Introduction

There are several advantages to growing trees in containers, including the efficient use of space and retention of roots at planting. At the same time, container growing poses unique challenges for producing high-quality root systems. A high-quality root system is relatively free from misdirected roots with root tips terminating at the exterior of the root ball and balanced coarse roots radially-oriented around the trunk in all cardinal directions.

The use of various container designs, including ribbing, grooves, different shapes, air-pruning holes, as well as the use of different materials such as mesh, coco coir, fabric and various types of plastic, have all attempted to improve root quality. However, the number of commercial container options currently available can be overwhelming.

In order to examine the effects of some of the features promoted by these container designs, we selected and studied the effect of five distinct containers with features shared by other containers in the marketplace (See Table 1, page 2).


Figure 1. Inside view of the RootSmart propagation tray using Ellepots and air-pruned roots.

The trial evaluated root quality and morphological characteristics of a subset of 480 bur oak (Quercus macrocarpa) seedlings.

As bur oak is a strong tap rooting species, it was chosen to examine the influence of different container features on this particular root system, which is prone to the types of root deflections the five studied containers are designed to deter.

Trees were propagated from seed and grown in the RootSmart™ wall-less, bottom-less air-pruning propagation tray (See Figure 1) and then transplanted into one of the five containers.
The RootSmart tray maximizes root quality at the propagation stage by minimizing the occurrence of root deflections typically occurring in association with solid plastic walls. Seedlings demonstrated a consistent, good overall root structure at the time of transplant.

Above and below ground characteristics were examined and recorded for a subset of four trees representative of each container type. The resulting data represents the quality of three years old container-grown bur oak stock.

Table 1. Overview of key features associated with each of the five containers evaluated in the current trial.

<table>
<thead>
<tr>
<th>Container</th>
<th>Key Features</th>
<th>Volume</th>
<th>Diameter</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>Circular, slick solid-walled black plastic</td>
<td>3 gallon</td>
<td>11 inches</td>
<td>9 inches</td>
</tr>
<tr>
<td>Coco Coir Pot</td>
<td>Circular, woven coarse coco coir fibre</td>
<td>3 gallon</td>
<td>11.5 inches</td>
<td>9 inches</td>
</tr>
<tr>
<td>Ercole</td>
<td>Circular with ribbed sides and air-pruning slits; plastic, extra channels and drainage holes at the bottom</td>
<td>2.5 gallon</td>
<td>11 inches</td>
<td>9 inches</td>
</tr>
<tr>
<td>Light Pot</td>
<td>Circular, flexible, thin white plastic meant to allow some sunlight through</td>
<td>3.9 gallon</td>
<td>10 inches</td>
<td>12.5 inches</td>
</tr>
<tr>
<td>Root Pouch</td>
<td>Circular, woven recycled plastic</td>
<td>3 gallon</td>
<td>10 inches</td>
<td>8.5 inches</td>
</tr>
</tbody>
</table>

Figure 2. Typical bur oak root system out of propagation using the RootSmart tray.

Figure 3. Quercus macrocarpa (bur oak) seedlings growing in each of the five studied containers.
Superficial Assessment (top growth and external root ball)
Results show Light Pot-grown trees with increased height and caliper as compared to other containers. This is likely explained by the Light Pot container larger volume (3.9 gallon) used in this study versus the smaller volumes of other containers (2.5-3.0 gallons).

Root ball quality was assessed by examining the periphery of the root ball upon removing it from its container and ranking root system quality according to the relative proportion of deflected roots (See Figure 4). The Standard, solid-walled container produced the lowest root ball quality and the Coco Coir Pot container produced the highest root ball quality, with the remaining three containers all of about equal quality.

In-Depth Root System Assessment
A superficial assessment of tree growth and root ball quality can sometimes help identify major issues, such as potentially stunted growth or circling and matted roots. However, a more in-depth study is needed to undercover overall root system quality.

Root systems from the same four trees per container were assessed superficially and then washed and evaluated (See Figure 5, page 4).

Major structural roots (the five largest roots per tree) and all first order lateral roots (>2 mm in diameter) were counted and characterized to identify the presence and type of deflections occurring inside of the root ball.

Figure 4. To get a sense of root system quality, the root ball is removed from the container and examined. A more comprehensive understanding of root ball quality is achieved by shaking off excess substrate to allow for an in-depth root system assessment.
Figure 5. Side (third column) and bottom (fourth column) views of washed Quercus macrocarpa root systems, grown in each of the five containers evaluated in the current trial.
Results showed the greatest overall number of root deflections associated with the Standard container. It was consistently the least effective at deterring the occurrence of root deflections in both major structural and first order lateral roots (See Figure 6).

Of the remaining container types, the Coco Coir Pot demonstrated the highest root ball quality, as well as the lowest overall occurrence of major structural and first order lateral root deflections (See Figure 6). This suggests it was the most effective of the five containers at producing quality roots in this particular tap rooting species (bur oak) and may be effective in other tap rooting species.

Root deflections were further categorized according to type, which is used as a general indicator of where and in what proportion root deflections occurred within the root system (See Figure 7).

Bottom deflected roots refer to roots that hit and were deflected off the bottom of the container, while side deflected roots refer to ascending, descending, circling and kinked root formations occurring along container walls.
Recommendations
Based on key findings from this container study, these are recommended best practices for choosing and using containers to ensure high quality root systems developed in propagation are sustained.

1. Upsizing at the appropriate time is critical
There is no substitute for upsizing root systems into larger containers when they have reached the limit of the current container. Some containers will reduce the incidence of deflected coarse roots but best practice requires getting to know the species you are growing and planning to upsize when roots have reached the container walls. Sometimes this may require a shift in the timing from when current upsizing happens to avoid roots becoming crowded and deflected.

In the current trial, in-depth root system assessments done at the end of 2019 – after only one growing season in containers – showed the bur oak root systems had already grown to the bottom of all containers and from a root growth perspective were likely ready to transplant or upsize. However, based

Table 2. Effect of container key features on bur oak (Quercus macrocarpa) rooting structure.

<table>
<thead>
<tr>
<th>Container</th>
<th>Summary of Main Findings</th>
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<tbody>
<tr>
<td>Standard</td>
<td>• Circling roots common&lt;br&gt;• Lowest number of first order lateral roots&lt;br&gt;• Heavy matting and circling at bottom of root ball</td>
</tr>
<tr>
<td>Coco Coir Pot</td>
<td>• Majority of root deflection occurred at container bottom&lt;br&gt;• High frequency of branching at container walls&lt;br&gt;• Many first order lateral roots, most of which branched at container wall&lt;br&gt;• Moderate matting of roots at container bottom</td>
</tr>
<tr>
<td>Ercole</td>
<td>• Majority of root deflection occurred at container bottom&lt;br&gt;• Moderate frequency of branching of first order lateral roots&lt;br&gt;• Heavy matting and spirally of roots within grooves at container bottom</td>
</tr>
<tr>
<td>Light Pot</td>
<td>• Majority of major structural roots deflected at container bottom&lt;br&gt;• Largest number of first order lateral roots, almost two-thirds of which were branching&lt;br&gt;• Heavy matting of roots at container bottom</td>
</tr>
<tr>
<td>Root Pouch</td>
<td>• Second best root quality for major structural roots and first order lateral roots after Coco Coir Pot&lt;br&gt;• Least amount of matting at container bottom due to ripping of roots when removing container&lt;br&gt;• Can be difficult to remove at planting due to roots growing into fibre, especially at container bottom</td>
</tr>
</tbody>
</table>
on height and caliper measurements these trees were not yet of sufficient above-ground size to be saleable in 2.5-3.9 gallon containers and were therefore kept in their containers for one more growing season.

The final height and caliper measurements for the trees in this trial taken at the end of 2020, were deemed appropriate according to above-ground standards for nursery stock. However, by that time the root systems demonstrated a variety of deflections associated with being held for too long. This observation is common among many tap rooting trees (oaks, hickories, etc.) that are difficult to produce in a nursery setting.

2. Solid walled plastic containers create deflected coarse root systems
Of all the containers tested, the solid-walled plastic containers consistently resulted in the highest proportions of deflected roots.

If you are growing in solid-walled containers, as a first step, consider buying a few different containers with various features (i.e. air-pruning, woven fibre/fabric or light-pruning). Pot up a few different species with various root system types to test performance and also for handling suitability, as well as fit with current production practices.

3. Match container applications to species rooting structures
As noted above, because different containers promote and use different features to manage root quality, investigate the fit of container features to the rooting systems you are growing.

Table 2 on page 6 provides a summary of main findings based on growing tap rooting bur oak trees. Surface rooting or heart-root species will produce different results. Try to consider inherent root morphologies of the trees you are growing and the impact of container designs on resulting root system quality.

4. Spend some time getting to know your root systems
Root washing and root characterization are a critical step in improving root quality and the application of best practices for root system management in nursery production. It is worth your while to wash root systems and investigate the effects of containers on root structure with your production team. This will also help understand the appropriate time for upsizing or transplanting different species and cultivars.

Above ground growth is not an indicator of root ball quality and different containers can create deflections not visible at the exterior of the root ball. In some cases, only by washing and teasing apart roots will serious defects be discovered. By examining roots and understanding the impact of container design on root morphology, more informed container selections can be made to support the growth and development of high-quality roots and by extension, long-lived and resilient trees.

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