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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

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on fine-root growth, lateral root spread and depth, root morphology close to the trunk and tree stability. Seedling establishment techniques have also received considerable attention in the literature. There is a renewed interest in root growth research, focusing on development and morphology in landscapes and tree nurseries. These efforts center around production and transplanting techniques, root spread, root regeneration and growth in urban sites. The purpose of this review is to collate information from the forestry and horticulture literature with respect to the cultural, management and planting effects on root growth in nurseries and landscapes.

Cultural Factors Affecting Root Growth

Grass and weed management—Nursery soil is cultivated, grassed and/or treated with herbicides to control weed growth. Tree root density is greatest under plots receiving herbicide for weed control and less for grassed or cultivated plots (3, 56). Many landscapes receive applications of mulch to discourage weed competition, buffer soil temperatures and for other reasons (95). This practice also increases tree growth after planting (37, 63, 78) and encourages root growth below and in the mulch (55, 113, 121). The effects of these soil management practices are most prevalent on roots close to the surface of the soil.

Grass is most competitive with tree roots if mowing is conducted infrequently. Turf roots are deeper and root density greater on unmowed or infrequently mowed turf than on regularly-mowed turf (8, 11, 14). Competition is most keen in the top soil layers (117) since roots on both turf and tree proliferate in this well-aerated, nutrient rich zone (27, 40, 99). Reduced surface-root density on trees in cultivated or grassed soil may be compensated for by increased root growth deeper in the soil, provided the site is not poorly drained or compacted. Although this has not been studied directly, Gurung (56) found that reduction of apple (*Malus* spp.) root growth at the shallow soil depths from application of a herbicide, was compensated for by enhanced growth in the deeper soil layers. Cultivation on wet or compacted sites is damaging to tree roots and would not be recommended for weed control since trees could not regenerate deeper roots to replace the surface roots damaged by cultivation.

Trees have a wider spreading root system under a grass sod than under cultivation due to the root pruning effect of cultivation (18, 83). Consequently, root balls dug from grassed plots may contain less roots than those dug from fields which are cultivated or treated with herbicides to control weeds.

Trees in field nurseries often are grown in weed-free strips of bare soil separated by grassed alleyways (4). Root growth and density is greater under the bare-ground herbicide strip than in the grassed alley. Mineral uptake by tree roots in the grassed area is small compared with uptake from the herbicide strip, even for established, 12-year-old trees (5).

Irrigation—Effects of irrigation on root growth of trees are variable (3). Most research has been conducted with apple trees. Irrigation increased root density only in the top 15 cm (6 in) but reduced density at the 15–30 cm (6–12 in) soil depth (53). In contrast, Doichev (26) found no effect of irrigation on apple root distribution . Variation in response among studies probably resulted from fluctuations in other uncontrollable factors which influence root growth such as soil type and climate conditions.

Method of irrigation influences root distribution. Compared to an unirrigated control, a more vertically-uniform root distribution resulted from low-volume irrigation with 2 heads, each located 45 cm (18 in) from the trunk. Flood irrigation limited root growth to the surface layers (65). Furrow and overhead irrigation produced equally dense root systems in apple. With both methods, most roots were in the top 0.6 m (2 ft) of soil, equally distributed to 1.8 m (6 ft) from the trunk. The main horizontal roots were deeper with furrow irrigation, perhaps due to deeper water penetration.

In arid climates, low-volume drip irrigation increases root density within a 30–40 cm (12–16 in) radius of the drip head on peach (*Prunus* spp.) (106) and apple (52). There was no effect on the portions of the root system not wet by the emitter. Drip irrigation encouraged apple root growth only within an area 0.6 m (2 ft) from the drippers (75). There were few roots outside of this area. Root distribution on citrus under trickle irrigation was no different from that under sprinkler irrigation (125). It is important to provide for adequate aeration in soil wet by a drip system by monitoring soil moisture beneath the dripper. If the soil stays too wet, root density can be locally reduced or forced to grow only close to the soil surface (122).

In temperate climates, trickle irrigation placed 15 cm (6 in) from the base of the trunk had no effect on root system depth in sugar maple (*Acer sacharinum*), honeylocust (*Gleditsia triacanthos*) and pin oak (*Quercus palustris*) (19). Compared to an unirrigated control, irrigation during the 3-year study increased fine root weight within the root ball in pin oak and sugar maple, not in locust. Live oak (*Q. virginiana*), red maple (*A. rubrum*) and Southern magnolia (*Magnolia grandiflora*) receiving low-volume drip irrigation from one drip emitter at the base of the trunk had roots extending to well beyond the branch dripline. There appeared to be no concentration of roots beneath the drip emitter. This was similar to root distribution on other species receiving occasional overhead irrigation (43). There is sufficient soil moisture for root growth well beyond the drip emitter in temperate climates (90).

Provided soil compaction, high water table or other factors are not limiting penetration of roots, depth of wetting exerts a powerful influence on depth of rooting (23). Roots penetrate deeper into soil as the wetting depth increases. Deep roots grow at the expense of roots in the middle soil profiles; there is no reduction in root density near the surface of the soil as wetting depth increases. However, there is a larger percentage of the root system in the shallow depths in soils kept continually moist than in those with periodic drying cycles (27).

Fertilization and nutrient levels—Localized nitrogen applications increase root density and lateral root branching only in the immediate area of application (33, 57). If half of the root system is fertilized, root growth will be enhanced only in the fertilized part (22, 100). The addition of fertilizer close to the trunk increases fine-root density there, but at the expense of growth on other portions of the root system (116). The increase in density is due to closer spacing between lateral roots at higher nutrient concentrations (82). Root density was reduced in the area around the drip emitter when a solution of 400 ppm nitrogen (from ammonium nitrate) was applied through the drip irrigation system (30). This probably resulted from the reduction in soil pH from 6.2 to 3.7 in the zone wetted by emitters that had been in place for 2 years. In addition, plants may not utilize more than about 80 ppm nitrogen in the soil solution so excess application is wasteful (87).

Over fertilization with nitrogen can retard development of fine roots in citrus (82) and perhaps in other tree species. As applied nitrogen increased from 50 to 300 ppm, shoot growth was encouraged at the expense of root growth (126). This may lead to greater water stress after transplanting as a reduced root system must support a large top. Phosphorus at levels greater than 85 ppm had no effect on root growth or shoot:root ratio.

Shoot Pruning—Top pruning stimulates shoot growth and reduces root growth (41, 61, 93). Light to moderate pruning during the growing season slows root growth for two or three months, as the plant replaces the removed shoot tissue (36). Top pruning young trees at transplanting reduced post-planting shoot growth (74, 120).

Root Pruning—Root pruning of trees in fruit, forest and landscape tree nurseries is an old and varied practice (59). It has been used as a horticultural tool to produce a sturdier tree, force development of a more compact, fibrous root system, retard top growth and increase transplant survival and post-transplant growth (84). The timing, frequency, severity and location of root pruning are governed more by practical experience and tradition than by scientific studies. Only recently have the effects of root pruning on pre- and post-transplant tree growth been studied.

A recognized plant response to root pruning is reduction of shoot growth. This has been found in apple (*Malus domestica*) (81), orange (*Citrus sinensis*) (1) and white spruce (*Picea glauca*) (84). Spring root pruning reduced shoot growth of 3-year-old apple 25% and of 4-year-old trees 40%. Early season root pruning reduced trunk expansion and shoot growth more than later season pruning (28, 98). The greatest reduction in white spruce height was caused by root pruning in mid-September, at the end of the growing season (84). A single root pruning of 5-year-old blue spruce (*Picea pungens*) reduced top growth so that 8-year-old unpruned plants were the same size as 10-year-old pruned plants (115). Root pruning Southern magnolia reduced leaf number, tree height, trunk caliper and total-tree leaf area and weight compared to unpruned controls (47). Reduced top growth may result from induced water stress, limited mineral absorption or reduced hormone synthesis (92).

According to Kramer and Kozlowski (72), each species has a characteristic shoot:root ratio. When the ratio is disturbed, plants respond by redirecting assimilates to replace the removed parts. Root pruning, while reducing shoot growth, stimulates root growth as the plant attempts to restore the pre-pruning shoot:root ratio (80, 94). Roots regenerated in response to root pruning originate primarily at or just behind the cut (15, 123). However, a portion of regenerated roots can originate from at least 10 cm behind the cut, depending on species (49). This likely accounts for the increase in fibrous roots within the root ball in response to root pruning reported for a number of species (47, 48, 115). Sycamore (*Platanus occidentalis*) regenerated an average of 32 new roots whereas live oak and Chinese elm (*Ulmus parvifolia* 'Drake') had less than 10. Crab apple regenerated about 20 and linden (*Tilia cordata*) 9 roots following root pruning (112). Within 2-4 years following planting, one of these dominates and outgrows the others (115).

Lower shoot:root ratios were induced by root pruning (6, 107), and were associated with improved post-transplant tree seedling performance (9). Root-pruned 3.3 cm (1.25 in) caliper Southern magnolia trees grew at a faster rate following transplanting than unpruned trees (47). However, others report no benefit to survival and post-transplant growth from pre-transplant root pruning seedling-sized forest species (29, 84). In general, there was no difference in the shoot:root ratios between single and double pruning treatments (47, 64). Bacon and Bachelard (6) and Benson and Shepherd (9) showed that shoot:root ratio and shoot growth were both reduced as the number of root prunings increased during a growing season. In one study, increasing the number of root prunings enhanced post-transplant growth (6), while in another, growth was reduced by multiple pre-transplant root prunings up to 5 years after transplanting (9). There does not appear to be a clear advantage to multiple root prunings.

Root Morphology and Development within the Root Ball

Container grown—Roots often circle along the outside of the root ball which is grown in a smooth-sided container. Container design can have a dramatic impact on root form within the container root ball (120). Root branching can be increased and circling reduced by placing obstructions along the inside of the container (118) or by introducing numerous holes in the side of the container. Plants grown in bottomless containers also had a highly branched root system (25). Increased root branching and number may help in plant establishment.

Field-grown—Root development within the root ball of a field-grown tree can best be described as variable. There is wide variation among species (34, 42, 104) and among individuals within a species (48). There appears to be more variation among root balls of oak trees (48, 105) than among individuals of other species such as crape myrtle (*Lagerstroemia indica*), bald cypress (*Taxodium distichum*) (51) and Southern magnolia (47).

A few to many 1-5 cm (0.4-2 in) diameter lateral roots originate from the primary root stock. Fine roots commonly associated with water and nutrient absorption (69) emerge from these larger roots and are located within the top 20 cm (8 in) of soil. They represent less than 50% of total root weight but comprise a large portion of total root length and surface area (102). Although untested, length and surface area may be better indicators of transplantability than root weight.

Root-pruning live oak 5 cm (2 in) inside the root ball 1 year prior to harvest and then again at the edge of the root ball 6 months before digging increased dry weight of fine roots inside the root ball 6-fold compared to unpruned plants (48). Root pruning Colorado blue spruce (*Picea pungens*) 20 cm (8 in) inside the edge of the harvested root ball 5 years before digging resulted in a 4-fold increase in root surface area within the root ball (115). Apparently, root density within the root ball can be increased by harvesting the ball beyond the point of root pruning.

Fabric field-grown—There are little data describing root structure inside of fabric field-grow containers, although some suggest from observation that there are more roots and the roots are smaller than those inside a traditional field-grown root ball (119). The response of trees to the fabric container appears to be species specific. There are reports of increased root weight inside the harvested fabric root ball compared to a field-grown root ball (38, 68). Some species' root balls appear to be unaffected by the fabric (68). There is one report of reduced root weight in the fabric container root ball (17). There appears to be an increase in root density within the fabric container root ball (38).

There is little evidence linking increased root dry weight within the root ball of fabric containers with reduced stress following transplanting or enhanced post-transplant shoot growth. In the only study conducted to test transplantability, increased root dry weight in fabric-grown root balls compared to field-grown trees corresponded to an increase in regenerated roots 60 days later only in one of five species tested (39). Root regeneration of 1 species was lower on trees grown in fabric bags than those grown in field soil.

Root Growth after Planting

Root development following transplanting varies with species, environmental conditions, physiological status, time of year, cultural practices and type of root system (10, 34, 71, 104). Five years after planting, root and shoot growth on pecan (*Carya illinoensis*) trees planted from containers was similar to growth on transplanted field-grown trees (73). Soil amendments in the backfill were ineffective for enhancing root weight, plant survival or shoot growth in soils ranging from silt loam (97) to fine sand (67). Other establishment techniques tested include variations of root ball slicing, teasing roots away from the periphery of the root ball and striking the root ball a number of times against a concrete surface to loosen roots from the medium (12, 108). None of these techniques improve woody plant root growth after transplanting to the nursery or landscape. However, mulching the area around the trunk increases root density in that area following planting (55).

Root system development on naturally regenerated trees differs from that on planted trees. Trees seeded-in-place tend to form tap roots where soil conditions permit; whereas, planted trees form few tap roots. Those formed on planted trees are smaller in diameter and more easily broken in wind storms than the single, thick tap root sometimes found on naturally regenerated trees (101).

Roots proliferate in corridors of loose soil caused by mechanical disturbance during land clearing and planting, and this can lead to increased windthrow. Alignment may result more from disproportionally enhanced growth rates in the less compacted soil than from root deflection (21). Diameter development of split root systems of Sitka spruce (*Picea sitchensis*) was regulated by the nutrient levels bathing a particular root (22). This suggests that the asymmetry frequently associated with tree root systems (103) results from cultural and environmental influences, not genetically controlled mechanisms. Despite these influences, root growth of Sitka spruce was found to be inherently regular and the species may possess mechanisms which ensure that the structural root system is more evenly spaced around the trunk than would result if growth was at random (62).

Container-grown plants—Water stress is considered the most important cause of death and poor growth of transplanted, container-grown plants (19). Until the root system extends significantly into the surrounding soil, the transplant depends on the 1- or 2-day water supply retained in the container media (24), and therefore must be irrigated frequently, as it was in the nursery, to avoid water stress.

The water supply in the container medium after planting is reduced by transpiration and by water movement from the coarse-textured medium into the often finer-textured landscape soil. Container media loose up to 85% of available water to the surrounding soil within a few hours after planting (85). If this water is not replaced, water stress causes root damage and death leading to top growth reduction and die back. Since water will not move from the soil into the container medium, only water falling directly on the root ball surface enters the root ball. Water applied to the surrounding soil is not available to the plant until roots grow into the soil. Therefore, broadcast irrigation early in the establishment period can waste water.

Although root spread diameter increases about 3 cm (1.2 in)/week in the first year after planting #3-sized container-grown *Juniperus chinensis* cultivars (44), about 50% of total root length remains in the container medium one year after planting (45). Mean root spread diameter was 1.5 m (5 ft) and maximum spread 2.2 km (7.2 ft) one year after planting. Juniper root spread diameter averaged 3.6 m (12 ft) and maximum spread was 4.8 m (16 ft), 3 years after planting. Southern magnolia, live oak and red maple planted from #1 sized containers had similar root spread diameters (4.3 m (14 ft) 3 years after planting (43).

Many trees produced for the landscape trade are grown in containers for a period of time during the production cycle. Although there is evidence to the contrary (91), roots deflected by container walls can cause root deformations which may lead to long-term tree growth problems (86). The significance of container-induced right-angled turns (kinks) in lateral roots is uncertain. Lindgren and Orlander (76) found that circling roots contributed to tree instability. Kinks were associated with restricted flow in the xylem or phloem (60). Roots deflected by obstacles in the soil frequently return to the pre-deflection orientation (124) and may ensure a firm hold in the soil (31). Few studies, however, describe the fate of circling roots caused by container tree production. Carlson et al. (16) found that root morphology on seeded-in-place trees was similar to that for trees planted from containers. More frequently, root morphology is altered by container production practices (58, 77). The resulting defects include kinked, circling or girdling roots and they can restrict growth of landscape plants (79).

Container-grown trees planted in a nursery or landscape sometimes develop lateral roots on only two or three sides of the plant (44, 45). Uneven soil pH, nutrient or water status can not account for the total lack of roots occasionally observed on one side of trees and shrubs planted from containers. High container medium temperatures cause root death on the south and west sides of containers exposed to the direct sun (66). Root circling and other root defects may also develop on container-grown plants. Although untested, these may be responsible for uneven root development following planting into field soil.

Results of one study showed that root deformation within the container may not have a long-term effect on growth of red maple (46). The majority of the root system emerged from adventitious roots initiated after planting, above, and presumably removed from the influence of the potential girdling effects of the circling roots in the bottom of the container. Perhaps some species adapted to wet sites such as red maple can avoid the potential problems of container-induced root deformations by developing adventitious roots close to the soil surface after planting. Long-term growth may be more affected by these root deformations on species producing a less adventitious, deeper root system originating from roots produced in the container (77). Vascular constrictions on deformed roots could inhibit proper root function and lead to reduced growth or tree stability problems (75).

Field-grown plants—Hand-dug or tree spade-dug soil balls planted in the nursery or landscape do not loose as much water to the surrounding soil as container-medium root balls. This is because the textural difference between the soil root ball and the surrounding soil is not as great as between container-medium root ball and surrounding soil. However, unlike container-grown plants, only a small portion (2–8%) of the root system is harvested with the tree on field-grown plants (42, 114). Recently-transplanted field-grown trees require frequent irrigation due to this dramatic reduction in the root system. Although roots begin to regenerate within a week or two after severing (2), the water demand of the top requires that roots stay moist at all times. Trees will be under water stress until the root system is restored to the original pre-transplant size which can take from one to as long as 10 years or more for larger trees (111).

Watson (111) developed a root growth model and assumed a root spread diameter increase of 0.9 m (3 ft)/year for trees in the northern United States. Coutts (20) found that root spread diameter of forest-grown 8-year-old Sitka spruce increased at a rate of 1.2 m (4 ft)/year. Root spread diameter was 6.1 m (20 ft), 2 years after transplanting 13 cm (5 in)-caliper live oak in Florida amounting to a 2.3 m (7.5 ft)/year increase in root spread diameter (Gilman, unpublished). On a transplanted field-grown tree, it will take about one year per 2.5 cm (1 in) of trunk caliper to regenerate the root system to the original pre-transplant size assuming a 2.3 m (7.5 ft)/year increase in root spread diameter. It may take longer in northern climates where root spread diameter appears to increase at a slower rate (111).

Trees planted bare-root have root growth rates similar to those on trees planted with a soil ball. Gilman (42) showed that 5-year-old honey locust, poplar (*Populus* × *generosa*) and green ash (*Fraxinus pennsylvanica*) planted in New Jersey had root spread diameters of 3.7 (12 ft), 5.2 (17 ft) and 2.1 m (7 ft), respectively, 3 years after planting. Initial elongation rates of intact roots (3.8 cm (1.5 in/week) and regenerated roots (6.4 cm (2.5 in/week) of bare-root planted 1-year-old green ash lasted for an average of 16 days (2). In order for the root system to continue expanding in size, new roots must be continually regenerated along the lateral roots because of frequent die back of the rapidly-growing root tip. This elongation/die-back process would be expected to produce weekly rates of root spread diameter increase of less than 2.8-6.4 cm (1.5-2.4 in)/week calculated from this data.

In summary, expect root system diameter of recently planted trees or shrubs to expand at a rate of from about 0.9-2.3 m (3-7.5 ft)/year, depending on completition from turf and other plants, species, climate, plant size, post-planting care and health of the plant.

Growth in Urban Sites

It is thought by some practitioners that tree roots extend beneath streets. This is not likely except in the most friable, well-drained soil since soils beneath streets are compacted to densities higher than that conducive to root growth (96). This reduces the oxygen concentration, and can increase carbon dioxide concentration to 20% under roadways (127). Soil temperature beneath roads may also reach lethal levels, preventing roots from exploring soil beneath streets (54). Some roots may grow in well-drained sandy soil beneath parking lots paved with asphalt. Some roots may continue to live after pavement is placed over an existing root system; however, roots of planted trees are often deflected by the curbing and do not extend under the street (89). Rather, they often grow beneath the sidewalk adjacent to the tree lawn because this area is highly favorable to growth of tree roots (7) and they extend into the lawn area beyond (58). As lateral roots enlarge in diameter, the sidewalk can be lifted making them hazardous.

Cultural practices designed to encourage deeper rooting beneath sidewalks can be successful in some situations. In friable, well-aerated soil, downward sloping physical barriers deflect roots to deeper soil layers. However, in typical urban soils which are compacted or poorly-drained (88, 96), roots directed toward the deeper soil layers grow up toward the surface of the soil once they extended beyond the barrier (109). Barker and Wager (7) suggest that trees produced with tall, narrow (columnar) root balls might develop deeper roots after planting and help prevent uplifting of sidewalks. However, deep containers reduce root branching and number of roots originating from the trunk (110), and the number of roots arising from the stem is correlated with growth rate (120). Also, research and experience show that trees planted in compacted urban soil perform best if roots are placed slightly shallower, not deeper that standard practice (50, 88). Trees planted too deep in compacted soil may not survive or may grow poorly.

Although it has not been demonstrated, selecting plants with root systems designed to fit the urban environment may be feasible (7) and could help trees, sidewalks and pavement coexist. Several studies have shown that individuals within a species can be classified according to root morphology. Sweet gum trees (*Liquidambar styraciflua*) from seedling lots having a greater number of lateral roots grew better following planting than those from seedling lots with a lesser number of laterals (70). Apple could also be classified into root morphology categories (13). This indicates that trees may be selected for their root characteristics.

Changing urban planting design from the concept of a planting pit to a planting space will help trees establish quicker and will increase life expectancy. Designing an enlarged island to accomodate several trees will provide the edge which trees need to remain healthy in urban parking lots. The planting space can also take the form of a long, continuous strip of soil parallel to the street in place of the traditional row of square planting pits separated by concrete. A very suitable but expensive alternative is to suspend the entire sidewalk over the soil on short pillars. This allows for root exploration beneath the entire sidewalk area. The objective is to provide as large a soil area as possible to allow for adequate root development.

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