Vol. 16 No. 2
July 2004

About TERI

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

The Bioresources and Biotechnology Division

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

The Mycorrhiza Network and the Centre for Mycorrhizal Culture Collection

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

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

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

Contents

Effect of soil pH on mycorrhiza in agricultural crops

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Most VAM (vesicular-arbuscular mycorrhiza) fungi adapt to a broad spectrum of edaphic conditions but a few of them or their physiological forms specifically adapt to extremes of soil pH or other edaphic factors. The effect of soil pH on the development and efficiency of VAM fungi in various agricultural crops is highlighted in this article. An account of the effect of pH on the efficiency of the mycorrhizal fungi in tree crops was published earlier in *Mycorrhiza News* (Singh 2000, 2001).

Effect of pH on efficiency of vesicular-arbuscular mycorrhiza in plants

In studies conducted at the Embrapa, CNPFT (Centro Nacional de Pes-quisa de F ruteiras Temperados), Caixa Postal 403, Pelotas RS, Brazil, maize (*Zea mays*) plants inoculated or not with *Glomus intraradices*-UTI43 were grown in sand culture in a greenhouse with or without MES (2 [N-morpholino]-ethane sulphonic acid) 2.0 mM with pH ranges of 4.0, 5.0, 6.0, and 7.0. Shoot and root dry matter yields were lower in plants grown with MES than in plants without MES and decreased as pH increased. Shoot concentrations of N (nitrogen), Ca (calcium), Mg (magnesium), Mn (manganese), and Zn (zinc) and nutrient contents were generally higher in the MES than in non-MES plants. Concentrations of N, Ca, Mg, and Mn increased and P (phosphorus), S (sulphur), and Fe (iron) decreased while contents of all measured nutrients except Mn and Zn decreased as pH increased. Concentrations of Mn, Fe, Zn, and Cu (copper) were higher in VAM than in non-VAM plants, while contents of P and Ca were higher in non-VAM than in VAM plants. Thus the MES had marked effects on mineral nutrient uptake and this factor should be considered when the MES is used to control pH of nutrient solutions for growth of maize (Medeiros, Clark, and Ellis 1993).

Studies conducted at the Department of Soil Science, Faculty of Agriculture, Padjadjaran University, Jatinangor, Indonesia on maize grown in plastic containers, using two acid soils (an oxisol and a ultisol) with pH adjusted to 4.7, 5.6, and 6.4 by liming (with different amounts of $CaCO_3$) showed that in both soils, liming increased shoot DW (dry weight), total root length, and mycorrhizal colonization of roots. Mycorrhizal inoculation significantly increased the root DW (in some cases), shoot DW, P concentration in shoot and root, and calculated P uptake per unit root length. Depletion of P in rhizosphere soil was dependent on soil pH in some cases, but at all pH levels the extent of P depletion in the rhizosphere soil was greater in mycorrhizal than in non-mycorrhizal plants. Mycorrhizal roots, however, used the same inorganic P sources as non-mycorrhizal roots. Thus, the results do not suggest that mycorrhizal roots have specific properties for P solubilization. Rather, the efficient P uptake from soil solution by roots determines the effectiveness of the use of different soil P sources (Nurlaeny, Marschner, and George 1996).

Studies conducted at the Department of Agronomy, University of Nebraska, Lincoln, USA on sorghum (*Sorghum bicolor*) plants grown in a greenhouse on acid Cecil sandy clay loam soil adjusted to five pH levels (4.1 to 5.8) and inoculated or not with *Glomus deserticola* showed that dry matter yield and mineral element uptake were markedly depressed at pH 4.1, were relatively high at pH 4.5, and remained fairly constant from pH 4.5 to 5.8 levels in mycorrhizal plants. Dry matter yields, root lengths, and mineral element contents of non-mycorrhizal plants (inoculated

* Compiled from TERI database—RIZA

with sterile VAM inocula) increased as soil pH increased, and these characteristics were similar to mycorrhizal plants only after the soil pH was 5.0–5.5. Mycorrhizal plants had higher total uptake of mineral elements and efficiency uptake of mineral elements (shoot element content / root dry matter ratio) than non-mycorrhizal plants. Available Al (aluminium) in acid soils may have been detrimental to VAM infection with sorghum roots and for VAM fungal activity at low soil pH (Raju, Clark, Ellis, *et al.* 1988).

Studies conducted at the Soil Microbiology Department, Rothamsted Experiment Station, Harpenden, Herts, the UK on clover and strawberry plants grown in a low-phosphate soil at pH 4.8 and pH 6.8 and inoculated with one to four species of *Glomus* showed that the inoculum containing four species was equally or more effective in promoting plant growth at both pH levels than inoculum with only a single species. Mixed inocula (multispecies) may therefore be used for field inoculation to ensure wider adaptation to different environmental conditions and greater consistency in benefits to the host plants (Koomen, Grace, and Hayman 1987).

In studies conducted at the Department of Soil Science and Plant Nutrition, Beijing Agricultural University, Beijing, China, *Trifolium repens* plants were grown for seven weeks in two sterilized soils (levisol and cambisol) in pots with five compartments. The central compartment was for the root growth, two adjacent compartments for growth of *Glomus mosseae,* and two outer compartments that neither roots nor hyphae could penetrate (bulk soil compartments). Phosphorus was supplied as $Ca(H_2PO_4)_2$ at the rate of 50-mg P/kg soil in the root compartment and 150-mg P/kg soil in the hyphal and bulk soil compartments. Nitrogen was supplied as $(NH_4)_2\ SO_4$ at the rate of 300-mg N/kg soil uniformly in all the compartments. In both soils, the soil pH decreased at the root–soil interface (rhizosphere) in the central compartment, and also at the hyphae–soil interface in the hyphal compartment. In both soils, shoot DW and P uptake were much higher in mycorrhizal plants compared to the non-mycorrhizal plants. Hyphae of the VAM fungus contributed 70% (combisol) or 80% (levisol) to total P uptake of mycorrhizal plants. In the hyphal compartment, concentration of water-extractable soil P in both soils and $NaHCO_3$-extractable soil P in levisol was drastically reduced. Soil P depletion profiles developed at the root–soil interface (rhizosphere) and hyphae–soil interface, and extended several millimetres from the hyphae surface into the soil. Thus, the hyphae of VAM fungi have the ability to form a zone of altered pH and a P-depletion zone in the adjacent soil (Li, George, and Marschner 1991).

Studies conducted at the Central Tuber Crops Research Institute, Sreekariyum, Thiruvananthapuram, India, on *Ipomea batatas* and *Manihot esculenta* showed that artificial inoculation with spores and root masses through the inert material (lignite) was effective. Spores in lignite slurry were viable for six months. The roots of both plants registered VAM infection of 80%–91% and 80%–85% within 15–29 days and 18–25 days of inoculation, respectively. Higher soil pH and P retarded the growth and establishment of VAM fungi in both the hosts (Potty 1988).

In studies conducted at the Station de Genetique et Amelioration des plantes, INRA, Dijon, France, micropropagated plants of two pineapple clones were inoculated with *Glomus* spp. or *G. intraradices* and grown in acid or alkaline soil with application of nutrient solution with or without P. The infection was greater with *Glomus* spp. than with *G. intraradices* and greater without the P application. Inoculation increased growth as measured by leaf number, fresh and DWs of aerial parts, or roots and leaf area. The effect was greater in plants grown in acid soil and in plants not given P. Inoculation with VAM fungi also resulted in larger and more efficient root system. Application of P increased the growth of plants that were not inoculated, reduced the effect of inoculation in acid soils, and prevented the effect of inoculation in alkaline soil (Guillemin, Gianinazzi, and Gianinazzi-Pearson 1991).

In studies conducted at the Research Station, Fruit Growing, Brugst 51, NL 4475, an Wilhel Minddors, the Netherlands, a declining plant species, *Arnica montana*, and two non-declining plant species from the same habitat, *Hieraceum pilosella* and *Deschampsia flexuosa*, were grown with or without *Glomus fasciculatum* in pots with an extremely nutrient-poor sandy soil to determine whether the decline of *A. montana* in Heathland vegetation could be caused by a detrimental effect of soil acidification on VAM fungi. The pots were percolated weekly with a nutrient solution with different pH values, of 5.5, 4.5, 3.5, and 2.5. At intervals of three weeks and up to 12 weeks, measurements were made on growth, nutrient uptake, and VAM infection. In most acid treatments, growth and nutrient uptake were reduced in all species but VAM infection decreased only slightly with decreasing pH of the treatments. Without VAM, *A. montana* died and *H. pilosella* hardly grew at most acid treatments. Leachate from most acid treatments had a pH of approximately 4.0 and contained considerable amount of Al dissolved from the solid phase of the soil. This might have played a role in the detrimental effects on plants in the case of most acid treatments. However, no evidence was found in this experiment that the decline of *A. montana* was due to detrimental effects of soil acidification on VAM of this species (Heijne, Dam, Heil, *et al.* 1996).

Effect of liming on efficiency of vesicular-arbuscular mycorrhiza in plants

In studies conducted at the Institute Für Bodenkunde, Universitat Göttingen, Germany, advantages and disadvantages of compensation liming were reviewed; liming should be moderate. Mild lime and application of three tonne per hectare caused no nitrate loading of groundwater. The risk of heavy metal mobilization was not greater than that when liming was not carried out and soil acidification continued to increase. Phosphate should be added to lime to immobilize individual heavy metals. Lime does not appear to have adverse effects on mycorrhizae and ground vegetation. Therefore, advantages of liming outweigh the disadvantages while the selection of appropriate fertilizers prevents damages to individual species when limed (Wenzel and Ulrich 1988).

In studies conducted at the Departmento de Ciencia do Solo, Escola Superior de Agricultura de Lavras, Lavras, Brazil, Brachiaria grass (*Brachiaria decumbens*) was grown in pots supplied with 0–6 g lime/kg soil, with or without soil inoculation with one of five fungal cultures isolated from the soils of different acidity and containing *Glomus* spp., *G. etunicatum*, *Gigaspora margarita,* and *Acaulospora morrowae*. Plant growth increased with up to 3.0 g lime/kg soil and decreased at higher rates. Mycorrhizal plants grew better than non-mycorrhizal plants in unlimed soil and with 4.5–6.0 g lime/kg soil. The ameliorative effects of VAM on growth in highly acidic or over-limed soils were related to nutrient uptake. The VAM fungi isolated from acid soil showed high symbiotic effectiveness and were better adapted to unlimed soil than those from non-acidic soils. The VAM root colonization, 90 days after planting, was little affected by liming (Siqueira, Rocham, Oliveira, *et al.* 1990).

Studies conducted at the AFRC Institute of Arable Crops Research, Rothamsted Experimental Station, Harpenden, Herts, the UK on main crop, potatoes (*Solanum tuberosum* L.), and spring oats (*Avena sativa*) successively grown over a period of three years on the long-term liming experiments at two sites, Rothamsted and Woburn, showed that a percentage of VAM colonization was little affected by soil pH from over an approximate range of 4–5 to 7–5. There was little effect of pH on crop yields. Up to nine species of coarse endophytes could be identified from spores (50 mm in diameter) in plots of pH 5.8 and above. There were markedly fewer spores at pH 5.5 and none in the most acid plots (Wang, Stribley, Tinker, *et al.* 1993).

A greenhouse experiment conducted at the International Livestock Centre for Africa, Addis Ababa, Ethiopia on an acid soil showed that tef (*Eragrostis tef*) plants failed to grow unless the soil was limed or inoculated with either of the two VAM fungi, *G. mosseae* or *G. macrocarpum*. Plant growth was increased by liming and to a lesser extent by VAM fungal inoculation. Lime also enhanced root colonization by VAM fungi. Shoot micronutrient content was generally increased as a result of inoculation and decreased by increased lime application (Mamo and Killham 1987).

An experiment was conducted for three years at the Ministry of Agriculture Pecheries Alimentat, Quebec, Serv Phytotech, St Hyacinthe, Canada to test the effect of lime application, P fertilization, and different tillage implements on the population of mycorrhizal fungi in soil of a poor and acid old prairie on which barley cropping was established. Although the treatments induced changes in soil pH and fertility, none of the treatments had a significant effect on the frequency of species or on the diversity of population. However, the fungal population changed and fungal diversity increased with time. In the initial stage, 13 VAM species from 3 genera were recorded but with time *Glomus caledonium* and *G. margarita* disappeared, while *G. geosporum*, a *G. clarum*-like and a *Scutellospora aurigloba*-like VAM fungi appeared after land was returned for cultivation (Hamel, Dalpe, Lapierre, *et al.* 1994).

Comparative efficiency of vesicular-arbuscular mycorrhiza at different pH levels

Studies conducted at the Department of Agronomy and Soils, Clemson University, Clemson, USA on corn (*Z. mays* Pioneer 3369 A), inoculated or not with five VAM fungi at two pH levels (5.7 and 6.1) on loamy sand soil showed that at pH 6.1 with six-month-old inoculum, shoot fresh weights significantly increased with *Gigaspora gigantea* and *G. mosseae* but not by *G. macrocarpus* var. *macrocarpus*, *G. macrocarpus* var. *geosporus*, or *G. margarita*. With one-month-old inoculum at 6.1 pH, only *G. mosseae* showed significant fresh-weight increase compared to the sterile control. At 5.7 pH, with a six-month-old inoculum, shoot fresh weights were significantly increased with *G. gigantea*, *G. mosseae*, *G. macrocarpus* var. *geosporus,* and *G. macrocarpus* var. *macrocarpus* whereas with a one-month-old inoculum at pH 5.7, fresh weights were significantly increased by *G. gigantea* only. There was 70% root infection by all VAM fungi. With a longer storage, *G. gigantea*, *G. mosseae,* and *G. macrocarpus* var. *macrocarpus* were more effective in increasing fresh weights at pH 5.7, whereas *G. margarita* was relatively ineffective at both pH levels (Struble, Skipper, and Smith 1979).

Studies conducted at the Department of Agronomy, University of Nebraska, Lincoln, USA, on sorghum (*S. bicolor*) grown at pH 4.0, 5.0, 6.0, and 7.0 (±0.1) in hydroponic sand culture and inoculated with *Glomus etunicatum* (UT 316), *G. intraradices* (UT 143), *G. intraradices* (UTI-126), and *Glomus* spp. showed that as pH increased, root colonization increased with *G. intraradices* (UT 126) and *G. etunicatum*, remained unchanged with *G. intraradices* (UT 143), and was low at pH 4 and high at pH 5.0, 6.0, and 7.0 with *Glomus* spp. *G. etunicatum* and *G. intraradices* (UT 143) were more effective than

Glomus spp. and *G. intraradices* (UT 126) in promoting plant growth irrespective of the pH. Shoot-P concentrations were lower in plants colonized by *G. etunicatum* and *G. intraradices* (UT 143) than in other two VAM fungi or in non-mycorrhizal plants. Neither the VAM isolates nor pH had an effect on shoot Ca, Mg, Zn, Cu, and Mn concentrations while the VAM isolates affected not only P but also the S, K (potassium), and Fe concentrations. The pH × VAM interaction was significant for shoot K, Mg, and Cu concentrations (Medeiros, Clark, and Ellis 1994).

Studies conducted at the Soil Microbiology Department, Rothamsted Experiment Station, Harpenden, Herts, the UK on clover and strawberry plants grown in a low P soil at pH 4.8 and 6.8 and inoculated with one or four species of *Glomus* showed that in spore production following multiple inoculation, *Glomus* spp. 'E3' was the most competitive species at pH 4.8 and *G. mosseae* at pH 6.8 (Koomen, Grace, and Hayman 1987).

Studies conducted at the School of Agriculture (Soil Science), University of Western Australia, Nedlands, Australia on subterranean clover showed that *G. fasciculatum* and *Glomus* spp. (WUM 16) differed in their ability to infect roots when soil pH was changed by liming. In a glasshouse experiment, *G. fasciculatum* infected extensively at each of the four levels of pH (range 5.3–7.5). *Glomus* spp. WUM 16 only infected extensively at the highest pH level. Liming the soil depressed plant growth but this effect was almost entirely overcome by inoculation with *G. fasciculatum*. In another experiment, it was found that *Glomus* spp. WUM 16 failed to spread from the existing infection within roots of subterranean clover when the soil pH was 5.3 or lower. The lack of spread of infection was associated with an inability of the hyphae of this fungus to grow in soil used unless the soil was limed to give a pH of at least greater than 5.3 (Abbott and Robson 1985).

In studies conducted at the Departmento Solas, Geologia e Fertilizanthes, ESALQ/USP, Caiza Postal 9, Piracicaba, Brazil, the behaviours of *G. margarita*, *G. macrocarpum,* and *Acaulospora scrobiculata* were evaluated in an acid dystrophic soil amended with four lime levels to give pH values of 4.4–5.6, and with two P levels to give P concentrations of 14.4 ppm (parts per million) and 3.7 ppm in treatments with or without the addition of soluble P. Subsamples of different soil treatments were used for spore germination assays in the laboratory and *Stylosanthus guianensis* root colonization experiments in the greenhouse. The population of *A. scrobiculata* was more tolerant to acid dystrophic soil conditions than *G. margarita* and *G. macrocarpum* populations, and the latter was the most sensitive to soil acidity. Root colonization was more affected by soil acidity variations than spore germination. *A. scrobiculata* and *G. macrocarpum* exhibited similar root colonization patterns, with high initial colonization rates decreasing with time, while *G. margarita* showed initial low root colonization rates increasing with time (Lambias and Cardoso 1988).

In studies conducted at the Rothamsted Experiment Station, the nine VAM fungi were assessed for their infectivity and growth effects in alpine strawberry cv. baron solemacher seedlings in sterilized low P soils (4 mg/kg and 8 mg/kg $NaHCO_3$-soluble P) limed to different pH levels. At pH 4, *Glomus clarum* greatly stimulated plant growth but the other fungi except *G. margarita* and *G. fasciculatum* E3, had little or no effect. The efficient endophytes at pH 5 were E3 *Acaulospora laevis*, and *G. clarum*. The largest plants were those growing at pH 7 and inoculated with *Glomus epigaeum* but *A. laevis* and *G. clarum* were ineffective at this pH. The most effective endophytes at pH 6 and 7 were *G. epigaeum*, *G. mosseae*, E3, *G. caledonium,* and *G. heterogama*, although results varied slightly between soils. Most endophytes infected well at all pH levels, even where they did not enhance plant growth. Although plant growth is affected by pH, soil P, and inoculum, the data shows that different endophytes vary enormously in their symbiotic effectiveness at different soil pH levels (Hayman and Tavares 1985).

Studies conducted at the Department of Tree Biology, National Botanical Research Institute, Lucknow, Uttar Pradesh, India showed that out of three VAM fungi tested, local isolates of *G. fasciculatum* were found to be relatively more tolerant with the highest number of spores (89 spores/g of soil) and 40.5% root colonization at pH 10.5. It may, therefore, be concluded that because *G. fasciculatum* was originally isolated from high pH soil site (pH 9.2), it had a higher efficiency in high salt conditions. The isolate that was found successful in higher pH ranges may be a physiological type adapted to similar edaphology. Generally, VAM fungal spores isolated from soil of a particular pH germinated best at that pH. The VAM fungi are usually adapted to particular edaphic conditions, characterized in part by soil pH. It is, therefore, possible to afforest difficult, high pH soils by using VAM isolates obtained from high pH soils (Sidhu and Behl 1995).

Information collected at the Agricultural Research Service, United States Department of Agriculture, Appalachian Soil and Water Conservation Research Laboratory, Beaver, USA on the response of VAM fungi and mycorrhizal host plants showed that *Acaulospora* spp. were widely reported in acidic soils. Also, *Gigaspora* spp. appeared to be more common in acidic soils than *Glomus* spp. Spores of some AMF (arbuscular mychorriza fungi) are more tolerant to acidic conditions and high levels of Al than others; *Acaulospora* spp., *Gigaspora* spp., and *Glomus manihotis* are particularly tolerant. Root colonization is generally less in low than in high pH soils. Percentage root colonization is generally not related to dry matter production. Maximum enhancement of plant growth in acid soil varies with AMF isolates and soil pH, indicating adaptation of AM isolates to edaphic conditions. Acquisition of many mineral nutrients other than P and Zn is enhanced by VAM fungi in acid soil and the minerals with enhanced concentration are those, which are commonly deficient in acid soils (for example, Ca, Mg, and K). Some AMF isolates are effective in overcoming soil acidity factors, especially Al toxicity, which restrict plant growth at low pH (Clark 1997).

Effect of pH on vesicular-arbuscular mycorrhiza at different temperatures

Pot culture experiments were conducted at the Institut fur Pflanzenbau und Tierhygiene in Den Tropen und Subtropen, University of Göttingen, Göttingen, Germany, on wheat (*Triticum aestivum*) and *S. bicolor* to study the effect of VAM fungi, *G. macrocarpum*, and *G. manihotis* at four soil pH levels (pH 4.5, 5.5, 6.5, and 7.5), at four soil temperatures (20 °C, 25 °C, 30 °C, and 35 °C), and fertilization with different rock phosphates. Controls were kept with soluble phosphate, MCP (mono calcium phosphate), and with no phosphate fertilizer (0P). Increase in shoot DW up to 143% could be obtained through VAM colonization of *T. aestivum* using kodjari rock phosphate as a P source. *T. aestivum* and *S. bicolor* when fertilized with any of the rock phosphates, except Kola, and colonized by VAM fungi, produced yields comparable with yields of plants fertilized with the MCP at soil pH levels of 5.5–7.5 and at a soil temperature of 25 °C. As the soil pH increased from 5.5 to 7.5, DWs declined. Likewise the yields decreased with increasing soil temperature and at 35 °C, VAM showed no effect at all treatments (Fabig, Moawad, and Achtnich 1989).

In further studies conducted at the above Institute, Burly tobacco plants were grown in a greenhouse at pH levels of 5, 6, or 7 at soil temperatures of 20 °C, 25 °C, 30 °C, or 35 °C and fertilized with the MCP or HA (hydroxylapatite). The HA-fertilized plants inoculated with *G. mosseae*, non-inoculated, and MCP-fertilized plants responded similarly to changes in pH or temperature. The response of host plants to environmental factors dominated the reaction; the inoculation modified it slightly only. The temperature optimum tended to shift from 30 °C at pH 5 to 25 °C at higher pH (pH 7). The VAM inoculation increased P uptake and growth considerably even in plants supplied with MCP. Development of the VAM in roots was fair to strong in all treatments. The best development of mycelium was at 30 °C, that of arbuscles at 25–30 °C, and of vesicles also at 25–30 °C (Khanaqa 1987).

Effect of pH on vesicular-arbuscular mycorrhiza efficiency under different fertilization treatments

Phosphorus fertilization

Studies conducted at the Institute fur Pflanzenbau und Tierhygiene, University of Göttingen, Göttingen, Germany, on *S. bicolor*, grown in greenhouse in pots with two soils limed to various pH values and fertilized with hardly soluble $Ca_5(PO_4)_3OH$ showed that the growth of non-mycorrhizal *S. bicolor* with a strong root system and high feeding power for phosphate was decreased with an increasing soil pH because of low availability of $Ca_5(PO_4)_3OH$ at higher pH values. Mycorrhizal plants of *S. bicolor* grew slightly better than non-mycorrhizal plants and reacted similarly to soil pH (Karagiannidis, Khanaqa, and Moawad 1981).

In studies conducted at the National Fertilizer and Environmental Research Centre, Tennessee Valley Authority, Musclo Shoals, USA, soybean cv. Essex were grown in non-sterile, acid (pH 5.2), infertile silt loam in a greenhouse to determine the effects of 0–160 mg P/kg soil as KH_2PO_4 and 0 g lime/kg, 1.5 g lime/kg, or 3.0 g lime/kg soil after soil inoculation with *G. fasciculatum* and *G. etunicatum*. Extractable soil Al was affected by the interaction between applied lime, applied P, and VAM fungal inoculation. P efficiency (g seed/mg P/kg soil) was maximal at 20 mg P/kg soil in all lime and VAM-fungal treatments. The VAM-fungal inoculation increased plant survival and protected soybeans from leaf scorch, thereby substituting the effects of lime and P. *G. etunicatum* inoculum was superior in ameliorating leaf scorch in the non-limed soil. The *G. fasciculatum* inoculum required more lime and P than *G. etunicatum* inoculum to increase seed yield relative to non-inoculated controls containing only native VAM fungi. The ability of the VAM-fungal inocula to enhance the efficiency of applied P and to decrease seed Cl concentration was increased by lime. Seed yield was negatively related to seed Cl concentration. Both VAM-fungal inoculation and lime application reduced this negative relationship and may have increased tolerance to both Cl and soil Al (Maddox and Soileau 1991).

Studies conducted at the Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, Bangalore, Karnataka, India on soybean grown in pots on acid soil (pH 5.1), supplied with 0 or 2.64 g lime/kg soil and 0, 10 g rock P/kg, 20 g rock P/kg, or 40 g rock P/kg soil and inoculated with *G. mosseae* showed that liming had no significant effects on soybean DW but it decreased P uptake. Mycorrhizal inoculation increased both DW and P uptake. Shoot DW increased with increase in the rate of P application while root DW was highest with the lowest rate of P application. Shoot P uptake increased with up to

20-g P/kg soil whereas root P uptake increased up to 40 g P/kg soil (Eranna and Parama 1944).

In studies conducted at the Department of Agronomy, Georgia Experiment Station, Griffin, USA, plants of *Trifolium repens* and *Lespedeza cuneata* were grown in methyl-bromide-fumigated soil containing 0.5 mM P/kg, 1.0 mM P/kg, 2.5 mM P/kg, or 5.0 mM P/kg of soil and inoculated with *G.margarita* in soil of pH 5.1, and with *A. laevis* in soil of pH 5.8. The inoculum of both the VAM fungi was isolated from soil having a pH of 4.0. Both *T. repens* and *L. cuneata* plants did not respond to *G. margarita* isolate, in terms of the VAM infection of roots. Shoot-tissue concentration of P was greater at the two lowest rates of P application (0.5 m. mol P/kg and 1.0 m. mol P/kg) when inoculated with *A. laevis*. Inoculation with *A. laevis* also resulted in different fungal infection rates in both plant species. The infection was nearly 70% for the two lowest P application rates, declining to 40% and 6%, respectively, at the next two P application rates (Milson 1988).

Nitrogen fertilization

In studies conducted at the Department of Soil Science, University of Reading, Whitenights, Reading, the UK, Sorghum cv. SSU2 plants were grown in split pots in two different soils with different initial pH values and P contents to investigate the effects of NH_4^+ (ammonium) and NO_3^- (nitrate) application on rhizosphere pH, and plant P uptake. In both soils, the NH_4^+ treatment resulted in higher plant DW and P content than NO_3^- treatment at all P levels. Mycorrhizal inoculation enhanced the differences. Sorghum plants acidified the rhizosphere soil at low soil-P status with both N forms and with or without the VAM. When N was applied as NO_3^-, rhizosphere pH increased gradually with increasing addition of P. It appears that pH change is an independent factor affecting P uptake regardless of whether the plant root is infected by VAM or not (Ortas, Harris, and Rowell 1996).

Organic fertilizers

A long-term experiment conducted at the Food and Agriculture Department, the Queen's University of Belfast, Northern Island, the UK, on cut grass land (consisting among others of *Lolium perenne*, *Agrostis stolonifera,* and *Poa* spp.) with fertilized and unfertilized controls at three application rates (50 m^3/ha, 100 m^3/ha, 200 m^3/ha) of pig and cow slurries for 19 years showed that despite contrasting long-term effects of the two types of slurries on soil pH, increasing application rates of both types of slurries produced a marked decrease in the overall mycorrhizal infection of plant roots in the sward with the corresponding increase in infection by the fine endophyte, *Glomus tenue*. Calculated correlation coefficients showed that mycorrhizal infection was related to sward botanical composition, especially the proportion of *L. perenne*. Furthermore, step-wise multiple regression analysis identified soil chemical properties, especially total Zn and pH, as the more important explanatory variables in preference to the botanical composition (Christie and Kilpatrick 1992).

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Infectivity and efficacy of four native vesicular-arbuscular mycorrhiza fungi on sugar cane (cv. CO 419)

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Introduction

The sugar cane (*Saccharum officinarum* L.) crop in many parts of India is cultivated on different soils. Most of these soils, particularly black soils, have low to medium P (phosphorous) content (up to 30 kg/ha). The P applied through fertilizers is fixed to a considerable extent, due to the presence of carbonates (5%–10%) in soil. Research carried out in the past few decades has well established that VAM (vesicular-arbuscular mycorrhiza) fungi can improve plant growth mainly through increased uptake of P, especially in low-P soil (Bowen 1978). The positive growth response is usually slower in soils where applied P is fixed rapidly (Abbott, Robson, and Parker 1979). Although sugar cane is known to harbour VAM association naturally in its root systems (Chandrakant, Moore, and Hapase 1989), significant variations in its intensity in different soils were observed (Chandrakant, Zende, and More 1989) and in different varieties under the same filed soil conditions (Chandrakant, Moore, and Hapase 1989). An effective mycorrhizal association is required for every crop of P uptake in nearly all soils as various soil factors such as soil pH (Hayman and Tavares 1985), soil moisture (Roger, Bert, and Anthony 1986), salinity (Poss and Jarrell 1985), and soil amendments – such as addition of fertilizers (Hayman 1975) and pesticides (Menge 1982) – are known to affect the performance of VAM fungus. Therefore, it requires selection of an appropriate fungus (Menge 1983). The two criteria used are infectivity and efficacy (Hass and Krikun 1985; Krikun, Haas, and Bar-Yosef 1987), besides the root colonization ability of the fungus to survive in soil.

The plant's growth response is usually dependent on the quantity of VAM formed early in the crop's growth season. Since different VAM fungi differ in their ability to form efficient VAM with different crop plants (Reddy and Singh 1990), four native VAM fungal species were tested in the present study for their efficiency on local sugar cane cultivar (cv. CO 419).

Material and methods

Isolation of vesicular-arbuscular mycorrhiza spores from soil

The isolation of VAM spores from the native soil was done by following the wet sieving and decanting method of Gerdemann and Nicolson (1963). Four different recognized spore types were purified and multiplied by raising single-spore cultures. The spores thus isolated were identified as *Glomus fasciculatum*, *Glomus mosseae*, *Gigaspora margarita*, and *Acaulospora laevis*.

Growth response of sugar cane to VAM inoculation (pot experiments)

A pot culture experiment was designed to study the growth response of sugar cane (cv. CO 419) to four different VAM fungal inoculants. The treatments included (control) uninoculated and inoculated with *G. fasciculatum*, *G. mosseae*, *G. margarita*, or *A. laevis* separately. All treatments were maintained in triplicates in steam-sterilized pots containing soil and sand in the ratio of 1:1. Two sugar cane seed sets each with a single bud were buried keeping the eye bud facing above in each of these pots.

The inoculum-containing VAM spores (45 ± 5 spores/g soil cum host root bits) was applied by the layering method (Jackson, Franklin, and Miller 1972) to ensure that all growing roots passed through it. After 40 days and 80 days of growth, the plants were uprooted. Their roots were washed carefully by dipping in water to remove soil particles adhering to the roots. The response of root and shoot growth was determined later by calculating their dry weight (Tables 1 and 2, and Plate 1).

Mycorrhizal efficiency

The MEI (mycorrhizal efficiency index) was calculated by taking the total dry weight of the plant and using the formula given below (Singh and Tilak 1990; Plenchette, Fortin, and Furlon 1983).

$$\text{MEI} = 100 \times 1 - \frac{\text{Non-mycorrhizal plant wt (weight)}}{\text{Mycorrhizal plant wt}}$$

Results and discussion

In the present investigation, growth response of sugar cane (cv. CO 419) 'seed sets' to four different VAM fungal (*G. fasciculatum*, *G. mosseae*, *G. margarita,* and *A. laevis*) inoculations were studied in pot culture experiments. Using a soil

Table 1 Growth response of sugar cane (cv. CO 419) to four VAM (vesicular-arbuscular mycorrhiza) fungi inoculation at the age level of 40 days

VAM fungi	*Dry weight** (g) *Shoot*	*Root*	*Total*	*Average height* (cm)	*Average leaf area* (cm)	*VAM association* (%)
Control (uninoculated)	0.78	0.15	0.93	20.98	8.54	0.00
Glomus fasciculatum	2.90	2.15	5.05	41.40	20.82	100.00
Glomus mosseae	2.80	2.30	5.10	31.66	12.77	100.00
Gigaspora margarita	3.20	2.10	5.30	31.03	11.18	100.00
Acaulospora laevis	3.87	2.60	6.47	38.10	19.97	92.50

* 'F' test significant at 1% level
SEm (standard error of mean) ± 0.1449
CD (critical difference) at 5% level = 0.4724

and sand mixture (in a ratio of 1:1), performance on both infectivity and efficiency were evaluated. Data on the response of sugar cane at two age levels (40 and 80 days) are presented in Tables 1 and 2, and Plate 1. It is clearly evident that sugar cane (cv. CO 419) exhibited a uniform response to all four VAM fungal inoculations, with a significant ('F' test significant at 1% level) enhanced growth rate (Tables 1 and 2).

The proliferation of root systems in VAM inoculated plants was also considerably high (Plate 1). However among the four VAM fungi tested, *G. margarita* and *A. laevis* were found to be more efficient and showed significantly improved plant biomass (root and shoot) at both age levels ('F' test significant at 1% level) (Tables 1 and 2). Subject to these two fungi inoculations, the plants' average height and average leaf area were also found to be generally higher (Tables 1 and 2) when compared with the others.

However, the intensity of association in the root systems was found to be almost 100% with all the inoculants at both age levels (Tables 1 and 2), showing characteristic endophytic structures

Table 2 Growth response of sugar cane (cv. CO 419) to four different VAM (vesicular-arbuscular mycorrhiza) fungi inoculation at the age level of 80 days

VAM fungi	*Dry weight** (g) *Shoot*	*Root*	*Total*	*Average height* (cm)	*Average leaf area* (cm)	*VAM association* (%)
Control (uninoculated)	1.60	1.00	2.60	47.37	28.58	0
Glomus fasciculatum	6.40	4.70	11.10	53.95	27.89	100
Glomus mosseae	5.00	5.40	10.40	59.39	31.03	100
Gigaspora margarita	8.50	6.80	15.30	68.62	32.20	100
Acaulospora laevis	6.70	6.10	12.80	68.30	33.49	100

*'F' test significant at 1% level
SEm (standard error of mean) ± 0.7514
CD (critical difference) at 5% level = 2.4195

G.f – *Glomus fasciculatum;* G.m – *Glomus mosseae;* Gi.m – *Gigaspora margarita;* A.l – *Acaulospora laevis*; C – control
Plate 1 Response of sugar cane (cv. CO 419) to four native vesicular-arbuscular mycorrhiza fungal inoculations at the age level of 80 days in a sterile soil–sand mixture

(vesicles and/or arbuscules) in its root system. The MEI of four VAM fungi (Table 3) in increasing the growth of sugar cane (cv. CO 419) ranged from 82% to 85% at the 40-day age level and 75% to 83% at the 80-day age level.

Differences in the performance of different species of VAM fungi, as in the present case (Table 2), have been reported in several host plants such as *Paspalum notatum*, *Allium cepa*, *Syzygium aromaticum*, *Glycine max*, and *Pennisetum typhoidium* (Mosse 1972, 1981; Powell 1975; Krishna and Dart 1984; Sanders 1975; Carling and Brown 1980; Hayman 1982; Krishna, Shetty, Dart, *et al.* 1985; Hass and Krikun 1985). Such variations in efficiency of VAM fungi could be attributed more to their ability in a specific soil plant system than to their apparent host specificity (Barea and Azcon-Aguilar 1983). The present study has also revealed that the two species of VAM fungi (*G. margarita* and *A. laevis*) – when inoculated by the layering method at the time of seed sets plantation – are more effective than *G. fasciculatum* and *G. mosseae* in enhancing the growth rate of sugar cane (Table 3 and Plate 1). Thus, screening experiments are always useful in selecting the most efficient VAM fungus for the crop to achieve maximum benefit. Others have also reported the superior performance of certain VAM fungal species on some crops in improving growth (Mosse 1975, 1977; Manjunath and Bagyaraj 1982), by showing a certain degree of host preference (Mosse 1975). This is largely decided based on the intensity of association and their influence on growth.

Table 3 The relative mycorrhizal efficiency of four different vesicular-arbuscular mycorrhiza fungal species on the growth of sugar cane (cv. CO 419) at two age levels

Vesicular-arbuscular mycorrhiza fungi	*Mycorrhizal efficiency* (%)	
	40 days	*80 days*
Glomus fasciculatum	82	76
Glomus mosseae	82	75
Gigaspora margarita	82	83
Acaulospora laevis	85	80

The growth-promoting ability of four different VAM fungi, in terms of mycorrhizal efficiency (Table 3), also showed that *G. margarita* and *A. laevis* were found to be relatively superior, and could be used for sugar cane inoculations.

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Mustard (*Brassica campestris* L.) cultivation reduces the vesicular-arbuscular mycorrhizal advantage of successive crops

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Introduction

The VAM (vesicular-arbuscular mycorrhizal) fungi are widely distributed and associated with more than 90% of land plants with the exception of a few families (Harley and Smith 1983). The special relationship established between plants and fungi implies a high degree of structural, physiological, and biochemical integration from which both the partners benefit (Azcon-Aguilar and Bago 1994). The VAM symbiosis is receiving attention because of its increasing range of application in practical fields like sustainable agriculture (Bethlenfalvay and Schuepp 1994). In general, agricultural practices, tendencies to use high-dose phosphate and other fertilizers decrease the colonization and effectivity of VAM (Menge, Steirle, Bagyaraj, *et al.* 1978; Braunberger, Miller, and Peterson 1991). In addition, growing non-mycorrhizal crops disturbs the ecology of the VAM in soil by blocking the carbon supply to the fungus and the biochemical changes in rhizosphere prevent germination of propagules, and decrease their viability (Stahl, Williams, and Christian 1988). As an obligate symbiont, the VAM fungi fail to survive without the host plant. Among non-mycorrhizal agricultural crops, most belong to Brassicaceae. The isothiocyanates produced by this family are potential inhibitors for colonization of VAM (Schreiner and Koide 1993).

In this experiment, a comparative study of the effects of growing a VAM host, potato (*Solanum tuberosum* L.), and a non-host, crop mustard (*Brassicca campestris* L.), on indigenous VAM fungal status in post-harvest condition and the yield of next host crop, wheat (*Triticum aestivum* L.), was made.

Material and methods

Two agricultural sample fields (A and B) in the same locality under same meteorological conditions having the same physical characteristics were chosen.

- In field A, mustard was grown for three years.
- In field B, potato was grown for five years.

The mustard field (A) was fertilized per acre with 55 kg urea (46% N_2), 39 kg DAP (di-ammonium phosphate) (with 18% N_2 + 46% P), 39 kg potash (60% K), and 1000 kg organic manure on an annual basis. The potato field (B) was fertilized per acre with 90 kg urea, 46 kg DAP, 60 kg potash, and 1500 kg organic manure on a yearly basis. The VAM spore density (100/g of soil) and chemical properties were tested (Jackson 1973).

After harvesting potato and mustard, 75 kg of soil was collected from each field at random up to a depth of 25 cm. The soil from each field was mixed well separately. Fifty polypots (25 × 10 cm) were filled with 1.5 kg of soil from fields A and B. Viable and certified seeds of wheat were surface sterilized with 0.5% sodium hypochlorite solution and germinated in sterilized condition. Four germinated seeds were transferred to each pot at 2–3 cm below-surface soil. At 20-cm gap, pots were arranged in the net house. The whole set was placed on a platform raised from ground level to prevent cross contamination by insects. Plants were watered as per requirement. Measurements were taken at 15th day, 30th day, 60th day, and 90th day for shoot height, biomass, and root colonization. In the final harvesting at the 90th day, length and weight of spikes, dry weight of plants and seed weight, and the VAM spore density were measured.

The root samples were collected, washed thoroughly in tap water, cut into one-cm long pieces, treated with 10% KOH solution, and stained with tryphan blue (Philips and Hayman 1970). The colonization percentage was measured with the following formula (Nicholson 1955).

$$\text{Root colonization \%} = \frac{\text{Total number of root pieces colonized}}{\text{Total number of root pieces observed}} \times 100$$

The spore population at the post harvested fields and after experiment were counted using the method of decantation by Gerdemann and Nicholson (1963). The crop dry weight was taken after oven drying at 80 °C for two consecutive days.

Results and discussion

After harvesting potato and mustard, the VAM fungal spore population varied considerably in the two fields, though the available P was same (Table 1). Mustard field had a spore density of 180 spores per 100 gm of soil and, 430 spores per 100 gm in the potato field (Table 2).

At the juvenile stage, the wheat plants showed no significant variation in shoot height and dry weight. After 60 days of the experiment, these two parameters were significantly high for field B treatment (Table 3). Colonization was greatly varied, but positively correlated with dry mass and shoot height in both cases.

At the final harvest on the 90th day, the dry weight and length of spikes of wheat was higher in field B treatment than in field A (Table 2). Wheat in earlier potato grown soil yielded 1.5 mg extra seed mass over mustard soil grown plants.

At the end of the experiment, spore population failed to multiply in mustard field soil, while in potato soil, high degree of multiplication occurred (Table 2). This result indicates that the isothiocyanate exudates of *Brassica* might have hindered the spore germination and colonization of the host plant wheat severely that did not exceed 40% at the 90th day (Schreiner and Koide 1993). Though the available phosphorus was high and same in these two treatments, in potato-field soil colonization increased up to 85% at the 60th day. The above experiment indicated the inhibitory effect of isothiocyanate on the VAM activity and that sustainability lasted longer in soil.

Table 1 Soil chemical properties of mustard and potato field

Soil properties	*Mustard field* (A)	*Potato field* (B)
Organic carbon (%)	0.53	0.57
Available phosphate (kg/ha)	250	250
Available potash (kg/ha)	188	133
pH	5.5	6.8
EC (Ds/m)	0.56	0.14

Table 2 Effect of two field soil on yield of wheat at final harvest and spore population in soil prior to and after the experiment

Field soil	*Dry weight of 10 spikes* (g)	*Length of 10 spikes* (cm)	*Weight of single seed* (g)	*Spore number per 100 g of soil*	
				before experiment	*after experiment*
Mustard soil (A)	4.95 ± 0.8	4.85 ± 0.8	29.3 ± 0.2	180 ± 2	192 ± 3
Potato soil (B)	6.48 ± 1.2	6.42 ± 1.2	30.8 ± 0.3	430 ± 4	710 ± 5

Table 3 Shoot height, dry weight, and vesicular-arbuscular mycorrhiza colonization of wheat plants grown in two soils

Days of measurement	*Shoot height* (cm)		*Dry weight of 10 plants* (g)		*Root colonization* (%)	
	Field A	*Field B*	*Field A*	*Field B*	*Field A*	*Field B*
15	18.17 ± 5.5	18.0 ± 5.1	1.96 ± 0.3	1.79 ± 0.11	0	4
30	20.23 ± 5.7	23.0 ± 5.5	6.85 ± 0.3	8.65 ± 0.34	4	28
60	31.7 ± 6.2	35.2 ± 6.7	8.5 ± 0.52	17.9 ± 0.78	30	85
90	35.32 ± 7.1	47.7 ± 5.4	10.75 ± 0.8	19.8 ± 1.2	40	85

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Cumulative effect of VAM fungi and vermicompost on nitrogen, phosphorus, potassium, and chlorophyll content of papaya leaf

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Introduction

The uptake of inorganic nutrients by plants is influenced by microorganisms in rhizosphere. Symbiotic endophytes such as mycorrhizae are examples of microorganisms involved in the uptake of vital plant-nutrient elements and translocation to host. There are reports providing evidence that most plants belonging to taxonomically higher order are infected with mycorrhizal fungi that assist in the uptake of nutrients, such as P (phosphorous), sulphur, and K (potassium); and micronutrients such as zinc, copper, manganese, iron, etc. (Sreenivasa 1992).

The use of inorganic fertilizers is costlier and also pollutes the environment through the process of denitrification, volatilization, and contamination of soil water through leaching. In order to combat this problem, it is necessary to adopt organic farming for a better yield and non-polluting environment. The VAM (vesicular-arbuscular mycorrhiza) and vermicompost are important components of organic farming and help in formation of fertile soil to a great extent. Therefore, the present study was carried out to know the cumulative effect of VAM fungi and vermicompost on NPK (nitrogen, phosphorus, potassium) and chlorophyll content of papaya leaf.

Materials and methods

The present investigation was carried out at the Department of Pomology, Kittu Rani Channamma College of Horticulture, Arabhavi. Reference inoculum of two VAM fungi, viz., *Glomus fasciculatum* and *Sclerocystis dussii* were multiplied and inoculated in papaya in the nursery. Mycorrhizal inoculation was done by placing the VAM inoculum uniformly at the rate of 5 g/bag at a depth of 5 cm, and further seeds were sown in the bags. Fifty days old, uniform and healthy seedlings were transplanted to the pots. Application of vermicompost at the rate of 650 g/plant/pot was done as per the treatments in the potting mixture.

Chlorophyll estimation was done by acetone extract method as described by Arnon (1949). Estimation of N was done by modified Micro Kjeldah method as outlined by Jackson (1967), P and K content were estimated as per the procedure by Jackson (1967).

Results and discussion

Table 1 indicates a significant increase in ‘P’ content when compared to other treatments. The increased ‘P’ content may be attributed to increase in uptake of P facilitated due to VAM colonization through various mechanisms that have been suggested by mycorrhizal plants. For instance, faster movement of P into mycorrhizal hyphae and solubilization of soil P could be some of the means (Hattingh, Gray, and Gerdemann 1973). Faster movement of P into the mycorrhizal hyphae was achieved by increasing the affinity of P ions and decreasing the threshold concentration required for absorption of P. Further solubilization of soil P was achieved by the release of organic acids and phosphates (Bolan 1991).

Increase in the N content in VAM inoculated plants was reported by many workers (Kessel, Paul, and Heinz 1985). The workers ascribed the increase in N content to improved nutrition and not to the fungal activity. Thus, mycorrhizae may improve the N nutrient not as a result of extensive absorbing surfaces, but by some mechanism that

Table 1 Effect of vesicular-arbuscular mycorrhiza fungi and vermicompost on nitrogen, phosphorus, potassium, and chlorophyll content of papaya petiole

	Nutrient (dry weight basis)			*Chlorophyll content* (mg/g fresh weight basis)		
Treatment	*N* (%)	*P* (%)	*K* (%)	*Chlorophyll ‘a’*	*Chlorophyll ‘b’*	*Total chlorophyll*
T_1	0.448	0.428	0.383	1.115	1.203	2.315
T_2	0.653	0.645	0.517	1.415	1.143	2.558
T_3	0.950	0.795	0.583	1.635	1.585	3.228
T_4	1.230	0.915	0.650	1.770	1.610	3.380
T_5	1.043	0.700	0.545	1.469	1.633	3.077
T_6	1.188	0.735	0.520	1.585	1.690	3.315
SEm (standard error of mean) ±	0.075	0.025	0.033	0.069	0.045	0.085
CD (critical difference) at 5%	0.272	0.074	0.098	0.205	0.133	0.252

T_1 = Control; T_2 = Vermicompost at the rate of 650 g/plant; T_3 = *Glomus fasciculatum*; T_4 = *Glomus fasciculatum* + vermicompost; T_5 = *Sclerocystis dussii*; T_6 = *Sclerocystis dussii* + vermicompost accelerates other parts of N uptake processes (Megan, Lloyd, and Patrick 1978).

Potassium content was higher in plants inoculated with *G. fasciculatum* compared to that of other treatment combinations in the container-grown plants (Table 1). Similar response of the VAM fungi for increase in K content was noted by Sukhada (1988) and Adivappar (2001) in papaya.

Increased chlorophyll accumulation was observed in the VAM plants (Table 1). Higher P levels in tissues (Table 1) as a result of root colonization by the VAM can be expected to increase the chlorophyll content, as P is one of the import components of chlorophyll. Increase in chlorophyll content was also reported by Richmond and Lang (1957) and Adivappar (2001).

There was an increase in the NPK and chlorophyll content in vermicompost-applied plants, which could be attributed to the worm cast that is a rich source of nutrients, humus-farming substances, N-fixers, and other beneficial microorganisms.

The efficacy of VAM plants increased with application of vermicompost (Table 1), wherein both the VAM species registered significantly higher values of the NPK and chlorophyll. This may be due to the additive effect of vermicompost. The chlorophyll content in VAM and vermicompost was higher even under the drought condition.

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New approaches

New technique to study mycorrhizal extra-radical mycelium

A simple IMT (inserted membrane technique) for sampling ERM (mycorrhizal extra-radical mycelium) was developed by Balaz M and Vosatka M (*Mycorrhiza* **11**(6): 291–296) as an alternative to the commonly used MFT (membrane filtration technique). The ERM of two types of mycorrhiza, orchid and AM (arbuscular mycorrhiza), was extracted by insertion of cellulose nitrate or cellulose acetate membrane filters (0.45–0.6 μm pore size) into the mycorrhizosphere of host plants. The membranes with adhered ERM were removed at harvest and stained with trypan blue for estimation of total hyphal length and with enzyme stains to indicate the viability of the ERM. There are two apparent advantages of the IMT over the MFT. Samples were cleaner and easier to observe, particularly when the hyphae are stained for enzyme activities. Also, the ERM remained intact and thus was also suitable for observation of the ERM morphology. There were statistically significant correlations between the lengths of the ERM extracted from clinoptinolite using the MFT and IMT for both mycorrhizal types tested, orchid mycorrhiza ($r = 0.63$) and AM ($r = 0.80$). Linear regression analysis indicated the best fit for the data obtained ($P < 0.05$, $n = 14$ for orchid mycorrhiza, and $P < 0.001$, $n = 26$ for AM).

Centre for Mycorrhizal Culture Collection

Comparison of arbuscular mycorrhizal fungal spore population and total microbial count in farmer's fields with various crop residue practices

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Rice and wheat are the two major crops in the IGP (Indo–Gangetic Plains) of South Asia comprising Bangladesh, India, Nepal, and Pakistan. The R–W (rice–wheat) systems represent 32% of the total rice area, and 42% of the wheat area in these countries (Ladha, Fischer, Hossain, *et al.* 2000). The importance of intensively cultivated R–W systems is fundamental for generating employment, income, and livelihoods for hundreds of millions of rural and urban population in South Asia. To improve the crop yield, farmers have been practising intensively irrigated R–W systems over the past couple of decades. A slow growth of productivity in agriculture and negative impacts of intensive agriculture on environmental quality suggested the infusion of a complimentary set of new agricultural technologies to boost productivity. Zero tillage and reduced tillage are such technologies recommended by the RWC (Rice–Wheat Consortium) and CIMMYT (International Maize and Wheat Improvement Centre) to sustain and enhance productivity of the R–W system at a reduced cost of production (Gupta, Hobbs, Ladha, *et al.* 2002). One of the newly emerging issues under increasing mechanization in the R–W areas is the management of straw after combiner harvesting of rice. As wheat is increasingly planted under zero tillage, it is imperative for farmers to remove rice straw and stubble without ploughing, and do this as fast as possible for the timely seeding of wheat. A large number of farmers in the high production area of the northern IGP are burning straw, which not only results in loss of organic matter, but also causes serious environmental problems. The present study was conducted to compare the AM (arbuscular mycorrhizal) fungal populations in two categories of zero-tilled fields: (1) residue was incorporated in the field, and (2) residue was burned.

During the study, a total of 12 farmers' fields (6 fields in each category) were selected from Karnal, Haryana, India. The irrigated R–W systems are practised in these fields. These fields shared similar soil properties and are in close proximity. Majority of the farmers are burning residue in this area but we were able to find a few farmers who were incorporating the residue. These fields were used to characterize soil pools (soil fertility and microbial parameters) in different treatments, and farmers fields were used as replications. Farmers of the area prefer combiner harvesting, and after harvesting they convert the remaining material into straw by a reaper. The soil sampling was done at a plowing depth of 0–15 cm by the nine-point method. In this method, the field was divided into nine parts and samples were taken from each part. The samples were composited and kept at –80 ^{0}C, until further analysis. The sampling was done at three durations: (1) at the time of sowing, (2) at the vegetative period, and (3) at the maturity phase.

The parameters analysed in the samples were: (1) total plate microbial count, (2) total plate fungal count, (3) AM fungal spore count and root colonization (root colonization would not be done at the time of sowing), and (4) soil chemical analysis (N, P, K, SOM [soil organic matter], pH, and EC [electrical conductivity]). The microbial count was found to be significantly higher in residue-incorporated fields as compared to the burned fields. The AM fungal spore count was also significantly higher in residue-incorporated fields with respect to the burned fields. The AM fungal spore number was very low in burned fields: 100–500 spores/kg soil in all fields. The soil chemical properties showed variable trends. No significant difference in pH and electrical conductivity was observed among the fields. However, organic carbon and N, P, and K contents were found to be significantly high in the residue-incorporated fields.

Thus, our study suggests that residue-incorporated fields are better from the point of soil microbes as well as soil fertility. However, developing rice straw industry alternatives to burning will require a large degree of cooperation and coordination among growers, balers, transporters, storage operators, and end-users. Rice straw collection is the most expensive of the three options currently being utilized by rice growers: open burning, soil incorporation, and collection. Study researchers estimated the following costs for each type of practice: open burning will cost 3–4 dollars per tonne, soil incorporation 20–35 dollars per tonne, and straw collection for off-field uses 28–43 dollars per tonne.

Soil incorporation of straws can be done if technologies for residue degradation can be sought. Treatment of straw with NaOH (sodium hydroxide) and NH_3 (ammonia) to improve its digestibility and intake has been extensively examined, and well-documented. However, both chemicals have the potential to be hazardous to animals, humans, and the environment, in addition to economic and technological limitations. Consequently, their application has been limited, especially in the developing countries. Treatment of rice straw with urea as a source of NH_3 under warm climates has been given more attention and has proved to be effective. However, the technology has not been widely taken up by farmers. Moreover, a standard level of 4%–6% urea for biologically effective treatment should be too much a source of non-protein N in the straw for efficient utilization by ruminants. Therefore, it is warranted to find treatment alternatives that will be not only be technically effective, but also be cost-effective and convenient to farmers. We are trying to degrade rice straw using suitable combinations of microbes.

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Recent references

The latest additions to the Network's database on mycorrhiza are published here for 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.

- *Agriculture Ecosystems and Environment*
- *Agrociencia*
- *Agronomie*
- *American Journal of Enology and Viticulture*
- *Annals of Forest Science*
- *Applied and Environmental Microbiology*
- *Biology and Fertility of Soils*
- *Bioscience, Biotechnology, and Biochemistry*
- *Canadian Journal of Microbiology*
- *Communications in Soil Science and Plant Analysis*
- *Crop Science*
- *Ecological Applications*
- *Ecological Monographs*
- *Ecology*
- *Ecosystems*
- *European Journal of Soil Biology*
- *Fems Microbiology Ecology*
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- *Hort Technology*
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- *Journal of Environmental Sciences-China*
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- *New Phytologist*
- *Oecologia*
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- *Physiological and Molecular Plant Pathology*
- *Phytochemistry*
- *Plant Ecology*
- *Scientia Horticulture*
- *Tree Physiology*
- *Water, Air and Soil Pollution*

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

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Printed and published by Dr R K Pachauri on behalf of the The Energy and Resources Institute, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi – 110 003, and *printed at* Multiplexus (India), C-440, DSIDC, Narela Industrial Park, Narela, Delhi – 110 040.