Effect of Container Size and Shape on the Growth of Northern Red Oak Seedlings

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Abstract. Northern red oak (Quercus rubra L.) seedlings were grown in six container configurations differing in diameter, length, and volume. More shoot and lateral root dry weight was produced in a cylindrical polyvinylchloride (PVC) container 15.4 × 36 cm containing 6335 cm² of potting medium than in containers with less medium volume. Seedling growth did not increase in a 15.4 × 110 cm container even though the potting medium volume was increased. Of all container variables measured, the ratio of potting medium surface area to potting medium depth (SA:D) showed the best correlation to seedling dry weight accumulation. Water or nutrient deficiencies could not be eliminated as factors contributing to differences in seedling growth.

Container size and shape influence plant growth, particularly dry weight distribution. Past studies have shown that plant growth increases with increased rooting volume (1, 3, 18). In addition, the potting medium surface area to depth ratio (SA:D) of a container is a useful measurement of container influence on plant growth (2). A thorough examination of the impact of container configuration on woody seedling root and shoot growth has not been reported.

Oak seedlings typically produce one or two small increments of vertical growth each growing season in the field (11). However, with adequate water and fertilizer under optimum environmental conditions, multiple flush oak seedlings can be produced in containers filled with appropriate growth medium (17). Because oak seedlings produce a large tap root, the effect of container length on seedling growth is of particular interest. We designed this study to evaluate the influence of six container configurations on the growth and development of red oak seedlings. Container length, diameter, and volume were examined.

Northern red oak seedlings were grown from acorns in one controlled environment room for 53 days under a 16-hr photoperiod, 26°C (day)/20°C (night) temperatures, 70% / 90% RH, and a photosynthetic photon flux density (PPF) of 240 to 250 μmol m⁻² s⁻¹. Acorns from a single open-pollinated tree (northern Wisconsin) were stored for a minimum of 4 months at 3°C, germinated, and then planted 2 cm deep in various-sized polyvinylchloride (PVC) pipe filled with a 1:1 sphagnum peat: sand mixture (v/v). The potting medium pH was 3.7. Once each week, seedlings were fertilized in proportion to container size (i.e., all received the same amount of nutrients per unit volume of potting medium) using a modified Hoagland's solution supplemented with urea (7, 9) and were allowed to drain freely. Tap water was added as needed to maintain potting medium moisture near field capacity (daily near the end of the experiment).

We used six different container sizes in this study (combinations of three diameters and two lengths, Table 1). Containers were constructed from Schedule 40 PVC pipe. Galvanized wire mesh was attached to the bottom of each length of PVC pipe to support the potting mixture and to permit drainage. Containers of each size with a single seedling were randomized in one of six blocks, yielding six plants per container size. Containers were adjusted so that all were at the same height in the growth room. At harvest, leaf area, stem length, and number of flushes were measured; the seedlings then were divided into shoot and root components and dried (72 hr at 65°C) for weight measurements.

Leaf conductance and leaf water potential were measured on the seedlings during the last week of the experiment to see if container size had any effect on water relations of the seedlings under the experimental water regime. Water was withheld from seedlings for a 24-hr period to approximate the minimum water deficit encountered during growth. Leaf conductances of mature second-flush leaves were measured at 0800 and 1500 HR on the day water was withheld, using a steady-state porometer (LI-COR model LI-1600). After irrigation at 0800 HR on the following day, leaf conductances were measured at 1200 HR on the same leaves. Leaf water potential measurements (nonstressed) of one mature, second-flush leaf of each plant were made with a pressure bomb 1 day before harvesting (15).

Because preliminary analyses showed that block effects were insignificant, we tested differences with analysis of variance (ANOVA) for a completely randomized design. Effects due to container diameter and length were tested with a two-way ANOVA; treatment individual contrasts to test specific hypotheses about different container dimensions were also analyzed: 15.4-cm-diameter containers vs. all others (15-rest); 7.6 vs. 4.3-cm-diameter containers (7-4); 15.4-cm short vs. 15.4-cm long containers (15S-15L); and 7.6-cm short vs. 4.3-cm long (equal volume) (7S-4L).

Container size and shape significantly influenced oak seedling growth (Table 2). The number of growth flushes per seedling and total number of leaves per plant increased in containers with large diameters and potting medium volumes. Shoot weight measurements showed that the greater the diameter of the container and potting medium volume, the larger the seedlings. However, long containers had consistently lower mean leaf and stem weight than the short ones of the same diameter (significance only for 15.4-cm-diameter containers).

Lateral root weight depended on container diameter and volume, but not on length (Table 3). Tap root and total root weight were not significantly affected by container size (Table 3). Individual contrasts showed that the significant differences observed in lateral root weight were attributable to differences between the 15.4-cm containers and all other pots. Tap root length (data not shown) corresponded to container length—the longer the container the longer the tap root.

Analyses of variance results (Tables 2 and 3) indicate that potting medium volume, diameter (area), and depth (column length) were potentially responsible for the observed differences in seedling growth. Linear regressions of total seedling weight against container variables showed that potting medium depth, volume, area, and the potting medium SA:D

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Table 1. Spatial characteristics of the PVC containers.

<table>
<thead>
<tr>
<th>Identification code</th>
<th>Container dimensions</th>
<th>Potting medium dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Diameter (cm)</td>
<td>Length (cm)</td>
</tr>
<tr>
<td>15 S 2</td>
<td>15.4</td>
<td>36</td>
</tr>
<tr>
<td>15 L 1</td>
<td>15.4</td>
<td>110</td>
</tr>
<tr>
<td>7 S 5</td>
<td>7.6</td>
<td>36</td>
</tr>
<tr>
<td>7 L 3</td>
<td>7.6</td>
<td>110</td>
</tr>
<tr>
<td>4 S 6</td>
<td>4.3</td>
<td>36</td>
</tr>
<tr>
<td>4 L 4</td>
<td>4.3</td>
<td>110</td>
</tr>
</tbody>
</table>

¹Characteristics of the identification code represent pot diameter, pot length, and the ranking of the pot according to volume, respectively (1 equals largest volume). PVC diameters: 15, 7, and 4 represent 15.4-, 7.6-, and 4.3-cm pipe, respectively. L = long and S = short.

²SA = potting medium surface area.

³SA:D = potting medium surface area to depth ratio.

Table 2. Mean shoot growth variables of northern red oak (Quercus rubra L.) seedlings grown in six different containers.

<table>
<thead>
<tr>
<th>Container type²</th>
<th>No. flushes</th>
<th>No. seedling leaves</th>
<th>Total leaf wt (g)</th>
<th>Total stem wt (g)</th>
<th>Total shoot wt (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 S 2</td>
<td>3.3 c</td>
<td>23 c</td>
<td>10.59 e</td>
<td>3.18 b</td>
<td>11.27 cd</td>
</tr>
<tr>
<td>15 L 1</td>
<td>3.2 bc</td>
<td>21 bc</td>
<td>8.09 d</td>
<td>2.73 ab</td>
<td>9.71 bc</td>
</tr>
<tr>
<td>7 S 5</td>
<td>3.0 bc</td>
<td>17 ab</td>
<td>6.98 cd</td>
<td>2.10 ab</td>
<td>5.82 a</td>
</tr>
<tr>
<td>7 L 3</td>
<td>3.0 bc</td>
<td>17 ab</td>
<td>5.60 bc</td>
<td>1.63 ab</td>
<td>7.70 ab</td>
</tr>
<tr>
<td>4 S 6</td>
<td>2.3 ab</td>
<td>13 a</td>
<td>4.18 ab</td>
<td>1.48 a</td>
<td>5.18 a</td>
</tr>
<tr>
<td>4 L 4</td>
<td>2.7 a</td>
<td>13 a</td>
<td>3.70 a</td>
<td>2.72</td>
<td>9.25</td>
</tr>
</tbody>
</table>

Significance
- Diameter
- Length
- Volume
- Contrasts 15-rest
- 7-4
- 15S-15L
- 7S-4L

Values in a column separated by Duncan’s multiple range test, P = 5%.

Table 3. Mean root growth variables of northern red oak (Quercus rubra L.) seedlings grown in six different containers.

<table>
<thead>
<tr>
<th>Container type²</th>
<th>Tap root wt (g)</th>
<th>Lateral root wt (g)</th>
<th>Total root wt (g)</th>
<th>Root : shoot ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 S 2</td>
<td>4.76 c</td>
<td>2.18 c</td>
<td>6.94</td>
<td>0.45 a</td>
</tr>
<tr>
<td>15 L 1</td>
<td>3.70</td>
<td>1.80 bc</td>
<td>5.50</td>
<td>0.50 a</td>
</tr>
<tr>
<td>7 S 5</td>
<td>3.48</td>
<td>1.34 ab</td>
<td>4.82</td>
<td>0.49 a</td>
</tr>
<tr>
<td>7 L 3</td>
<td>4.03</td>
<td>1.80 bc</td>
<td>5.82</td>
<td>0.83 b</td>
</tr>
<tr>
<td>4 S 6</td>
<td>3.63</td>
<td>0.94 a</td>
<td>4.58</td>
<td>0.79 b</td>
</tr>
<tr>
<td>4 L 4</td>
<td>3.36</td>
<td>1.73 bc</td>
<td>5.09</td>
<td>1.00 b</td>
</tr>
<tr>
<td>Mean</td>
<td>3.83</td>
<td>1.63</td>
<td>5.46</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Significance
- Diameter
- Length
- Volume
- Contrasts 15-rest
- 7-4
- 15S-15L
- 7S-4L

Values in a column separated by Duncan’s multiple range test, P = 5%.

Differentiation of shoot growth in woody seedlings usually have shown that maximum growth is obtained in containers with the greatest potting medium volume. Appleton and Whitcomb (1) grew eight species of woody plants, including Q. shumardii, in containers ranging in volume from 147 to 683 cm³ and found greatest height and stem caliper associated with the containers of greatest volume. In contrast, Hathaway and Whitcomb (8) grew Quercus shumardii in large containers having potting medium volumes between 676 and 1360 cm³ and found no difference in seedling height or shoot weight. The greatest growth of black walnut (Juglans nigra L.) occurred in containers with 9700 and 10,000 cm³ of potting medium (5, 6). Among the six containers tested in our study, the 15.4 × 36 cm container with a potting medium volume of 6333 cm³ (15S2) produced the largest seedlings in the shortest time. Further, for all containers of the same diameter, shoot growth was always less in long containers. Thus, long containers that provide space for unimpeded tap root growth may hinder top growth. Restriction of tap root growth in short containers may have enhanced lateral root development, thereby increasing shoot growth (12, 16).
Inadequate aeration, water deficits, and nutrient shortages can all limit plant growth in containers. Oxygen deficiencies are known to reduce root growth (10) and may be partly responsible for the reduced growth of seedlings in our long containers. Mutsaers (14) studied the effects of container root restriction and attributed reductions in plant growth to mineral shortages. In our study, plants were fertilized and watered in proportion to potting medium volume. Such procedures might leach nutrients out of the rooting zone in longer containers (E.I. Sucoff, personal communication), introducing potential mineral deficiencies. Therefore, mineral shortages cannot be excluded as a cause of reduced growth in those containers having less rooting volume.

Leaf conductance and leaf water potential of seedlings across treatments showed little variation if the plants were watered daily (nonstressed; Table 4). However, if the plants were not watered for a day (a mild stress), the stomatal conductances of seedlings grown in small containers (4S6,4L4) were significantly reduced, indicating potential water stress. A lack of root pressure in the 4.3-cm-diameter containers (4S6,4S4) at harvest in longer containers (E.I. Sucoff, personal communication) indicated that plants in the small containers were under some water stress. The surface of the long containers dried out faster than that of the short containers. Larson (13) withheld water from the upper or lower half of the root zone of a Quercus rubra seedling, and demonstrated that stressing the upper half of the root system reduced seedling growth without affecting the water relations of the shoot. An accelerated drying of the upper potting medium in the long containers might have induced a similar situation and could account for the reduced growth in long containers.

**Table 4. Mean water relations variables of representative second flush fully expanded leaves of northern red oak (Quercus rubra L.) seedlings grown in six different containers.**

<table>
<thead>
<tr>
<th>Container type</th>
<th>Stressed</th>
<th>Nonstressed</th>
<th>Leaf water potential; nonstressed</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 S 2</td>
<td>5.35 a</td>
<td>7.52 a</td>
<td>-0.75</td>
</tr>
<tr>
<td>15 L 1</td>
<td>5.81 a</td>
<td>7.15 ab</td>
<td>-0.58</td>
</tr>
<tr>
<td>7 S 5</td>
<td>5.49 a</td>
<td>6.29 ab</td>
<td>-0.60</td>
</tr>
<tr>
<td>7 L 3</td>
<td>5.65 a</td>
<td>6.54 ab</td>
<td>-0.73</td>
</tr>
<tr>
<td>4 S 6</td>
<td>2.16 b</td>
<td>3.98 c</td>
<td>-0.69</td>
</tr>
<tr>
<td>4 L 4</td>
<td>3.68 a</td>
<td>4.81 bc</td>
<td>-0.73</td>
</tr>
<tr>
<td>Mean</td>
<td>4.13</td>
<td>5.74</td>
<td>-0.68</td>
</tr>
</tbody>
</table>

Significance

- **Diameter**
  - * NS
  - * NS

- **Volume**
  - * NS
  - * NS

- **Length**
  - NS
  - NS

- **Contrasts**
  - 15-rest
  - NS
  - NS
  - 7-4
  - NS
  - NS
  - 15S-15L
  - NS
  - NS
  - 7S-4L
  - NS
  - NS

2 Characters of the identification code represent pot diameter, pot length, and the ranking of the pot according to volume, respectively (1 = largest volume). PVC diameters: 15, 7, and 4 represent 15.7-, 7.6-, and 4.3-cm pipe, respectively. L = long and S = short.

3 Stressed treatments were taken the day after an irrigation, and nonstressed measurements were taken on the same day as an irrigation.

*Values in a column separated by Duncan's multiple range test, *P* = 5%.
•*Significant at the 5% level or nonsignificant, respectively.

Effects of container size and transplanting date on the growth of tree seedlings. J. Env. Hort. 1:89-93.


**Literature Cited**

1. Appleton, B.L. and C.E. Whitcomb. 1983.