Strategies for Growing a High-Quality Root System, Trunk, and Crown in a Container Nursery

Companion publication to the *Guideline Specifications for Nursery Tree Quality*

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Foreword

This document presents strategies to assist growers in producing trees that conform to the *Guideline Specifications for Nursery Tree Quality* (Visalia, CA: Urban Tree Foundation). The strategies are based on most-recently-published and ongoing research, combined with the knowledge, skills, and know-how of both the practitioner and researcher, to produce high-quality root systems, trunks, and crowns . As research progresses and new strategies are developed, this document will be revised to incorporate state-of-the-art information.

In addition to being of immediate practical use for growers, this document should provide a basis for further discussion among nursery and landscape professionals and researchers. Many of the strategies herein have been in practice for years in nurseries in California and other parts of the country. While this document contains guidelines based on current and ongoing research, more research is needed to continue to learn what makes trees stable and healthy. It is our aim to encourage site- and species-specific research that will become the basis for more uniform implementation of methods known to produce quality trees in a cost-effective manner.

We appreciate the review of this document by nursery and landscape professionals and welcome your comments. We will periodically update the document as it is circulated, reviewed, and edited by growers and researchers. This process is essential to our goal of developing a user-friendly manual that will assist growers in the efficient production of high-quality trees.

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Guiding Principles for Growing Quality Trees for the Landscape

Good root systems start in the nursery at propagation in the liner stage and require attention each time a tree is shifted into a larger container. Large main mother roots should grow straight from the trunk without circling the trunk or deflecting downward. Temporary branches are important to trunk development because they build a strong trunk and root system. Shade trees grown in the nursery should have a strong central leader even if the leader will be lost at maturity. Installation contractors must provide simple root and shoot pruning treatments at planting to ensure that sustainable landscapes are created.

Acknowledgments

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Section 1: Roots
Defects

Root defects that develop during nursery production can lead to poor vigor (Fig. 1) and tree failure (Figs. 2b and c) in the landscape. However, most defects, such as circling roots in the root ball interior, can be mostly eliminated with appropriate and timely management in the nursery. Strategies in the nursery should focus on producing trees that have straight main mother roots growing to the edge of the container. Installation contractors should correct minor root defects near the trunk at planting, as well as root defects on the periphery of the root ball.

Straight roots growing from the trunk form a strong, wide root plate (Fig. 2a). Trees with a wide root plate are stable and require a large force to tip them over. Trees with deflected, kinked, or bent roots can develop a smaller root plate and represent lesser quality. When main woody roots are deflected and not straight, there may be no root plate and the tree can become unstable (Figs. 2b and 2c).

A tree's instability can result from the curved or bent shape of the main roots combined with increasing crown size. Growing trees without root management when shifting to a larger container size often results in bent and deformed roots. Some trees are able to remain stable despite root deformities, but they may lose vigor if circling roots meet the trunk and constrict sap flow (Fig. 1). A reduced growth rate often precedes the other signs of reduced vigor such as chlorotic foliage and dieback.

Figure 1. Poor vigor and dieback caused by stem-girdling roots. Trees in this condition will not reach maturity in the landscape.

Figure 2a. Straight roots growing from the trunk form a more or less circular root plate. Trees with straight roots are more stable than those with deflected roots.

Figure 2b. Tree failure resulted from circling roots in the nursery container and being planted too deeply. As the circling roots and the trunk grew in diameter, they eventually rested against each other. As a result the trunk was thinner below the soil than it was above. The root growing against the trunk caused this growth constriction (see entire tree, Fig. 2c). Removing root defects during production and at planting can prevent this.

Figure 2c. Increasing crown weight on a defective root system caused this tree to fall in a wind storm.

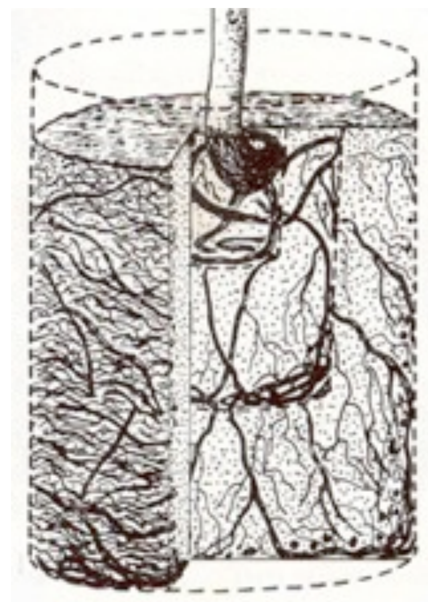
Like the crown, quality root systems result from appropriate active management. Root balls are often shifted through the production process with little or no correction in root system defects (Figs. 3a and b).

Planting too deeply can also cause defects at the root collar in trees such as maples and elms. Defects on finished trees may be correctable if woody roots have not become too large or abundant (Fig. 3b). When defects are hidden and inaccessible or involve large roots, corrective measures can be difficult or impractical to implement. When roots have been left untreated for too long, corrective measures can be time-consuming. The ability to correct old and severe defects depends on the severity of defects, species of tree, water management practices, size of roots that require cutting, and time of year. It is easier to remove these roots when the plant is younger than the tree pictured in Figure 3b. Ideally, roots should be inspected and defective roots managed at each shift to a larger container, reducing the need to prune heavy roots later.

It is often necessary to remove substrate from the top of the root ball to inspect for root defects (see Fig. 3b). Provided that the main roots are relatively straight (see Fig. 2a), tree quality and stability can be improved by removing kinked, circling, and stem-girdling roots from the top of the ball. Root defects should be removed at the point just behind the bend in the root (Fig. 4). The retained root segment should be relatively straight and should grow radially from the trunk. New roots typically grow from just behind the cut in a radial or fanlike pattern away from the trunk (see Fig. 11b). Some new roots grow down, up, or occasionally kink back toward the trunk. These should be corrected at the next shift.

Figure 3b. Substrate (3 in.) was removed to expose the top roots inside the container. A moderate amount of stem-girdling roots growing over the root collar is correctable. However, it is inefficient to allow defects to develop to this extent. It is best to prevent this by pruning roots at earlier stages and planting at the correct depth.

Top View



Side View

Figure 3a. Root defects are present at each container size: liner, #5 and #15 (Harris et al. 1999).

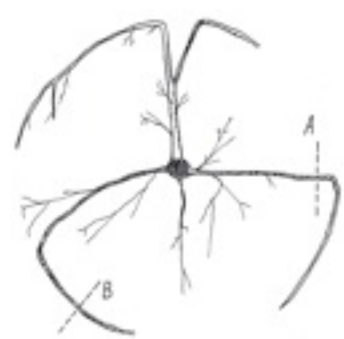


Figure 4. Cut defective roots back to the point just behind the bend (A). The retained root segment is straight. Cutting them at a point after the bend (B) is not recommended because the defect remains.

Liner Management

Objective: The root collar and inside portion of the liner root ball should be free of root defects, including circling or kinked roots and roots growing up or down the side of the container (Fig. 5).

Problem: In the liner stage, a tree's root system can develop in a matter of weeks once growth begins. Some species develop only one or two large main roots; others have a more fibrous root system. Often, roots grow to the edge or bottom of the container, then branch or deflect down, up, and around the periphery of the root ball, forming a type of shell. Without management, some of these small roots can eventually become large and woody, retain their deformed shape, and develop into a defect (Fig. 5). Root defects near the root collar can reduce the growth, vigor, and stability of the tree. The liner root ball should not be visible when the trunk of a larger tree is rocked in the container or planted in the ground. Left untreated, root defects that develop at the liner stage can be the most difficult to address later in production.

Practice: Trees and shrubs should be planted in liner trays and in other systems that minimize root defects and encourage branching of the root system inside the root ball (Fig. 6). Air pruning is especially efficient at causing a tap root to form branch roots. Liners should be shifted to larger containers before non-correctable root defects form. Table 1 gives several methods of eliminating root defects when liners are shifted to larger containers. Some of these methods may work better than others for certain species, container types, substrate types, liner stage, time of year, and tree age.

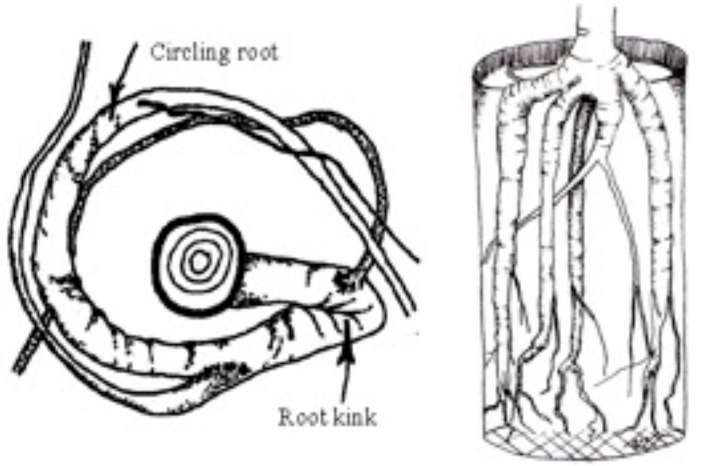


Figure 5. Circling and kinked roots originating in a liner pot (left). Circling and diving roots in an open-bottom liner pot (right). Both trees should be thrown out because defects are too severe to correct. The tree in Fig. 7a can develop these defects unless pruned and managed before shifting.

Figure 6. Traditional propagation pots encourage roots to grow around the pot or along the sides toward the bottom. Some roots then grow back toward the surface (right). Pots that air-prune on bottom and sides encourage branching of the tap root on seedlings and cuttings (top), forming smaller-diameter bottom roots and ample laterals near the surface.

Shaving, pruning, or "peeling off" the shell of roots on the periphery and bottom of the root ball cuts away most defects (Fig. 7). Adequate roots remain inside the root ball in most cases (Figs. 7e and 8). Some liners may be killed by this treatment but it is necessary to remove inferior plants from the inventory and prevent them from failing later in the landscape. Slicing root balls from top to bottom removes some defects but can retain roots oriented downward. Slicing can also leave intact bent root segments that generate new roots, which can grow close to the trunk. Air pruning can be a useful method to reduce root defects. Teasing or pulling roots apart and laying them straight in the substrate of the larger container can also reduce defects if done before roots become too stiff. These and other techniques are designed to encourage roots to grow radially from the trunk (Fig. 2a).

Water management is critical after root pruning to avoid severe wilting and stress. Trees should be irrigated to maintain the water requirements appropriate for the species and weather. In warmer and drier weather, the irrigation frequency and volume may need to be adjusted to accommodate the reduced and disturbed root system. Some growers strip leaves from certain trees to enhance survival.

Figure 7a. Inspect the root ball.

Figure 7b. Remove peripheral roots.

Figure 7c. Continue root pruning.

Figure 7d. Root pruning complete.

Table 1. Methods of reducing or eliminating root defects when liners are shifted to larger containers.

- Grow liners in propagation trays designed to reduce defects.
- Shift liners at the appropriate time.
- Score or slice the root ball from top to bottom in several places.
- Shave or peel off roots on the periphery of the root ball.
- Tease roots at the periphery so they lay straight in the substrate of the larger container.
- Prune off the corners from top to bottom of cube-shaped root balls.
- Remove the bottom of the root ball.

Figure 7e. At left, a liner root ball that is likely to develop permanent defects if not pruned. Roots form a "shell" at the substrate-container interface. Shaving or peeling away the peripheral roots can remove defects, resulting in a root system resembling the one at right, a liner root ball with the substrate removed to show a liner root system free of defects.

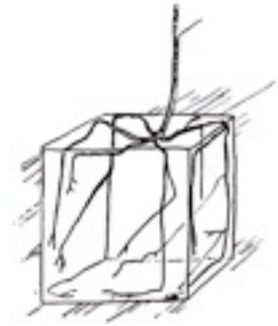


Figure 8a. Finished liner with roots deflected down and around the pot forming a type of root shell.

Poor root system: Liner root ball was not root pruned as it was shifted into a #1 container.

Good root system: Liner root ball was shaved (Fig. 7) when shifted into a #1 container.

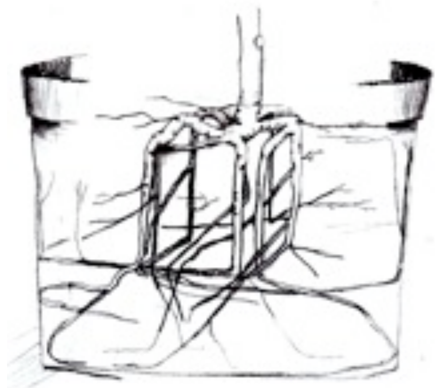


Figure 8b. Two months after shifting, roots that grew down and around the sides of the liner pot became woody and grew in diameter. These woody roots retained their original orientation, and many of the new roots produced in the #1 container grew from the bottom of the liner root ball.

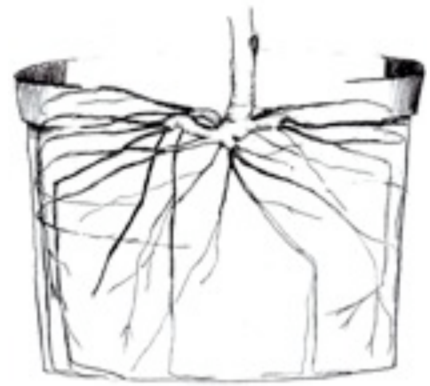


Figure 8d. Two months after root pruning and shifting, the new roots grew horizontally and downward. The roots at the top of the container originated from the top of the liner root ball, providing greater stability for the tree.

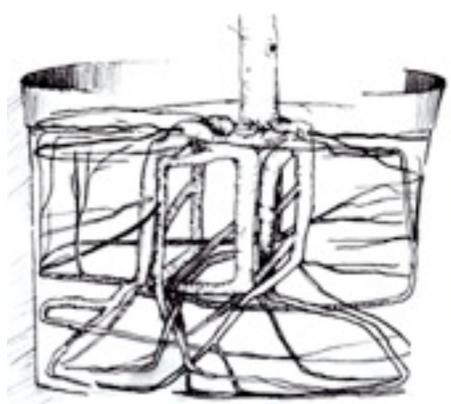


Figure 8c. Six months after shifting, the main woody roots that had been originally deflected by the liner pot continued to grow in diameter. Many roots that grew near the surface of the root ball originated near the bottom of the liner. The #1 container wall deflected a second set of roots up, down, and around. Some of these roots will become woody and grow into a second set of defects.

Figure 8e. Six months after root pruning and shifting, the main woody roots were oriented in a more natural form. Some main roots grew horizontally, while others grew downward. Both horizontal and vertical roots are needed for tree stability. The inner root ball was free from defects such as circling, stem-girdling, and kinked roots. However, this plant should be root pruned again when it is shifted to the next container size or planted in the ground.

Root System Management on Larger Containers

Objective: The root ball periphery should be free of larger circling, girdling, descending, ascending, and bottom-matted roots. Main roots near the substrate top surface should grow more or less straight to the edge of the container.

Problem: Roots growing on the periphery of the root ball often deflect down and around the container wall and can become large and woody (Fig. 9a). Larger roots at the periphery of #1 and larger containers can result from a rootbound liner, a liner planted with poor root branching or distribution, failure to root-prune the liner, a dominant tap root or lateral root, a tree remaining in a container for too long, and other factors. Small and medium-sized peripheral roots indicate better root distribution (Fig. 9b). Root defects often form on the interior of the root ball if roots are not managed at each shift.

Practice: Shifting before non-correctable defects form, root pruning, air-pruning, and teasing apart small roots at each shift to a larger container can significantly reduce root defects. Air-pruning happens when roots are purposely exposed to air in the absence of high humidity (Fig. 10). Root tips are killed, causing the plant to produce new branching roots. Growing trees in an open-bottom container above the ground air-prunes bottom roots and can reduce the diameter of roots growing toward the bottom of the container. The root ball improves because of an increase in lateral root growth and a more branched root system. Lateral roots that are air-pruned or chemically pruned on container sides also branch.

Root pruning can remove some or all of the outer roots and substrate from the top, sides, and bottom of the root ball (Fig. 11a). The straight portion of the roots on the interior is retained. In #3 containers and larger, roughly the outer 1 inch of substrate contains many of the defects. Teasing apart the outer surface of the root ball can be effective on young trees of certain species when roots are small in diameter (see Fig. 12). These strategies encourage new roots to grow radially away from the trunk. None of these techniques are very effective for treating defects on the interior of the root ball. Therefore, it is imperative that roots on the periphery be inspected and defects removed at each shift to a larger container. All techniques work best when roots are small in diameter.

Figure 9a. Large roots are growing on the periphery of the root ball. These should be removed by shaving or pruning away the bent portion of the roots; however, cutting roots of this size could kill some trees, depending on time of year and water management.

Figure 9b. Small roots are growing on the periphery of the root ball. This root ball should be shaved when shifted.

The trees in Figures 8e and 9b should be root-pruned when shifted to a larger container. Shaving works best because it is likely to cut roots back to a straight radial root segment attached to the trunk (Fig. 4). A shaved root ball will be smaller than it was before pruning (Fig. 13). There may be other ways to cut back roots so that retained roots are positioned radially and straight from the trunk. Slicing and scoring the root ball are less effective because 90-degree bends in main roots often remain (Fig. 4). Shaving continues the process of developing a quality root system that began when the liner was appropriately managed when shifted into the larger container. Root balls should be inspected and defects removed at each shift to a larger container to prevent the formation of large, defective woody roots on the interior of the finished root ball.

Figure 10. The valley oak root system grown in a container that prunes roots with air (top) has more lateral roots growing from the trunk and fewer root defects than a tree grown in a smooth-sided container (bottom).

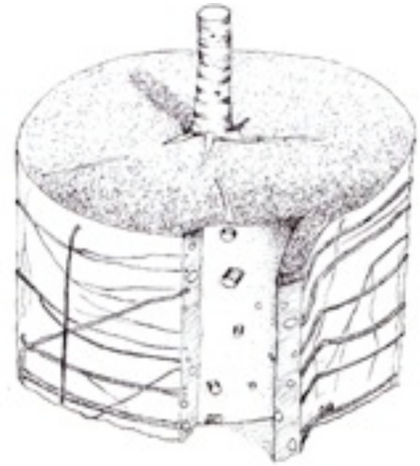


Figure 11a. Shaving, pruning, or "peeling" off the periphery of the root ball removes most of the root defects present at the periphery and bottom of the root ball.

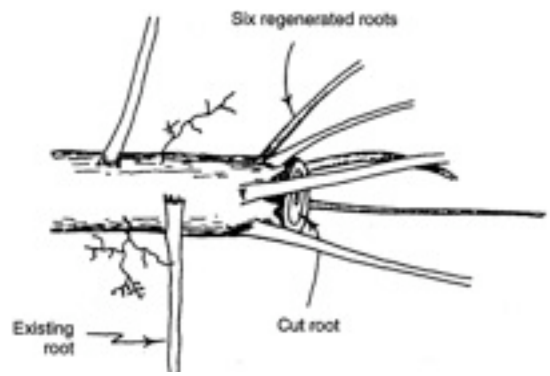


Figure 11b. New roots often grow radially away from the trunk in a fanlike pattern. Some roots may grow at a right angle to the cut root.

Figure 12. Teasing roots away from the root ball periphery encourages roots to grow radially away from the trunk.

Figure 13a. Roots matted at the #5 root ball periphery.

Figure 13b. A hand saw can be used to shave or peel away matted roots from the periphery of the root ball.

Figure 13c. Matted roots removed from the periphery of the #5 container prior to shifting. Note that remaining roots are straight and the root ball is slightly smaller than it was before pruning.

Figure 13d. Three months after root pruning, new roots grew radially from the trunk into the #15 container substrate.

Shaving, pruning, or scoring the periphery of the root ball can be done with a hand pruner, hand saw, machete, digging shovel, or other sharp blade (Fig. 13b). This process dulls sharp tools quickly but uniformly removes matted roots from the periphery and bottom of the root ball (typically about ½ to 1 inch on #1, deeper on larger containers; Fig. 13c). The tree is then ready to be shifted to a larger container or planted in the landscape.

New roots will grow from the cut root ends into the substrate in the larger container or the landscape (Fig. 13d). The resulting root system should have fairly straight roots growing radially from the trunk (Fig. 14 bottom and 15a). Without pruning, deflected roots can become woody and retain their bent form (Fig. 15b). Shaving or pruning away roots at the periphery each time the tree is shifted should prevent many of these bent roots from becoming permanent defects, while creating a more fibrous root ball.

Figure 14. This maple was not root-pruned when shifted to this #15 container; note the abundant root defects at the position of the #3 (top). The maple root ball periphery was shaved when shifted to a #15 container (bottom). Note the root defects at the position of the #3 are largely gone and new roots in the #15 are growing mostly radially away from the trunk.

Figure 15a. Washing the substrate away shows that root ball shaving developed a good root system with straight roots free of defects extending radially from the trunk.

Figure 15b. Washing substrate from the top of the root ball shows non-correctable root defects in a #45 container. These defects resulted from failing to prune the roots when shifting from the #5 and #15 containers.

Root Distribution within the Root Ball

Objective: The tree should be well-rooted but not overgrown in the substrate. When removing the container, the root ball should remain mostly intact. When tipping the tree from side to side, both the trunk and root ball should move as one. Root distribution should be uniform throughout the container substrate.

Problem: If a tree is poorly rooted or roots are poorly distributed, a large amount of substrate can fall away from the roots when shifting. Circling and large descending roots at the root ball periphery that are not cut during the shifting process may not extend radially or anchor into the new substrate. This can create a point of weakness. When the trunk is lifted or rocked (Fig. 16, right) the poorly rooted smaller root ball can partially separate from the substrate of the larger container's root ball.

Practice: Planting a liner with a balanced, branched root system containing ample root tips, and shifting the tree at the appropriate time, combined with mechanical and air root pruning, helps ensure good root distribution and a quality plant with a long life expectancy (Fig. 17). These techniques help prevent poor connections between smaller root balls and substrate in the larger container and often encourage more roots to grow into the top half of the root ball. Figure 13d shows how shaving the periphery of the root ball of the same species shown in Figure 16 yields better root distribution throughout the root ball.

Figure 16. This #5 root ball is not well secured to the #15 substrate because roots are growing from deflected roots primarily from the bottom of the #5 root ball (left). Pulling up on the trunk (right) causes the smaller root ball to partially separate from the substrate.

Figure 17. Roots should be evenly distributed inside the root ball (top). When the container is removed, the root ball should remain intact (left).

Depth of Root Collar

Objective: The root collar (the uppermost main horizontal mother roots) on the finished tree should be within the top 1 to 2 inches, and no large roots should cross over the main roots.

Problem: Trees planted too deeply can develop severe root defects at the root collar. Even trees of certain species (e.g., maples) planted at the proper depth can develop root defects. When shifted to a larger container these defects are more easily corrected on trees maintained at the original propagation level than on trees planted too deeply. Defects from deep planting include circling, stem girdling, and kinked roots growing over the root collar or around the trunk (Fig. 18a).

Practice: Trees should be positioned as close to the propagation level as possible unless main roots originate deeper than 1 inch below the substrate surface. If the liner is planted too shallowly, some surface roots could dry out and slightly impede tree growth. If planted too deeply, stem-girdling roots and other root defects may form. When shifting or planting into the landscape (Fig. 19b), substrate and root defects should be removed from the top of the root ball on trees planted too deeply. Substrate can be removed down to the root collar using water or air or by hand. Defective roots can be cut back to a point where the retained root segments are oriented radially from the trunk (Fig. 18).

Figure 18a. A circling root growing over the root collar.

Figure 18b. After removing circling roots, the remaining root segment should be oriented radially from the trunk and straight (Fig. 19a and b).

Figure 19a. The point where the uppermost root grows from the trunk should be positioned close to the substrate surface at each shift.

Figure 19b. Main roots at the top of the root ball should be oriented radially and straight away from the trunk.

Section 2: Trunk
Temporary Branches

Objective: Develop adequate trunk caliper so the tree can stand on its own without a nursery stake.

Problem: Early removal of lateral branches from the lower trunk (4 to 5 feet high) on young trees slows trunk caliper growth (Fig. 20). The combination of staking from a young age and early removal of temporary branches often creates a trunk with little or no taper and a tree that cannot stand on its own (Fig. 21). These practices lead to over-staking in the landscape and trunk breakage at the stake tie. Trees with no taper are difficult to transport and manage in the nursery and in the landscape. Roots, trunk, and crown grow slower if temporary branches are removed too early in the production process.

Practice: Keeping temporary lateral branches along the trunk of young trees allows trees to grow faster (Fig. 22). The length of temporary branches will vary according to your objectives. Longer temporary branches result in more caliper. In some circumstances, it may be desirable to head temporary branches in order to push more growth into the central leader. However, early removal of temporary branches can result in a tall and lanky tree. Headed temporary branches on trees sold to other nurseries as liner stock should not be considered downgrading factors.

The largest-diameter temporary branches should be removed at each pruning in order to keep trunk wounds small. Temporary branches do not have to be removed when trees are sold to another nursery for shifting stock, though it is important to communicate this to your customers so they know what they will be receiving from you. Temporary branches should typically be removed 6 to 12 months before sale to the end user. Temporary branches are most important for encouraging caliper growth in young trees (#15 container and smaller, Fig. 23 left). They can be removed from older trees (Fig. 23, right).

Figure 20. Good taper and caliper developed because of the many temporary branches along the trunk (left). Removing temporary branches too soon results in poor trunk taper, a weak tree, and less total growth (right).

Figure 21. Trees in the nursery are staked to form a straight trunk. This presents a problem only when low lateral branches are removed too soon from the trunk (left). When trunks are about the same diameter at the base as they are just below the crown, they lack trunk taper. This results in a weak tree unable to hold itself up (right).

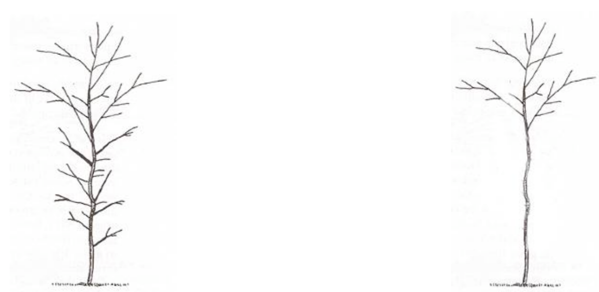


Figure 22. Leaving temporary branches along the lower trunk increases growth of the entire tree (left). The lower trunk will become thicker and roots will be stronger, allowing the tree to hold itself erect. Removing temporary branches too soon weakens the trunk and slows growth (right). In most circumstances, no more than 40% of the lower trunk should be cleared of temporary branches.

Straight Trunk

Objective: As the trunk extends up into the central leader (excluding clump forms), it should be mostly straight and vertical without exaggerated sweeps or sharp bends (Fig. 23). Trunks should also be free of large wounds.

Problem: The market desires a straight trunk that extends up into the central leader with few blemishes. Open or closed pruning wounds or existing headed temporary branches should not be considered blemishes because pruning wounds eventually close with new wood.

Practice: Not all trees require staking; however, many species need a stake to develop a straight trunk (Fig. 23). Bamboo stakes are a popular choice, but many other materials can be used including plastic, fiberglass, and metal. The trunk should be secured to the stake snugly to prevent rubbing, but not so tight that the trunk is girdled. Stakes should be small in diameter to prevent branch deflection. Large square wood stakes deflect branches, often leading to a misshapen or a flat-sided crown. The tree can be staked far up into the crown with a variety of materials (Fig. 24). There is no need for the stake to be attached to the ground once the tree can stand on its own.

Figure 23. Low temporary branches are most important on young trees (left). Low temporary branches are less important on older trees; however, they can be retained depending on the species (right). They can be removed prior to sale to the end user.

Figure 24. Staked trees develop ample caliper when low temporary branches are managed properly. Temporary branches should be cut back and removed over a period of time. These branches are most important in the earlier stages of production. Stakes can be pulled up the tree to help develop a straight leader to the top of the crown. Branches and the main leader on the tree in the sequence above were headed in order to develop a straight trunk and leader.

Section 3: Crown
Central Leader

Objective: Shade trees should have a single, relatively straight central leader, free of codominant stems or other vigorous upright branches that would compete with the central leader (Fig. 25). This does not apply to plants that have been specifically trained in the nursery as topiary, espalier, multi-stem, clump, or unique selections such as contorted or weeping cultivars.

The development of a high-quality crown hinges on the establishment of a central leader that is considerably larger in diameter than all branches. Some species will develop a central leader and crown on their own and require little or no intervention. Others require regular pruning. Pruning practices used in leader training include heading, branch subordination pruning, and staking. Some species can be grown with several leaders, including *Lagerstroemia*, *Photinia* standards, *Albizzia*, *Arbutus*, *Chitalpa*, *Eriobotrya*, *Malus*, *Prunus*, *Salix* and others.

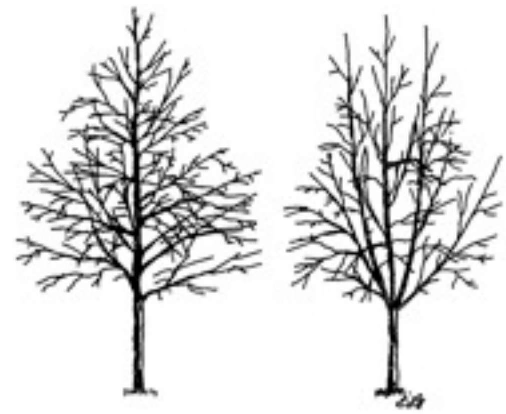


Figure 25. High-quality shade trees have one central leader (left). Poor-quality shade trees have two or more leaders (right).

Leader-dominant species (excurrent form)

Problem: Trees such as London plane tree (*Platanus* × *acerifolia)* will develop a well-shaped crown with a strong central leader without much intervention (see the Appendix for additional species). Trees with a strong central leader require only periodic subordination of aggressive branches to maintain the central leader (Fig. 26).

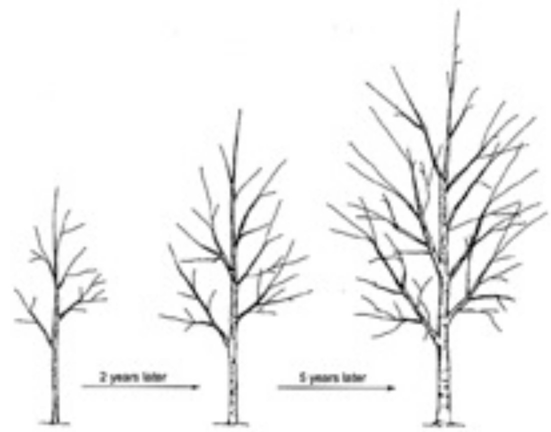


Figure 26. Excurrent (leader-dominant) trees sometimes develop good structure with limited intervention.

Practice: Reduction, or branch subordination pruning, is an important tool for developing an attractive and structurally sound crown. Branches that are vigorous and upright can be kept from becoming codominant with subordination pruning (Fig. 27). Subordination removes enough branches to slow growth by the desired amount. Codominant branches should be cut back to lateral branches, shoots, or buds pointed away from the central leader. In some cases codominant branches should be removed altogether, such as when they are nearly the size of the leader or when they cluster close together.

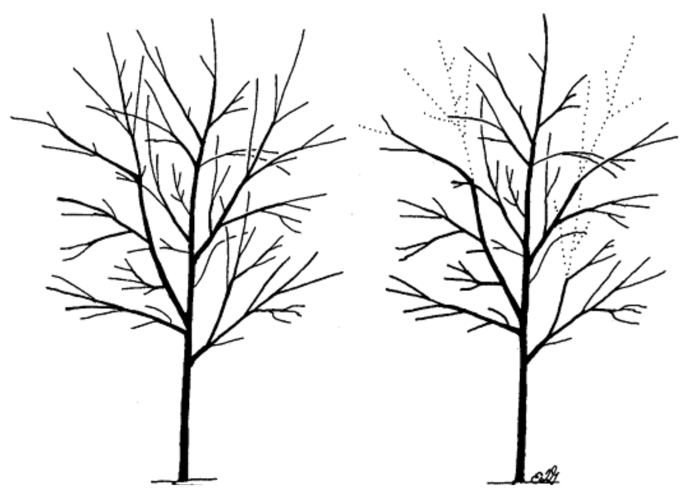


Figure 27. Subordination pruning reduces the length of codominant branches (dotted lines) back to a lateral branch pointed away from the trunk. The growth slowing effect is proportional to the amount removed.

Branch-dominant trees (decurrent form)

Problem: Trees such as elm (*Ulmus* spp.), zelkova (*Zelkova serrata*), and camphor (*Cinnamomum camphora*) are branch-dominant (see the Appendix for additional species). Species with this form typically develop codominant branches that grow as fast, or faster, than the central leader. These trees will grow into a round or vase-shaped form at a very early age. This growth habit requires regular pruning to shorten branches and develop an attractive and structurally sound crown. When trees of this form are not trained properly in the nursery, they can develop structural defects as they continue to grow in the landscape.

Practice: Branch management should begin early in the production process and continue until the tree is sold. Regular branch subordination and branch removal ensures that competing branches grow more slowly than the central leader and do not become codominant (Figs. 28a and 28b).

Branches in the crown should be less than half the diameter of the central leader measured 1 inch above the attachment. Branch tips should be below the tip of the central leader (Fig. 28b). Branches that are vigorous may require substantial subordination to slow their growth (Fig. 29). Branches should be cut back to shoots or buds pointed away from the central leader. Branches may need to be shortened repeatedly in the production process. In most cases, codominant branches should be removed altogether, especially if upright.

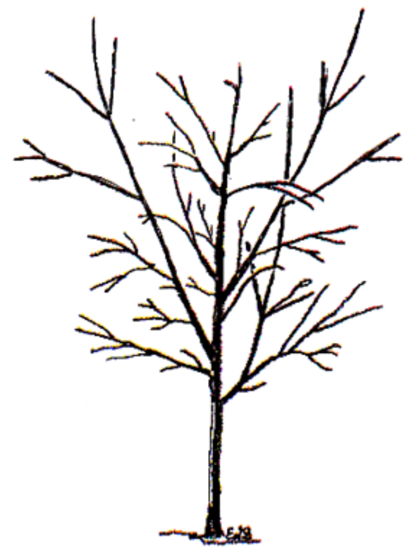


Figure 28a. Codominant branches typically grow as fast, or faster, than the central leader.

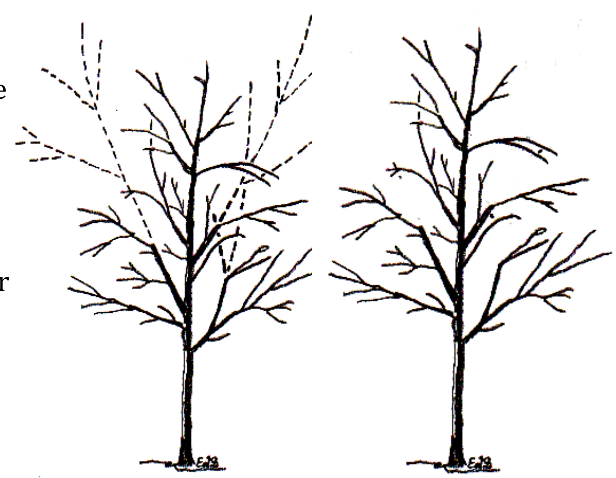


Figure 28b. Three codominant branches were subordinated (reduced) by 60 to 70% to slow their growth and encourage the central leader to develop.

Figure 29a. Codominant branches are typically vigorous and upright before pruning.

Figure 29b. A light subordination pruning showing removal of 30 to 40% of foliage.

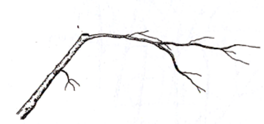


Figure 29c. A heavy subordination pruning showing removal of 60 to 70% of foliage.

Trees that do not branch

Problem: Trees such as Chinese pistache (*Pistacia chinensis*), jacaranda (*Jacaranda mimosifolia*) and honeylocust (*Gleditsia triacanthos*) often do not branch on their own at a young age (Fig. 30; see the Appendix for additional species). Trees without branches do not fare well in the marketplace. The practice of heading stems to promote branching without retraining a central leader can create codominant branches clustered close together (Fig. 31). This clustering is considered a structural defect because it becomes a weak point in the tree as it grows (Fig. 32). The structural weak point is largely due to the lack of follow-up pruning and staking in the nursery.

Practice: The central leader can be headed to promote branching; however, the tree should be trained with a new central leader (Fig. 33). One method of training a new central leader uses a bamboo stake tied in several places to the trunk. The stake should extend well beyond the heading cut. After heading the central leader, several new shoots should grow from below the point where the central leader was headed (Fig. 33). The most vigorous upright shoot should be selected and pulled tight against the stake. This shoot will become the new central leader (Fig. 34). The heading cut should not exceed about ¾ inch in diameter.

Shoots other than the one chosen for the new central leader should be headed to prevent them from becoming codominant. These shoots should be headed back to a bud oriented away from the central leader. This practice can be repeated throughout the production process to develop a full-branched crown.

Figure 30. Some species do not branch when they are young (see the Appendix for a list).

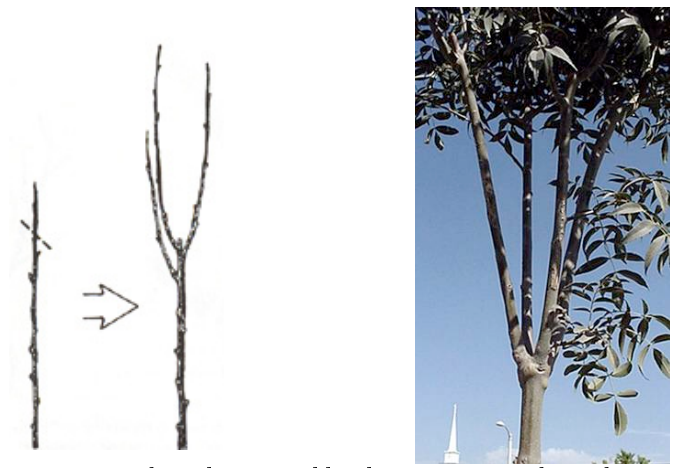


Figure 31. Heading the central leader encourages branching (left and center; from Harris et al. 1999). Poor branch structure results without follow-up pruning (right).

Figure 32. These trees probably failed because they were headed in the nursery without follow-up pruning.

Heading and Re-training the Central Leader

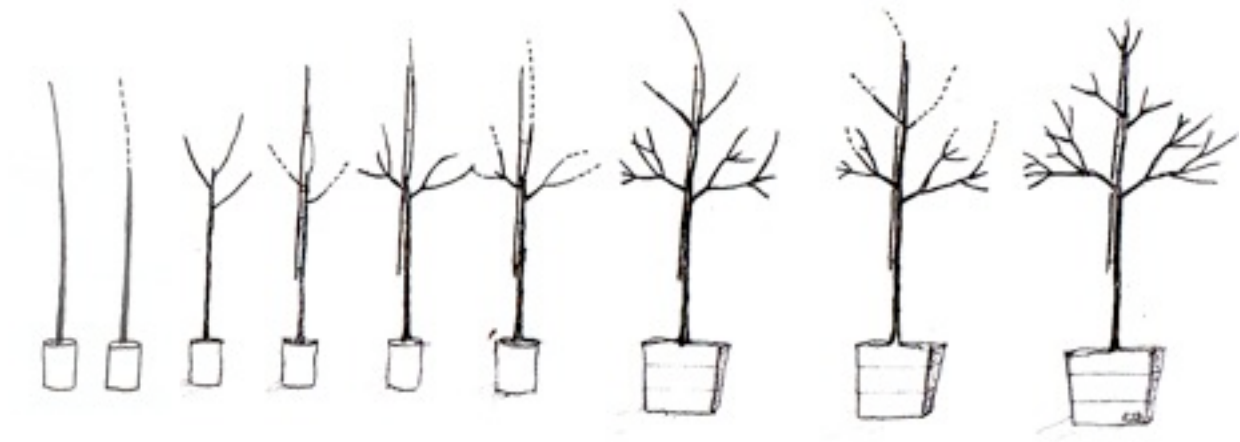


Figure 33. Heading the leader promotes branching (left to right). The top shoot is tied to a stake and the others are headed to promote branching. This process continues throughout the production process (see Fig. 34 for staking detail).

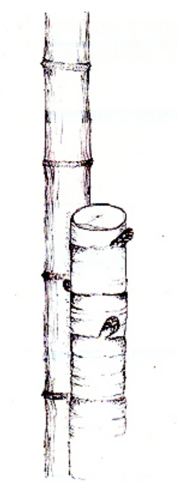


Figure 34a. The central leader is headed at the point where branches ar needed. A stake (left) is tied to the leader so it extends beyond the cut.

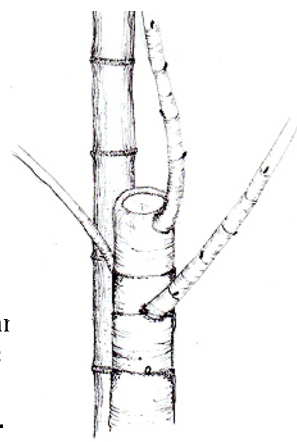
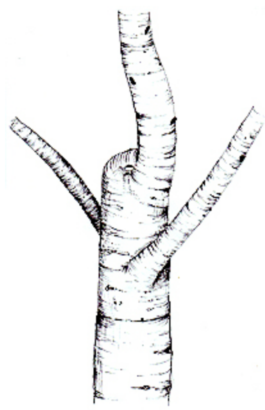


Figure 34b. Three buds developed into shoots just behind the heading cut. The top shoot is tied to the stake while the shoots are still soft.



igure 34c. The new leader is rowing larger. The pruning vound is almost closed. The vood in the new central leader vill harden and remain traight. The stake can be emoved or adjusted.

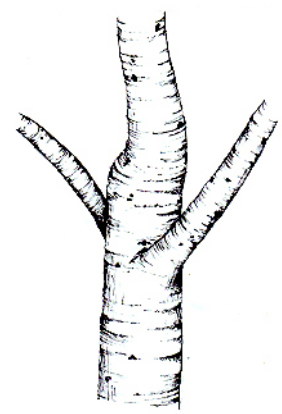


Figure 34d. The pruning wound is closed and the tree now has a new central leader with two branches. The two branches were headed (not shown in illustration) to slow their growth and to create more branches.

Branch Diameter

Objective: The diameter of all branches should be less than half the diameter of the trunk and the central leader as measured about 1 inch above the branch union (Fig. 35).

Problem: Branches larger than half the trunk diameter can grow too aggressively and compete with the central leader (Fig. 36, top). Branches that are smaller than the trunk are better attached and typically do not compete with the leader. Branches that are larger than the trunk have a weaker attachment to the trunk.

Practice: Branches with a diameter greater than half the trunk diameter should be removed or severely subordinated to slow their growth (Figs. 28b and 29).

Figure 35. This nearly finished nursery tree has good branch size in relation to the trunk and a strong central leader. Since these branches are small, they will be easy to remove as the tree grows in the landscape or is shifted to a larger container.

Figure 36. The branch on the right is large in relation to the central leader and should be removed or reduced in order to slow its growth (top photo). Branches should be less than half the trunk diameter, not the same diameter as the trunk. Medium-sized branches (see finger) can be pruned moderately in order to slow their growth (bottom). Smaller branches may not need pruning.

Branch Distribution

Objective: Main branches should be distributed along the central leader (Fig. 37a) and not clustered at a few points (Fig. 37b). Conifers often grow with many branches close together; in most cases, this is fine.

Problem: Clustered branches often outgrow the central leader, and this retards growth of the central leader (Fig. 37b).

Practice: When trees have clustered branches, they must be pruned in a timely manner, otherwise tree quality and salability will suffer. A combination of branch removal and branch subordination is required (Fig. 38). Ideally, the larger-diameter branches should be removed and the smaller branches cut back to a bud or shoot growing away from the central leader. This practice will maintain a structurally sound and well-distributed nursery crown. Pruning should be scheduled to avoid adverse impacts from environmental extremes of weather.

Figure 37a. This tree has a strong structure and well-spaced branches in relation to the trunk. Notice that the central leader has a uniform taper.

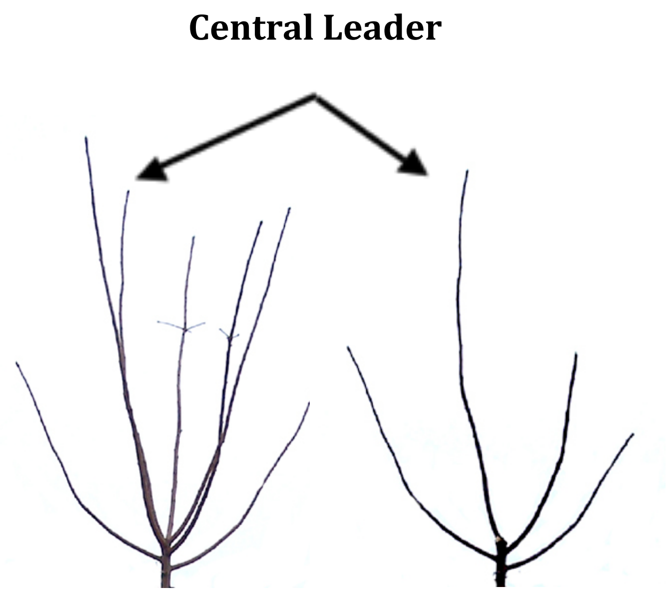


Figure 38. This is an example of how a cluster of branches could develop into codominant stems (left). The tallest stem takes over or several grow to choke out the leader. The cluster causes a reduction in the vigor and diameter of the central leader above the cluster. After selecting the central leader, the largest three branches were removed, and the remaining two smaller branches on the right were reduced by half. The branches were cut back to a bud pointed away from the central leader (right).

Figure 37b. A tree is weak when most branches are clustered together. Notice the significant reduction in diameter of the central leader just above the cluster of large branches. This indicates that the branches are growing more aggressively than what was the leader.

Crown Form

Objective: Trees should have a balanced form and not be misshapen by breakage, wind, pruning practices, pests, spacing, or other factors. A consistent tree form is an important attribute for sales and landscape value. It is easier for buyers to choose from a block of trees that have consistent nursery crowns.

Problem: Aggressive or oversized branches can cause the crown to become asymmetrical or one-sided, which reduces the salability of the trees.

Practice: Tree form can be improved by reducing, removing, and heading branches to create a uniform nursery crown (Fig. 39). Vigorous branches can be brought back into a consistent and uniform shape. Trees previously headed or topped, or those with a thin crown on one side, can be balanced by removing and reducing branches on the heavy side (Fig. 40).

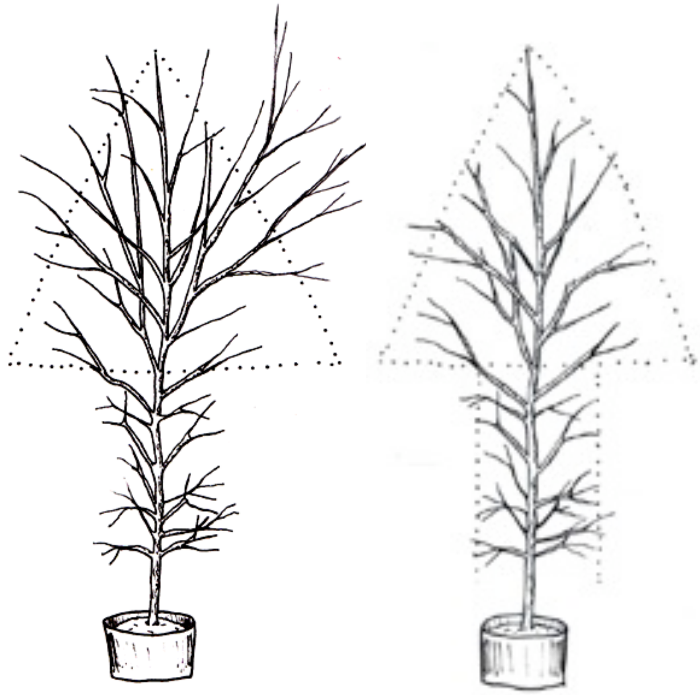


Figure 39. The crown is lopsided on the right side of the photo on the left. Reducing the large upright branch and heading some smaller branches results in a more uniform nursery crown (right). Ideally, branches growing outside an imaginary pyramid (dotted lines) should be pruned.

Figure 40. Before pruning (left), the crown is lopsided. After pruning (center), the central leader is more prominent and the crown is better balanced. Reduction cuts (right, arrow), removal cuts, and heading cuts can balance the nursery crown.

Bark Inclusion

Objective: Scaffold branches with bark inclusions in the crown should be removed or severely headed.

Problem: A branch is well attached to the trunk when a bark ridge is present (Fig. 41a). A bark ridge indicates that normal wood is growing over the union. Conversely, bark inclusions in the branch union reduce the strength of the branch attachment because bark and wood fold inward (Fig. 41b). This makes for a weak branch attachment.

Branches with inclusions tend to be vigorous and upright with narrow angles of attachment (Fig. 42). They shade the leader, which can prevent branches with good unions from developing higher in the crown. If not removed early in production, removal can later lead to a deformed crown.

Practice: Branches that have bark inclusions should be removed when the tree is young and before the branch becomes an important part of the crown. If removal will leave the crown one-sided, the branch should be subordinated. Branches with bark inclusions often require regular subordination.

Figure 41a. Branches with bark ridges on the top of the union are well secured to the trunk.

Figure 42. A union with a bark inclusion forms a V shape (see Fig. 41b). The union is weak and breaks apart easily because there is no wood on top of the union connecting branch to trunk.

Figure 41b. Unions with inclusions are weak and can easily break from the trunk. The crack is the bark inclusion.

Vigor and Foliar Characteristics

Objective: The current year's shoot growth should be vigorous (showing vitality) as indicated by appropriate shoot growth (length and diameter) throughout the crown for the age and size of the species or cultivar (Fig. 43). Trees should have no dead, diseased, infested, cracked, broken, distorted, or otherwise injured branches.

The size, color, and appearance of leaves should be appropriate for the time of year and stage of growth of the species or cultivar (Fig. 44). Leaves should not be undersized, misshapen, tattered, discolored (chlorotic or necrotic), or otherwise atypical in appearance (Fig. 45).

Problem: Trees that have poor health or lack vigor are often shifted into larger container sizes and allowed to remain in the production system. These practices are bad for growers and their customers. Shifting poor-vigor trees into the larger container sizes should be avoided when possible.

Practice: Less-vigorous trees should be culled and not shifted to larger containers. It is important to cull trees that exhibit poor health and poor vigor early in the production process to reduce cost. Management efforts should be focused on vigorous plants.

Figure 43. The tree on the left shows very poor vigor for the species, with only 3 inches of shoot growth. The tree on the right exhibits good vigor appropriate for the species, with 16 inches of shoot growth.

Figure 44. The tree on the left displays the appropriate leaf color. The tree on the right is partially chlorotic.

Figure 45. This tree shows scorched and chlorotic leaves.

Glossary

air root pruning. Root pruning done in containers that causes root tips to be killed by exposure to dry air, resulting in several new roots branching behind the dead root tip.

apical. Of or relating to the main upright shoot of a plant.

apical dominance. Inhibition of lateral buds by the terminal bud of a shoot.

branch union. The point where two stems, or a stem and a branch, meet.

branch. A stem that is smaller than the main trunk to which it is attached.

caliper. Trunk diameter measured 6 inches from the ground; if caliper is greater than 4 inches, the caliper measurement should be taken at 12 inches from the ground.

central leader. A continuation of the main trunk located more or less in the center of the crown, beginning at the lowest main branch (scaffold) and extending to the top of the tree. Also referred to as the dominant leader.

circling roots. One or more roots whose diameter is greater than 10% of the trunk caliper circling more than one-third of the trunk.

clear trunk. The portion of the trunk below the crown lacking lateral branches, including the portion of the trunk with shortened temporary branches below the crown.

codominant. Two or more vigorous, upright branches or stems of relatively equal size that originate from a common point, usually where the leader was lost or removed.

crown. The portion of a tree beginning at the lowest main (scaffold) branch extending to the top of the tree.

cultivar. A named plant selection from which identical or nearly identical plants can be produced, usually by vegetative propagation or cloning.

descending roots. Roots that grow to the container wall and down the inside of the pot. Also known as plunging or descending roots.

decurrent species. Species with strong apical dominance and weak apical control. Buds do not elongate in the season they were initiated (strong apical dominance); but, when they do elongate, they have growth equal to the central leader (weak apical control).

excurrent species. Strong apical control but weak apical dominance. Lateral branches are capable of elongating in the year they were initiated (weak apical dominance), but their elongation is under strong apical control.

finished tree. A tree in its final container.

heading cuts. Cutting through a stem or branch just above a live bud that is typically oriented away from the central leader.

included bark. Bark embedded in the union between a branch and the trunk or between two or more stems that prevents the formation of a normal branch bark ridge.

kinked root. A main mother root that is sharply bent.

lateral. Branches growing from the sides of the main trunk.

leader. The dominant stem, which usually develops into the main trunk.

liner. A plant in its first or second container.

liner tray. A small container or group of containers designed to hold germinating seeds or rooted cuttings.

main roots. The largest-diameter mother roots typically growing from the trunk or main taproot that form the main structure of the root system.

media. See **substrate.**

minor root defects. Small-diameter roots circling or crossing the top of the root ball.

peripheral roots. Roots growing in the outer inch of the container root ball sides and bottom.

radial. Positioned around a central point or axis.

propagation depth. Depth at which tree was positioned in the first container or field soil.

photosynthate. Sugar and other carbohydrates that are produced by the foliage and stems during photosynthesis.

reduction cut. Cutting a stem or branch back to a live lateral branch that is typically oriented away from the central leader; also referred to as a subordination cut.

root defects. Circling, kinked, or stem-girdling roots resulting from growing in a container. Roots that deflect up or down once they reach the container wall are also considered defects.

removal cut. Removing a branch back to the trunk, or removing a secondary branch from a main branch.

root ball shaving. Removing the outer substrate and roots on the periphery of the root ball, typically using a sharp blade or saw.

root collar. The base of a tree where the main roots and trunk meet. Also referred to as the root flare.

root flare: See **root collar**.

root plate. The combination of roots and soil close to the trunk that holds the tree erect in the landscape.

scaffold branches. Large main branches that form the main structure of the crown.

shifting. Removing the root ball from a container and placing it in a larger container; also referred to as repotting, bumping up, or stepping up, up canning.

stem-girdling root. A circling, bent, or straight root that touches or rests on the trunk or root flare that can become a permanent root.

subordinate. See **reduction cut**.

substrate. The mixture of bark, peat, sand, compost, wood, and other materials used in containers to grow plants at commercial nurseries. Also referred to as media.

tap root. The primary, typically large-diameter dominant root that emerges from a seed.

teasing the root ball. Gently pulling roots on the root ball periphery away from the periphery and positioning them more-or-less straight in a radial position in the substrate of a larger container.

temporary branch. A small branch that is temporarily retained along the lower trunk of young trees.

thinning cut. See **removal cut**.

trunk. The main stem of a tree, beginning at the root collar and ending at the lowest main scaffold branch.

taper. The thickening of a trunk or branch toward its base.

wound. A discontinuity resulting from removal of bark and cambium. Pruning cuts that are not closed over are not considered wounds.

Appendix

Selected branch-dominant shade tree species
Acacia
Bauhinea
Camphor
Celtis
Cercis
Cladrastis
Ficus
Fraxinus
Gleditsia
Koelreuteria
Laurastinus
Quercus
Ulmus
Zelkova

Selected leader-dominant shade tree species
Acer
Alnus
Brachychiton
Cedrus
Grevilia
Liriodendron
Liquidambar styraciflua
Magnolia grandiflora
Pinus
Platanus
Podocarpus
Sequoia
Sequoiadendron
Taxodium distichum

Selected tree species that do not branch on their own in the nursery
Delonix
Eucalyptus
Ginkgo
Gleditsia
Jacaranda
Koelreuteria
Pistacia
Pyrus

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