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Growth and Phosphorus Uptake by Tomato Cultivars as Influenced by Phosphorus Concentrations in Soil and Nutrient Solution

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Abstract. **Dry weight and P accumulation by tomato cultivars growing in soil and solution were determined. Tomato seedlings, 'Campbell-37', 'Campbell-27', 'Jet-Star', 'Knox', and 'Rutgers' were grown in a soil solution concentration of 0.62, 3.25, 6.50, 9.75 and 19.38 μM P. Significant growth response for all cultivars was in the concentration range of 0.62 to 6.50 μM P. P uptake increased over the entire P concentration range in soil solution. The plants utilized P more efficiently with a higher dry weight accumulation per mg P absorbed at low P than at high P concentration in soil solution with no differences among the cultivars.**

'Campbell-37', 'Knox', 'Rutgers', and 'Tipton' were grown in 113 and 226 μM P solution. A 63% increase in dry weight was obtained with tomato seedlings growing in 226 compared to the 113 μM P solution. 'Rutgers' produced the lowest plant dry weight and 'Knox' produced the highest. The root surface increased as the P concentration in solution increased. At both solution P levels, 'Knox' had the lowest root surface and 'Campbell-37' the highest. The root surface : shoot ratio decreased as P concentration in solution increased. A 73% increase in P uptake was obtained with doubling P concentration in solution. 'Campbell-37' had the highest total P uptake at both P concentration in nutrient solution.

Phosphate concentration in the soil solution is a critical factor for plant uptake of P. Several workers have shown that a critical level of P in soil solution for maximum plant growth varies among plant species (8, 15, 18). Differential ability in P uptake among genotypes of the same plant species has been reported for soybean (6), corn (14), sorghum (3), and tomato (9).

Besides the P concentration in solution and genotype growth pattern, the nutritional history of a plant is another factor that can affect profoundly its subsequent capacity to absorb ions (12). Reasons for such a behavior could be due to: an increased number of absorbing sites in P deficient plants (1, 16); the same number of absorbing sites operating more efficiently (20); or an increase in the absorption site affinity as indicated by a decrease in the apparent dissociation constant (4, 11).

The objective of this study was to characterize the relationship of P concentration in soil and nutrient solution with P uptake and growth of tomato cultivars.

Materials and Methods

Soil experiment. The experiment was conducted on samples of the surface 15 cm of a Russel silt loam soil, a typic hapludalf, with a moderate granular structure. The available P as determined by the Bray P1 test was 8 ppm, the soil : water pH 6.5, and 28% moisture content at ⅓ bar. Soil samples were sieved through a 1 × 1 cm opening screen, air dried, stored, and again sieved at the time the P treatments were applied.

Four P levels were established by mixing $NaH_2PO_4 \cdot H_2O$ with the soil which also received uniform treatments of 100 ppm N as NH_4NO_3 and 100 ppm K as KCl. A sorption isotherm (7) was used to determine the amount of fertilizer P needed to represent soil solution levels of 3.25, 6.50, 9.75, and 19.38 μM P. A check treatment without P addition was also included in the experiment. The soil was incubated for 72 hr at 70°C (2) and then added to 1 liter pots.

Five tomatoes, 'Campbell-27', 'Campbell-37', 'Jet Star', 'Knox', and 'Rutgers' were planted at each of the 5 P levels in the soil solution. The experiment was a split-plot design, replicated 4 times, with the P levels distributed in the plot, and the cultivars in the split-plot. Tomato seeds were sown, wetted, and thinned to one plant per pot 5 days after emergence. During growth, the plants received water to keep the soil at 20% to 25% moisture. Twenty-four days after emergence the tops were cut off at the cotyledonary node. Plants were dried in a forced air drier at 70°C, and dry weights were determined. The tissues then were ashed with $H_2SO_4 \cdot H_2O_2$ and analyzed colorimetrically for P (10).

Solution experiment. The experiment was set up in the greenhouse as split-plot design, with 3 replications, with temperatures of 60° night and 65° to 75°F day. The main plot was P levels 113 and 226 μM P, and the split-plot consisted of 4 tomato cultivars, Campbell-37', Knox', 'Rutgers' and 'Tipton'.

For the experiment, tomato seeds were sown 1 cm deep in vermiculite soaked once with Hoagland's nutrient solution minus P. Deionized water subsequently was added to the germination medium to maintain adequate moisture. In 7 days the seedlings were large enough to be transferred to the nutrient solution culture pots. Six uniform root-trimmed seedlings were transferred to 2.5 liter, opaque, polyethylene pots which contained a continuously aerated nutrient solution having the composition shown in Table 1. Phosphorus was added as $Ca(H_2PO_4)_2 \cdot H_2O$ at 113 μM and 226 μM at transplanting time. The solution pH was adjusted daily to 6.2 with NaOH or HCl. Each plant was supported by a polyurethane foam plug in a black polyethylene lid.

Plants were grown 21 days in solution. At the completion of the experiment, the plants were harvested separately and their fresh and dry weights were obtained. The root length was measured by using the Tennant (19) method. Plant shoot and root were dried at 70°C for 72 hr and digested in concentrated H_2SO_4

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Table 1. Nutrient solution utilized in the experiment.

Salts	Stock solution g/liter	ml stock/liter final solution
KNO_3	101.1	5
$Ca(NO_3)_2\ 4\ H_2O$	236.2	5
$MgSO_4\ 7H_2O$	246.5	2
$LaCL_3\ 7H_2O$	3.728	z
H_3BO_3	1.546	
$MnSO_4\ H_2O$	0.845	
$ZnSO_4\ 7H_2O$	0.575	
$CuSO_4\ 5H_2O$	0.125	
$(NH_4)_6Mo\ O_{24}\ 4H_2O$	0.0184	
Fe	y	

[z]1 ml of micronutrients stock solution was added to each liter of final solution.

[y]Fe was supplied by adding 1 ml of Fe stock solution to each liter of final solution. The Fe stock solution was composed by mixing 25 g of Sequestrene 330 Fe (sodium ferric diethylene-triamine penta acetate) plus 21.5 g of Fe $NH_4(SO_4)_2$/liter H_2O and contained 5 mg Fe/ml.

and H_2O_2. Total P was determined colorimetrically by the vanadomolybdate procedure of Jackson (10).

Mean root radius, ro, was calculated from ro = $(Fw/L)^{1/2}$, where Fw was the root fresh weight expressed in g, and L was the root length in cm. This formula assumed root specific gravity of 1.0 and cylindrical shape. Root surface (RS) was calculated from RS = 2 roL.

Results and Discussion

Soil experiment. Plant shoot dry weight increased with an increase in the P concentration in the soil solution (Table 2). Growth response for all cultivars was in the 0.62 to 6.5 μM P soil solution conc range. Significant differences in shoot dry weights between cultivars were observed in response to added P, and 'Rutgers' had the lowest shoot dry weight at optimum P.

Plant P, in response to increased P conc in the soil solution, increased from 0.16% (extreme deficiency) at the 0.62 μM P concentration to 0.38% (adequate) at the 6.5 μM P concentration (mean of all cultivars).

The phosphate use efficiency ratio, which is the plant dry weight (mg) per mg of P absorbed, decreased as P concentration in soil solutions increased (Table 3). The largest decrease was between 0.62 to 3.25 μM P in soil solution. As P deficiency in the plant was eliminated, the efficiency ratio decreased from 637 to 270. The plants used P more efficiently to accumulate dry matter at low P concentration than at high P concentrations in soil solution. There were no significant differences in efficiency ratio among the cultivars.

Total P uptake in tomato cultivars increased with an increase in the P concentration in soil solution (Table 4), with a large portion of the increased uptake in the range of 0.62 to 6.50 M P in soil solution. The average cultivar P uptake was 4%, 53%, 78%, and 92% of the maximum P uptake for the 0.62, 3.25, 6.50 and 9.75 μM P soil solution concentrations, respectively. Statistically significant differences in P taken up by cultivars were observed only when plants were fertilized. 'Campbell-37' and 'Knox' absorbed the highest amount of P at all P levels in soil solution.

Solution experiment. A significant increase in dry weight was obtained for tomato seedlings growing in the 226 μM P solution (Fig. 1). 'Rutgers' produced 16.5% and 25% less plant dry weight than 'Knox' respectively in the 113 and 226 μM P solutions. With an increased P concentration, the proportion of leaves in relation to the total dry weight increased 4.3% while the proportion of stem and root decreased 2.3% and 13.4% respectively (Fig. 1).

Table 3. Phosphorus absorption efficiency of tomato cultivars as influenced by P levels in soil solution.

	Efficient ratio (mg DW/mg P abosrbed)				
	P level in soil solution - (μM)				
Cultivar	0.62	3.25	6.50	9.57	19.50
Campbell-37	531 d[z]	315 a	253 a	224 a	214 a
Campbell-27	706 a	338 a	266 a	228 a	225 a
Jet-Star	710 a	342 a	288 a	264 a	232 a
Knox	632 ab	316 a	267 a	238 a	231 a
Rutgers	605 cd	338 a	278 a	227 a	209 a
Mean	637 a[y]	330 b	270 c	236 cd	222 d

[z]Means within column followed by different lower-case letters are significantly different at 5% probability level by Duncan's multiple range test.

[y]Mean P values followed by different upper-case letters are significantly different at 5% probability level by Duncan's multiple range test.

Table 2. Growth of tomato cultivars as influenced by phosphorus levels in soil solution.

	Shoot dry wt (mg)				
	P level in soil solution - μM				
Cultivar	0.62	3.25	6.50	9.75	19.50
Campbell-37	129 a[z]	926 a	1103 a	1143 a	1148 a
Campbell-27	98 a	899 a	994 ab	1029 ab	1068 ab
Jet-Star	114 a	753 b	1024 ab	1046 ab	1085 ab
Knox	127 a	925 a	1100 a	1127 ab	1145 ab
Rutgers	106 a	738 b	953 b	999 b	1024 b
Mean	115 c[y]	848 b	1035 a	1069 a	1094 a

[z]Means within column followed by different lower-case letters are significantly different at 5% probability level by Duncan's multiple range test.

[y]Mean P values followed by different upper-case letters are significantly different at 5% probability level by Duncan's multiple range test.

Table 4. Total phosphorus uptake by tomato cultivars as influenced by P levels in soil solution.

	P accumulation (mg/plant)				
	P level in soil solution - μM				
Cultivar	0.62	3.25	6.50	9.57	19.50
Campbell-37	0.24 a[z]	3.04 a	4.46 a	5.18 a	5.57 a
Campbell-27	0.14 a	2.72 ab	3.86 bc	4.53 bc	4.85 b
Jet-Star	0.17 a	2.36 b	3.69 bc	4.24 c	4.84 b
Knox	0.21 a	2.96 a	4.16 a	4.87 a	5.13 ab
Rutgers	0.18 a	2.32 b	3.56 c	4.47 bc	4.96 b
Mean	0.19 d[y]	2.68 c	3.95 b	4.65 ab	5.07 a

[z]Means within column followed by different lower-case letters are significantly different at 5% probability level by Duncan's multiple range test.

[y]Mean P values followed by different upper-case letters are significantly different at 5% probability level by Duncan's multiple range test.

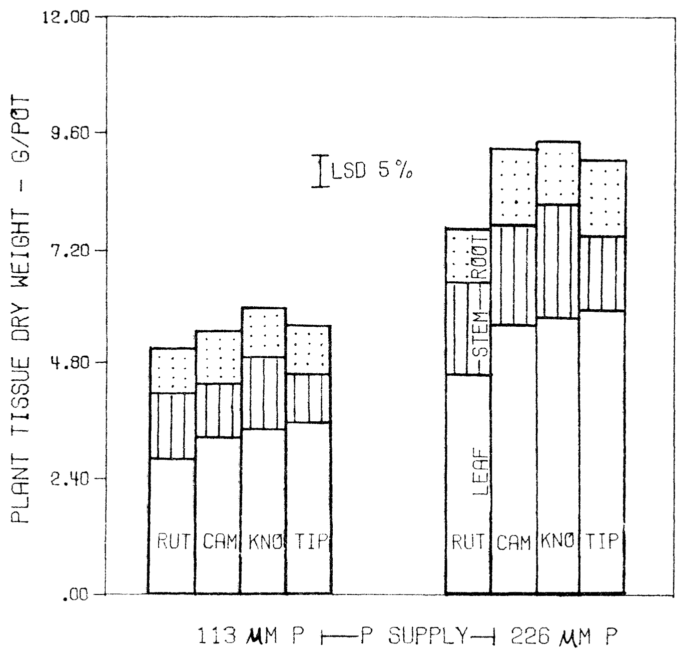

Fig. 1 Effect of P supply on tissue dry weight of tomato cultivars after 21 days of growth in nutrient solution.

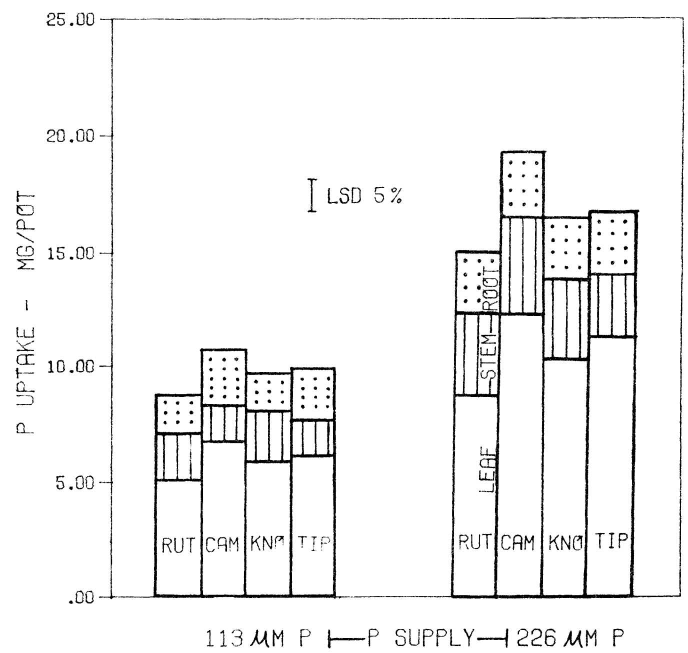

Fig. 3 Effect of P supply on P uptake in tissues of tomato cultivars after 21 days of growth in nutrient solution.

Root surface increased an average of 38.9% with an increased P concentration in solution and ranged from 34.2% for 'Rutgers' to 44.8% for 'Tipton'. At both solution P levels, 'Knox' had the lowest root surface, 17.0 and 23.5 dm^2/pot, respectively, and 'Campbell-37' had the highest values, 21.4 and 29.4 dm^2/pot respectively. The root surface : shoot ratio, contrary to the root surface values, decreased as P concentration in solution increased from 113 to 226 µM P (Fig. 2). This result agrees with observations on corn plants found by Schenk and Barber (17). The root surface : shoot weight ratio for 'Knox' was lower than for the other 3 cultivars at both P concentration. The different response of the cultivars to variation in P supply suggests that 'Knox', with the smallest root surface per unit of shoot dry weight, absorbs less P per unit of shoot than the other cultivars. At low P supply P concentration in 'Knox' leaves (0.18%) was smaller than in 'Tipton', 'Rutgers', and 'Campbell-37' (0.19, 0.20, and 0.22% respectively). At the high P supply, P concentration in 'Knox' leaves also was lower than in 'Tipton,' Rutgers', and 'Campbell-37' leaves.

Significant increase in P uptake in plant tissue (73%), was obtained with tomato seedlings growing in the 226 µM P solution, compared to 113 µM P (Fig. 3). At both P concentrations 'Campbell-37' had the highest total P uptake. Yet differences among 'Campbell-37' and the other cultivars were more pro-

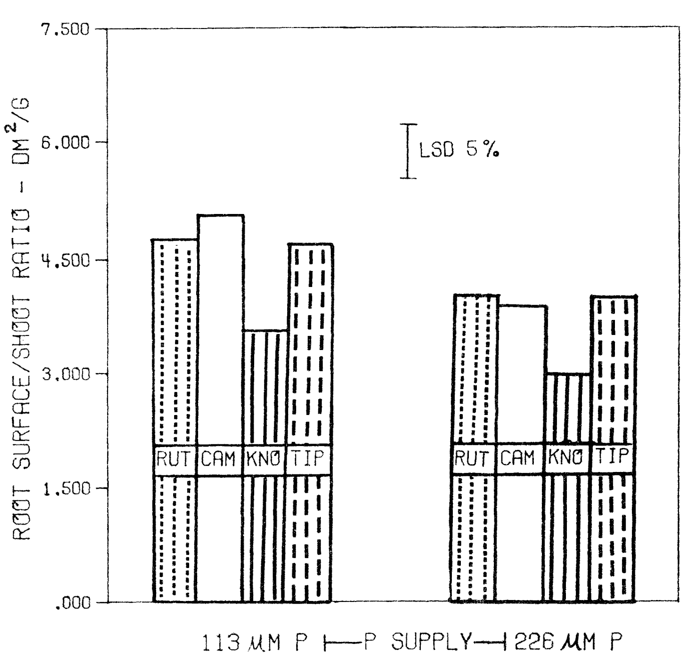

Fig. 2 Effect of P supply on root surface : shoot ratio of tomato cultivars after 21 days of growth in nutrient solution.

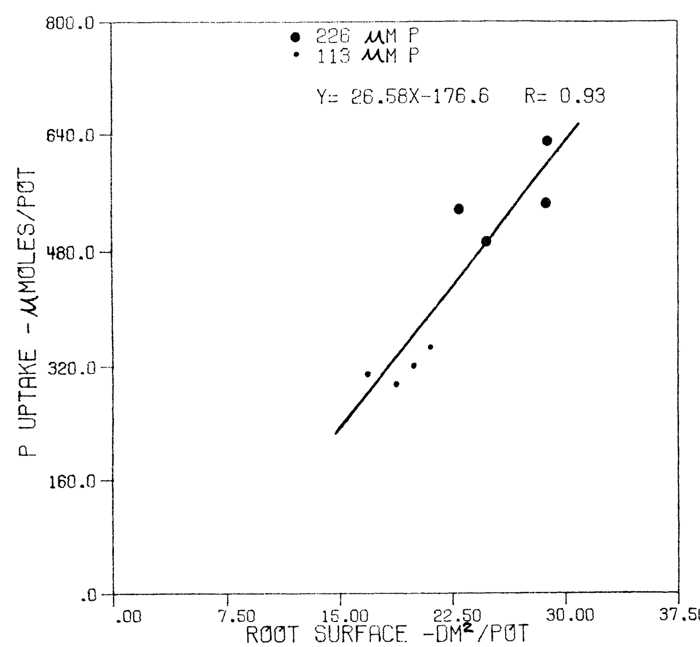

Fig. 4 Relationship between root surface and P uptake by tomato plants under different amount of P supply by nutrient solution. Each point is the cultivar average.

nounced at the higher P concentrations than at the lower concentration. At the 226 μM P solution concentration, cultivars accumulated proportionately more P in the leaves (3%) and stem (9%) and less in the roots (18%). Increased P uptake occurred concomitantly with increased root surface development of the cultivars as the P concentration increased in solution. A linear relationship was obtained between P uptake and root surface (Fig. 4).

Since no significant difference was found in cultivar response to available P, the P requirement for optimum growth of tomato seedlings on soils low in available P was satisfied by increasing the P concentration of the soil solution in the area occupied by the seedling root system to 6.5 μM P. The available P provided a P absorption rate that met the optimum growth requirements of the seedling and achieved a seedling composition at 28 days after emergence between 0.3% and 0.38% P, which can be used as an indicator of optimum P nutrition. Optimum P nutrition for tomato seedlings can be accomplished with a starter P fertilizer band either on the seed or under the seed or by starter solution with transplants.

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