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About TERI

A dynamic and flexible organization with a global vision and a local focus, TERI was established in 1974. While in the initial period the focus was mainly on documentation and information dissemination activities, research activities in the fields of energy, environment, and sustainable development were initiated towards the end of 1982. The genesis of these activities lay in TERI's firm belief that efficient utilization of energy, sustainable use of natural resources, large-scale adoption of renewable energy technologies, and reduction of all forms of waste would move the process of development towards the goal of sustainability.

The Bioresources and Biotechnology Division

Focusing on ecological, environmental, and food security issues, the Division's activities include working with a wide variety of living organisms, sophisticated genetic engineering techniques, and, at the grassroots level, with village communities. The Division functions through five areas—Centre for Mycorrhizal Research, Microbial Biotechnology, Plant Molecular Biology, Plant Tissue Culture, and Forestry/Biodiversity. The Division is actively engaged in mycorrhizal research. The Mycorrhiza Network has specifically been created to help scientists across the globe in carrying out research on mycorrhiza.

The Mycorrhiza Network and the Centre for Mycorrhizal Culture Collection

Established in April 1988 at TERI, New Delhi, the Mycorrhiza Network first set up the MIC (Mycorrhiza Information Centre) in the same year, and the CMCC (Centre for Mycorrhizal Culture Collection) – a national germplasm bank of mycorrhizal fungi – in 1993. The general objectives of the Mycorrhiza Network are to strengthen research, encourage participation, promote information exchange, and publish the quarterly newsletter, *Mycorrhiza News*.

The MIC has been primarily responsible for establishing an information network, which facilitates information sharing among the network members and makes the growing literature on mycorrhiza available to researchers. Comprehensive databases on Asian mycorrhizologists and mycorrhizal literature (RIZA) allow information retrieval and supply documents on request.

The main objectives of the CMCC are to procure strains of both ecto and VA mycorrhizal fungi from India and abroad; multiply and maintain these fungi in pure culture; screen, isolate, identify, multiply, and maintain native mycorrhizal fungi; develop a database on cultures maintained, and provide starter cultures on request. Cultures are available on an exchange basis or on specific requests at nominal costs for spore extraction/handling.

Contents

Mycorrhizal dependency, Part 1: selection of efficient mycorrhizal fungi

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Mycorrhizal dependency of plants is defined variously by mycorrhiza workers. Generally, when a particular plant species/variety/cultivar/genotype in association with mycorrhiza produces greater biomass than that in the absence of mycorrhiza under the same set of conditions and at any soil phosphorus level, then the species/variety/cultivar/genotype is considered as being dependent on mycorrhiza. To quantify the mycorrhizal dependency of a plant, it is necessary to conduct experiments in a soil that is most suitable for the growth of that plant and with a mycorrhizal fungus that is most efficient on that plant. Also, it is necessary to find the minimum soil solution phosphorus level at which maximum benefit may accrue to the plant, as generally the efficiency of mycorrhizal infection in the plant is inversely proportional to the soil solution phosphorus level. This write-up deals with the selection of efficient mycorrhizal fungi for different plants.

Selection of efficient VA-mycorrhizal fungi for agricultural crops

Cereal crops

Rice

Studies conducted at the Department of Agricultural Microbiology, University of Agricultural Sciences, GKVK Campus, Bangalore, India, on rice (Cv 'Prakash') showed that *Glomus intraradices* was more efficient in improving grain yield than was *G. fasciculatum*. The increase in yield with *G. intraradices* was 11% and with *G. fasciculatum* was 8% over uninoculated controls. With *G. intraradices* inoculation, the amount of phosphate fertilizer usually applied to the rice crop may be reduced by 50% (Secilia and Bagyaraj 1994).

Studies conducted at the Department of Botany and Microbiology, Nagarjuna University, Nagarjunanagar, Guntur, India, on eight varieties of upland rice raised in pots with sterilized soil showed that on all the varieties, *Acaulospora spinosa* was more effective in terms of levels of root colonization, formation of vesicles/spores, plant biomass, and grain yield than was *A. scrobiculata* (Ammani and Rao 1996).

Wheat

Studies conducted at the Biology Department, University of Western Sydney, Macarthur, Australia, on wheat var. s*wift* showed that local aeroponically produced VAM inoculum of sheared roots of Sudan grass infected with trap culture of *Glomus intraradices* was more effective in increasing yield at 0 kg phosphorus added per hectare under field conditions. At 10 kg phosphorus per hectare, aeroponic VAM inoculum (both locally produced and imported from USA) was more efficient in increasing the number of grains per spike than was a single isolate sand culture of *Gigaspora margarita*, which was more efficient in increasing the number of grains per spike at 20 kg phosphorus per hectare but less effective than sheared-root inocula of *G. intraradices* in increasing 1000-grain weight at this level of phosphorus (Asif, Khan, Khan et al. 1995).

Maize

Greenhouse studies conducted at the Department of Biology, University of Ottawa, Canada, on maize (*Zea mays*) hybrid 'Pioneer' 3905 inoculated with *Glomus aggregatum*, *G. etunicatum*, *G. mosseae*, and *G. versiforme* showed that leaf mass and protein concentrations were higher and carbon percentage lower in plants inoculated with *G. etunicatum* in comparison with uninoculated controls and other fungi. Nitrogen percentage was higher in plants colonized by *G. versiforme* or *G. aggregatum* than those inoculated with *G. mosseae*. Sugar concentra-

* Compiled from TERI database – Riza

tions in leaves were highest in plants inoculated with *G. versiforme*. However, the total shoot mass and AM colonization (26%–72%) did not significantly differ among treatments (Boucher, Dalpe, and Charest 1999).

Studies conducted at the Department of Agronomy and Soils, Clemson University, Clemson, USA, on corn (*Zea mays*) 'Pioneer' 3369A inoculated with five different AM fungi at two pH levels in loamy sand soil showed that at pH 6.1, using 6-month stored inoculum, shoot fresh weights significantly increased with *Gigaspora gigantea* and *Glomus mosseae* but not with *G. macrocarpus* var. *macrocarpus*, *G. macrocarpus* var. *geosphorus* or *Gigaspora margarita*. With 1-month-old inoculum, only *G. mosseae* showed significant fresh weight increase compared with the sterile control. At pH 5.7, with 6-month-old inoculum, shoot fresh weights significantly increased with *G. gigantea*, *G. mosseae*, *G. macrocarpus* var. *geosporus*, and *G. macrocarpus* var. *macrocarpus*. With 1-month-old inoculum, the fresh weight increased with *G. gigantea* only. All inoculated roots were observed to be over 70% infected for all VAM species (Struble, Skipper, and Smith 1979).

In experiments conducted at the Soil Microbiology Laboratory, G B Pant University of Agriculture and Technology, Pant Nagar, India, inoculation of maize with *Gigaspora margarita*, *Glomus fasciculatum*, and VAM-mixed endophyte individually caused 54%, 50%, and 58% and root colonization respectively. Mycorrhizal root infection decreased significantly with increasing levels of P (Rathore and Singh 1995).

Pulse crops

Groundnut

Studies conducted at the Texas Agricultural Experiment Station, College Station, USA, on five peanut (*Arachis hypogeae*) cultivars grown at four sites and inoculated with four VAM fungi showed that *Glomus deserticola* was the most effective species and *G. mosseae* was the least effective. Cultivar 'Florunner' was the most responsive. An inoculum mix of *G. deserticola*, *G. intraradices*, and *G. mosseae* resulted in greater whole-plant weights than when single species were used. *G. deserticola* inoculation produced shoot weights equivalent to those of the mix (Taber, Smith, Smith et al. 1987).

Pot culture experiments conducted at the Department of Biosciences, Sri Sathya Sai Institute of Higher Learning, Anantapur, Andhra Pradesh, India, on groundnut (*Arachis hypogeae*) showed that out of eight indigenous VAM species tested, *G. fasciculatum* produced the highest root–shoot length, dry weight, phosphorus content, and percent root colonization in comparison with other VAM species (Vijaykumar and Bhirarvamurthy 1999).

Studies conducted at the Laboratory of Plant Nutrition Faculty of Agriculture, Tokyo University of Agriculture and Technology, on cowpea, pigeon pea and groundnut showed that these legumes responded better to *Glomus* sp. than to *Gigaspora margarita*, in both topsoil (P = 72 ppm) and subsoil (P = 0.1 ppm). Despite low rates of root infection, shoot dry matter production was favoured by mycorrhizal inoculation and increases in shoot biomass were greater in subsoil than in topsoil. In groundnut, mycorrhization also raised P and Ca concentrations in topsoil (Ahiabor and Hirata 1994).

Pigeon pea

Studies conducted at the Tokyo University of Agriculture and Technology on pigeon pea (*Cajanus cajan*) were similar to those for groundnut. However, in pigeon pea, mycorrhization raised shoot concentrations of P and K in the topsoil (Ahiabor and Hirata 1994).

In studies conducted at the University of Gottingen, Grisebachstr, Germany, pigeon pea was grown in pots on non-sterilized phosphorus-fixing soil supplied with phosphorus from three sources, namely single superphosphate (10, 30, 60 kg P/ha) rock phosphate with a total P of 10.7% (50, 150, 300 kg/ha), and rock phosphate with a total P of 12.1% (50, 150, 300 kg/ha). The soil contained two native species, *Glomus albidum* and *G. intraradices*. Four other VAM species originating from the Cerrado ecosystem and *G. manihotis* were also used. The inoculum was applied at the rate of 2 g of air dry mixture of soil/roots/spores per plant. *G. clarum* proved to be the most effective fungus irrespective of the phosphorus source and level (Diederichs 1992).

Soybean

Studies conducted at the University of Agricultural Sciences, Dharwad, Karnataka, India, on soybean cv. AACS-58 sown in pots inoculated with *Glomus fasciculatum* or *Gigaspora margarita* and given 80, 60, or 40 kg P_2O_5/ha showed that seed yield was highest in plots inoculated with *Gi. margarita* + 80 kg P_2O_5 (1413 kg/ha). *G. fasciculatum* + 80 kg P_2O_5/ha gave a seed yield of 1405 kg /ha. Soil inoculation with mycorrhiza + 60 kg P_2O_5/ha gave a similar seed yield as with no inoculation + 80 kg P_2O_5/ha (Lingaraju, Sreenivasa, and Babalad 1994).

Studies conducted at the Soil Microbiology Research Group, Soil Science Division, Department of Agriculture, Bangkok, Thailand, on soybean and mung bean grown in various fields of Thailand showed that of six VAM species tested, *Acaulospora scrobiculata* 22 was the most effective for soybean in growth and crop yield. Per cent root colonization, however, varied with time and phosphorus nutrition in soybean (Vasuvat, Wadisirisak, Toomsen et al. 1987)

Mungbean (green gram)

Studies conducted by the Department of Agriculture, Thailand, showed that of the six VAM fungi tested, *Glomus intraradices* was the most efficient

for mung bean growth and crop yield. Unlike in soybean, per cent root colonization did not vary with time and phosphorus nutrition for mung bean (Vasuvat, Wadisirisali, Toomsen et al. 1987).

Cowpea

Studies conducted at Tokyo University of Agriculture, Tokyo, showed that along with pigeon pea and groundnut, cowpea also responded better to *Glomus* spp. than *Gigaspora margarita*, both in topsoil and subsoil. Also, the effect of VAM on this crop was greater in subsoil than in topsoil as compared with the control (Ahiabor and Hirata 1994).

Studies conducted at the Agronomy Department, Clemson University, Clemson, USA, on cowpea grown on methylbromide-fumigated soil inoculated or not inoculated with *Glomus etunicatum*, *G. claroideum*, or native VAM fungi and also with *Bradyrhizobium* strain 32 Hl showed that inoculation with native VAM fungi gave higher top dry weight for 25-kg and 50-kg phosphorus levels in the soil. Both *G. etunicatum* and *G. claroideum* inoculation gave a low top dry weight at lower P levels and slightly higher top dry weights at high P levels (Obura, Skipper, and Wagner 1987).

Black gram and green gram

In pot experiments conducted at the Nagarjuna University, Nagarjunanagar, Andhra Pradesh, India, black gram (*Vigna mungo*) and green gram (*V. radiata*) were grown in soil inoculated with *Acaulospora spinosa*, *A. morrowae*, and *Glomus epigaeum* (*G. versiforme*) and supplied with phosphorus as superphosphate, rock phosphate, or tricalcium phosphate. The root colonization was 68%–89% in black gram and 69%–93% in green gram. Colonization in both species was lowest in pots inoculated with *A. morrowae* + superphosphate and was best with *G. epigaeum* without adding phosphorus. Shoot dry weight, plant nitrogen and phosphorus concentrations, and 100-seed weight were highest with super phosphate application + *G. epigaeum* inoculation (Rao and Rao 1996).

Vegetable crops

Onion

A field trial was conducted at the Department of Horticulture, College of Agriculture, Hyderabad, India, to study the response of onion to inoculation with three VAM fungi at three phosphorus levels on a non-sterilized alfisol. Among the three VAM fungi, *Gigaspora margarita* proved to be the most effective inoculant in influencing the growth and performance. Inoculation of onion in the nursery with *G. margarita* at a phosphorus level of 17.5 kg/ha enhanced the number of leaves, dry matter accumulation, uptake of phosphorus, and yield of bulbs. Uptake of phosphorus and yield of onion bulbs with *G. margarita* inoculation at half the recommended phosphorus level were significantly higher than that achieved by the uninoculated plant at a full level of fertilization. *G. calospora* recorded a higher percentage of root infection at lower levels of phosphorus (Ramana and Babu 1999).

Capsicum

In studies conducted at the Tata Energy Research Institute, New Delhi, India, different types of nursery inocula formulations, namely mixed indigenous cultures and *Glomus intraradices*, were compared with commercially available inocula in pot experiments using capsicum and Polianthus as test plants. Soil-based inocula and soil beads produced the highest response in both crops. *G. intraradices* caused the highest yield in capsicum (112% increase in fruit yield). Among the commercial inocula, only *Mycorise* enhanced fruit yield (11%) in capsicum. Sheared-root inocula of *G. intraradices* resulted in high colonization (up to 68%), but the yield enhancement was lower than in the soil-based formulations. The mixed indigenous inoculum produced the highest number of spores and propagules whereas commercial inoculum produced the lowest (Gaur, Adholeya, and Mukerji 1998).

Tomato

In studies conducted at the Department of Plant Pathology, University of Kentucky, Lexington, USA, tomato (cv. 'Manpal') seeds were inoculated with *Glomus etunicatum* or *G. mosseae* at several inoculum levels (0.0, 0.1, 0.3, 0.5, 0.7, 1.0, or 10.0 propagules per g of autoclaved fine sand soil). At 2.5 weeks, significantly higher (P = 0.05) colonization index values (colonization per 0.5 g root fresh weight sample × total root dry weight [g]) were obtained for plants inoculated with *G. mosseae* than for those inoculated with *G. etunicatum*. A similar relationship was observed at subsequent dates (at 5, 6, 8 or 13 weeks). Conversely, *G. etunicatum* inoculation resulted in significantly higher ($P = 0.001$) shoot dry weights and plant heights than did *G. mosseae* inoculation or uninoculation plants at 6 and 13 weeks. With cv. 'Walter', plants inoculated with *G. mosseae* had significantly greater shoot dry weights and plant heights than those inoculated with *G. etunicatum* at 6 and 13 weeks (McGraw and Schenck 1981).

Fodder crops

Alfalfa

In studies conducted at the United States Department of Agriculture, Agricultural Research Service, Errc, Wyndmoor, USA, two cultivars of alfalfa (*Medicago sativa*), cv. 'Giboa' and cv. 'Moapa' 69, were inoculated in the glasshouse with three VAM fungi, namely *Glomus mosseae*, *G. intraradices*, and *Gigaspora margarita*, to evaluate their relative efficiencies. Along with alfalfa, *Papsalum notatum* was also inoculated with these three fungi to describe fungal parameters on a routine pot culture host. Percentage root length of *P. notatum* colonized by VAM fungi increased from 10 to 21

weeks, and all fungi sporulated during this period. In alfalfa, only colonization by *G. intraradices* increased over that time period, and this was the only fungus to sporulate in association with alfalfa at 10 weeks. *G. mosseae* did not sporulate after 16–21 weeks despite having colonized 30%–35% of the root length of both alfalfa cultivars. In vitro experiments in which RiTDNA-transformed roots of alfalfa were inoculated with VAM fungi showed normal mycorrhizal formation by *G. intraradices* and a hypersensitivity-like response to *G. margarita*. The colonized cells became necrotic and HPLC analysis indicated increased concentrations of phenolics and isoflavonoids in these root segments (Douds, Galvez, Becard et al. 1998).

Clover

Studies conducted at the Soil Science and Plant Nutrition Department, School of Agriculture, University of Western Australia, Nedlands, Australia, on clover (*Trifolium subterraneum*) inoculated with three species of *Acaulospora* in pots with 1.6 kg brown sandy soil showed that *A. trappei* was more effective in increasing plant growth per unit of root colonization than was *A. laevis* and an unidentified *Acaulospora* sp. In the experiment, three harvests (3, 5, and 7 weeks after sowing) using six quantities of inoculum (10–250 g/pot) were obtained. For all three fungi, increasing propagule number up to three weeks increased per cent root colonization. This propagule effect decreased with time, and at 5 and 7 weeks, there was no effect of propagule number on per cent root length colonized with *A. trappei* and the unidentified *Acaulospora* sp., but there was marked difference with *A. laevis* at 5 weeks, which disappeared at 7 weeks (Gazey, Abbott, and Robson 1992).

Finger millet

Studies conducted at the GB Pant University of Agriculture and Technology, Pant Nagar, Uttar Pradesh, India, on finger millet (*Eleusine coracana*) showed that out of six different VAM fungi (*Glomus caledonicum*, *G. mosseae*, *G. fasciculatum*, *G. epigaeum*, *G. versiforme*, *Gigaspora calsospora*, and *Gi. margarita*) tested, maximum root colonization and mycorrhizal efficiency were observed in plants inoculated with *G. caledonicum* (Tewari, John, and Tandon 1993).

Guar

Pot experiments conducted at the Department of Botany, JNV University, Jodhpur, Rajasthan, India, on guar (*Cyamopsis tetragonoloba*) showed that out of six VAM fungi (*Acaulospora morrowae*, *Glomus constrictum*, *G. fasciculatum*, *G. mosseae*, *Sclerocystis rubiformis*, and *Scutellospora calospora*), all collected from the rhizosphere of guar, *G. fasciculatum* caused a twofold increase in protein contents and a 50% increase in total sugar contents in pods as compared with controls (Mathur and Vyas 1995).

Tuber crops

Amorphophallus, Cassava, and Colocasia

In studies conducted at the Centre for Advanced Studies in Botany, University of Madras, Tamil Nadu, India, cassava (*Manihot esculenta*), *Amorphophallus paeonifolius*, and kachalu (*Colocasia esculenta*) were grown in both pots and field and were inoculated with *Gigaspora albida*, *Pisolithus tinctorius*, *Glomus mosseae*, or *G. aggregatum*. Joint inoculations with *G. mosseae* and *G. aggregatum* gave the highest tuber yield per plant in all three crops (Ganesan and Mahadevan 1994).

Studies conducted at the College of Agriculture, Velleyani, Trivandrum, Kerala, India, on cassava in pot cultures showed that inoculation with *Glomus fasciculatum* gave the highest shoot and root dry weight, plant height, and VAM infection when compared with those inoculated with *G. mosseae*, *G. constrictum*, *G. etunicatum*, *Acaulospora morroweae*, and controls (Sivaprasad, Sulochana, and Nair 1990).

Fruit crops

Pineapple, papaya, and banana

Studies conducted at the Departmento de Proteccion Vegetal, Centre de Investigation Y Technologia Agrarias La Laguna, Canary Islands, Spain, on papaya (*Carica papaya*), pineapple (*Ananas comosus*), and banana (*Musa acuminata*) showed that all the species were highly responsive to mycorrhizal conditions under greenhouse as well as field conditions when the AM inoculum was *Glomus* endophytes. *Glomus fasiculatum* was the most effective in improving plantlet growth and nutrition. *Acaulospora* sp. was ineffective and *Scutellospora* sp. was effective with banana only (Jaizme-Vega and Azcon 1995).

Strawberry

In studies conducted at the SLVA Ahrweiler, Walporzheimer Str. 48, Bad Neunahr-Ahrweiler, Germany, micropropagated and runner-propagated strawberry (*Fragaria* × *ananassa*) cv. Elvira and Elsanta were inoculated with *Glomus etunicatum*, *G versiforme* (two isolates), *G. mosseae*, *G. versiforme* 33-366 increased yield and runner production depending on cultivar and propagation method. Micropropagated plants had higher mycorrhization rates and suffered less from infection by *Phytophthora cactorum* than runner-propagated plants (Taube-Baab and Baltruschat 1996).

Other plants

Rajnigandha

In studies conducted at the Tata Energy Research Institute, New Delhi, India, on evaluation of different nursery inocula formulations, soil-based inocula and soil beads produced the highest response in both rajnigandha (*Polianthus tuberosa*) and capsicum. *Glomus intraradices* gave the highest increase

in spike length (45%) in rajnigandha. Among the commercial inocula, only *Mycorise* enhanced spike length (33%). Overall, AM colonization was higher in rajnigandha than in capsicum. Sheared-root inoculum of *G. intraradices* resulted in high root colonization (up to 68%), but the yield enhancement was lower than with soil-based formulation. The mixed indigenous inoculum produced the highest number of spores and propagules whereas the commercial inoculum produced the lowest (Gaur, Adholeya, and Mukerji 1998).

Passiflora

Greenhouse trials conducted at the Universidad Nacional de Colombia, Sede Palmira, Colombia (1200 m above sea level, at 24 °C) on *Passiflora ligularis* plants grown in soil sterilized and inoculated or not inoculated with *Acaulospora foveata*, *A. longula*, or *Glomus occultum* at pH 4.8 showed that *A. longula* was the most effective VAM fungus (Rodriguez, Hurtado, and Sanchez de Prager 1995).

Selection of efficient mycorrhizal fungi for tree crops

Selection of VA mycorrhizal fungi

VA mycorrhizal fungi form symbiotic associations mainly with hardwood trees of both forest and horticultural species.

Horticulture trees

Apple

Studies conducted at the Department of Horticulture, Ohio State University, Columbus, Ohio, USA, on apple (*Malus* × *domestica*) showed that *Glomus mosseae* exceeded *G. macrocarpum* in the rate of initial colonization, amount of maximum colonization, and persistence of arbuscules and external hyphae. Colonization by each fungus reduced fresh weight 11 days after inoculation but increased shoot and total fresh weight by day 38. Relative height growth rate and colonization at harvest of plants inoculated with *G. macrocarpum* were less than those of plants inoculated with *G. mosseae* or *G. mosseae* + *G. macrocarpum*, but greater than controls (Miller, Bodmer, and Schuepp 1989).

Citrus

In studies conducted at the United States Horticultural Research Laboratory, United States Department of Agriculture, Orlando, USA, rough lemon (*Citrus jambhiri*) was grown on fine sand amended with individual and combined populations of *Glomus mosseae*, *G. etunicatum* and *G. fasciculatum* (900 chlamydospores for a 15-cm pot). Mean plant heights for *G. mosseae, G. etunicatum*, and *G. fasciculatum* were 21.6, 34.6, and 52.5 cm, top weights were 6.4, 14.2, and 25.2 g, root weights were 14.3, 32.4, and 63.4 g, and chlamydospores were 67, 4, and 73/25 g soil respectively. All growth parameters were significantly different (P = 0.01) from each other and from uninoculated controls. In all combinations of two species, height varied between 38 cm and 42 cm, top weight between 18 g and 20 g, and root weight between 21 g and 26 g. None of the individual growth values differed significantly within each parameter. Sporulation in tests with *G. mosseae* and *G. etunicatum* was 5 and 0 chlamydospores per 25 g soil, with *G. mosseae* and *G. fasciculatum* was 6 and 25 chlamydospores per 25 g soil, and with *G. etunicatum* and *G. fasciculatum* was 5 and 6 chlamydospores per 25 g soil respectively. In the test with all the three species, height was 33.4 cm, top weight 13.6 g and root weight 15.7 g. In this test, only *G. mosseae* sporulated and that too only with one spore per 25 g soil (Nemec 1979).

Studies conducted at the Department of Agriculture Microbiology University of Agricultural Sciences, GKVK, Banglore, India, on the response of Trifoliate orange (*Poncirus trifoliata*) to 18 VAM fungi showed that *Glomus velum*, *G. caledonicum*, *G. marredum*, *G. macrocarpum* and *Acaulospora* sp. were the most effective in improving growth and nutrition, resulting in greater plant height, stem diameter, plant biomass, P, Zn, and Cu context. All the five fungi selected were statistically equivalent in improving growth and nutrition of *P. trifoliate*. Inoculation of the root stock with these fungi produced plants ready for budding in 14–15 months as compared with 22–24 months without mycorrhizal inoculation.

Zizyphus

Studies conducted at the Department of Botany, JNU University, Jodhpur, Rajasthan, India, on *Zizyphus mauritiana* raised in pots and inoculated with *Glomus fasiculatum*, *G. mosscae*, or *Scutellospora calospora* showed that *G. fasciculatum* was significantly more efficient than the other two VAM fungi in increasing seedling biomass and uptake of nitrogen, phosphorus, potassium, calcium, and magnesium after 98 days of inoculation. All fungi were collected from the rhizosphere of *Z. mauritiana* and the inoculum used in the experiment was in the form of roots of *Cenchrus ciliaris* colonized by each VAM fungus (Mathur and Vyas 1996).

Forest trees

Teak

Studies conducted at the University of Agricultural Science, GKVK Campus, Bangalore, India, on teak (*Tectona grandis*) stumps planted in polybags showed that on the basis of various plant growth parameters and nutritional status of the plants, *Glomus leptotichum* was the best AM symbiont for teak (Rajan, Reddy, and Bhagyaraj 2000).

Rubber

Studies conducted at the Rubber Research Institute of Malaysia, Kuala Lumpur, Malaysia, on rubber (*Hevea brasilienseis*) (PB5/51) seedling root

stock showed that after 22 weeks of growth in sterilized soil, with phosphorus added or not added, only 2 of the 10 VAM fungi (*Glomus clarum*, *Glomus* sp.) showed a significant increase in shoot dry weight compared with uninoculated controls, and none showed an increase in root fresh weight. Stem diameter and height growth from inoculation were not affected by any of the endophytes but infection by *Acaulospora dilatata*, *A spinosa*, *Gigaspora margarita*, *Entrophospora colombiana*, and an unknown *Glomus* sp. increased foliar phosphorus concentrations. The amount of root infected was not related to improved plant growth (Ikram, Mahmud, and Othman 1993).

Neem

Studies conducted at the Department of Agricultural Microbiology, GKVK, Bangalore, India, on neem (*Azadirachta indica*) seedlings inoculated at 45 days with nine VAM fungi showed that neem seedlings responded best to inoculation with *Glomus mosseae* followed by *G. fasciculatum* as regards plant height, stem girth, biomass, phosphorus content, zinc concentration, biovolume index, mycorrhizal root colonization, and spore number in the root-zone soil (Sumana and Bagyaraj 1999).

Babul

Studies conducted at the Department of Agroforestry, Haryana Agricultural University, Hissar, Haryana, India, on babul (*Acacia nilotica*) seedlings inoculated with *Glomus constrictum*, *G. mosseae*, and *G. gilmorei* (collected from old babul plantations) singly or in combination in a phosphorus-deficient soil showed that *G. mosseae* combined with *G. gilmorei* was the most effective in improving collar diameter, root–shoot dry weight, and length in comparison with uninoculated plants. *G. constrictum* was the least effective fungus (Mandal and Kaushik 1994).

Selection of ectomycorrhizal fungi – hardwoods

Oak

In studies conducted at the Department of Forest Resources, College of Forestry, University of Minnesota, USA, seedlings of three species of oak were grown in containers (receiving 75 ml Hoagland's solution per seedling) and inoculated with five isolates of *Pisolithus tinctorius*, three of *Suillus granulatus*, and one each of *S. luteus*, *Thelephora terrestris*, and *Cenococcum geophilum*. Root colonization differed significantly among fungal isolates and among oak species. *T. terrestris* was most effective in increasing nutrient uptake by the three oaks collectively. Individually, *S. granulatus* 263 was the most effective with *Quercus velutena, S. luteus* was the most effective with *Q. alba,* and *C. geophilum* was the most effective with *Q. robur* (Mitchell, Cox, Dixon et al. 1984).

Eucalyptus

In studies conducted at the CSIRO, Division of Forestry, Wembley, Australia, *Eucalyptus globulus* and *E. diversicolor* were grown in yellow sand at two levels of phosphorus (4 and 12 mg phosphorus/ kg sand). Both the tree species were inoculated with 16 ectomycorrhizal fungi, which included *Paxillus muelleri*, *Cortinarius globuliformis*, *Thaxterogaster* sp.; *Hysterangum inflatum*, *Hydrangium carneum*, *Hymenogaster viscidus*, *H. zeylanicus*, *Setchelliogaster* sp.; *Laccaria laccata*, *Scleroderma verrucosum, Amanita xanthocephala*, *Descolea maculata*, and *Pisolithus tinctorus*. At the time of harvest (100 days), uninoculated seedlings and those inoculated with *P. muelleri* and *C. globuliformis* had a low level of contamination from an unknown mycorrhizal fungus. *Thaxterogaster* sp. and *H. inflatum* developed a superficial type of mycorrhiza. All others formed typical pyramidal ectomycorrhizas. The dry weights of inoculated and uninoculated *E. globulus* seedlings at 12 mg phosphorus/kg soil did not differ whereas several isolates caused growth depression in *E. diversiecolor*. At 4 mg phosphorus, growth increases in inoculated seedlings were 0–13 times higher than the growth rate of uninoculated seedlings. *P. tinctorius* produced the largest growth increases in both *Eucalyptus* species. In general, isolates that developed more extensive mycorrhizas on roots produced the largest growth responses to inoculation. Isolates that increased plant growth also increased phosphorus uptake by the plant. Seedlings inoculated with *L. laccata* and *S. verrucosum* retained more phosphorus in their roots than did plants associated with the other fungal isolates (Burgess, Malajczuk, and Grove 1993).

Selection of ectomycorrhizal fungi – conifers

Pines

Studies conducted at the Institute National de laRecherche Agronomique, Centre de Recherche Forestiere, Champenoux, Seichamps, France, on *Pinus sylvestris* at different levels of phosphorus showed that even a low intensity of infection by *Laccaria laccata* greatly stimulated *P. sylvestris* growth in comparison with *Thelephora terrestris* and *Hebeloma crustuliniforme.* The ability of *L. laccata* to increase *P. sylvestris* growth seemed to be more related to its capacity to produce growth substances than to its capacity to stimulate phosphorus uptake. The poor efficiency of *H. crustuliniforme* in comparison with *L. laccata* at any level of phosphorus could result from differences in diversion of carbohydrates from the host to fungal structures (Tyminska, Tacon, and Chadoeuf 1986).
Studies conducted at the Centre Advanced Studies in Botany, University of Madras, India, on *Pinus patula* seedlings showed that up to the first six months, seedlings inoculated with *Thelephora terrestris* showed better growth, mycorrhizal development, and dry

matter production, but at later stage, seedlings inoculated with *Laccaria laccata* grew better of the two fungi. Under experimental conditions, *L. laccata* was found better for P. *patula* nurseries (Natarajan and Reddy 1994).

Studies conducted at the University of Murcia, Faculty of Biology Vegetal Botany, Murcia, Spain, on *Pinus halepensis* inoculated with three different basidiospore concentrations of *Pisolithus arhizus*, *Rhizopogon roseolus,* and *Suillus collinitus* showed that highest mean values of height, dry weight, and percentages of ectomycorrhizas were obtained with seedlings inoculated with *P. arhizus* in a sterile substrate (Torres and Honrubia 1994).

Douglas fir

In studies conducted at the Department de Patologia Vegetal, Institute Recerca i Technologia Agroaliamentarie Cabrils, Spain, 36 isolates from 27 species of native ectomycorrhizal species were tested with Douglas fir (*Pseudotsuga menziesii*) and 13 species were tested with two native and four introduced species of conifers in pure culture synthesis. Only eight fungi colonized over 50% of the short roots. *Laccaria laccata*, *Lyophyllum decastes*, *Pisolithus tinctorius*, and *Scleroderma citrinum* formed abundant mycorrhizas in all conifers tested. Twenty-three fungal isolates from 18 species formed ectomycorrhiza with Douglas fir. Nine fungi did not form ectomycorrhiza even though some of them were collected in pure stands of Douglas fir. *Lactarius deliciosus*, *Rhizopogon* sp., and *Suillus luteus* showed the highest host specificity (Parlade, Alvarez, and Pera 1996).

Sitka spruce

In studies conducted at the United States Department of Agriculture, Forest Service, Pacific Northwest Forest Range Experiment Station, Portland, Oregon, USA, containerized sitka spruce (*Picea sitkensis*) seedlings were inoculated at sowing with inoculum of *Pisolithus tinctorius*, *Laccaria laccata*, *Astraeus pteridis*, *Amanita pantherina* or *Cenococcum geophilum*, all common in sitka spruce forests. The inoculum was prepared in vermiculite culture and combined with a peat vermiculite potting mixture in a 1:7 ratio. The seedlings were grown for six months in 66-cm^3 cells in a greenhouse at Corvallis, Oregon (Location 1), environmental growth chambers at Juneau, Alaska (Location 2), and a small production nursery greenhouse at Petersburg, Alaska (Location 3). At locations 1, 2 and 3, respectively 100%, 100%, and 85% seedlings inoculated with *L. laccata* formed mycorrhiza and 100%, 98%, and 80% inoculated with *C. geophilum* formed mycorrhizae. Mycorrhizal short roots at locations 1, 2, and 3 respectively were 92%, 77%, and 38% for *L. laccata* and 91%, 12%, and 7% for *C. geophilum*. Positive mycorrhiza formation was not detected at any location with the other test fungi. Analysis of variance for growth parameters within each location for seedlings colonized by *L. laccata* and *C. geophilum* showed significant differences ($P = 0.05$) only for root collar diameter, root weight, and total weight at location 1. Tukey tests for differences among treatment means for these variables were not significant ($P = 0.05$); however, for all three variables, mean values for the control seedlings were greater than those for seedlings colonized by either fungus (Shaw and Molina 1979).

Two sets of experiments were conducted at the Department of Botany, University of Guelph, Guelph, Ontario, Canada, on *Picea mariana*, seeds of which were collected from an upland site with sandy soil and lowland site with peaty soil for raising seedlings. In one set grown under aseptic conditions in test tubes, seedlings were inoculated with *Hebeloma cylindrosporum*, *Laccarier laccata* and *Paxillus involutus*; in the other set, the seedlings were inoculated with *Laccaria bicolor*, *L. laccata*, *L. proxima* or uninoculated agar plugs. Differences between fungal treatments were pronounced. Both *L. bicolor* and *L. laccata* initiated good ectomycorrhiza formation and increased seedlings growth (Thomson, Mathes-Sears, and Peterson 1990).

Tamarack

Studies conducted at the Department of Forest Science, University of Alberter, Edmonton, Canada on containerized seedlings of tamarack (*Larix laricina*) (representing four provenances and 17 open-pollinated families) inoculated with four ectomycorrhizal fungi showed that during an 18-week period, *Laccaria laccata*, *Cenococcum geophilum*, and *Pisolithus tinctoruis* formed ectomycorrhizae with 60%, 7%, and 12% of the total short roots respectively. *Suillus granulatus* failed to form any mycorrhiza. Overall, the best growth was found in seedlings inoculated *L. laccata* (Zhu and Nauratil 1987).

Fern

In studies conducted at the Centre de Recherche en Biologie Forestiere, Universite Laval, Quebec, Canada, rooted plantlets of in vitro micropropagated fern, *Nephrolepis exaltata* var. *Whitmanii* were transferred to pots containing a brown peat-based mix and simultaneously inoculated with *Glomus intraradices*, *G. clarum*, *G. vesiculiferum*, or *G. versiforme*. Root colonization by *G. intraradices* and *G. clarum* was more rapid and extensive as compared with that of the other two fungi. The high-phosphorus control performed better than other treatments except for the fond number, which did not differ significantly. Among mycorrhizal treatments, plants inoculated with *G. vesiculiferum* showed the most significant increase in growth as compared with low-phosphorus control (Ponton, Piche, Parent et al.1990).

Appendix 1 List of efficient VA mycorrhizal fungi for different agricultural species

Plant species	*Efficient mycorrhizal fungus/ fungi*	*Mycorrhizal fungi tested*	*Parameters evaluated*	References
Agriculture crops				
Allium cepa (onion)	*Gigaspora margarita*	*G. margarita*, *G. calospora*, and a known VAM fungus	Leaf number, dry matter, P-uptake, bulb yield	Ramana and Babu (1999)
	G. calospora	*G. margarita*, *G. calospora*, and a known AM fungus	Root colonization	Ramana and Babu (1999)
Amorphophallus paeonüfolius	*Glomus mosseae* + *G. aggregatum*	*G. mosseae*, *G. aggregatum*, *Gigaspora albida*, *Pisolithus tinctorius*	Tuber yield/plant	Ganesan and Mahadevan (1994)
Ananas comosus	*Glomus fasciculatum*	*G. fasciculatum, Glomus* sp., *Acaulospora* sp., *Scutellospora* sp.	Plant growth, nutrition	Jaizme-Vega and Azcon (1995)
Arachis hypogeae	*Glomus* sp.	*G. etunicatum , Gigaspora margarita*	Shoot dry matter, nutrient uptake	Ahiabor and Hirata (1994)
	Glomus deserticola	*G. deserticola, G. mosseae, Glomus intraradices*, and another VAM fungus	Plant growth	Taber, Smith, Smith et al. (1987)
	Glomus fasciculatum	*G. fasciculatum* and seven other VAM fungi	Root–shoot length, dry weight, P-content, root colonization	Vijay Kumar and Bhiravamurthy (1999)
Acacia nilotica	*Glomous mosseae* + *Gigaspora gilmorei*	*G. mosseae, G. constrictum, Gigaspora gilmorei,* and their combinations	Collar diameter, root–shoot dry weight and length	Mandal and Kaushik (1994)
Acacia auriculaeformis	*Glomus etunicatum, G. macrocarpum*	*G. etunicatum, G. macrocarpum, G. fasciculatum, G. mosseae*	Height, diameter, biomass, P-uptake	Aggangan, Lorilla, and Cruz (1990)
Acer saccharum (sugar maple)	*Glomus macrocarpum*	*G. macrocarpum, G. clarum, G. epigaeum, G. mosseae*	Leaf number, mean lateral root number	Reid, Parker, Mitchell et al. (1988)
Azadirachta indica (neem)	*Glomus mosseae*	*Glomus mosseae, G. fasciculatum*, and seven other VAM fungi	Plant height, stem girth, biomass, P-content, zinc concentration, root colonizations	Sumana and Bagyaraj (1999)
Cajanus cajan	*Glomus clarum*	*G. fasciculatum* and seven other VAM fungi	Plant growth	Diederichs (1992)
	Glomus etunicatum	*G. etunicatum , Gigaspora margarita*	Shoot dry matter, nutrient uptake	Ahiabor and Hirata (1994)
Capsicum	*Glomus intraradices*	*G. intraradices*, indigenous mixed culture, commercial inoculum (Mycorise & C)	Fruit yield	Gaur, Adholeya, and Mukerji (1998)
Carica papaya	*Glomus fasciculatum*	*G. fasciculatum*, *Glomus* sp., *Acaulospora* sp., *Scutellospora* sp.	Plant growth, nutrition	Jaizme-Vega and Azcon (1995)
Colocasia esculenta	*Glomus mosseae* + *G. aggregatum*	*G. mosseae, G. aggregatum, Gigaspora albida, Pisolithus tinctorius*	Tuber yield/plant	Ganesan and Mahadevan (1994)

(*Continued*)

Appendix 1 Continued

Plant species	*Efficient mycorrhizal fungus/fungi*	*Mycorrhizal fungi tested*	*Parameters evaluated*	*References*
Cucumis sativus	*Glomus caledonium*	*G. caledonium*, *Glomus* sp.	P-uptake	Joner and Jokobsen (1994)
Cyamopsis tetragonoloba	*Glomus fasciculatum*	*G. fasciculatum*, *G. mosseae*, *Acaulospora morrowae*, *G. constrictum*, *Sclerocystis rubiforme*, *Scutellospora calospora*	Protein and sugar contents in pods	Mathur and Vyas (1990)
Eleusine coracana	*Glomus caledonicum*	*G. caledonicum*, *G. mosseae*, *G. fasciculatum*, *G. epigaeum* (*G. versiforme*), *Gigaspora calospora*, *G. margarita*	Mycorrhizal efficacy, root colonization	Tewari, Johri, and Tandon (1993)
Fragaria xananassa (micropropagated)	*Glomus versiforme* 36-366	*G. versiforme* (2 isolates), *G. mosseae*, *G. etunicatum*	Yield, production of runners	Taube-Baab and Baltruschat (1996)
Glycine max	*Acaulspora scrobiculata*	*A. scrobiculata*, *Glomus intraradices*, and four other VAM fungi	Plant growth, crop yield	Vasuvat, Nopamornbodi, and Thamsurakul (1987)
Lycopersicum esculentum	*Glomus etunicatum*	*Glomus etunicatum*, *G. mosseae*	Shoot dry weight, plant height	McGraw and Schenck (1981)
cv. *Manapal*	*G. mosseae*	*Glomus etunicatum*, *G. mosseae*	Root colonization	McGraw and Schenck (1981)
cv. *Walter*	*G. mosseae*	*Glomus etunicatum*, *G. mosseae*	Shoot weight, plant height	McGraw and Schenck (1981)
Manihot esculenta (cassava)	*Glomus fasciculatum*	*G. fasciculatum*, *G. mosseae*, *G. constrictum*, *G. etunicatum*, *Acaulospora morrowea*	Root colonization, plant weight, shoot and root dry weight	Sivaprasad, Sulochana, and Nair (1990)
Manihot esculenta (cassava)	*G. mosseae* + *G. aggregatum*	*G. mosseae*, *G. aggregatum*, *Gigaspora albida*, *Pisolithus tinctorius*	Tuber yield/ plant	Ganesan and Mahadevan (1994)
Medicago sativa	*Glomus intraradices*	*G. intraradices*, *G. mosseae*, *Gigaspora margarita*	Root colonization, fungal sporulation	Douds, Galvez, Becard et al. (1998)
Musa acuminata	*Glomus fasciculatum*	*G. fasciculatum*, *Glomus* sp., *Aculospora* sp., *Scutellospora* sp.	Plant growth, nutrition	Jaisme-Vega and Azcon (1995)
Oryza sativa cv. *Prakash*	*Glomus intraradices*	*G. intraradices*, *G. fasciculatum*	Grain yield	Secilia and Bagyaraj (1994)
Orzya sativa (upland rice)	*Acaulospora spinosa*	*Acaulospora spinosa*, *A. scrobiculata*	Plant biomass, grain yield, root colonization	Ammani and Rao (1996)
Passiflora ligularis	*Acaulospora longula*	*A. longula*, *A. foveata*, *Glomus occultum*, native soil VAM fungi	Root diameter, root weight, dry weight of aerial parts, total root length, spore number in soil	Rodriguez, Hurtado, and Sanchez (1995)
Persea americana	*Glomus fasciculatum*	*G. fasciculatum*, *Glomus* sp., *Acaulospora* sp., *Scutellospora* sp.	Plant growth, nutrition	Jaizme-Vega and Azcon (1995)
Phaseolus mungo (mung bean) *(Vigna radiata)*	*Glomus intraradices*	*G. intraradices*, *Acaulospora scrobiculata*, and four other fungi	Plant growth , crop yield	Vasuvat, Wadisirisak, Toomsen et al. (1987)
Polianthes tuberosa (rajnigandha)	*Glomus intraradices*	*G. intraradices*, indigenous mixed cultures, commercial inoculum (Mycorise)	Fruit yield, spike length	Gaur, Adholeya, and Mukerji (1998)

Trifolium (clover)	*Acaulospora trappei*	*A. trappei, A. laevis, Acaulospora* sp.	Root colonization	Gazey, Abbott, and Robson (1992)
Triticum aestivum wheat (var. swift)	*Glomus intraradices*	*G. intraradices, Gigaspora margarita*	Plant yield, number of grains/ spike	Asif, Khan, Khan et al. (1995)
Vigna mungo (black gram)	*Glomus epigaeum* (*G. versiforme*)	*G. epigaeum, Acaulospora spinosa, A. morrowae*	Root colonization, shoot dry weight, N and P concentrations	Rao and Rao (1996)
Vigna radiata (green gram)	*Glomus epigaeum* (*G. versiforme*)	*G. epigaeum, Acaulospora spinosa, A. morrowae*	Root colonization, shoot dry weight, N and P concentrations	Rao and Rao (1996)
Vigna unguiculata	G. etunicatum	*G. etunicatum, Gigaspora margarita*	Shoot dry matter, nutrient uptake	Ahiabor and Hirata (1994)
Vigna unguiculata cv. Katumanu K80	*G. etunicatum*	*Glomus etunicatum, G. claroideum, Glomus* sp.	Top dry weight	Obura, Skipper, and Wagner (1987)
Vigna unguiculata cv. California No. 5 black eye	*G. claroideum*	*Glomus etunicatum, G. claroideum, Glomus* sp.	Top dry weight	Obura, Skipper, and Wagner (1987)
Zea mays (Pioneer 3905)	*Glomus etunicatum*	*G. etunicatum, G. mosseae, G. aggregatum, G. versiforme*	Leaf mass, protein concentrations	Boucher, Dalpe, and Charest (1999)
Nephrolepis exaltata var. *whitmanii* (fern) micropropagated plants	*Glomus intraradices, G. clarum*	*G. intraradices, G. clarum, G. versiculiferum, G. versiforme*	Root infection	Ponton, Piche, Parent et al. (1990)
Tree crops				
Malus × *domestica* (apple)	*Glomus mosseae*	*G. mosseae, G. macrocarpum*	Root colonization, plant height, plant growth	Miller, Bodmer, and Schuepp (1989)
Hevea brasiliensis	*Glomus clarum, Glomus* sp.	*G. clarum, Glomus* sp., *A. spinosa, Gigaspora margarita, Entrophospora colombiana, Glomus* sp., and three other species	Dry weight	Ikram, Mahmud, and Othman (1993)
Leucaena leucocephala (K-8, K-28)	*Glomus mosseae*	*G. mosseae* and six other VAM fungi	Seedling growth	Byra Reddy and Bagyaraj (1988)
Tectona grandis	*Glomous leptotichus*	Not mentioned	Seedling growth parameters	Rajan, Reddy, and Bagyaraj (2000)
Zizyphus mauritiana	*Glomus fasciculatum*	*G. fasciculatum, G. mosseae, Scutellospora calospora*	Growth, root colonization, nutrient uptake	Mathur and Vyas (1996)
Citrus jambhiri (rough lemon)	*Glomus fasciculatum*	*G. fasculatum, G. mosseae, G. etunicatum*	Plant height, top weight, root weight, chlamydospores in soil	Nemec (1979)
Persea american (avocado)	*Glomus fasciculatum*	*Glomus fasciculatum, Acaulospora* sp., *Scutellospora* sp.	Plantlet growth and nutrition	Jaizme-Vega and Azcon (1995)

Appendix 2 List of efficient ectomycorrhizal fungi for tree crops

Plant species	*Efficient mycorrhizal fungus/ fungi*	*Mycorrhizal fungi tested*	*Parameters evaluated*	*References*
Eucalyptus globulus	*Pisolithus tinctorius*	*P. tinctorius, Paxillus muelleri, Cortinarius globuliformis, Thexterogaster* sp., *Hysterangium inflatum, Hydnangium carneum*, *Hymenogaster viscides*, *H. zealanicus, Setchelliogaster* sp., *Laccaria laccata, Scleroderma verrucosum, Amanita xanthocephala, Descolea maculata*, and three other fungi	Plant growth, P-uptake	Burgess, Malajczuk, and Grove (1993)
Eucalyptus diversicolor	*Pisolithus tinctorius*	*P. tictorius, Paxillus muelleri, Cortinarius globuliformis, Thexterogaster* sp., *Hysterangium inflatum, Hydnangium carneum*, *Hymenogaster viscides*, *H. zealanicus, Setchelliogaster* sp., *Laccaria laccata, Scleroderma verrucosum, Amanita xanthocephala, Descolea maculata*, and three other fungi	Plant growth, P-uptake	Burgess, Malajczuk, and Grove (1993)
Larix laricina (four provenances)	*Laccaria laceata*	*L. laceata, Cenococcum geophilum, Pisolithus tinctorius, Suillus granulatus*	Overall growth	Zhu and Navratel (1987)
Picea engelemanü (Engleman spruce)	*Amphinema bysoides and E. strain*	*A. bysoides, E. strain, Thelephora terrestris, Cenococcum geophilum, Mycelium radices-atro-viren, Tomentella* sp., *Laccaria* spp., *Hebeloma, Tuber, Suillus, Rhizopogon*	Diameter growth	Hunt (1990)
Picea sitkensis (Sitka spruce)	*Laccaria laccata, Cenococcum geophilum*	*L. laccata, C. geophilum, Pisolithus tinctorius, Astraeus pteridis, Amanita pantherina*	Mycorrhizal infection	Shaw and Molina (1979)
Pinus halepensis	*Pisolithus arhizus*	*P. arhizus, Rhizopogon rosovlus, Suillus collinitus*	Plant height, dry weight, mycorrhizal infection	Torres and Honrubia (1994)
Pinus patula (6 months)	*Thelephora terrestrus*	*T. terrestris, Laccaria laccata*	Growth, dry matter mycorrhizal infection	Natarajan and Reddy (1994)
Pinus patula (after 6 months)	*Laccaria laccata*	*T. terrestris, Laccaria laccata*	Growth, dry matter mycorrhizal infection	Natarajan and Reddy (1994)
Pinus sylvestris	*Laccaria laccata*	*L. laccata*, *Hebeloma crustuliniforme*, *Thelephora terrestris*	Plant growth	Tyminska, Tacon, and Chadoeuf (1986)
Pinus sylvestris	*Amanita muscaria, Lactarius rufus*	*A. muscaria, L. rufus, Laccaria laccata, Hebeloma crustuliniforme*	Seedling growth	Stenstrom (1990)
Pinus contorta (Lodgepole pine)	*Suillus* sp.	*E. strain, Amphinema bysoides, Thelephora terrestris, Cenococcum geophilum, Mycelium radices atrovirins, Tomentella* spp., *Laccaria* spp., *Hebeloma, Tuber suillus, Rhizopogon*	Diameter growth	Hunt (1990)

Pseudotsuga menzcesu (Douglas fir)	*Rhizopogon* spp.	*E. strain, Amphinema bysoides, Thelephora terrestris, Cenococcum geophilum, Mycelium radices atrovirins, Tomentella spp., Laccaria* spp., *Hebeloma, Tuber suillus, Rhizopogon*	Diameter growth	Hunt (1990)
Quercus alba	*Thelephora terrestris*	*Pisolithus tinctorius* (5 isolates), *Suillus gramulatus* (3 isolates), *Sullus luteus, Thelephora terristris, Cenococcum geophulum*	Nutrient uptake	Mitchell, Cox, Dixon et al. (1984)
Q. rubor	*Thelephora terrestris*	*Pisolithus tinctorius* (5 isolates), *Suillus gramulatus* (3 isolates), *Sullus luteus, Thelephora terristris, Cenococcum geophulum*	Nutrient uptake	Mitchell, Cox, Dixon et al. (1984)
Q. velutina	*Thelephora terrestris*	*Pisolithus tinctorius* (5 isolates), *Suillus gramulatus* (3 isolates), *Sullus luteus, Thelephora terristris, Cenococcum geophulum*	Nutrient uptake	Mitchell, Cox, Dixon et al. (1984)
Quercus petracea	*Paxillus involutus*	*P. involutus, Hebeloma crustuliniforme, Laccaria laccata*	Growth	Garbaye and Churin (1997)
Q. rubra	*Paxillus involutus*	*P. involutus, Hebeloma crustuliniforme, Laccaria laccata*	Growth	Garbaye and Churin (1997)

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Research findings

Morphological and cytochemical study of the pelotonic and non-pelotonic hyphae of the orchid *Spathoglottis plicata*

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Introduction

Orchids have a special type of endomycorrhizae in which the fungal hyphae produce very characteristic pelotons (coiled balls) in the host cortical cells (Senthilkumar and Krishnamurthy 1998). The mycorrhizal association with orchids has been the subject of intensive study, yet the nature of the relationship remains obscure. Peterson, Mueller, and Englander (1980) described a relationship involving at least two different fungi (a basidiomycete and an ascomycete). Later, Couture, Fortin, and Dalpe (1983) obtained isolates of a sterile fungus and *Oidiodendron griseum* from the roots of *Vaccinium.* Resolution of these differences is hampered by the inability to isolate and identity some of the fungi (Muller, Tessier, and Englader1985) and by the inability to differentiate the fungi by cytochemical procedures. To overcome the latter problem, we have used a variety of cytochemical and cytoenzymological procedures for direct differentiation of the fungi in roots. We describe here the procedure for pelotonic and non-pelotonic hyphae in the roots of *Spathoglottis plicata.*

Materials and methods

Spathoglottis plicata, an ornamental ground orchid commonly available in several parts of Sri Lanka containing the natural inoculum of *Rhizoctonia* was collected from the botanical garden of Peradaniya University, Sri Lanka. The mycorrhizal roots were cut into small pieces, washed thoroughly in water, and fixed in FAA (formalin – acetic acid – alcohol). Free-hand sections were made for several cytochemical procedures to understand the changes noticed in hyphae and in the host cells (Krishnamurthy 1998) (Table 1).

Results and discussion

Infection of the root is always by hyphae through root hairs, which are commonly at root tips. Usually, only a single hypha enters into each root hair, but occasionally two or rarely more than two find entry into a single hair. Fungal entry is always confined to the part of the root that has root hairs, and no other region of the root is infected (Burgeff 1959). Entry through root hairs as well as

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Table 1 Cytochemical procedures

Procedures employed and treatment time	*Substances to be localized, colour to be obtained*	*Rationale*
Acid fuchsin method (1% in distilled water)	Protein: Reddish pink (Robinow and Marak 1966)	Aldehydes of proteins react with acid fuchsin and get stained
Alcian blue (3%) solution in 0.1N sodium acetate buffer, pH 5.6	Carboxylated polysaccharides: blue (Gahan 1984)	Negatively charged carboxyl group of uronic acids of pectins bind to the cationic alcian blue by salt linkages at the isoindole conferred cationic sites
Chlorazol black E (in 1% methyl cellosolve 5 min)	Cellulose: black to bluish black (Krishnamurthy 1998)	Relation not clear
Commassie Brilliant Blue (0.02% in Clarke's solution 15 min)	Total proteins: blue (Krishnamurthy 1998)	Yields a stereo-chromatic reaction with all proteins
Fast green FCF (fast green FCF in 50 ml of 0.1 M phosphate buffer pH 8.0) 30 min	Basic protein and nuclei: green (Prento and Lyon 1973; Gahan 1984)	Deamination/acetylation/ trypsin extraction
Sudan black E	Lipids: black (Krishnamurthy 1998)	This dye gets selectively soluble in tissue lipids, thereby staining the complex black to blue black
Toluidine blue O (TBO) (0.5% in acetate buffer, pH 4.4)	Carboxylated polysaccharides: pink to reddish pink (Mc Cully 1966)	TBO is a meta-chromatic dye. Highly polymerized lignin shows orthochromatic blue colour and less polymerized lignin bluish colour

rhizodermis has also been reported by a few investigators (Peterson and Farquhar 1994; Senthilkumar and Krishnamurthy 1998). At the point of entry, no special features can be seen in the hypha. The enzymatic dissolution of the root hair wall by the fungus probably facilities its entry.

Entry into the cortex is always through the passage cells of the exodermis, and no instance of fungal mycelium in the thick-walled cells of the exodermis has been noticed. From this location, the hyphae again intracellularly enter into the cortex proper and some of the branches get into the cortical parenchyma cells for forming pelotons.

However, subsequent hyphae settle down gradually in the middle regions without forming pelotons. These cortical cells often show only hyphal filaments and no hyphal clumps or pelotons; in other words, the capacity to form pelotons is restricted to only the orchid mycorrhizae. As in many previously studied orchids, colonization was restricted to the cortex only. Penetration of hyphae into endodermis and central cylinder, as observed by Ruinen (1953) in a species of *Dendrobium*, was not observed in the present orchid.

However, as infection is a continuous process and all cells of the cortex are not colonized at the same time, there is often a mix-up of pelotons and pelotonic hyphal colonization across the entire cortex (Figure 1). One significant event in the orchid–mycorrhizal association is the lysis of the pelotons (Peterson and Currah 1990; Senthilkumar and Krishnamurthy 1998). Digestion was also observed randomly in the cortex and not in a defined zone of cells, designated as the 'digestion layers', which have been recognized in the inner cortex of some orchid species (Hadley 1982; Hadley and Williamson 1971). But interestingly, the digestion of non-pelotonic mycorrhizal elements was not noticed in the cortical cells. Fusconi and Bonfante-Fasolo (1984) described the mycorrhizae formed between *Arbutus unedo* and an unknown ascomycete symbiont and found a typical hartig net, intracellular colonization, and a thin fungal mantle.

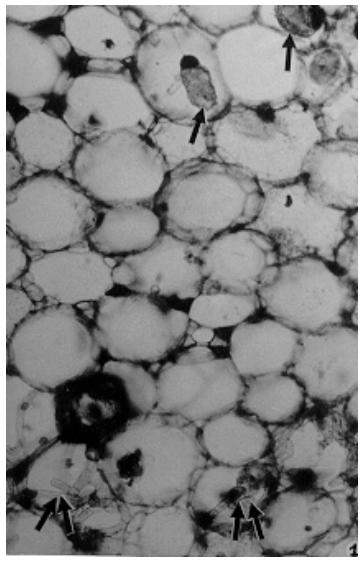


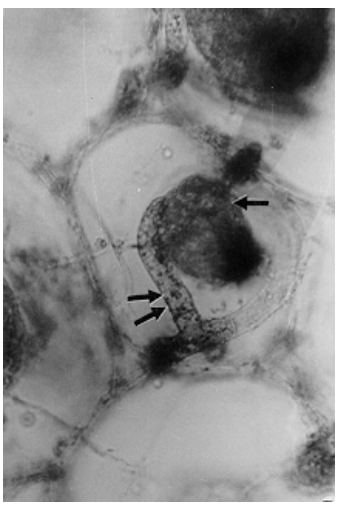
Figure 1 Cross section of root stained with Alcain blue to show the pelotons (single arrow) and non-pelotonic hyphae (double arrow) (× 150).

A number of investigators have carried out detailed structural and cytochemical studies on the

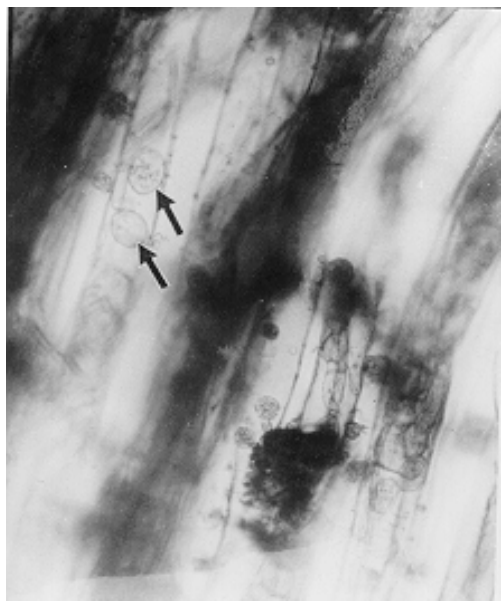
pelotons (Peterson and Currah 1990; Senthilkumar and Krishnamurthy, 1998). A number of these observations are confined to orchid mycorrhizas and non-pelotonic hyphae, as is also the case in the present study. The orchid mycorrhizae are fully filled with cytoplasm and get stained prominently with fast green, indicating their high histone content. The cytoplasm is rich in basic proteins and insoluble polyaccharides (Figure 2), and has fairly good amounts of lipids and cellulose. In *Platanthera*, Richardson, Petewrso, and Currah (1992) observed lipids polyphosphates in the hyphae in the initial stage of lysis. Non-pelotonic hyphae remained intact whereas pelotonic hyphae underwent digestion (Figure 3). Intense activity of carboxylated polysaccharides was found in the cell wall (Figure 2), although activity could also be detected to some extent in other regions. The present study indicated that there are good amounts of basic proteins, lipids, and cellulose, especially basic protein in the cell wall and cytoplasm of fresh non-pelotonic filaments. Barroso, Chaves, and Pais (1986) reported that there are a number of steroidal substances in the infected cells of *Ophrys lutea*. They may also perhaps be responsible for the positivity that was observed for lipid stains used in the present study. There is also a moderate activity of histones and poor activity of polysaccharides in the non-pelotonic hyphae. Non-pelotonic hyphae are separated from the lysing peloton by the presence of phenols in their walls. This is one of the reasons for the high activity of phenols in their walls.

Among these associations, one of the hyphae (orchid mycorrhizae) enters into root hairs and starts producing shorter hyphal cells. It may remain unbranched or often undergo branching; the two branched hyphae are seen parallel to each other in host root hair. One or both of these hyphal branches soon produce the so-called chlamydospores (Saksena and Vaartaja 1961). These chlamydospores are either terminally produced in these hyphae or are intercalary and may be produced singly or more commonly in chains, resulting in beaded or moniliform appearance (Figure 4). Chlamydospores are pyriform, oval, spherical, or club-shaped, the terminal ones often showing a beak. The hyphae producing the chlamydospores are rich in total proteins, carboxylated polysaccharides, and phenols. Sneh, Burpee, and Ogoshi (1991) and Senthilkumar, Krishnamurthy, and Vengadeshwari (1998) reported that these types of chlamydospores are

▲ **Figure 2** Cross sections of root indicating the presence of polysaccarides in the pelotons and colouration indicating the presence of phenols with TBO (× 650).



◀ **Figure 3** The cortical cell showing lysing pelotons (arrow) with non-pelotonic hyphae (double arrow).



▲ **Figure 4** Chains of chlamydospores in root hair about to be released (arrow) (× 650).

occasionally produced in epidermal cells and root hairs of the host. To the best of our knowledge, there is no report of these two types of association in the orchid *Spathoglottis plicata*, and there is no satisfactory explanation of the role of non-pelotonic mycorrhizae.

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Mass production of vesicular–arbuscular mycorrhizae using different hosts

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Introduction

Vesicular–arbuscular mycorrhizal (VAM) fungi form obligate symbiotic associations with the roots and other underground parts of most plants. Their association with plant roots indirectly resists penetration by nematodes, thus helping the plant in its growth and production. It is well known that VA mycorrhizal fungi improve the growth of plants by providing higher absorptive surface compared with root hairs, and thus help in the absorption of relatively immobile ions in soil, such as phosphorus, copper, and zinc (Bagyaraj, 1992). Continued efforts are on to develop mass production technologies for VAM fungi. Hence, using various hosts, a study was undertaken to compare the mass multiplication of VAM.

Materials and methods

Different host crops (11) were grown in pots containing sterilized soil, and a culture of VAM (*Glomus fasciculatum*) was added at 10 g/kg soil for multiplication. After one and two months, spores in soil and root colonization were recorded to find the suitable preferred host for VAM multiplication.

Results and discussion

Pearl millet (Cumbu) (*Pennisetum typhoides*) was found to be the best host—the spore population was 460 per 200 ml soil after one month (Table 1). This was followed by bhendi with a spore population of 268.8 per 200 ml soil after one month. In cotton, spore count reached 312.9 per 200 ml after the second month. The spore population was more than 100 in 200 ml soil of cowpea, maize, and red gram whereas in all other hosts, the count was less than 100. Sieverding and Leihner (1984) have reported that graminaceous and leguminous crops generally tend to increase VAM population whereas mycotrophic plants decrease the population of VAM fungi.

Table 1 Mass multiplication of VAM: host preference

Host	*Shoot length* (m)	*Shoot weight* (g)	*Root length* (cm)	*Root weight* (g)	*Spore count/ 200 ml soil*	*VAM colonization* (%)
Tomato						
Month I	61.8	19.9	17.8	6.6	25.9	20.0
Month II	79.3	43.2	14.2	15.3	87.1	43.9
Cumbu						
Month I	56.9	1.7	14.2	0.2	460.0	71.2
Month II	73.8	9.5	18.8	1.1	86.7	80.3
Cotton						
Month I	37.2	0.6	11.0	0.4	60.1	71.0
Month II	38.8	4.2	12.1	1.1	312.9	60.5
Bhendi						
Month I	27.6	6.0	13.3	1.3	268.8	74.5
Month II	44.6	12.0	13.3	2.4	222.9	70.0
Brinjal						
Month I	20.3	3.8	13.7	2.1	85.3	31.0
Month II	27.0	8.3	17.4	2.4	41.4	36.0
Cowpea						
Month I	39.1	6.7	14.7	0.7	167.0	67.0
Month II	86.5	9.8	11.8	1.5	199.0	70.0
Green gram						
Month I	37.7	2.4	10.1	0.6	113.0	68.0
Month II	34.9	3.1	27.7	4.3	73.0	49.0
Maize						
Month I	65.0	8.6	74.0	18.6	170.0	68.0
Month II	92.1	17.7	44.2	18.9	143.0	60.8
Red gram						
Month I	37.7	1.5	12.5	0.6	152.4	56.2
Month II	42.1	3.2	3.4	1.1	130.6	60.8
Black gram						
Month I	30.0	3.1	12.5	0.4	79.4	103.3
Month II	11.0	6.4	15.9	5.1	88.9	46.8

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A note on vesicular–arbuscular mycorrhiza development in *Albizia procera* in root trainers

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Root trainers are being effectively used to raise seedlings in forest nurseries. Different grades of potting mixture are used as potting media in root trainers (Mishra and Emmanuel 1997). In most cases, compost is a suitable substrate for raising seedlings in root trainers. It has been observed that compost does not contain an effective VAM population. However, a very sparse population of spores has been recorded in compost, which mostly occur as contaminants through soil, root bits, etc. Moreover, pure compost has an acidic pH, which can be amended by using sand. The role of VAM (vesicular–arbuscular mycorrhiza) in improving the quality and survival of forest tree seedlings is well documented. There is considerable variability in VAM development in different grades of potting mixture. An experiment was conducted to study VAM in the root trainer by using *Albizia procera* as the test species. The combination of treatments is as follows.

1 Pure compost, pH 5.8
2 Compost + sand (80:20), pH 6.4
3 Compost + sand (50:50), pH 6.4
4 Sand, pH 6.8

The capacity of root trainers was 300 cc. The compost contained *Glomus*, *Scutellospora*, and *Gigaspora* in very low quantity. When the compost is diluted by using sand, the population of propagules of VAM is reduced considerably. Seeds were sown in the root trainer after proper treatments (Rahangdale and Gupta 1998). The VAM culture containing root bits and soil was applied after initiation of seed germination (after 10 days). The inoculation was made by using the mix VAM culture prepared from *A. procera* by using *Panicum maximum* as the trap plant. The inoculum was applied at the rate of 25 g/root trainer with a capacity of 300 cc having 250 infective propagules. Infective propagules included *Gigaspora* spp., *Scutellospora* spp., *Glomus mosseae*, *G. intraradices*, and *Acaulospora scrobiculata*. VAM colonization in roots of *A. procera* was obtained by using the techniques of Phillips and Hayman (1970). The experiment was conducted for three months.

The compost contained a sparse population of VAM, particularly *Gigaspora*, *Scutellospora*, and *Glomus mosseae*. After dilution with sand, the population is reduced considerably. The pH of the potting media was also measured. After treatment with VAM, the spore number of VAM fungi increased in the potting mixture containing compost + sand (80:20, 50:50) and pure compost. However, spore development is low in pure sand. The per cent colonization of root by VAM was higher in plants grown in potting media having compost and sand (80:20) and pure compost. Spore population was lower in pure compost with pH 5.8. A similar trend was noticed by Raghvendra and Lakshman (1995). The height of plants varied from 31 cm to 15 cm in different treatments (Table 1). The height growth of *A. procera* was 31 cm, 27 cm, and 21 cm in pure compost, compost

Table 1 VAM status and seedlings growth of A. procera in root trainers in different combinations of compost after 4 months

Treatment	*Infection* (%)	*Shoot height* (cm)	*No. of nodules*	*No. of spores/ 100 g*	pH
Pure compost	45	31.00	20.00	180.00	5.8
Compost + sand (80:20)	50	27.00	34.00	200.00	6.4
Compost + sand (50:50)	40	21.5	33.00	260.00	6.4
Sand	40	20.00	18.00	189.00	6.8
SEM	+2.39	+2.54	+4.21	+18.05	
CD at 5%	9.39	9.95	16.53	70.00	

+ sand (80:20), and compost + sand (50:50) respectively. Verma and Jamaluddin (1994) reported that a mixture of *Glomus mosseae*, *G. fasciculatum*, *G. etunicatum*, and *G. aggregatum* enhanced growth of *Acacia nilotica* seedlings under different moisture regimes. In the present study, VAM inocula having a consortium of VAM fungi, namely *Glomus mosseae*, *G. aggregatum*, *G. intraradices*, *Scutellospora*, *Gigaspora*, and *Acaulospora scrobiculata*, colonized successfully in different potting media. However, mycorrhizal infection and spore number were low in pure sand. Rahangdale and Gupta (1998) noticed only a 26.6% infection of VAM in *A. procera*. However, in the present study, VAM colonization reached a level of 50%. Root nodule development was more when plants were grown in compost + sand (80:20 and 50:50). It is concluded that the potting mixture with pure compost or its amendment with sand require inoculation with VAM consortium to enhance the growth of *A. procera* in root trainers. The population of the VAM also multiplies significantly in such potting media.

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New approaches

Comparison of various techniques for recording AM colonization

The extent of AM colonization was assessed by Gange A C, Bower E, Stagg P G, Aplin D M, Gillam A E, Bracken M (1999) in 10 field-collected plant species—three annual forbs, three perennial forbs, three perennial grasses, and one annual grass (*The New Phytologist* 142(1): 123–132). The root system of each plant was split into four portions, and the mycorrhizal structures were revealed using four methods, i.e. epifluorescence microscopy (under which only arbuscules are generally visible) and three stains (chlorazol black E, acid fuchsin, and trypan blue) to evaluate the efficiency of each method and compare results by each method under standard laboratory conditions. The recorded colonization levels of arbuscules, total arbuscular mycorrhizal fungal material, and total fungal (arbuscular mycorrhizal + non-arbuscular mycorrhizal) material differed significantly with different visualization methods in a number of species. However, there were also interactions between a stain and plant species, indicating that the performance of a stain is dependent on the plant species being examined. In some cases (e.g. *Plantago lanceolata*), each visualization method produced the same level of colonization, whereas in others (e.g. *Dactylis glomerata*), each method gave a different result. The findings, therefore, suggest that the level of mycorrhizal colonization recorded in any particular plant species at a particular time is dependent on the technique employed.

Molecular methods for determining intra- and interspecific variations in ectomycorrhizal fungi

Molecular techniques were employed by Bonfante P, Lanfranco L, Cometti V, Genre A (1997) on genomes of 13 *Suillus* isolates from Mediterranean and Alpine regions by using a range of PCR-based techniques (*Microbiological Research* 152(3): 287–292). Amplification of the ITS (inter-transcribed spacers) region gave fragments of the same length irrespective of the species, whereas RFLP (restriction fragment length polymorphism) revealed interspecific variability. Random oligonucleotides for RAPD (random amplified polymorphic DNA) amplification and primers for microsatellites led to polymorphic fingerprints, revealing intraspecific differences. In addition, microsatellite fingerprinting allowed separation of strains with different symbiotic capabilities (e.g. *Suillus collinitus* strains 24 and 31) as well as strains originating from the same zone. The studies thus suggest that a range of molecular probes used on the same isolates can provide both specific fingerprints for selected fungal strains and tools to investigate the physiological characteristics of ectomycorrhizal fungi.

Centre for Mycorrhizal Culture Collection

Mycorrhiza in sustainable agriculture

Reena Singh and Alok Adholeya
Centre for Mycorrhizal Research, Tata Energy Research Institute, Darbari Seth Block, Habitat Centre, Lodhi Road, New Delhi – 110 003, India

The word 'sustain', from the Latin *sustinere* (*sub:* 'from below' and *tenere:* 'to hold'), means 'to keep in existence or maintain', and implies long-term support or permanence. As regards agriculture, 'sustainable' describes farming systems that are 'capable of maintaining their productivity and usefulness to society indefinitely. Such systems must be resource-conserving, socially supportive, commercially competitive, and environmentally sound.' (Duesterhaus, 1990). Sustainable agriculture was addressed by the Congress in the 1990 Farm Bill (FACTA [Food, Agriculture, Conservation and Trade Act] of 1990) under which the term 'sustainable agriculture' means 'an integrated system of plant and animal production practices having a site-specific application that will, over the long term

- satisfy human food and fiber needs
- enhance environmental quality and the natural resource base upon which the agricultural economy depends
- make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural
- biological cycles and controls
- sustain the economic viability of farm operations
- enhance the quality of life for farmers and society as a whole.'

The strategy being adopted in India as well as in other Asian countries essentially relies on two interrelated actions: first, a dramatic intensification of input of external resources such as water (irrigation systems), fertilizer, and a plethora of pesticides and other agrochemicals, and second, the introduction of modern, high-yielding, but generally also highly demanding crop varieties which are often planted in continuous, uniform monocropping systems. It is now clear that agricultural ecosystems subjected to continuous high intensification invariably exhibit degradation trends over the long term. This is mainly due to adverse effects on the soil structure, health, and fertility, along with an increase in number and intensity of pests. A recent broad survey of the IRRI (International Rice Research Institute) covering several intensively managed agricultural areas in India and the Philippines revealed that crop yields remained stagnant or even declined during the last decade and this was attributed to an intensification-induced degradation processes (Pingali, Hossain, and Gerpacho, 1997).

Such degradation of arable land is a major threat worldwide to the sustainability of agricultural production. During the last 40 years, nearly one-third of the world's arable land has been lost by erosion and continues to be lost at a rate of more than 10 million ha per year (Pimental, Harvey, Resosudarmo, et al. 1995). For example, in India, 2400 million tonnes of silt is estimated to be carried away through the rivers every year; furthermore, 4.5 million ha is affected by salinization and 6 million ha by waterlogging due to agricultural (mis-)management (Pingali, Hossain, and Gerpacio 1997). A more holistic, long-term approach to food production in sustainable agroecosystems is therefore urgently needed. The main goal of such an approach is to maintain economic crop production levels in a sustainable, ecologically sound way. To attain this goal, farming strategies have to be adopted that exploit and enhance inherent resources of the natural environment, such as soil fertility, biological nitrogen fixation, biological control of diseases, etc., rather than relying on high input of costly external resources.

The symbiosis of plants with AMF (arbuscular mycorrhizal fungi) is the most widespread mutualistic symbiosis in natural ecosystems, which has been estimated to occur on land growing wheat and pulses and almost all other important agricultural crops. It is well documented that mycorrhizal plants show improved growth, health, and resistance to abiotic and biotic stress as compared with non-mycorrhizal controls. These beneficial effects of AMF for the plants are expressed most under stresses such as nutrient limitation, drought, or heavy metal pollution. The AM symbiosis has also been shown to contribute substantially to soil conservation via its role in the formation of water-stable soil aggregates by extraradical mycelia and the bacteria associated with it. These aggregates are crucial for creating and maintaining a macroporous, water-permeable soil structure, which is a prerequisite for erosion resistance and aerobic microbial activity in the rhizosphere, necessary for efficient nutrient cycling. Due to these functional attributes, AM symbiosis is of particular relevance for low-input agriculture in the third

world as well as for the recultivation and management of degraded soils and wasteland. It is also of general relevance to the global endeavour to develop more sustainable forms of agriculture (for reviews, see Bethlenfalvay and Linderman 1992; Pfleger and Linderman 1994; Sieverding 1991; Smith and Read 1997).

The CMR (Centre for Mycorrhizal Research) group at TERI is actively involved in the activities related to sustainable agriculture. An integrated use of organic manure and mycorrhizal biofertilizer works wonders in the agricultural fields. The CMR has specific mycorrhizal fungi for many kinds of plants: vegetables (onions, potatoes, etc.), fodder crops (barseem, lucerne, sorghum, etc.), flowers (marigold, gladiolus, aster, etc.), trees (eucalyptus, poplar, etc.). Use of mycorrhizal fungi has been found to increase yields by 30%–50%.

Without doubt, an improved understanding and management of the symbiosis of plants with AMF in agroecosystems ultimately has a large social and environmental impact, particularly in low-input sustainable agriculture and in tropical agrosystems. It is certainly of great importance for India, where nearly one half of the districts have been classified as being highly deficient in plant-available phosphorus (Pingali, Hossain, and Gerpacio 1997).

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I, R K Pachauri, hereby declare that the particulars given above are true to the best of my knowledge and belief.

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Date: April 2001 Dr R K Pachauri

Recent references

Latest additions to the Network's database on mycorrhiza are published here for information of the members. The Mycorrhiza Network will be pleased to supply any of the available documents to bonafide researchers at a nominal charge.

This list consists of papers from the following journals, which are arranged in alphabetical order.

- *Annals of Forest Science*
- *Biology and Fertility of Soils*
- *Biotechnology Letters*
- *Ecology Letters*
- *FEMS Microbiology Ecology*
- *Fungal Associations*
- *Greece Agrochimica*
- *Journal of Experimental Botany*
- *Journal of Plant Growth Regulation*
- *Naturwissenschaften*
- *Nova Hedwigia*
- *Mycological Research*
- *Physiological and Molecular Plant Pathology*
- *Phytochemistry*
- *Plant Biology*
- *Potato Research*
- *The New Phytologist*

Copies of papers published by mycorrhizologists during this quarter may please be sent to the Network for inclusion in the next issue.

Name of the author(s) and year of publication	Title of the article, name of the journal, volume no., issue no., page nos [*address of the corresponding author]
Bereau M, Barigah T S, Louisanna E, Garbaye J*. 2000	**Effects of endomycorrhizal development and light regimes on the growth of *Dicorynia guianensis* Amshoff seedlings** *Annals of Forest Science* **57**(7): 725–733 [*INRA, Centre for Research Forestieres Nancy, F-54280 Champenoux, France]
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