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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

Role of mycorrhiza in tree plantings in the field. Part I. Field performance of mycorrhized plants

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Management of mycorrhizae and associated beneficial organisms in reforestation programmes comprises three major components—protection of indigenous soil communities, and evaluation of inoculation needs; integration of inoculation programmes into existing reforestation technology; and research. Adequate mycorrhiza formation is critical for ectomycorhizal trees growing on poor sites or in environments where seedlings must establish quickly to survive. Poor mycorrhiza formation reduces the chances of survival of seedlings and consequently, tree stocking which in turn leads to further loss of mycorrhizal inocula. Research is, therefore, needed on adaptation of mycorrhizal fungi to particular environmental factors; on interactions between tree seedlings and processes; and on the role of mycorrhiza and associated organisms in ecosystem structure and processes, particularly nutrient cycling, plant–plant interaction, and soil structure (Perry, Molina, and Amaranthus 1987).

Performance of mycorrhized plants on normal sites

Effect of mycorrhiza on survival rates

Studies conducted at the Forestry Research Institute, Seoul, Republic of Korea, on *Pinus rigida* seedlings inoculated with US strain of *Pisolithus tinctorius* on fumigated nursery soil and then transplanted in the field, showed that survival percentage of inoculated seedlings was 90% compared with 83% in controls (Lee, Park, and Lee 1988).

Inoculation of *Pinus resinosa* seedlings with *Hebeloma arenosa* in nursery significantly increased seedling survival following outplanting in the field but did not increase seedling growth in studies conducted at the Department of Plant Pathology, University of Wisconsin, Madison, USA. *H. arenosa* did not colonize roots growing from the root plug into the surrounding soil (MacFall and Slack 1991).

In studies conducted at the Department of Plant Pathology, Institute de Recerca i Tecnologia Agroalimentaries, Centre de Cabrils, Barcelona, Spain, bare-root Douglas fir seedlings inoculated with *Laccaria laccata* S-238 or uninoculated (infected by *Thelephora terrestris* or a *Suillus* sp.) in two Central France nurseries, were outplanted in a randomized block design at Pontavedra and in a completely randomized design at Garona. Survival after one growing season in the field differed considerably at the two reforestation sites, being much higher at Garona than at Pontavedra for all treatments. Within each site, survival of seedlings was not significantly related to either nursery source or inoculation treatment. Inoculated seedlings were taller than uninoculated seedlings irrespective of nursery source or site location and analysis of the data revealed that seedling growth after one growing season in the field was related to initial height (Alvarez, Parlade, and Pera 1990).

Studies conducted at Bioplanta, C P Campinas, SP, Brazil, showed that the number of surviving seedlings raised from heat treated, pregerminated seeds of cleopatra Citrus and inoculated with VAM in Styrofoam containers was 49168 from a total of 88960 seedlings (55.27%). Growth difference between the inoculated and non inoculated plants was much greater in fumigated soil than in non-fumigated soil where the uninoculated plants were colonized by native VAM fungi in two months (Lin, Mattos, Taveira, et al. 1987).

Studies conducted at the USDA (United States Department of Agriculture), Forest Service, Athens, GA, USA, showed that after eight years in the field, loblolly pine (*Pinus taeda*) with Pt (*Pisolithus*

* Compiled from TERI database – Riza

tinctorius) index of 88 and 68 had better survival than nursery run control seedlings (Pt index 0) (Marx and Cordell 1987).

Studies conducted at the University of Wyoming, Department of Botany, Laramie, USA, on ectomycorrhiza formation, survivability, and physiognomic characteristics of conifer seedlings encountered one and two years post fire showed that *Pinus contorta* germinated and was abundant throughout first growing season and survival was about 50% for east-facing burn and edge and west-facing burn treatments. *Abies lasiocarpa* germinated during May and June but was rarely encountered by September. Few or no mycorrhizae were formed until September but by September all surviving seedlings were ectomycorrhizal. The number of ectomycorrhizae was positively correlated with the number of primary needles and the root–shoot ratio (Miller, McClean, Stantom, et al. 1998).

Effect on growth parameters

Outplanting performance of mycorrhiza inoculated seedlings was reviewed at the USDA, Forest Service, Pacific Northwest Research Station, Corvallis, Oregon, USA. The reviewed work included 568 unique combinations for 66 host plants (16 VAM, 49 ectomycorrhizal, and 1 VAM + ectomycorrhizal), 74 fungal species (8 VAM, and 66 ectomycorrhizal), and 5 inoculum types. Of these, 267 entries list improvement in one or more plant growth parameters, 41 list deleterious effect, 7 entries list both positive and negative effect, and 253 list no impact on seedling performance. In ectomycorrhizal entries, 41 host plants belonged to Pinaceae, 6 to Fagaceae and one each to Casuarinaceae and Leguminoceae. Vesicular–arbuscular mycorrhizal host plants belonged to 16 families (Castellana 1990).

Studies conducted at the Department of Forest Resources, University of Minnesota, St Paul, USA, showed that the use of container culture and ectomycorrhizal inoculation with *Pisolithus tinctorius* significantly improved seedling root and shoot growth, water balance, and soil–plant liquid flow resistance of black oak seedlings outplanted under reforestation programmes. Seedlings planted without the benefit of ectomycorrhizal association may lack the growth potential necessary to compete with adjacent vegetation (Dixon, Garrett, Cox, et al. 1984).

Growth of *Pinus sylvestris* seedlings inoculated in the nursery with various forest mycorrhizal fungi (*Amanita muscaria*, *Lactarius rufus*, *Suillus variegatus*, *Tricholoma albobrunneum*, and an unknown fungus) was monitored for three years in field plantings in studies conducted at the Department of Mycology and Plant Pathology, Swedish University of Agricultural Sciences, Uppsala, Sweden. At outplanting, 10–40% of the root tips were mycorrhizal consisting of both the inoculated fungi and an indigenous nursery mycorrhizal fungus, *Thelephora terrestris*. Some of the inoculated seedlings were substantially smaller than the uninoculated seedlings. But after 2.5 years, seedlings in some of the treatments had up to 50% greater volume than the control seedlings. Even at low initial mycorrhizal colonization rates, some mycorrhizal species stimulated seedling growth. This was specially true for seedlings inoculated with *A. muscaria* — these were 50% smaller than control at the time of outplanting but grew rapidly to 20% larger than control 18 months after outplanting. This observation contradicts the general concept pertaining to the importance of seedling size at the time of outplanting (Stenstrom and Ek 1990).

Another study at the above university on *Pinus sylvestris* seedlings inoculated in the nursery with *Laccaria laccata* (isolate S 238 A, now known as *L. bicolor*), *Hebeloma crustuliniforme* (two isolates), and *Cenococcum geophilum*, showed that at the time of outplanting in the field 25–90% of the root tips were mycorrhizal with target fungi whereas 25–50% of the uninoculated control seedlings were spontaneously colonized by other fungi. Most of the inoculation in the nursery resulted in reduced seedling growth; growth rate inhibition was pronounced up to 1.5 years in the field except for seedlings inoculated with *C. geophilum*. By this time, seedlings inoculated with *L. bicolor* and *H. crustuliniforme* had 40–50% less volume than the control seedlings and the relative difference was maintained or was slightly decreased during following four years. The uninoculated nursery-produced seedlings had about 50% more volume than the corresponding control seedlings at outplanting. In the field, however, they grew relatively more slowly and consequently, were similar in growth to the control seedlings (Stenstrom 1990b).

Pinus spp., *Eucalyptus* spp., dipterocarps, and *Casuarina equisetifolia* were inoculated in the nursery with mycorrhizal tablets made from compressed mixture of basidiospores of *Pisolithus tinctorius* and *Scleroderma cepa* and then outplanted in the field in studies conducted at the Department of Forest Biological Sciences, University of Philippines. Inoculated seedlings showed an increase in height by 40–60%, diameter by 40–90%, and volume by more than 200% over the uninoculated plants. The positive response due to tablet inoculation in the nursery was observed even after three years in the field. In addition, mycorrhizal tablet inoculation was able to replace 60–85% of inorganic fertilizers required for the growth of pines and eucalypts in the field (Reynaldo and Cruz 1990).

Studies conducted at the Forestry Research Institute, Seoul, Republic of Korea, on *Pinus rigida* seedlings inoculated with US strain of *Pisolithus tinctorius* grown in fumigated nursery soil and then transplanted on exposed mineral soil, showed that height and root collar diameters of inoculated seedlings were 53% and 82%, respectively, more than those of uninoculated seedlings grown on non-fumigated soil. On outplanting, seedling growth

(dry weight) was 20% higher in inoculated seedlings. Height increment after transplanting was 31% more in inoculated seedlings than in controls. The Korean strain of *P. tinctorius* was less effective than the US strain (Lee, Park, and Lee 1988).

Studies conducted at the USDA, Forest Service, Athens, GA, USA, showed that after eight years in the field, loblolly pine with Pt (*Pisolithus tinctorius*) index of 88 and 68 had better growth than nursery-run control seedlings (Pt index 0). Volume and weight yield per acre were 50% greater for index 88 trees than controls. Distribution into four size classes showed that 67%, 81%, 80%, and 62% of index 88 trees were in the two largest classes of height, dbh, tree volume, and weight, respectively, compared to 53%, 63%, 59% and 39% of controls. Index 27, 46, and 68 trees were intermediate. Analysis also showed that average volume per acre positively correlated with Pt index more than 58. *P. tinctorius* can persist on a good-quality site and alleviate growth loss due to water deficit (Marx and Cordell 1987).

Comparative performance of mycorrhizal fungi

Studies conducted at the Heffley Reforestation Centre Ltd, Kamloops, British Columbia, Canada, showed that the fungi that established in nurseries are common in field plantings. In nurseries, the Engleman spruce is colonized only by *Thelephora terrestris* and *Laccaria* spp. under high nitrogen and phosphorus fertility but in low fertility, *Amphinema byssoides* and *E. strain* dominated. *Mycelium radices atrovirens* is also common at low fertility. On lodge pole pine, at low fertility levels, *E. strain*, *Suillus* sp., and *Mycelium radices atrovirens* are common. In field plantings, on normal reforestation sites, the fungi which produced significant increase in absolute or relative (annual increment as percentage of starting measurement) diameter growth as compared to control are *Amphinema byssoides* or *E. strain* on Engleman spruce, *Suillus* sp. on lodgepole pine, and *Rhizopogon* spp. on Douglas fir. The fungi which have been identified on spruce in Alberta and British Columbia of Canada include E. *strain*, *Thelephora terrestris*, *Cenococcum geophilum*, *Amphinema byssoides*, *Mycelium radices atrovirens*, *Tommentella* spp., *Laccaria* spp., *Hebeloma* like species, *Tuber* like species, and *Suillus* and *Rhizopogon* like species. The most abundant fungi on young seedlings are generally not members of *Agaricales* (Hunt 1990).

In studies conducted on *Pinus sylvestris* at the Department of Forest Mycology and Pathology, Swedish University of Agricultural Sciences, Uppsala, Sweden, non-aggressive forest fungi, especially *Amanita muscaria* and *Lactarius rufus*, tended to have the greatest benefits on seedling growth after outplanting in the field. Two-and-half-a years after outplanting, some of the inoculations resulted in seedlings with up to 40% more shoot volume that uninoculated controls. In contrast, rapidly colonizing, aggressive, and tenacious mycorrhizal fungi, especially *Laccaria laccata* and *Hebeloma crustuliniforme*, appeared to require too much of host's carbohydrate supply. Inoculations with these species, therefore, resulted in prolonged stunting. However, these fungi appeared to be better adapted to moist soils where they easily colonized pine roots. Inoculations with *L. laccata* and *H. crustuliniforme* also increased tolerance to drought stress (Stenstrom 1990a).

In studies conducted at the Institut Nationale Le la Recherche Agronomique, Equipe Microbiol Forestiere (INRA), Champenoux, France, nursery-grown *Quercus petracea* and *Q. rubra* seedlings were inoculated with *Paxillus involutus* or *Hebeloma crustuliniforme* or *Laccaria laccata* and at the end of first growing season, outplanted at two sites. *P. involutus* was the most competitive and efficient of the three fungi tested as its mycorrhizae were present seven years after outplanting and this markedly improved the growth of both oak species. In *Q. rubra*, growth stimulation was more marked during years with dry summer (Garbaye and Churin 1997).

Effect of fertilizers on mycorrhizal efficiency

In studies conducted at the Department of Plant Pathology, North Carolina State University, USA, loblolly pine seedlings were inoculated with 750 cm^3 mycelium of each of *Pisolithus tinctorius*, *Thelephora terrestris,* and *P. tinctorius* plus *T. terrestris* or left uninoculated and fertilized with either nitrogen (ammonium nitrate at 145 kg/ha) or NPK (ammonium nitrate, calcium dihydrogen phosphate, and potassium chloride at 145, 50, and 100 Kg/ha, respectively). The seedlings were then planted on two sites an average site and a poor site. After four growing seasons on the average site, there was no difference in height, stem diameter, or survival among mycorrhizal fungal or fertilizer treatments. On the poor site, trees with *T. terrestris* and unfertilized were taller than those in other treatments. Trees with ectomycorrhiza formed by *P. tinctorius* and fertilized with nitrogen were 21% taller than those with *T. terrestris* or *T. terrestris* plus *P. tinctorius* ectomycorrhizae in the first year (Grand, Raleigh, and Krugner 1979).

Loblolly pine (*Pinus taeda*) seedlings were outplanted on eight reforestation sites following inoculation in the nursery with either *Pisolithus tinctorius* or *Thelephora terrestris* or naturally inoculated in the field and with two levels of ammonium sulphate fertilizer in studies conducted at the Southern Forestry Research Centre, Hot Springs, USA. The results showed that the seedlings with a high incidence of *P. tinctorius* mycorrhiza or fertilized with high rate of ammonium sulphate survived best. Trees with low levels of *P. tinctorius* mycorrhiza survived poorest. Growth after one year in the field was also related to nursery practice but subsequent growth appeared to be related to site

quality and initial height. There appeared to be neither a treatment site interaction nor a carry-over effect beyond the first year (Mexal, Marx, and Morris 1979).

Effect of root pruning or suppression

Studies conducted at the USDA, Forest Service, Athens, GA, USA, showed that container-grown seedlings of loblolly pine and longleaf pine inoculated with *Pisolithus tinctorius* and planted on routine forest sites often failed to show improved field performance over uninoculated seedlings. However, when seedlings of both pines were chemically pruned with cupric carbonate in the greenhouse to alter root morphology and improve spread of *P. tinctorius* in egressed roots, they survived and grew better than uninoculated and untreated seedlings after two growing seasons (Ruehle 1987).

Shorea parviflora seedlings were collected nine months after logging, from beneath open, closed, and partially closed, canopies resulting from different logging treatments in studies conducted at the Institute of Terrestrial Ecology, Bush Estate, Midlothian, Scotland. Logging was done manually with minimal soil disturbance, compaction, or damage to the vegetation. Seedlings growing under closed canopy were smaller and had lower levels of mycorrhizal infection than those under open or partially closed canopies. Twenty-six ectomycorrhizal types were distinguished, and the greatest diversity was in seedlings under open or partially closed canopies. Based on their frequency (number of seedlings having a mycorrhizal type) and abundance (per cent infection of a mycorrhizal type if present), mycorrhizal types could be placed in two categories — those which occurred predominantly under the closed canopy and those which occurred both under open and partially closed canopies (Ingleby, Munro, Noor, et al. 1998).

Performance of mycorrhizal plants on difficult site

On degraded sites

Studies conducted at the Institut Nationale de la Recherche Agronomique, Laboratoire de Microbiologie Forestiere, Nancy, France, on Douglas fir (*Pseudotsuga menziesii*) seedlings inoculated naturally (with *Thelephora terrestris*) or artificially (with *Hebeloma cylindrosporum*) and planted on a Colluna healthland showed mortality rates of 13% and 31% respectively, three years after planting. Douglas fir seedlings inoculated naturally with *T. terrestris* or *Suillus* sp. or artificially with *Laccaria laccata* and planted on site following clear felling of a mixed coniferous broad-leaved stand, did not exhibit significantly different mortality rates but those inoculated with *L. laccata* had significantly greater height growth after one year (about 115 vs 60 cm) (Tacon, Bouchard 1991).

Vesicular–arbuscular mycorrhizal fungi including *Glomus fasciculatum*, *G. intraradices*, *G. dimorphicum*, *Scutellospora calospora*, and *S. gigantea* improved the growth of hardwood tree seedlings particularly on degraded alkaline soils according to studies conducted at the Biomass Research Centre, National Botanical Research Institute, Lucknow, India (Behl 1990).

In studies conducted at the Great Lakes Forestry Centre, Forestry Canada, Ontario, Canada, 14-week old nursery-grown seedlings of black spruce (*Picea mariana*) and jackpine (*Pinus banksiana*) inoculated with fragmented hyphae of one of the five ectomycorrhizal fungi — *Hebeloma cylindrosporum*, *Pisolithus tinctorius*, *Laccaria bicolor*, *L. proxima*, or *Rhizopogon rubescens* — were outplanted on two sites each, namely black spruce on peatland site and stony loam site and jack pine on stony loam site and sandy site. Inoculation of black spruce with *L. proxima* resulted in significantly better shoot growth on both sites and in higher foliar concentration of potassium and zinc on peatland site, and with *H. cylindrosporum* resulted in improved height growth on the peatland site after two years as compared to controls. Black spruce seedlings inoculated with *L. bicolor* were significantly smaller than uninoculated seedlings. This difference in size persisted for two growing seasons. Inoculation of jack pine with *L. proxima* resulted in significantly better shoot growth on both sites and significantly higher foliar concentrations of nitrogen, phosphorus, potassium, and zinc at stony loam site after two years. Inoculation with *H. cylindrosporum* and *L. bicolor* improved height growth of jack pine at stony loam site after two years over control plants. *P. tinctorius* did not form mycorrhiza on both species (Browning and Whitney 1992).

On Disturbed sites

Studies conducted at the Institute of Mycological Research and Development, USDA, Forest Service, Southeastern Forest Experiment Station, Forestry Science Laboratory, Athens, showed that forestation of routine planting sites and revegetation of drastically disturbed lands such as acid coal spoils, Kaolin spoils, burrow pits, and severely eroded sites in the eastern USA, have been significantly improved by planting tree seedlings tailored in the nursery by the ectomycorrhizal fungus *Pisolithus tinctorius*. *P. tinctorius* mycorrhizae improve seedling survival and growth on good-quality reforestation site especially during drought. On disturbed sites, *P. tinctorius* promotes the assimilation and absorption of nutrients, increases water absorption, reduces the absorption of toxic elements, and apparently reduces the overall stress inherent in these sites (Marx and Cordell 1998).
Soils were prepared by total ploughing to 50-cm depth following removal of stumps or top humus layers contaminated with heavy metals or by scarification of the site following preparation of individual planting holes with an auger in studies conducted at the Katedra Fitopatologii Lesnej

Akademia, Rolnicza, Krakow, Poland. The site was prepared by the removal of 90-year-old *Pinus sylvestris* stand from a moist coniferous site with average annual deposits of 0.61 mg/m^3 sulphur dioxide and 110.4 tonne/m^2 dust. Planting was carried out with two-year-old plants of *Pinus sylvestris, P. nigra*, *P. strobus*, *Larix decidua, Alnus incana*, *Betula verrucosa*, and *Quercus rubra*. Mycotrophy (living mycorrhizae as percentage of total number on 30 lengths of roots, each length of 3 cm) after six years was 13%–21% greater in total ploughed site than in individual planting hole site (Kowalski 1987).

Studies conducted at the USDA, Pacific Northwest Experiment Station, Corvallis, USA, highlighted investigations on the ability of soils to maintain viable population of ectomycorrhizal fungi following forest disturbances. Ectomycorrhizal formation on seedlings generally decreases as time between disturbance and reforestation increases because survival of propagules and input of spores of ectomycorrhizal fungi appear insufficient to maintain mycorrhizal potential of disturbed sites in the absence of host plants. Also, degree of organic matter lost from a site can influence populations of mycorrhizal fungi. Mycorrhizal formation was reduced by 90% and basal area by 43 % on Douglas fir seedlings grown in soils where forestry practices drastically reduced organic matter levels. Rapid mycorrhiza formation and improved seedling performance on Douglas fir seedlings in association with white leaf manzanite (*Arctostaphylos viscida*) were found comparable to adjacent annual grass areas. In another study, number and rapidity of ectomycorrhizal formation of Douglas fir seedlings increased with proximity to clumps of green-leaf manzanite. Also, ectomycorrhizal fungi supported by non-coniferous hosts can actively colonize feeder roots of coniferous seedlings (Amaranthus and Perry 1990).

Studies conducted at the University of Calgary, Department of Biological Sciences, Calgary, Canada, on ectomycorrhizal and arbuscular mycorrhizal response to clear-cutting and the application of 5-and 10-cm deep layers of chipped aspen (*Populus tremuloides*) wood in a boreal, mixed wood site dominated by aspen poplar showed that there was extensive mortality of aspen roots during first two years after cutting although many roots persisted for one year and small pockets of regenerating roots were detected after two years. Mycorrhizal colonization of aspen roots was 90–100% in all treatments indicating that inoculum potential of the ectomycorrhizal fungi was maintained for two years post-harvest. *Cenococcum geophilum, Cortinarius* spp., *Russula* spp., and *Tomentella* spp. were abundant on roots in all treatments and clear-cutting and wood chip application did not reduce the regeneration potential of these fungi. *Piloderma byssinum* occurred frequently on unharvested plots while *Hebeloma* was abundant in plots with 10-cm wood chips and *Mycelium radices atrovirens* in plots with 5-cm wood chips (Visser, Maynard, and Danielson 1998).

In studies conducted at the USDA, US Forest Service, S Main, Moscow, USA, western white pine and Douglas fir were outplanted on two sites (low altitude, relatively harsh site and a higher altitude, more moderate site) and were given four treatments — mounding surface horizons with competing vegetation, mounding with physical or chemical control of competing vegetation, scalping to control competing vegetation, and control (with no treatment). Mounding with no competing vegetation produced small seedlings (5–15 g for both species) with low numbers of ectomycorrhizal roots. Mounding with competing vegetation produced large seedlings (20–48 g) with moderate number of short roots. Scalping produced small seedlings (8–16 g) with high number of short roots. Controls produced small seedlings (8–13 g) with moderate number of short roots. Douglas fir produced more short roots on harsh site than on moderate site, high root–shoot ratio (above 1.0) on mounds with no competing vegetation on harsh site and on mounds with competing vegetation moderate site. Western white pine produced more ectomycorrhizae more rapidly than Douglas fir, produced high root–shoot ratio (above 0.60) in mounds with competing vegetation on harsh site (Harvey, PageDumroese, Jurgensen, et al. 1996).

On mined sites

Studies conducted at the Native Plants Inc., Salt Lake City, UT, USA, on field trials of *Salix viminalis* and *S. dasyclados* on a mined peatland site revealed statistically significant growth stimulation due to mycorrhiza formation after mycorrhizal inoculation after one growing season. In greenhouse, both species formed ectomycorrhizae with *Amanita* spp., *Cortinarius purpurascence*, *Entoloma nidorosum*, *Entoloma* spp., *Hebeloma crustuliniforme*, *H. pusillum*, *Laccaria bicolor*, and *Paxillus involutus*. In field trials, plants inoculated with *Entoloma* spp. were sometimes twice as large as control plants. However, such effects were observed only in plants receiving normal phosphate fertilization as opposed to low phosphate application and were not consistent from one season to another. With the inoculum of other species (*Cortinarius*, *Hebeloma*, and *Paxillus*), some evidence of growth enhancement was found in the field but these results were sometimes attributable to non-symbiotic effects of inoculation (Loree, Lumme, Neimi, et al. 1989).

One-year-old bare-rooted seedlings of loblolly pine (*Pinus taeda*), artificially inoculated with *Pisolithus tinctorius* and uninoculated controls (naturally infected with *Thelephora terrestris* and ectomycorrhiza), were outplanted on a surface mine site which had previously been contoured and hydroseeded with a mixture of herbaceous ground cover species in studies conducted at the Department of Range, Wild Life and Forestry, University of Nevada, Reno, USA. On half of each of

mycorrhizal plants, NPK fertilizer (336 kg/ha) was broadcast. After seven years, survival and growth of *P. tinctorius* inoculated trees were significantly improved relative to control. Fertilizer treatment elicited a significant reduction in survival and gave marginal growth responses in trees of both mycorrhizal treatments. Also, *P. tinctorius* infected seedlings had more nitrate and less zinc in their needles than control (Walker, West, McLaughlin, et al. 1989).

In studies conducted at the Division of Reclamation, Ohio Department of Natural Resources, Columbus, Ohio, USA, the success of reforestation programme of abandoned mined land on sites of 2–75 acres is attributed to the use of tree seedlings inoculated with ectomycorrhizal fungus, *Pisolithus tinctorius*. Traditional practices for reclaiming abandoned mined lands are expensive ($7000 per acre). Reforestation is, therefore, suggested as a cost-effective and low-maintenance alternative ($300 per acre) for reclaiming strip mines not eligible for traditional reclamation. Inoculated Virginia pine (*Pinus virginiana*) planted on barren shales (pH 2.8) had 99% survival, with mean diameter at breast height of 2.9 cm and mean height of 120.9 cm in February 1989 (Caldwell 1990).

Loblolly pine seedlings were transplanted on a pyretic coal mine site in a commercial reclamation in effort studies conducted at the Department of Plant Pathology and Horticulture and Landscape Horticulture, University of Kentucky Lexington, Kentucky, USA. After five years, the trees which became naturally infected with *Pisolithus tinctorius* or other ectomycorrhizal fungi which produce sporocarps had twice the height and stem diameter of the trees not associated with sporocarps. Soil pH was lower in the root zone of trees associated with *P. tinctorius* than in those not associated with *P. tinctorius* and sulphate was higher. No differences were found in ferric or ferrous ions or in population of two bacterial species, *Thiobacillus ferrooxidance* and *T. thiooxidans*, which catalyze production of sulphuric acid from pyrite. Apparently, *P. tinctorius* benefits its hosts by mechanism other than inhibition of *Thiobacillus* spp. (Hendrix, Hunt, and Maronek 1985).

In studies conducted at the Department of Environmental Biology, University of Guelph, Guelph, Ontario, Canada, seedlings of yellow poplar (*Liriodendron tulipifera*) were raised in nursery beds with all combinations of four mycorrhizal treatments — no inoculum, *Glomus* spp., *G. mosseae*, and natural stand soil — and four fertilizer treatments — no fertilizer, base (15:15:15 NPK, 560 Kg/ha), base plus two urea top dressings (39:0:0 NPK, 112 kg per ha), and base plus four urea top dressings — for one year. Nursery-raised plants were then outplanted at three locations — namely a reclaimed stripmined site, an eroded old field site (shallow to shale bed rock), and river terrace site. Fertilizer treatment significantly affected the size of the seedlings in the nursery but differences were smaller in the outplantings after two years. Mycorrhizal inoculation did not greatly affect seedling size in the nursery but affected post-planting height growth. Seedlings inoculated with *Glomus* spp. grew the most, followed by seedlings inoculated with natural soil, *G. mosseae*, and no inoculum treatments. Seedling survival and foliar concentration of nitrogen and phosphorus were not significantly impacted by treatments in the nursery. Seedling growth was best at the river terrace site and worst at the eroded field site. Difference in seedling growth on river terrace site due to site quality overshadowed differences due to mycorrhizae and fertilizer treatments. Both *Glomus* inoculated and natural soil inoculated seedlings grew better under harsher conditions (Williams and David 1993).

Seedlings of *Pinus contorta*, *P. flexilis*, and *Pica engelmannii*, colonized with *Pisolithus tinctorius*, *Suillus granulatus,* and *Cenococcum graniforme* or uninoculated (colonized by a wild fungus) in nursery, were outplanted on a high-altitude (3200 m) molybdenum tailing waste site covered with deep mine waste material in studies conducted at the Department of Forest and Wood Science, Colorado State University. Fort Collins, USA. The seedlings were given four fertilizer treatments – no fertilizer, 90 kg/ha phosphorus, 90 kg/ha phosphorus + 68 kg/ha nitrogen, and sewage sludge and wood chips at 4500 kg (dry weight) per ha. Combined mortality after two growing seasons, was 26.1%. There was significantly greater mortality in sewage sludge and wood chip treatment in both pines. Effect of mycorrhizal treatment on mortality was not significant. Height growth in all the three tree species was greatest with *S. granulatus* and the wild fungus while the height growth of seedlings infected with *P. tinctorius* was generally about half the growth of the best fungal treatment (Steven and Reid 1979).

On basalt soils

Studies conducted at Northern Arizona University School of Forestry, Flagstaff, Arizona, USA, on *Pinus ponderosa* grown in containers, inoculated in the nursery with mycelium of *Suillus granulates*, and outplanted along with uninoculated control on a basalt-derived soil during the middle of growing season showed that at the end of growing season, there had been no significant growth in either control or inoculated seedlings. However there was 70% survival in the controls as compared to 93.3% in mycorrhizal seedlings (Carnett Z J 1979).

Performance of mycorrhizal bare-rooted vs. container-grown seedlings

Research at the INRA, Centre de Recherches Forestieres de Nancy, Champenoux, Seichamps, France, shows that more than 80% of the forest trees are planted bare-rooted because the production cost of such plants is lower than that of the container plants. When lifted from the nursery, the plants loose in the soil a large proportion of their

root system, especially the apical parts, the mycorrhizae. Furthermore, all the connections between the soil and the plant through external mycelium and mycelial strands are destroyed. Then storage of plants before planting modifies mycorrhizal metabolism. During studies at the Institute, modification of the polypeptide profile as well as decrease in respiration have been recorded and related to mycorrhizal population evolution on the root system during the first year after plantation. Different types of ectomycorrhizae respond differently to transplantation stress. Some ectomycorrhizal fungi can thus be selected according to this criterion for controlled inoculation in the nursery (Al-Abras, LeTacon, and Lapeyrie 1988).

Lateral root development

In studies conducted at the USDA, Forest Service, Institute for Mycorrhizal Research and Development, Forestry Science Laboratory, Athens, USA, bare-rooted and container-grown loblolly pine (*Pinus taeda*) seedlings with *Pisolithus tinctorius* mycorrhiza were grown for 22 weeks and excavated at four-week intervals to study the development of lateral root system. The result showed that the pattern of lateral root growth from original root system differed between bare-root and container-grown seedlings. Bare-root seedlings produced 60% more laterals and had significantly more horizontal lateral root egress from the middle horizontal zone of the original root system than the container grown seedlings. Bare-root seedlings also had significantly more *Pisolithus tinctorius* mycorrhizae on egressed roots and the mycorrhizae were found at significantly greater distances from the original root system than those of container-grown seedlings after 22 weeks (Ruehle 1985).

Effect on survival

Studies conducted at the D L Phipps State Forest Nursery, Elkton, USA, showed that bare-root seedlings of Douglas fir (*Pseudotsuga menziesii*) survived and grew better during the first year than container-grown stock on a draughty site. After three years, survival still differed significantly but height growth did not. Shading improved survival and growth. Application of liquid suspension of spores of *Pisolithus tinctorius* was ineffective and no mycorrhizae developed from this fungus (Pilz and Znerold 1989).

In studies conducted at the Department of Forest Science, Texas A and M University, College Station, Texas, USA, survival of untreated bare-root seedlings, bare-root seedlings treated with Terra-Sorb root dip (a hygroscopic starch), container seedlings, and container seedlings inoculated with *Pisolithus tinctorius* was compared for two sources of loblolly pine (*Pinus taeda*) including one drought-resistant source and one source of short leaf pine (*P. echinata*) at 2, 6, 9, 14, and 21 months after planting on three drought-prone sites in Northeast Texas. Bare-root seedlings survived better than all container seedlings on the most severe site. On a more moderate site, container seedlings (without mycorrhizae) showed maximum survival and followed treated bare-root seedlings and then untreated bare-root seedlings (Echols, Meier, Ezell, et al. 1990).

Effect on growth parameters

Studies conducted at the School of Forestry, Fisheries and Wildlife, University of Missourie, Columbia, USA, on black oak (*Quercus velutina*) seedlings outplanted on two clearcut sites showed that container-grown seedlings exhibited height and diameter growth superior to bare-root stock, and mycorrhizal plants were better than non-mycorrhizal plants during the first two to three seasons. Thereafter, container-grown and bare-root seedlings, and mycorrhizal and non-mycorrhizal seedlings grew at comparable rates such that the differences in height and diameter were greatly reduced six years after outplanting (Parker, Moorhead, Pallardy, et al. 1985)

Effect on photosynthesis and water potential

In further studies conducted at the above university, northern red oak (*Quercus rubra*) containerized one-year-old stock inoculated with *Pisolithus tinctorius* and two-year-old bare-root, uninoculated seedlings were planted in two contiguous high quality oak sites each of which was divided between a shelter wood plot and clear-cut plot. Half of the seedlings were clipped at approximately 8 cm above the root collar. During the first year after over storey cuttings, seedlings in the shelterwood plot had significantly lower water potentials, photosynthetic and transpiration rates, and stomatal conductance than seedlings in the clearcut plot. The greater level of seedling water stress under the shelter wood was associated with restricted root system development and possibly greater competition from over storey trees for water than in the clearcut plot where herbaceous vegetation was just becoming established. Containerized seedlings had significantly higher seasonal average midday water potentials than did the bare-root seedlings following outplanting but both had similar photosynthetic and transpiration rates and stomatal conductance. Clippings of seedlings did not have a consistent effect on seedling growth or physiological responses during the first year (Crunkilton, Pallardy, and Garrett 1988).

References

Al-Abras K, Le Tacon F, and Lapeyrie F. 1988
Ectomycorrhizas stress during forest trees transplantation, ascertained by radiorespirometry and protein electrophoresis,
In *Proceedings of the Second European Symposium on Mycorrhizae*, p.4.
Prague: Czechoslovak Society for Microbiology, 115 pp.
[14–20 August, 1988 Prague, Czechoslovakia]

Alvarez I F, Parlade J I, and Pera J. 1990
First-year field performance of Douglas-fir seedlings inoculated with *Laccaria laccata* on two reforestation sites in northern Spain
In *Innovation and Hierarchical Integration*, p.2, edited by M F Allen
Wyoming: University of Wyoming, 324 pp.
[Proceedings of the Eighth North American conference on Mycorrhiza, 5–8 September 1990, Jackson, Wyoming]

Amaranthus M P and Perry D A. 1990
Ectomycorrhizae and forest regeneration on disturbed lands in the Klamath Mountains
In *Innovation and Hierarchical Integration*, p.4, edited by M F Allen
Wyoming: University of Wyoming, 324 pp.
[Proceedings of the Eighth North American conference on Mycorrhiza, 5–8 September 1990, Jackson, Wyoming]

Behl H M. 1990
Role of endomycorrhizae in fuelwood plantation nurseries for alkaline soil sites
In *Current Trends in Mycorrhiza Research,* p137–138, edited by Bhusan L J and H Chand
Hisar: Haryana Agricultural University, 210 pp.
[The Proceedings of the National Conference on Mycorrhiza, 14–16 February, 1990. Hisar, India]

Browning M H R and Whitney R D 1992
Field performance of black spruce and jack pine inoculated with selected species of ectomycorrhizal fungi
Canadian Journal of Forest Research **22**(12): 1974–1982

Caldwell C. 1990
Reforestation: a viable alternative for abandoned mined land reclamation
In *Proceedings of the National Symposium on Mining.* pp. 21–25, edited by D H Graves
[May 1990, Lexington, Kentucky]

Carnett Z J. 1979
Survival of ponderosa pine seedlings planted on a basalt soil in northern Arizona is improved by inoculation with a mycorrhizal fungus.
In *Proceedings of the Fourth North American Conference on Mycorrhiza*
Colorado: Colorado State University, v.p.
[24–28 June 1979, Colorado State University, Fort Collins, Colorado, USA]

Castellana M A. 1990
Outplanting performance of mycorrhizal inoculated seedlings: a review
In *Innovation and Hierarchical Integration,* edited by M F Allen, p 49.
Wyoming: University of Wyoming, 324 pp.
[Proceedings of the Eighth North American conference on Mycorrhiza, 5–8 September 1990, Jackson, Wyoming]

Crunkilton D D, Pallardy S G, and Garrett H E. 1988
Water relations and photosynthesis of northern red oak seedlings planted in a central Missouri clearcut and shelterwood
Vancouver, Canada, University of British Columbia Publication. pp. 243–250.

Dixon R K, Garrett H E, Cox G S, Pallardy S G. 1984
Mycorrhizae and reforestation success in the oak–hickory region
In *Seedlings Physiology and Reforestation Success*, edited by M L Duryea and G N Brown, p. 301–309.

Echols R J, Meier C E, Ezell A W, McKinley C R. 1990
Dry site survival of bare-root and container seedlings of southern pines from different genetic sources given root DIP and ectomycorrhizal treatments
Tree Planters' Notes **41**(2): 13–32

Garbaye J and Churin J L. 1997
Growth stimulation of young oak plantations inoculated with the ectomycorrhizal fungus *Paxillus involutus* with special reference to summer drought
Forest Ecology and Management **98**(3): 221–228

Grand L F, Raleigh, and Krugner T A. 1979
Field performance of loblolly pine in north Carolina following inoculation in the nursery with *Pisolithus tinctorius* and *Thelephora terrestris*
In *Proceedings of the Fourth North American Conference on Mycorrhiza*
Colorado: Colorado State University, v.p.
[24–28 June 1979, Colorado State University, Fort Collins, Colorado, USA]

Harvey AE, PageDumroese D S, Jurgensen M F, Graham R T, Tonn J R. 1996
Site preparation alters biomass, root and ectomycorrhizal development of outplanted western white pine and Douglas-fir
New Forests **11**(3): 255–270

Hendrix J W, Hunt C S, and Maronek D M. 1985
Relationship between the ectomycorrhizal fungus *Pisolithus tinctorius* associated with loblolly pine and acid-generating *Thiobacillus* spp. on an acidic strip mine site
Canadian Journal of Microbiology **31**(9): 878–879

Hunt G A. 1990
Nursery and field applications of ectomycorrhizal fungi in western Canada.
In *Innovation and Hierarchical Integration*, p.147, edited by M F Allen
Wyoming: University of Wyoming, 324 pp.
[Proceedings of the Eighth North American conference on Mycorrhiza, 5–8 September 1990, Jackson, Wyoming]

Ingleby K, Munro R C, Noor M, Mason P A, Clearwater M J. 1998
Ectomycorrhizal populations and growth of *Shorea parvifolia* (Dipterocarpaceae) seedlings regenerating under three different forest canopies following logging
Forest Ecology and Management **111**(2–3): 171–179

Kowalski S. 1987
Effects of soil preparation on mycotrophy of trees in rehabilitated stands in the Upper Silesian Industrial Region
Sylwan **131**(8): 19–30

Lee C Y, Park S K, and Lee W K. 1988
Inoculation effect of *Pisolithus tinctorius* on *Pinus rigida*
Research Reports of the Forestry Research Institute (Seoul) 37: 50–54

Lin M T, Mattos M A, Taveira J A, Lucena F B, Lima de C O. 1987
Large scale greenhouse production and field evaluation of mycorrhizal seedlings of citrus rootstock Cleopatra mandarin
In *Proceedings of the Seventh North American Conference on Mycorrhiza*, p. 296, edited by Sylvia D M, Hung L L and Graham J H
Florida: University of Florida, 364 pp.
[3–8 May 1987, Gainesville, Florida]

Loree M A J, Lumme I, Neimi M, Tormala T. 1989
Inoculation of willows (*Salix* spp) with ectomycorrhizal fungi on mined boreal peatland
Plant and Soil **116**(2): 229–238

MacFall J S and Slack S A. 1991
Effects of Hebeloma arenosa on growth of red pine seedlings in high-fertility nursery soil in Wisconsin
Canadian Journal of Forest Research **21**(4): 482–488

Marx D H and Cordell C E. 1987
Ecology and management of ectomycorrhizal fungi in regenerating forests in the eastern U S
In *Proceedings of the Seventh North American Conference on Mycorrhiza*, p.69–71 edited by Sylvia D M, Hung L L and Graham J H
Florida: University of Florida, 364 pp.
[3–8 May 1987, Gainesville, Florida]

Marx D H and Cordell C E. 1998
Specific ectomycorrhizae improve reforestation and reclamation in the eastern United States. pp 75–86
In *Canadian Workshop on Mycorrhizae in Forestry*

Mexal J G, Marx D H, and Morris W G. 1979
Plantation performance of loblolly pine following inoculation with mycorrhizal fungi
In *Proceedings of the Fourth North American Conference on Mycorrhiza*
Colorado: Colorado State University , v.p.
[24–28 June 1979, Colorado State University, Fort Collins, Colorado, USA]

Miller S L, McClean T M, Stantom N L, Williams S E. 1998
Mycorrhization, physiognomy, and first-year survivability of conifer seedlings following natural fire in Grand Teton National Park
Canadian Journal of Forest Research **28**(1): 115–122

Parker W C, Moorhead D J, Pallardy S G, Garrett H E, Dixon R K, Sander I L. 1985
Six-year field performance of container-grown and bare-root black oak seedlings inoculated with *Pisolithus tinctorius* and outplanted on two Ozark clear-cuts
Canadian Journal of Forest Research **16**: 1339–1344

Perry D A, Molina R, and Amaranthus M P. 1987
Mycorrhizae, mycorrhizospheres and reforestation: current knowledge and research needs
Canadian Journal of Forest Research **17**(8): 929–940

Pilz D, and Znerold R M. 1989
Comparison of survival enhancement techniques for outplanting on a harsh site in the western oregon cascades
Tree Planters' Notes **37**(4): 24–28

Reynaldo E and Cruz R E dela. 1990
Current status of nursery and field applications of ectomycorrhiza in the Philippines In *Innovation and Hierarchical Integration*, p.75, edited by M F Allen
Wyoming: University of Wyoming 324 pp.
[Proceedings of the Eighth North American Conference on Mycorrhiza, 5–8 September 1990, Jackson, Wyoming]

Ruehle J L. 1987
Field performance of container-grown loblolly and longleaf pine chemically root pruned with cupric carbonate
In *Proceedings of the Seventh North American Conference on Mycorrhiza*, p.103, edited by Sylvia D M, Hung L L and Graham J H
Florida: University of Florida, 364 pp.
[3–8 May 1987, Gainesville, Florida]

Ruehle J L. 1985
Lateral-root development and spread of *Pisolithus tinctorius* ectomycorrhizae on bare-root and container-grown loblolly Pine seedlings after planting
Forest Science **31**(1): 220–225

Stenstrom E and Ek M. 1990
Field growth of *Pinus sylvestris* following nursery inoculation with mycorrhizal fungi
Canadian Journal of Forest Research **20**(7): 914–918

Stenstrom E. 1990a
Ecology of mycorrhizal *Pinus sylvestris* seedlings: aspects of colonization and growth [Thesis]
Swedish University of Agricultural Sciences, 44 + 79pp. Uppsala.

Stenstrom E. 1990b
Variation in field response of *Pinus sylvestris* to nursery inoculation with four different ectomycorrhizal fungi
Canadian Journal of Forest Research **20**: 1796–1803

Steven C G, and Reid C P P1979
The use of mycorrhizal conifer seedlings in the revegetation of a high altitude mine site
In *Proceedings of the Fourth North American Conference on Mycorrhiza*
Colorado: Colorado State University, v.p.
[24–28 June 1979, Colorado State University, Fort Collins, Colorado, USA]

Tacon F le, and Bouchard D. 1991
Possibilities of controlled mycorrhization in temperate silviculture
Foret-Entreprise **74**: 29–41

Visser S, Maynard D, and Danielson R M. 1998
Response of ecto- and arbuscular mycorrhizal fungi to clear-cutting and the application of chipped aspen wood in a mixedwood site in Alberta, Canada
Applied Soil Ecology **7**(3): 257–269

Walker R F, West D C, McLaughlin S B, Amundsen C C. 1989
Growth, xylem pressure potential, and nutrient absorption of loblolly pine on a reclaimed surface mine as affected by an induced *Pisolithus tinctorius* infection
Forest Science **35**(2): 569–581

Williams P A and David A L. 1993
Mycorrhizae and fertilizer nursery treatments impact Yello-poplar seedlings outplanted at three locations in east Tennessee
In *Proceedings of the Ninth North American Conference on Mycorrhizae,* p.54
[8–12 August, 1993]

Research findings

Arbuscular mycorrhizal dependency of *Eucalyptus tereticornis* Sm: how real is it?

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Introduction

Most hosts of non-arbuscular mycorrhizal fungi never establish functional arbuscular mycorrhizal symbiosis in nature (Giovannetti and Sbrana 1998). Among the known ectomycorrhizal hosts, eucalyptus is an exception as it forms arbuscular mycorrhiza also (Malajczuk, Lindermann, Kough, et al. 1981, Lapeyrie and Chilvers 1985). Which of the eucalyptus mycorrhizae is functional: ectomycorrhiza or arbuscular mycorrhiza, or both? Results of some of the arbuscular mycorrhizal dependency or inoculation response studies of Eucalyptus (Bhat Narayan, Jayarajan, and Ramraj 1993, Sharma, Chauhan, and Adholeya 1999) are not convincing to answer the question. Results of this study on arbuscular mycorrhizal dependence of *Eucalyptus tereticornis* in a low-phosphorus alfisol suggest that the species may not be economically dependent on arbuscular mycorrhiza (Trappe 1989) in phosphorus-deficient Indian soils although its roots may be substantially infected by arbuscular mycorrhizal fungi.

Materials and methods

Dependency study was carried out twice in a nursery house using protocol for estimation of inoculation response of *E. tereticornis* seedlings against graded available phosphorus in transported laterite soil (coarse loamy Typic Haplustalf) having pH 6.0, organic carbon 0.27%, total nitrogen 0.03%, and available phosphorus and potassium 5.0 and 13.5 ppm, respectively. Available phosphorus status of the soil was raised to 15, 25, 50, and 100 ppm with single superphosphate by the usual process of incubation-equilibration for two months.

Maize root based mixed arbuscular mycorrhizal species (*Glomus mosseae*, *G. fasciculatum*, and *G. aggregatum*) effective inoculum developed in the usual manner was used to raise the most probable number of infective propagules of the treatment soil from 8 to 75 per gram. Mycorrhizal efficiency of the inoculum was tested against standard indicator plants. Heat-killed root inoculum in equivalent amount was used in the control set. Soil, plant, and mycorrhizal analyses were done following standards methods. Dependency was estimated as gain in efficiency of mycorrhizal plants in yield parameters at individual phosphorous levels (Powell and Daniel 1978, Plenchette, Fortin, and Furlan 1983) and the same estimate was used to compare mycorrhizal response of all parameters at any phosphorus level. Data presented are average of two experiments carried out during September–March 1996/97 and 1997/98.

Results and discussion

E. tereticornis seedlings raised in sterile sand were infected by arbuscular mycrorrhizal inoculation in steamed soil resulting in 90% root infection intensity at 100 days. Root–shoot dry weight ratio of the infected seedlings in inoculated soil increased significantly but this could not be concluded as 'atypical mycorrhizal response' as the inoculum used was crude arbuscular mycorrhiza infected root mass (Table 1).

Seedlings transplanted in normal treatment soil against graded phosphorus with added infected root inoculum showed unexpected response patterns. Irrespective of the levels of phosphorus at 110 and 240 days, mycorrhiza-inoculated plants responded negatively as compared to uninoculated plants, for both plant height and shoot dry matter yield, although phosphorus response of these parameters was positive, particularly at high levels

Table 1 Response of *Eucalyptus tereticornis* seedlings to arbuscular mycorrhizal inoculum in steamed soil at 100 days

Parameters	*Steamed soil*	*Steamed soil + root inoculum*	*Estimated t*[a]
Infective inoculm status, MPN per g	Nil	75	–
Plant height (cm/plant)	35.0	40.2	3.68
Root dry weight (g/plant)	0.127	0.297	3.74
Shoot dry weight (g/plant)	0.261	0.393	3.35
Root-shoot dry weight ratio	0.49	0.76	–
% root colonization	0	90.0	–
Shoot phosphorus content (mg/plant)	0.18	0.47	–

[a] $t_{0.05}$ value at 18 d.f = 2.21

(Tables 2 and 3). Except at 5- and 15-ppm phosphorus levels, plant height and shoot dry weight of mycorrhiza-inoculated plants at 110 days were less than that of uninoculated plants where the negative effect for shoot weight was significant at high soil phosphorus level. The positive shoot weight yield response of the inoculated plants at 110 days 5- and 15-ppm phosphorus levels, although translated to about 30% inoculation efficiency or relative mycorrhiza dependency, was only marginal and was terminated at 240 days (Table 3).

Root weight yield response to arbuscular mycorrhizal inoculum was different from that of shoot (Tables 2 and 3). Irrespective of the soil phosphorus level and at all levels, except 50 and 110 ppm, root dry weight of the inoculated plants at 110 days was significantly higher than that of the uninoculated plants. The difference was most pronounced at low phosphorus levels where shoot dry weight had shown a marginal positive response. At 240 days, this reversed as the root dry weight of inoculated plants was lower than that of the uninoculated plants. Characteristically, there was a corresponding decline in shoot weight also and the mycorrhizal inoculation efficiency or dependency estimate for shoot weight became negative even at the lowest phosphorus level (5 ppm). Both phosphorus concentration and content in shoot at 240 days, however, showed a predictable increase with inoculation where efficiency declined typically at high soil phosphorus levels (Figure 1). There was significant gain in root infection intensity due to inoculation, which also declined at high phosphorus levels.

Net change in whole plant dry matter due to inoculation was positive at 110 days till 15 ppm soil phosphorus but declined sharply with further increases, to get neutralized at about 60 ppm and negative at higher levels (Figure 2a). At all phosphorus levels, the incremental change in whole plant dry matter of inoculated plants at 110 days, partitioned more to roots than stems and above 20 ppm, the roots gained in dry matter apparently by depletion of shoots in addition to the gain of whole of the incremental dry matter due to inoculation (Figure 2a). At 240 days, the negative response in whole plant dry matter production due to inoculation was even more pronounced and advanced to very low soil phosphorus level (Figure 2b). The negative response at 240 days partitioned almost equally between root and shoot, particularly at high phosphorus levels.

Table 2 Response of *Eucalyptus tereticornis* seedlings to arbuscular mycorrhizal inoculation in an alfisol against graded phosphorus at 110 days

	Plant height (cm)			*Shoot dry weight* (g)			*Root dry weight* (g)		
Phosphorus levels	*UI*[a]	*I*[b]	*MIE*[c]	*UI*	*I*	*MIE*	*UI*	*I*	*MIE*
P_0 (5 ppm)	40.4^{CD}	40.8^{CD}	1.0	0.29^{D}	0.44^{BCD}	34.1	0.08^{C}	0.38^{AB}	78.9
P_1 (15 ppm)	41.3^{CD}	42.7^{C}	3.3	0.38^{BCD}	0.54^{ABC}	29.6	0.14^{BC}	0.52^{A}	73.1
P_2 (25 ppm)	55.0^{A}	43.2^{D}	–27.3	0.57^{ABC}	0.51^{ABC}	–11.8	0.16^{BC}	0.46^{A}	65.2
P_3 (50 ppm)	51.3^{AB}	41.4^{CD}	–23.9	0.61^{AB}	0.47^{ABCD}	–29.8	0.20^{ABC}	0.41^{A}	51.2
P_4 (100 ppm)	48.8^{B}	41.1^{CD}	–18.7	0.68^{A}	0.45^{BCD}	–51.1	0.29^{ABC}	0.32^{AB}	9.4
Mean	47.4	41.8		0.51	0.48	–6.3	0.17	0.42	59.5
S. Em ±		1.71			0.07			0.07	
$LSD_{0.05}$ (M x P)		4.88			0.19			0.21	
S.Em ±		0.76			0.03			0.03	
$LSD_{0.05}$ (M)		2.16			0.08			0.08	

[a] Uninoculated, [b] Inoculated, [c] Mycorrhizal inoculation effect

Table 3 Response of *Eucalyptus tereticornis* seedlings to arbuscular mycorrhizal inoculation in an alfisol against graded phosphorus at 240 days

	Plant height (cm)			*Shoot dry weight* (g)			*Root dry weight* (g)		
Phosphorus levels	*UI*[a]	*I*[b]	*MIE*[c]	*UI*	*I*	*MIE*	*UI*	*I*	*MIE*
P_0 (5 ppm)	63.8^{H}	65.7^{FG}	2.9	2.36^{E}	2.28^{E}	–3.5	2.64^{D}	2.80^{CD}	5.7
P_1 (15 ppm)	65.6^{FG}	74.8^{D}	12.3	2.66^{DE}	2.65^{DE}	–0.4	3.82^{BC}	2.70^{D}	–41.5
P_2 (25 ppm)	77.0^{C}	72.4^{E}	–6.3	3.96^{C}	3.02^{DE}	–31.1	3.67^{BC}	2.60^{D}	–41.1
P_3 (50 ppm)	81.2^{B}	68.4^{EF}	–18.7	4.35^{B}	3.04^{DE}	–43.1	4.43^{B}	2.97^{CD}	–49.2
P_4 (100 ppm)	86.1^{A}	66.6^{F}	–29.3	5.22^{A}	3.12^{D}	–67.3	5.53^{A}	3.56^{C}	–55.3
Mean	76.7	69.6	–10.2	3.71	2.82	–31.6	4.02	2.93	–37.2
S. Em ±		0.45			0.17			0.29	
$LSD_{0.05}$ (M x P)		1.28			0.49			0.84	
S.Em ±		0.20			0.08			0.13	
$LSD_{0.05}$ (M)		0.57			0.23			0.37	

[a] Uninoculated, [b] Inoculated, [c] Mycorrhizal inoculation effect

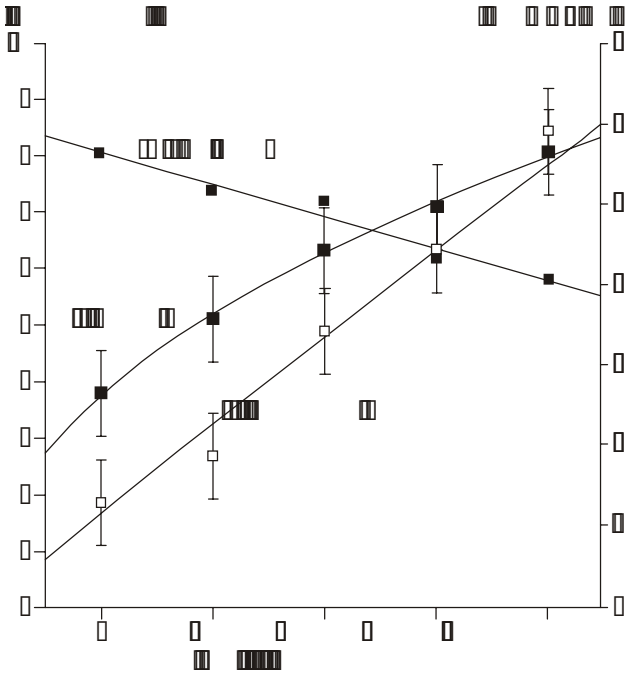

Figure 1 Shoot P content of mycorrhizal and non-mycorrhizal *E.tereticornis* plants at 240 days and gain in root infection intensity at 200 days due to inoculation

The observed negative mycorrihzal inoculation response of eucalyptus, even at a relatively low soil phosphorus level, may not be a unique case (Koide 1985) and can be explained by the high sink demand of mycorrhizal roots for photosynthate (Marschner 1995). Significantly, Sharma, Chauhan, and Adholeya (1999) reported almost similar results with a similar soil using phosphorus levels even lower than that used in this study. They reported 13%–26% dependency between 0.67 to 10 ppm Olsen's phosphorus and negative response at phosphorus levels higher than that at 112 days. The present study reports about 30% dependency at 110 days and negative dependency at 240 days between 5 and 15 ppm Olsen's soil phosphorus. It is doubtful whether such small dependency

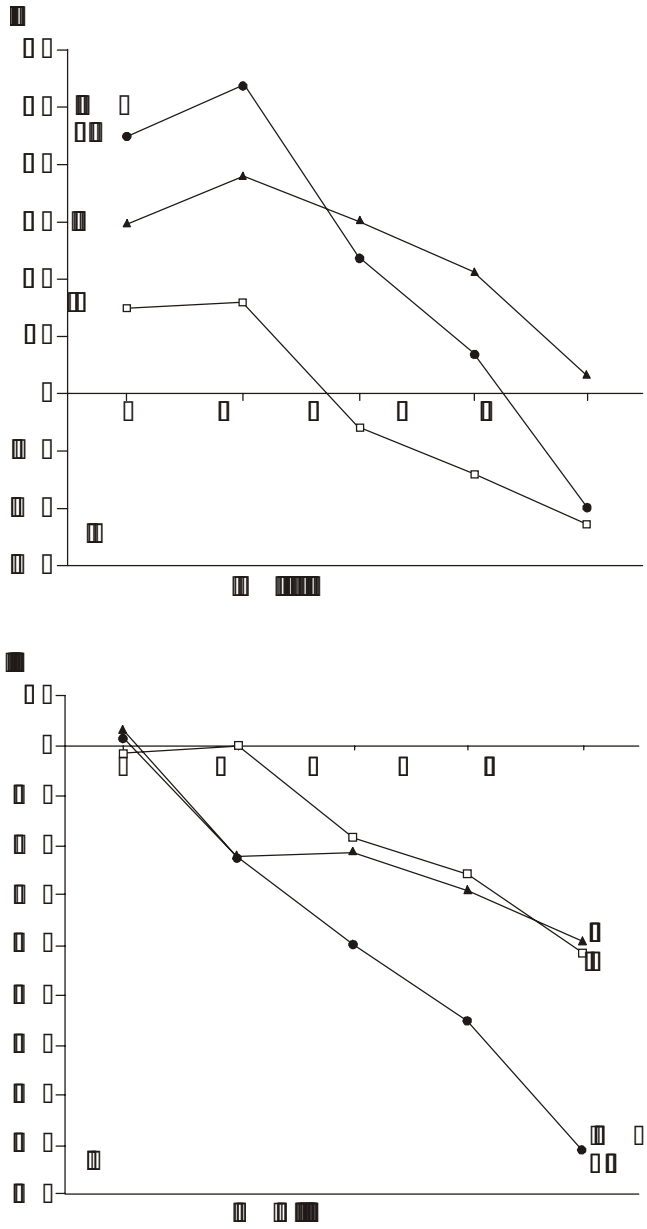

Figure 2 Partition of net change in dry matter content of AM inoculated *E. tereticornis* plants between shoot and root; (a) 110 days, (b) 240 days

estimates, as above, can be interpreted as significant (Sharma, Chauhan, and Adholeya 1999) particularly when the incremental shoot yield response even under management ambience of nursery culture is only marginal under strong phosphorus stress. Seedlings, 110–112 days old, may be too young to reflect arbuscular mycorrhizal dependency of a tree plant.

Non-mycorrhizal eucalyptus plants at 240 days responded to phosphorus by higher shoot weight formation apparently due to a parallel increase in root development. The response changed in mycorrhizal plants and there was a strong and significant decline in root weight resulting in a corresponding decline in shoot weight. This happened inspite of a significant gain in phosphorus acquisition in mycorrhizal plants where the gain apparently did not transform to increased shoot weight. Graw, Moawad, and Rehm (1979) reported a similar observation in sunflower (*Helianthus annuus*) which showed no response to inoculation in spite of strongly developed mycorrhiza and increased phosphorus uptake. Such negative mycorrhiza inoculation response in shoots would be the most logical response of a tree plant without any pronounced phosphorus deficit for growth but with limited photosynthetic capacity at early developmental stage to satisfy the extra cost of mycorrhization (Sanders 1993). The marginally positive mycorrhiza response at early seedling stage, at low phosphorus levels, may be due to the observed increase in root development (Figure 3) which has been often seen in inoculated tree seedlings casuarina and eucalyptus (Srinivas, Shanmugam, and Ramaraj 1989), *Acacia* (Sharma, Gaur, Bhatia, et al. 1995), *Dalbergia* (Agarwal and Chauhan, 1995), and *E. tereticornis* (Sharma, Gaur, Bhatia et al. 1995). Thus we conclude that *E. tereticornis* may not be an arbuscular mycorrhizal dependent tree plant at early developmental stage, although it is infected by arbuscular mycorrhizal fungi freely, improving its phosphorus acquisition efficiency in low-phosphorus soil. What happens at later stages needs to be seen.

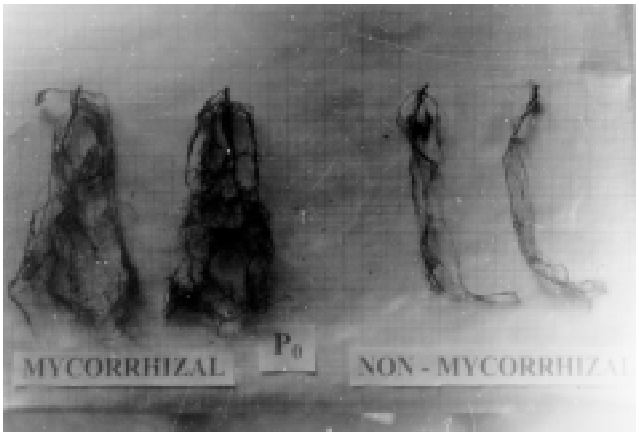

Figure 3 Root growth response of *E. tereticornis* to AM inoculation at 110 days as compared to no inoculation

References

Agrawal J and Chauhan V K. 1995
Growth responses of vesicular–arbuscular mycorrhizae on *Dalbergia sissoo*
In *Mycorrhizae*: *Biofertilizer for the Future*, pp. 438–440, edited by A Adholeya and S Singh
New Delhi: TERI. 548 pp.
[Proceedings of the 3rd National Conference on Mycorrhiza, organized by TERI, 13–15 March 1995, New Delhi, India]

Bhat Narayan M, Jeyarajan R, and Ramraj B. 1993
Response of six forest tree species to inoculation with vesicular–arbuscular mycorrhiza
Journal of Tree Science **12**(2): 77–81

Giovannetti M and Sbrana C. 1998
Meeting a non-host: the behaviour of AM fungi
Mycorrhiza **8**(3): 123–130

Graw D, Moawad M, and Rehm S. 1979
Investigations on host specificity and effectivity of VA-mycorrhiza
Zeitschrift für Acker-und Pflenzenbau (Berline) **148**: 85–98

Koide R. 1985
The nature of growth depressions in sunflower caused by vesicular–arbuscular mycorrhizal infection
The New Phytologist **99**(3): 449–462

Lapeyrie FF and Chilvers G A. 1985
An endomycorrhiza–ectomycorrhiza succession associated with enhanced growth by *Eucalyptus dumosa* seedlings planted in calcareous soil
The New Phytologist **100**(1): 93–104

Malajczuk N, Lindermann R G, Kough J L, Trappe J M. 1981
Presence of vesicular–arbuscular mycorrhiza in *Eucalyptus* spp. and *Acacia* spp. and their absence in *Banksia* sp. after inoculation with *Glomus fasiculatum*
The New Phytologist **87**: 567–572

Marschner H. 1995
Mineral Nutrition of Higher Plants
New York: Academic Press. 889 pp.

Plenchette C, Fortin J A, and Furlan V. 1983
Growth response of several plant species to mycorrhiza in a soil of moderate P fertility. I. Mycorrhizal dependency under field condition
Plant Soil **70**(2): 191–209

Powell C L and Daniel J. 1978
Mycorrhizal fungi stimulate uptake of soluble and insoluble phosphate fertilizer from a phosphate deficient soil
The New Phytologist **80**(2): 351–358

Sanders F E. 1993
Modelling plant growth response to vesicular-arbuscular mycorrhizal infection
Advance Plant Pathologist **9**: 135–166

Sharma M P, Chauhan R K S, and Adholeya A. 1999
Mycorrhizal dependency of *Eucalyptus tereticornis* on arbuscular mycorrhizal fungi in a semi arid alfisol
Bhopal: Barkatullah University. 53 pp.
[Proceedings of the 4th National Conference on Mycorrhiza, organized by the Institute of Microbiology and Biotechnology, Barkatullah University, Bhopal, and TERI, New Delhi, 5–7 March 1999, Barkatullah University, Bhopal, India]

Sharma M P, Gaur A, Bhatia N P, Adholeya A. 1995
Response of *Acacia nilotica* to indegenous vesicular–arbuscular mycorrhizal fungal inoculation and single superphosphate fertilization in degraded wasteland soils
In *Mycorrhizae*: *Biofertilizer for the Future*, pp. 331–335, edited by A Adholeya and S Singh
New Delhi: TERI. 548 pp.
[Proceedings of the 3rd National Conference on Mycorrhiza, organized by TERI, 13–15 March 1995, New Delhi, India]

Srinivas K, Shanmugam N, and Ramaraj B. 1989
Effect of VAM fungi on growth and nutrient uptake of forest seedlings
In *Mycorrhizae for Green Asia*, pp. 294–297, edited by A Mahadevan, N Raman, and K Natarajan
Madras: University of Madras. v.p.
[Proceedings of First Asian Conference on Mycorrhizae, organized by the University of Madras, 29–31 January 1988, New Delhi, India]

Trappe J M. 1989
The meaning of mycorrhizae to plant ecology
In *Mycorrhizae for Green Asia*, pp. 347–349, edited by A Mahadevan, N Raman, and K Natarajan
Madras: University of Madras. v.p.
[Proceedings of First Asian Conference on Mycorrhizae, organized by the University of Madras, 29–31 January 1988, New Delhi, India]

Effect of different rice (*Oryza sativa* L.) based cropping systems on population dynamics of native vesicular–arbuscular mycorrhizal fungi under rainfed upland ecosystem

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Introduction

The association of rainfed upland rice, grown under aerobic soil conditions, with native VAM (vesicular–arbuscular mycorrhizal) fungi has been reported (Maiti, Variar, and Saha 1995). Augmenting native VAM fungi population under rainfed upland rice agro-ecosystem, inherently poor in soil nutrient status, could enhance the advantage of such association. The present investigation evaluated different rice-based cropping systems which could augment native VAM fungi population in soil. The agro-ecosytem under study was predominantly monocropped with wet-season (June–October) rice.

Materials and methods

A long-term fixed plot experiment was conducted during wet seasons of 1993–97 in the experimental farm of Central Rainfed Upland Rice Research Station, Hazaribag. The four cropping systems evaluated were

1 CS_1: rice sole (1993–97)
2 CS_2: rice followed by toria (*Brassica campestris* L. var. *toria*) during 1993 and 1994, rice followed by horse gram (*Dolichos biflorus* L.) during 1995, maize (*Zea mays*) followed by niger (*Guizetia obyssinica* L. f. Cass) during 1996, and rice sole in 1997
3 CS_3: rice and red gram (*Cajanas cajan* L.) intercropping (1993–97)
4 CS_4: farmers' practice of crop rotation—rice sole in 1994, fallow in 1995, black gram (*Phaseolus mungo* L.) in 1996, and rice sole in 1997.

There were two sets of the experiment. The fallow period was subjected to three or four OSP (off-season [November to May next year] ploughing) in one set and NoOSP (without OSP) in the second. This amounted to eight treatments—T_1: CS_1 + OSP, T_2: CS_1 + NoOSP, T_3: CS_2 + OSP, T_4: CS_2 + NoOSP, T_5: CS_3 + OSP, T_6: CS_3 + NoOSP, T_7: CS_4 + OSP, T_8: CS_4 + NoOSP.

Except rice, other crops were local varieties being used by the farmers. During 1993/94, a local variety (brown gora) of rice was used which was replaced by an improved variety (Vandana) during 1995–97. Fertilizers were applied as follows

- CS_1 and CS_3 = 40:30:20 ($N:P_2O_5:K_2O$ in kg/ha)
- CS_2 = rice: same as CS_1; maize: 90:60:40 ($N:P_2O_5:K_2O$ in kg/ha)

n CS_4 = rice: same as CS_1; BG: no fertilizer.

The experiment was conducted in fixed, large (10´12 m^2) unreplicated plots. Infective propagules of native VAM fungi in soil were quantified using the MPN (most probable number) method (Porter 1976). Three samples (each consisting of five pooled sub-samples) from each plot were analysed at two stages—at the beginning of the crop season (June) and at the end of the crop season (September end) during 1995–98.

Results and discussions

In 1993, when the experiment was initiated, all plots had almost uniform native VAM fungi population (13 infective propagules per gram of soil) (Maiti, Variar, Singh, et al. 1997). By June 1995, different treatments resulted in varied populations ranging from 24 per gram of soil for T_1 to 210 per gram of soil for T_6 (Figure 1).

Highest residual positive effect on multiplication of VAM fungi population was observed in T_6 in June 1995 (Figure 1) but T_6 did not produce any substantial effect over T_5 in subsequent cropping seasons (June 1996–98). On the other hand, T_2, T_4, and T_8 increased native VAM fungi population over their OSP counterparts (T_1, T_3, and T_7) thus confirming the earlier findings (Maiti, Vairar, Singh et al. 1997) that NoOSP (October to next June) encouraged growth of natural weed flora (Table 1) including *Richardia* spp., *Euphorbia hitra*, and *Ageratum* spp. which harboured native VAM fungi and probably maintained already established mycelia networking extended from mycorrhizal roots as evidenced by Jasper, Abbott, and Robson (1989) and McGonigle, Evans, and Miller (1990) in maize. This led to a higher native VAM fungi population in NoOSP soils than OSP soils. In CS_3, however, no added advantage of NoOSP was noticed because the long duration local variety (Laxmi) was harvested during February/March next year leaving only 3/2 months (March/April to June) for OSP. During those dry months, there could hardly be any effective tillage (ploughing) in OSP plots; therefore, detrimental effects of OSP on survival of VAM fungi remained void.

In CS_2, toria as a sequence crop after rice (1994) reduced VAM fungi population because toria, a totally non-dependent crop on VAM, was not colonized by VAM fungi (Maiti, Variar, Singh, et al. 1997). Also, the subsequent (rice and horse gram) sequence was not suitable because of moisture stress; therefore, another cropping system (maize and niger) was tested. Shorter duration of maize (local variety) than rice (Vandana) allowed timely sowing of the sequence crop (niger) which could avoid acute moisture stress by getting established before the cessation of monsoon. Both the sequence cropping systems, however, led to substantial increase in native VAM fungi population with maximum increase in the latter sequence which also remained highest in June 1998 after the sole rice cropping in 1997. Farmer's practice of rotation (rice–fallow–black gram–rice), which was

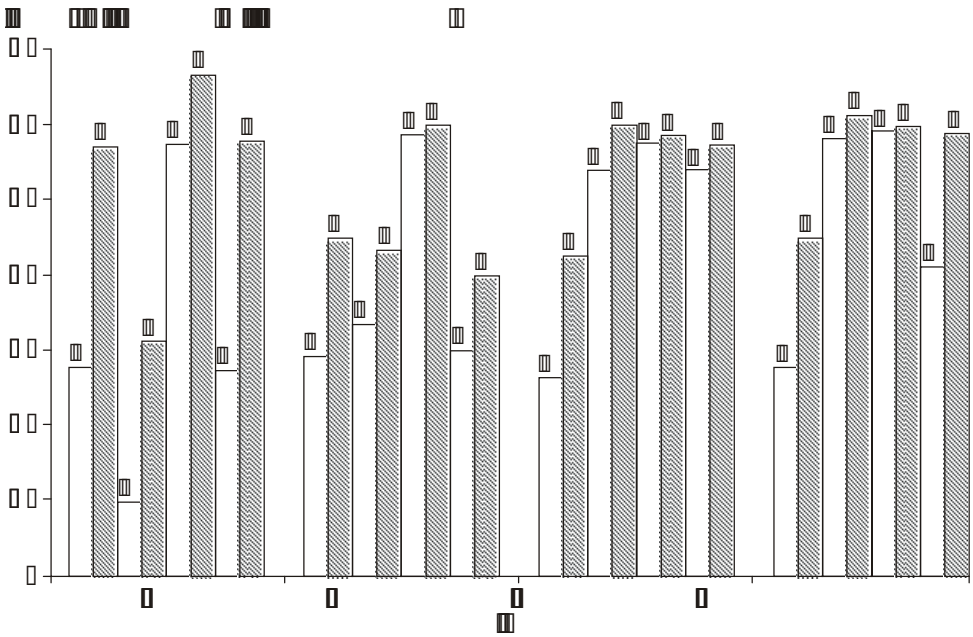

Figure 1 Effects of rice-based cropping systems on population dynamics of native VAM fungi at the begining of crop season (June) as a function of time

Note T_1: CS_1 (rice sole [1993–1997]) + OSP (off-season ploughing); T_2: CS_1 + NoOSP, T_3: CS_2 (rice then toria [1993 and 1994], rice then horse gram [1995], maize then niger [1996] , and rice sole [1997]) + OSP; T_4: CS_2 + NoOSP; T_5: CS_3 (rice and red gram intercropping [1993–97]) + OSP; T_6: CS_3 + NoOSP; T_7: CS_4 (rice sole [1994], fallow [1995], black gram [1996], and rice sole [1997]) + OSP; T_8: CS_4 + NoOSP

Table 1 Weed biomass during off-season (May) as influenced by agropractices

Treatments	*Total weed biomass during May (g/m²)*[f]		
	1995	*1996*	*1997*
T_1[g]	98.8[d]	106.2[e]	116.6[d]
T_2[h]	382.6[b]	456.6[c]	442.8[b]
T_3[i]	116.4[d]	101.2[e]	109.2[d]
T_4[j]	443.8[a]	523.6[b]	577.6[a]
T_5[k]	227.0[c]	241.0[d]	248.0[c]
T_6[l]	231.0[c]	242.0[d]	242.8[c]
T_7[m]	113.7[d]	247.2[d]	114.2[d]
T_8[n]	381.9[b]	674.1[a]	439.9[b]

[f] Mean of five samples; [g] CS_1 (rice sole [1993–97]) + OSP (off-season ploughing); [h] CS_1 + No OSP; [i] CS_2 (rice then toria [1993 and 1994], rice then horse gram [1995], maize then nigher [1996] , and rice sole [1997]) + OSP; [j] CS_2 + NoOSP; [k] CS_3 (rice and red gram intercropping [1993–97]) + OSP; [l] CS_3 + NoOSP; [m] CS_4 (rice sole [1994], fallow [1995], black gram [1996], and rice sole [1997]) + OSP; [n] CS_4 + NoOSP

Note Means in each column followed by a common letter are not significantly different at the 5% level by DMRT

followed in the same order during 1994–97, increased VAM fungi population after black gram but reduced after rice sole, because of higher capability of black gram to harbour VAM fungi than rice (Maiti, Variar, and Saha 1995)

In all treatments, VAM fungi population peaked during September, not June (Figure 2) because of the presence of living root. Between rice and rice + red gram intercropping, the latter was found in earlier studies (Maiti, Variar, Singh, et al. 1997) to augment native VAM fungi population. When this was compared to maize sequence cropped by niger and rice sole in alternate years, the latter had a more encouraging effect on enhancement of native VAM fungi population in soil. Though the farmer's practice of crop rotation with NoOSP led to similar results, this practice should not be encouraged under the concept of intensive cultivation and achieving sustainable productivity from upland ecosystem.

The information about the effects of cropping system on native VAM fungi population would be useful when integrated with other crop management practices to realize higher productivity from rainfed uplands.

References

Jasper D A, Abbott L K, and Robson A D. 1989
Soil disturbance reduces the infectivity of external hyphae of vesicular–arbuscular mycorrhizal fungi
The New Phytologist **112**(1): 93–99

Maiti D, Variar M, and Saha J. 1995
Colonisation of upland rice by native VAM under rainfed monocropped ecosystem
In *Recent Advances in Phytopathological Research*, pp. 45–51, edited by A K Roy, and K K Sinha
New Delhi: M D Publication

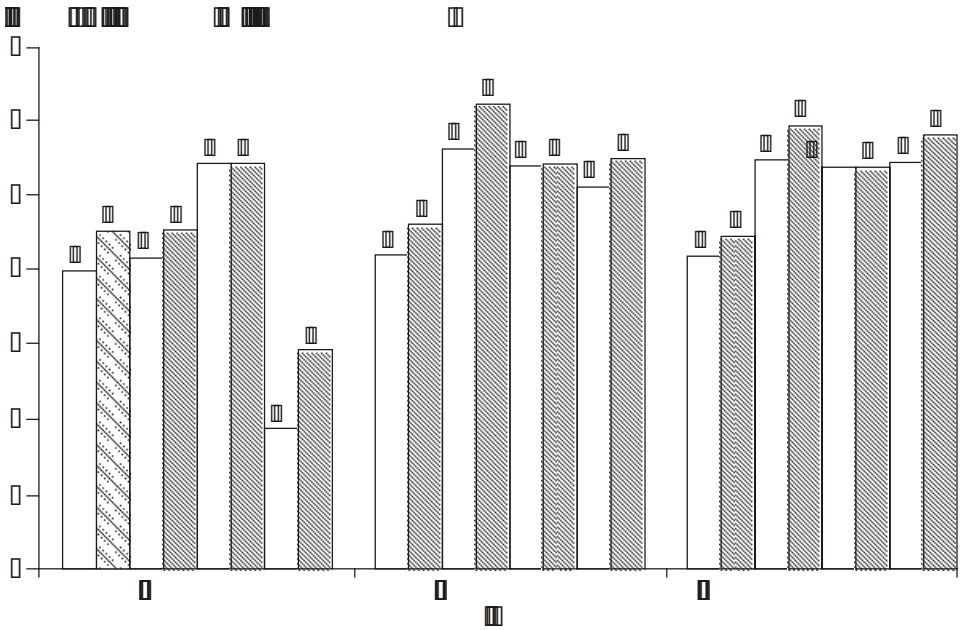

Figure 2 Effects of rice-based cropping systems on population dynamics of native VAM fungi at the end of crop season (September) as a function of time

Note T_1: CS_1 (rice sole [1993–1997]) + OSP (off-season ploughing); T_2: CS_1 + NoOSP, T_3: CS_2 (rice then toria [1993 and 1994], rice then horse gram [1995], maize then niger [1996] , and rice sole [1997]) + OSP; T_4: CS_2 + NoOSP; T_5: CS_3 (rice and red gram intercropping [1993–97]) + OSP; T_6: CS_3 + NoOSP; T_7: CS_4 (rice sole [1994], fallow [1995], black gram [1996], and rice sole [1997]) + OSP; T_8: CS_4 + NoOSP

Maiti D, Variar M, Singh R K, Singh C V, Saha J. 1997
Enhancing VA-mycorrhizal association in rainfed upland rice (*Oryza sativa* L.) based cropping system
Mycorrhiza News **8**(4): 11–13

McGonigle T P, Evans D G, and Miller M H. 1990
Effects of degree of soil disturbance on mycorrhizal colonization and phosphorus absorption by maize in growth chamber and field experiment
The New Phytologist **116**(4): 629–636

Porter W M. 1979
The 'most probable number', method for enumerating infective propagules of vesicular–arbuscular mycorrhizal fungi in soil
Australian Journal of Soil Research **17**: 515–519

New approaches

Estimation of total and living fungal biomass

Chitin and ergosterol contents of ectomycorrhizal roots were studied by ALF Ekblad, Wallander Hakan, and Nasholm Torgny (1998) in three sets of experiments to evaluate them as indicators of fungal biomass (*The New Phytologist* 138(1): 143–149). The first set of experiments showed that ageing has a marked effect on ergosterol concentration. The ergosterol content of seven-month-old, brown, shrunken, *Pinus sylvestris* – *Paxillus involutus* mycorrhizae was only 10 % of that found in white, turgid one- or four-month old specimens. This supports the hypothesis that the compound is a good indicator of living fungal biomass. Ageing has a lesser effect on chitin concentration since the chitin levels found in seven-month old mycorrhizae were 60% of the levels found in one- and four-month old specimens. Consequently, the chitin – ergosterol ratio increased from about 14-19 in one- and four-month-old mycorrhizae, respectively to about 110 in seven-month-old mycorrhizae.

In the second set of experiments, the authors found that variation in plant growth had no effect on the chitin–ergosterol ratio in whole root system of either *Alnus incana* or *P. sylvestris*, mycorrhizal with *Paxillus involutus*.

In the third set of experiments, the authors found a constant relationship between the two marker concentrations in 10-month old root system of *P. sylvestris* regardless of the fungal species involved, using *Paxillus involutus*, *Piloderma croceum* and *Suillus variegatus* as test organisms. Taken together, the results of the study suggest that both chitin and ergosterol give reliable but different relative measures of fungal biomass in mycorrhizal roots. Furthermore, the authors demonstrated that in combination, the chemical markers can be used to estimate both total and living fungal biomass derived from the chitin–ergosterol ratio.

A simple staining technique for VAM fungi

A simple, reliable, and inexpensive staining technique was developed by H Vierheilig, A P Coughlan, U Wyss, Y Piche (1998) for staining vesicular-arbuscular mycorrhizal fungal colonization in root tissues (*Applied and Environmental Microbiology* 64(12): 5004–5007). Apart from application in research, this non-toxic, high-quality staining method could also be of great utility in teaching exercises.

Roots were cleared by boiling in 10% KOH. Boiling time differed according to the type of plant—bean, soybean, and maize for 5 minutes; cucumber, wheat, barley, and ryegrass roots for 3 minutes. The roots were then rinsed several times with tap water. Cleared roots were boiled for 3 minutes in a 5% ink–vinegar solution with pure white household vinegar (5% acetic acid). Roots were destained by rinsing in tap water (acidified with a few drops of vinegar) or by rinsing in pure vinegar. Destaining time differed according to the type of ink (for blue or black inks, destaining time was 20 minutes with acidified tap water, and for red ink, destaining time was 10 minutes with vinegar). The inks tested by the authors were purple, green, red, blue, and black.

Erratum

See Volume 12, Number 2, P. 21 under the column "New approaches" line 9–11: '**Proceedings of the second international conference on mycorrhiza, Uppsala, Sweden, 5–10 July, 1998**' should read '**Proceedings of the first international conference on mycorrhizae, Berkeley campus, University of California, USA, 4–9 August, 1996**'

List of cultures available with the Centre for Mycorrhizal Culture Collection

S No	CMCC Code	Culture Name	Host
1	EM-1001	*Alpova diplophloeous*	*Pseudotsuga menziesii/ Alnus rubra*
2	EM-1129	*Alpova olivaceotinctus*	*Abies concolor, Pinus jeffreyi*
3	EM-1145	*Amanita murina*	*Eucalyptus bridgesina*
4	EM-1100	*Amanita muscaria var. farmosa*	*Populus tremuloides*
5	EM-1084	*Amanita muscaria*	*Pinus patula*
6	EM-1069	*Amanita muscaria*	-
7	EM-1146	*Amanita muscaria*	*Sous resineux*
8	EM-1060	*Amanita muscaria*	-
9	EM-1148	*Boletus cavipes*	-
10	EM-1277	*Boletus cavipes*	-
11	EM-1072	*Boletus edulis*	-
12	EM-1151	*Cenococcum geophyllum*	Picea
13	EM-1036	*Cenococcum geophyllum*	*Tsuga mertensiana*
14	EM-1035	*Cenococcum geophyllum*	*Pseudotsuga mengiesii*
15	EM-1150	*Cenococcum geophyllum*	Picea
16	EM-1149	*Cenococcum geophyllum*	Tilleul
17	EM-1252	*Cenococcum geophyllum*	Douglas
18	EM-1088	*Cenococcum geophyllum*	-
19	EM-1253	*Chalciporus piperatus*	-
20	EM-1153	*Ectendomycorrhizae*	*Pinus sylvestris*
21	EM-1154	*Ectendomycorrhizae*	*Pinus sylvestris*
22	EM-1155	*Ectendomycorrhizae*	-
23	EM-1157	*Elaphomyces granulatus*	Chene
24	EM-1156	*Elaphomyces granulatus*	Chene
25	EM-1108	*Gautieria otthii*	*Pinus bankesiana*
26	EM-1138	*Gautieria caudata*	*Arbutus menziesii, Pseudotsuga menziesii*
27	AM-1005	*Gigaspora margarita*	-
28	AM-1001	*Glomus etunicatum*	-
29	AM-1119	*Glomus geosporum*	-
30	AM-1004	*Glomus intraradices*	-
31	AM-1006	*Glomus mosseae*	-
32	EM-1158	*Gyrodon lividus*	*Alnus*
33	EM-1163	*Hebeloma crustuliniforme*	Pin noir d' Autricha
34	EM-1160	*Hebeloma circinans*	Picea
35	EM-1159	*Hebeloma calyptosporum*	Lisierie de pre
36	EM-1164	*Hebeloma crustuliniforme*	-
37	EM-1171	*Hebeloma crustuliniforme*	Douglus
38	EM-1172	*Hebeloma cylindrosporum*	Picea
39	EM-1173	*Hebeloma cylindrosporum*	-
40	EM-1170	*Hebeloma crustuliniforme*	Hetre
41	EM-1169	*Hebeloma crustuliniforme*	Picea
42	EM-1174	*Hebeloma edurum*	Picea
43	EM-1168	*Hebeloma crustuliniforme*	Chene
44	EM-1165	*Hebeloma crustuliniforme*	-
45	EM-1175	*Hebeloma edurum*	Hetre
46	EM-1008	*Hebeloma crustuliniforme*	*Pinus monticola, Tsuga heterophylla*
47	EM-1180	*Hebeloma sinapizans*	Picea
48	EM-1037	*Cenococcum geophyllum*	*Tsuga mertensiana*
49	EM-1015	*Hebeloma crustuliniforme*	*Pseudotsuga menziesii*
50	EM-1183	*Hebeloma truncatum*	-
51	EM-1182	*Hebeloma sinapizans*	Hetre
52	EM-1184	*Hebeloma vaccinum*	-
53	EM-1176	*Hebeloma ingratum*	*Tremble feuillus*
54	EM-1177	*Hebeloma mesophaeum*	-
55	EM-1185	*Hysterangium incarceratum*	*Eucalyptus sp.*
56	EM-1263	*Lactarius quietus*	Chene
57	EM-1122	*Laccaria farinacea*	*Tsuga mertensiana*
58	EM-1103	*Laccaria bicolor*	*Picea glauca*
59	EM-1105	*Laccaria laccata*	*Pinus resinosa*
60	EM-1186	*Laccaria amethystina*	Sousdes
61	EM-1079	*Laccaria laccata*	*Pinus patula*
62	EM-1076	*Laccaria laccata*	*Pinus patula*
63	EM-1083	*Laccaria fraterna*	*Eucalyptus globulus*
64	EM-1086	*Laccaria proxima*	Betula
65	EM-1085	*Laccaria laccata*	Betula
66	EM-1187	*Laccaria bicolor*	-
67	EM-1188	*Laccaria laccata*	*Picea sitchensis*
68	EM-1193	*Laccaria laccata*	*Sitka spruce*
69	EM-1196	*Laccaria tortilis*	Bouleau
70	EM-1195	*Laccaria proxima*	-
71	EM-1102	*Laccaria bicolor*	*Picea mariana*
72	EM-1192	*Laccaria laccata*	*Sitka spruce*
73	EM-1189	*Laccaria laccata*	*Quescus ilex*
74	EM-1190	*Laccaria laccata*	Hetre
75	EM-1191	*Laccaria laccata*	*Eucalyptus sp.*
76	EM-1104	*Laccaria laccata*	-
77	EM-1091	*Laccaria amethystina*	*Pseudotsuga menziesii*
78	EM-1058	*Laccaria laccata*	-
79	EM-1032	*Laccaria laccata*	Hemlock
80	EM-1033	*Laccaria laccata*	*Pseudotsuga menziesii*
81	EM-1042	*Laccaria laccata*	*Pseudotsuga menziesii*
82	EM-1275	*Laccaria proxima*	Picea, Pinus
83	EM-1066	*Laccaria laccata*	-
84	EM-1031	*Laccaria laccata*	*Pseudotsuga menziesii*
85	EM-1067	*Laccaria laccata*	-
86	EM-1065	*Laccaria laccata*	-
87	EM-1090	*Laccaria laccata*	-
88	EM-1009	*Laccaria laccata*	Alpine
89	EM-1207	*Laccinum scaber*	Charme
90	EM-1207A	*Laccinum scaber*	Charme
91	EM-1261	*Lactarius deliciosus*	*Pinus sylvestris*
92	EM-1279	*Lactarius hepaticus*	-
93	EM-1264	*Lactarius rufus*	*Sous resineux*
94	EM-1052	*Lactarius rufus*	*Larix larcina, Picea mariana*
95	EM-1260	*Lactarius chrysorrheus*	Chene
96	EM-1197	*Lactarius controversus*	Populus euramericana
97	EM-1262	*Lactarius deterrimus*	-
98	EM-1206	*Lactarius tabidus*	-
99	EM-1199	*Lactarius deterrimus*	-
100	EM-1198	*Lactarius controversus*	*Populus euramericana*
101	EM-1259	*Lactarius Chrysornheus*	Hetre

S No	CMCC Code	Culture Name	Host
102	EM-1204	*Lactarius subdulcis*	Chene
103	EM-1205	*Lactarius subdulcis*	Chene
104	EM-1202	*Lactarius rufus*	-
105	EM-1203	*Lactarius rufus*	*Sous resineux*
106	EM-1133	*Leccinum scabrum*	Picea pungens, Betula
107	EM-1106	*Leccinum insigne*	Mixed hardwoodforest
108	EM-1281	*Leccinum aurantiacum*	Tremble
109	EM-1113	*Martellia ellipsospora*	*Pseudotsuga menziesii*
110	EM-1130	*Melanogaster tuberiformis*	*Arctostaphylos viscidia*
111	EM-1125	*Melanogaster tuberiformis*	-
112	EM-1131	*Melanogaster varigatus*	*Arctostaphylos viscidia*
113	EM-1266	*Paxillus involutus*	-
114	EM-1134	*Paxillus involutus*	*Picea pungens, Betula*
115	EM-1209	*Paxillus involutus*	-
116	EM-1270	*Paxillus involutus*	-
117	EM-1267	*Paxillus involutus*	*Eucalyptus darlympleana*
118	EM-1268	*Paxillus involutus*	Chene
119	EM-1269	*Paxillus involutus*	Tremble
120	EM-1073	*Paxillus involutus*	-
121	EM-1208	*Paxillus involutus*	-
122	EM-1141	*Paxillus involutus*	*Castanea sativa*
123	EM-1217	*Paxillus involutus*	Chene
124	EM-1212	*Paxillus involutus*	*Populus euramericana*
125	EM-1282	*Paxillus involutus*	Abies, Piecea
126	EM-1055	*Phaeolepiota aurea*	Sitka spruce
127	EM-1047	*Phialocephala fortinii*	*Pinus*
128	EM-1219	*Piloderma*	-
129	EM-1002	*Pisolithus tinctorius*	*Tsuga canadensis*
130	EM-1057	*Pisolithus tinctorius*	-
131	EM-1010	*Pisolithus tinctorius*	*Loblolly pine, Pinus teada*
132	EM-1081	*Pisolithus tinctorius*	*Eucalyptus tereticornis*
133	EM-1059	*Pisolithus tinctorius*	-
134	EM-1005	*Pisolithus tinctorius*	Saw tooth Oak
135	EM-1006	*Pisolithus tinctorius*	Pin oak
136	EM-1034	*Pisolithus tinctorius*	Loblolly pine
137	EM-1271	*Pisolithus tinctorius*	*Pinus elliotii*
138	EM-1221	*Pisolithus tinctorius*	Chene
139	EM-1223	*Pisolithus tinctorius*	*Pinus caribaea*
140	EM-1224	*Pisolithus tinctorius*	Chene
141	EM-1004	*Pisolithus tinctorius*	Virginia pines
142	EM-1022	*Rhizopogon subareolatus*	*Pseudotsuga menziesii*
143	EM-1135	*Rhizopogon elleane*	*Pinus ponderosa*
144	EM-1019	*Rhizopogon fuscorubens*	*Pinus contorta*
145	EM-1110	*Rhizopogon vinicolor*	-
146	EM-1025	*Rhizopogon vulgaris*	*Pinus ponderosa, Pseudotsuga* menziesii, Abies
147	EM-1043	*Rhizopogon smithii*	*Pinus contorta*
148	EM-1040	*Rhizopogon mutabilis*	*Pinus ponderosa*
149	EM-1039	*Rhizopogon vulgaris*	*Pinus ponderosa*
150	EM-1029	*Rhizopogon cusickensis*	*Pinus ponderosa, Arbutus menziesii*
151	EM-1024	*Rhizopogon subcaerulescens*	*Tsuga, Pseudotsuga menziesii*
152	EM-1023	*Rhizopogon vulgaris*	*Pinus contorta, Abies amabilis*
153	EM-1013	*Rhizopogon arenicola*	Sitka spruce, lodge pole pine
154	EM-1044	*Rhizopogon colossus*	*Pinus ponderosa, Pseudotsuga menziesii*
155	EM-1038	*Rhizopogon ellenae*	*Arbutus menziesii, Pinus ponderosa*
156	EM-1134	*Rhizopogon evadens*	*Pinus ponderosa*
157	EM-1017	*Rhizopogon occidentalis*	*Pinus ponderosa*
158	EM-1049	*Rhizopogon rubescens*	*Pinus contorta, Abies lasiocarpa, Picea engelmani*
159	EM-1053	*Rhizopogon parksii*	*Picea engelmani*
160	EM-1048	*Rhizopogon subcaerulescens*	*Pinus contorta, Abies lasiocarpa Picea engelmani*
161	EM-1054	*Rhizopogon vulgaris*	*Tsuga mertensiana*
162	EM-1014	*Rhizopogon vinicolor*	*Tsuga heterophylla, Pseudotsuga menziesii*
163	EM-1050	*Rhizopogon rubescens*	*Pinus contorta, Abies lasiocarpa, Picea engelmani*
164	EM-1056	*Rhizopogon villosulus*	*Pseudotsuga menziesii*
165	EM-1028	*Rhizopogon clavitisporus*	*Pseudotsuga menziesii, Pinus ponderosa*
166	EM-1027	*Rhizopogon hawkerae*	*Pseudotsuga menziesii, Pinus* ponderosa, Abies
167	EM-1007	*Rhizopogon subcaerulescens var. subpannosus*	*Abies grandis, Pseudotsuga menziesii*
168	EM-1026	*Rhizopogon ochraceorubens*	*Pinus contorta*
169	EM-1018	*Rhizopogon subcaerulescens*	*Abies grandis, Pseudotsuga menziesii*
170	EM-1118	*Rhizopogon vinicolor*	Mixed coniferous forest
171	EM-1227	*Rhizopogon luteolus*	-
172	EM-1226	*Rhizopogon luteolus*	-
173	EM-1128	*Rhizopogon smithii*	Shasta fir
174	EM-1127	*Rhizopogon reaii*	*Pinus caribaea var. hondurensis*
175	EM-1228	*Rhizopogon nigrescens*	*Pinus caribaea*
176	EM-1229	*Rhizopogon roseolus*	Pinus
177	EM-1232	*Rhizopogon vulgaris*	-
178	EM-1231	*Rhizopogon subrerolatus*	Douglas
179	EM-1230	*Rhizopogon rubescens*	Pine
180	EM-1012	*Rhizopogon ochraceorubens*	*Pinus contorta, Abies lasicarpa*
181	EM-1119	*Rhizopogon occidentalis*	*Pinus ponderosa*
182	EM-1046	*Rhizopogon ellenae*	*Pseudotsuga menziesii*
183	EM-1063	*Rhizopogon vulgaris*	-
184	EM-1061	*Rhizopogon rubescens*	-
185	EM-1011	*Rhizopogon parksii*	*Pseudotsuga menziesii, Pinus lambertianas, Abies concolor*
186	EM-1109	*Rhizopogon rubescens*	*Pinus banksiana*
187	EM-1116	*Rhizopogon vulgaris*	*Pinus jeffreyi*
188	EM-1115	*Rhizopogon ochraceorubens*	*Pinus contorta*

S No	CMCC Code	Culture Name	Host
189	EM-1114	*Rhizopogon hawkerae*	Douglas fir
190	EM-1112	*Rhizopogon smithii*	*Pinus contorta*
191	EM-1126	*Rhizopogon fuscorubens*	*Pinus radiata*
192	EM-1140	*Rhizopogon ochraceisporus*	*Pinus ponderosa, Pseudotsuga menziesii*
193	EM-1142	*Rhizopogon rubescens*	*Pinus nigra*
194	EM-1143	*Rhizopogon vinicolor*	*Pseudotsuga menziesii*
195	EM-1132	*Sarcodon scabrosus*	*Alnus sinnata*
196	EM-1273	*Scleroderma aurantium*	-
197	EM-1235	*Scleroderma flavidum*	*Eucalyptus camaldulencis*
198	EM-1233	*Scleroderma cepa*	*Eucalyptus sp.*
199	EM-1107	*Scleroderma citrinum*	Hardwood forest
200	EM-1241	*Suillus grannulatus*	-
201	EM-1240	*Suillus granulatus*	*Pinus sylvestris*
202	EM-1030	*Suillus americanus*	*Pinus strobus*
203	EM-1075	*Suillus variegatus*	-
204	EM-1243	*Suillus luteus*	-
205	EM-1244	*Suillus luteus*	*Pinus sylvestris*
206	EM-1237	*suillus bellini*	-
207	EM-1238	*suillus bovinoides*	*Pinus sylvestris*
208	EM-1236	*suillus bellini*	-
209	EM-1074	*Suillus bovinus*	-
210	EM-1239	*suillus bovinus*	*Sous resineux*
211	EM-1136	*suillus luteus*	Pinus
212	EM-1137	*suillus luteus*	Picea
213	EM-1071	*Suillus luteus*	-
214	EM-1111	*Suillus lakei*	Douglas fir, Hemlock
215	EM-1123	*Suillus tomentosus*	*Pinus monticola, Tsuga heterophylla*
216	EM-1121	*Suillus brevipes*	*Pinus contorta*
217	EM-1124	*Suillus brevipes*	*Pinus contorta*
218	EM-1087	*suillus subluteous*	*Pinus Patula*
219	EM-1051	*Suillus tomentosus*	*Pinus ponderosa*
220	EM-1120	*Suillus granulatus*	*Pinus contorta*
221	EM-1021	*Suillus tomentosus*	Alder, Spruce, lodgepole pine
222	EM-1117	*Suillus punctatipes*	*Tsuga mertensiana, Abies lasiocarpa*
223	EM-1246	*suillus variegatus*	*Sous resineux*
224	EM-1245	*suillus variegatus*	*Sous resineux*
225	EM-1247	*Thelephora terrestris*	-
226	EM-1077	*Thelephora terrestris*	*Pinus patula*
227	EM-1062	*Thelephora terrestris*	-
228	EM-1249	*Tricholoma populinum*	*Populus euramericana*
229	EM-1248	*Tricholoma albobruneum*	Pine
230	EM-1250	*Tricholoma scalpturatum*	*Populus euramericana*
231	EM-1041	*Tuber melanosporum*	-
232	EM-1161	*Hebeloma crustuliniformi*	Picea
233	EM-1078	*Thelephora terrestris*	Betula
234	EM-1276	*Tricholoma ustale*	Hetre
235	EM-1144	*Wilcoxinia mikolae*	-
236	EM-1283	*Scleroderma verucosum*	Sal
237	EM-1284	*Scleroderma cepa*	*P. wallichiana*
238	EM-1285	*Lycoperdon Sp.*	*P. wallichiana*
239	EM-1286	*Russula Sp.*	*P. smithiana*
240	EM-1287	*Suillus Sp.*	*Pinus caribaea*
241	EM-1288	*Geastrum Sp.*	*Eucalyptus tereticornis*
242	EM-1289	*Pisolithus tinctorius*	-

Recent references

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]
Tybirk K*, Nilsson M C, Michelson A, Kristensen H L, Shevtsova A, Strandberg M T, Johansson M, Nielsen K E, RilsNielsen T, Strandberg B, and Johnsen I. 2000	**Nordic Empetrum dominated ecosystems: Function and susceptibility to environmental changes** *Ambio* **29**(2): 90–97 [*Tybirk K, NERI, Department of Landscape Ecology, Grenavej 14, DK-8410 Ronde, Denmark]
Murata H* and Yamada A. 2000	**marY1, a member of the gypsy group of long terminal repeat retroelements from the ectomycorrhizal basidiomycete Tricholoma matsutake.** *Applied and Environmental Microbiology* **66**(8): 3642–3645 [*Murata H, Forestry & Forest Products Research Institute, Division of Bio-resource Development, Tsukuba-Norin, Ibaraki 3058687, Japan]
Moore J D*, Camire C, and Ouimet R. 2000	**Effects of liming on the nutrition, vigor, and growth of sugar maple at the Lake Clair Watershed, Quebec, Canada.** *Canadian Journal of Forest Research - Revue Canadienne de Recherche Forestiere* **30**(5): 725–732 [*Moore J D, Ministry Resources Nat, Foret Quebec, Direct Rech Forestiere, 2700 Rue Einstein, St Foy, PQ G1P 3W8, Canada]
Quoreshi A M and Timmer V R*. 2000	**Early outplanting performance of nutrient-loaded containerized black spruce seedlings inoculated with *Laccaria bicolor*: a bioassay study.** *Canadian Journal of Forest Research - Revue Canadienne de Recherche Forestiere* **30**(5): 744–752 [*Timmer V R, University of Toronto, Faculty of Forestry, 33 Willcocks St, Toronto, ON M5S 3B3, Canada]

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]
Shishido M and Chanway C P*. 2000	**Colonization and growth promotion of outplanted spruce seedlings pre-inoculated with plant growth-promoting rhizobacteria in the greenhouse.** *Canadian Journal of Forest Research - Revue Canadienne de Recherche Forestiere* **30**(6): 845–854 [*Chanway C P, University of British Columbia, Department of Forest Science, Suite 270-2357 Main Mall, Vancouver, BC V6T 1Z4, Canada]
Hoiland K* and HolstJensen A. 2000	**Cortinarius phylogeny and possible taxonomic implications of ITS rDNA sequences.** *Mycologia* **92**(4): 694–710 [*Hoiland K, University of Oslo, Department of Biology, Division of Botany & Plant Physiology, POB 1045 Blindern, N-0316 Oslo, Norway]
Hackney C T*, Padgett D E, and Posey M H. 2000	**Fungal and bacterial contributions to the decomposition of Cladium and Typha leaves in nutrient enriched and nutrient poor areas of the Everglades, with a note on ergosterol concentrations in Everglades soils.** *Mycological Research* **104**: 666–670 [*Hackney CT, University of N Carolina, Department of Biology Science, Wilmington, NC 28403 USA]
Baar J* and Stanton N L. 2000	**Ectomycorrhizal fungi challenged by saprotrophic basidiomycetes and soil microfungi under different ammonium regimes in vitro.** *Mycological Research* **104**: 691–697 [*Baar J, Catholic University of Nijmegen, Department of Aquatic Ecology & Environmental Biology, Toernooiveld 1, fNL-6525 ED Nijmegen, The Netherlands]
Zambonelli A*, Iotti M, Rossi I, and Hall I. 2000	**Interactions between Tuber borchii and other ectomycorrhizal fungi in a field plantation.** *Mycological Research* **104**: 698–702 [*Zambonelli A, Dipartimento Prot & Valorizzaz Agroalimentare, Via Filippo Re 8, I-40126 Bologna, Italy]
Garnero L*, Lazzari B, Mainieri D, Viotti A, and Bonfante P. 2000	**TMchs4, a class IV chitin synthase gene from the ectomycorrhizal Tuber magnatum.** *Mycological Research* **104**: 703–707 [*Garnero L, University of Turin, Dipartimento Biology Vegetale, Viale PA Mattioli 25, I-10125 Turin, Italy]
Antoniolli Z I, Schachtman D P, OphelKeller K, and Smith S E. 2000	**Variation in rDNA ITS sequences in *Glomus mosseae* and *Gigaspora margarita* spores from a permanent pasture.** *Mycological Research* **104**: 708–715 [*Antoniolli ZI, University of Adelaide, Department of Soil & Water, PMB 1, Glen Osmond, SA 5064, Australia]
Gadkar V and Adholeya A*. 2000	**Intraradical sporulation of AM *Gigaspora margarita* in long-term axenic cultivation in Ri T-DNA carrot root.** *Mycological Research* **104**: 716–721 [*Adholeya A, Tata Energy Research Institute, Habitat Place, Lodhi Road, New Delhi – 110 003, India]
Blilou I*, Bueno P, Ocampo J A, and GarciaGarrido J. 2000	**Induction of catalase and ascorbate peroxidase activities in tobacco roots inoculated with the arbuscular mycorrhizal *Glomus mosseae*.** *Mycological Research* **104**: 722–725 [*Blilou I, CSIC, Department of Microbiology Suelo & Sistemas Simbiot, Estac Expt Zaidin, Prof Albareda 1, E-18008 Granada, Spain]
Muthukumar T* and Udaiyan K. 2000	**Arbuscular mycorrhizas of plants growing in the Western Ghats region, Southern India.** *Mycorrhiza* **9**(6): 297–313 [*Muthukumar T, Bharathiar University, Department of Botany, Microbiology Lab, Coimbatore – 641 046, Tamil Nadu, India]
Honig K, Riefler M, and Kottke I*. 2000	**Survey of *Paxillus involutus* (Batsch) Fr. inoculum and fruitbodies in a nursery by IGS-RFLPs and IGS sequences.** *Mycorrhiza* **9**(6): 315–322 [*Kottke I, University of Tubingen, Institute of Botany, Morgenstelle 1, D-72076 Tubingen, Germany]

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]
Muthukumar T* and Udaiyan K. 2000	**The role of seed reserves in arbuscular mycorrhizal formation and growth of *Leucaena leucocephala* (Lam.) de Wit. and *Zea mays* L.** *Mycorrhiza* **9**(6): 323–330 [*Muthukumar T, Bharathiar University, Department of Botany, Microbiology Lab, Coimbatore 641046, Tamil Nadu, India]
Liu A, Hamel C*, Hamilton R I, Ma B L, and Smith D L. 2000	**Acquisition of Cu, Zn, Mn and Fe by mycorrhizal maize (*Zea mays* L.) grown in soil at different P and micronutrient levels.** *Mycorrhiza* **9**(6): 331–336 [*Hamel C, McGill University, Department of Natural Resource Science, 21111 Lakeshore Road, St Anne De Bellevue, PQ H9X 3V9, Canada]
Mohammad A, Khan A G*, and Kuek C. 2000	**Improved aeroponic culture of inocula of arbuscular mycorrhizal fungi.** *Mycorrhiza* **9**(6): 337–339 [*Khan AG, University of Western Sydney Macarthur, Department of Biology Science, POB 555, Campbelltown, NSW 2560, Australia]
Wright W*, Fitter A, and Meharg A. 2000	**Reproductive biomass in Holcus lanatus clones that differ in their phosphate uptake kinetics and mycorrhizal colonization.** *The New Phytologist* **14**(3): 493–501 [*Wright W, University York, Department of Biology, York YO1 5DD, N Yorkshire, England]
Lodge D J*. 2000	**Ecto- or arbuscular mycorrhizas - which are best?.** *The New Phytologist* **146**(3): 353–354 [*Lodge DJ, US Forest Service, Centre Forest Mycology Research, USDA, Forest Prod Lab, Luquillo, PR 00773 USA]
Chen Y L, Brundrett M C, and Dell B*. 2000	**Effects of ectomycorrhizas and vesicular-arbuscular mycorrhizas, alone or in competition, on root colonization and growth of *Eucalyptus globulus* and *E-urophylla*.** *The New Phytologist* **146**(3):545–556 [*Dell B, Murdoch University, School of Biology Science & Biotechnology, Murdoch, WA 6150, Australia]
AhonenJonnarth U, VanHees P A W, Lundstrom U S, Finlay R D*. 2000	**Organic acids produced by mycorrhizal *Pinus sylvestris* exposed to elevated aluminium and heavy metal concentrations.** *The New Phytologist* **146**(3): 557–567 [*Finlay RD, SLU, Department of Forest Mycology & Pathology, Box 7026, SE-75007 Uppsala, Sweden]

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