American Journal of

Plant Nutrition and Fertilization Technology

ISSN 1793-9445

Academic Journals Inc.

www.academicjournals.com

American Journal of Plant Nutrition and Fertilization Technology 5 (2): 40-49, 2015
ISSN 1793-9445 / DOI: 10.3923/ajpnft.2015.40.49

Vesicular Arbuscular Mycorrhizal (VAM) Fungi: A Tool for Sustainable Agriculture

Abbasi, Hisamuddin, Ambreen Akhtar and Rushda Sharf
Section of Plant Pathology, Department of Botany, Aligarh Muslim University, Aligarh, 202002, India

Corresponding Author: Abbasi, Section of Plant Pathology, Department of Botany, Aligarh Muslim University, Aligarh, 202002, India

ABSTRACT

In the recent past, the use of chemical fertilizers in agriculture has substantially increased throughout the world. But, because of over demand of fertilizers, increase in cost of energy, the cost of fertilizers, both in terms of currency and energy, has been rising tremendously and will continue to rise. Moreover, excessive use of fertilizers is leaving bad to worse impacts on the soil and water body environment. Therefore, the concept of using VAM fungi as a bio fertilizer, in terms of cost effectiveness, energy saving and as environment friendly, is a promising perspective. The significance of VAM in augmenting food production is far and wide, therefore these can be used in sustainable agriculture. Mycorrhizae are the root-symbionts which obtain their nutrients from the plant and provide mineral elements like N, P, K, Ca, S and Zn to the host plant. This review is an attempt to explore the suppressing abilities of Arbuscular Mycorrhizal Fungi (AMF) against soil borne pathogens (root feeding nematodes and fungi), infecting various crops. We also determined the capabilities of AMF to increase the productivity of cereal crops, fruits and vegetable crops and highlighted future research directions in mycorrhizal technology.

Key words: Chemical fertilizers, VAM fungi, bio-fertilizers

INTRODUCTION

The word mycorrhiza is derived from classical Greek word for “mushroom” and “root”. In a mycorrhizal association, the underground mycellium are in contact with plant roots, but without causing any harm to the plant. Fossil evidence (Remy *et al*., 1994) and DNA sequence analysis (Simon *et al*., 1993) suggest that this mutualism appeared 400-460 million years ago. Vesicular arbuscular mycorrhizal fungi belong to the class Zygomycetes, order Endogonales (Benjamin, 1979) and family Endogonaceae. Mycorrhizal fungi are responsible in improving growth of host plant species due to increased nutrient uptake, production of growth promoting substances, tolerance to drought, salinity and synergistic interactions with other beneficial microorganisms (Sreenivasa and Bagyaraj, 1989). The soil conditions prevalent in sustainable agriculture are likely to be more favorable to AM fungi than are those under conventional agriculture (Bethlenfalvay and Schuepp, 1994; Smith and Read, 1997). The AM fungi are widely distributed in natural and agricultural environments and have been found associated with more than 80% of land plants, liverworts, ferns, woody gymnosperms and angiosperms and grasses (Smith and Read, 2008).

The natural role of mycorrhizosphere organisms may have been marginalized in intensive agriculture, since microbial communities in conventional farming systems have been modified due to tillage (Sturz *et al*., 1997; Mcgonigle and Miller, 1996) and high inputs of inorganic fertilizers, herbicides and pesticides (Gianinazzi *et al*., 2002). Microbial diversity in these systems has been reduced (Maeder *et al*., 2002) and the functional consequences of this loss of diversity are still uninvestigated. Indiscriminate use of inorganic fertilizers contributes enormously in stepping up agricultural production regionally and globally but at the same time its impact on soil fertility, environmental persistence, soil biodiversity, run off concentration and aquaculture pollution cannot be viewed superficially. Increased environmental awareness has progressively led to shift from conventional intensive management to low input crop production.

Conceivably, a wide range of management are available for the management of disease constraints in various crops, but their effective implementation depends on a sound understanding of the physiological response of plants to these stresses. The present article aims to review the main mechanisms involved in the biological control of diseases induced by soilborne phytopathogens after root colonization with AM fungi. For a better understanding of the possible influence of VA mycorrhizae on host plant, nutrition and on the symbiosis under practical conditions, will be given in more detail.

TRIPARTITE RELATIONSHIP AMONG HOST PLANT, AM FUNGI, BACTERIA AND PLANT NUTRITION

The cost of nitrogenous fertilizer is continuously escalating and the problem of deforestation is becoming grave, therefore, the potential of actinorhizal plants and study of symbiotic relationship needs attention. The potential of symbiosis has contributed much to the nitrogen and phosphate economy of natural ecosystems, particularly on infertile sites or in recently denuded areas (Wheeler and Miller, 1990).

In mycorrhizal symbiotic association a third component of bacteria seems to be loosely or tightly associated with the plants and the mycorrhizal fungi and most likely play a key role in mycorrhizal function. Garbaye (1994) acknowledged the term helper bacteria and defined as those bacteria, which support mycorrhizal establishment. The AM fungi have been found to release an unidentified diffusional factor, known as the myc factor, responsible in activating the nodulation factor's inducible gene MtEnod11. This is the gene which is involved in establishing symbiotic relationship with the nitrogen fixing, rhizobial bacteria (Kosuta *et al*., 2003).

Under natural conditions, bacteria associated with mycorrhizal fungi colonize the surface of extraradical hyphae or at least in some fungal taxa, live in the cytoplasm as endobacteria. The plant provides the fungus with photosynthetically derived carbohydrate, while the fungus supplies the plant roots with nutrients (Smith and Read, 1997).

The AM fungi are important to their hosts as they enhance the ability of plants to absorb phosphorus from soil, which is relatively inaccessible to the plants (Mcgonigle and Miller, 1996; Miller, 2000). However, the AM association may also increase the phytoavailability of micronutrients, e.g., copper and zinc (Smith and Read, 1997). In a study, absorption of trace elements, such as boron and molybdenum, was thought to be enhanced by VA mycorrhizae (Sieverding, 1991). In addition, it has been suggested that some AM associations are able to mobilize organically bound nitrogen, which the plants are unable to absorb (Hodge *et al*., 2001).

Symbiotic association of AM fungi with the plants seems influence the composition of bacterial communities in the mycorrhizosphere due to changes in root exudation patterns induced by AM colonization (Marschner and Baumann, 2003; Soderberg *et al*., 2002). The manipulation of crop rhizosphere with PGPR for biocontrol of plant pathogens has been found promising (Nelson, 2004; Ren *et al*., 2007). Changes in bacterial community structure may also be driven by complex interactions between plant species (or genotype) and fungal species involved (Marschner and Baumann, 2003; Marschner and Timonen, 2005). The increased host phosphorus provided by fungus supports rhizobial production of nitrogenase enzymes, which are important for nitrogen fixation (Puppi *et al*., 1994). The enhanced nitrogen status of the plant promotes further development of the mycorrhizal symbiosis.

The biofertilizer properties of plant growth promoting rhizobacteria are frequently ascribed to their ability to increase the bioavailability of inorganic and organic phosphorus and some of these bacteria have documented synergistic effects on nitrogen fixation and formation of mycorrhizal associations. Toro *et al*. (1997) demonstrated that both *Enterobacter* sp. and *Bacillus subtilis* promoted establishment of the AM fungus *Glomus intradices* and increased plant biomass as well as tissue nitrogen and phosphorus contents. Phosphorus content in tomato plants was increased when inoculated with the AM fungus *G. etunicatum*, or the phosphate solubilizing bacterium *Enterobacter agglomerans* (Kim *et al*., 1997). Additionally, the highest nitrogen and phosphorus uptake was observed when tomatoes were inoculated with both the organisms, suggesting that bacteria and AM fungi might together increase the rate of nutrient uptake by the plants.

MECHANISM OF DISEASE CONTROL

Following are the various benefits attributed to the plant through mycorrhizal symbiosis:

- The VA mycorrhiza increases plant tolerance to various biotic and abiotic stressants including alkalinity, toxicities associated with mining operations, heavy metals and mineral imbalance
- The VA mycorrhiza have a potential use as biofertilizer and replaces the fertilizer requirements of trees in areas of marginal fertility and reduces the needs of current levels of chemical fertilizer
- The mycorrhizal symbiosis plays a vital role in changing the ecology of a given site and mycorrhiza promotes mineral cycling and are key component of efficient and closed nutrient cycle of natural ecosystems

According to studies by Grandmaison *et al*. (1993), progressive binding of phenolic compounds in VAM roots is directly involved in the control of VAM endophytic establishment and development as it gradually reduces the plasticity and elasticity of the symbiotic matrix. Phenolic compounds bound to cell walls could also be indirectly responsible for the resistance of VAM roots to pathogenic fungi, since they result in increased resistance by cell wall to the action of digestive enzymes.

Certain flavonoids released from plants regulate activities of soil microbes at micromolar concentrations. Processes affected by these compounds include induction of nodulation gene transcription in rhizobial bacteria, promotion of chemotaxis in rhizobia, increase in growth role of several bacterial species and enhancement of *Glomus* spore germination and hyphal growth. Data on the amount and identity of flavonoids released from several crop plant species form a new basis for molecular genetics and ecological studies of the rhizosphere (Phillips and Tsai, 1992).

Several hypotheses have been put forwarded to explain the mechanisms of plant disease control by mycorrhizal fungi, these are: (a) Creating a mechanical barrier for the pathogen penetration and subsequent spread as in the case of sheathing mycorrhiza, (b) Thickening of cell wall through lignification and production of other polysaccharides which in turn hinder the entry of root pathogen (Dehne and Schoenbeck, 1979), (c) Stimulation of the host roots to produce and accumulate sufficient concentration of metabolites (terpenes, phenols etc.), which impart resistance to the host tissue against pathogen invasion (Krupa *et al*., 1973; Sampangi, 1989), (d) Stimulating flavonolic wall infusions as in the case of *Laccaria bicolor* which prevented lesion formation by the pathogen *Fusarium oxysporum* in roots of Douglas fir (Strobel and Sinclair, 1991), (e) Increasing the concentration of orthodihydroxy phenols in roots and detering the activity of pathogen (Krishna *et al*., 1985), (f) Producing antifungal and antibacterial antibiotics (Marx, 1972), (g) Competing with the pathogens for the uptake of essential nutrients in the rhizosphere and at the roots surface (Reid, 1990) and (h) Stimulating the microbial activity and competitions in the roots and thus preventing the pathogen to get access to the roots (Rambelli, 1973). Roots colonized by VAM fungi may also harbor more actinomycetes antagonistic to root pathogen (Secilia and Bagyaraj, 1987) and compensating the nutrient absorption system from damage to roots by pathogens.

ARBUSCULAR MYCORRHIZAL FUNGI AS A POTENTIAL TOOL IN BIO-CONTROL

Soil borne pathogens were controlled by using several agricultural practices, such as use of resistant cultivars, chemical fungicides, crop rotation and soil fumigation etc. There are many problems associated with controlling pathogens with long term persistent survival structures, due to difficulties in reducing pathogen inoculum and lack of good sources of plant resistance (Azcon-Aguilar and Barea, 1997). Therefore, many researchers were trying to use alternate approaches based on either manipulating or adding microorganisms to enhance plant protection against pathogens (Grosch *et al*., 2005). The beneficial microorganisms (antagonistic bacteria) (e.g., *Pseudomonas fluorescence*, *Bacillus subtilis*, etc.) and fungi (e.g., AMF, *Trichoderma*, etc.) compete with plant pathogens for nutrients and space, by producing antibiotics, by parasitizing pathogens, or by inducing resistance in the host plants, these microbes have been used for biocontrol of pathogens (Berg *et al*., 2007). It has been suggested that AM fungi increase host tolerance of pathogen attack by compensating for the loss of root biomass or function caused by pathogens (Linderman, 1994), including nematodes (Pinochet *et al*., 1996) and fungi (Cordier *et al*., 1996). Here we shall discuss two major soil-borne diseases viz., root knot disease caused by nematode and diseases caused by plant pathogenic fungi and their biocontrol by VAM fungi.

Root-knot nematodes have been reported to cause an annual loss up to 29% in tomato, 23% in egg plant 22% in okra, 28% in beans and so on, that may vary from crop to crop and country to country (Sasser, 1990). Root-knot nematodes and VAM fungi are members of the microbial population of the root region and they can compete with each other for the same site in the rhizosphere. The primary effect of VAM fungi on nematode infection appears to increase host tolerance in spite of damaging levels of plant parasitic nematode populations. The basis appears to be physical or physiological. The VAM fungi have also been shown to enhance the uptake of Ca, Cu, Mn, S and Zn in addition to P. Nematode damaged plants frequently show impaired water conductance through roots and deficiencies of N, B, Fe, Mg and Zn, particularly VAM induced Zn uptake has been shown to contribute tolerance to *Melodogyne incognita* in cotton. Hence, the beneficial VAM fungi might be expected to reduce or even eliminate the harmful effects imposed by root-knot nematodes and substantially reduce nematode development (Kantharaju *et al*., 2005). The interaction between VAM fungi and plant parasitic nematodes is given in Table 1.

The AM fungi may also interact with other root associated microorganisms, such as pathogenic fungi. More than 10,000 species of fungi are known to cause diseases of plants and are common in soil, air (spores) and on plant surfaces throughout the world in arid, tropical, temperate and alpine regions (Agrios, 2005). The diseases caused by fungal pathogens persist in the soil matrix and its residues on soil surface and are defined as soil borne diseases.

Table 1: Examples for root-knot nematode×mycorrhizal fungal interactions studied on various crops

Root-knot species	Crops	AM fungi	References
M. incognita	Tomato	*Glomus mosseae*	Sikora (1978)
	Papaya	*G. mosseae* *G. manihotis*	Del Carmen Jaizme-Vega *et al.* (2006)
	Ginger	*G. fasciulatum*	Nehra (2004)
G. mosseae	Okra	*G. mosseae*	Sharma and Mishra (2003)
	Brinjal	*G. fasciculatum*	Borah and Phukan (2003)
	Chilli	*G. mosseae*	Sundarababu *et al.* (2001)
	Green gram	*G. mosseae*	Jothi and Sundarababu (2001)
	Black gram	*G. mosseae*	Sankaranarayanan and Sundarababu (1999)
	Owpea	*G. fasciculatum*	Devi and Goswami (1992)
M. javanica and *G. mosseae*	Almond	*G. intradices*	Calvet *et al.* (2001)
M. hapla	Pyrethrum	*G. etunicatum*	Waceke *et al.* (2001)
	Carrot	*G. mosseae*	Sikora and Schonbeck (1975)
	Onion	*G. fasciculatum*	MacGuidwin *et al.* (1985)
M. arenaria	Peanut	*Gigaspora margarita*	Carling *et al.* (1995)
G. etunicatum and *G. epigaeus*	Cowpea	*G. fasciculatum*	Jain and Sethi (1988)
T. semipenetrans	Citrus	*G. mosseae*	O'Bannon *et al.* (1979)
Rotylenchulus	Tomato	*G. fasciculatum reniformis*	Sitaramaiah and Sikora (1982)
R. similis	Banana	*G. intradices*	Umesh *et al.* (1988)
R. citrophilus	Citrus	*G. intradices*	Smith and Kaplan (1988)

Table 2: Examples for plant pathogenic fungi×mycorrhizal fungal interactions studied on various crops

Pathogenic fungi	Crops	AM fungi	References
M. phaseolina	Cowpea	*G. fasciculatum*	Devi and Goswami (1992)
F. oxysporum	Cucumber	*G. etunicatum*	Hao *et al.* (2005)
	Tomato	*G. intradices*	Akkopru and Demir (2005)
	Tomato	*G. etunicatum*	Bhagawati *et al.* (2000)
	Chickpea	*G. fasciculatm*	Rao and Krishnappa (1995)
	Tomato and pepper	*G. mosseae*	Al-Momany and Al-Raddad (1988)
	Tomato	*G. intradices*	Caron *et al.* (1985)
	Pea	*G. fasciculatum*	Rosendahl (1985)
	Cucumber	*G. etunicatum*	Rosendahl and Rosendahl (1990)
V. dahliae, *G. vesiformae* and *S. sinuosa*	Cotton	*G. mosseae*	Liu (1995)
S. cepivorum	Onion	*Glomus* sp.	Torres-Barragan *et al.* (1996)
A. euteiches	Pea	*G. intradices*	Kjoller and Rosendahl (1997)
R. solani	Alfalfa	*G. intradices*	Guenoune *et al.* (2001)
P. parasitica and *G. intradices*	Tomato	*G. mosseae*	Pozo *et al.* (2002)
R. solani and *G. intradices*	Potato	*G. etunicatum*	Yao *et al.* (2002)

The interaction of AM fungi and plant pathogenic fungi has received considerable attention. Consistent reduction of disease symptoms has been described for fungal pathogens such as *Phytophthora, Gaeumannomyces, Fusarium, Chalara (Thielaviopsis), Pythium, Rhizoctonia, Sclerotium, Verticillium, Aphanomyces.* Cordier *et al.* (1996) showed that *Pthytophthora* development is reduced in AM fungal-colonized and adjacent uncolonized regions of AM root systems and that in the former the pathogen does not penetrate arbuscule containing cells (Table 2).

STATUS QUO AND FUTURE PROSPECTS OF MYCORRHIZAL APPLICATION

Available summary of publications devoted to the agricultural and environmental benefits of mycorrhiza show their utility in the number cereal crops, fruits and vegetable production. Wheat, barley and paddy amongst cereals have been investigated with reference to effect of VA mycorrhiza on growth, productivity and nutrient uptake.

Attempts have been made to explore the possibility of employing VAM technology in improving the production of vegetables, including potato, brinjal, tomato, lady's finger, lettuce, onion, pepper, cucumber, beans, tomato, muskmelon, watermelon, etc. Various fruit crops including citrus, papaya, orange, mulberry, apple and banana have been investigated for their response to inoculation of VAM.

Arbuscular mycorrhizal symbiosis must be considered an essential factor for promoting plant health and productivity. Careful selection of compatible host/fungus/substrate combinations, would allow more appropriate management of mycorrhizae in poor soils would allow substantial reduction in the amount of minerals used without losses in productivity, while at the same time permitting a more sustainable production management.

Production of inoculum is expensive due to overhead and labor costs. During research work inoculum is prepared in an amount enough to treat a small research plot. Under field conditions application requires more inoculum than can be produced in pots. However, commercial inoculum production of AM fungi is under the process of improvement for the past decade, although the future prospect of the business is still uncertain. With heightened interest in application of mycorrhizal fungi, due to their potential significance in not only sustainable crop production, but also in environmental conservation, it is likely that large scale production of inoculum would begin in the near future. Also, with the a basic understanding of the biology of AM fungi and refinement of application techniques for inoculum, the future of crop improvement and environmental conservation using mycorrhizal technology shows promise.

CONCLUSION

Worldwide, considerable progress has been achieved in the area of mycorrhizal technology. It has been demonstrated and proved that mycorrhizae have great potential for field application to improve productivity of cereal, fruit and vegetable crops and suppress nematode and fungal infestations. The public demand to reduce environmental problems associated with excessive pesticide usage has prompted research on reduction or elimination of pesticides and increasing consumer demands for organic or sustainably-produced food requires the incorporation of microorganisms, such as arbuscular mycorrhizal (AM) fungi. There is also an urgent need to strengthen further the regional collaboration so that benefits of technology advancements could reach those presently left behind.

REFERENCES

Agrios, G.N., 2005. Plant Pathology. 5th Edn., Academic Press, New York, USA., ISBN-13: 9780120445653, Pages: 922.

Akkopru, A. and S. Demir, 2005. Biological control of Fusarium wilt in tomato caused by *Fusarium oxysporum* f. sp. *lycopersici* by AMF *Glomus intraradices* and some rhizobacteria. J. Phytopathol., 153: 544-550.

Al-Momany, A. and A. Al-Raddad, 1988. Effect of vesicular-arbuscular mycorrhizae on Fusarium wilt of tomato and pepper. Alexand. J. Agric. Res., 33: 249-261.

Azcon-Aguilar, C. and J.M. Barea, 1997. Applying mycorrhiza biotechnology to horticulture: Significance and potentials. Sci. Hortic., 68: 1-24.

Benjamin, R.K., 1979. Zygomycetes and their Spores. In: The whole Fungus: The Sexual Asexual Synthesis, Kendrick, B. (Ed.). National Museums of Natural Canada, Ottawa, Canada, pp: 573-622.

Berg, G., R. Grosch and K. Scherwinski, 2007. Risk assessment for microbial antagonists: Are there effects on non-target organisms? Gesunde Pflanzen, 59: 107-117.

Bethlenfalvay, G.J. and H. Schuepp, 1994. Arbuscular Mycorrhizas and Agrosystem Stability. In: Impact of Arbuscular Mycorrhizas on Sustainable Agriculture and Natural Ecosystems, Gianinazzi, S. and H. Schuepp (Eds.). Birkhauser Verlag, Basel, Switzerland, pp: 117-131.

Bhagawati, B., B.K. Goswami and C.S. Singh, 2000. Management of disease complex of tomato caused by *Meloidogyne incognita* and *Fusarium oxysporum* f. sp. *Lycopersici* through bioagent. Indian J. Nematol., 30: 16-22.

Borah, A. and P.N. Phukan, 2003. Effect of interaction of *Glomus fasciculatum* and *Meloidogyne incognita* on growth of brinjal. Ann. Plant Prot. Sci., 11: 352-354.

Calvet, C., J. Pinochet, A. Hernandez-Dorrego, V. Estaun and A. Camprubi, 2001. Field microplot performance of the peach-almond hybrid GF-677 after inoculation with arbuscular mycorrhizal fungi in a replant soil infested with root-knot nematodes. Mycorrhiza, 10: 295-300.

Carling, D.E., R.W. Roncadori and R.S. Hussey, 1995. Interactions of arbuscular mycorrhizae, *Meloidogyne arenaria* and phosphorus fertilization on peanut. Mycorrhiza, 6: 9-13.

Caron, M., J.A. Fortin and C. Richard, 1985. Influence of substrate on the interaction of *Glomus intraradices* and *Fusarium oxysporum* f. sp. *radicis-lycopersici* on tomatoes. Plant Soil, 87: 233-239.

Cordier, C., S. Gianinazzi and V. Gianinazzi-Pearson, 1996. Colonisation patterns of root tissues by *Phytophthora nicotianae* var. parasitica related to reduced disease in mycorrhizal tomato. Plant Soil, 185: 223-232.

Dehne, H.W. and F. Schoenbeck, 1979. The influence of endotrophic mycorrizae on plant disease. I. colonization of tomato plants by *Fusarium oxysporum* F. Sp. *Lycopersici*. Phytopathololology, 95: 105-105.

Del Carmen Jaizme-Vega, M., A.S. Rodriguez-Romero and L.A.B. Nunez, 2006. Effect of the combined inoculation of arbuscular mycorrhizal fungi and plant growth-promoting rhizobacteria on papaya (*Carica papaya* L.) infected with the root-knot nematode *Meloidogyne incognita*. Fruits, 61: 151-162.

Devi, T.P. and B.K. Goswami, 1992. Effect of VA-mycorrhiza on the disease incidence due to *Macrophomina phaseolina* and *Meloidogyne incognita* on cowpea. Ann. Agric. Res., 13: 253-256.

Garbaye, J., 1994. Tansley review No. 76 Helper bacteria: A new dimension to the mycorrhizal symbiosis. New Phytol., 128: 197-210.

Gianinazzi, S., H. Schuepp, J.M. Barea and K. Haselwandter, 2002. Mycorrhizal Technology in Agriculture: From Genes to Biproducts. Springer, Switzerland.

Grandmaison, J., G.M. Olah, M.R. Van Calsteren and V. Furlan, 1993. Characterization and localization of plant phenolics likely involved in the pathogen resistance expressed by endomycorrhizal roots. Mycorrhiza, 3: 155-164.

Grosch, R., J. Lottmann, F. Faltin and G. Berg, 2005. Use of bacterial antagonists to control diseases caused by *Rhizoctonia solani*. Gesunde Pflanzen, 57: 199-205.

Guenoune, D., S. Galili, D.A. Phillips, H. Volpin, I. Chet, Y. Okon and Y. Kapulnik, 2001. The defense response elicited by the pathogen *Rhizoctonia solani* is suppressed by colonization of the AM-Fungus *Glomus intraradices*. Plant Sci., 160: 925-932.

Hao, Z., P. Christie, L. Qin, C. Wang and X. Li, 2005. Control of fusarium wilt of cucumber seedlings by inoculation with an arbuscular mycorrhical fungus. J. Plant Nutr., 28: 1961-1974.

Hodge, A., C.D. Campbell and A.H. Fitter, 2001. An arbuscular mycorrhizal fungus accelerates decomposition and acquires nitrogen directly from organic material. Nature, 413: 297-299.

Jain, R.K. and C.L. Sethi, 1988. Influence of endomycorrhizal fungi *Glomus fasciculatum* and *G. eplgaeus* on penetration and development of *Heterodera cajanion* cowpea. Indian J. Nematol., 18: 89-93.

Jothi, G. and R. Sundarababu, 2001. Management of root-knot nematode in brinjal by using VAM and crop rotation with green gram and pearl millet. J. Biol. Control, 15: 77-80.

Kantharaju, V., K. Krishnappa, N.G. Ravichandra and K. Karuna, 2005. Management of root-knot nematode, *Meloidogyne incognita* on tomato by using indigenous isolates of AM fungus, *Glomus fasciculatum*. Indian J. Nematol., 35: 32-36.

Kim, K.Y., D. Jordan and G.A. McDonald, 1997. Effect of phosphate-solubilizing bacteria and vesicular-arbuscular mycorrhizae on tomato growth and soil microbial activity. Biol. Fertil. Soils, 26: 79-87.

Kjoller, R. and S. Rosendahl, 1997. The presence of the arbuscular mycorrhizal fungus *Glomus intraradicesinfluences* enzymatic activities of the root pathogen *Aphanomyces euteiches* in pea roots. Mycorrhiza, 6: 487-491.

Kosuta, S., M. Chabaud, G. Lougnon, C. Gough, J. Denarie, D.G. Barker and G. Becard, 2003. A diffusible factor from arbuscular mycorrhizal fungi induces symbiosis-specific MtENOD11 expression in roots of *Medicago truncatula*. Plant Physiol., 131: 952-962.

Krishna, K.R., K.G. Shetty, P.J. Dart and D.J. Andrews, 1985. Genotype dependent variation in mycorrhizal colonization and response to inoculation of pearl millet. Plant Soil, 86: 113-125.

Krupa, S., J. Anderson and D.H. Marx, 1973. Studies on ectomycorrhizae of pine. IV. Volatile organic compounds in mycorrhizal and nonmycorrhizal root systems of *Pinus echinata* mill. Mill. Eur. J. Plant Pathol., 3: 194-200.

Linderman, R.G., 1994. Role of VAM Fungi in Biocontrol. In: Mycorrhizae and Plant Health, Pfleger, F.L. and R.G. Linderman (Eds.). APS Press, St. Paul, pp: 1-26.

Liu, R.J., 1995. Effect of vesicular-arbuscular mycorrhizal fungi on verticillium wilt of cotton. Mycorrhiza, 5: 293-297.

MacGuidwin, A.E., G.W. Bird and G.R. Safir, 1985. Influence of *Glomus fasciculatum* on *Meloidogyne hapla* infecting *Allium cepa*. J. Nematol., 17: 389-395.

Maeder, P., A. Fliessbach, D. Dubois, L. Gunst, P. Fried and U. Niggli, 2002. Soil fertility and biodiversity in organic farming. Science, 296: 1694-1697.

Marschner, P. and K. Baumann, 2003. Changes in bacterial community structure induced by mycorrhizal colonisation in split-root maize. Plant Soil, 251: 279-289.

Marschner, P. and S. Timonen, 2005. Interactions between plant species and mycorrhizal colonization on the bacterial community composition in the rhizosphere. Applied Soil Ecol., 28: 23-36.

Marx, D.H., 1972. Ectomycorrhizae as biological deterrents to pathogenic root infections. Ann. Rev. Phytopathol., 10: 429-441.

Mcgonigle, T.P. and M.H. Miller, 1996. Development of fungi below ground in association with plants growing in disturbed and undisturbed soils. Soil Biol. Biochem., 28: 263-269.

Miller, M.H., 2000. Arbuscular mycorrhizae and the phosphorus nutrition of maize: A review of Guelph studies. Can. J. Plant Pathol. Sci., 80: 47-52.

Nehra, S., 2004. VAM fungi and organic amendments in the management of *Meloidogyne incognita* infected ginger. J. Indian Bot. Soc., 83: 90-97.

Nelson, L.M., 2004. Plant Growth Promoting Rhizobacteria (PGPR): Prospects for new inoculants. Online Crop Manage. 10.1094/CM-2004-0301-05-RV

O'Bannon, J.H., R.N. Inserra, S. Nemec and N. Vovlas, 1979. The influence of *Glomus mosseae* on *Tylenchulus semipenetrans*-infected and uninfected *Citrus limon* seedlings. J. Nematol., 11: 247-250.

Phillips, D.A. and S.M. Tsai, 1992. Flavonoids as plant signals to rhizosphere microbes. Mycorrhiza, 1: 55-58.

Pinochet, J., C. Calvet, A. Camprubi and C. Fernandez, 1996. Interactions between migratory endoparasitic nematodes and arbuscular mycorrhizal fungi in perennial crops: A review. Plant Soil, 185: 183-190.

Pozo, M.J., C. Cordier, E. Dumas-Gaudot, S. Gianinazzi, J.M. Barea and C. Azcon-Aguilar, 2002. Localized versus systemic effect of arbuscular mycorrhizal fungi on defence responses to *Phytophthora* infection in tomato plants. J. Exp. Bot., 53: 525-534.

Puppi, G., R. Azcon and G. Hoflich, 1994. Management of Positive Interactions of Arbuscular Mycorrhizal Fungi with Essential Groups of Soil Microorganisms. In: Impact of Arbuscular Mycorrhizas on Sustainable Agriculture and Natural Ecosystems, Gianinazzi, S. and H. Schuepp (Eds.). Springer, Switzerland, pp: 201-215.

Rambelli, A., 1973. The Rhizashere of Mycorrhizae. In: Ectomycorrhizae, Marks, G.L. and T.T. Koslowski (Eds.). Academic Press, New York, USA., pp: 299-343.

Rao, V.K. and K. Krishnappa, 1995. Soil solarization for the control of soil-borne pathogen complexes with special reference to *Meloidogyne incognita* and *Fusarium oxysporium* f.sp. ciceri. Indian Phytopath., 48: 300-303.

Reid, C.P.P., 1990. Mycorrhizas. In: The Rhizosphere, Lynch, J.M. (Ed.). Wiley, Chichester, UK., pp: 281-315.

Remy, W., T.N. Taylor, H. Hass and H. Kerp, 1994. Four hundred-million-year-old vesicular arbuscular mycorrhizae. Proc. Natl. Acad. Sci. USA., 91: 11841-11843.

Ren, T.R., Y.H. Xie, W.W. Zhu, Y.H. Li and Y. Zhang, 2007. Activities and toxicity of a novel plant growth regulator 2-furan-2-yl-[1,3] dioxolane. J. Plant Growth Regul., 26: 362-368.

Rosendahl, C.N. and S. Rosendahl, 1990. The role of vesicular-arbuscular mycorrhiza in controlling damping-off and growth reduction in cucumber caused by *Pythium ultimum*. Symbiosis, 9: 363-366.

Rosendahl, S., 1985. Interactions between the vesicular-arbuscular mycorrhizal fungus *Glomus fascicuhtum* and *Aphanomyces euteiches* root rot of peas. J. Phytopathol., 114: 31-40.

Sampangi, R.K., 1989. Some recent advances in the study of fungal root diseases. Ind. Phytopth., 22: 1-17.

Sankaranarayanan, C. and R. Sundarababu, 1999. Role of phosphorus on the interaction of vesicular-arbuscular mycorrhiza (*Glomus mosseae*) and root-knot nematode (*Meloidogyne incognita*) on blackgram (*Vigna mungo*). Indian J. Nematol., 29: 105-108.

Sasser, J.N., 1990. Economic Importance of *Meloidogyne* in Tropical Countries. In: Root-Knot News (*Meloidogyne* sp.) Systematics, Biology and Control, Lamberti, F. and E. Tayler (Eds.). Academic Press, New York, USA.

Secilia, J. and D.J. Bagyaraj, 1987. Bacteria and actinomycetes associated with pot cultures of vesicular-arbuscular mycorrhizas. Can. J. Microbiol., 33: 1069-1073.

Sharma, H.K.P. and S.D. Mishra, 2003. Effect of plant growth promoter microbes on root-knot nematode *Meloidogyne incognita* on okra. Curr. Nematol., 14: 57-60.

Sieverding, E., 1991. Vesicular-arbuscular mycorrhiza management in tropical agrosystems. Deutche Gesellschaft fu r Technische Zusammenarbeit, GTZ No. 224. Federal Repuplic of Germany, pp: 371.

Sikora, R.A. and F. Schonbeck, 1975. Effect of vesicular-arbusculr mecorrhiza on the population dynamics of the root-knot nematodes. Proceedings of the 8th International Congress of Plant Protection, Volume 5, August 21-27, 1975, Moscow, pp: 158-166.

Sikora, R.A., 1978. Effect of endotrophic mycorrhizal fungus, *G. mosseae*, on the host parasitic relationship of *M. incognita* in tomato. J. Plant Dis. Prot., 185: 197-202.

Simon, L., J. Bousquet, R.C. Levesque and M. Lalonde, 1993. Origin and diversification of endomycorrhizal fungi and coincidence with vascular land plants. Nature, 363: 67-69.

Sitaramaiah, K. and R.A. Sikora, 1982. Effect of the mycorrhizal fungus *Glomus fasciculatus* on the host-parasite relationship of *Rotylenchulus reniformis* in tomato. Nematologica, 28: 412-419.

Smith, G.E. and D.T. Kaplan, 1988. Influence of mycorrhizal fungus, phosphorus and burrowing nematode interactions on growth of rough lemon citrus seedlings. J. Nematol., 20: 539-544.

Smith, S.E. and D.J. Read, 1997. Mycorrhizal Symbiosis. 2nd Edn., Academic Press, London, UK., ISBN-13: 978-0-12-652840-4, Pages: 605.

Smith, S.E. and D.J. Read, 2008. Mycorrhizal symbiosis. 3rd Edn., Academic Press, London, UK., ISBN-13: 9780123705266, Pages: 800.

Soderberg, K.H., P.A. Olsson and E. Baath, 2002. Structure and activity of the bacterial community in the rhizosphere of different plant species and the effect of arbuscular mycorrhizal colonisation. FEMS Microbiol. Ecol., 40: 223-231.

Sreenivasa, M.N. and D.J. Bagyaraj, 1989. Use of pesticides for mass production of vesicular-arbuscular mycorrhizal inoculum. Plant Soil, 119: 127-132.

Strobel, N.E. and W.A. Sinclair, 1991. Role of flavonolic wall influsions inn the resistance induced by *Laccaria bicolor* to *Fusarium oxysporium* in primary roots of Douglas fir. Phytopathology, 81: 420-425.

Sturz, A.V., M.R. Carter and H.W. Johnston, 1997. A review of plant disease, pathogen interactions and microbial antagonism under conservation tillage in temperate humid agriculture. Soil Tillage Res., 41: 169-189.

Sundarababu, R., M.P. Mani and P. Arulraj, 2001. Management of *Meloidogyne incognita* in chilli nursery with *Glomus mosseae*. Ann. Plant Prot. Sci., 9: 161-162.

Toro, M., R. Azcon and J. Barea, 1997. Improvement of arbuscular mycorrhiza development by inoculation of soil with phosphate-solubilizing rhizobacteria to improve rock phosphate bioavailability ((sup32)P) and nutrient cycling. Applied Environ. Microbiol., 63: 4408-4412.

Torres-Barragan, A., E. Zavaleta-Mejia, C. Gonazalez-Chavez and R. Ferrera-Cerrato, 1996. The use of arbuscular mycorrhizae to control onion white rot (*Sclerotium cepivorum* Berk.) under field conditions. Mycorrhiza, 6: 253-257.

Umesh, K.C., K. Krishnappa and D.J. Bagyaraj, 1988. Interaction of burrowing nematode, *Radopholus similis*-(Cobb-1983) Thorne 1949 and VA mycorrhiza, *Glomu fasciculatum* (Thaxt.) gerd and trappe in banana (*Musa acuminata* colla.). Indian J. Nematol., 18: 6-11.

Waceke, J.W., S.W. Waudo and R. Sikora, 2001. Suppression of *Meloidogyne hapla* by Arbuscular Mycorrhiza Fungi (AMF) on pyrethrum in Kenya. Int. J. Pest Manage., 47: 135-140.

Wheeler, C.T. and I.M. Miller, 1990. Uses of Actinorhizal Plants in Europe. In: The Biology of Frankia and Actinorhizal Plants, Schwintzer, C.R. and J.D. Tjepkema (Eds.). Academic Press, New York, USA., pp: 365-390.

Yao, M., R. Tweddell and H. Desilets, 2002. Effect of two vesicular-arbuscular mycorrhizal fungi on the growth of micropropagated potato plantlets and on the extent of disease caused by *Rhizoctonia solani*. Mycorriza, 12: 235-242.