Aluminum Toxicity Symptoms in Peach Seedlings

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Abstract. 'Elberta' (Prunus persica (L.) Batsch) peach seedlings were grown in nutrient solutions for 27 days with aluminum concentrations of 0, 222, 666 and 2000 μM; the 2000 μM concentration induced Al toxicity symptoms in leaves and severely restricted root growth. The early stage of Al toxicity was characterized by marginal chlorosis that later developed into necrotic areas that extended along the veins toward the midrib. Advanced stages of toxicity were characterized by collapse of the midrib, terminal dieback and defoliation of the seedlings which are typical symptoms of calcium deficiency in peaches. At high Al concentrations roots died back and new roots developed as irregularly shaped cylinders with constrictions and enlargements at the root apex.

Aluminum toxicity in annuals has been reported to induce a P deficiency (7, 4) and to reduce the uptake and utilization of Ca (8, 16). Evidently Al binds P on the root surface, cell wall, or in the free space of plant roots (15, 2, 3), which means that less P is available for metabolic activities within the cells. Aluminum at concn less than 10^{-4}M reduced both the initial and linear absorption phase of Ca. The reduction in Ca uptake was accompanied by a reduction in Ca transport (9).

Aluminum toxicity has also severely restricted root growth in peach seedlings (10). In this study we determined the concn of Al in solution required to induce Al toxicity symptoms in 'Elberta' peach seedlings and the nature of the symptoms over a range of Al concn.

Materials and Methods

'Elberta' peach seedlings were germinated and grown to a height of 8 to 12 cm in the greenhouse in sand that had been washed with distilled water. They were transplanted into 4-liter plastic pots (2 plants/pot) containing the following nutrient solution: 0.25 mMK_2HPO_4, 0.5 mM Ca(NO_3)_2, 0.5 mM KN_3, 0.5 mM MgSO_4, 0.5 mM NH_4NO_3, 75 μM Fe DTPA (diethylene triaminepentaacetic acid), 46 μM B, 9 μM Mn, 0.8 μM Zn, 0.3 μM Cu, and 0.05 μM Mo.

Solution pH was measured daily and maintained at pH 4.0 by adding either HCl or NaOH. The vigorously aerated solutions were changed at 7-day intervals before variable treatments were begun and monitored between changes to prevent depletion of nutrients. The experiment was conducted during Dec. and Jan. with natural and supplemental light to provide a 14-hr day.

Seedlings were grown for 28–30 days and 10 seedlings were harvested to estimate growth before application of treatments, and 10 seedlings were harvested to estimate growth before application of treatments, and 10 seedlings were harvested to estimate growth before application of treatments.

Table 1. The effects of Al concn on growth of 'Elberta' peach seedlings.

<table>
<thead>
<tr>
<th>Al concn (μM)</th>
<th>Increase in terminal length (mm)</th>
<th>Increase in lateral area (mm^2)</th>
<th>Dry wt increase (g/2 plants)</th>
<th>Leaves</th>
<th>Stems</th>
<th>Roots</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2953a^d</td>
<td>28.29a</td>
<td>10.72a 6.79a 3.72ab 21.22a</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>222</td>
<td>2798ab</td>
<td>22.32b</td>
<td>8.05bc 5.45ab 2.98bc 16.48abc</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>666</td>
<td>2449ab</td>
<td>22.93c</td>
<td>9.59ab 5.69ab 4.37a 19.65ab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td>1670b</td>
<td>17.37c</td>
<td>6.64c 3.66b 2.68c 12.99c</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

^dMean separation within column by Duncan’s multiple range test, 5% level.
0, 222, 666 or 2000 μM of Al, from K Al(SO₄)₂. During the treatment period, solutions were changed every 3 days and seedlings were harvested after they had grown for 27 days. Al toxicity symptoms developed after peach seedlings had been grown in the variable Al solutions for 23–24 days. Seedlings were harvested; separated into leaves, stems (lateral 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 (12).

### Results and Discussion

Terminal length and lateral initiation decreased (Table 1) as Al concn increased; however, the decreases were significant only at 2000 μM Al. Dry wt of leaves, stems and roots of seedlings grown at the highest Al concn were significantly less than those of the check. Dry wt of seedlings grown with 666 μM Al tended to be higher than that of seedlings grown with 222 μM Al. Dry wt of the roots was significantly greater at the 666 μM concn than at the 222- and 2000-μM Al concn. These data tend to follow those presented for citrus (11), where Al concn of 93 to 185 μM stimulated root but retarded shoot growth. The stimulation of root growth by 666 μM Al and the reduction in no. of laterals initiated suggests that Al may be altering the distribution of growth regulator in the peach seedling. The variability (Table 2) among seedlings was large and it is imperative that additional experiments be conducted with clonally propagated material. Since seedlings are so variable in their response to Al, breeders should be able to select rootstock and cultivars with greater tolerance to Al and to the acid soils of the Southeast.

In the early stage of Al toxicity, marginal chlorosis generally preceded necrosis (Fig. 1). It developed first at secondary vein reticulate unions. As chlorosis proceeded along the secondary veins to the midrib, necrosis of the secondary veins developed rapidly and progressed along the primary vein or midrib acropetally and basipetally faster than chlorosis. At 2000 μM Al, the veins collapsed within 1 or 2 days after chlorosis appeared. Necrosis first occurred either midway between the tip and base or just behind the apex where the leaf begins to widen rapidly.

Symptoms usually developed first on the 4th or 5th unfolded leaf below the stem apex (Fig. 2) and on leaves that were formed after Al treatments were begun. Symptoms developed on leaves of laterals before they developed on leaves on the main stem. Sometimes the lateral apex collapsed with no foliar symptoms; at other times, foliar symptoms developed 4 to 5 days later below the dead tip.

In the advanced stage of Al toxicity, defoliation usually began on the 4th or 5th unfolded leaf below the stem apex (Fig. 2) and on leaves that were formed after Al treatments were begun. Symptoms developed on leaves of laterals before they developed on leaves on the main stem. Sometimes the lateral apex collapsed with no foliar symptoms; at other times, foliar symptoms developed 4 to 5 days later below the dead tip.

### Table 2. Variability of growth measurements for 'Elberta' peach seedlings grown in nutrient solution.

<table>
<thead>
<tr>
<th>Growth measurement</th>
<th>Coefficient of variation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal (main plus laterals)</td>
<td>28</td>
</tr>
<tr>
<td>Increase in no. of laterals</td>
<td>34</td>
</tr>
<tr>
<td>Leaves (dry wt)</td>
<td>16</td>
</tr>
<tr>
<td>Stems (dry wt)</td>
<td>20</td>
</tr>
<tr>
<td>Roots (dry wt)</td>
<td>16</td>
</tr>
<tr>
<td>Increase in trunk area</td>
<td>16</td>
</tr>
</tbody>
</table>

Fig. 1. Aluminum toxicity symptoms of 'Elberta' seedling leaves illustrating 8 stages of toxicity symptoms compared to check. (A, check; B, marginal chlorosis; C, expanding chlorosis; D, beginning of marginal necrosis; E, beginning of midrib necrosis; F, midrib necrosis without marginal necrosis; G and H, necrosis expanding; I, abscised leaf.)
generally 1 to 2 days older than check seedling leaves when they unfolded. Seedlings were harvested when defoliation began and the Al toxicity syndrome could not be further characterized.

No Al toxicity symptoms were observed on 'Lovell' peach seedling leaves in sand cultures (10). This could have been caused by the precipitation of Al by the K$_2$PO$_4$-ion in the reservoir of nutrients. The Al and K$_2$PO$_4$-complex settled to the bottom of the reservoir and thus, the various concn of Al were too low to cause foliar symptoms. Solubility studies of Al (13, 14) have shown that the following reaction

$$\text{Al}^{3+} + \text{H}_2\text{O} \rightarrow \text{Al(OH)}^{2+} + \text{OH}^-$$

is controlled by pH. At pH 4.0, 90% of the Al is in the Al$^{3+}$ form. Preliminary results indicated that changing nutrient solutions at 3-day intervals and adjusting of pH daily to 4.0 maintained the Al in the Al$^{3+}$ form with no more than 5% error.

Roots in 222 and 2000 μM Al died back severely and little regrowth occurred. Dieback of roots in 666 μM Al was less and much regrowth occurred. Roots grown in Al solutions developed as a cylinder with constrictions and enlargements (Fig. 3). Many root tips from solutions containing Al were rounded as if they might develop into tubers. Elongation of tissue during the Al treatment.

The large decrease in Ca in the tissue with increase in Al may be detectable in roots of seedlings grown at the highest Al concn. A similar interaction has been reported for field-grown peach leaves (5). A possible explanation for this reduction in Ca concn is the source of Nitrogen and the low pH of the nutrient solution. It has been shown on Phaseolus (1) that NH$_4^+$-N at pH 4.5 interfered with Ca uptake but at 6.5 interference was reduced. In this experiment, pH was low and the NH$_4^+$/NO$_3^-$N ratio of 1:4 was present in all nutrient solutions.

Dieback of lateral apex, the slowness of leaves to unfold, and marginal and veinal necroses are typical Ca deficiency symptoms (6) and the result of reduced Ca uptake (Table 3). The development of Al toxicity symptoms on leaves that expanded before Al treatment supports the conclusion that the syndrome is that of Ca deficiency.

### Literature Cited


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Effect of Sulfur-coated Urea on Yield, N Uptake, and Nitrate Content in Turnip Greens, Cabbage, and Tomato

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Abstract. In a 3-year study sulfur-coated urea (SCU) resulted in differences in crop response which were related to the different N release rates. On Decatur silty clay loam at Normal, Alabama, SCU with relatively high N-dissolution rates performed best in terms of yield and N uptake for turnip greens, Brassica campestris L. (Rapifera group) while SCU with a slower dissolution rate performed better on Morrison sandy loam at Tuskegee, Alabama. On cabbage, Brassica oleracea L. (Capitata group) SCUs performed similar to ammonium nitrate (AN) and uncoated urea (UCU). With tomato, Lycopersicon esculentum Mill., spring-applied SCU with the highest dissolution rate, performed as well as split applications of AN, indicating the possibility for labor saving with SCU through reduced number of applications. Effect of SCU on nitrate accumulation was minimal. At harvest in the top 15 cm soil the total N content was highest in tomato plots treated with split AN, followed by SCU-A, SCU-C, and AN, respectively.

Most vegetable crops require a continuous supply of N for maximum yield, quality, and appearance. With conventional fertilizer sources, this is accomplished by supplementing basic application with one or more sidedressings. Slow-release N fertilizers may result in greater recovery of applied nutrients, reduction of N luxury consumption and nitrate accumulation, decreased leaching of N from soils, and longer N supply, thus requiring fewer applications.

Controlled-release fertilizers are of 3 types: biodegradable organic compounds, compounds of low solubility that release nutrients by slow dissolution and/or hydrolysis, and coated soluble fertilizers, such as SCU (3). The SCU used in the experiments reported here was produced by coating urea granules with molten sulfur, followed by a microcrystalline wax sealant which contained a microbicide and finally with a clay conditioner (5). Since processing engineering changes are still being made, SCU used in future experiments and demonstrations will likely be somewhat different than that used here. The characteristics of various controlled-release fertilizer sources of horticultural interest have been described (3, 5, 15).

Most evaluations of SCU have been done on forage and turf grasses and field crops (1, 2, 14). Prine obtained sorghum grain and forage yields from SCU that were equal to those with conventional fertilizers (17).

Slow-release fertilizers have generally given good results with broadcast applications on turf and slow-maturing crops. Yields and seasonal growth distribution of forage and turf grasses have usually been similar with a single spring application of SCU and 3 to 5 split applications of soluble N sources. However, their performance with vegetables under field conditions has not been adequately determined. Lorenz and coworkers (12) compared ammonium sulfate (AS) with ureaform, SCU, and uncoated urea (U) in field studies on potato, cantaloupe, and tomato with the N sources banded in the soil. Highest yields were obtained with AS. Yields from ureaform and SCU were similar but less than those from U. Nitrogen absorption, as determined by concn in petioles, or total N absorption by the entire plant, was in the same order as yields. About 90% of the N from AS and U had nitrified and leached in 40 days. In contrast, about 50% of the N from ureaform remained in the fertilizer band 120 days after application. Locascio and Fiskell (11) found significant difference (at 10% probability level) in marketable watermelon yields of 51.3 and 44.8 tons/ha produced from SCU and U treated plots, respectively.

Sulfur-coated urea, because of its controlled release of N may reduce NO₃-N accumulation in leafy vegetables. Brown and Smith (6) found that the greatest effect of N fertilizer on nitrate concn appeared to occur in short-duration crops, such as radishes, mustard, beets, and spinach, which tend to have nitrate levels as high as 0.68% NO₃-N on dry wt basis after application of 448 kg N/ha. Under heavy fertilization, similar accumulations have been reported in spinach and beets in New York (10). Fertilizer type did not significantly affect nitrate accumulation in spinach when topdressed but had a significant effect when sidedressed 1 week before harvest (4). Peck et al. (15) reported similar data for table beet.

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