The Influence of Factors Other than Soluble Phosphorus in the Nutrient Medium on the Phosphorus Content of Sugar Beet Plants[1]

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In spite of extensive literature reviews (10) and investigations of problems of soil phosphorus availability to plants, no widely accepted theory exists which adequately accounts for the many reported observations. Arnon (1)[3] cited the influence of ammonium and nitrate ions on phosphate absorption by barley plants to support his general theory that the absorption of phosphate would be expected to be depressed by the presence of high concentration of rapidly absorbable anions and enhanced by an increast in the concentration of rapidly absorbable cations. Pratt and Thorne (12) concluded that availability of phosphates is entirely a function of their solubility from pH 4.0 to 7.0 and that from pH 7.0 to 8.0 the dominant factor in availability is solubility, with physiological availability of minor importance.

Nightingale (8) stated that while specific information has not been found on how plant nutrients behave, ample nitrate supplies invariably repress phosphorus uptake. Pirson (11) observed that it has not yet been clarified whether an excess of an element causes disturbances which represent direct and specific consequences of this particular excess within the cell or whether the results are dependent upon the exclusion of another element, according to the pattern of competitive inhibition.

McGeorge (6) believes that pH of the soil solution, or more specifically of the root-solution contact interface, is an important factor in phosphorus uptake in calcareous soils. He emphasizes that at pH 6.0 more than 80% of the ionized soluble phosphorus is in the form $H_2PO_4^-$ and 17% is in the HPO_4^{--} form. At pH 7.0 only 30% of the soluble phosphorus is in $H_2PO_4^-$ and 70% in the HPO_4^{--} form. He shows that when the same concentration of phosphorus is present in the growth medium, the rate of phosphorus uptake is much greater at pH 6.0 than at pH 7.0. He also recognizes that solid $CaCO_3$ plays an important role in both solubility of phosphate and its assimilation by the plant.

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[3] Numbers in parentheses refer to literature cited.

Students concerned with availability of phosphorus in the soil have tried to relate the concentration of soluble phosphorus in soil solution to plant growth. Whitney and Cameron (15), by centrifugal displacement of soil solution, found that phosphorus concentration based on dry soil ranged from 0.46 to 0.53 ppm. Morgan (7) using oil displacement found similar results, 0.36 to 1.5 ppm of phosphorus on a dry basis. Parker and Pierre (9) observed that corn achieved maximum growth when culture solutions contained 0.13 ppm of phosphorus. Growth was very good at concentrations as low as 0.05 and good at 0.03 ppm of phosphorus. Dean and Fried (3) stated that studies have shown growth of plants to be impeded when 0.1 ppm or less of phosphorus is in solution, but that soils with displaced solutions containing less than 0.1 ppm support normal crop growth.

The experiment considered here was designed to determine the nutrient concentration and balance most suitable for the growth of sugar beet plants. In the course of this study it was observed that sugar beet plants growing in nutrient cultures similar in phosphorus concentration, produced plant tissue varying widely in phosphorus composition. The data in this paper are given to show the extent of these variations and to attempt an explanation as to some of the probable causes for variation in phosphorus content of plant tissue.

Methods and Procedure

Ten different nutrient cultures were studied. These were largely modifications of Hoagland's nutrient solution number 1 at one-half strength (4). Commercial monogerm variety SL 126 sugar beets were grown in cans of ten-gallon capacity filled with No. 2 vermiculite. Five small holes were punched in the bottom of each can to provide adequate drainage. The cans were then buried in field soil to within 1 inch of the top rim in order to maintain growing root temperatures comparable to field conditions. From 2 to 3 inches of coarse gravel had been placed below the cans to facilitate drainage and spread of water. In no instance did the plant rootlets protrude through the holes in the bottom of the cans. Twenty-five seeds were planted April 15, 1960, in each can. On June 29 these were thinned to leave a final stand of three plants per can.

The nutrient concentrations in each of the ten nutrient cultures as prepared, and the mean seasonal pH and phosphorus concentrations in the drainage solutions from each treatment are shown in Table 1. While no potassium was added to Low K treatment, the vermiculite provided about 15 ppm K in solution.

Table 1.—Nutrient concentration in various nutrient solutions, 1960.

No.	Description	Parts per million of various nutrients*									
								P		pH	
		NO_3-N	NH_4-N	K	Ca	Mg	Na	Nut. sol.	** Drain.	Nut. sol.	** Drain.
1	Check (1/2 Hoagland's)	105	....	110	145	50	18	15	5.4	7.6	8.0
2	1/2 K	105	....	55	165	50	18	15	4.1	7.7	8.0
3	Low K	105	....	15	205	50	18	15	3.4	7.6	8.1
4	1/2 N	70	....	110	145	50	18	15	5.0	7.8	8.1
5	1/4 N	30	....	110	145	50	18	15	5.5	7.7	8.0
6	$NO_3 + NH_4$	105	25	110	145	50	18	15	8.0	7.3	7.6
7	1/2 P	105	....	110	145	50	18	7.5	2.4	7.9	7.9
8	NH_4	....	75	110	145	50	18	15	2.9	7.4	6.0
9	1/2 Ca + 1/2 Mg	105	....	110	100	30	115	15	4.1	7.7	8.0
10	Check (Same as No. 1 except 1/2-N 9/1 to 10/1 No-N 10/1 to 10/15)	105	....	110	145	50	18	15	4.5	7.6	8.0
	LSD @ .01								1.4		

* Minor elements were provided in all nutrient solutions at the following concentrations: B= 0.25, Nu=0.25, Zn=0.028, Cu=.01, Mo=0.004, and Fe=4.5 ppm.

**Mean of 22 samplings of leachings.

One gallon of nutrient solution was applied to each can daily except during mid-July and August when one and one-half gallons were used. In the latter instance three quarts of solution were applied in early morning and three quarts about 2 PM daily.

Leaf blade and petiole samples were obtained, at two week intervals beginning July 1, one from each plant on eight sampling dates. These plant tissues were rinsed in distilled water and dried rapidly at 70° C, ground to pass a 40-mesh screen, and examined chemically by standard procedures. Phosphorus was determined by the Barton (2) procedure.

Experimental Results

Yield of sugar beets as affected by nutrient environment

The data on the yield of sugar beet roots are given in Figure 1. These show a considerable range in yield among treatments, varying from 1500 to more than 2900 grams of roots per square foot of can surface.

Changes in composition of nutrient solution and drainage

A slight change occurred in pH between the nutrient solution and that of the drainage solutions as shown in Table 1. In general the pH tended to increase. A striking exception is the ammonium solution treatment, which dropped 1.4 pH units.

Preliminary studies showed a drop in phosphorus concentration from 15 ppm in the nutrient solution to 4 or 5 ppm in the drainage waters when no plants were growing in the medium.

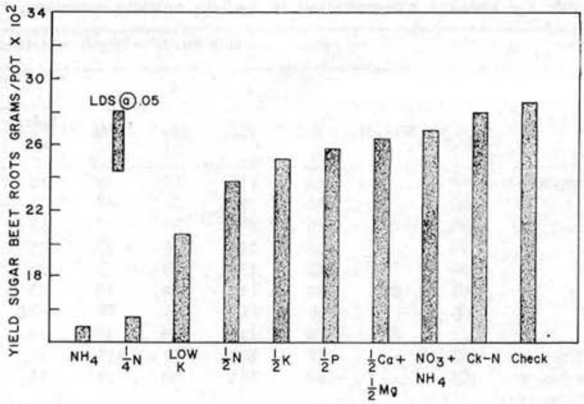

Figure 1.—Yield of sugar beet roots as affected by nutritional environment, 1960.

An equilibrium between phosphorus in solution and phosphorus absorbed on the surface of vermiculite or chemically precipitated is established almost immediately upon solution contact. Additional slight changes in phosphorus concentration were noted between nutrient and drainage solutions with all treatments. The concentrations of phosphorus in drainage solutions after equilibrium with vermiculite and plant absorption were well above the levels considered adequate in soil solution for crops such as corn (3,7,9,15). Nevertheless there were significant differences in phosphorus concentration of drainage solutions among the various treatments as shown on Table 1.

Influence of variation in nutrient cultures on the concentration of phosphorus in plant tissue.

The mean seasonal phosphorus compositions of sugar beet petioles, blades, and pulp as affected by nutrient cultures are

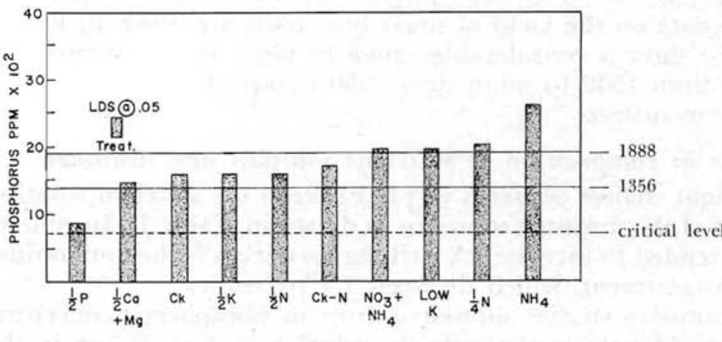

Figure 2.—Soluble phosphorus concentration in sugar beet petioles as affected by nutritional environment, mean for season 1960.

shown in Figures 2, 3, and 4. All nutrient cultures produced plants above the phosphorus "Critical Level" suggested by Ulrich (14) for well-nourished sugar beet plants (Figure 2). His proposed critical level is shown in Figures 2 and 3 as a horizontal dotted line. Wide variations occurred in phosphorus composition among petioles obtained from plants growing in solutions similar in phosphorus content. The cause of the high phosphorus content in petioles from treatments $NO_3 + NH_4$, Low K, 1/4 N, and NH_4 is not known with certainty. The last three of these treatments gave the lowest yields of roots (Figure 1). The solid horizontal lines are placed in Figures 2, 3, and 4 for comparative purposes.

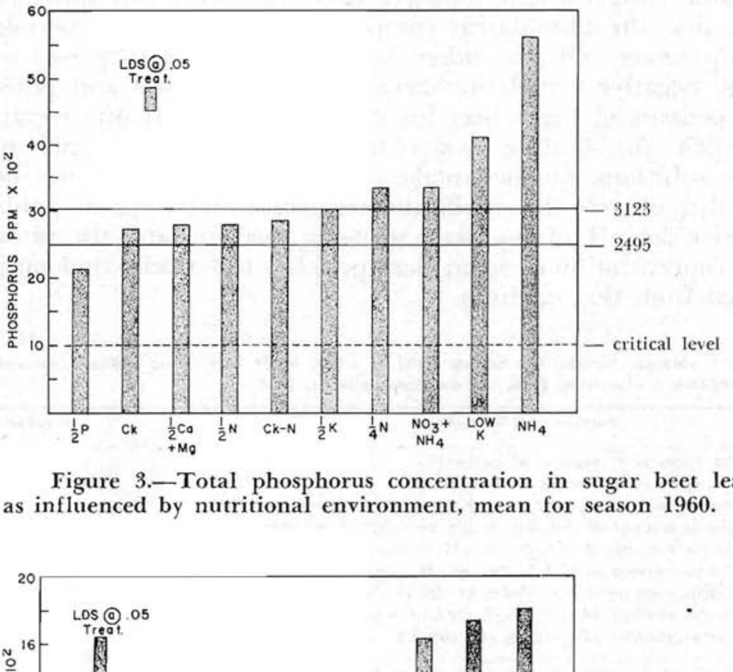

Figure 3.—Total phosphorus concentration in sugar beet leaf blades as influenced by nutritional environment, mean for season 1960.

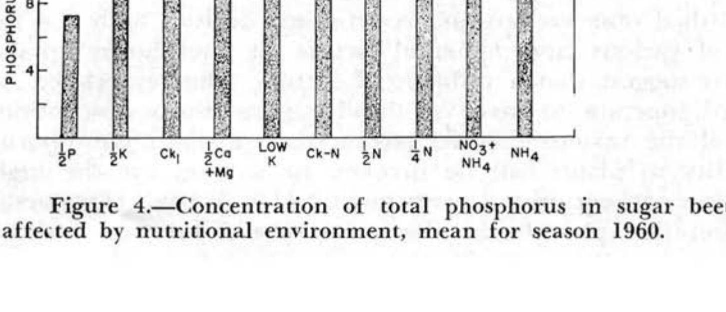

Figure 4.—Concentration of total phosphorus in sugar beet pulp as affected by nutritional environment, mean for season 1960.

These lines were obtained by taking the mean phosphorus concentration in plant tissue, obtained from the two highest yielding treatments, Check and Check—N, as shown in Figure 1. From this value, fiducial limits at .05 probability level were calculated and are used in these figures as points of reference.

Simple correlations were calculated for the purpose of identifying closely associated factors among yield of roots, phosphorus composition of plant tissue and phosphorus composition of nutrient solutions. The factors associated in a significant way are listed in Table 2. Reasoning from the conclusions of Pratt and Thorne (12) one rightly may expect to find a significant positive correlation between the phosphorus concentration in the nutrient solution and the phosphorus composition of sugar beet petiole and pulp tissue. On the other hand one may be surprised to note the negative correlation between yield of roots and phosphorus content of sugar beet leaves and petioles. If one recalls McGeorge's (6) finding, concerning the influence of pH in nurtient solutions, on the uptake of phosphorus, he will not be surprised to observe the significant negative correlations in Table 2 between the pH of the plant growing medium and the phosphorus concentration of sugar beet petioles, leaf blades and pulp produced from that medium.

Table 2.—Simple correlations among yield of roots, sugar beet tissue composition and nutrient solution composition from ten nutrient cultures, 1960.

No.	Factors of Correlation	r values*
1	Yield of roots vs P content of petioles	— .68
2	Yield of roots vs P content of leaf blades	— .74
3	Phosphorus content of petioles vs P in original solutions	+ .67
4	Phosphorus content of petioles vs pH in original solutions	— .75
5	Phosphorus content of petioles vs pH in drainage	— .69
6	Phosphorus content of leaf blades vs pH original solutions	— .65
7	Phosphorus content of leaf blades vs pH in drainage	— .81
8	Phosphorus content of pulp vs P content solutions	+ .63
9	Phosphorus content of pulp vs pH original solutions	— .60

* Required for significance @ .05 with 9 d.f. = 0.60

Discussion

Published observations and conclusions dealing with the influence of various environmental factors on phosphorus uptake by plants suggest that a number of factors, whether related or unrelated, operate to favor or hinder phosphorus absorption. Which of the various theories advanced to explain phosphorus availability to plants can be invoked to account for the high phosphorus concentration in treatment NH_4? Arnon's (1) general conclusion that phosphorus absorption would be enhanced by the presence of rapidly absorbable cations in the rooting medium is in harmony with the observed facts. McGeorge's (6) explanation that at pH 6.0 more than 80% of ionized soluble phosphorus is in the readily absorbable form, $H_2PO_4^-$ is not in conflict with the observed facts. The conclusions of Pratt and Thorne (12) that phosphate availability is a function of its solubility offer no help whatever. Why, in view of the favorable phosphorus uptake by plants in the NH_4 treatment, is the root yield so low? Possibly the nutrient balance concepts suggested by Shear and Crane (13) and Pirson (11) are near the mark. Nutrient elements can be as harmful to plant growth when taken up by plants in great excess as when in deficient supply. While the NH_4^+ ion may favor phosphorus absorption high concentrations in the plant may interfere with other vital physiological functions. The secondary effect, that of high phosphorus concentration within the plant, may produce unfavorable reactions with the small quantities of zinc or iron in the plant and thus limit essential enzymatic physiological functions. Whatever the cause of the harmful effect on growth of beet roots it was not inadequate phosphorus.

What theories can be offered to explain the high phosphorus concentration in beet tissue grown in solution ¼ N? The theories of McGeorge (6) and Arnon (1) offer no help. Again the explanation of Pratt and Thorne (12) is not enlightening. Nightingale's (8) observations that ample nitrate supplies repress phosphorus uptake provides a back door approach. The ¼ N treatment obviously provided a much lower concentration of nitrate ions than in any other treatment with the exception of the NH_4 treatment. Based on this theory alone one might expect the phosphorus concentration of plant tissue grown in the ¼ N treatment to be high in phosphorus.

The authors do not have a satisfactory explanation as to why Low K treatment should result in high phosphorus concentration in beet tissue. Tissue from this treatment contained high concentrations of calcium, magnesium, and sodium but it is not obvious why these cations should greatly favor phosphorus absorption.

The fourth treatment which favored high phosphorus uptake was $NO_3^- + NH_4$. The high phosphorus concentration in beet tissue from this treatment may result from a slightly favorable pH in the nutrient and drainage solutions according to the theory of McGeorge (6). Arnon's (1) explanation for the favorable influence of NH_4^+ and the unfavorable effects of NO_3^- on phosphorus uptake, hardly satisfies one in this case because large quantities of both ions are present. If it could be demonstrated that, apart from the influence of NH_4^+ ions on lowering the pH of absorbing root mediums, the NH_4^+ ions and $H_2PO_4^-$ ions were unusually congenial traveling companions, this would offer an explanation. Without this, the favorable influence of solution pH appears to offer the only justification for favorable phosphorus uptake.

The only treatment which resulted in low phosphorus concentration in beet tissue was ½ P. The obvious explanation for this is the relatively low phosphorus concentration in the nutrient solutions and in the drainage solutions from this treatment.

The five treatments which are not discussed individually, ½ Ca + Mg, Check, ½ K, ½ N and Check−N, appear to be adequately but not excessively provided with phosphorus. Nutrient solutions from these treatments have similar pH values and contain similar phosphorus concentrations. Of these treatments ½ N and Check−N tend toward a build up of phosphorus, particularly in the pulp tissue. This supports the conclusion of Nightingale (8) who observed that ample nitrate supplies repress phosphorus uptake. Treatments ½ N and Check−N were provided with a lower nitrate supply than was provided in the other three treatments.

The relatively high but uniform concentration of soluble phosphorus in nutrient culture solutions (Table 1) and the frequent renewals (once to twice a day) give little justification for assuming that high concentrations of phosphorus in specific beet tissue is a consequence of low yields.

The positive correlation between phosphorus content of leaf petioles and pulp and nutrient solutions (Table 2) must result largely from the relations between plant composition and solutions from treatment ½ P. All other treatments contained the same phosphorus concentration in solution but widely variable concentrations in plant tissue.

The high negative correlation shown between yield of roots and phosphorus concentration in leaf blades and petioles can be accounted for by the three low yielding treatments NH_4, ½ N, and Low K. These three treatments, for reasons previously indicated, produced plant tissue high in phosphorus.

The high negative correlations between phosphorus concentration in petiole, blade, and pulp tissue, and between pH nutrient and drainage solutions are accounted for largely by the relations found in two treatments, NH_4 and NO_3 + NH_4. Solutions from other treatments show relatively uniform pH values.

Conclusions

Many factors influence phosphorus uptake by sugar beet plants. No single theory of phosphorus availability accounts for all conditions of phosphorus absorption.

The mechanisms of nutrient absorption of anions and cations may well differ as Lundegardh (5) contends. Nevertheless an interdependence seems to exist among them for absorption by plant roots. There is an indication that the ammonium ion and the monovalent phosphate ion are congenial plant absorption companions.

At a given pH value of nutrient solution in the rooting medium, the rate of phosphorus absorption by sugar beets depends upon the quantity of soluble phosphorus present, as stated by Pratt and Thorne (12). The pH of the nutrient medium appears to be one of the important factors controlling the rate of phosphorus absorption, frequently over-riding the influence of solution concentration, McGeorge (6).

High concentration of nitrates in the solution medium tends to repress the uptake of phosphorus and low concentration is conducive to high phosphorus absorption by sugar beets.

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