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About TERI

A dynamic and flexible organization with a global vision and a local focus, TERI, The Energy and Resources Institute, was established in 1974 as the Tata Energy Research Institute. While initially, TERI's focus was mainly on documentation and information dissemination, research in the fields of energy, environment, and sustainable development was 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 Biotechnology and Management of Bioresources 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 grass-roots level, with village communities. The division functions through two areas—the Centre for Mycorrhizal Research, and Plant Tissue Culture and Molecular Biology. It 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 sharing of information among the network members and makes the growing literature on mycorrhiza available to researchers. Comprehensive database 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 or handling.

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Effect of elevated levels of CO_2

The normal concentration of CO_2 in air is estimated to be 0.03%–0.04%. In recent years, there has been a continuous increase in the percentage of CO_2 present in air due to the increase in human and animal population and combustion of fossil fuels. The elevated levels of CO_2 increase the photosynthetic activity, resulting in increased inputs of C (carbon) in soil. In order to understand plant growth responses to increased CO_2 levels, it is important to identify primary below-ground feedbacks, both positive and negative, resulting from greater inputs of C into the soil. The primary negative feedbacks include increased litter C/N (nitrogen) ratios and therefore reduced mineralization rates, increased immobilization of the available nutrients by a larger soil microbial pool, and increased storage of nutrients in plant biomass and detritus due to increases in the NPP (net primary productivity). These negative feedbacks share the common feature of reducing the amount of nutrients available to plants. Most primary positive feedbacks share the common features of being plant-mediated, and thus increase plant growth by means of increased plant nutrient uptake. The plant nutrient uptake may be increased through alterations in root architecture, physiology, or mycorrhizal symbioses. The increased C/N ratio of the plant tissue means that a given level of NPP can be achieved with smaller supply of N. Both negative and positive feedbacks to soil as a result of elevated air levels of CO_2 in may, however, vary greatly for different species and environmental conditions (Berntson and Bazzaz 1996).

The stimulation of plant growth by mycorrhizal fungi, however, depends upon the degree of dependence of the host on the mycorrhizal fungi and nutrient availability in soil. By modifying the inputs of C from plants to soil, elevated CO_2 may affect the biomass, infectivity, and the species/isolate composition of root symbionts. This has the potential to alter the community structure and ecosystem functioning (Diaz 1996).

Effect of elevated CO_2 on mycorrhizal colonization of plant roots

In studies conducted at the Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, USA, large, intact soil cores of nearly pure stands of *Pascopyrum smithii* (*Elymus smithii*) and *Bouteloua gracilis* were extracted; transferred to controlled environment chambers; and then exposed to a variety of water, temperature, and CO_2 regimes for four annual growth cycles. After two growth cycles in growth chambers, 54% of the root length was colonized by mycorrhizal fungi in *P. smithii*, compared with 35% in *B. gracilis*. Field control plants had a significantly lower mycorrhizal colonization. Increasing the CO_2 increased the mycorrhizal colonization in *B. gracilis* by 46% but had no effect in *P. smithii*. Temperatures 4 °C higher than the normal decreased the mycorrhizal colonization in *P. smithii* by 15%. Increasing the annual precipitation decreased the mycorrhizal colonization in both species. Simulated climatic change conditions of increased CO_2, increased temperature, and reduced precipitation decreased the colonization in *P. smithii* but had little effect on *B. gracilis*. After four growth cycles in *P. smithii*, trends of treatments remained similar but the overall mycorrhizal colonization rate decreased (Monz, Hunt, Reeves, *et al.* 1994).

In studies conducted at the Rangeland Resources Research Unit, United States Department of

Agriculture, Agriculture Research Service, Fort Collens, USA, *B. gracilis* was grown in soil-packed, column lysimeters in growth chambers maintained at the ambient levels of CO_2 (350 micro litres per litre) or enriched levels of CO_2 (700 micro litres per litre). Plants were deficit-irrigated. The growth chambers were maintained at day/night temperatures of 25 °C/16 °C and relative humidity of 35%/90%, with a 14-hour photoperiod to simulate summer conditions. After 11 weeks of growth, plants grown in CO_2-rich atmosphere had produced 35% and 65% greater total biomass and root biomass, respectively, and had nearly twice the level of VAM infection (19.8% versus 10.8%) than those of plants grown under the ambient levels of CO_2. Plants in the CO_2-enriched atmosphere also exhibited greater leaf water potential and higher plant water use efficiency. Under the conditions of the experiment, CO_2 enrichment increased root biomass and VAM infection via stimulated growth and adjustments in the C partitioning below ground (Morgan, Knight, Dudley, *et al.* 1994).

In pot experiments conducted at the Institut für Tropischen und Subtropischen Pflanzenbau der Universitat Göttingen, Germany, *Eupatorium odoratum*, *Sorghum bicolor,* and *Guizotia abyssinica* were inoculated with *Glomus macrocarpum,* fertilized with hardly soluble $Ca_5(PO_4)_3OH$ and supplied continuously with CO_2 at the rate of 1 litre/hour until the end of the experiment. Throughout the experiment, O_2 level was maintained at 16%. In *E. odoratum,* the dry matter increased up to 1% CO_2 level and decreased thereafter. VAM inoculation increased the dry weight. The mineral uptake (except N) showed minor effect at lower CO_2 levels but was strongly reduced at higher levels (16% CO_2). Uptake and concentration of P was more strongly improved by mycorrhiza than that by any other element. Mycorrhizal infection was slightly increased at lower CO_2 concentrations but decreased at higher concentrations. The number of vesicles decreased with increasing CO_2. At each CO_2 level, the infection intensity was very low and arbuscules were generally absent. In *S. bicolor*, the shoot dry weight showed no response to CO_2 and mycorrhizal inoculation. Root dry weight increased with mycorrhizal inoculation and with CO_2 (up to 4% level). The percentage of root length infected and the number of vesicles increased with the CO_2 level up to 4% and then decreased at 8% CO_2. Mycorrhizal infection intensity was very low and arbuscules were generally absent. In *G. abyssinica,* increase in soil CO_2 reduced dry matter in mycorrhizal and non-mycorrhizal plants, and inoculation increased dry matter significantly. With increasing CO_2 , mineral uptake decreased but mineral concentration increased. The infection rate and the number of vesicles increased up to 4% CO_2. The infection intensity was appreciably high but no arbuscules were observed (Saif 1981).

In studies conducted at the Department of Biology, University of York, UK, *Plantago lanceolata* and *Trifolium repens* were grown for 16 weeks in ambient (360 micro mol per mol) and elevated (610 micro mol per mol) atmospheric CO_2, inoculated with *Glomus mosseae* and supplied with P in the form of bonemeal. Plant growth analysis after seven sequential harvests showed that both species grew faster in elevated CO_2 and that *P. lanceolata* had increased the carbon allocation towards the roots. At a given time, the elevated CO_2 increased the percentage of root length colonized, the total root length colonized, and root and the external mycorrhizal hyphal density, and decreased the ratio of mycorrhizal hyphal density to total length of colonized root. The same trend was noticed for root length colonized by arbuscules. Hyphal density (colonization intensity) in roots was not affected by CO_2 levels. Thus, there was no direct permanent effect of elevated CO_2 on mycorrhizal functioning as internal mycorrhizal development and the mycorrhizal P uptake mechanism were unaffected (Staddon, Graves, and Fitter 1998; Staddon, Fitter, and Graves 1999).

Further studies conducted at the university on a non-leguminous plant–mycorrhizal fungal association (*Plantago lanceolata* with *G. mosseae*) simulation model showed that time had a more significant effect on the observed stimulation of mycorrhizal colonization by the elevated CO_2 than changes in the C allocation patterns or the below-ground C losses. There were two main mechanisms that negated a stimulatory effect of elevated CO_2 on internal mycorrhizal colonization: increased mycorrhizal C allocation to the external hyphal network and an increased rate of mycorrhizal respiration (Staddon 1998).

Studies at the Carnegie Institution of Washington's Department of Plant Biology, in Stanford, USA, on root colonization by VAM and other fungi of several plant species from two grassland communities after continuous exposure to elevated atmospheric CO_2 for six growing seasons showed that there were decreases in the percentage of non-mycorrhizal fungal root colonization in the elevated CO_2 for several plant species. The total AM root colonization percentage only increased significantly for one out of the five plant species in each grassland (sandstone and serpentine annual grassland). However, when dividing the AM fungal hyphae into two groups of hyphae (fine endophyte and coarse endophyte), there were significant responses of the AM fungi that were hidden when only the total percentage colonization was measured. The result also showed that changes in the fungal root colonization can occur after long-term CO_2 enrichment, and that the level of resolution of the study of AM fungal responses may have to be increased to uncover significant changes to the CO_2 treatment (Rillig, Field, and Allen 1999).

Studies at the University of Oslo, Sum, Norway, showed that the total VAM infection of roots was higher under elevated CO_2 but the proportion of

functional structures was not modified (Dhillion, Roy, and Abrams 1996).

Effect of elevated CO_2 on mycorrhiza under fertilizer treatments

Studies at the Department of Biology, Soil Ecology and Restoration Group, San Diego State University, San Diego, USA, on five co-occurring plant species from an annual Mediterranean grassland, grown in a monoculture for four months in pots inside the open-top chambers and exposed to elevated atmospheric CO_2, showed that the elevated CO_2 and fertilization altered the ratio of non-mycorrhizal to mycorrhizal fungal colonization in some plant species but not in others. The per cent root infection by non-mycorrhizal fungal species increased by over 500% in *Linanthus parviflorus* in the elevated CO_2 but decreased by over 80% in *Bromus hordeaceus*. The mean per cent infection by mycorrhizal fungi increased in all the species in response to elevated CO_2, but the increase was significant only in *Avena barbata* and *B. hordeaceus*. The per cent infection by mycorrhizal fungi increased, decreased, or remained unchanged for different plant hosts in response to fertilization. There was evidence of a strong interaction between the two treatments for some plant species and non-mycorrhizal and mycorrhizal fungi (Rillig, Allen, Klironomos, *et al.* 1998b).

In further studies at the university on *B. hordeaceus*, a grass from a Mediterranean annual grassland, changes in infection intensity were measured (rather than the more traditional per cent root infection) as an indicator of response to the elevated atmospheric CO_2 and soil-nutrient enrichment. The intensity was measured as the number of intraradical hyphae intersecting a microscope cross-hair for specific root diameter size classes. Intensity of infection increased when plants were exposed to elevated CO_2 and decreased when plants were fertilized. This finding thus provides evidence for an increase in the C allocation to the symbiont under elevated CO_2 even in absence of changes in per cent infection or mycorrhizal root length (Rillig, Allen, Klironomos, *et al.* 1998a).

Effect of elevated CO_2 on mycorrhizal fungi

In studies conducted at the Department of Botany, University of Guelph, Guelph, Canada, *Artemisia tridentata* seedlings were inoculated with either *Glomus intraradices*, *G. etunicatum, Acaulospora* sp., or *Scutellospora calospora* and grown at either ambient (350 ppm) or elevated (700 ppm) levels of CO_2. The elevated CO_2 caused the per cent arbuscular and hyphal colonization to increase in the two *Glomus* species but not in *Acaulospora* sp. or *S. calospora*. Vesicular colonization was not affected by the elevated CO_2 in any fungal species. In the extra-radical phase, the two *Glomus* species produced a significantly higher number of spores in response to elevated CO_2, whereas *Acaulospora* sp. and *S. calospora* developed significantly higher hyphal lengths (Klironomos, Ursic, Rillig, *et al.* 1998).

Studies conducted at the Institute of Botany, University of Basel, Basel, Switzerland, on *Prunella vulgaris* seedlings inoculated with different mycorrhizal fungi and grown at ambient (350 micro litres per litre) and elevated (600 micro litres per litre) levels of CO_2 using compartments accessible only to the AMF (arbuscular mycorrhiza fungi) hyphae showed that plant biomass was significantly greater at elevated than at ambient CO_2. Biomass of the root system increased by a factor of two. Colonization of the AM fungi inside the root remained constant, indicating that the total AMF inside the root system also increased by a factor of two. Length of the external AMF hyphae at elevated CO_2 was up to five times that at ambient CO_2, indicating that elevated CO_2 promoted allocation of the AMF biomass to external hyphae (Sanders, StreitwolfEngel, vanderHeijden, *et al.* 1998).

Effect of elevated CO_2 on uptake of phosphorus and other elements in plants

Studies conducted at the Rangeland Resources Research Unit, Fort Collins, Colorado, USA, *Bouteloua gracilis* grown in column lysimeters in growth chambers maintained at ambient (350 micro litres per litre) or enriched (700 micro litres per litre) CO_2, 25/16 °C day/night temperature, 35%/90% relative humidity, and a 14-hour photoperiod showed that plant P uptake was little influenced by the CO_2 regime though the plant N uptake was reduced by CO_2 enrichment (Morgan, Knight, Dudley, *et al.* 1994).

Studies conducted at the Institut fur Tropischen und Subtropischen, Göttingen, Germany, on three plant species inoculated with *G. macrocarpum* and exposed to a continuous supply of CO_2 at the rate of 1 litre/hour showed that mycorrhizal inoculation improved the uptake and concentration of P, Mg, K, Ca, and N in that order in *E. odoratum*. In *S. bicolor*, mycorrhizal efficiency in improving the uptake and concentration of different elements was in the order of P, K, N, Mg, and Ca. In *G. abyssinica,* the order of the mycorrhizal efficiency in improving the uptake and concentration of these elements was Mg, P, Ca, N, and K (Saif 1981).

Studies conducted at the Department of Biology, University of York, UK, on *Plantago lanceolata* and *T. repens* grown for 16 weeks in ambient (360 micro mol per mol) and elevated (610 micro mol per mol) CO_2 and supplied with bonemeal as a P source and inoculated with *G. mosseae* showed that the P content of the plant was increased in elevated CO_2 although the concentration of P in both the shoot and root tissue was unchanged. This was again a result of bigger plants at elevated CO_2. The P inflow was unaffected by the CO_2 concentration (Staddon, Graves, and Fitter 1998).

Studies at the University of Basel, Basel, Switzerland, on *Prunella vulgaris* inoculated with different mycorrhizal fungi and grown in ambient (350 micro litres per litre), and elevated (600 micro litres per litre) CO_2 showed that the concentration and contents of P in the stolons differed significantly between the ambient and elevated CO_2 but this either increased or decreased the extent of occupation of the root by the AM fungal isolates. To prove that increase in the external hyphal growth at elevated CO_2 would result in increased P acquisition by the plant, the plants were grown in pots with compartments accessible only to AMF hyphae but not to the roots. Plants did not acquire more P at an elevated CO_2 when the P was added to the compartment accessible only to AM fungal hyphae (Sanders, StreitwolfEngel, vanderHeijden, *et al*.1998).

Effects of light on mycorrhiza development

Plants manufacture food from atmospheric CO_2 and water in presence of light and chlorophyll in leaves. The photosynthates are carried to all parts of the stems and to the roots of plants. The carbohydrates and other nutrients in the root excudates on the surface of fine roots predispose these roots to infection by mycorrhizal fungi. The duration and intensity of light thus play an important role in colonization of roots by mycorrhizal fungi.

Effect of duration of light

Studies at the Institut fur Tropischen und Subtropischen Pflanzenbau, Göttingen, Germany, on *E. odoratum* grown in a growth chamber, supplied with monocalcium phosphate or hydroxylapatite, and inoculated with *G. macrocarpum* and a white reticulate fungus showed that the best effect was achieved at a 10-hour day length, but when fertilized with $FePO_4$, the highest VA mycorrhizal efficiency was obtained at a 14-hour day length. With *G. abyssinica* plants, efficiency of both fungi was always the highest at 18-hour day length. Clear differences in efficiency of the two endophytes were observed only in *E. odoratum* whose growth was more strongly increased by the white reticulate fungus than by *G. macrocarpum*. A definite relationship between infection intensity and efficiency of the VAM under different day lengths was most frequently observed in plants supplied with sparingly soluble phosphates (Diederichs 1983a).

Studies conducted at the Fruit Crops Department, University of Florida, Gainesville, Florida, USA, showed that compared to the natural glasshouse day light, the number of spores of *G. fasciculatum* on the roots of Sudan grass increased dramatically when mycorrhizal Sudan grass was exposed to extended photoperiods with mercury vapour or metal halide lamps of high intensity. Apparently, the level of sugars, but not of amino acids, in root exudates from two-month-old Sudan grass plants was correlated with spore production in *G. fasciculatum* (Ferguson and Menge 1982).

Studies conducted at the Division of Microbiology, Indian Agricultural Research Institute, New Delhi, India, on *Aeschynomene indica* showed that the dry weight of shoots and root and VAM colonization were progressively increased when *A. indica* plants were exposed to light for larger periods. However, a 12-hour light exposure was optimum for the growth of *A. indica* and maximum root colonization by the VAM fungi (Singh and Tyagi 1989).

Effect of intensity of light

In studies conducted at the Institut fur Tropischen und Subtropischen Pflanzenbau, Göttingen, Germany, on *Capsicum annum* and *Ageratum houstonianum*, inoculated with three VAM fungi, grown under different light intensities, and with or without P fertilization, *C. annum* fertilized with hydroxylapatite and inoculated with *G. macrocarpum* or a white reticulate fungus showed the highest mycorrhizal efficiency under full light. *C. annum* plants inoculated with *Acaulospora spinosa* responded only weakly to the light levels. With *A. houstonianum*, efficiency of all the three mycorrhizal fungi was lowest under full light. With P fertilization, the efficacy of the VAM was generally reduced. The P uptake was enhanced more by mycorrhiza than by plant growth. The influence of light intensity on the efficiency of the VAM depended on the host species, the fungus species, and the availability of P (Diederichs 1982).

Further studies at the above institute on *C. annum* and *E. odoratum* inoculated with two VAM fungi, grown at three light intensities, and fertilized with three types of phosphate of different solubilities showed that *E. odoratum* inoculated with *G. macrocarpum* or a white reticulate fungus showed an improved mycorrhizal efficiency with increasing light intensity only with $FePO_4$ as the P source. With *C. annum*, however, both the fungi enhanced mycorrhizal efficiency with increasing light intensity in all the three P treatments, namely monocalcium phosphate, hydroxylapatite, and iron phosphate. The P concentrations in the shoots of mycorrhizal plants were usually higher than those in non-mycorrhizal plants (Diederichs 1983b).

Studies at the Fruit Crops Department, University of Florida, Gainesville, Florida, USA, on Sudan grass showed that mycorrhizal inoculum of *G. fasciculatum*, as measured by the root infection and sporulation on Sudan grass, increased with increasing light intensity. Apparently, growing Sudan grass at greater light intensities and under extended photoperiods will increase the quantity and quality of commercial *G. fasciculatum* inoculum (Ferguson and Menge 1982).

Studies conducted at the Department of Applied Biology, University of Cambridge, Cambridge, UK,

on *Impatiens parviflora* plants grown on a boulder-clay woodland soil at four levels of irradiance with or without the addition of N and P fertilizers showed that the addition of ammonium nitrate and calcium phosphate fertilizers increased the dry weight yield and relative growth rate at all four levels of irradiance, and there was a true interaction between the level of irradiance and nutrient supply. At the three higher levels of irradiance, increased growth resulted from an increase in the unit leaf rate and leaf weight ratio. Lower rates of respiration occurred in the leaves of plants grown with fertilizers at high irradiance. Mycorrhizae were absent from all the fertilized plants, but were well-developed in all unfertilized plants at high irradiance and absent from unfertilized plants at the lowest irradiance (Peace and Grubb 1982).

In studies at the Department of Agricultural Biochemistry, University of Adelaide, Adelaide, Australia, onion (*Allium cepa*) plants were grown in autoclaved soil, low in P, either with or without root inoculum of *G. mosseae*, either with or without additional P of 1.0 milli mol P/kg soil and with mean irradiances of 600 (high) or 250 (low) micro mol/m^2/s. All the three factors interacted with each other. Mycorrhizal infection influenced P acquisition by roots over a wide range of soil P and light intensities, but it was more sensitive to low light (Son, Smith, and Smith 1988).

Studies conducted at the Department d 'Ecologie et de Pedologie, Faculte de Foresterie et de Geodesie, Universite Laval, Quebec, Canada, showed that four different light intensities exerted distinctly different effects on the formation, reproduction, and influence of vesicular-arbuscular mycorrhiza on *Allium cepa* plants. Over a growth period of 100 days, the rate of infection under low light intensities (5 klux and 10 klux) was more rapid and the percentage of infection was higher than the mycorrhizal plants cultivated under a light of 15 klux and 20 klux. The production of spores increased with light intensity. Plant growth was enhanced at all the light levels but was most pronounced under a 10 klux light regime (Furlan and Fortin 1977).

Studies conducted at the Phytoecology Laboratory, Department of Botany, University of Peshawar, Pakistan, showed that the roots of *Salvia hispanica* exhibited 87% infection and 29% average intensity under the full light condition. Under partial light conditions, the percentage and average intensity of arbuscular infection were 71.0 and 23, respectively (Muhammad and Hussain 1995).

Two greenhouse experiments (autumn–winter, Experiment 1 and summer–autumn, Experiment 2) were conducted at the Queensland Horticulture Institute, Department Primary Industries, Bundaberg Research Station, Australia, on capsicum (*Capsicum annum*) and tomato (*Lycopersicon esculentum*) under low light conditions (average daily solar irradiance of 8.4 MJ/m^2 (Experiment 1) and 13.4 MJ/m^2 (Experiment 2) in low-P growth medium (6 and 5 mg P/kg in Experiments 1 and 2, respectively). The plants were grown at 0 (P1), 9.2 (P2), 27.5 (P3), 82.5 (P4), and 248 (P5) of P (mg/kg of oven-dry soil) within a nylon mesh. The mesh excluded roots from the original sunflower (*Helianthus annuus*) host plants, to which either live (VAM+) or killed (VAM–) mycorrhizal (*Glomus etunicatum* and *G. mosseae*) inoculum had been added at sowing. The mesh allowed the fungal hyphae to grow into the growth medium contained in the mesh. At P1 in Experiment 2, increase in the dry weight of the whole VAM+ plants combination was 91.7-fold and 17.9-fold when compared with VAM– plants for capsicum and tomato, respectively. Root starch analysis indicated that the lower dry matter yields of VAM+ plants compared to more of VAM– plants at P2 or higher P treatments could be attributed to insufficient photosynthate production by VAM+ plants to meet the C demand of both the host and the endophytes within the relatively low-light environment of the greenhouse. At P1, P was more limiting than C, and the increased uptake of P as a result of colonization of plant roots by VAM resulted in a growth response. At higher P (P2 and above), C was more limiting than P due to the low light in the greenhouse, and the additional demand for photosynthate imposed by the endophytes on the host resulted in a growth depression relative to non-mycorrhizal plants (Olsen, Schaefer, Edwards, *et al.* 1999).

Studies at Duke University's Department of Botany, Durham, USA, on onion plants showed that shading decreased mycorrhizal infection and the effect was more pronounced with ammonium N ($[NH_4]_2SO_4$) than with nitrate N ($Ca\ [NO_3]_2\ 4\ H_2O$). The onion roots contained less carbohydrate in the ammonium nitrogen treatment than in the nitrate nitrogen treatment and the differences were greater in shaded plants. These results showed a direct relationship between root carbohydrate levels and early VAM infection in young onion seedlings (Wang, Coleman, Freckman, *et al.* 1987).

Effect of light quality

Studies at the Institute of Botany, Academy Science Czech Republic, Prague, Czech Republic, on the influence of the VAM fungus *Glomus etunicatum* and changes in light quality (decreased red/far-red ratio) on the growth of three clones of *Festuca rubra* (originating from mountain grassland region), showed that inoculation with VAM and low red/far-red ratio decreased both the number of tillers and biomass of the treated plants. Significant interactions between the treatments were found and most growth parameters were reduced further when both treatments were applied simultaneously. Inoculation with VAM fungus reduced the maximum height of tillers, whereas low red/far-red ratio increased it. Response to one treatment was strongly modified by

the other treatment. Differences in plasticity were found for three *F. rubra* clones (Skalova and Vosatka 1998).

Effect of mycorrhiza on net carbon exchange rate

Studies were conducted at the Department of Entomology and the Institute of Ecology, University of Georgia, Athens, USA, on gas exchange and C allocation patterns in two populations of *Panicum coloratum*, an African C4 grass, grown in split-root pots, containing partially sterilized soil with one side either non-inoculated or inoculated with *Gigaspora margarita*. Mycorrhizal infection on one-half of the split-root system caused a 20% increase in the net C exchange rate. Effect on the net C exchange rate was less in tillers on the opposite side of the plants from the infected half of the roots. The rate at which photosynthates were stored in leaves was 45% higher and sink activity (concentration of labelled photosynthates in stem phloem tissue) more than 50% higher in inoculated plants compared to non-inoculated plants. The VAM fungi caused a greater storage of photosynthates in the low-grazing ecotype while the net C exchange rate and stomatal conductance, along with most of the C allocation patterns, were nearly identical in the low-grazing and high-grazing ecotypes in non-inoculated plants (Wang, Coleman, Freckman, *et al*. 1989).

Studies conducted at the Departmento de Fisiologia Vegetal, Universidad de Navarra, Pamplona, Spain, on mycorrhizal-nodulated and P-compensated nodulated *Medicago sativa* plants under well-watered and drought conditions showed that under watered conditions, the CER (CO_2 exchange rate) and PPUE (photosynthetic P use efficiency) were approximately 30% and 55% higher, respectively, in the VAM than in non-VAM plants while the specific nodule activity was similar in both the groups. Throughout the drought, the CER, PPUE, and nodule activity maintained significantly higher values in mycorrhizal plants. The internal CO_2 concentration was always higher in P-compensated plants than in VAM plants. Leaf area ratio significantly decreased in the P-compensated plants in response to drought treatment whereas mycorrhizal plants maintained fairly constant values (Sanchez-Diaz, Pardo, Antolin, *et al.* 1990).

Studies conducted at the Department del Microbiologia del Suelo Y Sistemas Simbioticos, Granada, Spain, on lettuce (*Lactuca sativa*) grown in pot cultures under controlled environment chambers, and exposed to 3, 4, or 5 g of NaCl per kg of dry soil and inoculated with one of the three VAM fungi showed that transpiration, CER, stomatal conductance, and WUE (water-use efficiency) were higher in mycorrhizal plants than in non-inoculated controls. At 5 g NaCl, both photosynthesis and the WUE in the inoculated plants were 100% greater than those in the non-inoculated plants. The content of P in P-fertilized, non-AM plants was similar to or higher than that in *G. mosseae*- and *G. fasciculatum*-colonized plants. Plants colonized by *G. deserticola* had the highest P content regardless of the salt level. Thus, the effect of *G. mosseae* and *G. fasciculatum* on salt tolerance could not be attributed to a difference in the P content. The mechanisms by which these two fungi alleviated salt stress appeared to be based on such physiological processes as increased CER, transpiration, stomatal conductance, and WUE rather than on nutrient uptake (N or P) (Ruiz-Lozano, Azcon, and Gomez 1996).

Studies at the University of Sheffield's Robert Hill Institute, Sheffield, UK, on *T. repens* inoculated with VAM and with foliar N and P contents of non-mycorrhizal plants manipulated to be no lower than those of mycorrhizal plants showed that the youngest fully expanded leaf of mycorrhizal plants had a higher CER than that in non-mycorrhizal plants. Also, specific leaf area was higher in mycorrhizal plants, a response that maximized the area available for the CO_2 assimilation per unit of the C invested. There was no evidence that the additional C gained was converted to biomass production in the mycorrhizal plants. It was the fungus, by acting as a sink for assimilates, that stimulated the rate of photosynthesis of its plant partner as the additional C gained by colonized plants was allocated to the mycorrhizal fungus (Wright, Scholes, and Read 1998).

Effect of mycorrhiza on photosynthesis

Effect of mycorrhiza in P-fertilized or stressed plants

In studies at the Department of Land, Air and Water Resources, University of California, USA, *Phaseolus vulgaris* was grown in solid-phase-buffered sand culture at 0.4 (severely deficient), 1.0 (limiting), and 27.0 (non-limiting) microM phosphorus, with or without foliar application of 15 g ammonium polyphosphate/litre; 19, 21, and 23 days after sowing; and with or without sand inoculation with *G. macrocarpum*. Photosynthesis in mycorrhizal plants was inversely correlated with the P stress. Mycorrhizal and foliar P effects were the most pronounced at low root P availability. In non-mycorrhizal plants, severe P stress decreased photosynthesis, but intermediate P stress did not (Lynch, Lauchli, and Epstein 1991).

Studies at the University College, Dublin, Ireland, on barley (*Hordeum vulgare*) grown in sand culture with five levels of calcium phosphate (50, 100, 200, 400, and 800 mg of P per kg of soil) and inoculated with *G. mosseae* showed that mycorrhizal infection declined from 3.3% at 50 mg P to 1.5% at the highest P concentration. There was no difference in dry mass at 50 mg in mycorrhizal and non-mycorrhizal plants but at this lowest rate of P supply, mycorrhizal plants had higher rates of photosynthesis and greater P- and N-use efficiencies.

Mycorrhizal enhancement of maximum photosynthetic rate at the lowest P level was associated with a higher stomatal conductance, but was not related to increased leaf P (Fay, Mitchell, and Osborne 1996).

Studies conducted at the Instituto Politecnico Nacional, Centre Invest and Estudios, Avanzados, Unidad Irapuato, Mexico, on three materials of maize with different genetic improvement, germinated from seeds on a sterilized mixture of sand and sandy loam soil supplied with Long Ashton nutrient solution to supply P at 22 µg per ml and inoculated with *G. fasciculatum* showed that mycorrhiza enhanced the net photosynthesis in all the three maize materials with higher values in non-breeded plants. Stomatal conductance increased in inoculated non-improved plants (Gomez, Moreles, Hernandez, *et al.* 1998).

Studies at the Department of Plant and Soil Biology, University of California, Berkeley, USA, showed that photosynthetic rates were not affected by *G. fasciculatum* infection under P treatment of 40 or 200 micro g of KH_2PO_4 per g of soil (Fredeen and Terry 1988).

Effect of mycorrhiza in water-stressed plants

Studies at the University of California, Riverside, USA, on cowpea (*Vigna unguiculata*) showed that mycorrhizal plants recovering from water stress had greater values of net photosynthesis and leaf conductance under low to moderate soil P levels than those under high soil P levels (Faria 1985).

Studies were conducted at the Faculty of Agriculture, Somali National University, Mogadishu, Somalia, on photosynthetic rates of seven-day-old seedlings of sorghum cv. NK-367 grown in greenhouse pot trials, inoculated with *G. intraradices,* and irrigated to field capacity for seven days after inoculation followed by three irrigation regimes, namely dry (irrigating when soil water potential was –0.56 to –1.4 MPa), moderately dry (–0.15 to 0.08 MPa), and wet (–0.03 to 0.06 MPa). Plant dry weight was greater in inoculated plants under all irrigation regimes. Photosynthetic rate and stomatal conductance were significantly greater in VAM-colonized plants compared to those in non-inoculated plants under dry or moderately dry conditions (Ibrahim, Campbell, Rupp, *et al.* 1990).

In studies at the Department of Microbiology and Environmental Sciences, G B Pant University, Pant Nagar, India, five-week-old VAM and non-VAM maize plants were exposed to osmotic potentials of 0, –2, –5, and –10 bars with a leaf water potential of –3, –5, –8, and –12 bars after eight hours of exposure. The net photosynthesis ($^{14}CO_2$ dpm [disintegrations per minute]/cm^2) increased significantly in both groups at 0, –2, and –5 osmotic potentials. At very low osmotic potential (–10 bar), there was a significant increase in $^{14}CO_2$ assimilation by the VAM plants (10.36%). On lowering the water potentials, the rate of decrease in the assimilation of CO_2 in the VAM plants was very little as compared to that in the non-VAM plants. No change was observed in the leaf water potentials in the two groups of plants to indicate a mycorrhizal influence on stomatal regulation (Ramakrishnan, Johri, and Gupta 1990).

Studies at the CSIC (Consejo Superior de Investigaciones Cientificas), Department of Microbiology, Suelo, Estacion experimental Zaiden, Granada, Spain, on lettuce (*L. sativa*), inoculated with *G. mosseae*, grown at 80% water-holding capacity, and supplied with N as NO_3, NH_4, or NO_3 + NHO (3 : 1, 1 : 1, or 1 : 3 ratio) showed that mycorrhizal plants increased the photosynthetic activity and proline accumulation. These mechanisms may be important in adaptation by the plant to drought conditions (Azcon, Gomez, and Tobar 1996).

Further studies at the above station on lettuce grown in two-compartment containers (one accessible to fungal hyphae) and inoculated with *Glomus deserticola* or *G. fasciculatum* (supplemented with P) showed that *G. fasciculatum* caused a significant increase in the net photosynthesis and the rate of water-use efficiency compared with that caused by *G. deserticola* and in P-supplemented plants. In contrast, *G. deserticola* treatment was the most efficient, affecting N, P, and K nutrition; leaf conductance; and transpiration (Ruiz-lozano and Azcon 1995).

Studies conducted at the Navarra University, Pamplona, Spain, on *Medicago sativa* grown in P-deficient soil, inoculated with *Rhizobium meliloti* and/or *G. mosseae* and subjected to water stress (down to –0.7 MPa of soil water potential) after 40 days showed that *G. mosseae,* caused changes in stomatal conductance, photosynthesis, P uptake, and root : shoot dry weight ratio. *G. mosseae* also increased the nitrogenase activity and N-fixation where leaf water potential was –0.5 MPa (Pena 1985).

In experiments conducted at the Western Regional Research Centre, United States Department of Agriculture, Albany, USA, on soybean (*Glycene max*), plants were grown in a greenhouse or growth chambers and inoculated with *G. mossea*e and/or *Bradyrhizobium japonicum* with control plants provided with nutrient solution containing P and/or N in amounts needed for growth rates similar to symbiotic plants. Rates of photosynthesis were higher in VAM-inoculated plants than those in non-VAM plants though concentrations of P and N in leaves of most symbiotic plants were within the ranges considered deficient. In plants supplied with N, leaves of VAM-inoculated plants contained more starch than those of non-VAM plants. When the VAM plants were compared to plants supplied with different levels of P (high P, low P), the P concentration in leaves was similar in the VAM and low-P plants but as the VAM plants had larger

leaves, the total amount of P was similar in VAM and high-P plants. Specific rates of CO_2 uptake were similar in all plants but because of greater leaf area, the VAM plants had a greater total photosynthesis and consequently greater total biomass (Brown and Bethlenfalvay 1990).

Effect of mycorrhiza on respiration in plants

In studies at the School of Biological Sciences, the University of Sydney, New South Wales, Australia, elevated levels of gas exchange were found in mycorrhizal plants removed from their pots than in non-mycorrhizal control plants. Six-week-old seedlings of *Solanum nigrum* removed from the soil and therefore detached from the hyphae respired at a one-and-a-half times faster that than non-mycorrhizal plants. At the same harvest, mycorrhizal *Allium porrum* had a level of gas exchange four times that of controls. Five-month-old mycorrhizal seedlings of *Ceratopetalum apetalum* respired three times faster than the control plants. Differences were found in the relative exchange of O_2 and CO_2. This led to quite different respiration quotients ranging from 0.8 for *C. apetalum* to 1.1 for *A. porrum* (Michael and McGee 1992).

Studies were conducted at the National Grassland Research Institute in Nishinasuno, Tochigi, Japan, on the evolution of (CO_2)-C14 from onion roots and intraradical hyphae of *G. margarita* examined by radiorespirometry after addition of C-14-labelled glucose or sucrose to mycorrhizal and non-mycorrhizal roots. In mycorrhizae, the respiration rate from glucose was about twice that from sucrose. The respiration rate from glucose in the mycorrhizae was much higher than that in the non-mycorrhizal roots, but no differences between mycorrhizal and non-mycorrhizal roots were found in the respiration from sucrose. The C-14-labelled glucose, fructose, and sucrose were added to the intraradical hyphae isolated from the mycorrhiza by enzyme digestion and homogenization, and subsequent evolution of (CO_2) C-14 was measured. The hyphae mainly used glucose as a substrate for respiration. The respiration rate from glucose was much higher than that from sucrose and fructose, which were used only to a small extent (Solaiman and Saito 1997).

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This paper has been compiled from TERI records in Riza.

Research findings

Arbuscular mycorrhizal fungal occurrence in non-cultivated disturbed and non-fertile land of Bettiahraj, Bettiah, Bihar

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Introduction

Arbuscular mycorrhizal fungi, or AMF, help in the conversion of non-fertile soils into fertile and productive soils. Such fungi are commonly found in soils deficient in nutrients, and may compete with bacteria, actinomycetes, and other fungi. The AMF also help in transport and uptake of phosphorus, besides helping in plant growth and thereby in increasing biomass and yield. Infection by AMF of crop plants and forest trees leads to the spread of hyphae and formation of vesicles/arbuscules inside the root cortex of various host plants. In the present investigation, an attempt has been made to find the quantitative and qualitative AMF association in wild plant species growing in their natural habitat and their occurrence at different depths in soil from non-cultivated and non-fertile land of Bettiahraj, Bettiah, Bihar.

Materials and methods

A survey was conducted on the occurrence of AMF on plants growing in non-cultivated, disturbed, and non-fertile land of Bettiahraj in northern Bihar (West Champaran district). The non-cultivated land of Bettiahraj is rich in many wild plant species but dotted with a large number of pits and heaps. In order to survey the AMF infection and spore population, the roots and rhizospheric soil from wild plant species were collected randomly. For determination of the AMF spores present at different depths, soil samples were collected separately from four different depths (approximately 8, 15, 23, and 30 cm) from each spot. Soil samples (200 g each) were taken randomly, covering an area of about 15 hectares of the non-cultivated land, and collected in separate polythene bags for further study in laboratory.

Mycorrhizal spores in soil were assessed by the wet-sieving and decanting technique (Gerdemann and Nicolson 1963). Roots were stained with trypan blue and assessed for vesicles, arbuscules, mycelium, and per cent root colonization (Giovannetti and Mosse 1980; Phillips and Hayman 1970). Spores were identified using the manual of Schenck and Perez (1990).

Results and discussion

A variety of spores were recovered from soils and root washings, mainly belonging to the genus *Glomus*. However, azygospores of *Acaulospora* or *Gigaspora* and sporocarps of *Sclerocystis* were also recovered, though these were rare.

The number of AMF spores at different depths of soils is presented in Table 1. The largest number of spores was recovered at a depth of 15 cm, followed by 8 cm, 23 cm, and 30 cm, in that order.

Out of the 10 plant species screened for AMF infection, only 8 displayed it (Table 2). The infection was maximum in *Cyperus rotundus* (40%) and minimum in *Croton bonplandianum* (4%). The roots of *Rumex dentatus* and *Pteris vittata* showed a complete absence of root infection but spores were present. It was also observed that the total number of AMF spores in 10 g of rhizosphere soil collected from different wild plant species varied from 8 to 16. Five species of *Glomus* namely, *Glomus fasciculatum*, *G. aggregatum*, *G. mosseae*, *G. constrictum*, and *G intraradices*; two species of *Acaulospora* namely, *A. tuberculata* and *A. laevis*; and one unidentified spore each of *Giagaspora* and *Sclerocystis* were observed. *G. fasciculatum* seems to be the predominant species, followed by *G. aggregatum*, *G. intraradices*, *G. mosseae*, *G. constrictum*, *A. tuberculata*, *A. laevis*, *Gigaspora* sp., and *Sclerocystis* sp.

The mycorrhizal infection consisted of hyphae, vesicles, and arbuscules. The percentage infection varied with the plant species. As multiplication of an endomycorrhiza depends on its association with plant roots, the number of its spores in soils at different depths is likely to differ, as shown in the present study. The activity of mycorrhizal population, in terms of root infection and the number of spore, has been shown to be greatly affected by soil conditions (Mukerji, Sabharwal, Kochar, *et al.* 1984). In the present study, species of *Glomus* were widespread in the non-cultivated soils.

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Table 1 Population of AMF (arbuscular mycorrhiza fungi) spores at different depths in soil collected from various spots of non-cultivated land

	The number of AMF spores at different depths (mean ± SD) *in 10 grams soil*[a]				
Spot number	*8 cm*	*16 cm*	*23 cm*	*30 cm*	*AMF*
1	9 ± 0.82[a]	12 ± 0.47	10 ± 0.82	8 ± 1.25	Gf, Ga
2	10 ± 0.82	14 ± 0.82	10 ± 1.63	9 ± 0.47	Gf, Ga, Gi
3	10 ± 0.82	11 ± 1.25	9 ± 1.25	9 ± 1.25	Gf, Ga
4	9 ± 0.94	11 ± 0.94	9 ± 2.16	9 ± 1.25	Gf, Gc
5	10 ± 1.25	13 ± 1.25	10 ± 1.70	9 ± 1.25	Gf
6	10 ± 0.47	13 ± 1.25	9 ± 0.94	9 ± 0.47	Ga, Gf
7	9 ± 1.25	12 ± 1.63	8 ± 0.82	8 ± 2.05	Gf, Ga
8	9 ± 0.82	8 ± 0.82	8 ± 0.47	7 ± 0.82	Gf, Gi
9	9 ± 0.82	10 ± 1.25	8 ± 1.25	9 ± 1.25	Gf, GC, Sc
10	9 ± 0.47	9 ± 0.89	7 ± 1.25	9 ± 0.94	Gf, AL
11	10 ± 1.70	14 ± 2.62	9 ± 1.41	8 ± 1.25	Gf, AL
12	11 ± 0.94	12 ± 1.25	10 ± 1.70	6 ± 4.32	Ga, Gm
13	11 ± 2.94	12 ± 3.56	9 ± 0.82	8 ± 2.16	Gf
14	10 ± 3.56	12 ± 1.88	6 ± 2.36	4 ± 2.94	Gf, G
15	6 ± 0.47	7 ± 0.82	5 ± 0.82	3 ± 1.89	Gf, AL
16	9 ± 1.25	12 ± 2.87	8 ± 0.82	5 ± 0.82	G, Sc
17	7 ± 1.25	8 ± 1.25	3 ± 1.25	2 ± 1.70	Gf, Ga, Gi
18	4 ± 0.82	6 ± 0.82	4 ± 1.25	6 ± 1.25	Gf, Ga
19	11 ± 0.82	12 ± 0.47	9 ± 0.82	6 ± 1.25	Gf, Ga, Gm
20	9 ± 0.82	10 ± 2.05	6 ± 1.25	3 ± 1.25	Gf, GC
21	10 ± 0.82	13 ± 0.82	7 ± 0.82	4 ± 0.82	Gf, Ga
22	7 ± 1.25	9 ± 1.25	5 ± 0.82	5 ± 1.63	Gf, Gi
23	7 ± 1.25	8 ± 1.25	3 ± 1.25	2 ± 1.25	Gf, Ga
24	10 ± 1.25	11 ± 0.94	3 ± 1.25	3 ± 1.25	Gf, AL, At
25	11 ± 0.82	13 ± 0.82	7 ± 0.82	4 ± 0.82	Gf, AL, GC

[a] Mean of three replicates

Gf – *Glomus fasciculatum*; Ga – *Glomus aggregatum*; Gi – *Glomus Intraradices*; Gm – *Glomus mosseae*; Gc – *Glomus constrictum*; G – *Gigaspora spp.*; AL – *Acaulospora laevis*; At – *Acaulospora tuberculata*; Sc – *Sclerocystis spp*.

Table 2 AMF (arbuscular mycorrhiza fungi) infection in roots of different wild plant species growing in their natural habitat

	Hyphal type						
Plant species/family	*Broad*	*Thin*	*Arbuscles*	*Vesicles*	*Infection level* (%)	*AMF spores per 10 gm soil*	*AMF spp.*
Cynodon dactylon (Graminae)	0	+++	++	+++	36	12[a]	Gf, Ga
Cyperus rotundus (Cyperaceae)	0	+++	++	+++	40	13	Gf, Ga, Gc
Croton bonplandianum (Euphorbiaceae)	0	+++	+	+	4	8	Gf, At
Rumex dentatus (Polygonaceae)	0	0	0	0	0	9	Gf, G
Cassia tora (Leguminosae)	++	0	0	+	28	11	Gf, Gi, Gc
Scirpus articulatus (Cyperaceae)	0	+++	+	++	12	12	Gf, Ga, AL
Lycorpersicum esculentum (Solanaceae)	++	0	+	+++	9	14	Gf, G, Sc
Pteris vittata (Fern)	0	0	0	0	0	10	Gf, Gi
Solanum sp. (Solanaceae)	0	++	++	+++	30	12	Gf, Ga, Gm
Leonurus sibiraus (Labiatae)	0	++	+	++	25	10	Gf, Ga, Gm

+ = Poor; ++ = Moderate; +++ = Abundant; 0 = Absent

[a] **Mean of three replicates**

Gf – *Glomus fasciculatum*; Ga – *Glomus aggregatum;* Gi – *Glomus intraradices*; Gm – *Glomus mosseae*; Gc – *Glomus constrictum;* G – *Gigaspora.* spp.; At – *Acaulospora tuberculata*; AL – *Acaulospora laevis*; Sc – *Sclerocystas* spp.

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Effect of different microorganisms and inorganic fertilizers on seedling growth of *Albizia procera*

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Introduction

Albizia procera (Roxb.) Benth. is one of the multipurpose leguminous tree species widely used for plantations specially in agroforestry systems. In the tropical region, particularly in the states of Chhattisgarh, Madhya Pradesh, Maharashtra, and Orissa, it is one of the species of choice by farmers to increase the productivity of their land. It is mostly planted on field bunds and on vacant land. By virtue of its fast growth, this species is well-known for yielding good timber, fuel, and fodder. A huge quantity of seedlings is required by farmers, panchayat, and the forest department for undertaking the plantation of this valuable species.

There are two important functional groups of microorganisms – AM (arbuscular mycorrhizal) fungi and bacteria – associated with plant roots, which play a significant role in the growth and development of this species. The AM fungi, *Rhizobium*, and *Azotobacter* are amongst the major functional microbes that occupy a niche in maintaining the nutrient economy of this fast-growing species. The AM fungi provide P while *Rhizobium* and *Azotobacter* are responsible for providing N to the plants (Mosse 1973; Gordon, Wheeler, and Perry 1979). Most of the fast-growing species require large quantities of N and P elements as well as sufficient water for growth and development. It is only the biotropic mycorrhizal fungi that break down the complex salts of P into simpler utilizable forms (Abbott and Robson 1977). In the present study, the role of the AM fungi, *Rhizobium,* and *Azotobacter* has been studied for quality seedling production.

Material and methods

The experiment was conducted in polythene bags measuring 25 × 9.5 cm. The bags were filled with previously sterilized potting mixture of sand, soil, and farmyard manure in equal proportion. The experiment was conducted in the nursery of TERI (The Energy and Resources Institute) in Jabalpur.

Seeds for the experiment were collected from a single elite (phenotypically superior) tree of *A. procera* growing near Bilaspur, Chhattisgarh. Malformed and infected seeds were removed from the collected seeds. Before sowing, the seeds were soaked in ordinary sterilized water for 24 hours. Two seeds were sown in each polythene bag during July 1998. After germination, only one plant was maintained. The nursery experiment was set up with 25 plants in each treatment.

For inoculation, the cultures of AM fungi, *Rhizobium* and *Azotobacter* were isolated from the rhizosphere of the previously planted *A. procera* trees. The number of fungal spores was estimated by wet-sieving and decanting techniques of Gerdemann and Nicolson (1963). Viable VAM spores were extracted by sucrose centrifugation techniques (Daniel and

Skipper 1982). The root colonization of VAM was measured by the procedure recommended by Phillips and Hayman (1970). The AM fungi comprising *Glomus mosseae*, *G. intraradices* Schenck and Smith, *Acaulospora* sp., *Gigaspora* sp., and *Scutellospora* sp. were used as inocula. The isolated AM fungi were cultured and maintained on maize plants (*Zea mays*). The strains of *Rhizobium* were isolated from *A. procera* by adopting the standard procedure described by Vincent (1970). The cultures were routinely maintained on YMA (yeast mannitol agar). The cultures of *Azotobacter* were also isolated from the soil where *A. procera* trees were growing. Its culture was maintained on Ashby's mannitol agar. Liquid cultures of *Rhizobium* and *Azotobacter* having a bacterial population 10^6 were taken as the bacterial inoculant. The inocula of AM (25 g soil inoculum + roots), Rhizobium (10 ml), and Azotobacter (10 ml) were applied after germination of the seedlings, particularly at the time of removing the second seedling in each. Nitrogen and phosphorus were applied singly and in combination in three different doses, namely 180 mg, 360 mg, and 540 mg of N and 250 mg, 500 mg, and 750 mg of P for each bag. The fertilizers were given at the same time when biofertilizers were applied.

Data were recorded six months after the treatment. The growth parameters were collar diameter, height, root length, fresh and dry weight of shoots and roots, and nodule number. Each reading is an average of 25 plants in each treatment. The results were statistically analysed.

Results and discussion

The results of treatment with different organisms and fertilizer doses on the growth of *A. procera* are recorded in the accompanying table. All treatments showed a significantly higher value in shoot length, collar diameter, and number of nodules over control. All parameters except the root and shoot heights recorded the maximum values with *Rhizobium*.

Increased growth in tree species because of the application of AM along with other beneficial fertilizers has been reported by a number of workers. In the present study, nodulation was suppressed by application of high doses of nitrogen. However, lower doses of nitrogen and phosphorus significantly increased the collar diameter and weight of seedlings. The present study also confirmed that AM inoculation singly or in combination with bacterial fertilizers significantly improved the growth of *A. procera*.

Effect of AM (arbuscular mycorrhiza), Rhizobium, Azotobacter, and inorganic fertilizers on the growth of *Albizia procera*

Treatment	*Shoot height* (cm)	*Root length* (cm)	*Collar diameter* (cm)	*Number of nodules*	*Fresh shoot weight* (g)	*Fresh root weight* (g)	*Dry shoot weight* (g)	*Dry root weight* (g)
250 mg P	49.30	16.36	1.91	20	17.60	16.30	11.90	12.20
500 mg P	48.60	17.18	2.00	30	25.40	19.70	16.00	15.80
750 mg P	61.30	15.81	1.78	30	38.00	17.80	26.20	13.80
180 mg N	51.00	19.45	2.00	40	24.20	20.20	17.80	18.40
360 mg N	74.00	24.45	1.49	23	22.90	15.80	16.90	17.40
540 mg N	65.00	20.16	1.41	19	22.80	14.70	16.40	9.90
180 mg N + 250 mg P	70.30	21.39	2.00	29	37.30	16.60	26.10	14.90
360 mg N + 500 mg P	54.60	16.70	1.58	27	20.70	13.90	15.60	10.90
540 mg N + 750 mg P	52.00	14.10	1.49	19	20.90	13.10	14.50	10.50
Rhizobium	58.33	17.86	2.50	46	44.60	34.00	29.80	28.00
Azotobacter	43.33	18.31	2.00	18	27.90	21.70	19.00	17.50
All organisms	58.30	17.30	1.90	38	38.70	19.10	25.30	16.70
AM alone	53.60	15.25	1.80	26	31.00	20.20	18.30	13.10
Control	30.00	12.31	1.10	10	14.90	12.10	12.60	9.80
SEM ±	2.98	0.82	0.09	2.46	2.39	1.44	1.48	1.27
CD at 5 %	9.10	2.51	2.28	7.52	7.30	4.41	4.52	3.89

CD – critical difference; SEM – standard error of mean

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Status of arbuscular mycorrhiza in mango in six districts of Uttar Pradesh

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Mango, *Mangifera indica* L., is one of the most important fruit crops occupying nearly half of the total area under fruit in India. It accounts for nearly 65% of the total world production and earns foreign exchange worth more than 240 million rupees annually (Randhawa 1980; Pandey 1991). Unfortunately, mango orchards are poorly managed with regard to their nutrient requirements. Mycorrhizal association of plants is a rule rather than exception as more than 80% of the plants are mycorrhizal (Gerdemann 1968). Mycorrhiza helps in the absorption of nutrients (that are not easily available to plants) and water (Smith and Read 1997). Little information is available on the degree of mycorrhization of mango roots. A preliminary survey of nurseries and orchards was carried out in six districts of Uttar Pradesh to record the mycorrhizal status of some commonly grown varieties in the state.

Materials and methods

A survey of mango nurseries and orchards of different age groups (0–5, 5–10, and >10 years old) in six districts of Uttar Pradesh was carried out. Root and soil samples were collected randomly. From each district, 10–15 subsamples were drawn from different collection points and later composited to form a sample. Thoroughly mixed 1-kg soil samples were processed in the laboratory following the wet-sieving and decanting technique (Gerdemann and Nicolson 1963) to count the number of mycorrhiza spores. To assess the degree of mycorrhizal colonization, thoroughly washed roots were stained in trypan blue after treating with hot 10% KOH aqueous solution (Phillips and Hayman 1970). Stained roots were cut into 1-cm segments, randomly picked, and examined under a stereomicroscope for the mycorrhizal association. Colonization was determined by Nicolson's formula (1955), which is as follows.

$$\text{Root colonization (\%)} = \frac{\text{Number of root segments colonized}}{\text{Total number of root segments examined}} \times 100$$

Results and discussion

It is evident from the accompanying table that the mycorrhizal colonization of mango roots was greater in nurseries (22.5%–31.7%) than in orchards (11.6%–27.6%). Among the nurseries of different

Mycorrhizal colonization and sporulation around different varieties of mango in six districts of Uttar Pradesh

Age	*Barabanki/Dasheri*	*Bulandshahar/Chausa*	*Faizabad/Amrapali*	*Malihabad/Dasheri*	*Meerut/Ratual*	*Varanasi/Langra*
			District/variety			
			Colonization (%)			
Nursery						
Mean ± SD	22.5 ± 7.2	26.2 ± 7.0	31.7 ± 6.2	26.4 ± 7.7	28.4 ± 9.0	27.6 ± 8.6
Range	10–35	15–35	25–40	15–40	15–40	10–40
n (sample size)	10	6	3	10	5	10
0–5 years						
Mean ± SD	25.4 ± 6.7	26.0 ± 5.5	24.4 ± 5.9	22.7 ± 6.9	20.9 ± 7.0	24.6 ± 9.3
Range	15–35	15–33	16–35	10–35	10–30	10–40
n (sample size)	8	8	10	15	8	10
6–10 years						
Mean ± SD	18.4 ± 5.8	13.2 ± 4.2	15.3 ± 5.5	18.5 ± 8.5	15.0 ± 4.4	13.5 ± 6.7
Range	10–25	8–20	8–25	10–35	10–20	5–25
n (sample size)	5	5	8	10	6	8
Above 10 years						
Mean ± SD	13.2 ± 3.3	12.4 ± 5.7	11.6 ± 4.7	11.7 ± 6.0	12.4 ± 5.3	12.4 ± 5.7
Range	8–20	5–25	5–20	5–25	5–20	5–25
n (sample size)	10	12	10	15	10	15
			Number of spores / 100 g of soil			
Nursery						
Mean ± SD	318.5 ± 65.2	321.7 ± 64.4	301.7 ± 83.7	342.0 ± 101.2	356.0 ± 71.7	307.0 ± 117.7
Range	200–410	200–400	200–405	200–450	250–450	100–410
n (sample size)	10	6	3	10	5	10
0–5 years						
Mean ± SD	270.0 ± 43.7	314.4 ± 69.2	271.0 ± 79.2	261.3 ± 74.4	190.0 ± 89.2	313.0 ± 94.5
Range	220–350	120–430	160–415	145–410	80–350	180–450
n (sample size)	8	8	10	15	8	10
6–10 years						
Mean ± SD	205.0 ± 52.7	226.0 ± 41.8	195.6 ± 53.0	155.5 ± 73.2	106.8 ± 49.3	193.8 ± 77.4
Range	140–300	180–300	130–300	60–300	50–200	60–300
n (sample size)	5	–	8	10	6	8
Above 10 years						
Mean ± SD	64.0 ± 27.0	71.2 ± 37.0	84.0 ± 60.9	71.8 ± 42.4	90.0 ± 39.1	90.2 ± 46.5
Range	30–120	30–165	30–200	36–180	32–150	30–250
n (sample size)	10	12	10	15	10	15

mean + SD = average value of root colonization or spore density + standard deviation; n = number of samples

varieties, the highest mean colonization value (31.7%) was recorded on *Amrapali* in Faizabad and the lowest (22.5%) on *Dasheri* in Barabanki district. Among orchards of different varieties, the highest mean colonization value (26.0%) was recorded on *Chausa* in Bulandshahar and the lowest (11.6%) on Amrapali in Faizabad district. The age of the orchards had a marked influence on colonization: as the age increased, colonization decreased. The colonization of young (0–5 years) orchards varied from 20.9% to 26.0% whereas it was 11.6%–13.2% in old orchards (more than 10 years).

The number of spores was higher in nurseries (301.7–356.0/100 g of soil) than in orchards (64.0–314.4); the highest value (356.0) was recorded around *Rataul* variety in Meerut and the lowest (64.0) around *Dasheri* in Barabanki district. Among orchards of different varieties, the highest mean spore density (314.4/100 g soil) was recorded around *Chausa* in Bulandshahar and the lowest (64.0/100 g soil) around *Dasheri* in Barabanki district. The age of the orchards had a marked influence on the spore population: it decreased as the age increased. The spore population around young orchards was 190.0–314.4 and 64.0–90.9 in old orchards.

There does not appear to be any varietal specificity of the mycorrhiza in mango. However, the degree of mycorrhization and sporulation decreased with the age of the plant. This could be attributed to the soil disturbance during cultural operations performed in young orchards of up to 10 years. Although there were a few cultural operations in the old orchards, reduction in mycorrhizal colonization and spore population could be attributed to the compactness of soil, poor aeration, etc. at deeper soil profiles where feeder roots are distributed. Greater mycorrhization and higher number of spores in the nurseries, on the other hand, where cultural operations were minimum, could be attributed to the good quality of soils (rich in organic matter, properly aerated, porous, and moist, with good structure and a normal pH, etc.) in which nurseries are usually raised (Gerdemann 1968; Smith and Read 1997).

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New approaches

A novel method for culture-independent assay of fungal enzymatic activity

A novel method is described by Agerer R, Schloter M, and Hahn C (2000) for a culture-independent assay to test the enzymatic activity of different fungal strains using fresh fruit-body explants taken from metabolically active areas of fungi (*Nova Hedwigia* 71(3–4): 315–336, 2000). Hydrolases (chitinases, exoglucanases) activity was measured using methyl umbelliferyl-labelled substrate analogs; for oxidases (phenoloxidases, peroxidases) activity, natural substrates such as guaiac gum or pyrogallol/H_2O_2, were used. To exclude the potential enzymatic activity of bacteria attached to fruit bodies, antibiotics were used. The results suggest that most ectomycorrhizal fungi tested were able to form peroxidases. Some genera could also produce phenol oxidases: for example, almost all strains of *Lactarius*, *Russula*, and *Laccaria* could do so. Other genera did not exude phenol oxidases into the test medium. This was the case for almost all strains of Boletaceae. Other genera, for example *Cortinarius* and *Tricholoma*, did not show any genus-specific enzymatic activity pattern.

Three trap culture cycles produce higher spore count and species diversity in trap cultures

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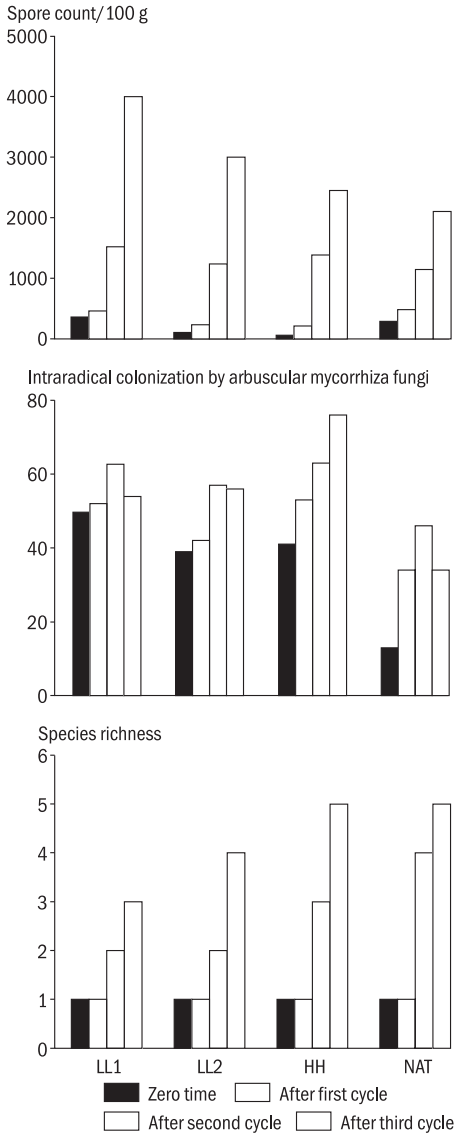
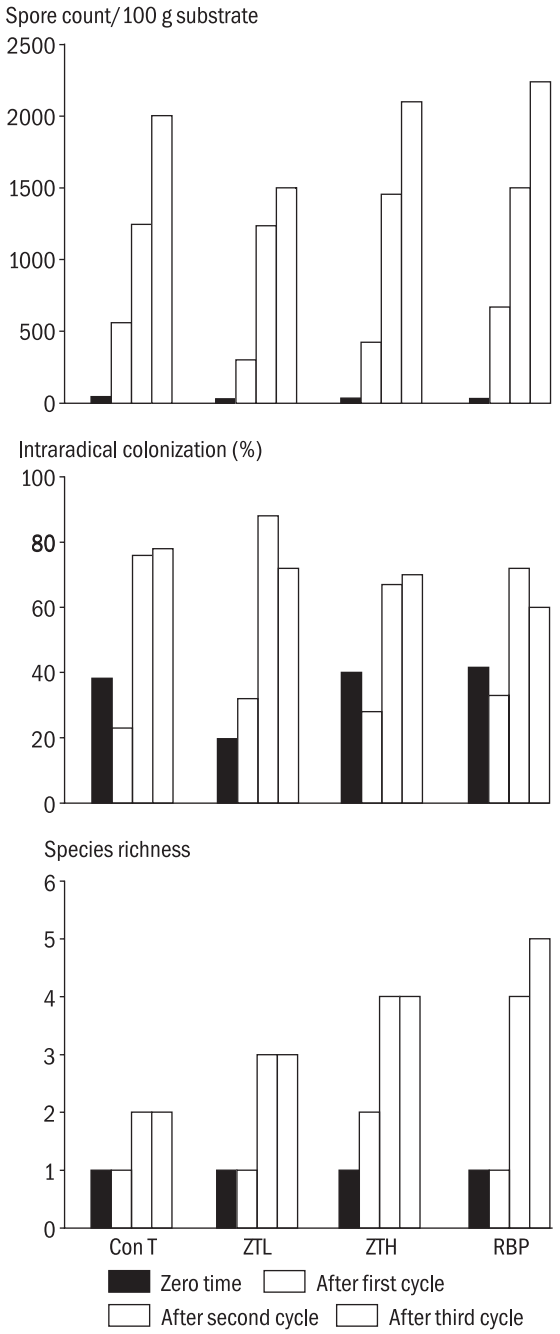
The introduction of pot culture technique of Mosse and Thompson (1984) has rendered the production of AM (arbuscular mycorrhizal) inoculum technically feasible. Generally, 'pot cultures' are raised by growing an inoculated host plant in a sandy soil supplemented with a nutrient solution with low levels of phosphorus. But there are many other potting mixes used for trap cultures, for example expanded clay, peat, perlite, vermiculite, soilrite, water-absorbing polymers, and a variety of other substrates. The cultures are monitored for sporulation by routine sampling. Spores produced in the pot culture are in a condition more conducive to identification than those collected from the field, which usually consist of complex mixtures of species, the composition of which changes over time.

Trap cultures from five locations (Budaun, Badshahpur, Ghaziabad, Gual Pahari, Pachmari, and Palwal) were established, as given by Singh and Adholeya (2001). From each location, five fields were selected, on which were grown the crops meant to serve as a trap crop. Trap cultures were monitored for three culture cycles for spore count (using the modified wet-sieving and decanting technique described by Gerdemann and Nicolson 1963), intraradical root colonization (Biermann and Linderman 1981), infectivity potential (Sharma, Gaur, Bhatia, *et al.* 1996), and species richness. The use of successive trap culture technique led to comparison of values of sporulation rate, per cent root colonization, and infectivity potential of the AM fungi found in most plant communities at the time of collection and after each culture cycle (three/four months each) in greenhouse using different hosts (Figures 1–5). Although isolation from spores has the advantage that these may belong to an identified fungus and result in a single species isolate, not all the AM fungi produce sufficient quantities of spores in field soils to allow isolation or identification—trap cultures can reveal species not observed to sporulate in soils (Miller, Domoto, and Walker 1985; An, Hendrix, Hershman, *et al.* 1990; Stutz and Morton 1996). In natural habitats, the AM fungi also have hyphal networks, old root fragments, etc.,



LL1 – low input, low yield; LL2 – low input, high yield; HH – high input, high yield; NAT – natural undisturbed habitat

Figure 1 Mycorrhizal parameters (spore count, per cent root colonization, and species richness) in the wheat fields of Budaun



ConT – conventionally tilled; ZTL – zero-tilled and manual harvesting; ZTH – zero-tilled and combiner harvesting; RBP – raised bed plantation

Figure 2 Mycorrhizal parameters (spore count, per cent root colonization, and species richness) in the wheat fields in Ghaziabad

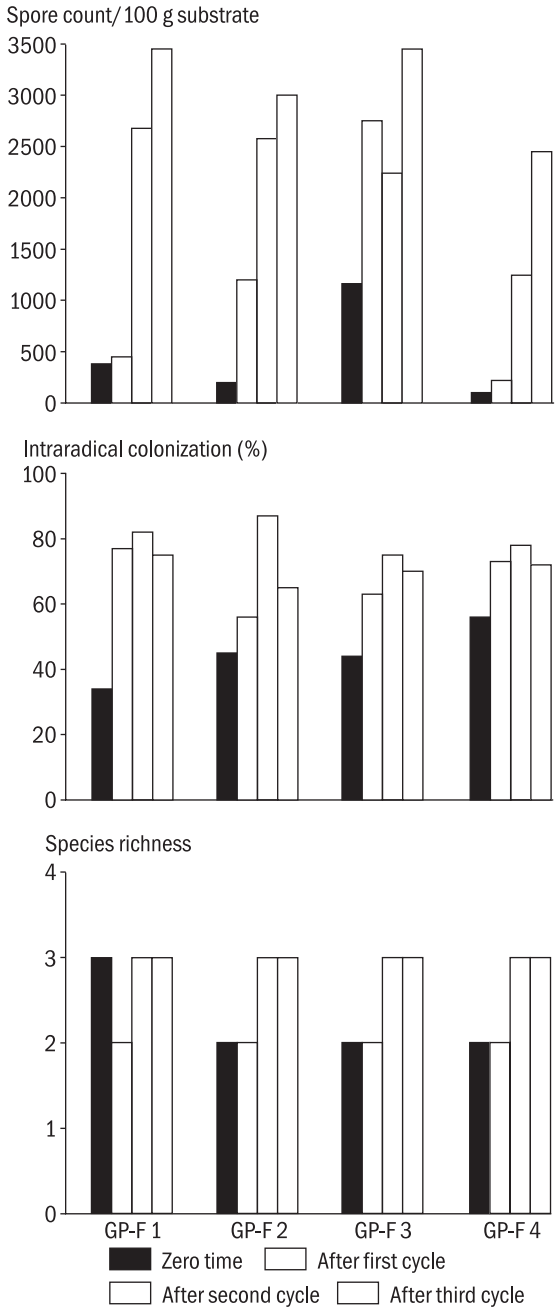


Figure 3 Mycorrhizal parameters (spore count, per cent root colonization, and species richness) in the wheat fields in GP (Gual Pahari) with four fertility levels (F1, F2, F3, and F4)

which function as propagules. Spores present in soils may fail to germinate if they are old or parasitized. Trap culturing methods often produce more healthy spores than the soils from which they were started, but usually result in a mixture of species, which changes with the subsequent culture generations (Morton, Bentivenga, and Wheeler 1993; Bever, Morton, Antonovics, *et al.* 1996).

In the present study, direct field sampling showed up to six species per sample. Comparable numbers of species were recovered from one cycle of trap culture. However, 75% of the species richness measured after two or three trap culture propagation cycles had not been detected in the first cycle (see the accompanying table). This is in agreement with the observation by Stutz and Morton (1996) that

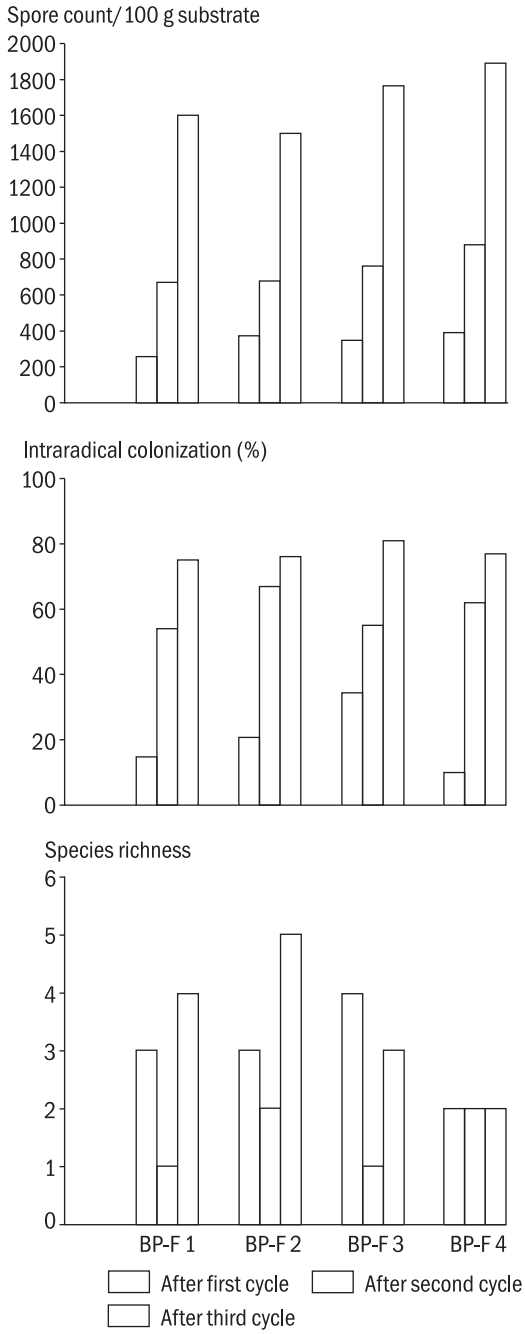


Figure 4 Mycorrhizal parameters (spore count, per cent root colonization, and species richness) in wheat fields in BP (Badshahpur) with four fertility levels (F1, F2, F3, and F4)

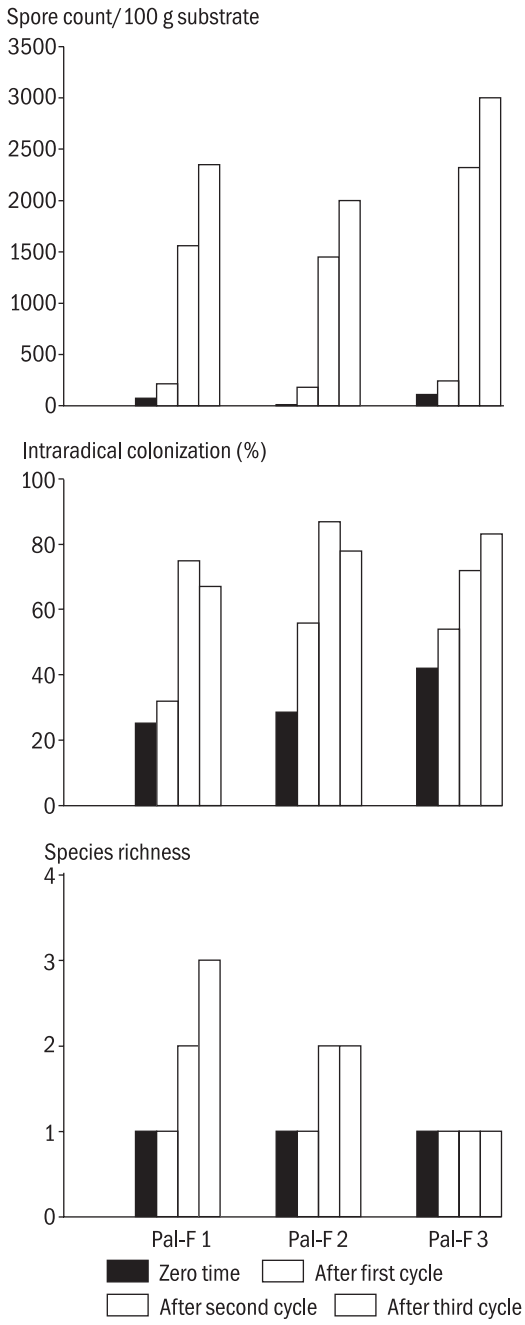


Figure 5 Mycorrhizal parameters (spore count, per cent root colonization, and species richness) in wheat fields in Pal (Palwal) with three fertility levels (F1, F2, and F3)

additional cycles of pot cultures are required for fungi colonizing the roots to begin to produce spores in detectable quantifies.

Sometimes, the number of species isolated from trap cultures exceeded those identified from field-collected spores, suggesting that fungal surveys based solely on spore observations are inaccurate. However, some cultures were unsuccessful either because of the failure of spores either to germinate or to colonize the roots, or both, under the growing conditions used. Stürmer and Bellei (1994) also observed that only 2 of the 12 species of the AM fungi from sand dune soils in Brazil were successfully cultured.

Table 1 Arbuscular mycorrhiza fungi species recorded in the fields from different regions

	Budaun				*Ghaziabad*				*Gual Pahari*				*Palwal*		
Species	LL1	LL2	HH	NAT	ConT	ZTL	ZTH	RBP	GP-F1	GP- F2	GP-F3	GP-F4	Pal-F1	Pal-F2	Pal-F3
Entrophospora infrequens								+							
Glomus albidum				+		+	+								
G. fulvum		+													
G. intraradices	+	+			+	+	+	+	+	+	+	+	+	+	+
G. microcarpum								+							
G. monosporum									+						
G. mosseae	+	+													
Scutellospora calospora	+	+	+		+	+	+	+	+	+	+	+			
Scutellospora coralloides													+	+	

LL1 – low input, low yield; LL2 – low input, high yield; HH – high input, high yield; NAT – natural undisturbed habitat; ConT – conventionally tilled; ZTL – zero-tilled and manual harvesting; ZTH – zero-tilled and combiner harvesting; RBP – raised bed plantation; GP – Gual Pahari; F – fertility level; Pal – Palwal

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Recent references

The latest additions to the network's database on mycorrhiza are published here for the members' information. The Mycorrhiza Network will be pleased to supply any of the available documents to bonafide researchers at a nominal charge. This list consists of papers from the following journals.

- *Analytical Biochemistry*
- *Annals of Forest Science*
- *Applied Soil Ecology*
- *Biologia Plantarum*
- *Canadian Journal of Botany-Revue Canadienne De Botanique*
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- *Ecological Entomology*
- *Environmental Microbiology*
- *European Food Research and Technology*
- *Forest Ecology and Management*
- *Global Change Biology*
- *Journal of Environmental Quality*
- *Mycologia*
- *Mycorrhiza*
- *Nova Hedwigia*
- *Physiologia Plantarum*
- *Plant and soil*
- *Science*
- *Soil Biology and Biochemistry*

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

Name of the author(s) and year of publication	Title of the article, name of the journal, volume no., issue no., page nos [address of the first author or of the corresponding author, marked with an asterick)
Abril AB*, Bucher E H.2004	**Nutritional sources of the fungus cultured by leaf-cutting ants** *Applied Soil Ecology* **26**(3): 243–247 [Centre Zool Aplicada, University of Nacl Cordoba, CC 122, RA-5000 Cordoba, Argentina]
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Forthcoming events

Conferences, congresses, seminars, symposia, and workshops

Gainesville, Florida, **USA**
10–14 April 2005

Second Joint Conference of the International Working Groups on Legume (IWGLV) and Vegetable Viruses (IWGVV)
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New Delhi, **India**
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International Conference on Microbial Diversity: current perspectives and potential applications
Prof. T Satyanarayana, Department of Microbiology, University of Delhi, South Campus, Benito Juarez Road, New Delhi – 110 021, India

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Tel. +91 11 2410 2008 • *Website* http//www.dur.ac.uk/~des0www4/unsaturated/conferences/http://www.iic.ac.in/md2005

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