CG	16+	60.7	c	7.7	9240	2871	3.5	8	-	4.0	4.0	240.1
Selkirk loam II												
Ap	0-9	19.9	l	7.2	4268	2277	65	12	-	24.8	18.8	56.2
B_{2g}	9-12	41.3	c	7.3	6552	2896	108	9	4.2	22.5	29.2	155.9
C	12-18	46.9	c	7.8	8064	2228	4	9	5.7	13.1	5.4	212.8
Paulding clay												
Ap	0-6	61.2	c	5.3	6552	4628	14	33	-	35	84.8	79
G_1	6-12	69.1	c	5.8	6048	6633	6	18	-	12	44.6	76.4
G_2	12-18	66.5	c	5.9	5880	8093	33	18	-	13.9	57.9	65.3
G_3	18-24	69.5	c	6.1	6384	8786	70	13	-	10	50.0	50
G_4	24-36	71.5	c	6.7	7392	7747	12	13	-	7.8	45.6	99

Pickford silty clay I												
Ap	0-8	30.8	sic	5.1	4200	742	70	25	5.9	31.7	12.4	53.0
A_2G	8-13	50.5	sic	7.1	6216	3020	413	12	2.0	28.3	3.8	131.9
B_2G	13-23	64.9	c	7.7	9408	4826	--	17	-	21.0	7.9	151.5
C	23+	74.6	c	7.9	10080	4579	7	16	-	16.3	-	143.0
Pickford clay II												
Ap	0-8	40.8	c	7.2	9408	1559	95	13	-	17.9	30.2	61.6
B_{1g}	8-11	53.8	c	7.3	8736	2228	145	15	-	17.3	11.7	71.3
B_{2g}	11-15	50.8	c	7.3	8568	2426	185	13	-	20.5	7.9	80.2
B_{3g}	15-36	51.8	c	7.2	7728	2351	215	10	-	24.3	4.9	89.3
Pickford clay III												
Ap	0-8	85.9	c	5.1	6888	8539	9	9	-	45.2	156.4	48.5
B_g	8-15	81.8	c	5.8	8568	10048	7	19	-	32.8	114.8	47.6
C_{1g}	15-30	90.2	c	7.0	10248	8613	138	13	-	31.6	37.1	187.9
C_2	30+	70.4	c	7.6	8904	7994	180	10	-	15.4	9.9	350.2
Hoytville clay I												
Ap	0-7	50.2	c	6.0	6216	3529	42	25	6.4	27.3	97.6	156.0
G_1B	$7-12\frac{1}{2}$	42.0	c	6.3	5880	4826	61	15	9.9	3.4	48.0	198.0
G_2B	$12\frac{1}{2}-44$	44.0	c	6.6	5880	6559	90	12	10.0	2.2	46.0	210.9
Hoytville clay loam II												
Ap	0-8	40.0	cl	5.9	8904	2970	10	10	4.7	22.4	25.2	187.8
AG	8-12	45.7	c	6.2	9744	5841	6	7	4.4	5.7	20.6	238.3
B_1G	12-21	43.9	c	6.8	9744	5941	35	8	-	9.6	17.8	244.8
B_2G	21-26	44.8	c	7.0	10248	6262	27	31	-	24.1	42.8	307.4
C	26+	44.5	c	7.7	10584	7747	4	13	-	15.4	8.9	275.5

[a] The following are abbreviated: c = clay; si = silt, l = loam.
[b] Spurway reserve phosphorus soil test with one to eight soil to solution ratio (44).
[c] Bray 1 soil test with one to eight soil to solution ratio (9).
[d] Phosphorus fraction from Chang and Jackson (13).

Table 63. The correlations of chemical and physical properties of ten Michigan soil profiles.

	Linear correlation coefficients									
	Ca	Res. P	Water solu. P	NaS_2O_3 Ext. Fe	Bray 1 P	Al-P	Clay content	Ca-P	Fe-P	Soil pH
Ammonium acetate extractable calcium	----	-.22*	-.42**	.16	-.00	.14	.47**	.40**	-.10	.22*
Reserve phosphorus 1:8		----	-.06	-.27*	-.19	-.01	-.19	-.02	-.35**	.34**
Water soluble phosphorus			----	-.07	.27*	-.00	-.36**	-.05	.23*	-.25*
Sodium dithionite extractable iron				----	-.18	-.17	.67**	.20	.48**	-.29**
Bray 1 phosphorus					----	.55**	.09	-.25*	.30**	-.35**
Aluminum-phosphate						----	.13	-.38**	.43**	-.31**
Clay content							----	-.04	.44**	-.28**
Calcium-phosphate								----	-.34**	.39**
Iron-phosphate									----	-.71**
Soil pH										----

It has been pointed out early that the soluble phosphate is a function of calcium activity so that if the activity of calcium increased phosphorus activity in solution should be decreased by precipitation of calcium and phosphorus according to the solubility product.

The aluminum phosphate fraction is very highly correlated to the Bray 1 soil test indicating that it removes all or a portion of this fraction quite readily, and is negatively correlated to soil pH. The aluminum activity in soil solution is decreased by increasing the pH since the solubility product of gibbsite predicts a precipitation of $Al_2O_3 \cdot H_2O$ at a high pH. The aluminum phosphate content in these soil profiles are quite similar and in general decrease with depth in the profile.

The iron phosphate fraction shows a significant correlation with iron content, aluminum phosphate, clay content, water soluble phosphorus and Bray 1 soil test phosphorus. These relations may or may not be interrelated themselves as they all are significantly correlated with soil pH and it may be more of an effect of pH on each variable than an interaction between variables. The negative correlation of iron phosphate is much the same relation as discussed above with aluminum phosphate in that the iron activity in soil solution decreases as the pH is raised. In general, the content of iron phosphate varied as much within a soil series as between soil series.

The calcium phosphate in the soil from apatite minerals is extracted by the 0.5N H_2SO_4. The amount of this fraction appears to be a function of pH and calcium activity as shown by the high positive linear correlation of each with this variable. The calcium phosphate is very similar and relatively high within each soil series except the Pickford which shows a large variation between profile samples. In general, these soils reflected their calcareous nature by high calcium phosphate contents.

The Bray 1 phosphorus soil test in the surface horizons varied from 10 to 42 pounds per acre phosphorus and decreased in all cases but one with depth in the profile. This indicates that considerable phosphorus fertilizer would be needed for production of sugar beets on these soils.

CHAPTER V

SUMMARY AND CONCLUSIONS

Field and greenhouse studies were conducted from 1959 through 1961 to determine the effect of time and method of application of fertilizer on the growth and chemical composition of sugar beets on a Kawkawlin-Wisner silty clay loam soil complex. Four rates of phosphorus (0, 87, 174, and 348 pounds per acre) were plowed under prior to planting sugar beets each year. Three rates of a complete fertilizer were applied at planting time (0, 150 and 300 pounds per acre of 5-20-10 in 1959 and 1960 and 6-24-12 in 1961). The planting time fertilizer was placed in a band 3/4 inch to the side and two inches below the seed in 1959. Two placements were used in 1960 and 1961: in 1960--in a band $1\frac{1}{2}$ inches to the side and two inches below the seed or in a band 3/4 inch to the side and two inches below the seed, and in 1961--in a band $1\frac{1}{2}$ inches to the side and three inches below the seed or in a band three inches under the seed.

Three rates of phosphorus (0, 33, and 66 pounds per acre) containing P^{32} tagged ammonium phosphate were used in the greenhouse study on soils obtained from the field where the application of the four rates of plow down phosphorus was used. In the greenhouse study, one pot of each treatment was incubated at 25° C. at field capacity for 59 days prior to planting, the second pot was planted without incubation.

Laboratory studies were conducted to determine chemically extractable and available phosphorus in the Kawkawlin-Wisner soil as affected by addition of phosphorus fertilizer. In addition, the forms of inorganic phosphorus of ten Michigan soil profiles were characterized according to the procedure of Chang and Jackson.

The data can be summarized briefly as follows:

1) Early growth, phosphorus uptake, phosphorus content and yield of beets showed a marked response to plow down phosphorus applications in the field and greenhouse.

2) Planting time fertilizer increased early growth at each of the four levels of plow down phosphorus, increased phosphorus content of plants at blocking time at each of the four levels of plow down phosphorus in 1959, but only the lower levels in 1960 and 1961, increased phosphorus content of leaf petioles at 0 and 87 pounds of phosphorus per acre in 1959 and 1960, but had no effect on phosphorus content of petioles in 1961.

3) The growth and phosphorus uptake by young beets was greatest when placement of planting time fertilizer was in a band three inches directly under the seed as compared to 1½ inches to side and three inches below the seed. The uptake of phosphorus, calcium, and potassium at time of blocking was greatest where planting time fertilizer was placed in a band directly under the seed. Placement of each level of application of planting time fertilizer in a band under the seed increased yield of beets at all levels of plow down phosphorus.

4) The phosphorus content in the green tissue of the sugar beet petioles (extracted with sodium acetate) decreased from July to August and then increased in September. It was increased by plow down phosphorus levels, but was not influenced by planting time fertilizer. These data suggest that the inorganic phosphorus content of sugar beet petioles should not be allowed to drop below 0.15 per cent on dry weight basis at any time during the growing season in order to assure an adequate supply of phosphorus for highest yields.

5) The calcium content of sugar beets was decreased by each addition of planting time fertilizer when planting time fertilizer was

moved to directly under the seed; but total uptake at blocking was increased by all fertilizer additions.

6) The sucrose content and apparent purity of the sugar extract was not affected by phosphorus applications.

7) The levels of phosphorus plowed down were best reflected with the Bray 1 soil test solution. This indicated that the critical phosphorus soil test level for sugar beet production should be approximately 70 pounds per acre and that at least 15 pounds of phosphorus per acre should be used at this soil test level in the starter fertilizer and placed in a band three inches under the seed.

8) The available phosphorus as determined by P^{32} uptake by sugar beets in the greenhouse was markedly affected by the plow down phosphorus levels, and was highly correlated with the Bray 1 extractable phosphorus.

9) The uptake of phosphorus in the greenhouse by sugar beets 40 days after planting did not correlate with A-values but was highly correlated with water soluble phosphorus. The uptake 51 days after planting was highly correlated with A-values, Bray 1 extractable phosphorus, aluminum phosphate, and water soluble phosphorus. The uptake of phosphorus in the greenhouse did not correlate with iron and aluminum phosphate as extracted by Chang and Jackson's phosphorus fractionation procedure.

10) The extractable phosphorus as determined by Bray 1 solution was 26, 44, 73, and 117 pounds per acre phosphorus, where 0, 87, 174, and 348 pounds of phosphorus were plowed down, respectively. The corresponding A-values were found to be 28, 57 176, and 240 pounds per acre.

11) Incubation of the soil in the greenhouse for 59 days at field capacity increased early growth and phosphorus uptake, and decreased the A-values of the soil.

12) The field and greenhouse applications of phosphorus were highly correlated with Bray 1 extractable, water soluble, and aluminum phosphate form of phosphorus.

13) In the laboratory study of ten Michigan soil profiles it was found that: a) Bray 1 extractable phosphorus varied from 10 to 42 pounds per acre in surface horizons, decreased with depth of horizons, and was highly correlated with aluminum phosphate, b) the aluminum phosphate contents were quite similar and in general decreased with depth,
c) that the calcium phosphate in the form of apatite was quite similar in nine of the ten soils and in general increased with depth of horizon,
d) that the iron phosphate varied as much within a soil series as between soil series and in general decreased with depth of horizon, and
e) calcium phosphate was negatively correlated with Bray 1 extractable, water soluble, aluminum, and iron phosphate.

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