By L.R. Costello

Adventitious Roots

Occurrence and Management in Urban Trees

LEARNING OBJECTIVES

The arborist will be able to

- define and identify adventitious roots.
- explain how and why adventitious roots occur.
- discuss the function of adventitious roots.
- determine appropriate management techniques for adventitious roots.

Although adventitious roots do not routinely occur on urban trees, they are by no means rare. They are found on many species, and arborists will encounter them at some point in their careers. Therefore, it is important to be able to identify adventitious roots and know something about their development and function. With this background information, informed decisions can be made regarding their management. This article provides a review of some of the literature describing adventitious roots and then discusses tree management implications.

What Are Adventitious Roots?

Adventitious roots have been defined in both technical and nontechnical terms. Esau (1977) states that adventitious roots are roots that arise at sites other than their usual sites, such as roots originating on stems or leaves. Zimmerman and Brown (1971) offer a more technical definition, saying adventitious roots arise from "buds in parenchyma tissue not directly associated with apical meristems and in places not dictated by their normal phyllotactic pattern." Barlow (1986) lands somewhere between the previous two definitions, saying adventitious roots are roots that "arise on parts of the plant not originating from the embryonic root; that is, the roots arise on parts of the shoot."

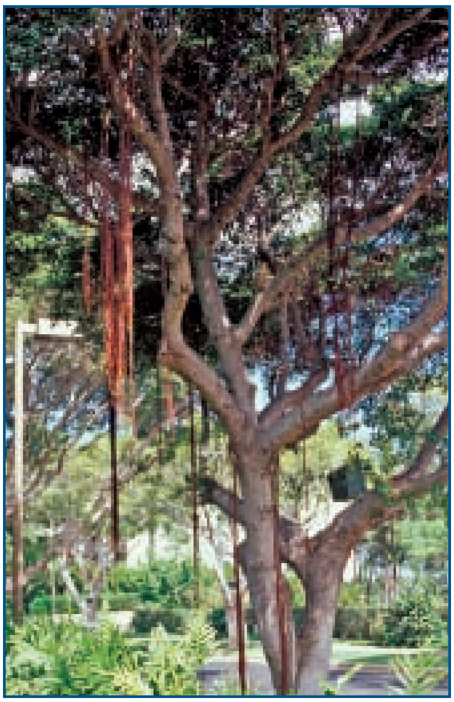

Figure 1. The aerial roots growing from the branches of this fig (*Ficus* spp.) are adventitious.

Figure 2. Large, handlike, adventitious roots developed on the stem of this Moreton Bay fig (*Ficus macrophylla*) in Santa Barbara, California.

Kramer and Kozlowski (1979) add that adventitious roots may form on twigs, branches, leaves, aerial stems, underground stems, and old roots.

Occurrence, Types, and Causes of Adventitious Roots

Adventitious roots occur naturally on many species of both terrestrial and aquatic plants. The aerial roots of *Ficus* spp., the clasping roots of *Philodendron* spp., the strangling roots of *Metrosideros* spp., the stilt roots of mangrove *(Rhizophora mangle)* and screw pine (*Pandanus* spp.), the nodal roots of corn (Rost et al. 1998), and the nest roots of orchids are all adventitious (Barlow 1986) (Figures 1 through 5).

Paolillo and Zobel (2002) confirmed the occurrence of adventitious roots in 22 species from 19 families in nine orders of dicotyledonous plants. Shoemake et al. (2004) reported that the provenance of sycamore *(Platanus occidentalis)* affects adventitious root development.

Esau (1977) asserts that the entire root system of monocots is adventitious because the embryonic root (radicle) does not live long enough to generate true roots. Allen

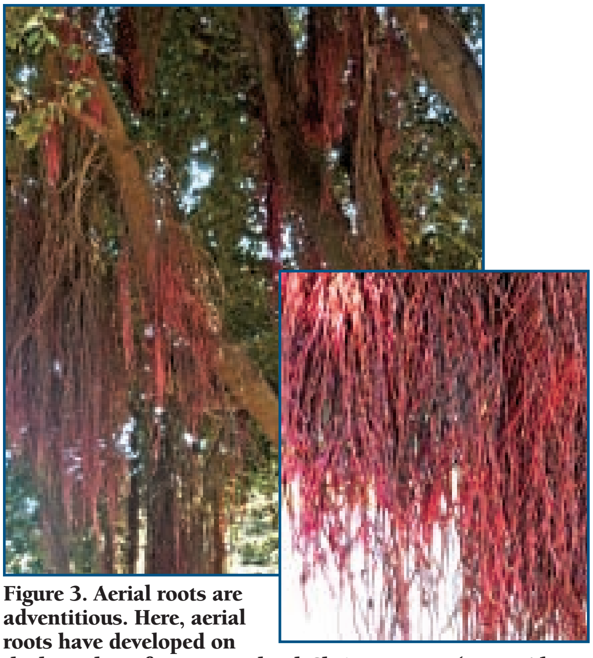

Figure 3. Aerial roots are adventitious. Here, aerial roots have developed on the branches of a New Zealand Christmas tree (*Metrosideros excelsus*) in San Francisco. Inset: close-up of aerial roots.

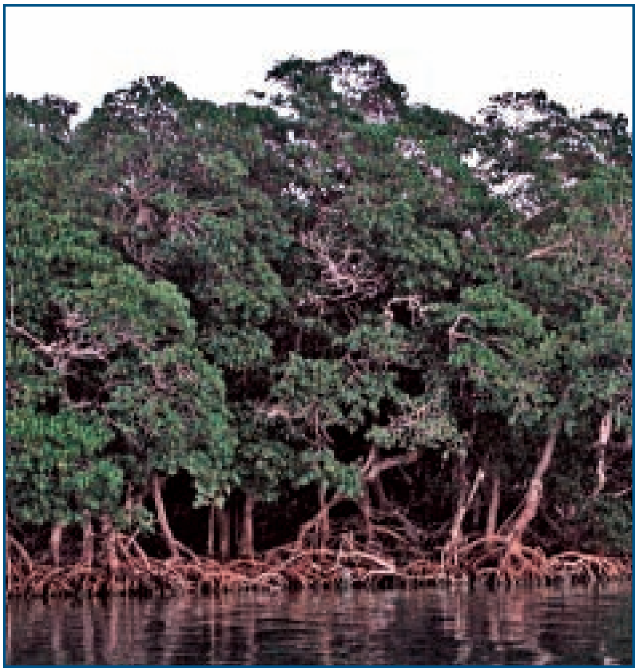

Figure 4. Exposed to water-level fluctuations in the tidal zones of the Florida Keys, mangrove (*Rhizophora mangle*) develop adventitious roots on the lower trunk.

(2004) indicates that "when a palm seed germinates, it produces a seedling root, or radicle. Soon, however, the radicle stops functioning and is replaced by roots produced from an area of the stem called the root initiation zone. All of a palm's subsequent roots are adventitious. They initiate from the stem at their maximum diameter and do not produce secondary growth in thickness" (Figure 6).

Adventitious roots form on many genera in response to flooding, including *Acer, Alnus, Eucalyptus, Fraxinus, Liriodendron, Melaleuca, Nyssa, Populus, Salix, Ulmus, Pinus, Picea, Sequoia, Taxodium*, and *Thuja* (Kozlowski 1984). Following a flooding episode, "the most common type of root regeneration is the development of adventitious roots on the stem above the soil, usually within the flood zone. They are initiated directly on the stem and are designated *adventitious water roots*" (Kozlowski 1984). The formation of adventitious water roots is considered to be an important adaptation to flooding: They are active in the absorption of water and mineral elements while the primary roots are submerged (Gill 1975). Jackson and Drew (1984) add that "adventitious roots probably survive while the original roots die because the new roots emerge from the stem close to the water surface where water and oxygen are available and where anaerobically generated toxins are absent."

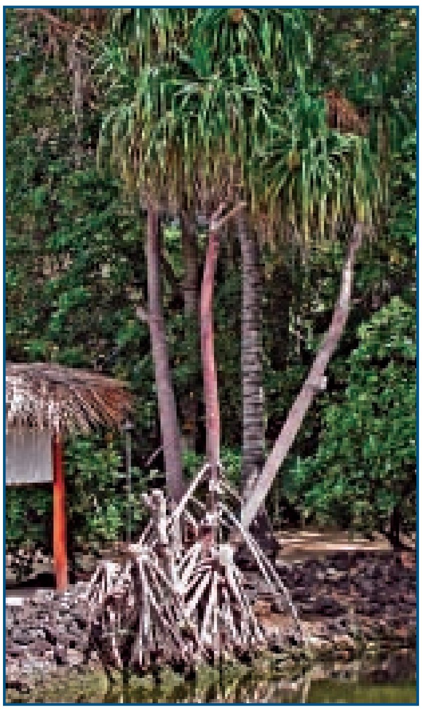

Figure 5. The adventitious roots on the stem of this screw pine (*Pandanus tectorius*) are called stilt roots because they are thought to provide support.

Adventitious roots can be induced for horticultural purposes as well. In plant propagation, roots that form on stem or leaf cuttings are adventitious, as well as those generated from air layering and tissue culture (Loreti 1988). These

Figure 6. Roots developing from a palm stem are adventitious.

roots can be stimulated by various propagation practices, including hormone treatments and wounding (Davies and Hartman 1988; Loach 1988). Pieces of stem from willow (*Salix* spp.) and poplar (*Populus* spp.) can develop adventitious roots simply by being placed in moist soil. Roots can develop on begonia and African violet leaves by being placed in water. Monterey pine *(Pinus radiata)* has been found to produce adventitious roots both from stem cuttings and by air layering (Cameron and Thomson 1969).

The Web site for the 4th International Symposium on Adventitious Root Formation (2004) provides an overview of research topics about woody plant propagation and adventitious root formation: www.ces.ncsu.edu/nreos/forest/feop/roots.

Atmospheric moisture determines whether adventitious roots form on *Eucalyptus robusta*: In the drier climates of Australia, they do not form adventitious roots, while in the humid regions of Hawaii, they form freely (Lanner 1966). Detritus accumulating among epiphytes growing in the canopy of bigleaf maple *(Acer macrophyllum)* creates an environment suitable for adventitious root formation (Nadkarni 1981). In many tropical species, adventitious roots are considered to be evolutionary adaptations.

Insects and pathogens also induce adventitious root formation on certain species. Stems of tomato develop adventitious roots in response to infection by the bacteria *Pseudomonas solancearum* and *Corynebacterium michiganens* (Grieve 1941) and the aster yellows virus (Rasa and Esau 1961). A gall midge *(Mayetiola poae)* was found to induce root formation on stems of *Poa nemoralis*, while a wasp *(Pontania proxim)* induced adventitious roots on *Salix purpurea* (Beyerinck 1885). Certain epiphytes have adventitious roots that develop in association with ants. For example, *Dischidia rafflesiana* forms "ant leaves": Ants bring water, humus, and detritus into cup-shaped leaves, which stimulates adventitious root formation from petiole tissues.

In addition, adventitious roots form in response to the physical removal of roots or injury to roots. Bannan (1942) found that species of *Taxus*, *Thuja*, *Juniperus*, *Abies*, *Picea*, and *Larix* formed adventitious roots when wounded. Injury to the primary root system from the application of fill soil can lead to the development of adventitious roots on the lower stem (Figure 7). Adventitious root formation has been reported for valley oak *(Quercus lobata)* following injury to primary roots (Britton 1990) and for Monterey pine *(Pinus radiata)* following fill soil installation (Costello 1995) (Figure 8).

Although not common, adventitious roots can form when branches partially separate from the tree. In one recent case, roots were found in the attachment zone of a failed, large-diameter branch of California laurel *(Umbellularia californica)*. Apparently, roots formed (prior to full branch failure) because moisture was trapped between the branch and trunk, creating an environment suitable for root initiation. The presence of these roots gives an indication that partial separation occurred prior to failure, although it is difficult to estimate the length of time. Roots growing in this location did not likely contribute substantially to the tree's water balance, but their growth in diameter may have played a role in further separation of the branch and trunk.

Finally, in field production nurseries and in the landscape, adventitious roots can develop on young trees that have been planted too deeply or when soil is "hilled up" around the stem from tillage practices. Moist soil in contact with trunk tissues likely stimulates root formation. Although these roots are functional physiologically, they can become stem-girdling roots (Johnson and Hauer 2002).

Function of Adventitious Roots

The principal physiological function of adventitious roots is the absorption of water and nutrients from their surroundings (Barlow 1986). This function can be critical

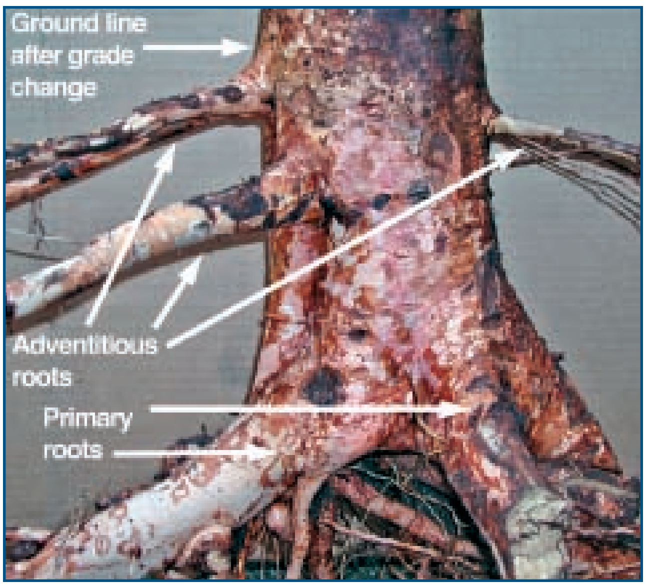

Figure 7. Adventitious roots developed on the trunk of this Australian brush cherry (*Syzygium paniculatum*) following the installation of fill soil over the primary roots. A similar response can occur when trees are planted too deeply.

Figure 8. A root crown excavation revealed adventitious roots on the trunk of this Monterey pine (*Pinus radiata*). These roots developed in response to fill soil being placed over the primary roots.

when the primary root system has been substantially impaired. Noting that some trees produce adventitious roots that compensate for extensive root loss from disease, Harris et al. (2004) state, "the new roots supply the tree with adequate water and nutrients."

Adventitious water roots serve a critical role in supplementing absorption when flooding diminishes the function of primary roots (Kozlowski 1984). Jackson and Drew (1984) note that adventitious roots forming as a result of flooding "replace many functions of the original, defunct root system, and thus aid survival and partial recovery." These functions include supplying water, nutrients, and hormones. Shoot regrowth, new leaf emergence, recovery from leaf curling, and resumption of transpiration rates to pre-flood levels have all been reported as plant responses following adventitious root formation (Kozlowski 1984). The small, adventitious roots of mangrove *(Rhizophora mangle)*, called pneumatophores, "absorb oxygen and increase its availability to submerged roots" (Rost et al. 1998).

For some species, adventitious roots can provide a structural function. Rost et al. (1998) state that aerial roots provide "additional mechanical support for the shoot system, and thereby permit further shoot enlargement: Adventitious roots can be pillars and buttresses [Figure 9]. Prop or pillar roots allow the banyan *(Ficus bengalensis)* to reach a spectacular size: Specimens have been found with a canopy 500 to 600 meters [approximately 1,600 to 2,000 feet] in circumference supported by many hundreds of prop roots, some up to 3.7 meters [12 feet] in girth." They add that the prop roots of corn not only "absorb water and minerals, but they also support the plant in the soil."

Adventitious Roots and Tree Management

Although aerial, stilt, and prop roots are of botanical interest, adventitious roots that develop on the lower stem are of greatest arboricultural interest. As noted earlier, these roots can develop in response to impacts to the primary root system, and their presence provides an indication that root injury occurred at some point. In urban landscapes, grade changes (fill soils), flooding, root disease, and mechanical injury can lead to the formation of adventitious roots on the lower stem. These roots can develop on either mature trees or young trees, and there are specific arboricultural implications for both.

In mature trees, adventitious roots on the lower stem are important for two reasons: (1) they contribute to the water balance and mineral supply of the tree, and (2) they indicate that the primary root system may have sustained some level of injury. If the injury was severe, then the anchorage function of the root system may be diminished, increasing failure potential. As noted by Matheny and Clark (1994), "while adventitious roots can keep the tree green and alive, they usually are not sufficient to support the mature tree unless they develop when the tree is young."

Where adventitious root development is suspected in mature trees, a careful root crown inspection is warranted. Excavating the soil at the base of the trunk to the root collar will expose the lower stem and any adventitious roots. This can be done using pneumatic or hydraulic excavation tools or by hand using digging tools. For information on conducting root crown inspections, see Britton (1990), Matheny and Clark (1994), Johnson and Hauer (2002), and Harris et al. (2004).

If adventitious roots are found during a root crown inspection, two matters merit attention: (1) retention of adventitious roots, and (2) further inspection of primary roots. It is important to understand that adventitious roots play a beneficial role in maintaining tree health: They absorb water and mineral elements and are active in hormone synthesis. They supplement these key functions of the primary root system. In cases where the activity of the primary root system has been substantially compromised, adventitious roots likely play a major role in maintaining water balance and mineral supply.

Considering their contribution to tree health, adventitious roots should be retained whenever possible. Their removal will have some impact on tree water balance and, in some cases, severe water deficits may follow. Smiley (1999) recommends that "adventitious roots over one-quarter inch [in diameter] should not be removed from the trunk because they may be providing substantial amounts of water and nutrients to the tree."

Figure 9. Aerial roots on this New Zealand Christmas tree (*Metrosideros excelsus*) have grown into the ground and become prop, or support, roots.

In cases where primary roots have been injured, a tree's structure as well as its physiology may be affected. The structural strength of relatively large-diameter roots can be compromised when a loss of root function occurs. Kane and Ryan (2002) caution that adventitious roots indicate that a loss in structural strength may have occurred in the primary root system. Harris et al. (2004) note that "arborists must be concerned with the structural stability of trees following flooding." If a loss in the structural strength of support roots has occurred, then an increase in failure potential will follow.

Although adventitious roots supplement key physiological functions of the primary root system, it is not likely that they substantially supplement the support function. They may provide some support in small trees, but this effect likely diminishes in mature trees. Harris et al. (2004) note that adventitious roots "typically are not large enough to provide mechanical support for a mature tree." Matheny and Clark (1994) add that "adventitious roots may be adequate to keep the tree alive but often are not sufficiently strong to keep a large tree anchored."

Where adventitious roots have developed on the lower stem of mature trees, an examination of the root crown and structural roots is warranted. Matheny and Clark (1994) state that "the excavation should continue below the adventitious roots so that the integrity of the original support roots can be determined." Both the health and soundness of structural roots should be assessed. Determine whether the bark and vascular tissues are alive, and check for wood decay. In cases where structural roots have been adversely impacted, a careful assessment of tree hazard potential is warranted. For information on how to conduct a tree hazard assessment, see Matheny and Clark (1994).

For young trees, the presence of adventitious roots has implications different from those of mature trees. Nursery trees can develop adventitious roots on the lower stem if they have been planted too deeply or have had soil deposited above the root collar. Either situation may occur while the tree is in the nursery or after it has been planted in the landscape. Although these adventitious roots may have functional roles in water and mineral absorption and possibly in support, they can become stem-girdling roots (Johnson and Hauer 2002) (Figure 10). Young trees with stem-girdling roots can decline, become structurally weak, or both (Watson et al. 1990). Nursery stock should be inspected for adventitious root formation and, if found, corrective actions should be taken. At planting, the root collar should be positioned at or slightly above grade, not below grade (Watson and Himelick 1997). For information on the management of stem-girdling roots, see Johnson and Hauer (2002).

Whether in young trees or mature trees, adventitious root formation on the lower stem can be minimized or prevented. For mature trees, avoid the placement of fill soil in contact with the trunk, minimize the potential of flooding injury, maintain conditions in the root zone that are unfavorable for root disease, and avoid mechanical injury to roots. For young trees, select nursery stock with healthy and well-distributed root systems, and follow recommended planting practices.

Figure 10. Adventitious roots that developed on this Monterey pine (*Pinus radiata*) became circling and girdling roots.

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