# SOIL MOISTURE AND ABSORPTION OF WATER BY TREE ROOTS[1]

by T. T. Kozlowski

**Abstract.** Shade trees undergo periodic dehydration because the rate of absorption of soil water lags behind the rate of transpirational water loss from tree crowns. The rate of absorption of water from wet, warm, and well-aerated soil is controlled largely by the rate of transpiration. However, absorption of water often is impeded by low soil moisture content, a small or slow-growing root system, poor soil aeration, low soil temperature, a high concentration of the soil solution, or combinations of these. As the soil dries down from field capacity, the rate of absorption of water is reduced because of increased resistance to water movement in the soil and within the tree as well as loss of soil-root contact. Poor soil aeration in compacted or flooded soils decreases water absorption by inhibiting root growth, inducing decay of roots, and suppressing development of mycorrhizae. Low soil temperature reduces absorption of water by decreasing the permeability of roots, increasing the viscosity of water, and inhibiting root growth. High concentrations of deicing salts and fertilizers in the soil solution may reduce absorption of water by osmotic effects.

Shade trees are so constructed that they tend to lose a great deal of water. They expose a very large leaf surface area that is perforated by numerous microscopic pores (stomata) through which water evaporates from the leaf interior to the atmosphere in a process called transpiration. When environmental conditions favor high transpiration rates, tree crowns often dehydrate which decreases their growth and survival. Water deficits in leaves occur not only during droughts, but also develop periodically to some degree even when the soil is well watered. This is because the water balance of a tree is controlled by the relative rate of transpiration from the tree crown and the rate of absorption of water by the roots. During the day the rate of transpiration is higher than the rate of absorption. As a result, trees tend to dehydrate during the day, particularly on hot, sunny days. During the night, however, when the rates of both transpiration and absorption are low, the rate of absorption of soil water is higher than the rate of transpiration. Hence trees tend to refill with water during the night (Fig. 1). The lag of absorption behind transpiration during the day occurs because of the resistance to water movement present in the soil, roots, and leaves (41). In healthy trees there is little resistance to water movement in the stem. However, in some diseased trees (e.g., those with oak wilt or Dutch elm disease) water movement is inhibited by blocking of the water-conducting vessels (36). Upward water movement may be impeded in stems of cuttings by blocking of the water-conducting vessels with tyloses in broadleaved trees or by blocking of bordered pits in the water-conducting tracheids of conifers (23).

When environmental conditions favor high rates of transpirational water loss, the roots function primarily as passive absorbing organs and the rate of absorption of water is controlled largely by the rate of transpiration. This is especially true when the soil is wet (but not waterlogged), warm, and well aerated. Often, however, absorption of water is impeded by a low soil moisture content, a small root system, poor soil aeration, low soil temperature, or a high concentration of the soil solution. Such adverse conditions, which characterize many urban soils (12, 32), cause an increase in the lag of water absorption behind transpiration, thus inducing dehydration of tree crowns.

## Availability of Soil Moisture

Trees obtain most of their water from the soil. However, under some conditions other sources also are important, though usually to a lesser degree. For example, atmospheric moisture in the form of dew or fog may prevent or postpone dehydration of tree crowns. The water requirements of tree crowns may also be partly fulfilled by water stored in leaves, stems, roots, and fruits. In addition, trees may obtain some water from adjacent trees through root grafts.

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Nevertheless, the very large amount of water required to sustain tree growth is obtained primarily from the soil (29).

The amount of water in the soil varies widely over time and almost never is ideal for maximum absorption by roots. Usually there is too much or too little water in the soil, and mostly the latter. The major sources of water for shade trees are rainfall and irrigation water. However, a portion of this water is lost by surface runoff and some evaporates before it can percolate into the soil. The amount that is lost by evaporation varies with atmospheric conditions and with soil texture, color, and porosity.

The water in the soil consists of:

1. *Gravitational water*, which occupies the large soil pores and drains away under the influence of gravity.
2. *Capillary water*, the most important source of water for plants, which is held by surface forces as films around particles, in angles between them, and in capillary pores.
3. *Hygroscopic water*, the water in air-dry soils which is held so firmly by the soil particles that it can move only as vapor and is generally unavailable to plants.
4. *Water vapor*, which occurs in the soil atmosphere and is not used directly by plants.

Although gravitational water is available to trees it usually drains away too fast in soils with good drainage to be important. The rate of drainage decreases quite rapidly with time and, after a few days, water movement appears to stop. This cessation of drainage has led to the concept of "field capacity" or the water content at which downward water drainage is negligible (16). At field capacity, which is considered the upper limit of available soil water, capillary movement of water is very slow. The lower limit of available soil water is usually considered to be the "wilting percentage," the soil water content below which many plants cannot extract enough water for good growth. Both the field capacity and wilting percentage are higher in fine soils than in coarse soils. Also, the range between field capacity and wilting percentage is greater in fine-textured than in coarse soils (Fig. 2). As soil dries from the field capacity to the wilting percentage, water is released more gradually from fine than from coarse soils.

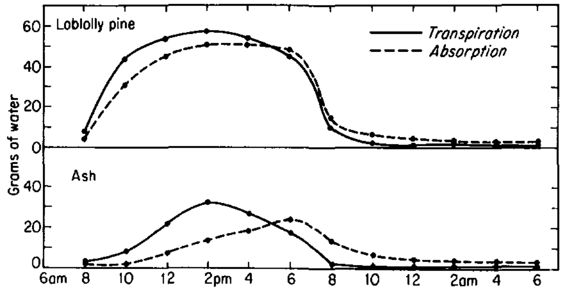

**Figure 1. Diurnal variations in rates of transpiration and absorption of water by loblolly pine (*Pinus taeda*) and white ash (*Fraxinus americana*) trees. From Kramer (37).**

If a small amount of water is applied to a large volume of air-dry soil of uniform texture and good drainage the soil will be wetted uniformly to a certain depth after equilibrium has been attained. The gravitational water occupying the large pores will drain downward, leaving only capillary water in the zone of wetted soil. The water content of this wet layer of soil will then be rather uniform throughout and the boundary at the base of the wet layer will be quite distinct, with air-dry soil immediately below it. The layer of wet soil may now be considered to be at field capacity. In the example cited, a fine-textured soil, which holds more capillary water than a coarse soil does, would be wetted to only a few inches whereas a coarse, sandy soil might be wetted to a depth of a foot or more. The moisture content of clayey soil at field capacity might be as high as 30%; of a very sandy soil perhaps only 5%. A second addition of water equal to the amount previously applied to this soil will only briefly increase the moisture content of the surface layer, which was at field capacity shortly after the first application. The second increment of water will flow through the wet layer of soil into the dry soil below it and, after equilibrium is attained, the depth of the soil layer at field capacity will be approximately doubled.

As a soil dries the rate of absorption of water by tree roots decreases. Resistance of wet soil to water movement is low because only small forces are necessary to move water through water-filled pores. However, as the soil dries down appreciably the resistance to water movement increases. Considerable soil resistance results from a loss of soil-root contact because of root shrinkage (22, 65). The resistance in the tree to water transport also increases as the soil dries, partly as a result of increased tension on the water in the conducting elements in stems (45). Changes in plant resistance to water movement may also occur in the roots as the soil dries because of suberization of roots and loss in root viability (38).

## Size and Growth of the Root System

Water in the portion of the soil that is not permeated by roots is largely unavailable for absorption by tree roots. Capillary movement of soil water from wet to dry regions in soil with a moisture content at or below field capacity is very slow. Furthermore, the soil immediately surrounding the absorbing roots dries rapidly. Hence, continuous root extension into zones of wet soil is important for sufficient absorption of water to replace the water lost by transpiration and thereby prevent dehydration of leaves (40). For these reasons trees with deeply penetrating, highly branched, and rapidly growing roots absorb water most efficiently. A high root-shoot ratio (indicative of relatively high capacity for absorption of water and low capacity for transpirational water loss) is particularly important for growth and survival of trees, especially under drought conditions. For example, *Eucalyptus socialis* trees grew better than *E. incrassata* trees on dry sites because of the higher root-shoot ratio of the former (50). Mortality of transplanted *Pseudotsuga menziesii* seedlings with low root-shoot ratios was high (20). Many transplanted *Pinus palustris* trees died because the needles lost water faster than their roots could replace it by absorption (3). Pruning of needles to a 5-inch length resulted in a 30% decrease in water loss and a 30% increase in survival. Clipping of needles was most beneficial on good sites and in years of average rainfall. Clipping of needles may also decrease tree growth by reducing the photosynthetic surface, but this is much less important than survival of transplants (35).

Evergreens that are transplanted with bare roots, or even with a root ball of soil, undergo a physiological shock because their capacity for absorbing water is suddenly greatly reduced at a time when high rates of water loss by transpiration continue. During lifting and handling of transplants many of the small absorbing roots are lost, disrupting the previous close contact of the root system with a large volume of water-supplying soil. Such loss of roots often is associated with dehydration of transplanted trees because they usually lose water faster than they can replace it by absorption.

Watson and Himelick (69) reported that the roots of a typical undisturbed shade tree with a 4-inch stem diameter were absorbing water and mineral nutrients from about 20 cubic meters of soil. After this tree was dug with a spade and transplanted, the soil volume containing the roots was only 0.35 of a cubic meter (the volume of the root ball). This amounted to only 2% of the soil volume from which the roots absorbed water before the tree was transplanted. Hence transplanting success will depend largely on the capacity of roots to begin growing rapidly and establish intimate contact with the soil beyond the root ball so as to absorb adequate amounts of water. Woods (71) attributed the high survival rate of *Pinus caribaea* transplants to rapid initiation of root growth. In dry regions it is especially important to confine transplanting to the time of year when high capacity for root growth occurs. In areas of high rainfall the adjustment of planting schedules is less important (28).

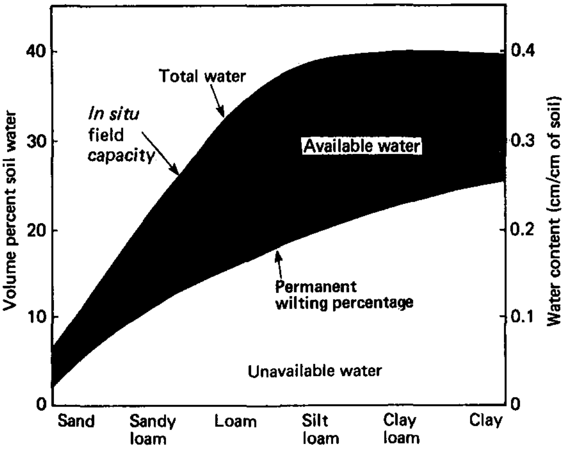

**Figure 2. Relative amounts of available and unavailable water in soils of different textural grades. The amounts are given as percentages of soil volume and as centimeters of water per centimeter of soil. From Cassell (9).**

**Root growth potential** (RGP). Considerable attention has been given to factors influencing root growth potential (RGP), a measure of the capacity of planting stock to rapidly grow new roots. RGP varies seasonally, and also differs with climate, cultural practices, and cold storage environments.

RGP is closely associated with bud dormancy and is highest when the chilling requirement for dormancy release is fulfilled. The magnitude of the root growth response is influenced by availability of stored carbohydrates. Hence RGP increases during the winter, reaches a maximum in late winter or early spring, and decreases rapidly just before the buds open. It follows that RGP is strongly influenced by the time of year when planting stock is lifted and placed in cold storage.

If the nursery climate varies from year to year, the date on which RGP is highest will also vary. In California, the seasonal peak in RGP was controlled by the number of hours that seedlings in the nursery were exposed to low air temperature.

Undercutting, wrenching, and root pruning have been used to condition nursery seedlings for planting. Such preparation involves drawing a sharp blade under the nursery bed at a 10-15 cm depth to sever the root systems (undercutting), and then drawing a dull blade at an angle beneath the undercut seedlings to prevent deep penetration of new roots and to increase soil aeration (wrenching). These practices lead to inhibition of shoot growth, induction of dormancy by increasing water deficits, and accelerated branching of roots. The end result is a seedling with a high root-shoot ratio (4, 51, 52, 60). On Vancouver Island, *Pseudotsuga menziesii* seedlings in their second year of growth that were wrenched in the nursery, lifted in October, and stored at 2°C until May, showed a 25% higher survival rate than unwrenched trees one year after planting (67). RGP can also be increased by water stress in late summer. For example, RGP was higher in seedlings exposed to drought for 6 weeks before lifting than in seedlings that were watered regularly. The increase was attributed to more favorable water balance resulting from better stomatal control in the stressed seedlings (53, 54).

**Cold storage of nursery stock.** Because storage temperatures slightly above 0°C are adequate to break bud dormancy, seedlings that have not received enough chilling when they are lifted in the nursery will continue to release bud dormancy in cold storage and RGP will be increased. By comparison, seedlings with buds that are not physiologically dormant at the time of lifting, or those that have been exposed to enough chilling in the nursery to break bud dormancy, will have their RGP decreased while in cold storage. In addition, high storage temperatures will maintain high respiration rates of planting stock, thereby reducing stored carbohydrates, further lowering RGP.

Successful cold storage of nursery stock depends on several factors. Seedlings must be dormant to withstand prolonged storage. With nursery stock lifted early in the autumn or late in the spring, survival may decrease with prolonged storage. To prevent dehydration in storage, nursery stock should be packed in moisture-proof film, or stacked bundles should be covered with a moisture-proof envelope. To prevent molding the temperature should be kept constant and low. Storage between −2°C and −5°C has given good results with most conifers, provided they are dormant. Finally stock should be lifted from the nursery when the foliage is dry; roots should be kept moist; and small, diseased, and injured stock should be culled (21). Ritchie and Dunlap (51) have an excellent discussion of the physiology of RGP and practical methods of controlling it.

**Transplanting practices.** All of the work of developing planting stock with high capacity for rapid root growth may be meaningless if good transplanting procedures are not followed (27, 35). Descriptions of methods of transplanting shade trees are beyond the scope of this paper. For excellent discussions of recommended techniques of transplanting shade trees, the reader is referred to Himelick (19), Whitcomb (70), and Watson (68).

## Soil Aeration

Poor soil aeration in compacted or flooded soils often decreases the capacity of roots for absorbing water by causing decay of roots and inhibiting root formation and elongation. The decay of roots in poorly aerated soil is associated with weakening of the host tree, capacity of root-rotting fungi to tolerate low oxygen contents, and attraction of zoospores to root exudates (31, 32, 34). Because root growth often is decreased more than leaf growth by poor soil aeration, the small root system cannot absorb water fast enough to replenish the water lost in transpiration, causing dehydration of tree crowns (30, 31, 33).

The effects of soil compaction and soil flooding in reducing root growth have been well documented (1, 14, 30, 31, 33, 34, 35). Root penetration and establishment of *Pinus rigida*, *P. nigra*, and *Picea abies* trees were greatly reduced in compacted silt loam and sandy loam soils (73). Whereas *Ailanthus altissima* seedlings in a non-compacted soil had deeply penetrating root systems, the growth of roots in a compacted soil was confined to the soil surface layer (49). When downward growth of *Pseudotsuga menziesii* roots was restricted in a compacted soil most roots grew laterally in the uncompacted surface layer of soil (18).

Drastic reductions in root growth of flooded trees have been reported for many species including *Malus* (10), *Citrus* (58, 59), *Fraxinus pennsylvanica* (56), *Platanus occidentalis* (62), *Quercus macrocarpa* (63), *Betula papyrifera* (61), *Ulmus americana* (47), *Pinus halepensis* (57), *Pinus strobus* and *Pinus resinosa* (64). All the woody roots of *Pinus contorta* seedlings survived flooding whereas all the non-woody roots died (11).

Some species of flood tolerant trees have the capacity to produce adventitious roots which can compensate physiologically for loss of much of the original root system. For example, the flood-tolerant *Betula nigra* produced many adventitious roots when flooded, whereas the flood-intolerant *B. papyrifera* did not (48). The absorption of water by flooded *Fraxinus pennsylvanica* was much higher in seedlings with adventitious roots than in those from which such flood-induced roots were severed (56). Removal of flood-induced adventitious roots from *Platanus occidentalis* seedlings reduced their growth, further emphasizing the importance of such replacement roots (66).

The root systems of many trees are modified by development of mycorrhizae, formed as a result of invasion of young roots by hyphae of certain fungi. The mycorrhizal association is one in which the tree supplies carbohydrates and other metabolites that benefit the fungus. In turn the fungus increases absorption of water and mineral nutrients. Mycorrhizae increase the absorbing surface of the root system (5). In fact the volume of soil exploited by a mycorrhizal root may be up to 10 times that of a non-mycorrhizal root (6). Some evidence shows that drought tolerance of woody plants in arid regions is increased by mycorrhizae (2, 43). Mycorrhizae are particularly advantageous to trees growing in low fertility soils (44).

Poor soil aeration decreases the capacity of roots for absorbing water and mineral nutrients by inhibiting development of mycorrhizae. Mycorrhizal fungi are strongly aerobic; hence poor soil aeration reduces mycorrhizal associations in trees (13, 15). In compacted soils mycorrhizae may be found only in the uppermost layers whereas in uncompacted soil they occur to much greater depths (26).

### Soil Temperature

When atmospheric conditions are conducive to high rates of transpiration and water absorption is impeded because the soil temperature is low, tree crowns tend to dehydrate. In California orange trees wilted during the winter because of slow absorption of water from cold soils (8). Low soil temperatures reduce absorption of water directly by decreasing the permeability of roots to water and indirectly by increasing the viscosity of water. As the soil temperature decreases from 25 to 5°C, the resistance to water flow through the roots is approximately doubled. Low soil temperatures also limit absorption of water by inhibiting root extension (41). Nambiar et al. (46) attributed dehydration of *Pinus radiata* transplants to the inhibitory effect of low soil temperature on root regeneration.

Much winter injury to evergreen shrubs and trees results from dehydration of leaves rather than from direct thermal injury (32). Such injury occurs largely because absorption of water cannot replenish the water lost by transpiration from the leaves. Because the soil water is cold or frozen the rate of absorption of water is negligible during sunny winter days when appreciable amounts of water evaporate from the leaves (24, 25). Furthermore, when the temperature of tree stems drops to a few degrees below 0°C, the water in the conducting xylem elements may freeze, preventing water movement to the crown even if some of the roots are in unfrozen soil (17, 72). The results of these conditions are dehydration of tree crowns, and scorching, killing, and shedding of leaves. The extent of winter desiccation injury is influenced by the time of soil freezing, depth of frozen soil, depth of snow, air humidity, and wind velocity (28).

## Concentration of Salts in the Soil Water

Sudden exposure of tree roots to high concentrations of deicing salts or fertilizers in the soil water may lead to dehydration of tree crowns. This response often is attributed to reduced water absorption because of the osmotic effects of the salts. Hence, a tree may be subjected to physiological drought even if the soil water is at field capacity (42). However, this response is an oversimplification because when plant roots are transferred from dilute to more concentrated solutions, the plants usually wilt at first but recover after a day or two as they gradually absorb salts and undergo osmotic adjustment. Plants with roots exposed to gradually increasing concentrations of salt do not dehydrate as rapidly as those with roots suddenly exposed to very concentrated salt solutions. Reduced absorption of water in saline soils may also be associated with a decrease in root permeability caused by dehydration, increased suberization, and inhibition of root growth (39). High salt concentrations in the soil may also injure young feeder roots, especially those of trees growing on sandy soils, further decreasing absorption of water (41).

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## Abstracts

LOFGREN, D.E. 1986. **How to write specs.** Ground Maintenace 21(1):112,114.

Properly prepared specifications are vital to achieving consistently smooth business relations with customers and clients. Know exactly what you want, and spell it out clearly. Make your requirements results oriented. Learn also to quantify by giving yourself and others measurable guideposts. Quantification factors include those that specify: time, distance, volume, weight, area, unit (per worker, machine), and cost. Spell out restrictions. Make your specifictions clear, concise and self-contained. Whenever practical, keep your specifications as a separate document from your written contract.

MORGAN, D. L. 1986. **Repairing storm-damaged trees.** Grounds Maintenance 21(1): 54-58.

Cascading tree limbs laden with ice and snow are the expectations of a beautiful winter season. Yet such scenes are the undoing of the arborist and homeowner who must bear the expense and effort of repairing damage caused by nature in her splendor. Drastic pruning is sometimes necessary after an ice or snow storm. When large limbs are damaged enough to present a threat to life or property, complete the pruning as quickly as possible. First, assess the damage. If the tree is badly split or limbs critical to its natural shape or health are broken, remove the entire tree. Proper pruning is one of the best things you can do to a tree to keep it healthy. Done improperly, is one of the worst. Proper pruning means removing branches without injuring the branch collar. Topping trees is still inadvisable. No matter how it's done, topping will cause disfiguration and possibly serious damage. If a weak Y (or crotch) appears, cabling or bracing may be required. A great deal of controversy has emerged during the last decade over the use of tree paints on wounds and cuts. Although opponents argue that wound dressings retard the tree's natural healing processes and seal in moisture (thereby creating conditions favor-to pathogenicity), pathologists studying oak wilt and other highly virulent diseases spread by insects remind us that paints may discourage these vectors from depositing fungal pathogens in tree.