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ROOT SYSTEMS OF TREES-FACTS AND FALLACIES

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Abstract. Roots perform vital functions for the health and well being of trees. Despite many years of research, these critical organs continue to be poorly understood. A gamut of factors; environmental, cultural, and others, dictate the health of roots and in turn the health of the entire tree. A great deal of literature exists which incorrectly describes root growth. Roots are primarily found in the upper few inches of soil and absorbing roots essential for water and mineral uptake are beyond the dripline.

Résumé. Les racines remplissent des fonctions vitales pour la santé et le bien-être des arbres. En dépit de plusieurs années de recherche, cet organe critique continue d'être mal compris. Un ensemble de facteurs environnementaux, culturels et autres, orientent la santé des racines et en retour, la santé de l'arbre en entier. Beaucoup d'écrits existent qui décrivent incorrectement la croissance des racines. Les racines se retrouvent principalement dans les premiers pouces de sol et les racinelles, essentielles pour l'absorption de l'eau et des éléments minéraux, s'étendent au-delà de la projection de la cime au sol.

Thomas Perry in his 1982 review "The Ecology of Tree Roots and the Practical Significance Thereof" (19) wrote an excellent summary of root growth and factors influencing their development. It is the authors' desire to summarize research subsequent to his paper, and discuss what current studies have disclosed in order to facilitate a better understanding of root growth processes.

A root is an underground portion of a plant, that absorbs and conducts moisture and minerals, and provides support (20). Researchers have been successful at classifying and understanding some functions of roots, but still have a limited understanding of the root zone. Roots comprise less than 50% of a plant by dry weight, but their surface area is invariably much higher, when

developing in a relatively unrestricted environment, than that of shoots (11).

Morphology and Function of Roots

Roots are of two basic types, woody and non-woody. Nonwoody roots are found mostly in the upper layer of soil and incorrectly called "feeder roots". They provide minimal anchorage but store significant amounts of carbohydrates in specialized units called amyloplasts. Their primary function is absorption of water and mineral elements and are best referred to as absorbing roots (19). Tubular extensions of epidermal cells known as root hairs, significantly increase the absorptive surface area of the root. These root hairs have a thin cuticle layer which offers little resistance to water and mineral element uptake into the plant. Some roots are also coated with a slimy material known as mucigel, which promotes a more intimate contact with soil particles. Once inside, essential mineral elements and water can then be translocated throughout the plant as described by the cohesion-tension theory (20). Many roots do not have root hairs as in pines, but possess mycorrhizae. Mycorrhizae are fungi which live symbiotically with roots. The fungi are able to gain organic compounds from the plant and they in turn increase mineral element and water absorption capability of roots. It has been shown that deliberate inoculation of fungi can enhance root growth in some plants (24).

Woody roots are large lateral roots which form at root-stem bases and serve as anchorage and support for the tree. They form the framework and

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are distinct for each species (19). They also serve important roles in water, mineral, and organic compound transport, as well as storing carbohydrates (28). Some trees have striker roots (sinker roots) which extend vertically downward until obstacles or insufficient oxygen prevents further growth (19). Striker roots are much like tap roots in that they function to store water and food energy.

Another type of root is adventitious. It often forms spontaneously at the root-stem base from large basal roots and develops as a result of injury. Mechanisms which trigger or stimulate their formation are not yet fully understood. Flood tolerant species such as *Salix*, *Nyssa*, and *Platanus*, develop adventitious roots when flood stressed, apparently as an oxygen gathering adaptation (15). Still, other roots found on English ivy (*Hedera helix*), poison ivy (*Toxicodendron radicans*) and some types of *Euonymus spp.* are all examples of roots which help these species climb on vertical surfaces.

Challenging Myths with Research

Horizontal root spread. The concept of horizontal root spread achieved by trees in relation to a plant's branch spread or "dripline" has long been misunderstood. Roots of trees were believed to grow to branch tips (dripline) with the majority of fibrous roots concentrated at the dripline. Research, however, has shown ample evidence to the contrary.

Gilman (6) demonstrated with honeylocust (*Gleditsia triacanthos*), poplar (*Populus generosa*), and green ash (*Fraxinus pennsylvanica*) that roots grow well beyond the dripline. His study examined entire root systems which were excavated to determine the portion of the root system present beneath the branch dripline. All three species had greater root length outside the branch dripline than within. Poplar was the extreme, with 77% of root length beyond branches. Ash and honeylocust trees had 52% and 59% of total root length extending past the dripline, respectively. To further demonstrate that roots do grow out beyond the dripline, Gilman states that 35% of the poplar's roots were located greater than two times the distance from the trunk to the branch dripline. He also reported that increasing root spread

among species corresponded with an increase in root spread: crown spread ratio. Watson and Sydnor, (30), found Colorado Blue Spruce (*Picea pungens* 'Glaucua') to have 60% of their absorbing roots beyond the dripline. Maximum root spread ranged from 1.68 times the dripline distance (radius) for green ash to 3.77 times for southern magnolia (*Magnolia grandiflora*) (7). Current research shows that roots of honeylocust and poplar extend 2.9 times beyond the dripline radius from the trunk. Whitcomb (32) examined sugar maple (*Acer saccharum*) and found root growth 30' beyond the branch tips. Such information is not, however, unique. Rogers and Vyvyar (21) reported in 1934 that root systems of apple (*Malus sp.*) extended far beyond the branches. In spite of this it has only been in recent times that the extent of lateral root spread in trees has been emphasized. The underestimation of root extension is not simply an academic problem, but has led to severe injuries to woody plants from misapplied herbicides, especially soil sterilants, as well as fertilizers, soil-injected insecticides, and other treatments. Indeed, even product labels allude to the dripline as is the case in Triox (18), Ross Root Feeders (22) and others commonly used. Applicators often assume that chemicals can be safely applied when outside the dripline (3)(4). This lack of understanding of root growth can result in great losses to nearby plantings. Often, a greater percentage of roots, if determined by weight, are found within the "dripline". However, absorbing roots which are essential for water and mineral element uptake, are predominantly found beyond the periphery of a tree's canopy.

Root depth. In addition to lateral root spread, being underestimated, root depth in trees has also been grossly exaggerated. Deep root systems are the exception rather than the norm in trees. Some pines found in Texas may grow roots 10' or more downwards (26), and mesquite (*Prosopis glandulosa*) has been known to send roots penetrating to depths of 80' in the soil, (14) but this is uncommon for most species. Root distribution of shade trees is often very shallow. Little root growth, if any, occurs below 48" although this soil depth often is not explored by trees (29)(11). Knowing that most absorbing roots are indeed in the top few inches of soil, reveals why they are so easily

uplifted during slight soil disturbances. The concept of "shallow rooted" or "deep rooted" trees is not factual (19).

Soil Oxygen Deficiencies

Flooding. Root development in the top few inches of soil, especially in disturbed clay sites (urban soils), occurs because deeper soils are often waterlogged. This waterlogged soil is oxygen deficient which results in an atmosphere where respiration cannot occur. Water normally holds less than 1/10,000 as much oxygen as air (19). Soils that are not well aerated contain roots which are thicker, shorter, distorted and with fewer root hairs. Also as the oxygen supply decreases, the ability of a root to grow and penetrate the soil decreases. Prolonged soil flooding may lead to anaerobic conditions resulting in an accumulation of substances potentially lethal to the roots (27)(28). Some species of *Prunus*, for example, have roots containing cyanophoric glucosides, which quickly convert to cyanide in waterlogged soils (15).

Barriers. Construction such as asphalt paving can reduce soil oxygen levels from 18% to as low as 3% in some instances. Besides pavement, plastic barriers, which have been widely used under various mulch materials, have created problems by reducing gaseous exchange (17). One improvement is the advent of numerous weed barriers which "breathe".

Construction and compaction. Reduced soil aeration is one of the most common types of construction damage to trees (23). Compaction from heavy machinery or other sources, and even the most minute grade changes, can result in severe oxygen starvation to trees' roots. A new planting can establish after a grade change, but one cannot expect an established tree to tolerate this type of change in soil level. Some trees will adapt by developing shallower roots from adventitious growth, where oxygen is more available. However, many cannot adapt quickly enough before they succumb to suffocation.

Secondary effects of oxygen starvation. Besides directly killing trees from lack of soil oxygen, sublethal stresses can lead to numerous secondary problems. Any weakened tree will have its defense system compromised. High

moisture can lead to subsequent root decay caused by *Phytophthora* and other disease causing fungi (15). Disease and insect related problems, resulting from oxygen induced stresses, can decrease leaf production which in turn lowers carbohydrate production needed for proper root growth. These stresses create a cyclical effect on shoot and root growth leading to decline and possibly death of the plant. In addition, water and mineral relationships are affected by reduced permeability of roots to water. Hormonal products may also be altered in roots growing under low oxygen conditions. Lastly, excessive moisture resulting in low oxygen may severely hamper effective mycorrhizal colonization.

Root adaptations. A practical lesson often observed from trees being planted in oxygen deprived soils is the location of where new roots grow. Roots will respond to low oxygen supply by growing closer to the soil surface as indicated in studies on honeylocust (8). This work indicated that shallow planting of trees enables quicker establishment due to root growth made possible by better oxygen relations in that region. In areas where soils are heavy clay, trees benefit by planting them a few inches above grade.

Temperature. Temperature can also significantly affect root growth. Soil temperatures below freezing cause root growth to nearly cease. Temperatures above 35°C may be lethal (11). Effects from temperature are most profound when plants are grown in containers (16). Besides container grown stock, urban plantings, especially those in raised planters, are also not exempt from heat or cold injury. Graves and Dana (10) speak of the excessive root zone temperatures particularly from nearby asphalt and concrete, and the consequences of tree and shrub decline in these plantings. Optimum temperature for root growth is 16-27°C.

Competition for resources. Root systems will also be stressed when planted into a highly competitive area. Sod competition exacerbates other stresses such as chemical elemental deficiencies and drought, as well as indirect damage to trees' roots occurring from pesticides intended for care of the lawn (28). Watson (31) found that grass plants growing in the root zone of trees inhibited

fine root development of those trees. This can then lead to reduced water and mineral element absorption. Other research (33) has suggested that trees will not suffer if first established before planting surrounding turfgrass. Additionally, mulch is beneficial in some cases to enhance root growth. Mulching in conjunction with grass removal may be best for fine root development, although too much mulch has been shown to decrease oxygen supply to roots (9). In any case, besides removing grass immediately around the tree's trunk to reduce competition for water and mineral elements, lawn mower injury from mowing grass next to trees and any allelopathic effects from grass such as *Festuca sp.* are minimized (12).

Pruning. The merits of pruning newly planted trees is still up for debate. Various researchers have looked at root and/or shoot pruning on bare root stock, stock in the field, and other growing situations. *Malus* 'Melrose' when subjected to root pruning had reduced shoot length and leaf size when compared against control trees (25). Gilliam et al. (5) found that shoot pruning of *Ilex crenata* 'Compacta' resulted in reduced root growth, whereas tip pruning resulted in increased root growth. However, 50% shoot removal proved not to be beneficial. When Colorado blue spruce (*Picea pungens* 'Glauca') root systems were pruned five years prior to transplanting, root number and surface area were enhanced (30). However, shoot and root pruning studies conducted on bare-root Sargent crabapple (*Malus* 'Sargentii') and Newport Plum (*Prunus cerasifera* 'Newportii') had only nominal effects on root and shoot growth of either species (1)(2).

Staking. Staking is also somewhat controversial for newly planted trees. However, research has definitively shown that prolonged or too rigid of staking does not allow for sway of the tree resulting in inferior root growth as well as other undesirable effects to the tree (13).

Countless other factors can be cited as playing direct or indirect contributory roles in healthy root growth or the lack thereof, as apparent by the great number of root monographs written. Further research of root systems will continue, and many more myths will be dispelled about trees' roots.

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Abstracts

APPLETON, B.L. 1988. Fertilizing landscape trees and shrubs: the revised version. Arbor Age 8(10):12-14.

As research has given us a clearer understanding of how plants grow, many recommendations have needed to be revised accordingly. The objective for mature trees and shrubs should be to maintain the existing growth without overstimulating new growth. They should be fed every two to four years. With young or newly transplanted trees and shrubs, the objective should be to accelerate growth—especially root growth—in order to establish the plants in the landscape successfully. Rather than rely on soil tests or visual inspections, many people prefer to simply set up a regular fertilization schedule. Many areas of the United States have soils with adequate levels of phosphorus and potassium, so nitrogen is the nutrient that is most likely to be needed. In addition, nitrogen readily leaches (washes) through the soil, whereas phosphorus and potassium do not. This is another reason why those two nutrients require less-frequent application. The most common form of direct fertilizer application is also the one that recent research has shown to be generally the most effective, especially relative to cost. It involves simply broadcasting the desired fertilizer (in dry granular form) on the soil or turf surface under the trees and shrubs.

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Anyone who has grown *Euonymus* is well aware of euonymus scale, which infests and often kills many varieties of this versatile ornamental. It was accidentally introduced into North America many years ago from Asia. No natural enemies were ever introduced to control it. Several natural American enemies do feed on the exotic invader, but they are ineffective. Two tiny predatory beetles which thrive on euonymus scale have been imported from Korea by the USDA. These beetles are part of an integrated pest management control tactic that is becoming an effective weapon in our battles against insect pests.