RELATION OF FINE ROOT DEVELOPMENT TO SHADE TREE GROWTH AND SURVIVAL[1]

by Virgil K. Howe

The major factor controlling the survival and growth of an urban tree is its ability to produce a root system that successfully exploits a sufficient volume of soil to supply the moisture and mineral nutrient demands of the aerial organs. This statement assumes atmospheric conditions that permit normal photosynthetic activities in the foliage. Since most of our urban trees are subjected to conditions not found in their normal habitats, special problems arise in successfully exploiting the soil. This is particularly true of indigenous mature trees in stands invaded by developers. The ecology of the stand is dramatically altered by construction activities and by the subsequent actions of the homeowner who generally provides a new plant species, usually grass, to compete with the tree for water and minerals. If the volume of soil that is suitable for exploitation is limited, the trees are at a disadvantage with a vigorous grass competition and dire consequences for the tree may result. Only those trees with a highly efficient and extensive fine root system can maintain a sufficient absorbing surface to compete with grass. It is the nature, extent and maintenance of the absorbing surface that is the major focus of this paper.

The intensive study of a tree fine root system is very difficult. Observations are made either in disturbed situations or under artificial conditions. Both methods reveal much about the macroscopic features of the root system but tell us little about the extent and nature of the interface between the absorbing surface and the soil solution.

The internal anatomy of a typical fine root of a pot-grown oak includes a well-developed stele with conspicuous xylem; an endodermis that may not be well defined; a cortex of two to three cell layers and an epidermis. Externally, a conspicuous root cap is usually present and a few millimeters from the tip a profusion of root hairs develops. It is generally thought that most mineral elements and much of the water is absorbed through the root hairs. While the numbers and length of root hairs vary, there is no doubt that their presence increases the surface absorbing area. Estimates as to the extent of increase range from two to 20X. The absorbing area is further increased by secondary branch roots that arise internally. These secondary roots also possess root hairs. Thus, an elaborate branching root system would enhance the plants ability to develop an extensive absorbing area.

While the system just described can be impressive, there appears to be alternative systems in nature. Extensive examinations of the fine roots from many trees fail to reveal the presence of root hairs or, if present, their numbers are sparse. Instead, the vast majority of the fine roots will be invaded by fungi which results in a structure known as a mycorrhiza. In many trees, mycorrhizal fine roots are the rule while uninfected fine roots are the exception.

Most of our urban tree species have one of two types of mycorrhizae. The conifers, oaks, beeches and others possess encomycorrhizae. This form is characterized internally by the invasion of the fungal hyphae between the cells of the epidermis and cortex. Externally, the fungus forms a mantle around the fine root enclosing the tip and stimulates the production of secondary fine roots which also become infected and form mycorrhiza. Thus a very intricate and extensively branched fine root system is produced. The fungi producing ectomycorrhizae are most often mushrooms and puff balls. Trappe (1) has developed an extensive listing of tree-fungus partnerships.

A second type of mycorrhiza, endomycorrhiza, is found on a number of shade tree species but is best known on maple and ash. Endomycorrhizae often do not appear different externally from non-mycorrhizal fine roots. However, microscopic ex-

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amination of the root tissues reveal the presence of intracellular vesicles and/or arbuscles. The fungi involved in the formation of endomycorrhizae belong to the family Endogonaceae.

Mycorrhizae are generally distributed throughout the fine root system of the tree. They are found in greatest abundance in the upper soil layers. These soils have high organic content, good porosity and favorable oxygen tension. When the depth of the soil layer best suited for mycorrhizal development is limiting, the tree is more dependent upon a limited volume of soil from which to obtain water and minerals.

A major function of mycorrhizae is their contribution to the nutrition of the tree. Many studies have been conducted to show not only the increase in growth of tree seedlings due to the presence of mycorrhizae (2,3,4,5,6,7,8,9,10) but also the marked increase in mineral composition of the plant tissues and organs (11,12,13,14,15,16, 17,18,19,20,21,22). In addition, nutrient exchange between the two partners has been demonstrated (23,24,25,26,27,28,29). There remains to be solved the question of how mycorrhizal fine roots are more efficient in exploiting the soil for mineral cations than are non-mycorrhizal fine roots. There are at least two plausible explanations. Fungi are aggressive competitors for metallic cations and can vie successfully with grass roots for any limited cations. Since grass fine roots also possess endomycorrhizae, some trees may share the same fungal partner with the grass and receive a proportionate share of the available nutrients.

The second possibility is that the fungal partner in a mycorrhizal relationship augments or supplants the root hairs and increases the surface absorbing area of the fine root system many times over the area provided by root hairs alone. While there are no satisfactory means yet available to demonstrate the extent of soil invasion by the hyphae of mycorrhizal fungi, we do know that the fungi are capable of rapid and extensive hyphal growth. Such a system would provide a rapid means of invading the rhizosphere soils and of competing vigorously for the available nutrients. Coupled with evidence that mycorrhizae aid in water conservation, it is imperative that trees possess a vigorous fine root system and a vigorous fine root system in many urban trees is composed largely of mycorrhizae.

As was stated earlier, most of our urban trees are subjected to environmental conditions not found in their native habitats. Often our urban environment is very harsh and conditions are detrimental to the survival of fungi producing mycorrhizae. As a result, there is a loss of surface absorbing area in the fine root system. When the magnitude of the loss is such that sufficient water and minerals cannot be supplied to the crown, decline symptoms soon become evident. If the adverse conditions of the rhizosphere are not alleviated, dieback will progress until a crown-root balance is achieved or, failing to reach that balance, death of the tree may result.

Our studies indicate that soil pH, oxygen tension and fluctuations in soil moisture and temperature are the critical factors in the rhizosphere environment (30,31). Mycorrhizal fungi are aerobic, acid-loving organisms that are intolerant of temperature extremes. They thrive in the upper horizons of undisturbed forest soils covered by insulating layers of litter. When attempts are made to utilize mature trees for landscaping purposes, conditions are often altered too drastically by the opening of the stand. This begins with the movement of heavy equipment into the stand bringing about traumatic injury to the trees and compaction of the soil. There is often grading changes resulting in fill or soil removal. The stand is generally opened and the undergrowth removed allowing increased radiant energy to reach the ground. Since the litter cover is generally lost and with it the modifying effects it produced, elevated temperatures and increased water evaporation result. Because homeowners desire a lawn, a lime-base fertilizer is frequently used to help establish the grass. This results in an elevated soil pH which is very detrimental to the mycorrhizal fungi. With the cumulative effect of all these insults, there is little hope that the remaining trees in an invaded stand can survive. Most die in a relatively short time.

There are precautions and remedial actions that can be taken to enhance tree survival even when considerable disturbance has taken place (32).

The primary concern must be to maintain a vigorous fine root system that can function efficiently to provide the needs of the tree crown. Failure to do so will bring about the loss of the tree at least as a functional entity in a landscape setting.

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