Tree Root Growth and Development. I. Form, Spread, Depth and Periodicity[1]

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Abstract

Root form is governed by seedling genetics and soil characteristics including texture, compaction, depth to the water table, fertility, moisture content and other factors. Trees develop lateral roots growing parallel to the surface of the soil. These are generally located in the top 30 cm (12 in) of soil. Fine roots emerge from lateral roots and grow into the soil close to the surface. If soil conditions permit, some trees grow tap and other vertically oriented roots capable of penetrating several feet into the soil. Many trees, particularly those planted in urban landscapes, do not generate tap roots. Lateral roots spread to well beyond the edge of the branches. Their growth in governed by competition from other plants, available water, soil temperature, fertility, stage of shoot growth and other factors.

Index words: Forest sites, landscape sites, root types, environmental effects

Significance to the Nursery Industry

It should be clear that root form, spread and depth vary significantly from one site to the next. Root depth is somewhat predictable within a broad range, but operators of landscapes and nurseries could more precisely manage trees and shrubs under their care by digging in the soil to determine the location of roots. This could be performed easily in a number of exemplary sites within the area of operation. This would help employees gain a better understanding of the resource they manage and would go a long way to educate the consumer in the principles of tree care. Roots on open grown trees spread generally to about 3 times the edge of the branches, and perhaps farther for trees in the forest. As suburbs are carved out of native woodlots and the value of trees are recognized, tree care professionals continue to manage an increasing number of large forest-grown trees. A thorough understanding of the root system on these trees will help landscape planners and managers provide a higher level of service to their clients. Trees, shrubs, ground covers, turf, weeds, other plants and the soil in a landscape or nursery comprise an integrated system of leaves, branches and roots. Manage the system, not the plants. Roots are an important and often forgotten part of the system.

Introduction

Root system morphology of trees can influence survival, stability, growth and transplantability (65). The root system which develops on trees seeded-in-place is a function of seedling genetics, soil characteristics such as texture, compaction, fertility, depth to the water table and moisture content, soil insect activity and other factors. Root morphology on planted trees is also influenced by pre-planting nursery production practices, tree age at planting, planting method and post-planting cultural practices. Pre- and post-plant cultural practices outweigh species differences in influencing root system morphology (10).

Knowledge of factors influencing root growth and development will help nursery operators select quality planting stock and implement efficient production practices. Landscapes will be managed more effectively with a thorough understanding of tree and shrub root growth and development.

Early Root Development

Tap root—The first root to emerge from a tree seed is called the primary or tap root (64). A tap root does not continue to develop on every tree. They are most obvious on seedlings and are often found on genera such as *Pinus* and those with large seeds e.g. oaks (*Quercus* spp.) and walnuts (*Juglans* spp.) (47). Soil conditions permitting, a tap root occurs most frequently on trees in a naturally regenerated forest growing where the seed germinated in place (48). Many trees do not develop tap roots. Tap roots sometimes occur on planted trees in nurseries (26, 67) but are probably rare in landscape sites because of compacted soil, low oxygen supply and other factors (24, 45). Occasionally, a tap root persists and grows straight down into the soil to depths of 0.9–2.4 m (3–8 ft) until it meets a water table, impermeable soil layer, compacted soil or other low oxygen environment. It branches at this point and/or is deflected horizontally (46). If present, the tap root is usually largest just beneath the trunk and decreases rapidly in diameter deeper in the soil (60). In shallow, poor or disturbed soils typical of urban areas (45), the tap root branches into several

[1]Received for publication January 2, 1990; in revised form May 16, 1990. Florida Agricultural Experiment Station Journal Series No. R-00408.
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Special thanks to Dr. Gary Watson for critically reviewing this manuscript.

roots and becomes indistinguishable from the rest of the root system (60, 62). Tap roots do not develop on trees growing in soils with poor drainage or with a high water table. These soils are common in many areas of the country. The tap root is thought to function in water adsorption and tree stability (20).

The tap root on trees which have not germinated and grown in place (e.g. propagated, planted or transplanted trees) is almost never intact as a single, straight, descending root and is frequently absent altogether (10). Vertically oriented roots formed on planted trees are smaller in diameter and more easily broken in wind storms than a single tap root sometimes found on naturally regenerated forest trees (60). Often, roots are pruned when trees are moved up to a larger container or transplanted in the field. Root branches develop and the dominance of a single tap root is destroyed (31). After planting in a well-drained soil, several descending roots may emerge from the pruned or intact roots circling the bottom of a container. Typically, these are located beneath the trunk and are smaller in diameter than a single tap root.

Oblique roots—Many species are capable of producing oblique roots which grow down at a steep angle. They originate from the primary root or shallow lateral roots close to the trunk (20) during the first 1–4 years after seed germination, and are smaller in diameter than the tap root, if one is present (17). Oblique roots can penetrate several to many feet into the soil if soil conditions permit (41). They may branch several times and generally bare only a few small-diameter fine roots. Their function is probably to stabilize the tree in the soil (60) and provide for some water uptake. Horizontal lateral roots typically do not emerge from these roots.

Lateral roots—Lateral roots originate either from the primary root or as adventitious roots from the base of the trunk (17, 64). Between 4 to 11 major lateral roots are generated during the first 3 to 7 years after germination and grow horizontally through the soil. These will generally remain as the largest diameter, most dominant lateral roots for at least 30 years (13). The largest 5 lateral roots comprise about 80% of the total root system cross-sectional area (13, 30). Their points of attachment to the trunk are usually at or near the groundline and are associated with a slight swelling of the trunk. These major roots branch within several feet of the trunk to form a network of long untapered rope-like roots about 1.2–5.0 cm (0.5–2.0 in) in diameter (9). They advance parallel to the soil surface at a depth of 2.5–30 cm (1–12 in), depending on species, soil profile, texture, density and moisture content and management practices (35, 46, 58). A large portion of the total root system length and surface area is represented by these and the fine roots emerging from these lateral roots (37). Other, less dominant small-diameter roots emerge from the trunk at points between the major roots (13).

Lateral root growth is largely determined by local growing conditions. If a root tip on one lateral root grows into an area of superior nutrient or water content, growth on this root will be stimulated (16, 18). This lateral root will grow larger than the other major lateral roots. Roots can not sense that there is an area of superior nutrient or water content nearby, instead they grow into it by random chance (62). This process can lead to an unevenly distributed root system with only a few large, well-developed laterals. Providing for a uniform soil environment may help encourage a more uniformly distributed root system (60). It is not known if this will increase transplant survivability or post-transplant growth.

Fine roots—Fine roots originate from all along the basic root framework. They advance outward, down and most frequently up toward the soil surface (46, 58, 62), branching 3 or 4 times to form fans or mats terminating in thousands of fine, short tips. They are not concentrated at the branch dripline (at the edge of the branches) but are distributed throughout the total area covered by the root system (32, 50). Frequently, in a forest setting there is a concentration of fine roots near the trunk (59). Fine roots are generally located within the top 20 cm (8 in) of soil (67) originating from horizontal lateral roots (46, 72). Some fine roots emerge from the deeper roots but their development is often limited. Most absorption of water and minerals takes place through the fine roots, since they represent a large portion of total root surface area (37). Srivastava et al. (61) found that 55% of total root biomass was in roots 2 mm or less in diameter.

Older-Tree Root Development

Deep roots—As trees grow older, deep roots comprise a decreasing portion of the total root system, even if a tap root was dominant in the seedling and sapling stages (41). Deep roots still function in support (20, 60) and water absorption. They are located within the branch dripline, with a concentration directly beneath and close to the trunk. Tap roots are frequently unrecognizable or very small in relation to the rest of the root system.

Lateral roots—Lateral roots are more or less evenly distributed around the trunk in sandy, well-drained soil (17), although there are many exceptions (62). Since lateral roots emerge from the trunk and root system close to the soil surface, an easily recognizable root collar develops as a pronounced selling at the base of the trunk. This is thought to develop in response to lateral trunk movement caused by the wind. Lateral roots help keep the tree erect (15).

The 4 to 11 major lateral roots are oval in cross section close to the trunk because they enlarge in the vertical direction more than in the horizontal direction (72). They taper rapidly away from the trunk and branch into numerous 2.5 cm (1 in) diameter round, long rope-like roots with many side branches. These side branches also grow to be long and untappered and branch several times into a network of fine roots. Lateral roots grow away from the trunk, generally far out beyond the edge of the branches (26, 62, 67). Roots frequently change direction (73), apparently in response to meeting obstacles and roots of adjacent trees (62).

Rogers and Vyvyan (55) divided orchard-grown apple root systems into quarters and reported that as much as 51% of root weight could be found in a single quarter. This one-sided root distribution may account for some tree transplanting-death since a smaller portion of the root system may be harvested than on a tree with roots well distributed around the trunk. It is not possible to predict the distribution of roots around the trunk.

Sinker roots—Soil conditions permitting, sinker roots originate from the lower side of lateral roots (14) and grow straight down for 1–2 m (3–6 ft) (46, 52). Most are located within the branch dripline. They are smaller in diameter than lateral roots, branch infrequently and initiate only a small number of finer roots. They may function in water uptake and help to anchor the plant in the soil (14). In compacted or other soil with a low oxygen content, sinker roots emerge and grow parallel to the soil surface on top of the adverse soil layer (46). In trees not tolerant of flooding, vertical roots are killed in persistently water logged soil making them susceptable to wind throw (20).

Fine roots—Fine root density on large trees is greater than that on sapling-aged trees (22, 41). Root density may be greater near the surface in the older tree than on the sapling if the natural organic layer on the soil surface is left relatively undisturbed (6), and there is no competition from nearby plants (69).

Root Spread

Numerous field excavations and soil coring studies in the forest, orchards and tree nurseries clearly indicate that roots spread beyond the dripline and they are not concentrated at the dripline. Stout's (62) extensive excavations of forest tree root systems in a closed-canopy stand showed that roots of several oak, hickory (*Carya* spp.), maple (*Acer* spp.) and other genera grow to well beyond the dripline. Open-grown trees in forest clearings also have roots extending to outside the branch tips (33). Further study found that the ratio of root spread to branch spread on nursery-grown trees was species dependent (27). Maximum root spread ranged from 1.7 times the dripline for green ash (*Fraxinus pennsylvanica*) to 3.7 for Southern magnolia (*Magnolia grandiflora*). Mean root spread averaged about 3 times the branch spread (27, 67). Orchard-grown pear (*Pyrus* spp.) and apple (*Malus* spp.) roots extend from 2–3 times the branch dripline (53, 55). Roots extending farthest from the trunk are consistently found near the soil surface. Coile (11) found that the horizontal extent of roots is reached at a certain tree age. This indicates that root spread:branch spread ratio may decrease as trees age.

The ratio of root spread to branch spread appears to be related to the shape of the crown. One year after planting, roots of the narrow, columnar-shaped 'Torulosa' juniper (*Juniperus chinensis*) spread to 3.2 times the branch spread; whereas, root tips of the spreading 'Hetzii' juniper (*J. chinensis*) were only 1.5 times as far from the trunk as were the branch tips (28). Frequently, tree roots extend to encompass a roughly circular area 4–7 times the area beneath the branches. The diameter of this area may be 1, 2 or more times the height of the tree (9) or shrub (28).

Less than half of the root system is located beneath the branches. Watson and Sydnor (68) found that about 60% of Colorado blue spruce (*Picea pungens*) root surface area and weight on 8-year-old trees was outside of the dripline. Gilman (26) excavated 5-year-old honey locust (*Gleditsia triacanthos*), green ash and poplar (*Populus* × *generosa*) and found 59%, 54% and 77% of total root length outside of the dripline, respectively.

Root spread can be predicted from trunk diameter or branch crown radius for Southern magnolia, red maple (*A. rubrum*), poplar, honey locust and green ash (27). Magnolia root systems appeared to be less branched than other root systems. Although roots were farther from the trunk than in other species, root density appeared to be less. In contrast, green ash had roots relatively close to the trunk and there was little soil uncolonized between adjacent roots. Live oak (*Q. virginiana*), red maple, poplar and honey locust had root system morphologies between these two extremes.

Root Depth

Ninety-nine percent of the tree root system is located in the top 0.9 m (3 ft) of soil (11, 21), although there are a few examples of much deeper penetration, particularly in the Southwestern United States and other areas where soils are young, loose and deep (21). Maximum rooting depth is usually established during the seedling or early sapling stage on seeded-in-place trees (39) and perhaps within the first several years after planting on transplanted trees (10). Most roots of nursery-grown trees are in the top 30 cm (12 in) of soil, even on well-drained sandy soils (24, 30, 67). The deepest roots are frequently restricted to the area directly beneath or close to the trunk (9). The root system is generally shallower at greater distances from the trunk (27, 67).

Fine roots are typically found growing in the leaf litter in the forest (38), among turf roots (46) and in and directly beneath organic mulch in the landscape (66). Competition with turf and other vegetation reduces root density near the soil surface (66, 70). Soil cultivation and other soil disturbances, prunes roots near the soil surface, restricts lateral root spread (2), reduces tree stability (57) and probably slows overall plant growth. Soil cultivation may encourage development of a deeper root system in well-drained soils.

A deep root system is desirable if transplanting to a well-drained site, since the deep roots would have sufficient oxygen to live and carry out normal functions at the new site. The deep root system may help the tree survive initial transplanting period since deeper soil layers dry out slower than the surface layers. However, many landscape sites are poorly-drained for at least a portion of the year and many roots on a tree with a deep root system will suffocate from lack of oxygen (34). Trees to be planted in poorly-drained landscape sites should be grown in soils and under cultural conditions encouraging shallow root systems. Trees grown in soils and under production practices encouraging deeper root systems should only be planted in loose, well-drained soils where no standing water is expected for any portion of the year. This tailored planting practice may increase transplant survival and growth.

Effects of water table—Root development in soils with a high water table is restricted to the area above the water table due to lack of sufficient soil oxygen at greater depths (34). White and Pritchett (71) showed that fine roots of slash pine (*Pinus elliotti*) trees were concentrated higher in the profile as depth to the water table decreased. If the water table is 30 cm (12 in) below the soil surface, roots of all but the most wet-site tolerant species, e.g. bald cypress (*Taxodium distichum*) will not penetrate below this depth. On sites where water stands on the surface for several days after a moderate rainfall, root development will also be restricted to the surface layers. A "pancake" type root system will be evident when the tree is dug from the field. Plants produced in these soils may transplant best into landscape soils with poor drainage.

Trees with a flat "pancake" type root system can be difficult to dig since there may be no roots in the bottom of a traditionally-shaped root ball. Consideration may be given to digging a wider and shallower-than-normal root ball to capture more of the root system (63). Transportation of odd-shaped root balls may require unusual techniques.

Effects of soil texture—Most studies indicate that root branching is more prevalent on trees growing in sandy soils than in clay and other fine-textured soils (12, 55), although there is at least one study reporting more branching in the finer-textured soil (44). The root system in sandy soil has shallow major laterals with vertically descending sinker roots close to the trunk. In some clay soils, major lateral roots slope down and grow into the subsoil until they reach a zone where oxygen is limiting. The main lateral root system is deeper in heavier soils (55). In a fine clay soil with a low oxygen content or poor drainage, root systems can resemble those produced in a soil with a high water table. If cracks penetrate deep into the soil, oxygen can reach the deeper profiles and some roots on species capable of producing deep roots may grow down through the cracks.

Effects of soil compaction—Compacted soil is common in many new planting sites (3). In compacted soil, root growth is restricted by low soil oxygen supply (56) and mechanical impedance (36). Container studies show that woody plants respond to compaction by producing a shallow root system (44, 74). Roots in compacted field soil are redirected up toward the soil surface from deeper layers (24). Gilman et al. (23) showed that whereas a number of trees survived periods of reduced soil oxygen, only those capable of producing a shallow root system grew well. No tap root develops and there is a greater number of shallow adventitious roots and increased branching of deeper roots in compacted soils (34). These adventitious roots are longer, straighter and larger in diameter than deeper roots, indicating vigorous growth. Only roots growing from the top portion of root balls or those reaching the soil surface by virtue of being redirected from the deeper soil layers are likely to develop as a significant part of the permanent structural root system (24, 28). Roots often spiral around in the loosened backfill soil in the planting hole until they reach the soil surface and can leave the planting hole or grow into cracks in the compacted soil.

Species differences—Natural rooting depth varies among tree species (8, 17, 29) but is largely influenced by cultural and environmental conditions (5). Seeded-in-place *Pinus radiata* growing in a well-drained soil develop descending roots as well as a shallow root system (60). Red maple (30) and probably other trees, produce mostly shallow roots with few deep roots, even in well-drained, sandy soil. However, if pines and maples were grown on the same high water table or compacted soil, the root system morphologies in light would be almost indistinguishable from each other. Descending roots would be aborted, twisted or deflected by the water table or low soil-oxygen content, or they may not be apparent at all (46). This is common in some tree nurseries and many urban landscape sites.

Seasonal Periodicity of Root Growth

The period of maximum growth of roots on trees is governed by species, stage of shoot development, soil moisture content, soil nutrient content, soil temperature, root pruning, top pruning, tree age and other factors. Most authors agree that in the spring, root growth begins before shoot growth (5, 39). In temperate climates, many species such as the stone fruits, apple, blueberry (*Vaccinium corymbosum*), raspberry (*Rubus idaeus*) and some oaks have a maximum period of root growth in April and May, followed by a rest period during shoot growth and leaf expansion and then a second root growth period in the fall, beginning after shoot growth ends (1, 4, 54). Some research does not support this two-peak pattern. For example, root growth begins just as leaf expansion is complete on pear, plum (*Prunus* spp.) and birch (*Betula* spp.) and ends just before leaf-fall (39, 43). Shoot growth alternates with root growth in vigorous sapling-sized trees capable of multiple flushes (49).

Annual patterns of root growth appear to vary among species. Mugho pine (*Pinus mugho*) roots grew from April through November, with peak activity in the summer (40). Scots pine (*Pinus sylvestris*) had highest activity from March through August (52), earlier than the July through September period for Sitka spruce (*Pinus sitchensis*) (19). However, because there were wide deviations of environmental and cultural conditions among studies, some variation in reported root growth activity may not reflect true species differences. No study showed a peak in root activity during the winter, attributable largely to low soil temperature. Peak activity was usually found in the spring or summer. Root growth seems to be uniformly retarded during active shoot growth, although Ford and Deans (19) found no indication that root activity ceases during the period of shoot elongation.

Of all the environmental conditions, soil moisture and temperature have the largest influence on root growth. Some estimated that these two factors account for more than 80% of the variability in root growth activity (59). When soil temperature is not limiting, a soil water deficit readily reduces rate of root growth regardless of the stage of shoot activity. However, roots are capable of quickly resuming growth several days after irrigating dry soil. The most intense root growth occurs when soil temperatures are between 19–28 C (68–84 F) depending on species (7, 42, 51). Intense root growth during the summer is probably a result of adequate soil moisture and suitable soil temperatures.

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Tree Root Growth and Development. II. Response to Culture, Management and Planting[1]

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Abstract

Cultural factors influencing root growth in the landscape or nursery include soil management, irrigation, fertilization, shoot pruning and root pruning. These affect root density, depth of penetration, spread, vertical distribution in the soil profile and mineral uptake. Root morphology varies widely among genera, species and individuals within a species. The distribution, length and weight of roots within the root ball of transplanted field-grown trees can be modified with cultural management practices. Growth of transplanted trees may be affected by these modifications. Root spread diameter increases at a rate of 0.9-2.4 m (36–96 in)/year following planting. From 1 to 10 years is required to replace the pre-transplant root system for trees transplanted from field nurseries. Root system in urban environments can be modified by cultural techniques which direct their growth.

Index words: Turf competition, soil management, irrigation, fertilization, pruning, transplanting, root ball, urban environment, landscape management, nursery management

Significance to the Nursery Industry

Roots on trees and shrubs planted in nurseries and landscapes are influenced by culture and management. Turf competition reduces root density near the surface of the soil. Well-managed drip irrigation causes a localized increase in root growth. Nutrient applications can increase or decrease root density, depending on application techniques and the amount applied. Root ball structure and density can be manipulated by production techniques such as container type and root pruning. Root extension after planting is somewhat predictable within a wide range of values and may vary with climate, production method, competition from other plants and plant species, size and health. Tree and shrub roots commonly extend from 2–3 times the distance from the trunk to the edge of the branches. This relationship is established within 3 years following planting 5–7.6 cm (2–3 in) caliper trees. Incorporation of these principles into management plans will help promote efficient use of resources.

Introduction

Considerable time has been devoted to the study of tree root growth and development in forest settings. Studies enumerate the effects of cultural and management conditions

[1]Received for publication January 2, 1990; in revised form May 16, 1990. Florida Agricultural Experiment Station Journal Series No. R-00406.

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Special thanks to Dr. Gary Watson for critically reviewing this manuscript.