Phosphorus Nutrition of Sugarbeet Seedlings

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Introduction

Sugarbeet plants in the field frequently require phosphorus fertilization for satisfactory growth (13)[2]. The need for phosphorus by sugarbeet plants can be determined by means of plant analysis, using the soluble phosphorus concentration of 750 ppm in the petioles of recently matured leaves as the reference value indicating a phosphorus deficiency. This value has been found to reflect the P status of the plant quite accurately from the time of thinning to harvest (17). Recently it has been necessary to estimate the P status of sugarbeet seedlings when the petioles are too small for convenient sampling, as at the cotyledon stage of development (13). To solve this problem a study was conducted with sugar beet seedlings in the greenhouse by the culture solution technique, to find, if possible, a more convenient part of the seedling to sample and to relate these results to growth and mineral composition of the plant tissue analyzed.

Materials and Methods

Plant culture

Sugarbeet seedlings were grown in the greenhouse in half-strength Hoagland's nutrient solution, prepared without P, and modified to include Na and Cl (Table 1). Phosphorus was added as KH_2PO_4 for the P treatments in the amounts of 0.00, 1.25, 2.50, 5.00, 10.00, 20.00, 40.00 and 80.00 mg P per 6 plants, i.e., per 20 liters of solution. Aeration of all solutions was started 5 days after transplanting. The pH values of the solutions were adjusted to 5.3-5.7 with either 1.0 N H_2SO_4 or 1.0 N NaOH. This was done initially after adding the salts, and thereafter daily as required. The tanks were painted on the outside with aluminum and on the inside with a non-toxic plastic (Amercoat No. 33) . Masonite covers for the tanks were varnished with valspar on the underside and with aluminum on the upper side. Six holes, about equally spaced, served to hold six sugarbeet seedlings in each cover.

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[2] Numbers in parentheses refer to literature cited.

Table 1.—Chemical composition of nutrient solution when sugarbeet seedlings were transplanted*.

Salts added in mmol/l		Microelements in mg/l	
KNO_3	3.00	B, as H_3BO_3	0.250
K_2SO_4	0.50	Mn, as $MnSO_4 \cdot H_2O$	0.250
$Ca.(NO_3)_2 \cdot 4H_2O$	2.50	Zn, as $ZnSO_4 \cdot 7H_2O$	0.025
$MgSO_4 \cdot 7H_2O$	1.00	Cu, as $CuSO_4 \cdot 5H_2O$	0.010
$CaCl_2 \cdot 2H_2O$	0.25	Mo, as MoO_3	0.005
NaCl	0.50	Fe, as E•D•T•A(8)	2.500

* The eight P treatments are given in the text.

Sugarbeet seeds (*Beta vulgaris*), var. F58 554 H1, i.e., F_1 hybrid, were planted on May 1, 1967. They were treated with Phygon XL at the 1% rate and planted about 2 cm deep in vermiculite held in Amercoated metal germinating trays. The seeds and then the small seedlings were watered daily with one tenth strength modified Hoagland's nutrient solution, without phosphorus addition.

The seedlings appeared on May 5, 1967 and were transplanted May 15, 1967, when they were in the cotyledon stage. The individual plants were supported inside a cork ring by non-absorbent dacron fiber. The outside and inside diameters of the ring were approximately 6 and 4 cm, respectively, and 2 cm in thickness. Six of the seedlings were taken at random for each 20-liter capacity tank. The eight phosphorus treatments were replicated ten times and were arranged in the greenhouse in a randomized complete block design.

Harvesting

The plants were harvested on May 26, only 11 days after transplanting. The plants at harvest showed a gradation of deficiency symptoms from severe to none.

Twelve plants from two pots of the same treatment and adjacent blocks were combined, in order to have enough plant material for chemical analysis. The tops were cut from the fibrous roots, at lateral root initiation, weighed and separated into a) cotyledons, b) first pair of leaves (older), c) second pair of leaves (younger) and d) hypocotyl. The leaves were separated into blades and petioles. The blades of the younger leaves were designated as YB, and their petioles as YP; the blades of the older leaves as OB, and their petioles OP; the cotyledons as Cot, the fibrous roots as FR, and the hypocotyl as Hypocot, as used in the tables and concentration comparisons.

Each kind of plant material was weighed and dried separately. The fibrous roots were treated as outlined below.

Preparation of samples

As soon as the plants were separated and weighed, as described above, they were placed into paper bags and dried at 70° to 80° C in a forced-draft oven to constant weight; dry weights were then taken. The fibrous roots were washed with distilled water, centrifuged for 5 minutes at 39 × *g*, weighed fresh and after drying.

The other plant parts were not washed, because the air of the greenhouse was carbon filtered free of dust and the plants had not been sprayed or dusted with fungicides or insecticides.

All dried plant material was ground in a Wiley mill, equipped with a 40-mesh stainless steel sieve and steel cutting blades. The small amount of plant material from the low P treatments was ground in an oscillatory ball mill made of plastic (Wig-L-Bug amalgamator, Crescent Dental Mfg. Co., Chicago, Illinois). The ground plant samples were stored in plastic containers until analyzed.

Chemical analysis of plant material

The dry ground plant material was analyzed for: a) Soluble Phosphate in 2% acetic acid, and for total phosphorus by the ammonium-molybdate-stannous-chloride method (9); b) Nitrate-nitrogen by the phenoldisulfonic acid method, after removing chlorine (9); c) Potassium and sodium by the flame emission technique (9), using a Beckman model D.U. spectrophotometer with flame attachment in conjunction with a photovolt model 520 photomultiplier unit and d) Calcium and magnesium by the atomic absorption spectroscopy technique (2), using the Perkin-Elmer instrument, model 303. The digestate for the total P determination was also used for the K, Na, Ca and Mg analyses.

Results and Discussion

Visual symptoms of phosphorus deficiency

Plants deficient in phosphorus were smaller in size. The leaves and cotyledons were shorter in length and narower in width and had a characteristic dark green color. As the deficiency became more intense the leaves and cotyledons developed golden areas, that became necrotic. The fibrous roots of the healthy plants were almost white, whereas those of deficient plants changed in color from a brown to dark brown and then to a dark gray. As a rule, the stunting and reduced growth of phosphorus deficient plants was easily recognized by making direct comparisons to adjacent non-deficient plants.

Effect of phosphorus supply on seedling dry weight and dry matter percentage

The degree of deficiency, the mean dry weight of various plant parts, total tops, fibrous roots and the dry weight ratio of tops to roots of sugarbeet seedlings in relation to phosphorus treatment are given in Table 2. An increase in P supply affected the growth of the older blade tissue most and the cotyledons least. The tops were influenced more by phosphorus supply than the fibrous roots.

A statistical analysis of the dry weight of the tops for two adjacent treatments indicated that all P additions from 0 through 10 mg P/6 plants produced significant increases over the preceding treatment. An increase in P supply from 0 to 80 mg P/6 plants increased the dry weight of the older blades by as much as 15 times but the cotyledons only 2 times and the dry weight of the tops 11 times and the fibrous roots only 4 times.

The growth of the plant parts, younger blades, older blades, younger petioles and older petioles, increased significantly with increased P supply until 10 mg P/6 plants had been supplied. The growth of the cotyledons, hypocotl and fibrous roots stopped at the 5 mg P/6 plants supply.

Tops, relative to fibrous roots, increased from a ratio of 1.36 to 3.94 as the plants changed from a state of phosphorus deficiency to non-deficiency. These data indicate that with a limited P supply most of the phosphorus was retained by the fibrous roots resulting in the growth of the fibrous roots at the expense of the tops.

The percentage dry matter of sugarbeet seedlings decreased significantly as the phosphorus supply increased (Table 3) and the seedlings were no longer deficient in phosphorus. The values decreased up to 5 mg P supply/6 plants for the cotyledons and up to 10 mg P supply for the older blade, older petiole, hypocotyl and fibrous root tissues. Thereafter these percentages did not change significantly.

Effects of P supply on distribution and accumulation of P in sugarbeet seedlings

The soluble phosphorus in 2% acetic acid was the highest in the older blade and cotyledon tissues and least in the younger petioles, older petioles and hypocotyl tissues (Table 4). In terms of percentage change the soluble P concentrations of the OB[3], Cot[3], YB[3], FR[3], OP[3] and YP[3] tissues at the 20 mg. P supply increased by 229%, 219%, 108%, 65%, 31% and 13% over that of the hypocot[3] tissue, respectively.

[3] Symbols used: Y = young; O = Older; B = blade; P = petiole; Cot = cotyledon; Hypocot = hypocotyl; FR = Fibrous root.

Table 2.—Effects of phosphorus supply on deficiency symptoms of tops and fibrous roots and on dry weight of various parts of sugarbeet seedlings.

P supply mg/6 pls	Deficiency symptoms	Dry weight, mg/12 plants*									
		YB**	OB	YP	OP	Cot	Hypo-cot.	FR	Tops	Total	Top: FR
0.00	severe	—+	85a	—+	—+	112a	51a	183a	248a	431	1.36a
1.25	severe	—+	165b	—+	—+	140b	54a	238a	359b	597	1.51a
2.50	moderate	—+	356c	—+	37a	160b	94b	373b	660c	1032	1.77a
5.00	slight	244a++	765d	20a	109b	208c	198c	713c	1542d	2505	2.16ab
10.00	none	486b	1044e	48b	158c	226c	240c	809c	2202e	3011	2.72b
20.00	none	583b	1171e	59b	173c	241c	258c	691c	2483e	3174	3.59c
40.00	none	646b	1261e	82b	184c	258c	253c	735c	2683e	3418	3.65c
80.00	none	919b	1310e	88b	190c	258c	274c	721c	2838e	3559	3.94c

* All values are means of five replications, except where shown otherwise in Tables 4-10.

** Symbols used: Y = young; O = older; B = blade; P = petiole; Cot = cotyledon; Hypocot = hypocotyl; FR = fibrous root.

\+ No plant material in these categories.

++ Means in a column followed by the same letter are not different at the 1% level of significance.

+++ The number of values in the mean is less than five, Tables 4-10.

Table 3.—Effect of phosphorus supply on percentage dry matter of sugarbeet seedling material.

P supply mg/6 pls	Percentage dry matter*						
	YB**	OB	YP	OP	Cot	Hypo-cot	FR
0.00	——+	15.5c	—+	——+	10.4c	10.4c	14.0b
1.25	——+	10.2b	—+	—+	10.3c	9.6c	13.6b
2.50	——+	9.4b	—+	10.0c	8.3b	10.0c	11.5b
5.00	10.4b++	8.2b	8.7a	7.5b	7.3a	9.8c	9.3b
10.00	9.1ab	7.3ab	7.4a	5.9a	6.8a	9.0ab	7.9ab
20.00	9.0ab	7.1a	7.3a	5.7a	6.9a	8.8a	7.0a
40.00	9.9b	7.6ab	8.0a	5.9a	7.3a	9.4ab	7.2a
80.00	10.1b	7.6ab	8.2a	5.9a	7.2a	9.3ab	6.9a

* For footnotes see Table 2.

Table 4.—Effects of phosphorus supply on 2% acetic acid soluble phosphorus concentration of sugarbeet seedling material.

P supply mg/6 pls	Soluble P concentration in ppm (dry basis)*						
	YB**	OB	YP	OC	Cot	Hypo-cot	FR
0.00	——+	590a	——+	——+	240a	190+++	300a
1.25	——+	1240a	——+	——+	430a	400a	910a
2.50	——+	1470ab	——+	610+++	560ab	500a	1430ab
5.00	2010a++	2110ab	1170+++	940a	1720ab	990a	1900ab
10.00	2960b	4230ab	1880+++	1930b	4970c	2130b	3070abc
20.00	7150c	11280c	3880+++	4490c	10950d	3430b	5670c
40.00	8480c	12660c	4430+++	4960c	11820d	3600bc	7130c
80.00	8060c	11990c	4170	4640c	11620d	3320bc	8240c

* For footnotes see Table 2.

The total phosphorus concentration of the OB and Cot tissues was higher than that of any other plant part, and the least in the OP and hypocot tissues, at the 20 mg P supply (Table 5). In terms of percentage change the total phosphorus concentration of OB, Cot, YB, FR and YP was 140%, 125%, 103%, 29% and 28% higher than that of the hypocot and OP tissues, respectively.

Table 5.—Effects of phosphorus supply on total phosphorus concentration of sugarbeet seedling material.

P supply mg/6 pls	Total P concentration in ppm (dry basis)*						
	YB**	OB	YP	OP	Cot	Hypocot	FR
0.00	——+	720a	——+	——+	320a	500+++	770a
1.25	——+	1690a	——+	—+	600a	800a	1770a
2.50	——+	1810ab	—+	1320+++	840ab	1090a	2800ab
5.00	4250a++	2650ab	3000+++	1670a	2420ab	2180b	3340b
10.00	5660a	5380c	4420+++	2820b	5920c	3630c	4450b
20.00	10610b	12510d	6700+++	5090c	11750d	5220d	6710c
40.00	12400b	13330d	7680+++	6000c	12630d	5330d	8280c
80.00	12230b	13520d	7410	5660c	12600d	5410d	9600c

* For footnotes see Table 2.

Numerous experiments have demonstrated (1, 3, 4, 5, 12, 16) that the phosphate ion tends to accumulate in those portions of the plant undergoing the most rapid growth. On the basis of total phosphorus concentration the different plant parts can be classified as follows:

OB > Cot > YB > FR > YP > OP > Hypocot.

But since the Cot had already stopped growing at the time of harvest, this method of classifying tissues in relation to growth appears not to be a valid one.

Relation of tissue phosphorus to growth

The soluble P and the total P concentrations of the 1) OB, 2) OP, 3) Cot and 4) hypocot tissues were plotted against the corresponding fresh and dry weight of the plant part and fresh and dry weight of the tops.

These results in general show that the use of soluble P concentration of the various plant parts is preferable to total P to diagnose the P status of the sugarbeet seedlings, because it is easier to determine this form of P and it reflects the P status of the plant satisfactorily. But if it is necessary to determine cations at the same time, the total P concentration can be used, since this form of P can be determined easily from the digestate of the HNO_3-$HClO_4$ digestion. The specific plant part to use for chemical analysis is more difficult to decide. If the selection is based on the sharpness of the transition zone, the hypocot and OP tissues would be preferable. But unfortunately the hypocot tissue has the disadvantage of a narrow phosphorus range. On the other hand the curves for the OB and Cot tissues do not have a sharp transition zone but they do have a wide range of P concentrations. Similar results were observed for the total P concentration of the plant parts. So the general conclusion may be drawn that for the determination of the critical P concentration of the sugarbeet seedling it is preferable to analyse the OP tissue. But when it is too difficult to sample it, the OB or the Cot tissues may be used as well.

Plottings of the dry weight of the tops against the soluble P concentration in the 1) OB, 2) OP, and 3) Cot tissues are given in Figures 1, 2 and 3. The figures illustrate how the soluble P concentration in these plant tissues change with P supply and plant growth. The nearly vertical portion of the curve, which includes the treatments from zero to 5 mg P/6 plants, shows a zone of P deficiency. This zone is characterized by increases in top weight, with an increase in P supply. From 10 mg up to 80 mg P/6 plants there is a zone of P adequacy.

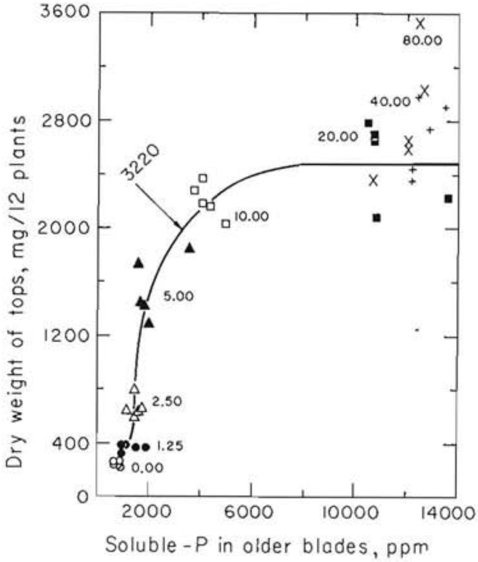

Figure 1.—Relation of dry weight of tops to soluble P concentration in older blade tissue of sugarbeet seedlings. The critical soluble P concentration at a 10% reduction from satisfactory growth, indicated by arrow, is approximately 3220 ppm. The numbers with the accompanying symbols show the mg of P per six plants added as KH_2PO_4.

In this case when the P supply increases the soluble P concentration in the plant tissues increases, but the top weights remain relatively constant. The portion of the curve between these two zones is the zone of transition (18). This zone for the OB, OP, and Cot tissues includes a range from 2110 to 4230, 940 to 1930 and 1720 to 4970 ppm of soluble P, respectively.

The soluble P concentration at a 10% reduction from the satisfactory top growth is approximately 3220 ppm, 1460 ppm and 3320 ppm for the OB, OP, and Cot tissues, respectively (Figures 1, 2, and 3). These values are referred to as the critical soluble P concentration, and can serve as a convenient point of reference in estimating the P status of sugarbeet seedlings. Sugarbeet seedlings containing much less P than their critical concentration at the time of sampling are deficient in P. These plants can be expected to respond favorably to P additions if all other factors are adequate for growth and the period of P deficiency is not too short. Plants with P values within the transition zone might increase slightly in growth, but plants with tissue values above the critical concentration cannot be expected to increase significantly in growth with increased P supply.

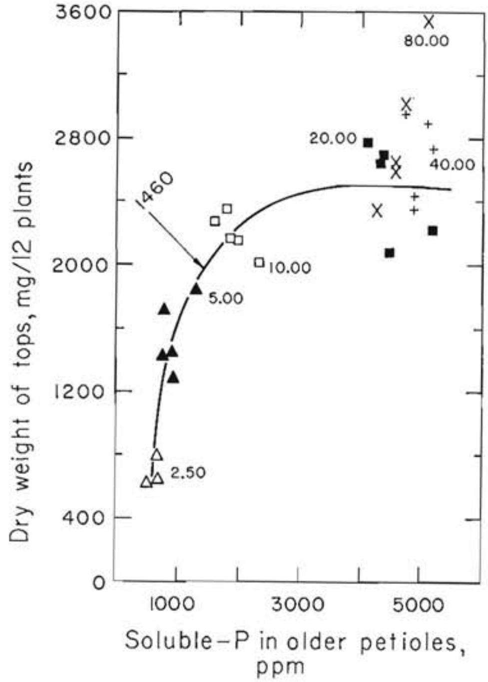

Figure 2.—Relation of dry weight of tops to soluble P concentration in older petiole tissue of sugarbeet seedlings. The critical soluble P concentration at a 10% reduction from satisfactory growth, indicated by arrow, is approximately 1460 ppm. The numbers with the accompanying symbols show the mg of P per six plants added as KH_2PO_4.

The estimated critical soluble P and total P concentration values, at 10% reduction from satisfactory growth, are given in Table 6. An inspection of this table shows that the estimated critical values for phosphorus are almost the same, for a particular plant part and form of phosphorus, whether the fresh or dry weight of the tops or of the plant part are used for plotting the data. The only exception is for the Cot tissue, where the critical values differed appreciably for the plottings of fresh or dry weight of tops or of Cot. This is perhaps due to the fact that at the time of harvest the Cot tissue had stopped growing.

Effects of phosphorus supply on tissue nitrate N concentration

The nitrate N values of the various parts of the sugarbeet seedlings are given in Table 7. As the P supply was increased the values for the OB, YB and YP tissues increased to a maximum. Then they decreased with P addition. In the Cot tissue the nitrate N concentration was relatively low for all P treatments.

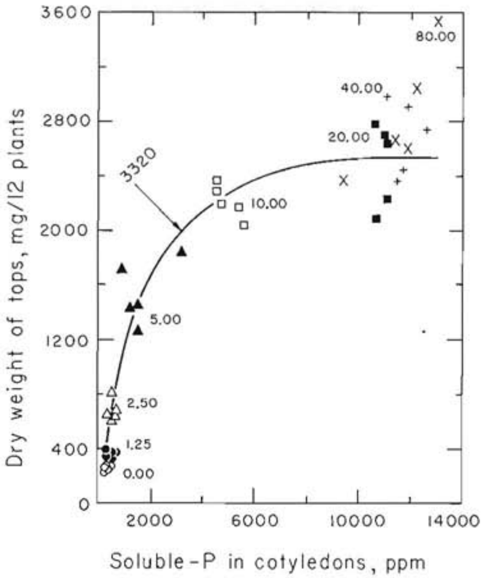

Figure 3.—Relation of dry weight of tops to soluble P concentration in cotyledon tissue of sugar beet seedlings. The critical soluble P concentration at a 10% reduction from satisfactory growth, indicated by arrow, is approximately 3320 ppm. The numbers with the accompanying symbols show the mg of P per six plants added as KH_2PO_4.

The nitrate N values decreased at first with increased P supply and then they followed the same pattern as in the OB tissue.

In the OP and FR tissues the nitrate N concentrations increased to a maximum with P treatment and then did not change significantly with a larger P supply. The values for the hypocot tissue decreased at first with P treatment, as in the Cot tissue, and they followed the pattern of the OP and FR tissues. Apparently phosphate enhances nitrate uptake preferentially. This is also suggested by the low top to FR ratio since the FR, because of small top size, should have the capacity to absorb nitrate to meet top needs.

Effects of phosphorus supply on K, Na, Ca and Mg concentration of seedling parts

The potassium concentration of various plant parts, as a rule, increased as the P supply was increased and after it reached a maximum it did not change significantly with P supply (Table 8). This general increase in K concentration with P supply may indicate that K uptake depends on the uptake of phosphate (7) or nitrate (15), directly or indirectly, or on the increase in K concentration as the P supply, from KH_2PO_4, in the culture

Table 6.—Critical phosphorus concentration values in ppm (dry basis), at 10% reduction from satisfactory growth.

Measurement and plant part used for growth comparison	Soluble P, ppm				Total P, ppm			
	OB*	OP	Cot	Hypocot	OB	OP	Cot	Hypocot
F.W. Tops	3,640	1,460	3,330	1,640	4,260	2,290	4,580	3,070
D.W. Tops	3,220	1,460	3,320	1,640	4,260	2,290	4,370	3,070
F. W. OB	3,220	------	------	------	4,160	------	------	------
D.W. OB	3,170	------	------	------	4,060	------	------	------
F.W. OP	------	1,590	------	------	------	2,340	------	------
D.W. OP	------	1,460	------	------	------	2,240	------	------
F.W. Cot	------	------	2,180	------	------	------	2,960	------
D.W. Cot	------	------	1,560	------	------	------	2,240	------
F.W. Hypocot	------	------	------	1,510	------	------	------	2,860
D.W. Hypocot	------	------	------	1,300	------	------	------	2,650

* Symbols used: O = older; B = blade; P = petiole; Cot = cotyledon; Hypocot = hypocotyl; F.W. = fresh weight; D.W. = dry weight.

Table 7.—Effects of phosphorus supply on nitrate nitrogen concentration of sugarbeet seedling material.

P supply mg/6 pls	Nitrate-nitrogen concentration in ppm (dry basis)*						
	YB**	OB	YP	OP	Cot	Hypocot	FR
0.00	------+	340a	------+	------+	2690b	11230+++	1610a
1.25	------+	1160a	------+	------+	1970b	9910+++	1910a
2.50	------+	890a	------+	5140+++	760a	7770+++	3340ab
5.00	5030b++	1880ab	9670+++	13620a	1370a	7130a	7140b
10.00	7520c	3950c	10340+++	19200b	2810b	9360a	9460b
20.00	4550b	2260ab	13620+++	21580b	2280b	9200a	9450b
40.00	2650b	1500ab	11810+++	20450b	1720ab	8950a	9100b
80.00	2060a	1190a	11600	20850b	1490ab	8840a	9720b

* For footnotes see Table 2.

Table 8.—Effects of phosphorus supply on potassium concentration of sugarbeet seedling material.

P supply mg/6 pls	% K concentration (dry basis)*						
	YB**	OB	YP	OP	Cot	Hypocot	FR
0.00	------+	4.34a	------+	------+	7.9a	9.6+++	3.58a
1.25	------+	7.20b	------+	------+	9.0b	11.2d	3.32a
2.50	------+	7.17b	------+	9.1+++	9.4c	8.8c	3.40a
5.00	5.58a++	8.24b	8.2+++	11.4a	10.9c	7.5b	4.84b
10.00	6.55a	9.11b	9.4+++	13.3b	12.0d	8.0a	5.99b
20.00	7.90ab	8.82b	10.4+++	13.9b	12.1d	8.3a	5.85bc
40.00	7.83ab	7.53b	10.0+++	13.5b	12.3d	8.1a	6.07b
80.00	7.90ab	8.21b	10.1	13.8b	12.1d	8.2a	6.52bc

* For footnotes see Table 2.

solution was increased. It is also to be noted that all K values were relatively high, with values for the OP tissue reaching 13.9% K, dry basis.

All the sodium concentration values, except for the Cot and

Table 9.—Effects of phosphorus supply on sodium concentration of sugarbeet seedling material.

P supply mg/6 pls	% Na concentration (dry basis)*						
	YB**	OB	YP	OP	Cot	Hypocot	FR
0.00	——+	0.50b	——+	——+	1.35b	0.24+++	0.18b
1.25	——+	0.87bc	——+	——+	1.37b	0.21c	0.25b
2.50	——+	1.38c	——+	0.64+++	1.64b	0.17c	0.36b
5.00	0.38c++	0.85bc	0.10+++	0.26b	1.35b	0.04b	0.09a
10.00	0.20b	0.51b	0.05+++	0.08a	1.15a	0.00	0.09a
20.00	0.12a	0.37a	0.04+++	0.06a	0.96a	0.00	0.08a
40.00	0.14a	0.38a	0.02+++	0.06a	1.04a	0.00	0.11a
80.00	0.11a	0.34a	0.01	0.05a	0.96a	0.00	0.09a

* For footnotes see Table 2.

OB tissues, were very low (Table 9), and these tended to increase and then decrease with P supply. The decreases in Na concentration with P supply may be due to a potassium-sodium competition (15) since, when P was increased, K supply was also increased by about 3.23%. It is also known (6, 10, 11, 14) that the Na concentration in plants increases in case of poor root aeration. But here the greatest Na uptake was not associated with the most root injury, i.e. lowest P supply.

The highest Ca and Mg concentrations were observed in the P deficient plants, with exceptions for the zero P treatment, where the Mg concentrations of the OB and Cot tissues were the smallest (Tables 10 and 11). With adequate P supply the Ca and Mg concentrations within a plant part remained relatively constant. Among the plant parts the photosynthetic tissues, including the Cot, were much higher in Ca and Mg than contiguous conducting tissues. The Ca and Mg values tended to parallel each other except in the FR tissue, where, unexpectedly, the Mg values differed by being very much higher than these of Ca and by decreasing rapidly with P treatment. The Cot tissue were relatively high in Ca and Mg and changed little with P treatment.

Summary and Conclusions

1) Sugarbeet seedlings at the cotyledon stage responded to phosphorus treatment within a few days after transplanting to culture solutions.

2) Deficiency symptoms of leaf blades and cotyledons increased with decreased phosphate concentration of all plant parts.

3) Phosphorus deficiency increased the percentage dry matter of all parts of the seedling.

4) The phosphorus status of sugarbeet seedling can be determined from the soluble or total phosphorus values for petioles

Table 10.—Effects of phosphorus supply on calcium concentration of sugarbeet seedling material.

P supply mg/6 pls	% Ca concentration (dry basis)*						
	YB**	OB	YP	OP	Cot	Hypocot	FR
0.00	——+	1.79b	——+	——+	1.95b	0.53+++	0.69b
1.25	——+	3.28c	——+	——+	2.98c	0.57c	0.67b
2.50	——+	2.26b	——+	2.27+++	2.72c	0.56c	0.56b
5.00	0.86a++	1.46a	0.75+++	1.40b	1.97b	0.34b	0.49ab
10.00	0.81a	1.36a	0.44+++	0.96a	1.90b	0.29b	0.49ab
20.00	0.81a	1.33a	0.46+++	1.01a	1.83b	0.27ab	0.46a
40.00	0.80a	1.35a	0.36+++	0.99a	1.77a	0.26ab	0.54ab
80.00	0.78a	1.30a	0.36	0.96a	1.79a	0.27ab	0.54ab

* For footnotes see Table 2.

Table 11.—Effects of phosphorus supply on magnesium concentration of sugarbeet seedling material.

P supply mg/6 pls	% Mg concentration (dry basis)*						
	YB**	OB	YP	OP	Cot	Hypocot	FR
0.00	——+	1.03a	——+	——+	1.27a	0.46+++	6.22b
1.25	——+	1.75c	——+	——+	1.78b	0.48c	4.64b
2.50	——+	1.32b	——+	0.75+++	1.71b	0.37b	3.13b
5.00	0.74a++	1.29b	0.46+++	0.82c	1.60b	0.26a	2.56a
10.00	0.81a	1.35b	0.45+++	0.68b	1.59b	0.26a	2.81a
20.00	0.75a	1.29b	0.37+++	0.56a	1.49ab	0.24a	1.65a
40.00	0.71a	1.24ab	0.35+++	0.55a	1.42a	0.23a	1.80a
80.00	0.66a	1.19a	0.36	0.51a	1.40a	0.24a	1.48a

* For footnotes see Table 2.

of the first pair of leaves formed or for their blades or cotyledons. This cannot be done effectively by analyzing the entire seedling or its tops. The critical soluble phosphorus value is approximately 1460 ppm and 3220 ppm for the older petiole and blade tissues, respectively, and 3320 ppm for the cotyledons, dry basis.

5) Phosphorus deficiency decreased the nitrate nitrogen concentrations in the fibrous roots and older blade tissues. Smaller decreases in nitrate concentration took place in the conducting tissues and cotyledons. Similar decreases in potassium concentration took place in the fibrous roots, cotyledons, petioles and blades. All potassium values were relatively high with values for the older petioles reaching 13.9% potassium, dry basis.

6) Phosphorus deficiency increased the sodium and calcium concentrations in all plant tissues, and that of magnesium in the fibrous roots and hypocotyl.

7) Among the plant parts analyzed the photosynthetic tissues were much higher in calcium and magnesium than contiguous conducting tissues. The calcium and magnesium values tended to parallel each other except in the fibrous roots, where the magnesium values became very much higher than those of cal-

cium. The magnesium values decreased rapidly with phosphorus supply and after they reached a minimum did not change significantly with more phosphorus added.

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