About TERI
TERI is an autonomous not-for-profit, research institute established in 1974 and is involved in research activities in the fields of energy, environment, biotechnology, forestry, and the whole range of sustainable development issues. More specifically, its activities are geared to promoting large-scale use of renewable forms of energy, protecting the earth’s ozone layer, mitigating the threat of climate change, and reversing the loss of forest cover and biodiversity, all of which transcend national boundaries and require solutions through global cooperation.

About the Bioresources and Biotechnology Division
The Biotechnology Division seeks to achieve sustainable development through wide-ranging research, from microbes on the one hand to giant forest trees on the other. The Division has four areas: Microbial Biotechnology, Plant Molecular Biology, Plant Tissue Culture, and Forestry/Biodiversity.

The Division also incorporates the Asian Network on Mycorrhizae which coordinates research activities in the field in Asia. A National Facility on Germplasm of Mycorrhizal Fungi has also been established. It has been demonstrated that these organisms are efficient tools for growth enhancers and reclamation of barren sites overburdened with fly ash.

About Mycorrhiza Network and CMCC
The Mycorrhiza Network, located at the Tata Energy Research Institute (TERI), New Delhi, was set up in 1988 with an important component—the Mycorrhiza Information Centre (MIC). With effect from December 1993, a germplasm bank facility named Centre for Mycorrhizal Culture Collection (CMCC) started functioning as a composite project with the Mycorrhiza Network. The general objectives of the Mycorrhiza Network are to strengthen research, encourage cooperation, promote exchange of information, and publish a quarterly newsletter, Mycorrhiza News. The MIC is primarily responsible for establishing an information network in the region that makes available to the researchers the growing literature on mycorrhiza and facilitates information sharing among the members. A database on mycorrhizal literature is operational for information retrieval and supply to researchers, 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 at CMCC and provide starter cultures on request. Cultures from CMCC are available on an exchange basis or on specific requests at nominal costs for spore extraction/handling.
Role of mycorrhiza in tree nurseries—Part III. Comparative performance of mycorrhizal fungi

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Comparative root colonization and growth response

Tree roots are colonized by mycorrhizal fungi mostly on the basis of their specificity and dependence on a particular mycorrhizal fungus. Percentage of root colonization does not, however, always reflect the corresponding increase in growth parameters of the infected host. Comparative root colonization by mycorrhizal fungi on conifers and hardwoods is discussed.

Comparative root colonization and growth response in conifers

With ectomycorrhizal fungi

Studies conducted at the University of Calgary, Canada, on Jack pine seedlings grown for 20 weeks in a peat-vermiculite medium and inoculated with solid carrier mycelial inoculum showed that the use of low amounts of fertilizer resulted in seedling size below standards for planting out. This low fertilizer amount, however, permitted infection of more than 90% short roots when inoculated with *Thelephora terrestris*, *Laccaria proxima*, *Hebeloma* sp. or E-strain fungus (a white spruce mycorrhiza forming fungus), about 50% root colonization when inoculated with *Cenococcum geophilum*, *Pisolithus tinctorius*, 32% by *Lactarius paradoxus*, and 17% by *Sphaerosporella brunnea*. Inoculation with *Amphenema byssoides*, *Hydnium immbricatum*, and *Tricholoma flavovirens* resulted in no infection (Danielson, Visser, Parkinson 1984).

In studies conducted at the University of Agricultural Sciences, Agricultural Research Station, Arsekera, Karnataka, *Pinus nigra* var. Corsicana seedlings were grown for seven days under sterile conditions and then planted singly in containers in sterile, brown acidic nursery soil which was inoculated with one each of the three isolates of *Laccaria laccata* or one isolate of *L. bicolor*. The plants were then grown for fifteen weeks in a glass house at 22–31 °C with a 16-hour photoperiod.

Within two to three months, short roots became mycorrhizal. However, percentages of mycorrhizal short roots were not significantly different between treatments (43%–55%) as compared to control with 29% infection. 20%–25% of non-inoculated controls were colonized by *Thelephora terrestris* rather than *Laccaria* spp. Seedling growth (shoot lengths, and shoot and root dry weights) were significantly greater with one (and sometimes two) of the *L. laccata* isolates and with *L. bicolor* than with other two *L. laccata* isolates (Ramaiah, Perrin 1990).

In studies conducted at the Forest Research Institute, Hanoi, Vietnam, out of six pure strains of mycorrhizal fungi tested on *Pinus merkusii*, three showed good symbiotic effect (stem volume increasing by 150%–350% by the ninth month) and two strains had average symbiotic effect and one strain showed symbiotic capability (Giao, Nham 1988).

In studies conducted at the Madras University, Tamil Nadu, India, *Pinus patula* seedlings were raised from surface sterilized seeds sown on stem-sterilized shola soil and inoculated with vegetative inocula of early stage fungi, *Thelephora terrestris* and *Laccaria laccata*. The inoculation gave superior growth in shoot height, mycorrhizal development, root collar diameter, and dry matter production when compared to controls. For the first seven months, growth parameters were greater in *T. terrestris*...
Overall best growth was found with effects were found in shoot height and root variables. and 32% among families. Significant provenance mycorrhizal formation was 20% among provenances laccata inoculated seedlings, greatest difference in and 12% of the total short roots, respectively. P. ponderosa inoculated with of Wisconsin, USA, on one-year old lation (Zhu, Navratil 1987). Mycorrhiza News on containerized seedlings of Sciences, University of Alberta, Edmonton, Canada, (Natarajan, Reddy 1992).

Studies conducted at the Forest and Range Experiment Station, United States Department of Agriculture, Forest Service, Berkeley, USA, on Abies mangifica, A. concolor, Pseudotsuga menziesii, Pinus lambertiana, and P. ponderosa inoculated with Rhizopogon vulgaris, Hebeloma crustuliniforme, Pisolithus tinctorius (Oregon and California isolates), Laccaria laccata, and Amanita muscaria showed that in stem caliper, shoot and root length, and dry weight and per cent mycorrhizal colonization, P. tinctorius (California isolate) was the most promising fungus after one year. After two years, P. tinctorius (California) was dominant with A. magnifica, and A. concolor; A. muscaria with P. menziesii; R. vulgaris and uninoculated treatment with P. lambertiana; R. vulgaris, L. laccata and uninoculated with P. ponderosa. H. crustuliniforme and P. tinctorius (California) had a depressing effect on P. ponderosa (Bega 1979).

Studies conducted at the Forest Faculty, Stellenbosch University, South Africa, showed that differences in growth in pines caused by inoculation of soil with ground sporophores of Rhizopogon luteolus or spores of Pisolithus tinctorius were minor and inoculation with either fungus increased mycorrhizal infection of roots and seedling growth when compared with controls in two trials. There was no difference in other two trials also (Donald D G M 1979).

Studies conducted at the Department of Forest Sciences, University of Alberta, Edmonton, Canada, on containerized seedlings of Larix laricina representing four provenances and 17 open pollinated families showed that during an 18-week period after inoculation with vegetative inocula of Laccaria laccata, Conococcum geophilum and Pisolithus tinctorius formed ectomycorrhizae with 60%, 7%, and 12% of the total short roots, respectively. Suillus granulatus failed to form any mycorrhizae. For the L. laccata inoculated seedlings, greatest difference in mycorrhizal formation was 20% among provenances and 32% among families. Significant provenance effects were found in shoot height and root variables. Overall best growth was found with L. laccata inoculation (Zhu, Navratil 1987).

Studies at the Department of forestry, University of Wisconsin, USA, on one-year old Pinus resinosa and P. ponderosa inoculated with Conococcum granuliforme or Thelephora terrestris and additionally inoculated with Coprinus ephimerus along with each mycorrhizal fungus showed that C. ephimerus did not reduce the growth or enzymatic activity of feeder roots. Several seedlings showed sinuous morphology or serpentinosis of tap root which probably resulted from antibiotic secretions by T. terrestris; C. ephimerus is commonly used in the production of composted fertilizers (Iyer 1981).

Studies conducted at the Natchez Forest Research Centre, International Paper Company, Natchez, Mississippi, USA, on Pinus taeda in two nurseries inoculated with ecotypically different isolates of Pisolithus tinctorius by incorporating vegetative mycelia of each isolate in nursery soil showed that certain isolates were superior to others in enhancing seedling growth in terms of height, diameter, biomass, and ectomycorrhizal infection throughout the growing season. However, the seedling growth enhancement varied with isolates, with time and type of nursery soil (France et al. 1981).

Studies conducted at the Wageningen University of Agriculture, Biological Station, Kampswe, The Netherlands, on Pinus sylvestris seedlings showed that after nine months’ growth on peat and primary stand humus, ectomycorrhizal development with Suillus bovinus was significantly greater than that on secondary stand humus or podsolic sand. With Rhizopogon luteolus, the reverse was true (growth on secondary stand humus was higher than the growth on primary stand humus). Ectomycorrhizal development with Laccaria bicolor in podsolic sandy soil did not differ from that in primary stand humus (Baar, Elferink 1996).

**Comparative root colonization and growth response in hardwoods**

With ectomycorrhizal fungi

In studies conducted at the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Division of Soils, Queensland, Australia, seeds of Acacia mangium were germinated axenically and transferred to 150 mm diameter petridishes containing Melin Norkrans Modified (MNM) agar medium and inoculated with cultures of putative ectomycorrhizal fungi isolated from sporocarps of species of Pisolithus (two isolates), Scleroderma, Tiliopilus, Laccaria, Labrinthomyces, Boletus, Hysterangium, and Melajczukia. Seedlings were then transferred to a mist chamber in nursery tubes containing 200 g of fumigated granitic sand and inoculated with highly effective strains of Bradyrhizobium and provided with a low phosphorus slow release fertilizer. Five months after transplanting, species of Boletus, Hysterangium,
and *Melajczukia* failed to initiate ectomycorrhiza. *Scleroderma*, one isolate of *Pisolithus* and *Laccaria* formed ectomycorrhiza and increased seedling growth by 50%–100% when compared to uninoculated controls. With second isolates of *Pisolithus*, roots were well colonized but there was no growth response. The remaining two fungi behaved erratically and colonized roots of only some individual seedlings which tended to have higher dry weights (Rodell et al. 1992).

In studies conducted at the Pusat Penelitian dan Pengembangan, Hutan, Bogor, Indonesia, 45-day old seedlings of *Hopea odorata*, *Vatica sumatrana*, *Shorea stenoptera*, *S. compressa*, and *S. pinanga* were grown in pots with fumigated red yellow podzolic soil and incorporated with fresh inocula of *Russula* sp., *Scleroderma* sp., and *Boletus* sp. After six months' growth, shoot-root ratios were increased in all species except *S. compressa*. Growth responses of *H. odorata*, *V. sumatrana*, *S. stenoptera*, and *S. compressa* were best when inoculated with *Scleroderma* sp. while with *S. pinenga*, the best inoculum was *Russula* sp. (Santoso 1988).

With vesicular–arbuscular mycorrhizal fungi

Studies conducted at the National Institute of Biotechnology and Applied Microbiology, Los Banos, Philippines, on *Acacia auriculaeformis* grown in pots on fumigated soil and inoculated by either of the four vesicular–arbuscular mycorrhizal (VAM) fungi by placing 50 spores one inch below pregerminated seeds showed that *Glomus etunicatum* and *G. macrocarpum* were more effective than *G. fasciculatum* and *G. mosseae* in increasing height, biomass, diameter, and phosphorus uptake after nine months' growth. All inoculations, however, increased these parameters significantly over non-inoculated plants. The former two fungi also promoted a much greater module weight than the latter two although per cent infection was similar in all the treatments (59%–64%) compared with 16% in controls (Aggangan et al. 1990).

Studies conducted at the school of Forestry, Fisheries and Wild Life, University of Missouri, Columbia, USA, on sugar maple (*Acer saccharum*) inoculated with any one of the four VAM fungi namely *Glomus clarum, G. epigaeum, G. macrocarpum*, and *G. mosseae* showed that colonization by VAM increased mean leaf number per seedling from 2.8 to 3.7 and mean lateral root number from 34 to 43 but had no effect on various other growth parameters. *G. macrocarpum* inoculum most strongly affected seedling variables. Maximum VAM production (44% of the root length colonized) was with *G. macrocarpum* and added magnesium hydroxide. Only *G. clarum* produced mycorrhizae at low pH but it had little effect on seedling variables during a 10-week growth period (Reid et al. 1988).

Studies conducted at the Department of Agricultural Microbiology, University of Agricultural Sciences, GKVK Campus, Bangalore, India, on two Hawaiian giant cultivars (K$_9$, K$_{30}$) of *Leucaena leucocephala* showed that out of seven VAM fungi, three showed promise from a preliminary screening trial with fungi obtained from *L. leucocephala* rhizosphere. *Glomus mosseae*, a local isolate, was the best that could be used to obtain healthy, vigorously growing seedlings of *L. leucocephala* both on oxisols and vertisols (Byra Reddy, Bagyaraj 1988).

Comparative efficiency of native versus exotic mycorrhizal fungi

**Ectomycorrhizal fungi**

In studies conducted at the Centro de Pesquisa Agropecuaria dos Cerrados, Planaltina, Brazil, *Pinus caribaea* seedlings were grown in pots supplied with 30 ppm phosphorus (producing 2.72 ppm extractable phosphorus and showing the maximum effect of mycorrhizal infection) and inoculated with seven fungal isolates. After 60 days, an exotic *Pisolithus tinctorius* isolate (299) produced 84% ectomycorrhizal colonization of root systems, compared with 52%, 67%, and 44% produced by isolates VP8640, VP8618 (*Rhizopogon nigriscens*), and VP8648 (*P. tinctorius*) collected from cerrado soils. The other isolates (including one *Suillus* sp.) produced few or no mycorrhizal roots (Vieira, Peres 1990).

Studies conducted at the Departamento Biologica Geral and Department de Fitopatologia, Universidade Federal de Vicoa, Brazil, on *Eucalyptus* sp. inoculated or uninoculated with indigenous *Pisolithus tinctorius* or introduced *Paxillus involutus* showed that percentage of colonization by both fungi was highest when inoculation was done at 45 days on plants and after that there was a slight decrease. The last sampling date showed percentages that were equal to the first date for *P. tinctorius* but were 15% greater for *P. involutus* (Muchove et al. 1990).

Studies conducted at the Forest Research Institute, Seoul, South Korea, on *Pinus rigida* seedlings grown in fumigated soil, inoculated with US and Korean strains of *Pisolithus tinctorius* and then transplanted in exposed mineral soil showed that height and root collar diameter with the US strain were 53% and 83% higher than those inoculated with the Korean strain and uninoculated seedlings.
Vesicular–arbuscular mycorrhizal fungi
Studies were conducted at the Instituto Venezolano de Investigaciones Científicas, Caracas–A, Venezuela, to see the effects of VAM inoculation on the growth of cacao seedlings in nursery soils treated with either copper oxychloride or methyl bromide. Cacao seedlings responded well to indigenous VAM fungi which included Scutellospora calospora as a dominant species, resulting in significant increases in height, dry weight, and concentration of phosphorus, copper, and zinc in leaves in relation to sterile controls. The introduced VAM fungi, Glomus occultum and Acaulospora appendiculata, also increased height but not statistically significantly. Scutellospora pellucida, another introduced fungus, and A. appendiculata doubled phosphorus uptake of seedlings. Previous methyl bromide soil sterilization resulted in the lowest copper and zinc uptake in seedlings. Previous methyl bromide soil sterilization. Previous methyl bromide soil sterilization resulted in the lowest copper and zinc uptake in seedlings but this effect was ameliorated by VAM inoculation. Copper oxychloride treatment depressed growth to the same level as the sterile control although its residual effect did not kill VAM. It could change the competitive relations among VAM species, and, in this case, seemed to affect the more efficient native fungi adversely (Cuenca et al. 1990).

Comparative tolerance of mycorrhizal fungi to drought
In studies conducted at the Department des Sciences, Forestieres, Universite Laval, Quebec, Canada, Jack pine (Pinus banksiana) and black spruce (Picea mariana) seedlings were inoculated with five mycorrhizal fungi and mycorrhizal seedlings were then subjected to known water stress by exposing their roots to a solution of polyethylene glycol or planted into a specially designed system which allowed simulation of a drought cycle in forest soil. The fungi that grew in pure culture under low water potential in a simultaneous experiment also increased the drought resistance of black spruce. The ability of some fungi to form rhizomorphs extending into the mineral soil layer or to stimulate root growth also correlated with increased drought tolerance of black spruce. In contrast, the fungi had little effect on the drought tolerance of Jack pine seedlings which showed relatively higher ability to tolerate water stress independent of their mycorrhizal status (Boyle 1990).

In studies conducted at the College of Forest Resources, University of Washington, Seattle, USA, the ability of 55 isolates of 18 species of ecto-mycorrhizal fungi to tolerate imposed water stress adjusted with polyethylene glycol applied to the petridish units was examined. For 87% of the isolates, growth rate was inhibited by the initial water potential treatment applied, and with the remaining seven isolates, growth rates increased with initial water potential treatment. No growth was evident under the imposed stress treatments for isolates of Laccaria bicolor, L. laccata, and Lactarius controversus; growth occurred only in controls. Drought tolerant species demonstrated by an ability to grow at a water potential of −3 mega Pascal (MPa) included Boletus edulis, Cenococcum geophilum, Rhizopogon vinicolor, and five out of eight Suillus spp. Species intolerant of −1 MPa included Hebeloma crustuliniforme, L. bicolor, L. laccata, and Suillus caeruleus. Fungal drought tolerance was poorly correlated with estimates of annual precipitation for collection locations. Re-isolation of L. bicolor increased growth rate and water stress tolerance when compared with the same fungus prior to re-isolation (Coleman et al. 1989).

Studies conducted at the Division of Forestry and Forest Products, CSIRO, Wimbley, Australia, on seedlings of Karri (Eucalyptus diversicolor) raised on a yellow sand with a moisture gradient of −4.5 kPa (above field capacity) to −0.14 kPa (near waterlogged) and inoculated with Descolea maculata, Pisolithus tinctorius, and Laccaria laccata showed that all fungi enhanced seedling growth above that of uninoculated seedlings. In soil near saturation, however, there was no response to inoculation. Reduced mycorrhizal formation in relation to increasing soil moisture occurred, to various degrees, for all fungi, particularly in P. tinctorius. L. laccata maintained a relatively high number of mycorrhizal roots at all moisture levels except at the wettest soil treatment. An isolate of D. maculata from a swamp environment did not produce a greater number of mycorrhizal roots at high soil moisture than an isolate of this species from a forest environment (Bougher, Melajczuk 1990).

Comparative performance of mycorrhizal fungi in photosynthesis and water use efficiency
In studies conducted at the Department of Soil Science, Oregon State University, Corvallis, Oregon, potted seedlings of Douglas fir (Pseudotsuga menziesii), inoculated with three ectomycorrhizal fungi (Rhizopogon vinicolor — FSL788-5, Laccaria
laccata — S238-A, or Hebeloma crustuliniforme — HeCr2), were grown in a greenhouse for six months under well-watered conditions and then transferred to a growth chamber where measurements were made as the soil dried. R. vinicolor enhanced both net photosynthetic rate and stomatal conductance compared to non-mycorrhizal controls in the soil-water potential range of −0.05 to −0.50 MPa, despite 0.2 to 0.3 MPa lower leaf water potential. H. crustuliniforme tended to enhance while Laccaria decreased net photosynthesis rate and stomata conductance of host seedlings in this range of soil water potential but neither fungus affected leaf water potential (Dosskey et al. 1991).

Studies conducted at the Institute National de la Recherche Agronomique (INRA), Nancy, Laboratoire de Bioclimato Pogie et J’Ecophysiologie Forestieres, Champenoux, France, on Douglas fir (Pseudotsuga menziesii) seedlings inoculated with Laccaria laccata or Thelephora terrestris and grown at 10 mg and 40 mg phosphorus per litre levels showed that L. laccata was more efficient than T. terrestris in increasing water use efficiency and photosynthesis, partly due to improved phosphorus nutrition. Phosphorus deficiency reduced both the above parameters (Guehl, Garbaye 1990).

In studies conducted at the School of Forestry, Auburn University, Auburn, USA, Eucalyptus camaldulensis seedlings inoculated with Pisolithus tinctorius and Thelephora terrestris were grown in well-watered soil or were subjected to long-term soil water stress of up to 1.0 MPa over a 13-week period in a glass house. After the 13th week, all seedling containers were watered to field capacity and then water was withheld to induce a short-term drought. Diurnal measurements of seedling photosynthesis rate, leaf stomatal conductance, and leaf water potential completed before, during, and after short-term drought were similar both in larger seedlings colonized by P. tinctorius and smaller T. terrestris seedlings during the short-term drought period although they were growing in equal soil volume. P. tinctorius seedlings maintained higher photosynthesis rates over the course of the short-term drought (Dixon, Hiol-Hiol 1992).

Studies conducted at the Forest Research Institute, Nigeria, Ibadon, Nigeria, on Pinus contorta seedlings exposed to three levels of irradiance and supplied with three levels of nitrogen fertilizer and inoculated with either Pisolithus tinctorius or Suillus granulatus showed that the photosynthetic rates with P. tinctorius were 1.87 mg CO₂·cntdot.h·dm⁻². Cntdot.h⁻¹. These rates were marginally greater than 1.41 mg CO₂·cntdot.dm⁻² in non-mycorrhizal plants (Ekwebelem, Reid 1983).

In studies conducted at the Department of Forest Science, Oregon State University, Corvallis, USA, on Pinus ponderosa seedlings grown in root observation chambers and inoculated or uninoculated with Hebeloma crustuliniforme or Laccaria bicolor, root-tips initiated during 8–12 months of the growing period were classified monthly as light, intermediate or dark. H. crustuliniforme, and to a lesser extent L. bicolor, retarded progression of root-tips from light to dark and finally black as compared to controls. The amount of 14C (estimated by labeled 14CO₂) in light L. bicolor and H. crustuliniforme mycorrhizae was 2.3 and 1.8 times greater as compared to light control root-tips (Durall et al. 1994).

**Comparative tolerance of mycorrhizal fungi to heavy metals**

Studies conducted at the Department of Botany, University of Toronto, Ontario, Canada, on birch (Betula papyrifera) seedlings inoculated with either nickel tolerant Scleroderma flavidum or Lactarius rufus (which does not increase nickel tolerance) and exposed to 85 µM nickel showed that L. rufus provided some initial protection against nickel toxicity. Water uptake (taken as an indicator of the progression of nickel toxicity) in S. flavidum infected seedlings was least affected by nickel and was significantly higher than that in L. rufus infected or uninoculated plants after week 10. Total dry weight of S. flavidum tissue per root was significantly greater than that of S. rufus in both nickel treated and control seedlings and this amount increased with time (Jones, Hutchinson 1988). In studies conducted at the Department of Botany, University of Toronto, Ontario, Canada, isolates of Hebeloma crustuliniforme, Rhizopogon rubescens, and Suillus tomentosus obtained from basidiocarps collected from different age Pinus banksiana plantations were grown individually for four weeks in nutrient solution containing 37, 150, 370 or 740 µM aluminium (Al) combined in factorial design with 25, 125, 250, or 500 µM calcium (Ca) and maintained at pH 3.8. Growth of all fungi was reduced at 370 µM Al. Increment in external Al concentrations resulted in reduced mycelial concentrations of calcium, magnesium, and potassium and increased mycelial concentrations of Al, phosphorus, and iron in H. crustuliniforme. High external Al concentrations resulted in reduced mycelial concentrations of all elements except Al and phosphorus in R. rubescens and increased mycelial concentration of all elements except calcium for S. tomentosus. Growth of H. crustuliniforme was stimulated by step-wise increment in external calcium concentration from 25 to 500 µM while increments...
in calcium had no effect on the growth of *R. rubescens*. High external levels of calcium acted synergistically with high external Al concentrations to reduce growth of *S. tomentosus*. Thus, alterations in calcium and Al ratios of soils may influence the succession of ectomycorrhizal fungi (Browning, Hutchinson 1991).

Studies conducted at the School of Environmental Biology, Curtin University of Technology, Perth, Western Australia, on three isolates of *Pisolithus tinctorius*, collected from three sites (a 30-year old abandoned coal mine—pH 4.3, Al: 164 ppm; a 10-year old rehabilitated site—pH 5.1, Al: 6 ppm, and a forest site—pH 5.3, Al: 2 ppm) and grown in pure culture on MNM medium for Al tolerance showed that abandoned mine site isolate demonstrated mycelial growth on up to 2000 ppm Al with a threshold of 90 ppm before Al accumulation occurred. In contrast, growth of the rehabilitated and forest site isolates was limited by 22 ppm and 12 ppm Al, respectively, with significant metal accumulation at low (1–4 ppm) substrate Al. Electron microprobe analysis of *Eucalyptus* seedlings inoculated or not with Al tolerant (mine site) or Al-sensitive (forest site) isolates and grown in Al-contaminated soil demonstrated that Al accumulation within hyphal wall and metal presence within the cytoplasm affected the degree of Al tolerance in the host plant. The presence of Al in the cytoplasm coincided with significant accumulations of sulphur indicating a role for phytochelatins as a biochemical basis for tolerance to Al in mine site isolates. Retention of Al within the hyphal mantle led to decreased Al levels across the root proper. In contrast, non-ectomycorrhizal plants demonstrated consistently high Al levels in all root tissues with negligible quantities of calcium and magnesium. Dry weight analysis confirmed Al accumulation within roots of seedlings inoculated with Al-tolerant isolates and limited metal tolerance to the shoot but forest site isolate and non-inoculated plants contained as much Al in shoots as in roots. Plants with Al-tolerant isolates were taller with greater root-shoot dry mass and increased mycorrhizal infection and had double the amount of total nitrogen, phosphorous, and potassium than that of forest site isolate plants (Egerton-Warburton *et al.* 1992).

**Comparative tolerance of mycorrhizal fungi to pH**

Studies conducted at the Department of Soil Science, Oregon State University, Corvallis, USA, on *Liquidambar styraciflua* seedlings raised on surface soil and sub-surface soil with organic matter 8.87 and 0.10, respectively, and adjusted to a range of pH from 5.1 to 8.1 by liming with increments in CaCO₃ showed that two VAM species, i.e., *Glomus fasciculatum* and *G. mosseae* strikingly enhance seedling growth (stem, height, collar diameter, leaf number, and area and tissue dry weight) to different degrees depending upon their pH tolerance. *G. fasciculatum*, with about 40% root colonization, stimulated the earliest (within four to six weeks) and longest growth response at the lower pH values (5.1 and 5.9). Conversely, *G. mosseae* with 15% colonization stimulated equivalent, although later, growth (beginning at about three months) but at higher pH values (6–8). It did not enhance growth at pH 5.1 although it colonized seedlings (Davis *et al.* 1983).

Studies conducted at the Department of Microbial Ecology, University of Lund, Sweden, on five ectomycorrhizal isolates and two unidentified isolates showed that *Paxillus involutus* was the only fungus affected both by the pH increase and by different treatments in relation to growth and survival when these fungi were grown in unsterilized humus collected from *Pinus sylvestris* forests that had been treated with varying amounts of wood ash (3 and 7.5 tonnes per ha) and dolomite lime (2 and 5 tonnes per ha). No other fungus grew saprophytically. But when four-week old *P. sylvestris* seedlings were introduced into the system, all fungi showed similar changes in infection potential in response to pH irrespective of the fact whether lime or ash had been used (Erland, Soderstrom 1991).

Studies conducted at the CSIRO, Division of Forestry, Wembley, Australia, on *Eucalyptus globulus* inoculated with one of six fungal isolates (*Laccaria laccata* isolates A and B, *Descolea maculata*, *Setchelliogeaster* sp., *Pisolithus tinctorius* A and B) and grown in pots in phosphorous-deficient soil in temperature controlled glass house at two levels of pH (pH 5 and pH 6) showed that inoculation increased the uptake of phosphorous and growth of plants from all isolates at both levels of pH, though greater at pH 6 particularly for two *L. laccata* isolates. Isolates that colonized roots most extensively increased plant growth to the greatest extent. *D. maculata* was most effective fungal isolate at pH 5 and both the *D. maculata* and *L. laccata* A isolates were most effective at pH 6. The *L. laccata* isolates formed more hyphae in soil (on a per port, per m of fine root and per m of colonized fine root basis) than other fungal isolates but were not always more effective in increasing plant growth (Thomson *et al.* 1996).

**Comparative performance of mycorrhizal fungi on fumigated soil**

Studies conducted at the Centre National de Recherches Forestieres (CNRF), Champenoux,
Seichamps, France, on Douglas fir and Norway spruce grown under normal nursery conditions, with or without fumigation at different levels of fertility and inoculated with pure cultures of *Hebeloma cylindrosporum*, *Boletus granulatus*, and *B. luteus* showed that tree species only benefitted from *H. cylindrosporum* at any level of fertility and that also only on fumigated soil. *H. cylindrosporum* gave 35% better growth and 43% better survival in Douglas fir than other normal mycorrhizal fungi. For Norway spruce, growth increase was 64%. In fumigated soil, after two years without transplantation, *H. cylindrosporum* mycorrhizae had almost completely disappeared. Without fumigation, however, *H. cylindrosporum* continued to give better growth (49%) in Douglas fir and 110% in Norway spruce than normal mycorrhizal fungi (Tacon le 1981).

**Comparative growth depressing effect by mycorrhizal fungi**

Some mycorrhizal fungi have growth depressing effect at least in initial stages on their hosts. Studies were conducted at the Pacific South West, Forest and Range Experiment Station, Forest Service, United States Department of Agriculture, Berkeley, California, to determine growth depressant effect (GDE) on *Abies magnifica*, *A. concolor*, *Pseudotsuga menziesii*, *Pinus lambertiana*, and *Pinus ponderosa* when inoculated with *Cenococcum graniforme* A-167, *Amanita muscaria* S-179, *Laccaria laccata* S-184, *Hebeloma crustuliniforme* S166-B or *Pisolithus tinctorius* S-216 or S-360. On the basis of stem diameter and root and shoot dry weights GDE was found on *A. magnifica*, none on *A. concolor* by A-167, S-184, S-216, S-360; on *P. lambertiana* by S-79, S-360; and on *P. ponderosa* by S-179, S-360 (Bega 1981).

References


A modified procedure for mounting spores of arbuscular mycorrhizal fungi

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Introduction
Perfect preparation and preservation of microscopic mounts is an essential prerequisite for mycologists. The semi-permanent mounts of spores of arbuscular mycorrhizal (AM) fungi of coastal sand dunes of west coast of India (Kulkarni, Raviraja, Sridhar 1997) in polyvinyl alcohol-lacto-glycerol (PVLG) mountant (Koske, Tessier 1983; Schenck, Perez 1990) did not last long. After observing under oil immersion objective, wiping the oil from the surface of the cover glass without disturbing the specimen/nail polish seal was difficult. The remaining traces of oil on the cover glass reduced the photographic quality of the specimen. In addition, the slides were spoiled due to high humidity of coastal weather particularly during wet season by fungal growth on the slides and cover glass. Hence, a modified approach was employed to prepare permanent slides of AM spores. The modified procedure is a combination of techniques outlined for AM fungi (Koske, Tessier 1983; Schenck, Perez 1990) and marine fungi (Kohlmeyer, Kohlmeyer 1979). This article consists of the details of the modified procedure.

Materials and method
Following are the materials and steps involved in the modified procedure.

- A large square cover glass (22 mm²) was attached to the microscope slide by the addition of a drop of distilled water.
- A drop of PVLG (polyvinyl alcohol, 8.33 g; distilled water, 50 ml; lactic acid, 50 ml; glycerine, 5 ml) (Koske, Tessier 1983) was placed at the centre of the cover glass.
- Selected AM spores were transferred to the drop of PVLG.
- The PVLG drop with spores was covered with a small square cover glass (18 mm²).

- The slide thus prepared was then heated in an oven at 50–70 °C overnight (which hardens the PVLG).
- The edges of the mount were sealed with a thin layer of Canada balsam and allowed to dry for 30–60 minutes (DPX mountant also serves as a substitute to Canada balsam).
- A drop of Canada balsam was placed on the small cover glass.
- The double cover glass was then turned over and placed on a clean slide (the mountant spread and surrounded the small cover glass).
- The slide was preserved horizontally till the mountant hardened.
- Later, the excess mountant at the edges of the large cover glass was peeled out with the help of a needle.

For the purpose of observation of AM spore walls, preruptured spores from other slides may be transferred to PVLG on large cover glass at Step 3. The spores can also be ruptured after applying the small cover glass over PVLG at step 4.

Results and discussion
The present modified method of permanent mount preparation of AM fungal spores is ideal, particularly for tropical regions with high humidity and/or long wet season which spoils the semi-permanent slides very quickly. Repeated observations of the permanent slides under oil immersion objective and wiping the oil with xylene did not cause any disturbance or damage to the specimen and seal. Semi-permanent PVLG mounts should be preserved horizontally since PVLG does not solidify completely (Schenck, Perez 1990), but the slides prepared by the modified procedure owing to hardened PVLG and permanent seal could be preserved vertically. Though this method is time consuming, the results are far better than the semi-permanent slide. In addition, to facilitate easy transport, the permanent mounts become good voucher specimens for deposition in herbaria.

Acknowledgements
The authors are grateful to the Mangalore University for granting permission (to K R Beena) to carry out this study at the Department of Biosciences, Mangalore University.
Growth response of carrot (*Daucus carota* L.) to a selective VA mycorrhizal inoculant in an unsterile soil

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Department of Botany, Gulbarga University,  
Gulbarga – 585 106

**Introduction**

Application of an efficient vesicular-arbuscular mycorrhizal (VAM) fungus is amply proved to be an effective biofertilizer in improving the efficiency of phosphorous uptake and increase in crop production without the application of high levels of phosphate fertilizer (Hayman 1980). However, the selection of an efficient VAM fungal species, which can help to enhance phosphorous supply and the choice of the genotype, which can get maximum benefit of the VAM association, are the two important factors which may improve the existing VAM-plant association (Menge 1983; Krikun et al. 1987).

There are only a few reports on the response of VAM inoculations in tuber crops like potato (Black, Tinker 1977; Potty 1988; Rai 1990), cassava (Potty 1988) and sweet potato (Potty, Indira 1990) from India. The response of carrot to mycorrhizal inoculation has not been fully investigated except that it is found to be highly dependent on mycorrhizae (Plenchette 1982). For those plants having coarse root system as in tuber crops, the mycorrhizae is of special importance since extramatrical mycelium can only supplement the absorbing area.

In the present study after preliminary trials, *Glo- mus mosseae* was selected and tested on two varieties of carrot (*Daucus carota* L.) to study its efficiency on growth and yield in unsterile soil.

**Materials and methods**

Two carrot varieties, Local and SKG, were raised in 32 cm pots containing unsterilized soil-sand mixture (1:1) having high pH and low available phosphorous (Table 1). Ten seeds of each variety were sown in each pot with an addition of *Glomus mosseae* inoculum at the rate of 50 ml/pot (a mixture of root pieces and extramatrical chlamydospores and soil) at a depth of 3–5 cm in the pot. Carrot seeds were sown just above the inoculum layer and later covered with the soil. Appropriate controls without inoculum were maintained. There were three replicates for each variety.

<table>
<thead>
<tr>
<th>Composition</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand</td>
<td>67.04</td>
</tr>
<tr>
<td>Fine sand</td>
<td>9.20</td>
</tr>
<tr>
<td>Silt</td>
<td>4.20</td>
</tr>
<tr>
<td>Clay</td>
<td>19.56</td>
</tr>
<tr>
<td>Total organic content</td>
<td>5.20</td>
</tr>
<tr>
<td>Organic carbon</td>
<td>0.42</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>0.00113</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>0.012</td>
</tr>
<tr>
<td>EC</td>
<td>0.43 mmhos/cm</td>
</tr>
<tr>
<td>pH</td>
<td>8.9</td>
</tr>
</tbody>
</table>

After 45 days growth the plants were thinned out retaining only four healthy plants per pot. After 90 days of establishment the plants were harvested carefully and the roots were washed free of the adhering soil for taking measurements. The per cent mycorrhizal infection was determined by observing the roots after staining (Phillips, Hayman 1970) and by using the method of Read et al. (1976), i.e.,

\[
\text{% VA infection} = \frac{\text{No. of infected segments}}{\text{Total no. of segments examined}} \times 100
\]

The fresh weights of both the root and shoot systems were recorded separately. Dry weight of shoots and roots were recorded after drying to constant weight at 70 °C.

**Results**

The percentage mycorrhizal infection of carrot roots, both inoculated and uninoculated (control),
are presented in Table 2. Although, the native mycorrhiza in unsterile soil caused 20% and 15% infection in the var. Local and SKG, respectively, inoculation with *Glomus mosseae* increased per cent infection (Table 2) substantially (significant at 0.01% level). The proliferation of fibrous roots in inoculated plants was very high. The mycorrhizal association was found confined only to lateral fibrous roots and the rootlets with quite abundant intrametrical mycelium and formation of arbuscules spreading almost throughout the cortex. The vesicles, though occasional, were found to be very conspicuous. The fleshy tap root was found completely free from mycorrhizal infection.

Table 2. Per cent mycorrhizal infection of roots of carrot in unsterile soil inoculated with *Glomus mosseae*

<table>
<thead>
<tr>
<th>Variety</th>
<th>Control</th>
<th>Inoculated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>20.00</td>
<td>70.00</td>
</tr>
<tr>
<td>SKG</td>
<td>15.00</td>
<td>50.00</td>
</tr>
<tr>
<td>P=0.01</td>
<td>4.80</td>
<td>6.50</td>
</tr>
</tbody>
</table>

The dry weight and fresh weight of both root and shoot system were found increased due to inoculation with *Glomus mosseae* and was significantly high in the variety Local when compared to SKG. The yield was found increased nearly by 270% in Local and 42% in SKG over non-inoculated control plants (Table 3).

**Discussion**

Plenchette (1982) has reported that at 100 μg/g available P the relative mycorrhiza dependency of carrot (*Daucus carota* var. Nantaise) is 99.2%. Schenck et al. (1975) have reported that different cultivars of the single plant species differ in harbouring VAM in their root system. Similarly, in the present study both the varieties (Local and SKG) differed in their response to native inoculum and/or to the inoculant both in terms of per cent root colonization (Table 2) and vegetative growth and tuber yield (Table 3). Mosse (1974) pointed out that if the introduced endophytes can be more beneficial to plant growth than the indigenous ones, the present findings have important practical application. Similar observations were reported in unsterile soils with efficient strains of VAM (Mosse, Hayman 1971; Khan 1972; Bagyaraj, Manjunath 1977) and the plants infected with VA mycorrhizae taking more phosphate from P-deficient soils is well documented (Tinker 1975). Black, Tinker (1980) have also observed positive response of potato to VAM application in its growth and yield under natural conditions in soils having low available phosphorous. Thus, keeping in view the improved plant growth and yield to the extent recorded in this study, it is quite likely that inoculation with efficient VAM fungus in spite of the presence of native ones could be beneficial to practical agriculture.

**Acknowledgement**

The authors wish to express their sincere thanks to Dr G R Naik, Professor and former Chairman, Department of P G Studies in Botany, Gulbarga University, Gulbarga for providing the necessary facilities.

**References**


VAM fungi associations in a protected grassland

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Introduction

The vesicular–arbuscular mycorrhizal (VAM) fungi are ubiquitous in both natural and man-made ecosystems (Hayman 1982). It is now well known that VAM fungi play a vital role in plant growth, particularly in drier areas with nutrient-deficient soils. Since naturally occurring VAM fungi are well adapted to the conditions of their natural occurrence due to their long process of evolution, they can be of immense use for various plants as compared to exotic VAM. Screening of VAM fungal species is essential in areas hitherto not studied to prepare a calendar of existing VAM fungi with their distribution. Though looking at their importance and role in terrestrial ecosystems, a large number of such reports of VAM are available for different areas, more areas are to be surveyed to complete the task to prepare a database on a national level including different geographic and agro-climatic zones.

In view of the above, the present survey was undertaken in a protected grassland of tropical deciduous forest region in Sagar, Madhya Pradesh, to furnish the information on the occurrence and association of VAM with different dominant and common grassland plants.

Materials and method

After selection and identification of dominant and common species of the grassland vegetation, root samples of grasses were collected in the month of August and forbs in the month of October. The root samples were washed thoroughly in tap water and cut into 1 cm long pieces. Roots were stained with 0.1% acid fuchsin. Improved procedure of Phillips, Hayman (1970) was followed to determined the VAM colonization in roots.

The percentage colonization of VAM was calculated by using the following formula:

\[
\text{% colonization} = \frac{\text{Total no. of colonized root pieces}}{\text{Total no. of root pieces examined}} \times 100
\]

The manual for the identification of VAM given by Schenck, Perez (1990) was followed for the identification of chlamydospores and intact VAM spores.
Conclusion

It is evident from Table 1 that all plant species are colonized with VAM fungi. The root colonization ranges from 46% to 100%. Comparatively higher colonization was found in grasses than in forbs. Among the different VAM fungi, *Glomus aggregatum*, *G. fasciculatum*, and *G. intraradix* were the most dominant species found associated with almost all the grasses. Other species were *Acaulospora* sp., *Gigaspora* sp., and *Scutellospora* sp.

The heavily colonized plant species can easily be harvested and could be of immense use for isolation and mass multiplication of VAM.

### References


### Table 1. Percentage colonization and VAM species distribution in grasses and forbs

<table>
<thead>
<tr>
<th>Name of plant species</th>
<th>% Colonization</th>
<th>G. aggregatum</th>
<th>G. fasciculatum</th>
<th>G. intraradix</th>
<th>Acaulospora sp.</th>
<th>Gigaspora sp.</th>
<th>Scutellospora sp.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Chloris barbata</em> Sw.</td>
<td>100%</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Cymbopogon martinii</em> (Roxb) Wats.</td>
<td>78%</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Digitaria sanguinalis</em> (Linn) Scop.</td>
<td>100%</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Heteropogon contortus</em> (Linn)</td>
<td>82%</td>
<td>+</td>
<td></td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>P. Beauty</td>
<td>100%</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Paspelum distichum</em> Linn.</td>
<td>100%</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Setaria glauca</em> (Linn) P. Beauv.</td>
<td>100%</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Sporobolus diander</em> (Retz.) P. Beauv.</td>
<td>100%</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Forbs</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ageratum conyzoides</em> (Linn).</td>
<td>90%</td>
<td>+</td>
<td>—</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Dictytera verticillata</em> Nees.</td>
<td>96%</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Eclipta erecta</em> (Linn)</td>
<td>52%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Euphorbia geniculata</em> Orteg.</td>
<td>90%</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Euphorbia hirta</em> Linn.</td>
<td>88%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>+</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Justicia quinqueangularis</em> Keon.</td>
<td>80%</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Lantana camara</em> Linn.</td>
<td>74%</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Lagascea mollis</em> cav.</td>
<td>62%</td>
<td>—</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Malvastrum coromandelianum</em> (Linn)</td>
<td>82%</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Garcke</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Penisetrophe bicalyculata</em> (Retz) Nees.</td>
<td>52%</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Rungia parviflora</em> (Retz) Nees.</td>
<td>60%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Sonchus arvensis</em> Linn.</td>
<td>94%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>+</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Vernonia cinerea</em> (Linn.) Less</td>
<td>84%</td>
<td>+</td>
<td>+</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td><em>Vicoa indica</em> (Linn.) DC</td>
<td>46%</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

### New approaches...

Under this column appear brief accounts of new techniques, modifications of available techniques, and new applications of other known techniques, etc., in mycorrhiza research that have been published in reputed journals during the last two or three years.

Determination of chitin in fungi and mycorrhizal roots by HPLC

A method to measure chitin content in fungi and ectomycorrhizal roots with high performance liquid chromatography (HPLC) was developed by Ekblad A, Nasholm T, 1996 (*Plant and Soil* 178(1): 29–35, 1996). Measurement of fluorescence of 9-fluorenyl methyl chloroformate (FMOC-Cl) derivatives of glucosamine were made on acid hydrolysates of pure...
chitin, chitin-root mixtures, and fungal-root mixtures. The method was applied on five isolates of ectomycorrhizal fungi and ectomycorrhizal and non-ectomycorrhizal *Pinus sylvestris* roots. Interference from amino acids was removed by pretreatment of samples with 0.2 NaOH. This pretreatment did not reduce the recovery of chitin. The HPLC method was compared with colorimetric chitin method by measurement on root-fungal mixtures with known fungal content. The HPLC method gave the estimate of fungal biomass which was equal to the expected while the colorimetric method showed values significantly by lower (PL0.001) than the expected. The present chitin method offers a sensitive and specific tool for the quantification of chitin in fungi and in ectomycorrhizal roots.

Assessment of mycorrhizal colonization by fungal specific sterols

The extent of mycorrhizal colonization in plants is generally assessed by microscopic counting or by determination of fungal cell wall chitin. According to Bothe H, Klingner A, Kaldorf M, Schmitz H, Hundeshagen B, Kernebeck H (*Expercentra 50: 999–925, 1994*), the chitin method is of limited values as prior to HPLC analysis, the heavy salt load in the samples to be assessed has to be removed and this step cannot easily be performed quantitatively. The authors have found that the degree of mycorrhizal colonization can be measured conveniently by determining fungal-specific sterols. Plants colonized by VA mycorrhizal fungi show a specific synthesis of 24-methylene cholesterol and an enhanced level of campesterol (= 24 methyl cholesterol).

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**Forthcoming events...**

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
<th>Location</th>
<th>Contact Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>23–28 May 1999</td>
<td><em>Tropical Restoration for the New Millennium.</em> San Juan, Puerto Rico</td>
<td></td>
<td>John Parrotta, Restoration Conference Program Chair, IITF USDA Forest Service PO Box 25000, Rio Piedras PR 00928-5000, USA 1-787-766 6263 <a href="mailto:j-parrotta@uprl.upr.clu.edu">j-parrotta@uprl.upr.clu.edu</a></td>
</tr>
<tr>
<td>14–16 June 1999</td>
<td><em>The Role of National Forest Programs to Ensure Sustainable Forest Management.</em> Joensuu, Finland</td>
<td></td>
<td>Ms Brita Pajari, European Forest Institute Torikatu 34, FIN-80 100 Joensuu Finland 358-13 124 393 <a href="mailto:anssi.niskanen@efi.fi">anssi.niskanen@efi.fi</a></td>
</tr>
<tr>
<td>28–30 June 1999</td>
<td><em>Forest Engineering for Tomorrow.</em> Edinburgh, Scotland</td>
<td></td>
<td>Geoff Freedman, Forestry Engineering Greenside, Peebles Scotland, UK 44-1721 732 448 <a href="mailto:geoff.freedman@forestry.gov.uk">geoff.freedman@forestry.gov.uk</a></td>
</tr>
<tr>
<td>11–16 July 1999</td>
<td><em>Forest Biotechnology: Into the Next Millennium.</em> Oxford, UK</td>
<td></td>
<td>Malcolm Campbell, Department of Plant Sciences University of Oxford South Parks Road Oxford OXI 3RB, UK 44-1865-275074 <a href="mailto:malcolm.campbell@plants.ox.ac.uk">malcolm.campbell@plants.ox.ac.uk</a></td>
</tr>
<tr>
<td>12–16 July 1999</td>
<td><em>Off-forest Tree Resources of Africa Workshop.</em> Arusha, Tanzania</td>
<td></td>
<td>Prof. Roger Malimbwi, Faculty of Forestry Sokoine University of Agriculture PO Box 3009 Chuo Kikuu Morogoro, Tanzania 255-56-4648 <a href="mailto:forestry@sua.ac.tz">forestry@sua.ac.tz</a></td>
</tr>
</tbody>
</table>
23–25 August 1999
International Teak Conference: Teak Beyond Year 2000. Chiang Mai, Thailand
For further information, please contact:
  Director,
  Forest Tree Seed Centre
  Muak-Lek
  Saraburi
  Thailand
  Fax: 66-36-341 859

September 1999
New Approaches to Integrated Management of Primary and Secondary Forests for the 21st Century. Belem, Brazil
For further information, please contact:
  Natalion Silva
  Brazilian Agricultural Research Corporation
  CP 48, CEP 66240
  Belem, Para
  Brazil
  Fax: 55-91-226 9845
  E-mail: natalino@cpatu.embrapa.br

1–7 September 1999
Seminar on Sustainability of Plantations. Curitiba, Brazil
For further information, please contact:
  Dr Carlos Ferreira
  National Center of Forest Research
  EMBRAPA, XX
  Fax: 55-41 766 1276
  E-mail: bellote@cnpf.embrapa.br

9–23 September 1999
27th International Forestry Students Symposium: Forest History — the Link to Our Future. Gottingen, Germany
For further information, please contact:
  IFSS 99 Organising Team
  IFSA Secretariat, Buesgenweg 2
  37077 Gottingen
  Germany
  Fax: 49 551 3796992
  E-mail: ifss@ifsa.net

18–22 October 1999
Impact of Logging on Biodiversity. Hanoi, Vietnam
For further information, please contact:
  Titiek Setyawati
  Research Fellow
  CIFOR, PO Box 6596
  JKPWB Jakarta 10065
  Indonesia
  Fax: 55-41 766 1276
  E-mail: t.setyawati@cgt.net

18–23 October 1999
II Latin American Symposium on Advances in the Production of Forest Seeds. Santo Domingo, Dominican Republic.
For further information, please contact:
  Rodolfo Salazar
  CATIE, Turrialba
  Costa Rica
  Fax: 506-556-556 7766
  E-mail: rsalazar@catie.ac.cr

News from members ...

UAS professor honoured
Dr D J Bagyaraj, Professor and Head, Department of Agricultural Microbiology of the University of Agricultural Sciences, Bangalore, was honoured with the Professor S R Vyas Memorial Award. This award, instituted by the Association of Microbiologists of India, is conferred biennially on a scientist for his outstanding contributions to microbiology. This award is in recognition of his research work on mycorrhizal fungi and their role in agriculture, horticulture, and forestry. Dr R S Paroda, Director General, Indian Council of Agricultural Research presented the award.

Prof. Bagyaraj has also been conferred with an honorary appointment to Research Board of Advisors by the American Biographical Institute, USA.

A new species of VAM fungus honouring Prof. Bagyaraj
A new species of VA mycorrhizal fungus isolated from Allahabad has been named as *Glomus bagyarajii*, in recognition of the contribution of Prof. D J Bagyaraj, University of Agricultural Sciences, Bangalore, to the field of mycorrhizal research. The fungus produces abundant bright yellow to yellow brown spores with four wall layers, subtending hypha hyaline to pale yellow, cylindrical or funnel shaped. Germination is by regrowth of the subtending hypha. This research publication has appeared in the recent issue of *the Philippine Journal of Sciences* 126: 233–242.
Recent references

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

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

- American Journal of Botany
- Annals of Botany
- Applied and Environmental Microbiology
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- Biologia
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- Texas Journal of Science
- Tree Physiology

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

**Annals of Botany 82(6), 1998**
Bryla D R, Koide R T (University of Nevada, Department of Environment and Resource Science, Reno, NV 89557 USA). Mycorrhizal response of two tomato genotypes relates to their ability to acquire and utilize phosphorus, 849–857

Tarhanen S (University of Kuopio, Department of Ecology and Environmental Science, POB 1627, FIN-70211 Kuopio, Finland). Ultrastructural responses of the lichen Bryoria fuscescens to simulated acid rain and heavy metal deposition, 735–746

**American Journal of Botany 85 (12), 1998**
Wilson G W T, Hartnett D C (Kansas State University, Division of Biology, 232 Ackert Hall, Manhattan, KS 66506 USA). Interspecific variation in plant responses to mycorrhizal colonization in tallgrass prairie, 1732–1738

**Applied Soil Ecology 10(3), 1998**
Huhta V, Persson T, Setala H (University of Jyvaskyla, Department of Biology and Environmental Science, Jyvaskyla, Finland). Functional implications of soil fauna diversity in boreal forests, 277–288

**Applied and Environmental Microbiology 64(12), 1998**
Vierheilig H, Coughlan A P, Wyss U, Piche Y (University of Laval, Centre Recherches Biologie Forestiere, Pavilion CE Marchand, St Foy, PQ G1K 7P4, Canada). Ink and vinegar, a simple staining technique for arbuscular–mycorrhizal fungi, 5004–5007

**Biologia 53(5), 1998**
Hanel L (Academy of Science Czech Republic, Institute of Soil Biology, Na Sadkach 7, CZ-37005 Ceske Budejovice, Czech Republic). Distribution of nematodes in soil, mycorrhizal soil, mycorrhizae and roots of spruce forests at the Boubin Mount, Czech Republic, 593–603

**Biology and Fertility of Soils 28(2), 1999**
Singh S, Kapoor K K (Haryana Agricultural University, Department of Microbiology, Hisar 125004, Haryana, India). Inoculation with phosphate-solubilizing microorganisms and a vesicular arbuscular mycorrhizal fungus improves dry matter yield and nutrient uptake by wheat grown in a sandy soil, 139–144

Wu B, Watanabe I, Hayatsu M, Nioh I (University of Shizuoka, Faculty of Agriculture, Department of Applied Biological Chemistry, Shizuoka 4228529, Japan). Effect of ectomycorrhizae on the growth and uptake and transport of N-15-labeled compounds by Pinus tabuliformis seedlings under water-stressed conditions, 136–138

**Biotropica 30(4), 1998**
Becker P, Lye O C, Goh F (University of Brunei Darussalam, Department Biology, BE-1410 Gadong, Brunei). Selective drought mortality of dipterocarp trees: no correlation with timber group distributions in Borneo, 666–671

**Canadian Journal of Botany — Revue Canadienne de Botanique 76(7), 1998**
Jumpponen A, Trappe J M (Department of Agriculture Research Sweden, POB 4097, S-90403 Umea, Sweden). Performance of Pinus contorta inoculated with two strains of root endophytic fungus, Phialocephala fortinii: effects of synthesis system and glucose concentration, 1205–1213

**Environmental and Experimental Botany 40(3), 1998**
Rouhier H, Read D J (University of Lund, Centre for Microbial Ecology, Ecology Building, S-22362 Lund, Sweden). Plant
and fungal responses to elevated atmospheric carbon dioxide in mycorrhizal seedlings of *Pinus sylvestris*, 237–246

**FEMS Microbiology Letters 170(1), 1999**

Iltner P, Schinner F (Innsbruck University, Institute of Microbiology NF, Technikerstr 25, A-6020 Innsbruck, Austria). Influence of nutrient solution on Al-tolerance of Pseudomonas sp., 187–190

**Forest Ecology and Management 111(2–3), 1998**

Ingleby K, Munro R C, Noor M, Mason P A, Clearwater M J (Institute of Terrestrial Ecology, Bush Estate, Penicuik EH26 0QB, Midlothian, Scotland). Ectomycorrhizal populations and growth of *Shorea parvifolia* (Dipterocarpaceae) seedlings regenerating under three different forest canopies following logging, 171–179

**Forest Ecology and Management 113(1), 1999**


**Hortscience 33(7), 1998**

Goicoechea N, Szalai G, Antolin M C, SanchezDiaz M, Paldi E (Universidad de Navarra, Department Fisiol Vegetal, C Irunlarrea S-N, E-31008 Pamplona, Spain). Influence of arbuscular mycorrhiza and rhizobium on free polyamines and proline levels in water-stressed alfalfa, 706–711

Yang W Q, Goulart B L, Demchak K (Pennsylvania State University, Department of Horticulture, University Park, PA 16802 USA). Mycorrhizal infection and plant growth of highbush blueberry in fumigated soil following soil amendment with arbuscular mycorrhizal fungi different genera on *Vaccinium angustifolium* and endo-forms, 225–228

**Journal of Ecology 86(6), 1998**

Skene K R (University of Dundee, Department of Biological Sciences, Dundee DD1 4HN, Scotland). Cluster roots: some ecological considerations, 1060–1064

**Journal of Plant Physiology 153(5-6), 1998**

Matsuda Y, Hiji N (Nagoya University, School of Agricultural Sciences, Forest Products Laboratory, Chikusa Ku, Nagoya, Aichi 4648601, Japan). Spatiotemporal distribution of fruitbodies of ectomycorrhizal fungi in an *Abies firma* forest, 131–138

Mohammad M J, Pan W L, Kennedy A C (Jordan University of Science & Technology, Faculty of Agriculture, Department of Natural Resources & Environment, POB 3030, Irbid, Jordan). Seasonal mycorrhizal colonization of winter wheat and its effect on wheat growth under dryland field conditions, 139–144

Bodker L, Kjoller R, Rosendahl S (University of Copenhagen, Institute of Botany, Department of Mycology, Oster Farimagsgade 2D, DK-1353 Copenhagen K, Denmark). Effect of phosphate and the arbuscular mycorrhizal fungus *Glomus intraradices* on disease severity of root rot of peas (*Pisum sativum*) caused by *Aphanomyces euteiches*, 169–174


Boddington C L, Dodd J C (University of Kent Campus, Biotechnology MIRCEN, International Institute of Biotechnology, Canterbury CT2 7YW, Kent, England). A comparison of the development and metabolic activity of mycorrhizas formed by arbuscular mycorrhizal fungi different genera on two tropical forage legumes, 149–157

Dickie I A, Koide R T, Stevens C M (Pennsylvania State University, University Park, Program Ecology, 111 Ferguson Building, PA 16802 USA). Tissue density and growth response of ectomycorrhizal fungi to nitrogen source and concentration, 145–148

**Mycorrhiza 8(3), 1998**

Giovannetti M, Sbrana C (University of Pisa, Dipartimento di Chimica e Biotecnologie Agrarie, Via del Borghetto 80, I-56124 Pisa, Italy). Meeting a non-host: the behaviour of AM fungi, 123–130

**Mycorrhiza 8(4), 1999**


Cantelmo A J, Ehrenfeld J G (Rutgers State University, Cook College, Department Ecology, Evolution & Natural Resources, New Brunswick, NJ 08903 USA). Effects of microtopography on mycorrhizal infection in Atlantic white cedar (*Chamaecyparis thyoides* (L.) Mills.), 175–180

Chen A, Chambers S M, Cairney J W G (University of Western Sydney (Nepean), School of Science, Mycorrhiza Research Group, POB 10, Kingswood, NSW 2747, Australia). Utilisation of organic nitrogen and phosphorus sources by mycorrhizal endophytes of *Woollsia pungens* (Cav.) F. Muell. (*Epacridaceae*), 181–187


Schweiger P F, Thingstrup I, Jakobsen I (Riso National Laboratory, Plant Microbe Symbioses Plant Biology & Bio-geochemistry Department, DK-4000 Roskilde, Denmark). Comparison of two test systems for measuring plant phosphorus uptake via arbuscular mycorrhizal fungi, 207–213


Koide R T, Suomi L, Stevens C M, McCormick L (Pennsylvania State University, Department Horticulture, University Park, PA 16802 USA). Interactions between needles of *Pinus resinosa* and ectomycorrhizal fungi, 539–547


Schmidt S, Stewart G R, Turnbull M H, Erskine PD, Ashwath N (University of Western Australia, Faculty of Science, Chemistry Building, Nedlands, WA 6907, Australia). Nitrogen relations of natural and disturbed plant communities in tropical Australia, 95–104


Blee K A, Anderson A J (Utah State University, Department of Biology, Logan, UT 84322 USA). Regulation of arbuscule formation by carbon in the plant, 523–530


Nehls U, Beguiristain T, Ditengou F, Lapeyrie F, Martin F (INRA, Centre Recherche Nancy, Equipe Microbiologie Forestiere, F-54280 Champenoux, France). The expression of a symbiosis-regulated gene in eucalypt roots is regulated by auxins and hypaphorine, the tryptophan betaine of the ectomycorrhizal basidiomycete *Pisolithus tinctorius*, 296–302


Van Auken O W, Brown S C (University of Texas, Division of Life Sciences, San Antonio, TX 78249 USA). Importance of arbuscular mycorrhizae to drymass production of a native Texas C-3 and C-4 grass, 291–304

*Tree Physiology* **19**(1), 1999

Jentschke G, Winter S, Godbold D L (University of Wales, School of Agriculture & Forest Science, Bangor LL57 2UW, Gwynedd, WALES). Ectomycorrhizas and cadmium toxicity in Norway spruce seedlings, 23–30

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