

## TREES AND MYCORRHIZA

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### 1. INTRODUCTION

Mycorrhiza represents a very remarkable and unique relationship between the feeder roots of higher plants and certain fungi that live in close association with

them. In this association, the fungi increase moisture and nutrient uptake and also protect the roots from many pathogens. They, thus, compete or cooperate with adjacent fungal hyphae. Mycorrhizal hyphae of the same compatibility group may fuse, creating a single mycelial network similar to the root grafting phenomenon in plants. The resulting mycelial network may encompass several host plants, often belonging to different species. While mycorrhizae form a part of the root system, the fungi do not occupy all of the root length. They are associated mostly with the finer absorbing roots (Harley and Smith, 1983). These occur closer to the soil surface in tropical and temperate forests. In arid soils, they are concentrated at the depths where the roots proliferate, near the permanent water table below the sand layer.

A wide range of fungi including some of the fastidious Zygomycetes, Ascomycetes and Basidiomycetes, form mycorrhizal association with members of the same family or others. Stahl (1900) recognized that different host species responded differently to mycorrhizal infection; he divided plant families into (a) non-mycotrophic, (b) facultatively mycotrophic and (c) obligately mycotrophic.

Mycorrhizal fungi can colonize the roots of even the non-mycotrophic plants (Tommerup, 1984). In many such cases they may even act as parasites. Woods and Brock (1964) suggested that forest trees can share resources *via* their mycorrhizal hyphae. They cut down one individual tree, labelled the stump with isotopes of Ca and P, and traced the isotopes in several surrounding individuals. Chiarello *et al.* (1982) found a similar pattern in an annual mycorrhizal community (Whittingham and Read, 1982; Francis, *et al.*, 1986). Brownlee *et al.* (1983) and Finlay and Read (1986) found that  $^{32}\text{P}$  flow was unidirectional. The mycelial network picked up the  $^{32}\text{P}$  from a single point and transported it through the mycelial network which encompassed several plants.

Grime *et al.* (1987) found that the incorporation of mycorrhizae increased the diversity of the community by increasing the mass of the subordinate individuals, thus suggesting an equalised resource allocation. However, Caldwell *et al.* (1985) had demonstrated that even if plants were interconnected, nutrients were preferentially acquired by one individual over the neighbour. Apart from nutrient mobilization and distribution, they also play a significant role in root-pathogen interactions. Protection from root pathogens by blocking entry points, altering the host physiology by changing the composition of root exudates, depletion of nutrients that could be otherwise used by pathogens are some of the mechanisms of protection afforded by mycorrhiza.

Manipulating these complex symbiotic relationships to the advantage of the farmer had been the mission of many workers. Fungi belonging to the Basidiomycetes and Ascomycetes have been cultured and are amenable to large scale multiplication *in vitro*. In contrast, many of the Zygomycetous fungi can be grown only in association with the host roots. Even then, since most of these are capable of multiplying in association with grasses and millets, production of active inoculum is possible.

Currently, mycorrhizal research is on the threshold of a new phase of development where host-specific/ preferential associations have been identified for several plants, including the plantation crops. The role of VAM in rapid mobilization of P

to make it available to the hosts has been clearly established. Just as the N-fixing organisms are cultured for use as bio-fertiliser in agriculture, the production and use of mycorrhizal inoculum offer promise for efficient nutrient mobilization and providing physical barrier against soil pathogens. Molecular biology studies may help in unravelling the mystery of the obligate nature of the symbiosis, and thus facilitate the multiplication of many of these fungi in the laboratories, and subject them to genetic manipulation to produce more efficient strains.

Work is in progress in studying the specific polypeptides known as "mycorrhizins" induced by mycorrhizal infection, and the processes involved in their production. Dikaryons of *Pisolithus* sp. and *Laccaria bicolor* showing wide variability have been synthesized in the laboratory. Plant breeders have even thought of evolving pulse varieties responsive to mycorrhizal infection (Mosse, 1990).

Thus, this branch of science called as 'Mycorrhizology' has come to stay to help reap richer harvests from Nature while living in harmony with her in an ecofriendly soil environment.

## 2. HISTORICAL PERSPECTIVE

The early reports on mycorrhizae were quite sketchy, incomplete and often misinterpreted (Trappe and Berch, 1985). The earliest report about this phenomenon of symbiotic root infection by these fungi was by Meyen (1829). According to Hatch (1973), Elias Fries of Sweden was the first to recognize the fungal nature of the outer covering of *Monotropa* roots (Fries, 1832). In 1840, Hartig (Theodore) published the 'Complete natural history of the cultivated forest plants of Germany' in which he has provided diagrams of roots of various types and their longitudinal sections. He has described the fungus mantle around the ectomycorrhizal roots as persistent 'periderm'. The intercellular fungal network was referred to as 'peculiar wall structure'. He also described the development of the white swollen asparagus type of structures that grew and swelled during spring through summer and which later shrank and became brown during winter. Thus, even though incomplete and misinterpreted, he was the first to observe the fungus mantle and the 'Hartig net'. This intercellular 'Hartig net' was later brought to the notice of the world by Robert Hartig (1886), the illustrious son of Theodore Hartig, and also the father of forest pathology.

Unger (1840) described the intimate relationship between roots of *Monotropa hypopitys* and *Picea abies*. His suggestion that *Monotropa* obtained nutrients indirectly from tree roots, though not based on the fungal connection between the two species, was closer to being correct than were other hypothesis of the times. This has kindled interest in *Monotropa* roots and many observations were published in the journal 'The Physiologist'. Lees (1841) described the root system of *Monotropa hypopitys* and associated beech roots. He added a critical comment that 'the whole root mass is observed with a hirsuture that appears like a byssoid fungus. A close examination shows ultimate hairy fibres fixing the roots of *Monotropa* to the rootlets of the beech and seeming to absorb nutrients from the alburnum of the latter'. Thus,

though he did not consider the hairy fibres to be fungal, he almost proposed that a mycorrhizal fungus provided nourishment to its host and that achlorophyllous plants are epiparasites on associated trees by way of a shared mycorrhizal fungus, a hypothesis that was first experimentally verified by Bjorkman (1960). Rylands (1942) confirmed that the 'byssoid substance' was fungoid. However, he did not feel that they performed any essential function in the economy of 'Monotropa'.

Later the Tulasne brothers (Tulasne and Tulasne, 1841) detailed the intimate relationship between tree rootlets and *Elaphomyces granulatus* (Hypogenous Ascomycete), although they did not mention a fungal mantle on the rootlets themselves. They felt that the fungus parasitised the rootlets, because that was the ordinary condition of the lower plants in general. They pointed out that the sphere in which *E. granulatus* was enclosed was always composed of a single species and that the roots were alive while the fungus lived, and weakened and dried when the fungus dies. Thus, they could recognize the fungal involvement in Ectomycorrhizae. Vittadini (1842) had a different interpretation. He said 'it is our decided opinion, that beyond all doubt the higher plants absorb nutrients from the fungus by their rootlets'. Thus he was the first one to state that roots derive nourishment from the fungus. He did not believe that the relationship was mutualistic.

Nageli (1842) while examining the roots of several *Iris* species frequently observed fungal structures within old cells. He found structures that could be equated with arbuscules and vesicles. He did not detect the entry of these fungi into the roots nor traced their origin. However, he did not believe that their origin was by spontaneous generation. Later in 1847, Reissek presented a description of endophytes in orchids. He found their presence to be quite a common thing in many species of orchids. However, he did not believe that the root fungus was absolutely necessary for the growth and reproduction of orchids. He is also credited to have used root maceration techniques for isolating and growing the endophyte *in vitro*. Schacht (1854) corroborated many of the observations of Nageli and Reissek. He subscribed to the idea that these endophytes were fungi and they penetrated and entered the root from outside, and were definitely not products of spontaneous generation.

Pfeffer (1877) proposed the idea of mutualism in fungus-root associations. Frank (1877) presented this concept more convincingly for the fungus-alga associations. He proposed the term 'Symbiotismus' - a living together in which both organisms benefited from a mutually balanced relationship. This term was the forerunner of the word 'Symbiosis' - a term elaborated upon by de Bary (1879). During this period, scientists also got interested in the relationship between conifers and truffles (Rees, 1885).

Kamienski (1881) described the morphological and anatomical details of the relationship with *Monotropa hypopitys* and fungal symbionts. He concluded that the fungi play the role of a mediator in nutrient uptake for the achlorophyllous humus-dwelling *Monotropa*. Gibelli (1883) observed the much branched rootlets in *Quercus*, *Corylus*, *Ostrya* and *Carpinus* roots and designated them as 'Coralloid' structures, a term used even today. He regarded the condition as parasitic not pathogenic and with very little detrimental influence on the host.

A.B. Frank, a distinguished German forest pathologist, commissioned to promote truffle-growing in Prussia, is the one who coined the term mycorrhiza. He derived this term from the Greek word 'Mykorhiza' to denote the mutualistic association between the host tree and the fungus which covered its roots without causing any detriment to the tree. He found that the fungal mantle covered the tree rootlets completely. From this, the hyphae penetrated root and grew between the cells. Hyphae also grew outwards into the soil. Trees when infected in the first year remained so throughout life. Frank showed that mycorrhizal infection was a beneficial symbiosis between trees and fungus. By the beginning of the 20th Century, ectomycorrhiza was accepted as a normal phenomenon in most of the woody plants. Observations made by Frank suggested a correlation between the abundance of mycorrhizae and humus content of soil leading to the view that mycorrhizae are concerned with the utilization of compounds found in the forest humus and passing them onto the host.

Subsequent workers recorded the close relationship between the fruiting bodies of the traced mycelium of fungi and mycorrhizal roots. The ectomycorrhizal organs were also classified into species (Peyronel, 1917). Melin (1917) was the first to isolate, culture and back inoculate fungi of ectomycorrhiza. Many of the fungi thus collected were cultured and subjected to physiological studies.

Stahl (1900) opined that intense mycorrhizal development can be correlated with the paucity of available nutrients. This was corroborated by the observations of Melin (1917) and that of Hatch (1937) who concluded that within the saturation range, better nutrition increased both growth and mycorrhizal development, but above this level, low or unbalanced supply of nutrients (NPK) increased infection. The positive correlation between mycorrhizal infection and nutrient uptake was demonstrated by Bjorkman (1942). Studies by Warren Wilson (1951) brought out the important finding that infection of seedlings takes place after the primary leaves come out. Fries (1941), Rayner and Nielson-Jones (1944) studied spore-germination and related phenomena, and concluded that mycorrhizal fungi are ecologically obligate biotrophs, dependent on their host for carbon compounds and growth factors. The hosts in turn are obligate symbionts in soils of low or unbalanced nutrient supplying power.

The existence of heterorrhizic root systems in ectomycorrhizal trees was understood by Hatch and Doak (1933). It was clear that the state of mycorrhizal roots in *Pinus* was due to the properties of the rootlet itself as well as to the effects of the fungus which generated continued growth and branching. Slankis (1948) explained that the exudates of *Boletus variegatus* an ectomycorrhizal fungus and of dilute  $\beta$ -indole acetic acid solution had similar effects on root growth and proliferation.

Through the years 1917 to 1950, researches indicated that fungal infection increased growth and nutrient uptake. In soils of moderate nutrient deficiency mycorrhizal seedlings grew faster in height and weight and they tended to have lower shoot/root ratios (McComb, 1943). Mycorrhizal plants contained more of N, P & K compared to controls. The fungi were not efficient solubilizers (Mitchel *et al.*, 1937; Stone, 1950). Harley and McCready (1950) and other workers made use of radio-isotopes to study phosphate uptake in ectomycorrhizal plants.

By about 1900, the wide prevalence of endophytic vesicular arbuscular mycorrhiza was well-known. Dangeard (1900) gave evidence of VA mycorrhizal presence in poplar roots. He sketched the fungal structures like vesicles and arbuscules and called the fungus to be '*Rhizophagus*' and assigned it to Chytridiaceae.

Janse (1896) named the 'Vesicles' as 'Vesicules' (French), and was also the first one to use KOH to stain infections in coffee roots. The objectives of subsequent investigations were (1) to study the occurrence of VAM in different plant families or geographic locations (Peyronel, 1924; White, 1929; Jones, 1924), (2) to compare mycorrhizal and non-mycorrhizal plants (Laycock, 1945) and (3) to identify and culture mycorrhiza (Butler, 1939; Stahl, 1949).

After the initial spurt of activity a dull period followed. Again in 1950's there was a resurgence of activity in the VA mycorrhizal field. Text books fully devoted to mycorrhizae began to appear (Kelly, 1950). Mosse (1953) evolved the technique of establishing pure pot cultures of VAM fungi. Gerdemann and Nicolson (1963) learned to sift out the mycorrhizal spores from the soil using the nematological sieves and established pot cultures of several species. Many have even tried culturing VAM in cell free extracts (Adholeya and Khanna, 1990; Becard and Piche 1991).

Effects of mycorrhizal inoculation on plants were a favourite subject of many scientists and this included tree species, especially during the juvenile stage (Mosse and Hayman, 1971; Narayana Bhat, 1991). Gerdemann (1975) and Menge *et al.* (1980) proposed the concept of mycorrhizal dependency of a host, and Plenchette *et al.* (1983) gave it a numerical expression as, the ratio of the weight of a mycorrhizal plant compared to a non-mycorrhizal plant converted to percentage.

Another important landmark was the development of a technique of clearing and Trypan-blue staining of roots developed by Phillips and Hayman (1970). Many visual methods were developed for quantifying mycorrhizal infection in roots (Giovanetti and Mosse, 1980). Techniques for assaying mycorrhizal inoculum using the most probable number (of infective propagules) has become quite popular (Porter, 1979). Thus, mycorrhizal studies are now poised to take a quantum leap into the future, and their uses in nutrient mobilization, pathogen suppression and enhancement in growth, are becoming active fields of investigation the world over.

### 3. CLASSIFICATION OF MYCORRHIZA

Based on the host-fungus relationship the mycorrhizae have been classified into the following seven categories (Harley and Smith, 1983).

#### *Endomycorrhiza*

Some of the phycomycetous fungi belonging to the family Endogonaceae are not known to occur in the free-living form. They are difficult to be brought into culture. These form mycorrhizal associations with a wide variety of plants, belonging to the Bryophyta, Pteridophyta, Gymnospermae and a majority of families of the Angiospermae- herbs, shrubs and trees. They have aseptate hyphae and form coralloid intracellular structures known as the arbuscules and produce swollen

vesicles of various shapes. They form solitary spores or well organised sporocarps inside or outside the host. These are the 'vesicular arbuscular mycorrhizae', abbreviated as VAM.

### *Ectomycorrhiza*

This form of mycorrhiza is widely prevalent among the tree species, especially under subtropical and temperate regions. Basidiomycetes belonging to Amanitaceae, Boletaceae, Cortinariaceae, Russulaceae, Tricholomataceae, Rhizogonaceae and Sclerodermataceae (Marx, 1972) are the fungal symbionts often encountered in these associations. Tree species belonging to the families Pinaceae, Salicaceae, Betulaceae, Fagaceae, Tiliaceae, Rosaceae, Leguminosae and Juglandaceae are the other components (Meyer, 1973). In this type of association the ectomycorrhizal fungi form a structure called mantle or sheath which encloses the rootlet. From this, hyphal strands radiate outwards into the substrate. Hyphae also penetrate inwards between the cells of the root to form the 'Hartig net.' At times or as a stage in development, the 'Hartig net' may become totally absent. This state is known as 'perirhizic' mycorrhiza. In this, the external cells of the host in contact with the fungal sheath are modified as transfer cells. Members of *Endogone* while forming ectomycorrhiza usually have a very thin sheath and well-developed 'Hartig net.' However, the fungus does not invade the cortical cells.

### *Ectendomycorrhiza*

In this form, the sheath may be much reduced or even absent. The 'Hartig net' is well developed and the hyphae also penetrate into the host tissues.

### *Arbutoid mycorrhiza*

This form has a well developed 'Hartig net'. Sheath is usually much reduced or even absent. The fungal hyphae penetrate into the cells of the host. In addition, there is intracellular penetration. They form fungal coils in the cells. These fungi belong to Basidiomycetes and the hosts belong to Ericales.

### *Monotropoid mycorrhiza*

The monotropoid mycorrhizal roots are found among the members of 'Monotropaceae', a set of achlorophyllous plants. They have a well developed fungal sheath enclosing the roots. From this, the hyphae run between the cells of the epidermis or cortex forming a network (Hartig net). Specialized unbranched haustoria penetrate the epidermal cells and go through a complicated developmental pattern as the host plant grows and flowers. The fungus is often associated with the mycorrhizal roots of neighbouring plants.

### *Orchidaceous mycorrhiza*

Here also the autotrophs may be wholly or partially achlorophyllous for part of their life cycle. They are associated with Basidiomycetes that are capable of decomposing lignin and cellulose. The fungus penetrates the host tissue, and after

a period of vegetative activity, undergoes general or local disintegration. In certain cases, the orchids may be associated with fungi that are actively parasitic on other autotrophic plants and thus get nutrients siphoned out of them.

### *Ericoid mycorrhiza*

In many Ericaceae and related families the hair-like roots are enmeshed in an extensive external web of hyphae which also penetrate the cortical cells of the rootlet. These fungal symbionts usually are members of Ascomycetes. The Basidiomycete genus *Clavaria* has also been found to form mycorrhizal association. Ericoid mycorrhizae normally do not form the sheath.

Of the seven types of mycorrhizae, the most important ones, ectomycorrhizae and the endomycorrhizae, are discussed below.

## 4. ECTOMYCORRHIZAE

### 4.1. Host Specificity

Ectomycorrhizae have been found to be selective in nutrition. Due to their relative inability to use cellulose or lignified materials as carbon sources, they rely on simpler carbohydrates. Thus as a group, they depend on plant roots for their sustenance. This is corroborated by the fact that many of them are not able to form fruit bodies when detached from their hosts (Laiho, 1970). It has also been observed that most species of Ectomycorrhizal fungi are not host specific. However, wide variability exists among the species.

The ability of a single species of host to form mycorrhizae of more than one sort is widespread. Under natural conditions they may form either ectomycorrhiza or vesicular arbuscular mycorrhiza; species of *Pinus* may form ecto-or ectendomycorrhiza.

Mycorrhizal fungi are perennial in nature and need a permanent food base from where they can translocate food to their growing tips. They use products of current photosynthesis. Thus non-specificity to particular hosts is of selective advantage to the fungus for its survival in that particular ecological niche. It is quite common to find that the same plant hosts a number of symbionts. Trappe (1962) found that at least eight different species of fungi could form mycorrhiza with *Betula pendula* and *B. pubescens*. Giltrap (1979) expanded this list to accommodate 40 species of basidiomycetes that form mycorrhiza with *Betula*. Similarly, *Pinus sylvestris* and *P. strobus* (Harley and Smith, 1983) have been reported to be harbouring more than two dozen species of fungi belonging to about a dozen genera.

However, there are certain plants which form mycorrhiza with a limited number of fungi. *Alnus* is one such plant where from among the 30 or so fungi present in the community only five of them form mycorrhizal association with *Alnus* (Molina, 1979).

Molina and Trappe (1982) reported sporocarp specific host associations. This could be restricted to a particular species (narrow host range), a single genus or a wider group (wide host range). This has been, therefore, referred to as ecological specificity; eg. *Laccaria laccata* and *Pisolithus tinctorius* are conifer-specific fungi,

whereas *Alpova diplophoeus* is specific to *Alnus*. *Rhizopogon* fruits only with members of pinaceae.

Another feature of these associations is that, in young plantations though a large number of fungi thrive, as the plantations age, many fungi are eliminated (Malajczuk *et al.*, 1982). This may be due to a shift in root exudates, accumulation of litter and leachates from them, exhaustion of nutrients, gradual accumulation of phenolics and similar compounds, shifts in soil reaction etc. These types of shifts have far-reaching influence, especially in replanting programmes when establishment of seedlings becomes difficult unless supplemented with necessary symbionts.

#### 4.2. Plant Response to Ectomycorrhizal Fungi

There is evidence that ECTM fungi increase nutrient uptake (Lee, 1982). Ashton (1956) found that growth of *Eucalyptus regnans* was increased by 184 per cent in 17 months when inoculated with *Mesophellia* sp. Pryor (1956) obtained 88 per cent increase in the growth of *E. devis*, *E. pauciflora* and *E. macrorhyncha* after 6 months of inoculation with *Scleroderma* sp. *Laccaria laccata* promoted growth of *E. globulus* seedlings by 220 per cent (Burgess and Malajczuk, 1989). Positive response of Caribbean pine to inoculation with *Rhizopogon leuteolus* was reported by Ekwebelam (1979). Similar results were recorded in inoculations with *P. tinctorius* and *L. laccata* (Lee, 1982 and Valdes *et al.*, 1983). Quintos and Valder (1987) reported that 90 per cent of the *P. tinctorius* inoculated pine seedlings were mycorrhizal compared to 60 per cent of the uninoculated control. Volume and dry weight were increased by 165 and 60 per cent respectively over control. Heinrich and Patrick (1986) found that inoculation with ectomycorrhizal fungi increased P-uptake in *Eucalyptus*. Total N & P content of *Pinus densiflora* seedlings inoculated with *P. tinctorius* increased by 188 and 144 per cent respectively over control (Lee, 1982).

#### 4.3. Ecto-Endo Mycorrhizal Complex

The complex of ecto-endo mycorrhizae was more efficient than when individually present in some forest trees. Complex of *G. mosseae* and *Paxillus involutus* increased the dry weight and P-content of hybrid poplars more than either fungus (Lopezaguillon & Garbaye, 1989). In *Eucalyptus*, VAM fungi were more prevalent on young seedlings whereas ECTM fungi took over as the plant aged (Chilvers *et al.*, 1987). However, both types of symbionts could be present simultaneously in the cortex of the same root. The VAM fungi colonized the inner part of the cortex whereas ECTM fungi were restricted to the outer cell layer (Boundarga *et al.*, 1990). In *Eucalyptus* sp., *G. fasciculatum* and *P. tinctorius* form physiologically active and efficient mycorrhizae (Boudarga & Dexheimer, 1988).

#### 4.4. Root Pathogens and Ectomycorrhizae

Many mycorrhizal fungi not only help to improve seedling growth but also protect them against diseases (Molina, 1982). Zak (1964) suggested that

ectomycorrhizal fungi in addition to their physiological influence on plants, may also protect the delicate unuberized feeder roots from attack by pathogens. Sasek and Musilek (1968) found that certain ectomycorrhizal fungi inhibited *Rhizoctonia solani*, *Pythium debaryanum* and *Fusarium oxysporum*. Sasek (1967) grew pine seedlings on polyurethane discs floating in liquid medium. *Scleroderma aurantium* has also been shown to reduce the incidence of disease caused by *Pythium* and *Fusarium*. *Suillus bovinus* was effective against *R. solani* while *Amanita citrina*, *Lactarius helves* and *Rusulla fragilis* were effective against *P. debaryanum*. *Fomes annosus* was inhibited by antibiotics produced by several ectomycorrhizal fungi (Sasek and Musilek, 1968). Hyppel (1968 a & b) also demonstrated that water-soluble inhibitory compounds produced by *Boletus bovinus*, a fungi symbiont of *Picea abies* (Norway spruce), protected the seedlings from attack by *Fomes annosus*. Marx (1969a) found that *Leucopaxillus cerealis* var. *piceina* inhibited *F. annosus* slightly while severely inhibiting *Cylindrocladium scoparium*, many species of *Pythium*, *Rhizoctonia*, *Phytophthora* and *Polypus* and *Sclerotium bataticola*. However, it did not afford protection against *Armillaria mellea*, *Fusarium oxysporum*, *Rhizoctonia crocorum* and *Thanetophorus cucumeris*.

The antibiotic produced by this symbiont was identified as diatreyne nitrile, a polyacetylene (Marx, 1969 b). This could inhibit the germination of zoospores of *Phytophthora cinnamomi* at as low a concentration as 50-70 ppb and could kill them at 2 ppm. *Laccaria laccata* inhibited 16 species of *Pythium* and *Phytophthora*. Marx and Bryan (1969) found that *Scleroderma*, a fungal symbiont of pine and pecan inhibited five *Phytophthora* species and four *Pythium* species which caused damage to the feeder roots. Park (1970) reported that an unidentified *Lactarius* sp. a symbiont on barswood (*Tilia americana*) inhibited feeder root pathogens like *Pythium irregulare* and *R. solani*. *Pinus resinosa* seeds presoaked in the culture filtrate of *Lactarius* sp. has 93 per cent germination in contrast to the seven per cent in non-treated seeds.

Marx (1970) found that *Thelephora terrestris*, a widespread fungal symbiont on many trees species inhibited *Pythium aphanidermatum*, *P. irregulare* and *P. spinosum*. Zak (1971) reported that *Rhizopogon vinicolor*, symbiont of douglas-fir, inhibited the growth of *P. cinnamomi*, *Pythium debaryanum*, *P. sylvaticum*, *Fomes annosus* and *Poria weirii*. Wingfield (1969) reported that loblolly pine seedlings survived better when *P. tinctorius* was allowed to form mycorrhizae before inoculation with *Rhizoctonia solani*. Kuo and Tang (1981) showed that *Boletus* sp. and *Suillus grevillei* reduced mortality of pine seedlings caused by *R. solani* and *Fusarium oxysporum*. Sylvia and Sinclair (1983) observed that a diffusible substance produced by *Laccaria laccata* inhibited mycelial growth and delayed spore germination of *Fusarium oxysporum*.

Stack and Sinclair (1975) regarded antibiotics and competition as inadequate explanation for root protection of Douglas fir seedlings by *Laccaria laccata*, because this fungus did not inhibit *Fusarium oxysporum* in pure culture tests on media rich in nutrients. Park (1960) suggested that high levels of nutrients mask the antibiotic effect. Smiley and Cook (1973) and Elad *et al.* (1980) noted that low vigour of pathogens may reduce its tolerance to antagonism.

Natarajan and Govindasamy (1990) reported that *Suillus brevipes* inhibited all the common root pathogens tested viz. *Armillaria mellea*, *Cylindrocladium parvum*,

*C. scoparium*, *Fusarium oxysporum*, *F. solani* and *Rhizoctonia solani* in dual agar culture. Zhao Zhi-peng and Kuo Shiu-chien (1989) demonstrated that *Boletus griseus* and *Laccaria amethystina* produced intracellular antibiotics against *Rhizoctonia solani*. According to Narayana Bhat *et al.* (in press) *in vitro* studies indicated that *R. leuteolus* and *P. tinctorius* isolate-2 were highly antagonistic to the mycelial growth of *P. aphanidematum*, the causal organism of damping off of *Eucalyptus tereticornis*. *R. leuteolus* significantly reduced damping off in pot culture.

Zak (1964) and Marx (1972) suggested a number of mechanisms by which mycorrhizal fungi might protect roots against soil pathogens. They include, physical protection by the mantle, antibiotics, competition for sugars exuded from the root, stimulation of antagonistic microflora associated with the mantle and production of antimicrobial metabolites.

## 5. ENDOMYCORRHIZAE

Endomycorrhizae of the vesicular-arbuscular (VA) type occur on almost all soils and on most of the tree species native to the tropics and sub tropics. They are not host specific. According to Hayman (1982) VAM association is ubiquitous and occurs in plants growing in the arctic, temperate, and tropical regions. Their occurrence has been reported from all the continents and from a wide range of cultivated plants (Thapar and Khan, 1973; Thomazini, 1974; Janos, 1975 and Tinker, 1982).

Early studies in India have shown the occurrence of Rhizophagus in association with *Litchi chinensis* (Pandey and Misra, 1971) and of VAM in coconut (Lilly, 1975). Thapar and Khan (1985) during their survey in eight States and 21 locations, isolated 15 species of VAM belonging to various genera of which *Glomus macrocarpum* was the most widely prevalent species. Rao *et al.* (1987) observed VAM colonization in twenty aromatic plant species examined. The presence of VAM on different tree species was recorded by Jagpal and Mukerji (1987), Sharma *et al.* (1987) and Nair and Girija (1988). Mohankumar *et al.* (1988) recorded VAM colonization in 53 plant species belonging to 30 families growing along the coastline of Tamil Nadu. Rangarajan *et al.* (1988) in an extensive survey in the Western Ghat region observed prevalence of VAM association in plant communities existing at altitudes ranging from 300 to 2240 M above MSL. Very recently, Raghupathy and Mahadevan (1993) reported VAM association in a large number of plants belonging to several families occurring in the tropical plains of Tamil Nadu. Narayana Bhat (1993) observed VAM in 24 out of 25 forest tree species located in Coimbatore district. *Glomus* sp. was widely encountered in most of the tree species.

VAM association has been reported from Indonesia (Suhardi and Tasiman, 1988). Chong (1987) reported the presence of VAM in forest and flowering ornamental trees from Malaysia. Redhead (1977) reported VAM association in the moist lowland rain forests and the dry Sahel zone of Nigeria. Hall (1975) and Hayman (1978) found VAM association in New Zealand forests and the predominance of *Glomus* and *Acaulospora* species. Hafeel and Gunatilake (1988) found 95 percent of tree species occurring in tropical forests of Sri Lanka to be endomycorrhizal. Chalermpongse (1987) found VAM association in most tree species in the dry

deciduous and semi-evergreen dipterocarp ecosystem in Thailand.

There are over two hundred species of VA mycorrhizal fungi reported so far. They belong to six common genera (Glomaceae, Order Endogonales) viz. *Acaulospora*, *Enterophospora*, *Gigaspora*, *Glomus*, *Sclerocystis* and *Scutellospora*.

### 5.1. Endomycorrhizae and Specificity

Specificity in micro organisms covers a range of concepts from host-specificity to effectivity. While considering specificity, it is important to find out what determines the distribution of different endophytes, whether they differ in their ability to adapt to varying environs and whether they differ in their effectivity. According to earlier reports, certain families like Cruciferae and Chenopodiaceae were considered to be immune to VAM, but this has been disproved (Kruckelmann, 1975). However, certain plants like soybean and maize appear to be more mycorrhizal than other crops like potato or bean (Kruckelmann, 1975; Schenck and Kinloch, 1974 and Strzemska, 1975). According to Woolhouse (1975), phosphate deficiency in a host cell results in the release of a signal, possibly in the form of phosphates, that disrupts the action of protective host lectins. The fungi then invade the cells and phosphate deficiency is corrected. Thereupon the lectins resume action preventing pathogen entry. One theory states that phosphate deficiency induces membrane leakage which in turn favours fungal invasion. (Graham *et al.* 1981; Ratnayake *et al.*, 1978). Another theory is that volatile compounds secreted by plant roots direct fungi towards host roots. According to Fries and Birraux (1980), Koske (1982) and Gemma and Koske (1988), when the plant is under stress, it signals the fungus to invade and correct its deficiency. That explains why most plant species are susceptible to VAM infection. VAM fungi do not normally exhibit any strain or species specificity to particular host plants, except, perhaps, some host preferences. The same plant may at any given time, be infected by more than two species (Molina, 1979; Graham *et al.*, 1982 and Abbot & Robson, 1985).

One type of specificity is genotype-dependent. The extent to which a variety or species is mycorrhizal is determined by the host background, i.e. the kind of host root exudates or other barriers to VAM incidence. In tree crops very few reports are available in this aspect. Instances of host preference have been reported in *Araucaria* (Bevege, 1971). Thomas and Ghai (1987) observed genotype dependent variation in VAM colonization of one year old coconut seedlings belonging to 17 cultivars and four hybrids raised in sandy loam soils. More number of roots of the tall cultivars were colonized. The cultivar Laccadive Ordinary recorded a maximum of 95.2 per cent colonization, closely followed by British Solomon Islands with 94.4 per cent while Kappadam had minimum colonization among the tall cultivars. Among the dwarf types, Gangabondam had the maximum colonization (75.2%) while Malayan Yellow Dwarf had the minimum occurrence (62.4%). The hybrid combination West Coast Tall X Chowghat Orange Dwarf registered the maximum colonization of 84.0 per cent while Malayan Yellow Dwarf x WCT had the minimum.

It has been observed that mycorrhizal colonization varies even among related groups of trees. Oilpalm, coconut and arecanut are colonized by VAM differently.

VAM colonization was less in coconut in comparison to oilpalm and still lower in arecanut when compared to that of coconut (Rohini Iyer & Narayana Bhat, unpublished).

Again, the extent of VAM colonization depends on the host physiology. Comparisons were made between a set of coconut palms affected with an MLO induced root wilt disease (disease index 25 - 50%), and another set of palms of comparable age, which were apparently healthy (disease index 0 -10%) in the same region. The percentage of roots colonized in the diseased palms was of the order of 57.2 while in the apparently healthy group, this figure was 72.8 (Thomas, 1988).

Preliminary studies made in cacao accessions at the Vittal Station of the Central Plantation Crops Research Institute (CPCRI) showed that drought sensitivity and resistance could be related to VAM susceptibility. In addition, it was also seen that the few drought-tolerant plants studied, harboured more of *Glomus versiforme* in contrast to the drought sensitive ones (Iyer & Moosa, 1993).

Yet another form of specificity is the ecological specificity. Under controlled conditions, it may be possible to get mycorrhizal establishment in plants. However, when the same symbionts are introduced in the field under natural conditions, mycorrhizal establishment may be retarded or prevented in certain areas while it may do well at other places. Thus ecological specificity does operate in nature which influences the prevalence of the dominant VAM flora of the locality. Koske (1987) suggested that selection of the fungal flora depended not so much on the nutrients, organic matter or other variables, as it did on the climate.

However, it has been noticed that the number of VAM fungal species increases in mixed stand of crops in coconut based high density cropping system when compared to a pure stand of coconut, thus suggesting that host-directed selection pressures do exert their influence on the VAM flora in soil (Iyer *et al.*, 1986; Thomas, 1988).

## 5.2. Nutrient Uptake

Evidence is available that the efficiency of endophytes varies. An efficient colonizer need not be an efficient symbiont. This was demonstrated in a phosphorus deficient unfertilised soil where onions were grown. Uninoculated onions when planted became mycorrhizal. However, they remained small and phosphorus deficient compared to similar plants inoculated with a non-indigenous mycorrhizal fungus (Mosse *et al.*, 1969; Mosse and Hayman, 1971). The effectivity of a particular endophyte is related to the soil characteristics and is not necessarily related to intensity of infection (Mosse, 1972).

Available evidence suggests that VA mycorrhizae improve plant P-uptake by virtue of the network of external hyphae that explore the soil beyond the root hair zone and absorb available phosphate from the soil solution. This is translocated within the hyphal network and the inflow follows a gradient i.e., from the higher concentration to the lower one. Once within the root, transfer takes place after the digestion of fungal organs like arbuscules or hyphae. Thus, the efficacy of an endophyte will depend upon the extent of mycelial spread in the soil and the

number of connecting hyphae. Hyphal development in soil depends on various factors like pH, presence of inhibitory microbes, temperature etc. Also, hyphal connections between individual plants of the same or different species have been demonstrated in VAM fungi (Magrou, 1936; Hirrell and Gerdemann, 1979).

Chiarello *et al.* (1982) found that members in a plant community can share resources through the interconnecting VAM hyphae. Whittingham and Read (1982) found transport of  $^{32}P$  between plants interconnected by mycorrhizal hyphae, but no transfer between a VA mycorrhizal plant and a non-mycotrophic plant. Grime *et al.* (1987) found that the addition of mycorrhizae increased the diversity of the community by increasing the mass of the subordinate individuals. They suggested that the mycorrhizal fungi, by interconnecting several individuals, equalized the resource allocations and allowed the less competitive species to coexist. This information is not in agreement with those of Caldwell *et al.* (1985) who demonstrated that even if the plants were interconnected, nutrients were preferentially acquired by one individual over the neighbour. Thus, it is not yet time to make generalizations in this field.

### 5.3. Effect of VAM Fungi on Growth of Trees

One of the early works on the effect of mycorrhizal infection on trees was published by Mosse (1957). The test plants used were either apple seedlings or leaf-bud cuttings rooted in vermiculite and later transplanted. Sporocarps of VAM fungi were used as inoculum. She reported significant increase in dry matter gain by the mycorrhizal plants. Both quantitative and qualitative differences were evident. After an initial lag phase, the mycorrhizal plants overtook the control plants in all the parameters studied. They became greener and grew steadily into larger plants. The VAM fungi had infected the roots very well and the benefits might have been bestowed either directly or indirectly by modifying the soil.

Redhead (1975) conducted a series of experiments on *Khaya grandifolia*, one of Nigeria's well known mahogany trees, to study the effects of various environmental factors on the development of VAM and its effect on the host and *vice versa*. He found that plants inoculated with surface-sterilized spores of VAM fungi exhibited maximum dry weight accumulation in comparison to those inoculated with an equal number of unsterilized squashed ones. The surface sterilization had helped to eliminate hyper-parasites and also weak and morbid spores. When spores were squashed, there was every likelihood of their getting damaged badly and losing germination capacity. VAM infected plants were large and healthy. Moisture had significant effect on infection. However, the number of spores was not necessarily correlated with infection.

Janos (1975) studied the effect of VAM on *Inga oerstediana* (Mimosaceae), *Sickingia maxonii* (Rubiaceae) and *Vitex cooperi* (Verbenaceae) by inoculating them with natural VAM combined with dried cacao roots. Appropriate controls were also maintained. Plants were observed upto six months. It was observed that at the close of the experiment, mycorrhizal plants were significantly taller than the others, with numerous, larger leaves. The fleshy photosynthetic cotyledons were retained by

two species for a longer period in comparison to the controls.

Two interesting responses to insect damage were also observed. The mycorrhizal euphorbiaceous seedlings were preferentially attacked by the larvae of a gyromited which destroyed the shoot apex. Mycorrhizal plants responded dramatically to this loss by release of one or more axillary buds which developed into vigorous new leadershoots; whereas this response was not so much seen in the controls. Simultaneously, plants were affected by defoliators. The inoculated plants regenerated and were restored to normalcy fast while the uninoculated plants suffered more. In the uninoculated plants, earlier abscission of cotyledons must have resulted from the rapid exhaustion of cotyledonary mineral reserves. Similarly, replenishment of nutrients lost due to herbivory could not have been possible without mycorrhization. Menge *et al.* (1978) compared mycorrhizal with non-mycorrhizal citrus seedlings which received various amounts of fertiliser. Brazilian sour orange was far more dependent than Troyor citrange. Thus, non-mycorrhizal seedlings of sour orange fell into the P-deficient range. Mycorrhizal Troyor citrange plants which received no fertilisers were equal in size to non-mycorrhizal plants which were supplemented with 42 kg P/ha. Similarly, mycorrhizal Brazilian sour orange trees were equal to those of non-mycorrhizal plants which received 560 kg P/ha.

Kandasamy *et al.* (1987) reported the beneficial effects of mycorrhizal inoculation on seedlings of *Azadirachta indica*, *Parkinsonia aculeata* and *Ailanthus exelsa*. Inoculation with *Glomus fasciculatum* enhanced the dry weight of seedlings by 53.8, 43.9 and 62.0 per cent respectively when the effect was assessed after 45<sup>th</sup> and 90<sup>th</sup> day of inoculation.

Srinivas (1987) studied the response of seedlings of *Eucalyptus tereticornis*, *Leucaena leucocephala*, *Acacia nilotica* var. *indica* and *Casuarina equisetifolia*, to inoculation with *Glomus fasciculatum*, *G. epigeum* and *Acaulospora morrowae*, in a P-deficient unsterile soil. Inoculation of VAM fungi significantly increased plant-height biomass and the uptake of P, N and K when measured 90 days after planting in comparison to control seedlings. *G. fasciculatum* inoculated *Eucalyptus*, *Leucaena* and *Acacia* were significantly more vigorous while in *Casuarina* both *G. fasciculatum* and *A. morrowae* were equally effective in influencing plant height. The native soil also had VAM fungi, but probably, they were not so efficient compared to the introduced ones. This study proves that it is possible to inoculate seedlings and improve their biomass without disturbing the other microflora.

Byra Reddy and Bagyaraj (1988) studied the efficacy of seven VA mycorrhizal fungi in increasing biomass accumulation in two Hawaiian giant cultivars of *Leucaena leucocephala* in oxisols and vertisols with *Glomus mosseae*. Maximum VAM colonization was observed in K8 cultivar inoculated with *Glomus mosseae* and in K28 inoculated with *Gigaspora margarita*. This was also reflected in the number and weight of root nodules, total plant dry weight and also P content. *Glomus versiforme* was the next best fungal symbiont.

Mohandas (1988) studied the response of inoculation with *G. fasciculatum* and *G. mosseae* in *Carica papaya* var. 'Coorg honey' using unsterile soil in pot cultures.

The plants were supplemented with 1/4, 1/2 or full dose of P. Plant height, dry matter, and P content in roots were significantly higher in VAM-treated plants. Maximum increment was noticed in plants receiving 1/4 dose of P that had *G. mosseae* as the symbiont.

The interaction of *Glomus mosseae*, *G. fasciculatum* and *Gigaspora margarita* as a mixed inoculum with varying phosphorus levels in oranges was studied by Panja *et al.* (1990). There were considerable interactions between the levels of available phosphorus and VAM infection status throughout the 180 days of growth. Addition of VAM inoculum to both sterile and non-sterile soils altered the response pattern to added P levels. Yield potentials of these plants at the lowest P level were higher than that of the respective soil plant systems where no VAM inoculum was added, more significantly for the sterile non-mycorrhizal set of plants. However, the response decreased with increasing levels of P supplementation. Root:shoot ratios of mycorrhizae inoculated plants were significantly lower even at the higher P level. This indicated that crop improvement was not exclusively through increased mobilization of soil phosphorus. VAM inoculation was effective in causing a net increase in photosynthetic area and also in photosynthetic efficiency.

The effect of VAM inoculation on coconut was studied at the Central plantation Crops Research Institute (Rohini Iyer, unpublished). VAM inoculum was applied in the planting furrows in nursery where seednuts were sown. Since coconut takes a long time to germinate and since the roots take still more time to penetrate the husk and come out, it is necessary to keep the inoculum active. For this, *Sorghum bicolor* seeds were sown in the furrows. Presence of test organisms were verified after two months by studying the sorghum roots and also analysing the soil in the furrow. These plants were retained in the nursery for two years. Since coconut seedling depends mainly on the endosperm during the first year of its growth this was necessary. VAM fungi used in this study were *Glomus macrocarpum*, *G. versiforme*, *Gigaspora margarita* and *G. calospora*. At the end of two years, plants inoculated with *Gigaspora margarita* and *G. calospora* had higher fresh weight and more number of split leaves, followed by those inoculated with *Glomus* species. All treatments were better than control. After planting in the main field, plants inoculated with *Glomus* species have recorded greater height and more number of leaves.

Narayana Bhat *et al.* (1994) reported the positive field response of three forest tree seedlings, viz. *Acacia nilotica*, *Casuarina equisetifolia* and *Leucaena leucocephala* to inoculation with VAM fungi in a P-deficient oxisol. They recorded 36, 39 and 41 per cent increase in biomass over the control in the respective treatments.

#### 5.4. VAM in Disease Control

Mycorrhizal fungi are members of the microbial population of the root region and they can compete with other members of that population in order to have a unique niche for themselves. Therefore, they might be expected to play some part in the antagonism, prevention, or exclusion of disease-causing organisms. The interactions between VA-mycorrhizal infections and plant pathogens are clearly complex and may involve (a) competition for actual sites of infection on the root,

(b) changes in the nutrition of the host plant, (c) enhancement of tolerance of the host plant to infection by the mycorrhizal fungi and (d) provision of physical barriers to compensate for the damage to roots caused by the pathogens (Zak, 1964). Effects of mycorrhizal infection can also include aggravation of the disease. However, there are only very few instances where the interaction of VA mycorrhiza with pathogens has been studied in trees.

Feldmann *et al.* (1989 & 1994) reported utilization of *Glomus etunicatum* as a factor in an integrated approach to control the South American leaf blight caused by *Microcyclus ulei* on 14 month-old rubber plants. *Hevea* clones Fx 3925, Fx 4098 and IAN 6158 propagated by budding, were inoculated with *Glomus etunicatum*. Plants were grown under field conditions in Manaus, Smagon, Brazil, in black 15-1 polyethylene bags. After an incubation time of five months, when the leaves were in stage B, they were sprayed with a suspension of 150,000 spores/ml *Microcyclus ulei* spores. The trees infected with VAM had an enhanced resistance against the disease. The lesion size and production of conidia by the pathogen were significantly lowered in VAM inoculated plants even though the number of lesions remained unchanged, suggesting that the resistance response of the plant was significantly enhanced by VAM treatment. Further, it showed that while penetration by the fungus and its early development within the host was not affected, the subsequent spread was limited as also its capacity to sporulate. In addition to enhancing resistance, *G. etunicatum* also caused an increase in the biomass. Thus, combined with agronomic management, breeding and use of other biocontrol agents, VAM inoculation forms an essential component in an integrated management system.

Interaction of VAM *Glomus macrocarpum* with *Meloidogyne incognita* in *Leucaena leucocephala* has been studied by Sundararaju *et al.* (personal communication). From among many cultivars, K-8 was found to be most susceptible to root-knot nematodes. Hence this variety was used for pot culture studies. Plants were inoculated simultaneously and sequentially with VAM fungus *Glomus macrocarpum* and nematode *Meloidogyne incognita*. Plants that had been inoculated with VAM fungus, three weeks prior to nematode inoculation, suffered minimum from nematode infection. Plants in this category also had more vigorous growth compared to those which received the nematode simultaneously or earlier.

Gunjal and Patel (1992) reported that dual inoculation with *Frankia* and the two mycorrhizal fungi (*Glomus fasciculatum* and *Gigaspora calospora*) afforded maximum protection against *Trichosporium vesiculosum* wilt suggesting the potential of using the symbionts as biocontrol agents against pathogens. In addition, the inoculated plants also gained in biomass.

### 5.5. Rhizobium - VAM - Tree Species Interaction

Occurrence of VAM in nodulated leguminous crops is a typical example of double symbiosis involving a bacterium that fixes atmospheric nitrogen in root nodules and makes it available to host and a fungus that improves the P nutrition of plants. Thus, the legumes derive double benefits from such double symbiosis

(Abbott *et al.*, 1979). VAM not only stimulates plant growth but also promotes nodulation and nitrogen fixation (Crush, 1974). This appears to be due to the more effective phosphorus nutrition of legumes as a consequence of the mycorrhizal infection. The coexistence of a bacterium and a fungus as root endophytes of legumes leads to the increased synthesis of polygalacturonase at the infection site (Azcon-GDe Aguilar *et al.*, 1980).

Significant response to VAM inoculation and *Rhizobium* in pot culture has been recorded in a number of tree species. Cornet and Diem (1982) found that in a P-deficient soil, inoculation of *Acacia raddiana* and *A. holosericea* with *Glomus mosseae* and *Rhizobium*, increased shoot weight by 170 and 850 per cent respectively and nodule weight 10-12 fold. Chang *et al.* (1986) reported that inoculation with both *Rhizobium* and *G. fasciculatum* resulted in the highest number of nodules, seedling weight and uptake of N and P in *A. auriculiformis*. According to Kandasamy *et al.* (1988) combined inoculation of *Rhizobium* and *G. fasciculatum* to *A. mellifera* resulted in increased mycorrhizal colonization, nodular weight and biomass production by 141.4, 9.1 and 16.0 per cent respectively over control 90 DAS. Similar results were obtained in subabul too. Rangarajan *et al.* (1988) reported that inoculation of *Rhizobium* and *G. fasciculatum* and *Gigaspora calospora* individually and in combination to *A. mellifera* and *A. nilotica*, significantly increased the biomass production, nodule dry weight, and mycorrhizal colonization over control 90 DAS. Similar reports of increased biomass and nodule dry weight to double inoculation of VAM and *Rhizobium* are available in a number of tree species (Sharma *et al.* 1990; Dela Cruz *et al.*, 1988; Huang *et al.*, 1983; and Huang *et al.*, 1985). In dual inoculation, VAM alone improved nodulation by native *Rhizobia*, whereas *Rhizobium* inoculation alone increased the colonization of roots by native mycorrhizal fungus. These results suggest a synergistic effect or additive interaction between VAM and *Rhizobium* with consequent effect on nodulation, N-fixation and P-uptake. N is an essential component of the energy transfer of compounds (ATP and other nucleo-proteins), the genetic information system (DNA & RNA) and cell membrane (phospholipids) (Gardner *et al.*, 1985).

## 6. CONCLUSION

Mycorrhizae represent one of the poorly understood symbiotic systems which have a widespread occurrence. Harley (1968) recognized a gradation in the interactions between plant and fungus from parasitic to mutualistic. Recently, mechanisms of recognition in mycorrhizal symbiosis has been studied by many workers (Allen, 1991) and this would help in selecting suitable crop endophyte combinations. One potential area of practical application of mycorrhizae has been in the sphere of reclamation of disturbed landscapes like mine spoils (Marx 1975, Allen, 1991) where introduction of symbionts has helped in quicker establishment of forest cover.

Wind and small mammals help to spread the inoculum from initial foci to large stretches of area. Conversely, industrialization and heavy metal deposits have prevented the development and establishment of Ectomycorrhizae in the moun-

tains of central Britain and the forests have died there. Heather could establish in these areas, thanks to the Ericoid mycorrhiza which can withstand the heavy metal poisoning (Bradley *et al.*, 1982). Mycorrhizal symbiosis has to be studied with respect to the carbon cycle in terrestrial systems, to understand the valuable role played by the organisms in response to climate change. Genetic engineering studies have to be strengthened to preserve and to induce variability in these organisms so that mycorrhizal symbiosis could be manipulated to the advantage of the farmer by combating pathogens, increasing biomass out-put and, above all, by establishing an environment-friendly plant cover.

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