ROOT-SHOOT RATIOS [1]

by Richard W. Harris

New ideas and information about ideas that are not widely accepted by horticultural practitioners and researchers have made revising the *Arboriculture* book interesting and rewarding. I would like to share one of them with you.

The root-shoot ratio is usually given as the ratio of the weight of the roots to the weight of the top of a plant. For most trees under normal conditions, the root-shoot ratio is 1:5 to 1:6 (10,18); the top is 5 to 6 times heavier than the roots. If it were not for the weight of the trunk, however, the top and roots would weigh about the same (18).

A cultural practice that brings about a reduction in the root-shoot ratio of a tree is commonly thought to be detrimental for the well being of the tree. That is, proportionately more top than root growth is thought not to be in the best interests of a tree. However, any factor which improves growing conditions, such as favorable weather, fertilization, irrigation, aeration, or pest control, results in a reduced root-shoot ratio (weight).

A change in the relative weights of the roots and top is not an accurate or valid measure of plant response to a changed situation. A more useful comparison is the root surface or length to the transpiring leaf surface of a plant. The roots within the dripline of a tree are estimated to have 2.5 to 4.5 times more surface area than do the leaves (one side) of the tree (18).

Root length is probably a better measure than the surface area of the absorbing ability of roots. Water moves slowly in soil so that a small root is almost as effective as a larger one in absorbing water and nutrients. Roots grow in length to explore soil. In addition, root hairs and the mycorrhizal roots (root-fungus associations) of most tree species greatly increase moisture absorption. According to Perry (18), mycorrhizae "functionally amplify the effective surface of the finer roots a hundred times or more". Under normal conditions, even though the top of a tree may increase in weight more than the roots, the roots of a plant are well able to supply the top with water, nutrients, stored carbohydrates, and certain growth regulators.

Except for injury to the roots, a reduction in the root-shoot ratio is almost always in response to more favorable growing conditions. An increase in the root-shoot ratio, on the other hand, would indicate that a plant was probably growing under less favorable conditions.

Most plants are able to adapt to changing conditions if the changes are not too drastic or rapid. If the top is pruned, relatively more carbohydrates are utilized to restore the top and less are available for the roots. Conversely, if roots are damaged or nutrients and water become limiting, relatively more carbohydrates go to roots and less to the top. If nitrogen is limiting, roots grow proportionately more than the top and more nitrogen is shunted to leaves which may keep chlorophyll and photosynthesis proportionately higher in relation to total nitrogen availability.

Phosphorus and Potassium are Seldom Deficient for Trees

Nitrogen, phosphorus, and potassium are present in fertilizers known as *complete* or *balanced*; other nutrients may also be present. These three nutrients are commonly considered to be deficient in most soils for field and vegetable crops, bedding plants, and turf. Even though hundreds of field experiments have shown that most soils contain sufficient levels of phosphorus and potassium for trees and large shrubs, complete fertilizers (N,P,K) are still universally recommended for trees (2,15,16,23).

Phosphorus and potassium are deficient for trees in fairly specific soils. Local extension agents and knowledgeable plantspeople should know if

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either nutrient is deficient in their region and, if so, where. If either is deficient, usually it is best to apply more than would normally be applied in the recommended rates for complete fertilizers.

Applying nutrients to be "safe" without knowing they are deficient wastes time and money, and can lead to salt build-up in the soil and to water pollution. High amounts of phosphorus can cause iron and manganese deficiencies in broadleaved trees (26) and palms (Henry Donselman 1990, personal communication). High fertility inhibits mycorrhizae formation thereby jeopardizing disease protection (27) and absorption of nutrients in short supply.

Nitrogen is the nutrient to which threes most commonly respond. Nitrogen can be effectively applied on the surface, while in some landscape situations subsurface application of phosphorus and potassium may be needed in order to have the nutrients in close proximity to the roots.

Nitrogen-Phosphorus and Root-Shoot Growth

As already mentioned, an increase in soil fertility is commonly associated with a reduction in the root-shoot ratio; that is, shoot growth increases more in weight than root growth (3).

Nitrogen is the nutrient that is universally deficient. The most visible response is increased shoot growth. On the other hand, phosphorus, also an essential nutrient, is seldom deficient for trees in most regions. When phosphorus is applied to trees, top growth is seldom affected. These responses have led to the notion that nitrogen stimulates top growth at the expense of root growth and that phosphorus stimulates root growth. Authors of several publications state or imply that phosphorus primarily stimulates root growth and nitrogen shoot growth (1, 2, 15, 16, 17, 20, 24).

It is commonly thought that an increase in top growth without a similar increase in root growth places a plant in jeopardy. The discussion about root-shoot ratios should put that notion to rest.

Research finding support the supposition that both nitrogen and phosphorus stimulate both root and shoot growth. When nitrogen is optimum but phosphorus deficient, phosphorus addition stimulates shoot growth as well as root growth (6, 9). Similarly, when phosphorus is optimum and nitrogen deficient, additions of nitrogen stimulate both root and shoot growth. In split-root experiments with spruce, Philipson and Coutts (19) found that when deficient, additions of nitrogen stimulated more root growth than did phosphorus.

Gilbertson, Kendle and Bradshaw (7), report that first-year fertilization of birch and sycamore-maple trees planted in a china-clay-waste site in England resulted in 50 percent more root than shoot growth and that the root-shoot ratios increased the greater the nitrogen application. They state, "There seems little evidence for the common belief that N promotes shoot growth whilst P is for roots". Although not significant, Walmsley (25) in England found similar trends.

Experiments in mature unirrigated almond orchards in California are of interest. Orchards were fertilized little or not at all because it was thought the extra growth would use up the ground water before the crop matured. However, nitrogen greatly increased growth and yield; other nutrients, including phosphorus, were without effect (21). Root growth must have increased enough to supply adequate water for the larger leaf surface and crop.

Epstine (4), Halfacre and Braden (8), Kramer and Kozlowski (11), and Mader and Cook (14) make no mention of the root-promoting ability of phosphorus in their reviews of plant nutrients.

Even though addition of nutrients that are deficient in the soil may stimulate more shoot than root growth (weight not surface area), it should not be a problem unless the root system is physically restricted or excessive shoot growth results. Excessive shoot growth is usually kept in "balance" with the roots by increasing temporary afternoon water deficits as leaf area begins to "outgrow" the ability of the roots or conducting xylem to supply enough water. In fact, it has been shown that as soil moisture becomes limiting, roots can generate nonhydraulic signals to the top of a plant that inhibit leaf growth without causing detectable water deficits in the shoots (12).

Trees Can Adapt to Nutrient Levels

The foliage of most trees is dark green even though nutrient deficiencies significantly limit growth. Ingenious experiments in Sweden have shown that tree seedlings can adjust to low levels of various nutrients so that even though root and shoot growth are reduced, their foliage is able to regain a healthy appearance (5, 6, 9).

When, for example, optimum nitrogen supplies misted on tree seedling roots were markedly reduced, shoot growth which had been the maximum desired was reduced, leaves yellowed, root growth was reduced though not as much as shoot growth, and roots grew long with little branching (9). However, if nitrogen continued to be supplied at this lower rate which was proportional to the increase in plant weight (growth), even though below optimum, growth stabilized at the slower rate and leaf color returned. Chlorophyll and the rate of photosynthesis returned to levels proportionately greater than the stabilized nitrogen supply or growth rate. Even though the total starch content was less in seedlings receiving suboptimum nitrogen supplies because of less total growth, the concentration of starch was comparable to that at the higher nitrogen level (13).

Ingestad and Lund (9) postulate that leaf-color-deficiency symptoms occur primarily when a plant does not adjust rapidly enough to a decreasing internal-nutrient supply. Growth of a plant dilutes its internal nutrient level unless the plant has an increasing supply of nutrients.

When the internal nutrient level of seedlings was maintained, seedling growth increased exponentially. In other words, if suboptimal supplies (not concentration) of nutrients were increased 5 percent over the day before, plant growth increased about 5 percent over the day before.

This research has important implications for the care of trees, young as well as old. For young trees to grow rapidly, they must have increasing amounts of nutrients available. An increasing nutrient supply would be available by: 1) a plant increasing its rooting volume, 2) the soil having a high cation-exchange capacity, or 3) fertilizing.

The Swedish researchers (9) point out that except for trees growing in severely impacted sites, almost all mature trees have dark green foliage even though they have never been fertilized. I now look at native stands of trees with awe and new respect, knowing it should be possible to have good leaf color, low to moderate growth, and trees in balance with their surroundings with little or no fertilization needed. Nutrition and pruning costs would be reduced.

These findings, however, may not apply to nutrients whose availability is impaired by extremes of soil reaction or physical condition.

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