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# Mycorrhizae: Your Silent Partner

In virtually every tree you trim, fertilize, aerate, or transplant, there is a hidden, almost-invisible silent partner working to maintain the health and vitality of that tree. Your clients have no knowledge of its existence. Most arborists know very little about it. And yet everything you do to the tree affect its capacity to do its job.

Your silent partner is mycorrhizae, beneficial fungi associated with the tree roots. In the simplest terms, mycorrhizae assist plant roots in the uptake of water and minerals from the soil. Actually, there is much more to than that. Let's start by discussing the nature of mycorrhizae, and how to preserve, protect and promote them for maximum benefit.

The word is of Greek origin, from 'myco' for fungus and 'rhiza' for root. It is a structure built from the mutually beneficial interaction of a small (non-woody) absorbing root and a particular type of fungi. They work together and they are a team. Science calls this relationship 'symbiotic', which is defined as "the intimate living together of two kinds of organisms, especially where such association is of mutual advantage."

Virtually all trees and more than 92% of plants worldwide have mycorrhizae. There are thousands of species of fungi that form these relationships. Without the mycorrhizae, forests as we know them would not exist. And without them, our urban forests, and landscape trees and shrubs, would not survive.

***Mycorrhizae* greatly increase root surface area. *Actinorhizal* (nitrogen fixing) roots from an alder.**

In nature, as new roots grow, they first develop root hairs for uptake of water and dissolved minerals from the soil solution. Then, gradually, over a period of several weeks, most of the absorbing roots are colonized by these beneficial fungi.

Mycorrhizae function through a network of fungal 'threads' which connect tree roots to water and minerals in the soil. It is a 'living bridge' of nutrition. At one end, tiny fungal threads enter between or through the outer cells of the absorbing roots and grow inside the root tissues, forming structures for the exchange of nutrients. At the other end, fungal threads or groups of fungal threads fan out through the soil, vastly expanding the volume of soil from which the roots may draw their raw materials.

What does each partner (symbiont) get from the association? The fungus gets sugar and other compounds that are manufactured by the leaves. Fungi cannot live without the products of photosynthesis (carbohydrates). It is estimated that in natural ecosystems, trees and plants give up, or, more properly, 'invest' 15-30 percent their current phosynthates to the mycorrhizal fungi (Read 1991, Soderstrom 1991). That a big investment.

The roots, in exchange for this investment, receive a host of essential benefits:

- Hundreds to thousands of times greater volume of soil from which to absorb water and essential nutrients (Castellano & Moline 1989);
- The full balance of all available essential nutrients, and as needed;
- Significantly improved uptake of certain hard-to-get nutrients, such as phosphate, zinc, copper and other minerals;
- Protection from soil pathogens (*Phytophthora cinnamomi*, *Pythium*, *Fusarium oxysporum*,*Rhizoctonia solani*) (Wingfield 1968, Marx 1973, Marx & Krupa 1978);
- Improved water uptake, storage and transport capacity;
- Significantly increased tolerance of drought, high soil temperature, high salinity, and soil toxins (Sinclair, Lyon and Johnson 1987);
- Growth regulators, which stimulate vital processes including root elongation and branching, thus increasing the total number of feeder roots produced (Castellano & Molina 1989);
- Antibacterial/antifungal substances antagonistic to root pathogens, generated by more than 100 species of mycorrhizal fungi (Marx & Krupa 1978);
- Protein from the cell walls of the fungal threads inside the roots, which live only a few days, as they die and are replaced (Howard 1947);
- significantly increased soil aeration, water infiltration rate, and water-holding capacity. The mycorrhizal threads 'glue' the soil particles together into humus-containing aggregates, creating crumb-structure and larger pores (macropores) between the soil aggregates;
- Extending the life of the absorbing roots by producing hormones which decrease the rate of cell wall thickening and aging;
- Significantly increased capacity for soil penetration. The fungal threads are extremely thin, approximately l/5 the diameter of aroot hair, and so are able to penetrate soil micropores inaccessible to the roots (Schlechte 1976).

Evidence suggests that the mycorrhizal association evolved as a survival mechanism for both the associated fungi and the higher plant, allowing each to survive together in an environment of low soil fertility, periodic drought, disease, temperature extremes and other natural stresses. Because of this coevolutionary process, mycorrhizae are as common on the root systems of trees and other plants in natural soils as chloroplasts are in the leaves (Marx, Maui & Cordell 1990).

This association is incredibly efficient. It has been estimated that it would require at least 100 times more photosynthate to develop and sustain a root system large enough to gather water and minerals equal to that provided by the mycorrhizae. Another way to look at is that these fungi can draw raw materials from a given volume of soil for one percent of the photosynthate that would be needed by a tree to develop and maintain a root system capable of doing the same. (Read 1991).

Mycorrhizae have been and continue to be studied extensively. Some of the earliest research was carried out between about 1905 and 1940 by Sir Albert Howard, a graduate of Cambridge University in England. He was a practical researcher who managed, experimented on, and restored many 'worn out' or 'dead' farms in India, England and the west Indies, where soil fertility had been destroyed by excessive use of chemicals and improper agricultural practices. He was an honorary fellow of the Imperial College of Science, Director of the Institute of Plant Industry in Indore, India, and an agricultural advisor to states in central India.

Howard observed that soils rich in humus were full of mycorrhizal fungi, and that the fungal threads appeared to constitute a living bridge of nutrition between the humus in the soil and the roots. During his 35 years of research, he developed a system for maximum efficiency in composting so as to create the highest quality of humus. In his words, "the mycorrhizal association therefore is the living bridge by which a fertile soil (one rich in humus) and the crop are directly connected, and by which food materials ready for immediate use, can be transferred from soil to plant ... The wonderful double process by which nature causes the plant to draw its nurture from the soil… The mechanism by which living fungus threads invade the cells of the young root and are gradually digested by these... Where humus was wanting, the mechanism (mycorrhizae) was ineffective. The plant was (mainly) limited to the nurture derived by absorption of the salts in the soil solution (through root hair water absorption); it could not draw on these rich living threads, abounding in protein ... It is clear that the doubling of the process of plant nutrition was one of those reserve devices on which rests the permanence and stability of nature. Plants deficient in the mycorrhizal association continue to exist, but they lose both their power to resist shock and their capacity to reproduce themselves ... Here we have a simple arrangement on the part of nature by which the soil material on which these fungi feed can be joined up, as it were, with the sap of the tree… These fungus threads are very rich in protein and may contain as much as 10 per cent of organic nitrogen. This protein is easily digested by the enzymes in the cells of the roots. The resulting nitrogen complexes, which are readily soluble, are then passed into the sap current and so into the green leaf. The marriage of a fertile soil and the tree it nourishes is thus arranged" (Howard 1947).

Over the past 30 years there has been a gradual expansion of research. The U.S. Forest Service has conducted extensive research with the purpose of assisting in rapid reforestation following logging operations. There has also been agricultural research, particularly involving reestablishment of mycorrrhizae following soil sterilization. Over 10,000 research papers have been published and a tremendous amount of valuable information has been discovered concerning mycorrhizae.

- Mycorrhizae seem to have evolved to provide the plant with adequate water and minerals. It gives the plant more when the demand increases and less when the demand deceases. We can't balance the fertilizer (inputs) like the mycorrhizae can (Menge pers. comm. 1993).
- Many species may exist at any one time in a forest stand, more than 25 species may be involved on the roots of one mature tree, and one fungal network can interconnect the roots of 50-70 trees (Marx - mycorrhizae conference, 1994).
- There are two principal types of mycorrhizal fungi:

    **Ectomycorrhizae** are formed in association with most important forestry trees, including pine, hemlock, spruce, fir, oak, birch, beech, eucalyptus, willow, poplar, cedar, cypress, larch, hickory, chestnut, pecan and hazel. They are distinguished by the fact that the form and structure of the tiny absorbing roots are altered (they are shorter, changed in color, usually swollen substantially and branched, and are covered with a sheath or mantle) and the "invading" fungal threads do not enter into the root cells, but grow only between the cells and over the surface of the roots. Ectomycorrhizal fungal threads growing out through the soil form 'hyphal strands,' which are like miniature braided ropes of 30-100 or more individual threads. These strands are thick enough to be visible to the naked eye (Marx pers. comm. 1995).

    **Endomycorrhizae** (of which the VAM, vesicular-arbuscular mycorrhizae are the most widespread) are formed in association with nearly all important agricultural crops, vines, grasses, legumes, desert plants (including palms), ericaceous plants (rhododendron, blueberry, azaleas, etc.), mosses, ferns, and most broad-leaved plants, including all species of maple, elm, sycamore, ash, cherry, walnut, dogwood, locust, holly, magnolia, redbud, ginko, laurel, palmetto, myrtle, orange, pear, plum, apricot, redwood, cedar, sweetgum, locust, etc. Endomycorrhizae are distinguished by the fact that the 'invading' fungal threads enter and colonize the root cells without causing any visible changes in root form and structure. Unfortunately, from a research and management stand point, the fungal threads which grow out through the soil are extremely thin and do not form strands, so they are not visible to the naked eye. Roots must be stained and observed under a microscope to discern fungal structures and degree of colonization.

Certain tree species including alder, eucalyptus, Casuarina, cypress, juniper, linden, elm, apple and arbutus, can form associations with either ecto- or endo-mycorrhizae, depending upon age and available inoculum in the soil.

In nature, mycorrhizae are far more common than non-mycorrhizal roots (Menge 1985). It can take 3-5 weeks for mycorrhizae to develop to the point where they becomes visible under a microscope for endomycorrhizae, or to the naked eye for ectomycorrhizae. Therefore, there are always at least some non-mycorrhizal roots present. In the fall, after root growth slows down significantly, the proportion of mycorrhizal roots may be as high as 90%, but, on average, in natural soils it is probably about 60% (Marx conf. 1994).

- Endomycorrhizal fungi are generally believed to be the most abundant fungi of any kind in soil (Gerdemann & Nicolson 1963).
- The accumulation of phosphorus by mycorrhizae is striking. Although total phosphorus in most soils is adequate to support plant growth, much of the supply is bound in insoluble forms that are scarcely available to non-mycorrhizal roots (Sinclair, Lyon and Johnson 1989). It takes 5 to 10 times the normal phosphate level (6 -20 ppm) found in most forest soils to compensate for the absence of endomycorrhizal fungi (Marx conf. 1994).
- Mycorrhizal fungi mingle with litter-decomposing organisms in the humus layer and there obtain nutrients from organic sources that would be unavailable to the non-mycorrhizal plant (Sinclair, Lyon and Johnson 1989).
- Where soils have been fumigated, e.g., methyl bromide, to kill pathogens, inoculation of the soil with mycorrhizal fungi has resulted in growth increases over control trees of: citrus by 1600%, grapes by 4900%, pine by 323%, peaches by 80%, avocado by 254%, yellow poplar by 167% (Menge 1985; Powell 1984; Menge, et al. 1980).
- Certain types of mycorrhizae release chelating compounds (called siderophores) that are especially important in iron nutrition (Graustein, et al. 1977, Powell et al. 1980).
- Ectomycorrhizae (which includes oak species) predominate in the organic layers of the soil. In a 250-year-old fir-larch forest study it was found that the tips of 95 percent of external fungal threads (those growing out away from the root) were located in the humus (66 percent), in decayed wood( 21 percent) and charcoal from forest fires (8%), (Harvey, et al. 1979). Thus, numbers, diversity, and activity of beneficial soil organisms can be reduced by repeated removal of organic matter from a site (Amaranthus, Trappe & Molina 1989),
- The protective mechanisms against disease include creation of a physical barrier against root penetration by pathogens, manufacture and excretion of antibiotics, and stimulation of other pathogen-inhibiting rhizosphere organisms (Zak l964, Marx 1972).
- Perhaps the most succinct overview of the lessons learned by forestry research is presented in a book entitled "Maintaining the Long-Term Productivity of Pacific Northwest Ecosystems," edited by D. Perry, et al, with contributions from M.P. Amarantus, J.M. Trappe and R.J. Molina (1989). The pertinent statement is as follows: "Forest managers should be aware that the yield-enhancing attributes of soil organisms are the product of diverse, complex interactions within natural systems that have co-evolved over millennia. Thus, the best long-term management approach is to minimize drastic or cumulative impacts to the forest environment so as to retain a balance of beneficial organisms.

To do this, forest managers should:

- Minimize disturbance severity - that is, intense burns, extensive soil compaction and erosion;
- Emphasize retention of organic matter;
- Emphasize rapid revegetation of sites by indigenous host species and associated beneficial soil organisms. Although there is no 'magic bullet' for maintaining or enhancing forest productivity, there is great opportunity to use soil organisms as 'tools.' A new era is emerging in our understanding of forest ecosystems. Incorporating the concept of the 'living soil' in our evaluation of site productivity is part of this new, expanding view" (Amaranthus, Trappe & Molina 1989).

**Preserving, Protecting & Harnessing Mycorrhizae**

Minimize pruning of live branches and foliage. There are many valid reasons to prune live branches and foliage, but health improvement is not one of them. Pruning in most cases has an overall weakening effect on tree health. The more often the tree is pruned and the more leaves removed, the harder it is on the tree. Foliage removal reduces total photosynthates. If you remove half the leaves, you reduce manufactured photosynthates by 50%, and it would seem therefore that all parts of the tree would then get half their normal allocation. But the tree will allocate a disproportionate amount of current photosynthates to the top to compartmentalize the pruning wounds, leaving the roots and mycorrhizae with less than half their normal photosynthate requirement. Some mycorrhizae die, and the roots die back (Marx conf. 1984). Without extensive mycorrhizae, the volume of soil from which the tree can absorb water and nutrients is dramatically reduced. Nutrient deficiencies may become apparent. The roots system is predisposed to disease.

The following excerpts are from the 1991 USDA book - Armillaria Root Disease. Resistance to pathogenic organisms is the rule rather than the exception in forest trees. If this were not so, they (trees) would have ceased to exist" (Shain 1968). Although all trees have some capacity to resist infection, this resistance requires substantial energy. "Production of physical and chemical barriers depletes the host's energy reserves, and trees of less than optimal vigor may not have the energy reserves required to resist infection and are therefore predisposed to disease, The association of Armillaria root disease with defoliation (or other types of impaired canopy function) is one of the best documented interactions. This relationship has been consistently observed and reported in forest studies... Foliage diseases can weaken trees by reducing or eliminating leaf surface area available for photosynthesis" (Shaw & Kile, 1991). Maximize tree health by pruning live branches and foliage as infrequently and as minimally as possible.

**Practice Good Soil Management.**
Soil conditions that encourage good root development also encourage the mycorrhizae.

- Water thoroughly but infrequently. Apply enough water to penetrate 12-24 inches deep, and then let the soil dry out between waterings to restore high oxygen levels (but not to wilting point). Never overwater.
- Prevent/correct soil compaction. Mycorrhizae are aerobes. Prevention is far more efficient and effective than correction.
- When the soil is already compacted:
- Before planting - Cultivate to undo the compaction, and, where drainage is acceptable, mix high quality composted organic materials into the top 4-6 inches of soil throughout the entire area to be planted (not deeper than about 6 inches to prevent anaerobic decomposition, nutrient tie-up and production of toxic gases). Resulting rapid root/mycorrhizal growth, earthworms and other microbial activity will "undo" the compaction and structure the soil in a way no rototiller or tractor could possibly do;
- For established trees – 'core-vent' the soil (make many holes in the root zone and fill with porous, relatively non-water-holding material like pea gravel, pumice, coarse screened sand, etc).
- Do not allow soil addition (grade change). Even as little as 2 or 3 inches of soil added on top of original grade can weaken the roots/mycorrhizae enough to predispose the tree to disease.
- Do not allow extensive root/mycorrhizae damage from trenching, soil removal, extensive digging (to install new plants or otherwise), rototilling, etc.
- Do not install groundcover plants: or other extensive plantings that will compete with the tree roots/mycorrhizae for soil space, water, oxygen and nutrients. Where such plantings already exist, and it is practical to do so, gradually remove them, one section at a time, over a prolonged period of time, by pulling them up out of the soil.

**Don't poison the Mycorrhizae**
Fumigation with biocides or pesticides such as methyl bromide, chloropicrin, dazomet, 1,3 -D, vapam and vorlex may destroy or inhibit root colonization by mycorrhizal fungi. Application of many soil fungicides such as arasan, banzot, benomyl, botran, carbendazim, carbofuran, chloramformethane, chlorothalonil, dichlofluanid, ethirimol, lanstan, Mancozeb, mylone, quintozene (PCNB), sodium azide, thiabendazole, thiophanate, thiophanate-methylthiram, triadimefon (Bayleton), tridemorph, vitavax, Zineb and Ziram have also been reported to be harmful to certain types of mycorrhizae, but not to all (Menge 1985; Johnson & Pfleger 1992). Paint and paint thinner, cleaning solvents and other such toxic substances can be deadly to the mycorrhizae and to the tree.

**Apply Mulch**
Gradually re-establish the forest-floor ecosystem by applying and maintaining a 2-4 inch thick layer of mulch on the soil surface. In general, start with two inches thick of coarse material containing plenty of leaves (coarse, so that it does not mat down & restrict gas exchange; leaves, because they are nutritionally better balanced & break down rapidly, releasing their nutrients for re-absorption). The best value is tree-trimming chips that have either been chipped with a disc-chipper or have been tub-ground and screened to exclude large chunks. Composted sewage sludge has also proven very valuable in facilitating or stimulating mycorrhizal development, and should be considered where heavy metal concerns can be satisfied. Wherever possible, establish a practice of letting the fallen leaves remain on the soil surface. Remember that it takes more water to get through the mulch and that the mulch will keep the soil wet for a longer period of time, so cut back the frequency of irrigation and increase the duration of each cycle. Gradually build up the mulch thickness to 4 inches or more. New absorbing roots and mycorrhizal fungal threads will proliferate in and just below the mulch layer.

**Apply Mycorrhizal Spores**
Do this to establish or improve root colonization as needed:

- Where soil sterilants, excessive pesticides or fungicides have been used;
- Where there is no topsoil (has been removed or subsoil placed over it);
- Where the soil has been flooded or become waterlogged, (particularly fora prolonged period);

- With most container-grown trees, even where the media was not sterilized or frequent fungicides applied. Bark, sand, subsoil, wood shavings, perlite and other similar materials, so frequently used in container mixes, should not be expected to have viable mycorrhizae;
- Where tree vitality is poor; you may wish to introduce a more efficient species of mycorrhizae. Some mycorrhizal species are much more tolerant of poor soil conditions, stimulatory to and protective of the roots, and efficient at gathering essential nutrients.

You can inoculate a tree or a site by gathering topsoil and surface litter from under healthy trees of the same species, or you can buy a prepared inoculum, several of which are available.

Ectomycorrhizal inoculation is being extensively used every year on many millions of forest seedlings in the U.S. and in other countries. Soil sterilants are employed first, to remove all pathogens and all microbial competitors (a technique which could not be employed in an established landscape setting.) An inoculation is considered successful if the fungus initially becomes established on at least 50% of the root system of the tiny seedling. Growth and survival rates at planting are very significantly improved. The most widely-used ectomycorrhizal fungus, *Pisolithus tinctorius*, was isolated, cultured, extensively tested and brought to use in the forest industry by Dr. Don Marx, who was awarded the Nobel prize for his efforts.

While *Pisolithus tinctorius* fungal inoculum is available for sale to the landscape/arborist industry, testing as to efficacy on established trees in the landscape has only just recently begun. Soil pH is an issue. Forestry testing determined that seedlings did best with soil pH of 6.0 or below. However, some initial landscape testing at neutral soil pH has shown growth improvements. Competition from existing soil mycorrhizae for colonization sites on absorbing roots may limit effectiveness. More research is needed and being done.

**Mycorrhizae often cause roots to branch profusely.**

It may not be necessary to inoculate some trees because of wind dissemination of spores. Ectomycorrhizal spores are very small (in the range of 10 microns), and most are spread by wind. Endomycorrhizal spores, on the other hand, are quite large (as large as 2500 microns for some species), and most species generally are not wind disseminated, but rather are often spread by small animals. In either case (endo- or ecto-), where valuable trees are involved, it would be wise not to leave inoculation to chance. By using commercial inoculants, you are assured of achieving a high concentration of biologically active spores (from some of the most effective and efficient mycorrhizal species known at this time), in the exact location where you want them.

**The role of mycorrhizae in native oaks in the landscape**

Healthy oaks have abundant mycorrhizae, which are visible to the naked eye. In our dry, southern California climate, the long-term continued existence of native oaks can only be understood in the context of this beneficial root-fungus relationship. 'Drought-tolerance' does not mean that these trees can live without water all summer. On the contrary, like all other trees and plants, the native oak must have some water available to it every day of its life, or it will die.

Adaptation is the key word. In a functional sense, native oaks, and other native tree and plant species in our area, survive, and even flourish, because they can adapt to their environment by:

- Closing their stomates when the heat is intense, and when soil moisture is low.
- Maintaining a dense canopy of leaves that shades and cools the air and soil beneath.
- Maintaining a layer of leaf mulch on the soil surface that moderates soil temperatures and minimizes evaporation.
- 'Feeds' the beneficial soil microorganisms which help improve soil structure, facilitating rapid root growth, improved water infiltration and soil gases exchange.
- Recycling essential-nutrients by decomposition of fallen leaves and debris into humus, and ultimately re-absorbing them.
- Developing a secondary root system that can grow over 30 feet deep, and establishing and maintaining a symbiotic relationship with the mycorrhizal fungi.

In their native ecosystem, oaks can survive for hundreds of years without any supplementary watering, however, on disturbed sites they are not as adaptable. Therefore, they usually benefit from some summer irrigation. Disturbances in tree's natural environment include:

- Loss of roots and their absorptive capacity.
- loss of root function due to paving, which effectively reduces soil aeration and water penetration
- Removal of a significant proportion of live branches and foliage
- Removal of natural leaf litter (the richest and most available source of mineral nutrients for the mycorrhizae and roots) .
- Installation of inappropriate landscaping in the root zone, e.g., groundcover or other dense root-competitive plantings like ivy, vinca and turf.

Once these changes occur, oaks can no longer be considered as adaptable as other natives in natural settings. In essence, they become 'exotics,' requiring special care. In many cases their life span is greatly reduced. Trees unable to adapt, weaken, becoming increasingly more susceptible to pests. Changes in the soil greatly influence health. Exposed soil surfaces lose their natural porosity, become harder and often crust-over. There is, less water penetration, increased water runoff and soil erosion, particularly on slopes. Without a layer of natural leaf litter, soil temperature and evapotranspiration increases. Soils thus become hotter, drier, less porous and more resistant to root growth. In addition, drought stress occurs much earlier in the summer, leading to increasing drought-stress. This forces the stomates to close to conserve water. This in turn reduces photosynthate production, which not only impacts the roots and mycorrhizae, but the entire tree as well.

Under these circumstances, 'disturbed' tree needs supplemental irrigation, but it must be applied with judiciously. The soil moisture status should be monitored (with soil probe or moisture sensor), and water applied only as needed, bearing in mind that watering too often is more dangerous than watering too infrequently. As part of an overall restoration effort, which must include mulch and may include fertilizer, many arborists have settled on a watering program of:

- Avoiding application of any water onto or near the root crown;
- Thoroughly watering the root zone of native oaks once per month in the summer (with enough water to penetrate at least 12 inches into the soil;
- Watering no more frequently than once a month.

Gradually, over a period of several years, as health evidenced by an increased denser canopy and increased leaf surface area, and soil conditions improve by the application of mulch, watering can be reduced

All of the tree's functional systems make up one integrated whole. The growth of 'native'oaks that exist in a disturbed environment may improve when soil conditions around them are made more favorable for root and mycorrhizae growth. Judicious summer irrigation and the restoration of a permanent mulch layer 'primes the pump' by increasing moisture availability to the roots. Ultimately, this will increase the rate of photosynthesis. With more photosynthate available, and a more balanced mineral nutrients available from the mulch, the 'living fungus bridge' (mycorrhizae) will in turn be better nourished, thus more capable of providing their many benefits. In exchange for an investment of 15-30% of total photosynthate, mycorrhizae gather water and nutrients from a volume of soil that is hundreds to thousands of time larger than the roots alone can exploit. What more 'cost-efficient' adaptation could exist in nature?

**Conclusion**
All living organisms require a regular, balanced supply of nutrients. This is as true for trees and microorganisms as it is for man. If there is a deficiency, or an excess, in fact if there is any imbalance of nutrients, then normal development will cease, and abnormal development will result. If the imbalance is severe, death will eventually result. (Schutte 1964).

Mycorrhizal fungi are an essential and irreplaceable part of nature's balancing act. They are responsible for the majority of water and mineral uptake from natural soils, the manufacture of critically important stimulating and protective substances, enhanced tolerance of adverse conditions, and the creation, maintenance and restoration of good soil structure.

Most of our landscape trees have evolved in forest communities. Their root systems have co-evolved with symbiotic fungi, thus, the resulting biological structure, and associated mycorrhizae, with its vast network of fungal threads, should be regarded as the primary, natural, and normally functioning water and nutrient absorption system of a tree (Marx conf. 1994, Soderstrom 1991).

Construction, landscape installation and many current landscape maintenance practices all involve some degree of damage or stress to roots and mycorrhizae. The goal of maintaining healthy trees requires a thorough understanding of the fundamental biological requirements of the tree, and required actions to prevent or mitigate damage. We can do this by minimizing pruning, managing the soil appropriately, or by avoiding pesticides, biocides, etc., applying and maintaining mulch, and, when appropriate, inoculating the soil with the spores of commercially available mycorrhizal species with a demonstrated efficacy.

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