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Plant-Soil Organism Symbiosis
The Importance of Mycorrhiza

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Editor's Note: The use of mycorrhiza is fairly new to the turf industry and studies are not fully developed for their use in turf. Use of the organisms in forestry and nursery industries is better documented. This article is published to provide a general knowledge of mycorrhiza and how they work in forest soil as reported by a research team from the World Bank. The Bank's guidelines are created to assure proper use of World Bank loan funds. Therefore, it can be said the use of mycorrhiza has been recognized for specific industries around the world. This article might change your attitude about soil health, plant fertility, clipping removal and overuse of pesticides.

Productivity of the forest plant community is a consequence of the interaction of tree shoots and roots with the environment. One of the more important, and perhaps the least understood, zones of biological interaction is the soil immediately surrounding the root — the rhizosphere. Numerous microorganisms colonize this region and influence plant growth through physiological effects on uptake, storage and cycling of nutrients.

Despite their importance, soil organisms are rarely considered when degraded sites are replanted, trees are established on farmer's fields or when existing forests are manipulated. Yet, we know some interactions between soil organisms and plants can be essential to plant survival and normal growth. One such interaction termed 'mycorrhiza,' literally 'fungus-root,' is the association between specialized root inhabiting fungi and the roots of living plants.

In this mutually beneficial association, or symbiosis, each partner receives nutrients while also contributing to the other partner's survival. This development of plant and fungus together over time, or coevolution, has become an 'obligate' association in many cases. Obligate means each organism requires the presence of the other. In other cases, both organisms benefit from the association but do not require the symbiosis for survival. The association is especially critical in disturbed areas or areas that have been progressively degraded over time since rhizosphere organisms can be affected by shifts in land management practices.

IN THIS ISSUE

Protecting or restoring the diversity of rhizosphere microorganisms through proper management practices is essential to maintenance of ecosystem health and resiliency. The practical importance of mycorrhizal fungi to tree establishment is discussed in this report. The recent work with mycorrhiza on dipterocarp species could change the face of plantation forestry, forest rehabilitation and sustainable management in Southeast Asia.

Introduction

Forest researchers and managers are becoming more aware of the diversity of life forms and associations which make up the living soil that supports existing forest communities. Much of this biological diversity is hidden from view beneath the soil surface.

Soil organisms can total as many as 10,000 species per gram of soil; such orders of magnitude are never found above ground. The biological soil resource is one of the most important factors governing soil fertility (Figure 1). Through close mutual interaction between trees and soil organisms, conditions are created that govern forest systems and productivity.

Severing the close linkages between trees and the soil organisms has significantly contributed to degradation of many ecosystems, particularly tropical ecosystems, so restoring these links will be critical to any rehabilitation of degraded sites.

Scientists have studied microscopic organisms for years. The technical nature of these studies has resulted in terminologies difficult, not only for laymen, but also for many scientists to understand. In the course of this text it will be necessary to use these terms. Every effort will be made to include explanations in the text.

The aim of the report is to examine the important and intricate relationship which higher plants (such as trees and shrubs) have with soil microorganisms, in this case mycorrhizal fungi.

Discussion

Fungi, unlike higher plants, lack chlorophyll pigment, which is necessary to the process of photosynthesis. During photosynthesis, plants produce carbohydrates from carbon dioxide and water using sunlight.

Though we normally think of fungi as mushrooms, these are only one of the fruiting bodies of some types of fungi. The actual growth form of fungi is an immense network of fine threads called hyphae. The mat of hyphal threads is called the mycelium.

Mycorrhiza refers to the symbiotic association between fungal mycelia and plant roots. Benefits accrue to both organisms. The fungus gains essential carbohydrates from the plant and the plant gains improved access to soil nutrients and moisture through the fungi's extensive hyphal network, which functions like additional fine feeder roots for the plant.

Under circumstances resulting in the removal of higher plants, such as deforestation and grading, the food supply for many microorganisms disappears and, though they can sustain life through special adaptive responses for short periods, they eventually die. When this happens, soils become virtually sterile and inhospitable to both the higher and lower forms of organisms. This is also true of many of the mycorrhizal fungi.

The re-establishment of the mutualistic relationship of mycorrhizal fungi and host plants is then key to any restoration activity, particularly from the practical standpoint where trees are being reintroduced to degraded sites.

Soil-Plant Relationships

The importance of soil to forest production is well documented. Soils provide the reserves of water and nutrients, and provide the matrix for the biological processes involved in nutrient cycling. In return, plants play a role in soil formation and they provide energy that sustains the biological processes and, either directly or indirectly,

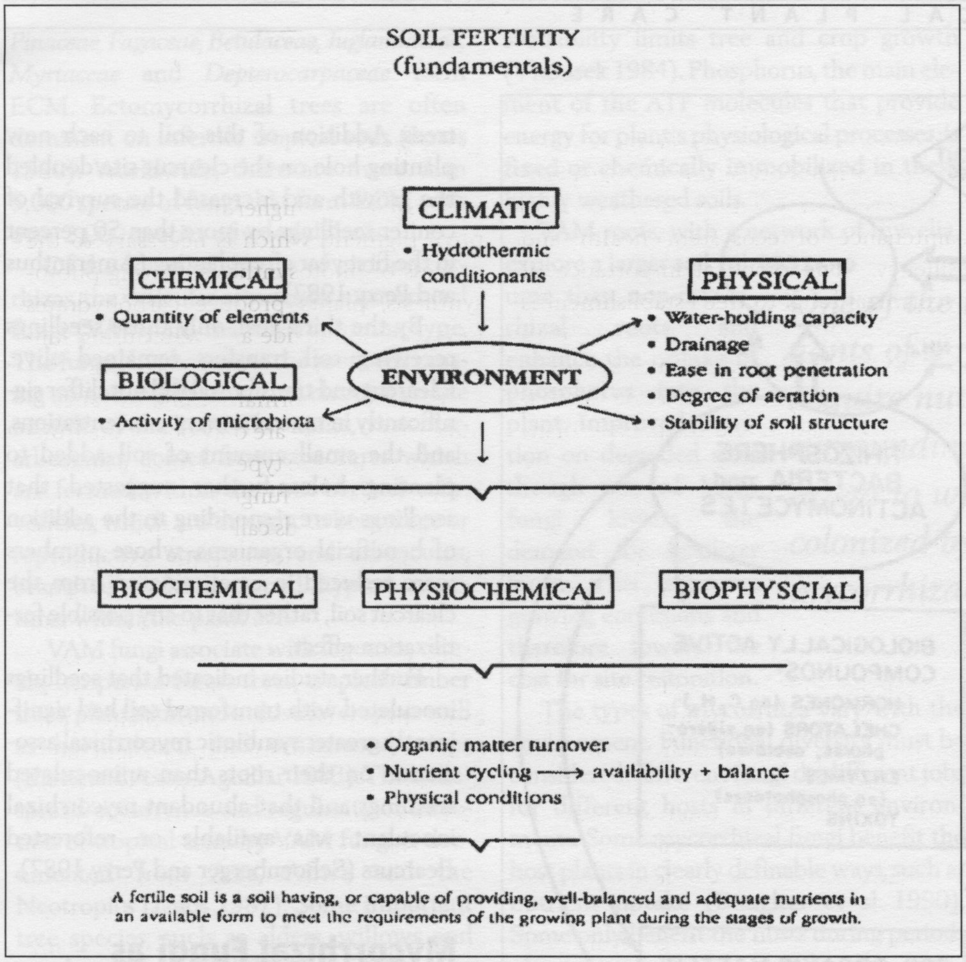

Figure 1. Summary of factors that affect soil fertility.

they create much of the structure within soils (Figure 2).

Plants allocate a large proportion of their photosynthates to roots. In forest ecosystems, trees may divert up to 80 percent of the net carbon fixed above ground in the leaves to below ground processes (Fogal 1985, Vogt et al. 1982). Some of this goes to root growth; however, a relatively high proportion may be used to feed organisms in the rhizosphere (root zone) and the soil.

The wide variety of life forms that participate in the below-ground forest community range from the smallest living organism to small mammals. These include viruses, bacteria, actinomycetes, fungi, algae, protozoa, arthropods, earthworms, amphibians, reptiles and mammals (Elliot et al. 1980, Coleman et al. 1984, Ingham et al. 1985).

Estimates of the number of organisms are impressively large. For example, up to a billion bacteria and actinomycetes and several kilometers of fungal filaments can be present in less than a thimbleful of forest soil. The tremendous amounts of energy that trees divert below ground support the rich assortment of organisms that benefit tree growth through decomposition, capture and uptake of nutrients, nitrogen fixation, protection against disease causing pathogens, buffering against moisture stress and maintaining soil structure (Persson 1983, Louisier and Parkinson 1984).

Perry et al (1989) described a situation in the western United States at high elevation of the Klamath Mountains where repeated failure of reforestation in previous productive forest could be directly related to major shifts in beneficial soil microorganisms following clearcut of old growth forests. Studies of soil microorganisms

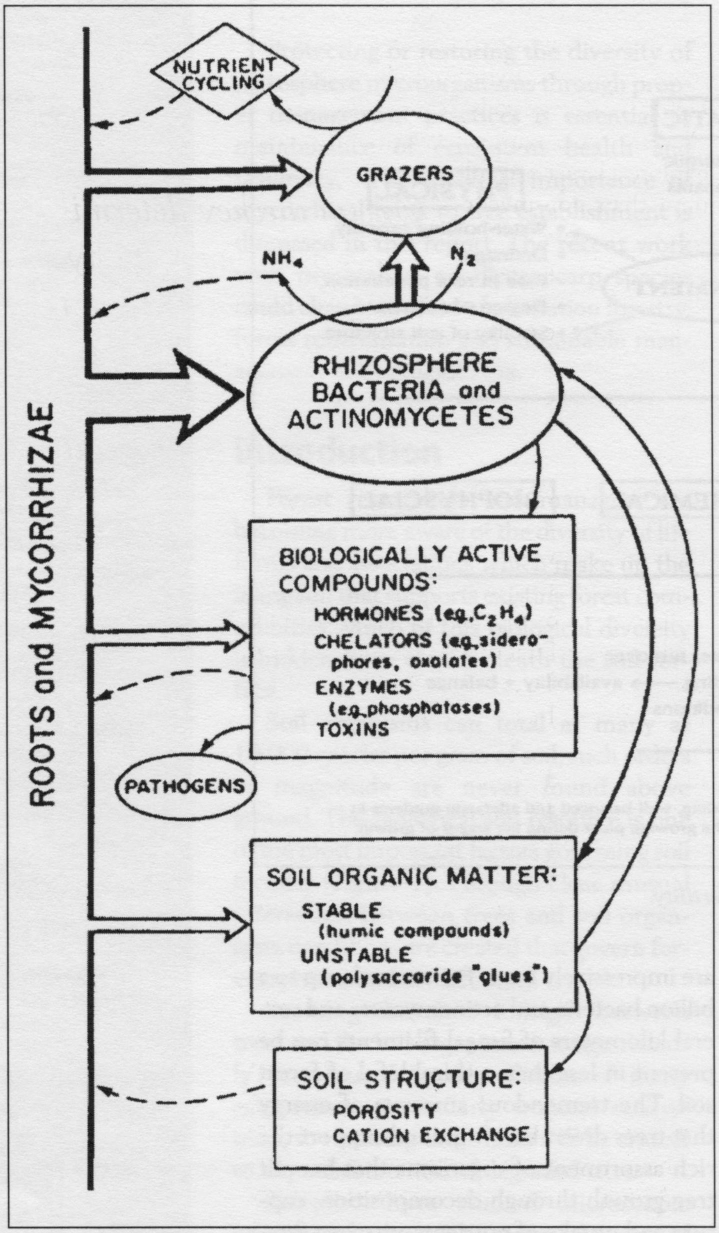

Figure 2. Diagram of biotic processes within the mycorrhizosphere. Perry et al 1987.

beneath forest and clearcut sites showed dramatic increases in bacteria and actinomycetes antagonistic to plants and reductions in beneficial microbes, such as mycorrhizal fungi.

In experiments at these clearcut sites, small quantities of soil (150 g) were collected from the root zone of healthy conifer trees. Addition of this soil to each new planting hole on the clearcut site doubled the growth and increased the survival of conifer seedlings by more than 50 percent in the first year after planting (Amaranthus and Perry 1987).

By the third year, only those seedlings receiving soil transfers remained alive. Clearcut and transfer soil did not differ significantly in macronutrient concentrations, and the small amount of soil added to planting holes further suggested that seedlings were responding to the addition of beneficial organisms, whose numbers were reduced in or eliminated from the clearcut soil, rather that to any possible fertilization effect.

Further studies indicated that seedlings inoculated with transferred soil had significantly greater symbiotic mycorrhizal association on their roots than uninoculated seedlings and that abundant mycorrhizal inoculant was available on reforested clearcuts (Schoenberger and Perry 1982).

Mycorrhizal Fungi as Key Species

Of the various soil organisms, perhaps the most is known about mycorrhizal fungi. Roughly 90 percent of plant species belong to families thought to form symbiotic mycorrhizal associations (Harley and Smith 1983; Malajczuk 1992). The fungal partner, the mycorrhizal fungus, can be classified into two broad groups: ectomycorrhizas (ECM) and endomycorrhizas.

Ectomycorrhizas are so termed because of their external modification of the root characterized by:

(1) development of an external fungal sheath around the fine root tissue and

(2) penetration of the fungus between (not into) the cells of the root cortex (the support tissue of greatest volume in the root).

Trees forming ECM include most of the commercially important species in the temperate and boreal forests and 70 percent of the species planted in the tropics (Evans 1982). Trees belonging to the

Pinaceae, Fagaceae, Betulaceae, Juglandaceae, Myrtaceae and *Depterocarpaceae* form ECM. Ectomycorrhizal trees are often dominant on infertile tropical soils (Janos 1980). Worldwide, there are more than 5,000 species of fungi that form ECM with over 2,000 species of woody plants.

Of the three subgroups of endomycorrhizas, the vesicular-arbuscular mycorrhizal fungi (VAM) are the most common type. The fungal hyphae enter the root cells causing no noticeable structural changes on the outside of the root. The name, vesicular-arbuscular, comes from structures which are formed within the root cortical cells: vesicles, which are thought to be storage or reproductive structures; and arbuscules, branched multiple-tipped hyphal structures within the plant cell.

VAM fungi associate with legumes, cereals, temperate forest trees, tropical timber trees, plantation and industrial crops as well as horticultural and ornamental crops (Barea and Axon-Aguillar 1983). The widespread occurrence and regularity of infection of tropical trees by VAM fungi is documented from Asia, Africa and the Neotropics (Janos 1987). Some important tree species, such as alders, willows and eucalyptus form both ECM and VAM fungal associations.

One of the key determinants of a root's ability to acquire nutrients from the surrounding soil is the extent to which it is colonized by appropriate mycorrhizal fungi (Harley and Smith 1983). Mycorrhizas improve seedling growth and survival by enhancing uptake of nutrients and water and increasing root life span. Mycorrhizae help protect the root against other organisms and against environmental stresses, such as heavy metal toxicity or soil salinity (Harley and Smith 1983; Malajczyk et al 1992). Mycorrhizae are thought to be crucial for acceptable growth and survival in many cases.

Tree species, such as pines and oaks, grown on sites void of ECM die or do not grow well unless inoculated (Mikola 1970, 1973; Marx 1980). The symbiosis is also critical for VAM forming trees, including the majority of tropical tree and many temperate deciduous families. On low fertility soils of the tropics, lack of phosphorus availability limits tree and crop growth (Vitousek 1984). Phosphorus, the main element of the ATP molecules that provide energy for plant's physiological processes, is fixed or chemically immobilized in these highly weathered soils.

VAM roots, with a network of mycelia, explore a larger soil volume than non-mycorrhizal roots and enhance the uptake of phosphorus into the plant. Improved nutrition on degraded sites though use of VAM fungi lowers the demand for fertilizer input. This improves growing conditions and therefore lowers the cost for site restoration.

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The types of mycorrhiza vary with the environment. Functional diversity must be considered: different fungi do different jobs for different hosts in different environments. Some mycorrhizal fungi benefit the host plants in clearly definable ways, such as nutrient uptake (Bougher et al 1990). Some only benefit the hosts during periods of extreme temperature or drought, at certain times during plant development, or following disturbance. Indirectly, mycorrhizal fungi influence important ecosystem properties, such as soil structure and moisture storage. The diversity of mycorrhizal fungi contributes to the 'buffering capacity' of the forest ecosystem, or the ability of the systems to withstand and recover from disturbance (Moorland and Reves 1979).

An interesting and very important study carried out by the Forestry Research Project in Indonesia has changed significantly the approach to planting species of the valuable dipterocarps. It was formerly believed that dipterocarps could not be established on open sites and it remains a fact that dipterocarps seed irregularly and seeds are usually recalcitrant; that is, lose viability rapidly. The study found that dipterocarps have obligate mycorrhizae and die or stagnate if these are not present. However, these fungi are killed when soil temperatures exceed 32 degrees C — hence the need for shade.

An experiment has been carried out

planting inoculated depterocarps on a grassland site in full sunlight. All plants were mulched and have established well and are demonstrating excellent growth.

Maintaining mycorrhizal diversity helps minimize site degradation by assuring plant adaptability to unpredictable or varying environments. This has special significance in forest ecosystems that now face unprecedented changes due to human activity.

Mycorrhizal species are central to successful tree species establishment and the concept of biological diversity. Because mycorrhizal fungi have a great influence on the survival of plants in new and reclaimed sites, the tree health and site quality, we believe they are the cornerstone to proper establishment of functional forest ecosystems.

Mycorrhizal Diversity and Forest Productivity

Of the estimated 10 million species of life on earth, only some 1.4 million have been named (May 1988). Incomplete knowledge of the numbers and distribution of organisms is particularly striking for some groups of organisms, such as mycorrhizal fungi. Many surveys document mycorrhizal fungal associations with forest tree species in India, Sri Lanka, Malaysia, the Philippines and other Asian forests. Information on collection and identification of the fungal symbionts, however, is just becoming available. For example, until quite recently, no large scale systematic exploration of mycorrhizal fungi associated with eucalyptus had been described in Australia.

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In three recent expeditions to Australian tropical and temperate rainforests in Queensland and Tasmania, more than 2,000 specimens were collected, including several new families, over a dozen new genera and as many as 100 new species. Expeditions of this nature help to develop a base for understanding the relationship of mycorrhizal fungi and forest function.

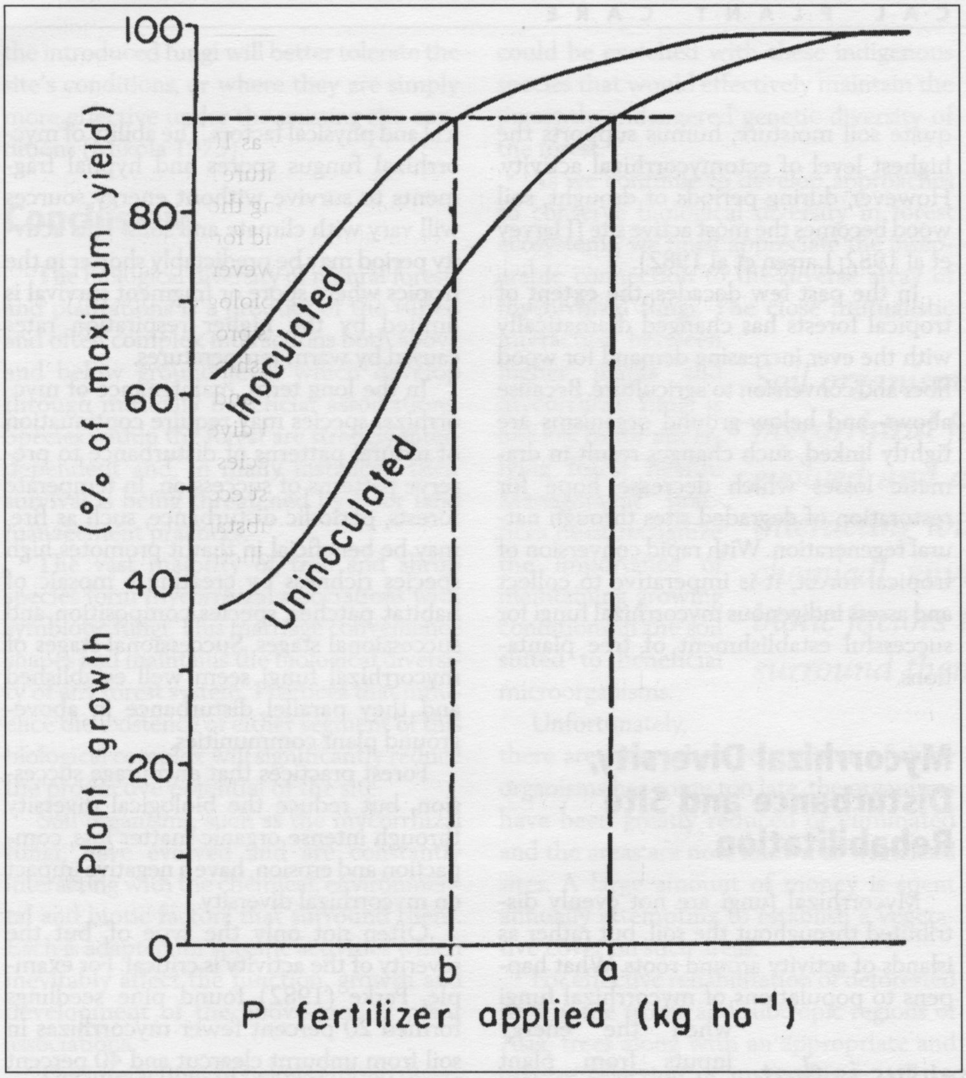
There is, however, no simple relationship between biological diversity of an ecosystem and its productivity. Nor is there a simple relationship between loss of biological diversity and productivity losses. Productivity and diversity vary depending upon which species and ecosystems are involved. In forest ecosystems, loss of mycorrhizal fungi substantially decreases primary plant productivity due to reduced acquisition of nutrients and water and loss of protection against other organisms.

The effect of mycorrhizal diversity on forest productivity is evident where indigenous host plants are planted outside their native range. ECM trees, especially pines in the tropics, grow poorly or may not survive in the field without their fungal symbionts that high yields are obtained; that is, when inoculum is applied as pure cultures or in soil collected from beneath indigenous stands.

Mycorrhizal Dynamics

In the forest environment, the mix of mycorrhizal species is constantly changing. Assessment of trees for their association with the fruiting bodies (mushrooms, toadstools or truffles) of ECM fungi show marked spatial and temporal distribution. Similar patterns of distribution have been observed for many different forest species in both temperate and tropical environments (Moss et all 1981; Mason et al 1983; Hilton et al 1987). Studies by Mason et al and Malajczuk (1987) of birch and eucalyptus stands indicated successional patterns of distribution of sporocarps (fruiting bodies) of specific mycorrhizal fungal genera.

Furthermore, not only do the dominant species of mycorrhizal fungi change with stand age, but the fungi's species diversity also increases with age of the forest. Janos (1980) hypothesized that late successional trees (invading species like some legumes)



Phosphorus response curves of mycorrhiza inoculated and uninoculated plants. Powell 1984.

and those on richer soils may or may not be part of a fungal association.

Invariably these successional changes in the fungal species are dynamically linked to the above-ground plant community. While some mycorrhizal fungi are not selective towards a particular plant species root, many are specific in their association with particular plant species. Douglas fir, for example, forms mycorrhizal associations with hundreds of fungi that are incompatible with other conifers, oaks or alders. Thus, as above-ground communities change, the diversity of mycorrhizal fungi below ground also changes.

Mycorrhizal diversity may also be closely tied to the structure or variety of forest communities within the forest ecosystem. Any change in the forest floor litter will affect populations of ECM fungi since they predominate in the immediate vicinity of fine roots and the organic layers of soil (Trappe and Goal 1977); Harvey at al 1979).

Any variety of trees or weeds left on a managed site will contribute substantially to maintenance of mycorrhizal fungi by providing essential nutrition, just as a variety of habitat types, such as large woody material on the forest floor, will promote fungal diversity.

Habitat diversity can also promote mycorrhizal diversity as conditions change within a growing season. In periods of adequate soil moisture, humus supports the highest level of ectomycorrhizal activity. However, during periods of drought, soil wood becomes the most active site (Harvey et al 1982; Larsen et al 1982).

In the past few decades, the extent of tropical forests has changed dramatically with the ever increasing demand for wood fiber and conversion to agriculture. Because above- and below-ground organisms are tightly linked, such changes result in dramatic losses which decrease hope for restoration of degraded sites through natural regeneration. With rapid conversion of tropical forest, it is imperative to collect and assess indigenous mycorrhizal fungi for successful establishment of tree plantations.

Mycorrhizal Diversity, Disturbance and Site Rehabilitation

Mycorrhizal fungi are not evenly distributed throughout the soil, but rather as islands of activity around roots. What happens to populations of mycorrhizal fungi when the energy inputs from plant roots are eliminated? Since mycorrhizal fungi are often entirely dependent upon utilizing carbon directly from the roots (they do not decompose organic matter for their energy source as other, saprophytic fungi do) they die, form resting spores or are replaced. If the energy source is not restored, populations of organisms depending upon those plants are lost or replaced by saprophytic organisms. The ability of forest soils to maintain viable populations of mycorrhizal fungi depends upon environmental, biological and physical factors. The ability of mycorrhizal fungus spores and hyphal fragments to survive without energy sources will vary with climate and soils. This activity period may be predictably shorter in the tropics where spore or fragment survival is limited by the higher respiration rates caused by warm temperatures.

The consensus is that inoculation of tree seedlings with mycorrhizal fungi is extremely valuable where the indigenous fungi are not abundant, where the introduced fungi will tolerate the site's conditions better, or where they are simply more effective under the existing site conditions.

In the long term, maintenance of mycorrhizal species may require continuation of natural patterns of disturbance to preserve patterns of succession. In temperate forests, periodic disturbance, such as fire, may be beneficial in that it promotes high species richness by creating a mosaic of habitat patches, species composition and successional stages. Successional stages of mycorrhizal fungi seem well established and they parallel disturbance in aboveground plant communities.

Forest practices that encourage succession, but reduce the biological diversity through intense organic matter loss, compaction and erosion, have a negative impact on mycorrhizal diversity.

Often not only the type of, but the severity of the activity is critical. For example, Parke (1982) found pine seedlings formed 20 percent fewer mycorrhizas in soil from unburnt clearcut and 40 percent fewer mycorrhizas in burnt clearcut than seedlings grown in undisturbed forest soil in northwest California and southern Oregon.

Deforestation provides the extreme of site disturbance. The challenge to tree planting or establishing plantations on already degraded sites in the tropics is to use technologies that restore mycorrhizal populations to planting sites, assure tree growth and production. To date, results from replanting activities in the tropics vary, even though much effort has been concentrated on tree selection and site preparation, because we have ignored mycorrhizal fungi as a vital component for restoration

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Conclusions

The biological diversity of natural forests and plantations is a product of the varied and often complex interactions both above and below ground level which develop through mutually beneficial associations. Species within the forest are strongly interdependent and, in many instances, their survival is being threatened by poor land management practices.

The vast majority of tree and shrub species form mycorrhizal associations with symbiotic fungi. This marriage convenience shapes and maintains the biological diversity of any forest system. Practices that influence the existence of either segment of this biological complex will significantly reduce the productive potential of the site.

Soil organisms, such as the mycorrhizal fungi, have evolved and are constantly interacting with the chemical, environmental and biotic factors that surround them. Each is adapted for specific activities which inevitably affect the function, growth and development of the above-ground plant associations.

The interactions of below-ground diversity and above-ground forest ecosystems were once viewed as interesting, but rather irrelevant phenomena. Increased and continued scientific study is finally highlighting their importance in the healthy functioning of ecosystems. From these studies, we now recognize that certain interactions, such as that between mycorrhizal fungi and plants, are undeniably essential.

Dipterocarp studies in Indonesia could have a major influence on the future of forestry throughout Southeast Asia. These new findings will change all this so that Southeast Asian forest planners will have to return to the drawing board and allocate these valuable species. This is a major role in forest planting and land rehabilitation. Vast areas lost to the ubiquitous and noxious imperata grass (Imperata cylindrica) could be recovered into dipterocarp forest. The logged-over, often burned forest land could be enriched with these indigenous species that would effectively maintain the presently endangered genetic diversity of the forest.

As we continue to develop approaches to conserve biological diversity in forest ecosystems, we must appreciate the inseparable connection to the diverse array of mycorrhizal fungi. The close mutualistic interaction between higher plants and mycorrhizal fungi is one key factor underlying forest health. Management practices must recognize the importance of maintaining growing conditions in the soil suited to beneficial microorganisms.

Soil organisms, such as the mycorrhizal fungi, have evolved and are constantly interacting with the chemical, environmental and biotic factors that surround them.

Unfortunately, there are areas where recognition of these organisms has come too late, the organisms have been greatly reduced or eliminated and the areas are now known as wasteland sites. A large amount of money is spent annually attempting to establish a vegetative cover on such areas.

For effective rehabilitation of deforested sites in the tropic and subtropic regions of Asia, trees along with an appropriate and diverse selection of mycorrhizae will be needed as components of forestation programs. The message which becomes clear from the extensive study of plan symbioses is that establishment practices must be directed at both the above- and below-ground communities. In some cases, direct inoculation will be adequate. But for sites that have long been without vegetation, establishment practices will have to be directed towards soil amelioration by whatever means possible.

In Praise of Turf

Lawn Maintenance From an Eastern Homeowner's Perspective

By Richard J. Hull

About three million years ago, our earliest ancestors flourished in the savannas of East Africa. This was a landscape dominated by grasslands and scattered trees. It was a good place for early humans to emerge since the grasslands provided food in the form of abundant game along with grains and other fruits. The trees provided protection from predators and materials for tool making.

Early hominids were encouraged to walk upright so they could look over the grass for danger and this, in turn, freed their hands for activities other than locomotion, such as carrying objects, using tools and weapons and signaling to others. In short, the East African grasslands constituted an environment ideally suite for the emergence of human. Grasslands supplied food, provided protection and encouraged enterprise in the making of tools, clothing, weapons and objects of art.

When present-day people are given a choice of preferred landscapes, those in which they feel secure, but also find interest, they invariably chose open, park-like settings involving a low, nonrestricting and nonthreatening ground cover and trees.

When present-day people are given a choice of preferred landscapes, those in which they feel secure, but also find interest, they invariably chose open, park-like settings involving a low, nonrestricting and nonthreatening ground cover and trees (Ulrich 1986). The inclusion of a water feature also increases affinity for the landscape. It appears that we carry within our subconscious an innate appreciation for the landscape that sustained our distant ancestors and promoted the advance of human society. It is, therefore, not surprising that when people design landscapes in which they feel secure and comfortable, they invariably include a broad expanse of closely mowed grassland, tall shade trees and a pond or flowing stream.

The English garden, that reached its fullest development in the 18th Century, faithfully incorporated these basic landscape elements in a highly formal style. A century later, more naturalistic treatments of the same design elements were introduced to America by landscape architects, such as Frederick Law Olmsted. Again, those open, unconfined landscape features that people find reassuring and pleasing were freely incorporated in both formal and naturalized renderings of domestic and public landscape designs.

It should come as no surprise that contemporary domestic landscapes invariably incorporate broad expanses of open lawns with tall shade trees and marginal plantings of shrubs and herbaceous flowering plants. Where individual lot sizes are small, merged front lawns provide broad open expanses and a community landscape emerges. I contend that what some have described as an American obsession with lawns may be, in fact, a response to much deeper fundamental human needs.

People respond favorably to a vegetated environment. The simple knowledge that an area of lawns and trees is in their neighborhood increases people's sense of well being and connectedness to their surroundings (Kaplan and Kaplan 1989). The ability to observe a parklike setting from a hospital window was shown to increase the recovery rate from surgery and reduce the incidence of postoperative complications (Ulrich 1984). These psychological and physiological benefits of an environment endowed with trees, lawns and ornamental plantings are being recognized. Such planted areas are increasingly being incorporated into the design of office buildings, shopping malls, and urban renewal projects.

In designing the home landscape, these less tangible factors are especially important. There, plants exert their psychological and therapeutic benefits but in a multiple use context. Home grounds serve far more than an aesthetic function. This is where children play, residents relax, families gather and parties are held. For these purposes, the lawn plays a central role.

Lawns are open, unencumbered, nonthreatening and inviting. A broad expanse of lawn virtually calls out to grab a Frisbee, throw a softball, set up a badminton game, etc. Few surfaces are safer for children to play with less chance of injury. A well maintained lawn provides a thick cushioned surface, offers little attraction for bees or other stinging insects, and has even been found to contain many fewer deer ticks than adjacent woodlands or rough, unmown areas (Maupin et al. 1991). Other ground covers may offer a similar aesthetic benefit but none is as suitable for or tolerant of human activity as a well maintained lawn.

Dr. James Beard, the generally recognized dean of turfgrass science, enumerates several practical advantages of turf over other land covers (Beard 1996). These include the cooling effect of transpiring leaf surfaces without obstructing the free flow of air. It has been shown that homes surrounded by lawns and other vegetation have significantly lower air conditioning costs than similar homes surround by paved or sparsely vegetated surfaces.

Lawns capture water and promote infiltration, thereby preventing runoff and contributing to the recharge of underground water reserves. The structure of a dense turf provides innumerable channels by which rainwater will enter the soil. The density of turfgrass plants and surface thatch accumulation increases the retention of water within the turf and reduces runoff.

In a study conducted at Pennsylvania State University (Linde et al. 1998), researchers found that to measure significant runoff from turf covering a 9 to 11 percent slope, irrigation water had to be applied at 5.5 inches per hour. This is equivalent to a once in a hundred year rainfall event. In short, lateral runoff from turf is in most places a rare events and turf is among the most water conserving ground covers known.

The ability of lawn turf to prevent runoff greatly reduces water discharge into storm drains, thereby reducing the incidence of sewage outflow and contamination of streams, ponds, lakes or bays. While comparative research is limited, the structure of alternative vegetative covers is such that their ability to retard runoff would generally be much less than that of a dense turf.

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Turfgrasses build soils. Grasslands have created some of the best soils on earth. Most of the deep fertile soils of the Midwest and Plains states evolved under a cover of perennial grasses that were regularly grazed and burned. A well maintained lawn also has the capacity to improve soil quality. For many residential sites, this may be a lawn's most important function.

A Kentucky bluegrass turf produces up to 14,300 pounds of roots per year, about 50 percent of which turns over and contributes directly to soil organic matter (Beard 1996). The organic components of a soil increase its water and nutrient holding capacity and improve soil structure, which favors increased aeration. This, in turn, promotes further root growth, as well as large populations of earthworms and other beneficial soil animals. You may have noted that sod farmers never appear to reduce their soil level even though small amounts are removed with each harvest. The turf generates more new soil materials than would likely ever be removed by sod harvesting.

Lawn turf also conserves soil. Few ground covers can equal grasses in preventing soil erosion caused by water flow or wind. Soil erosion can clog drainage systems and disfigure the land and water bodies. Lawns contribute virtually nothing to the erosion load and actually serve as effective buffer zones separating and protecting water bodies from the overland flow of water and sediments originating from upland sites. Dust and other atmospheric particulate matter are readily captured by turf and other vegetation, thereby improving air quality. In urban and suburban areas, this can be an especially valuable function of landscape vegetation.

Lawns along with other vegetation provide a number of useful services, such as noise abatement, removal of gaseous pollutants (carbon monoxide, sulfur dioxide and nitrogen oxides) from the air, wildlife habitat and glare reduction. In the dry western states, lawns have been shown to provide homes substantial protection from wild fires.

This substantial litany of benefits offered by turf must come at some price. There must be a downside to maintaining a lawn. While the negative aspects of home lawns have been much publicized, the reality is actually not all that bad. It mainly comes down to the intensity of lawn management that is practiced, which in turf is based on the standards set for a turf area.

Many homeowners are concerned over the possibility of contaminating their wells with fertilizers and pesticides used on their lawn. This issue has been extensively researched throughout the country and found to be essentially no problem.

Those who want a lawn comparable to the turf seen on televised golf tournaments might have to make a substantial investment in materials and labor. On the other hand, a perfectly functional lawn, one that provides all the benefits mentioned above, can be had with comparatively little effort or cost. There is not sufficient space for me to expand on lawn maintenance to support adequately the previous statement, but a few points can be made.

Most well established lawns need little water, fertilizer or pesticides. The validity of this statement centers on two simple practices: leaving the clippings where they lie and mow high (between two and three inches). Many homeowners ruin their lawns by removing clipping and cutting their grass too short. If clippings are retained, nothing is removed from the lawn and therefore little needs to be replaced.

A two- to three-inch cut will provide grass plants large enough to grow a deep extensive root system that will be better able to absorb nutrients and water. Such a lawn will also compete more effectively with weeds and shade the soil surface sufficiently to prevent many annual weed seeds from germinating.

If it fails to rain, water only those lawn areas that are critical, highly visible or heavily used. Even then, water deeply but infrequently. This will promote deeper rooting and conserve what water is present by reducing transpiration. If a lawn is not watered during a drought, it will turn brown, but will green up again as soon as the rains return. A lawn composed of good turfgrasses is rarely killed by drought unless it is subjected to heavy wear or improper irrigation.

Fertilize sparingly, concentrating on the late fall and early spring. One pound of nitrogen per 1,000 square feet per year will normally suffice. Again, this depends on not removing clippings. Such a regimen will not produce the thickest turf in shaded areas but might permit the encroachment of wild flowers, such as bluets and violets, which can be welcome additions. Such plants will not tolerate the use and abuse to which lawngrasses are often subjected. Some restrictions may be in order. Where you want a thick lawn, use ground limestone to bring the soil pH to about 6.0 to 6.5 and use superphosphate to maintain adequate soil phosphate levels. Use potassium and nitrogen in about equal amounts.

Many homeowners are concerned over the possibility of contaminating their wells with fertilizers and pesticides used on their lawn. This issue has been extensively researched throughout the country and found to be essentially no problem. Nitrate is the most troublesome fertilizer component because it is produced within the soil regardless of the form of nitrogen fertilizer applied (organic or inorganic). It is also highly mobile within the soil and can easily leach into ground water during periods of heavy rain. However, the extensive root system of grasses absorbs nitrate readily and efficiently removes it from the soil water (Petrovic 1990).

Most researchers have found that that only five to ten percent of applied nitrogen is lost from turf via all routes (except clipping removal) and nitrate leaching normally accounts for about half of that. In a comparison of several suburban/rural land uses, Golf et al. (1990) reported that a well maintained home lawn leached less nitrate to ground water than any land use studied with the exception of an unfertilized native forest. Any nitrate contamination of ground water in residential areas is probably derived from septic systems and leach field and not from fertilizer applied to the lawn.

The situation with respect to pesticides is equally encouraging. Most home lawns receive relatively few pesticide applications, mostly herbicides for broad-leaved weeds and crabgrass. Even lawn care companies almost never use fungicides or nematicides and apply insecticides only on an as-needed basis, if at all. Most encouraging is the observation that many pesticides have a strong affinity for the thatch layer found on the soil surface of most turf. Here pesticides are retained and degraded and very little ever actually enters the soil. In the soil under turf, microorganism populations are so active that any pesticides passing through the thatch are quickly decomposed. The net effect is that very few pesticides or their metabolites leach through a turf layer and are rarely found in ground water (Kenna 1995).

A lawn is an important, if not integral, part of the domestic landscape. Most outdoor activities take place on a turf covered surface. These living green carpets not only serve their utilitarian function but also contribute beauty and enhance the environmental quality of the urban/suburban landscape. One can effectively argue that lawns are often too large and domestic landscapes should be more diverse. This is a matter of judgment and taste and I will not challenge such statements.

What clearly is not supported by the scientific record, however, is the notion that lawns and their maintenance are somehow harmful to the environment and should be replaced by safer ground covers. A green living environment enhances the human spirit and provides a feeling of security and tranquillity. Lawns are part of such a setting and those who enjoy them need not be concerned over whether they are personally irresponsible for feeling that way.

Dr. Hull is a professor of Plant Science at the University of Rhode Island. He has studied turfgrass nutrition and ecology for more than 30 years. This article was initially published in the newsletter of the Rhode Island Wild Plant Society (Sept. 1999) in response to a "Why Mow" theme presented by the Society.

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Taking soil samples

Soil sampling — collecting soil for laboratory testing — is the first step in the process of determining the levels of plant nutrient elemetns at a particular site. Accurate soil testing and interpretation of the results begins with the proper techniques for sampling. Any mistakes made in sampling can lead to improper management strategies and wasted time and money.

Where sampling is done depends on the type of information the turfgrass manager is seeking. General sampling is done on a site or sites where the topographic, management, use and environmental conditions are similar. Problem site sampling should be done where information about a specific site or problem area is needed.

General and problem area sampling

General sampling is done to get an overview of nutrient levels and their balance over a large site(s) with consistent conditions. General samples should be taken so that theya re representative of the whole site and should not include any soil from any problem areas within the sampling site. The number of samples taken from any given area within a site should be relative to the relationship of the square footage of the area to the total square footage of the site.

For example, if the site can be divided into three areas A, B and C, and the relationship of the square footage of each area is 3 to 2 to 1, then three samples should be taken from area A, two from area B and one from area C.

Consistently following this practice will assure that sampling will accurately reflect the nutrient levels of the whole area at the time of testing and that comparison of current and future testing results will provide an accurate long-term picture of the nutrient levels of that site.

Specific or problem-area sampling is done to areas of limited size within a site which have specific conditions that are different enough from the general site conditions that the area exhibits symptoms inconsistent with the whole site.

Problem-area sampling should be done only when the other possible causes of turfgrass decline (insect, diseases, traffic, compaction, management, etc.) have been eliminated.

Sample cores should be taken in a uniform manner and only from within the problem area. Also, another separate test sample should be taken from just outside the problem area to provide a comparison.

Sampling volume, depth and frequency

The miminum amount of soil that is needed for testing is about one cup. If you are sampling from a large site with 30 to 50 cores, the individual cores can be thoroughly mixed and the one cup sample can be obtained from the mixture. On smaller sites, the minimum number of cores that should be taken is seven or eight.

The soil sample should be taken where the largest mass of roots for a particular species occurs. The following table illustrates where in the soil profile the mass of roots occurs for bluegrass, bentgrass and bermudagrass.

TABLE 1

Percent of root mass profile

Depth	Bluegrasses	Bentgrasses	Bermudagrasses
0 to 3 in.	89%	83%	80%
3 to 6 in.	7%	13%	12%
6 to 9 in.	4%	4%	8%

For all three species most of the root mass occurs in the top three inches; therefore, sampling should be confined to the top three inches of the soil profile. Try to avoid including cores that are less than three inches in the sample, if possible. If three-inch cores are not available, increase

ADDITIONAL TIPS ON SOIL SAMPLING

The following techniques apply no matter what information is being sought:

- Sampling can be done any time the soil is not frozen.
- Above ground, undecomposed thatch that has no roots growing in it should not be included.
- Thatch that is decomposed and has a substantial portion of roots growing in it should be included.
- Plastic buckets and mixing utensils should be used to collect large multisite composite samples.
- Avoid using any galvanized utensils or buckets in taking or mixing cores as they may contaminate the samples.
- Wait at least two weeks after a fertilizer or amendment application before sampling.
- Remember that pH readings are generally higher in cool weather.
- Clean all sampling equipment after each sample is obtained, as residues from one site can affect the results for another site.
- Establish a consistent method and frequency of testing so the results of repeated testing can be accurately compared.

the number of cores in the sample to compensate for the lost soil volume.

In established, stable, well-balanced higher C.E.C. (Cation Exchange Capacity) soils (>15), bi-annual sampling should be enough. In less stable, established but well-balanced lower C.E.C. soils (<15), annual sampling is necessary. In poorly balanced soils, no matter what the C.E.C., annual or semi-annual sampling is essential.

Where monitoring of just soil pH is required, sampling can be done two to four weeks after an amendment application has been made. Newly constructed or renovated areas should be monitored up to four times a year, as nutrient levels will change rapidly in these unstable soil conditions.

No matter what sites you are testing and no matter which techniques you are using, be consistent. Once you have selected the boundaries of a sampling site, do not change them. Once you have established a sampling technique for a site, do not change. The information in soil test reports is only as good as the sampling techniques that you employ.

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