

Aluminum-induced Calcium Deficiency in Peach Seedlings¹

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Abstract. Total nutrient content, uptake rates, and distribution were determined for seedlings of peach [*Prunus persica* (L.) Batsch] grown in nutrient solutions containing 0, 222, 666, and 2000 μM Al. Generally, total nutrient content decreased in the peach seedling organs as Al concentration increased. The responses obtained with increased Al concentration were linear with some nutrients and curvilinear with others and varied with plant organ. As Al concentration increased, the uptake rates for P, Ca, Mg, Zn, and Mn decreased but those for K and Fe increased. Aluminum did not alter the translocation of most nutrients; however, a greater percentage of the absorbed Ca accumulated in the leaves than in the roots or stems. Thus, aluminum toxicity in peaches may be related to a reduction in Ca uptake rate and not to inhibition in translocation of Ca.

The soils of the Southeast are inherently acid and infertile. Below pH 5.5, Al is the major exchangeable cation present in most of these soils. Since Al is present in concentrations sufficient to suppress root growth in some crops, it may be an important growth-limiting factor (1, 2). Acidity in surface soils can easily be neutralized by liming, but when the subsoil is also strongly acid the problem is compounded even with annual crops. Subsoil acidity problems may be even greater with perennial crops such as peaches, because incorporation of chemical amendments is restricted to the surface soil and NH_4^+ is the usual N source.

The foliar symptoms induced by increasing Al concn in peach seedlings have been previously reported (8). Peach seedling roots injured by high concn of Al are characteristically stubby, angular, and thickened; fewer lateral roots develop (9). The epidermal cells of injured peach roots generally collapse, and root hair eruption sites fail to heal properly, which lead to basal constriction of root hairs. Aluminum has been shown to reduce the Ca concn in roots and the concn of other nutrients in leaves, stems, and roots of peach seedlings grown in nutrient solution (8). However, the effects of Al concn on total nutrient content, uptake rates, and distribution were not clearly defined. Thus, the objectives of this study were to determine these effects with particular emphasis on Ca nutrition.

Materials and Methods

'Elberta' peach seedlings were prepared for experimental use similar to the method reported earlier (8). Solution pH was measured daily and maintained at 4.0 by adding HCl or NaOH. The vigorously aerated pretreatment solutions were changed at 7-day intervals and monitored between changes to minimize nutrient depletion.

The experiment was conducted in the greenhouse at a temp of $24 \pm 5^\circ\text{C}$. Sunlight was supplemented with fluorescent light to produce a minimum of 4 klx at the canopy for a 16-hr day. The variable Al treatments of 0, 222, 666, and 2000 μM of Al from K Al (SO_4)₂ · 12 H₂O were applied after 21 days of pretreatment. The K concn was maintained in all solutions at 1.1 mM by the addition of KCl. The concn of the other nutrients was maintained as previously reported (8). During the Al treatments, nutrient solutions were changed every 3 days and seedlings were harvested after 27 days. Preliminary results indicated that changing nutrient solution at 3-day intervals and adjusting pH daily to 4.0 maintained the Al in the Al^{+3} form with no more than 5% error (8).

Seedlings were separated into leaves, stems (laterals plus main

axis), and roots; and freeze dried. The freeze-dried samples were ground to pass a 40-mesh screen. The concn of K, Mg, Ca, Zn, Mn, Fe, and Al were determined by atomic absorption spectrophotometry. Phosphorus concn was determined on the ashed tissue by the ascorbic acid method of Murphy and Riley (10).

The uptake rates of K, P, Ca, Mg, Zn, Mn, Fe and Al were calculated according to the equation of Williams, modified by Carroll and Loneragan (3). The equation was

$$I_m = \frac{M_2 - M_1}{WR_2 - WR_1} \cdot \ln \frac{WR_2 / WR_1}{t_2 - t_1} \quad [1]$$

where I_m is uptake rate per g of root, M is total elemental content in peach seedlings (leaves + stems + roots), WR is root wt, and t is time. Subscripts 1 and 2 denote initial and final harvests.

The elemental distribution in peach seedlings was calculated according to the equation

$$\% E = \frac{\text{TO}(L)_2 - \text{TO}(L)_1}{\text{TS}_2 - \text{TS}_1} \times 100 \quad [2]$$

where E is the % of the total elemental content in the seedling organ, L is leaves, TO is the total μg of the element in the organ, TS is the total μg in the peach seedling, subscripts 1 and 2 denote initial and final harvest. The E value was calculated for roots and stems following the same procedure.

The experimental design was 5 replicates in a randomized complete block with two plants per 5-liter plastic container. Data were treated by standard analysis of variance.

Results and Discussion

Root growth appears to be a more sensitive indicator of Al toxicity than leaf growth. The first sign of Al toxicity is necrosis and severe stunting and thickening of the roots that is probably due to the inhibition of cell division (5). Since the uptake of a given nutrient depends partly on the volume of roots present, any condition that affects growth will alter nutrient uptake and perhaps the redistribution of nutrients in the plant.

The nutrient content of peach seedling organs is shown in Table 1. Increasing Al concn significantly decreased the content of P, Ca, Mg, Zn, and Mn in leaves and the decrease seemed linearly related to Al concn. Iron content was significantly reduced only at the highest Al concn. Only K and Al were significantly increased by increasing Al concn, and these increases occurred only at 666 μM Al concn.

The stem contents of K, Fe, and Al were not significantly changed by increasing Al concn. Calcium, Mg, Zn, and P were significantly reduced by increasing Al concn. However, P content was not decreased until the Al concn was increased to 666 μM Al.

The root contents of Ca, Mg, Zn, and Mn were significantly

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Table 1. The influence of Al concn on nutrient content in peach seedling organs.

Element	Plant ^Z organ	Nutrient content (μg/2 plants)			
		Al concn			
		0μM	222μM	666μM	2000μM
P	Leaves	24,507a ^Y	19,285ab	16,412b	9,645c
	Stems	12,797a	12,069a	7,275b	4,936b
	Roots	11,760ab	15,914a	15,812a	7,736b
K	Leaves	363,224b	294,853b	571,198a	312,500b
	Stems	96,612a	85,766a	69,648a	58,868a
	Roots	76,390a	97,284a	135,876a	76,036a
Ca	Leaves	30,963a	24,400ab	20,898b	9,336c
	Stems	18,719a	12,924b	10,609b	4,781c
	Roots	1,755a	104b	25b	0b
Mg	Leaves	31,326a	23,884ab	21,921b	10,528c
	Stems	10,505a	7,173b	6,409b	3,707c
	Roots	7,673a	4,598ab	3,288b	2,435b
Zn	Leaves	410a	324ab	288ab	199b
	Stems	199a	134b	99c	78c
	Roots	160a	125ab	97bc	48c
Mn	Leaves	1,162a	928ab	701b	326c
	Stems	127a	108a	112a	56c
	Roots	471a	253b	183b	73c
Fe	Leaves	989a	876a	826a	583b
	Stems	110a	110a	106a	98a
	Roots	915bc	1,211b	1,786a	794c
Al	Leaves	1,568b	1,525b	2,045a	1,464b
	Stems	854a	891a	776a	677a
	Roots	958c	9,134b	16,489a	8,542b

^ZDry wt of organs and nutrient concn used in calculating nutrient content have been reported previously (8).

^YMeans separation in rows by Duncan's multiple range test, 5% level.

decreased by high Al concn, although the relation was not linear. Iron and Al contents were highest at the 666 μM Al concn. Potassium was not affected by Al concn. When the nutrient content of individual organs is considered, the leaves appear to be a better indicator of the Al concn in the nutrient solution than stems or roots.

The peach seedlings roots were washed in distilled water for approximately 1 min and subsequently immersed in distilled water for measuring root volume. Since only about 2 min were required for rinsing and measuring root volume, the elemental analysis of root tissues should reflect the element content within the cells. The uptake rate of a nutrient may be altered by ionic interaction in the soil, nutrient solution, or free space in the root. The utilization and translocation can be further affected by ionic interactions after uptake. The interactions before and following uptake may or may not be related. Our discussion will be limited to the uptake and translocation of the elements.

The influence of Al concn on nutrient uptake rates in peach seedlings is presented in Table 2. The uptake rates of Ca and Mn were reduced with each increased increment of Al concn, and so were rates for Mg except that uptake rates were similar at the 222 and 666 μM Al concn. The uptake rates for P and Zn were not reduced until the Al concn exceeded 222 μM. The uptake rate for Fe was significantly higher at the 222 μM Al concn than at the highest Al concn. Potassium uptake rate was increased significantly only at the 666 μM Al concn. This was the Al concn at which the greatest increase in dry weight of peach seedling roots (8) and the highest Al uptake rate occurred.

Aluminum toxicity (7) in black pepper (*Piper nigrum* L.) was associated with reduced uptake of Ca and Mg and an increase in the uptake of K and Al. The ratio of K:Ca + Mg in the black

Table 2. The influence of increasing aluminum concentration on nutrient uptake rate in peach seedlings.

Al concn (μM)	Nutrient uptake (μM/g-roots per day ^Z)							
	K	P	Ca	Mg	Zn	Mn	Fe	Al
0	196b ^Y	21a	22a	33a	0.185a	0.579a	0.649ab	1.83c
222	185b	20a	17b	24b	0.146a	0.462b	0.723a	7.99b
666	293a	13b	11c	17b	0.094b	0.292c	0.566ab	11.60a
2000	182b	6c	6d	9c	0.069b	0.169d	0.493b	8.03b

^ZRoot wt used in calculating uptake rates have been previously reported (8).

^YMeans separation within columns by Duncan's multiple range test, 5% level.

pepper shoots was used as an index of Al injury. The significant decrease in Ca uptake rate (Table 2) and the subsequent reduction in Ca concn in roots (8) with increasing Al concn also appears to be a good indicator of Al toxicity in peaches. The high uptake of K at 666 μM Al concn is not understood.

The influence of increasing Al concn on nutrient distribution is given in Table 3. A larger percentage of Ca and Zn accumulated in the leaves as Al concn in the solution was increased. The increase was caused by the reduction in nutrient content in the roots (Table 1). The data suggest that the leaves may have a stronger sink for Ca and Zn than do the stems or roots. Increasing Al concn had no influence on the distribution of Mg among the peach organs (Table 3). The only influence appeared to be related to inhibition of Mg uptake (Table 2). The reduction in the Fe content appears to be related to a reduction in uptake rate (Table 2).

Aluminum concn did not affect significantly the accumula-

Table 3. The influence of increasing Al concn on nutrient distribution in organs of peach seedlings.

Elements	Peach organs	Nutrient distribution (% E) ^Z			
		Al concn			
		0μM	222μM	666μM	2000μM
P	Leaves	48a ^Y	36a	32a	37a
	Stems	28a	29a	17b	21b
	Roots	24b	34ab	51a	43ab
K	Leaves	83a	76a	80a	80a
	Stems	4a	3a	2a	0a
	Roots	15a	22a	18a	21a
Ca	Leaves	63c	71b	73b	80a
	Stems	34a	30a	28a	23b
	Roots	3a	0b	0b	0b
Mg	Leaves	64a	71a	75a	65a
	Stems	19a	18a	17a	18a
	Roots	16a	11a	9a	17a
Zn	Leaves	64c	69bc	84ab	96a
	Stems	24a	20ab	14ab	4b
	Roots	14a	14a	6ab	0b
Mn	Leaves	64a	72a	66a	72a
	Stems	8a	7a	13a	13a
	Roots	27a	21a	20a	14a
Fe	Leaves	54a	45a	31b	34b
	Stems	4a	4a	3a	4a
	Roots	42a	51a	66a	62a
Al	Leaves	48a	14b	10b	12b
	Stems	25a	7b	4c	5b
	Roots	27c	79b	86a	83ab

^ZDry wt and nutrient concn used in calculating E have been reported previously (8).

^YMeans separation in rows by Duncan's multiple range test, 5% level.

tion of K, Mg, Mn, and Fe in the roots. The large decrease in Mn content in the roots (Table 1) with increased Al concn did not result in a shift in accumulation in the stems or leaves as occurred with Ca and Zn (Table 3). Increasing Al concn reduced the P uptake rate (Table 2) and a larger percentage of P tended to remain in the roots (Table 3). This indicates that Al reduced P translocation, perhaps by precipitation of P on the root surface or in the root cells. As Al concn in solution increased, Al translocation decreased and Al accumulated primarily in the roots. It has been suggested that in annuals Al and P precipitate on the root surface and induce a P deficiency that may often indicate Al toxicity (6). However, the Al-toxicity symptoms in peach seedlings leaves reported previously (8) resembled Ca rather than P deficiency.

The translocation of Ca appeared to be enhanced by increasing Al concn, and the percentage of Ca translocated to the leaves was increased. Aluminum inhibited the uptake of Ca and perhaps reduced the permeability of the plasmalemma for Ca entry. Aluminum reduced the Ca associated with free space of barley roots (4), and the same mechanism may have been affecting the accumulation of Ca in the peach seedling roots as Al was increased. Aluminum toxicity in peach seedlings appears to be related to the accumulation of Al in the roots. This follows results with other crops. Aluminum was found to be associated with the cell wall in barley roots (6), and with corn the root epidermis appeared to be an effective barrier to Al entry (12). However, Al penetrated the corn root where a secondary root forced its way through the endodermis, cortex, and epidermis of the root (11).

Increasing Al concn in nutrient solution reduced the concn of P, Ca, and Mg in both leaves and roots in 'Elberta' seedlings (8) and the uptake rates of these nutrients (Table 2). The Al-toxicity symptoms developed and reported (8) were those of Ca deficiency. The significant decrease in total Ca (Table 1) and the uptake rate (Table 2) are the primary effects of increasing Al concn on Ca uptake by peaches. The deficiency was induced by reduction in the uptake of Ca; the translocation of Ca from the root and stems was enhanced after the initiation of Al treat-

ments. We are presently conducting an experiment to determine if Al-induced Ca deficiency can be corrected by increasing Ca concn when the Al ions are present in nutrient solution.

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Characteristics of Red Maple Progenies from Different Geographic Areas¹

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Abstract. Variation analysis showed significant variation among red maple (*Acer rubrum* L.) progenies grown from seed collected throughout the species' natural range with respect to height, diameter, autumn color, winter injury, earliness of flushing and cessation of growth. Northern progenies showed slowest growth, most reddish autumn color, earliest flushing and budset, and least winter injury. Most traits were significantly correlated with several geographic and climatic variables, and genetic and phenotypic correlations among traits indicated that multiple-trait selection could be effective.

Red maple is becoming increasingly important as a landscape tree. It is the second most frequently planted species in municipalities of the northeastern U.S. (4). Little recognition has been given to genetic variation within this species. The species

covers a wide geographic range including the eastern U.S. and southern Canada, and it therefore offers climatic variation and geographic distances essential for genetic differentiation (7).

Many problems of adaptation of red maple to various sites, including achievement of adequate cold hardiness, suitable growth rate, and good autumn color, could be solved if more were known about the degree of genetic variability within the species. In 1971, seed was collected from throughout the natural range of red maple. Many cooperators assisted in seed

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