Chapter 10
Arbuscular Mycorrhizal Fungi as Biocontrol Agents for Parasitic Nematodes in Plants

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Abstract The use of synthetic fertilizers and pesticides has not only caused damage to environment but has caused detrimental impacts on the health of people. In order to feed the ever growing population and prevent environmental contamination and decrease the impact on human health organic farming is being promoted all over the world. The use of Arbuscular mycorrhiza fungi to boost agricultural productivity is considered a better alternative as it has strong influence on plant interactions by aiding plants in resource acquisition, disease suppression, and tolerance to soil pollution and play a decisive role in plant development. It also enhance the supply of water and nutrients (phosphate and nitrogen), to the host plant. In return, up to 20% of plant-fixed carbon is transferred to the fungus; hence the nutritional exchange is bidirectional. AMF acts as a biocontrol agent for various crops and thus reduces the burden of pesticides in agro-ecosystems. Advance research is needed to develop farming systems that optimize the use of natural resources such as mycorrhizal fungi for sustainable agricultural production. The present chapter is an attempt to study the role of AMF in controlling different plant parasitic nematodes along with its important advantages for the crop production.

10.1 Introduction

The increase in the yield of agriculture has been achieved by the introduction of inorganic fertilizers and pesticides (Reddy and Wang 2011). Today, agricultural practices are dependent on the chemical fertilizers and pesticides and use of

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nitrogen, phosphorus and potassium based fertilizers increased the crop productivity to large extent. However, increased dosage of chemical fertilizers caused serious effects on soil fertility that caused not only environmental pollution but also killed the beneficial microorganisms present in soil and thus increased resistance in pests against these pesticides. The poisonous chemicals which are applied in agricultural orchards are absorbed by plants; enter the food chain through vegetables and cereals causing many health problems. To overcome the problems a sustainable agricultural approach by involving microbial technology such as Mycorrhizae as biofertilizer and biocontrol agents is required (Dwivedi and Padmanabh 2002) as they play a fundamental role in nutrients fixing, solubilizing and mobilizing nutrients. Mycorrhizae have significant effect on the rhizosphere as they interact with other soil biota such as phosphate solubilizing bacteria, plant growth promoting rhizobacteria, plant pathogens and other bioagents, which results in a significant positive or negative effects on plant growth (Paulitz and Linderman 1991) hence, play a important role in sustainable farming system because AMF are efficient when nutrient availability is low and nutrients are bound to organic matter and soil particles. Arbuscular mycorrhizal fungi are obligate root symbionts that colonize more than 80% of all land plant species. They increase plant growth through improved nutrient uptake in exchange for photosynthetic carbon from their host (Smith et al. 2010). Hence, AMF has a strong potential to increase the agricultural productivity and may help in conservation of environment by reducing the burden of fertilizers and pesticides.

AMF provide their favourable services to almost all terrestrial ecosystems, from grasslands to forests, deserts and agro-ecosystems as it is present in one or the other species in these ecosystems. The formation of symbiotic relationships with the majority of land plants, including many important crops is the key for its establishment in such ecosystems (Smith and Read 2008) and generally provide nutrients, especially phosphorus, to plants in exchange for plant carbohydrates (Smith and Read 2008). Further, they can provide protection against pathogens (Sikes et al. 2009) and drought (Auge 2001). With the advent of modern genetic engineering, AMF is tested for many other crops and success rate is quite appreciable, thus novel transgenic crop plants with superior yields and improved traits for resistance to insect pests and pathogens, tolerance to herbicides, and improved ability to endure environmental stress has been created (Sharma and Srivastava 2008). The improvement in soil structure and soil properties by mixing AMF enhances the sustainability of waste lands (Wilson et al. 2009), and by reducing nutrient losses after rain-induced leaching events that will help in the restoration of wastelands and reclamation of barren areas (Van der Heijden 2010) round the year as different species are active during different seasons. Merryweather and Fitter (1998), that makes it suitable for different plant species under different environmental conditions (Ravnskov and Jakobsen 1995). Several studies indicated that diverse AMF communities may improve plant productivity and ecosystem functioning as observed in (van der Heijden et al. 1998; Vogelsang et al. 2006). AMF may become significant in escalating crop productivity in acid soils because they may stimulate Phosphorus uptake in highly P-fixing conditions. Enhanced uptake of P is generally regarded as the most significant benefit that AMF provide to their host plant, and plant P status is often the main controlling factor in the plant-fungal relationship (Graham 2000). The present necessity in agriculture for high yields as quickly as possible may be an ongoing necessity for the future of food production. Smith and Read (1997a, b) pointed out that incorporation of cultural practices will increase AMF diversity. Sustainable production of food crops in the tropics is often severely constrained by the fragility of soils, being prone to several forms of degradation. Making better use of the biological resources in these soils can contribute to enhanced sustainability. Mycorrhizal fungi constitute an important biological resource in this respect. Therefore, the aim of the present chapter is to study the role of AMF in controlling different plant parasitic nematodes along with its important advantages for the crop production.

10.2 AMF and Organic Agriculture

The association of AMF brings significant changes in the host plant and its environment by changing the rhizosphere level, soil structure, carbon deposition, microbial diversity and in part through changes in exudation of roots. The out-come of plant interactions with other organisms, including pathogens and beneficial microbes is due to then shifts in the microbial communities of the rhizosphere (Berta et al. 2002, 2005; Artursson et al. 2006; Lendzemo et al. 2007; Cipollini et al. 2012; Effmert et al. 2012) with multiple modifications in the rhizosphere within the host plant. Therefore, it is believed that introduction of AMF for organic agriculture has diverse benefits. Organic farming by AMF will preserve and conserve the environment's balance, increases natural resources and develops healthier and better products. Agricultural systems use large quantities of inorganic fertilizers and pesticides is a method to alleviate food shortages. However, the introduction of heavy chemicals in agricultural systems cause serious problems, such as disturbance of agricultural ecosystems, and have high environmental costs. The degenerative effects of intensive farming practices on soil fertility and ecological balance are surfacing which needs immediate attention for sustaining the productivity rate (Narayanan 2005; Dubey and Shukla 2014). However, the major problem in most developing countries is the poor nutritional status of soils due to less content of the organic matter (Narayanan 2005; Dubey and Shukla 2014). AMF is seen as an ecological production management system that will promote and enhance biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony. The aim of introduction of AMF into agricultural ecosystems is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people (National Organic Standards Board 1997). However, a lot will depend on the efficiency of AMF inputs in the promotion of the productivity on the organic contents of the soil. Mycorrhizal fungi are now common in agricultural systems and are particularly relevant for organic agriculture because they can act as natural fertilisers, enhancing plant yield. Moreover, mycorrhizal fungi can directly and indirectly contribute to plant productivity in organic farming systems (Van der Heijden et al. 2008). Low-input organic farming systems have increasingly aroused interest due to their focus on natural resource conservation and reduction of environmental degradation. The characteristics of general principals of organic farming include: (1) elimination of synthetic biocides; (2) addition of organic fertilizers to the soil, including farmyard manure, compost and crop residue, and slow release mineral fertilizers such as rock phosphate; and (3) crop rotation practices must be encouraged (Van der Heijden et al. 2008). Organic farming relies heavily on active soil microbial communities and AM fungi play a vital role in agro ecosystem function. It has been reported that compared to conventional systems of organic farming, AMF has increases microbial colonization, propagule numbers, and species diversity (Eason et al. 1999; Oehl et al. 2004; Ryan et al. 2000).

10.3 Role of AMF in Soil Improvement

The health of plants is closely linked to soil health, managing the soil in different ways that conserve and enhance the soil biota can improve crop yields and quality. Agricultural management also has profound effects on soil communities (Zadehbagheri et al. 2014b). A varied soil community will not only help prevent losses due to soil-borne pests and diseases but also speed up decomposition of organic matter and toxic compounds, and improve nutrient cycling and soil structure. Microorganisms are the most abundant members of the soil biota. They include species responsible for nutrient mineralization and cycling, biological control agents against plant pests and diseases, species that generate substances capable of modifying plant growth, and species that form mutually beneficial symbiotic relationships with plant roots (SP-IPM 2004). The most abundant members of the vast community of soil organisms that develops mutually beneficial relationships with plant roots and contributes majorly to plant growth are called mycorrhizal fungi. They are versatile organisms with complex ecological ramifications in the soil system that has been complicated to study and understand (Kapoor et al. 2004; Cavagnaro et al. 2006). The phytocentric concept of AMF that has prevailed since the naming of these organisms is being replaced by a holistic vision recognizing that AMF are a key element of soil functioning and health rather than a plant root component (Zadehbagheri et al. 2014a, b). The most common and best known of these associations are the AMF (Powell and Bagyaraj 1984). AMF have been suggested to improve biodegradation of persistent organic pollutants because of the immense size and very high surface interface with soil. AM fungi are of importance as they play a vital role in metal tolerance (Del Val et al. 1999) and accumulation (Zhu et al. 2001; Jamal et al. 2002). AMF associations have a direct effect on soil structure, which is especially important in mixed culture systems, where cultivations and low levels of soil organic matter tend to result in damaged soil structure. AMF association with crop components in mixed culture systems have been reported to have a great impact in soil structure (Borie et al. 2000; Franzluebbers et al. 2000; Wright and Anderson 2000; Rillig et al. 2003; Rillig 2004). The essential ecological role played by AMF is their capacity to influence directly the diversity and composition of the aboveground plant community confirmed that plant species richness can be altered not only by climatic and edaphic factors, but also by soil microbial assemblages (Van der Heijden et al. 1998; Scheublin et al. 2007; Facelli et al. 2010). In addition, they improve plant growth, help in contaminant removal, reduce the need for fertilizer application in commercial plant production, and improve the soil structure and health. Although, relatively few specific plant-fungus combinations have been studied for their efficacy and application in remediation and resource conservation, the existing data on the benefits for mycorrhiza are promising.

10.4 Mechanism of Inhibition by AMF

Different mechanisms are reported to explain bio-control by AMF including biochemical changes in plant tissues, microbial changes in rhizosphere, nutrient status, anatomical changes to cells, changes to root system morphology and stress alleviation (Hooker et al. 1994). Various workers have demonstrated the protective effect of mycorrhizal symbioses against root pathogenic fungi (Caron 1989; Dehne 1982). The complex interactions between pathogens, AMF and plant are consequences of disease reduction within host plants colonized by AMF (Harrier and Watson 2004). The damage caused by soilborne pathogens is inhabited by AMF symbiosis (Azcon-Aguilar et al. 2002). *Phytophthora parasitica* propagation decreases when tomato root is colonized by *Glomus mosseae* and *P. parasitica* compared with non-mycorrhizal tomato roots (Cordier et al. 1996). The contribution of phosphate by AMF lessen the damage caused by *P. parasitica* in tomato (Trotta et al. 1996). The time required by *Ganoderma boninense* to infect and kill oil palm plant and the seedlings is greatly reduced (Rini 2001). AMF has shown no indirect interaction with soilborne pathogen through antagonism, mycoparasitism and or antibiosis (Harrier and Watson 2004). AMF may enhance host tolerance to pathogen by increasing the uptake of essential nutrients rather than phosphorus which are otherwise deficient in the non-mycorrizal plants (Gosling et al. 2006). The nutrient uptake resulted in more dynamic plants and make the plant itself may be more resistant or tolerant to pathogen attack (Linderman 1994). The uptake and translocation of nitrogen by hyphal fungus is controlled by host plant's demand for N (Hawkins and George 2001). AMF increase host resistance of pathogen attack to compensate the loss of root functional activities and biomass caused by soil borne pathogens (Linderman 1994) including fungi and nematodes (Cordier et al. 1996). AM fungi enhanced uptake of Zn, S and Ca (Clark and Zeto 2000) and also Iron (Fe) acquisition has been enhanced, apart from phosphorus and Nitrogen uptake. It is found that AM plants that are grown at low pH had higher Fe gain than AM plants grown at high pH (Treeby 1992). Manganese gain generally was lower in AM plants compared to non AM plants (Azaizeh et al. 1995). Copper and zinc concentrations increased in leaves of AM soybean plants, sulfur acquisition was enhanced in sorghum colonized by *Glomus fasciculatum* (Raju et al. 1990), boron content was enhanced in AM maize shoot and calcium (Ca), sodium (Na) and magnesium (Mg) was also increased compared to the non AM *Gigaspora gigantia* soybean plants in low Phosphorus.

Plants colonized by AMF vary from non-mycorrhizal plant in rhizosphere microbial community that cause changes in root respiration rate quality and quantity of the exudates (Marschner et al. 2001) is another proposed mechanism. Few researchers believe that that AMF changes the composition of functional groups of microbes in the mycorrhizosphere, including the numbers and/or activity of pathogens antagonists (Secilia and Bagyaraj 1987). Fluctuations in the functional groups of microbes, including more facultative anaerobic bacteria in mycorrhizosphere of AMF colonized *T. Subterraneum* has been observed. The total number of bacteria isolated from rhizoplane of *T. subterraneum* and *Zea mays* increased due to AMF colonization (Meyer and Linderman 1986). Physical competition between endomycorrhizal fungi and rhizosphere microorganisms to occupy more space in the root architecture is one of the mechanism proposed to explain the interaction between AMF and soil microorganisms (Bansal and Mukerji 1996). Morphological and anatomical changes as observed by Dugassa et al. (1996) in tomato and cucumber can be one more explanation to inhibit pathogens. A limited data in support for the carbon compounds received by the root has been cited in literature (Smith and Read 1997a, b). The higher carbon demand may inhibit the pathogen growth when AMF have primary access to the photosynthate (Linderman 1994).

10.5 Arbuscular Mycorrhizae as Biocontrol Agents of Plant Parasitic Nematodes

Plant-parasitic nematodes, including endoparasitic nematodes and AMF often survive collectively in the rhizosphere colonizing the same area in roots of host plants. The association between AMF and nematodes (Hussey and Roncadori 1982; Elsen et al. 2003; de la Peña et al. 2006) and nematode reduction (Sankaranarayanan and Sundarababu 1994; John and Bai 2004; Kantharaju et al. 2005; Siddiqui and Akhtar 2007), no effect (Hasan and Jain 1987) or an increase in numbers of nematodes (Atilano et al. 1981) has been reported from earlier times. Various studies confirmed that AMF enhances host tolerance or resistance in many plant/nematode systems and induce systemic resistance against plant-parasitic nematodes in the roots (Elsen et al. 2008). Marro et al. (2014) reported that plant-parasitic nematode *Nacobbus aberrans* induces gall formation in the roots and causes severe losses to diverse crops. Few nematodes of this group show inclination for certain hosts with different behaviour that make nematode management difficult. The authors argued that a possible biological control alternative to decrease the damage caused by this species may be the use of arbuscular mycorrhizal fungi (AMF). The consequence of *Glomus intraradices* on tomato plants inoculated with the nematode at transplanting. The use of AMF favoured tomato biomass and decreased the number of galls on the plants inoculated with the nematode at transplanting.

AMF is used as biocontrol agents to decrease infestation by root-knot nematodes as it is believed that AMF and plant parasitic nematodes compete with each other for the same site. The population of *Tylenchulus semipenetrans* infesting citrus is controlled by the dose of AM fungus of 500 chlamydospores per tree (Pandey et al. 2004). Rodriguez Romero and Jaizme-Vega (2005) reported that micro-propagated plants of banana (*Musa acuminate*) cv. Grand Naine were inoculated with *Glomus manibotis* initially and then by *Meloidogyne javanica* that reduced the number of galls and the population of *M. javanica* with no harmful effect on root colonization by the mycorrhizal fungus. The interactive effect of mycorrhizal fungus, *Glomus fasciculatum* with root knot nematode, *Meloidogyne incognita* and their effect on tomato was studied by Shreenivasa et al. (2007). Nematode population, number of galls and root knot index was significantly reduced by *G. fasciculatum* and increased the growth, phosphorous uptake, plant biomass and productivity of tomato compared to plants inoculated with nematode alone. Hajra et al. (2013) studied the biocontrol of nematodes by arbuscular mycorrhizal (AM) fungi and reported significant variations in different parameters. The mycorrhized plants showed increase in leaf area and plant height than non-mycorrhizal plants, but mycorrhizal plants exhibited a sharp drop off in nematode- infected plants due to xylem vessels damage. The capability of mycorrhizal fungi, oil palm bunch refuse and sawdust mulches on banana growth and nematode infection has been investigated by Omolara (2014). Sawdust mulch enhanced leaf area by 215%, mycorrhizal fungi by 234% and oil palm bunch refuse by 267%.

Nematodes are diverse group comprising free-living nematodes and plant and animal parasites that are present all over the world in various habitats (Ferraz and Brown 2002). Many species of plant-parasitic nematodes (PPN) can act as pests on a wide range of economically important agricultural crops. The use of biological control organisms, such as AMF is an environmentally friendly alternative to manage PPN (Bajaj et al. 2015, 2017). AMF can may alleviate plant stress caused by abiotic and biotic factors, including PPN (Gianinazzi et al. 2010; Singh et al. 2011; Vos et al. 2012a). The biocontrol effect of AMF was also seen in different plant species and against many pathogens, although, successful biocontrol has also been observed against aboveground pathogens such as *Alternaria solani* in tomato (Harrier and Watson 2004; Whipps 2004; Fritz et al. 2006; Pozo and Azcón-Aguilar 2007; Jung et al. 2012). Necrotrophic and biotrophic pathogens were reported to be inhibited by AMF, either directly or indirectly (Veresoglou and Rillig 2012). Greenhouse and field experiments indicated defensive effects against PPN by AMF in plants such as banana, coffee and tomato (Calvet et al. 2001; Vos et al. 2012b; Alban et al. 2013; Koffi et al. 2013).

AMF significantly decreased seed germination of a few obligate root parasitic plant species like *Strigam hermonthica* (Lendzemo et al. 2005, 2006; Hearne 2009; Gworgwor and Weber 2003) and *Orobanche Cumana* (Louarn et al. 2012) and thus have a potential in biocontrol against obligate root parasitic weeds. Li et al. (2012) reported, inoculation with AM fungi inhibited haustorium formation in facultative root hemiparasitic *Pedicularis tricolor*. Further, phosphorus transfer from the host plant into *P. tricolor* and *Pedicularis rex* was significantly decreased. The growth of hemiparasites was inhibited after AM inoculation, suggesting that AMF have a potential in the management of *Pedicularis* species (Li et al. 2013).

The effects of *Fusarium oxysporum*, a soil-borne biocontrol agent (BCA) was studied against *Striga hermonthica*, on fungal and arbuscular mycorrhizal fungal (AMF) taxa in rhizospheic clay and sandy soil of maize. 'Foxy-2' that was used against *S. hermonthica* promoted total fungal abundance and stimulated AMF *Gigaspora margarita* abundance. No adverse effects were shown by 'Foxy-2' on indigenous rhizosphere fungal communities indicating its environmental safety as BCA against *S. hermonthica* (Zimmermann et al. 2016).

Present study deals with the biocontrol of *Fusarium* wilt of chickpea using arbuscular mycorrhizal fungi (AMF) *Glomus hoi* (Gh), *Glomus fasciculatum* (Gf) and *Rhizobium leguminosorum Biovar*. (Rl), which are the important members of rhizosphere and biological control agents, like AMF, Gh, Gf and RI were studied on both the patho- system of *Fusarium oxysporum* f. sp. ciceris (Foc) and chickpea (*Cicer arietinum*). The differences were exhibited on colonization and nodulation of two biocontrol agent reciprocal interactions. The decrease in nodulation of Rl particularly and colonization of AMF significantly decreased in treatment of Foc +AMF than control. The single biological control agent inoculations were more effective than dual inoculations (AMF+Rl) and the morphological parameters of chickpea showed decrease in treatments which present Foc. In addition to this, all biological control agent increased total contents of P and N in treated plants compared to controls (Singh et al. 2014).

The obligate symbionts that colonize the roots of the most cultivated plant species are known as AMF and almost all types of ecological situations may be found naturally in most of the species. Endoparasitic nematodes and arbuscular mycorrhizal fungi, together colonize the same area of the rhizosphere roots of host plants during interaction. The members of the microbial populations like AM fungi and root knot of the plant rhizosphere compete with each other for the same site in rhizosphere. Hence, AM fungi can be used as biocontrol agents to reduce infestation by root-knot nematodes. Systemic resistance against plant-parasitic nematodes in the roots of higher plants improved host nutrition.

Antagonism has been demonstrated and believes to be the result of or may be due to improved host nutrition (Youssef and El-Nagdi 2015). *Verticillium dahliae* Kleb is a vascular pathogen that alters water status and growth of pepper plants and causes drastic reductions in yield. Its control is difficult because it can survive in field soil for several years. The application of AMF as bioprotector agents against *V. dahliae* is an alternative to the use of chemicals which, in addition, is more respectful with the environment. Some AMF can improve the resistance of

Capsicum annuum L. against *V. dahliae*. This is especially relevant for pepper cultivars (i.e. cv. Piquillo) that exhibit high susceptibility to this pathogen. Compared with non-mycorrhizal plants, mycorrhizal pepper can exhibit more balanced. A balanced antioxidant metabolism in leaves of mycorrhizal pepper has been observed after pathogen inoculation that delays the development of disease symptoms and photosynthesis decrease in *Verticillium*-inoculated plants. The higher deposition of lignin in xylem vessels of stem cells was shown as compared to non-mycorrhizal plants. AMF has been used as bioprotector agent against *V. Dahlia* and improved the resistance of *Capsicum annuum L* against *V. Dahlia*. Non-mycorrhizal plants of the arbuscular and ectomycorrhizae out of the known mycorrhiza are the most abundant and wide spread that promote plant growth by enhancing nutrient acquisition and promoting growth hormones. The increase in the resistance in plants against plant pathogens and surface area of root system for better absorption of nutrient from soil may be achieved by using AMF, hence may be used as biofertilizer and as biocontrol agents (Goicoechea et al. 2010).

Sui et al. (2014) observed AM colonization in roots of *P. kansuensis*, although much lower than those of its adjacent host species of hemiparasite. The relation between AM levels and the number of haustoria was negative for field samples of the hemiparasite. A significant reduction in plant dry weight (DW) with strong suppression in the production of haustorium and marked reduction in the survival rate of *P. kansuensis* after inoculation with AM fungi was observed. On the other hand, inoculation with *G. mosseae* enhanced root DW and whole plant DW of parasitized host plants. A positive repressive effect of AMF on growth performance of *P. kansuensis*. Leta and Selvaraj (2013) pointed out that *G. aggregatum* and *T. harzianum* ATh1 isolate can block the severity of disease caused by *S. cepivorum* in onion. Use of these bio-control agents could be promoted as an active component of bio-intensive Integrated Disease Management Program (IDMP), under organic mode. Vigo et al. (2000) confirmed that effects on numbers of infection loci on tomato root necrosis are one mechanism *via* which AMF achieve biocontrol of this pathogen. The rate of spread of necrosis within roots showed no changes caused by the AMF. Inoculation with the pathogen after 26 days at harvest revealed 61% of roots of noncolonized plants were necrotic compared with only 31% in AMF-colonized plants. Dehariya et al. (2015) investigated the effect of individual and co-inoculation of Trichoderma species and arbuscular mycorrhizal fungi on growth, mycorrhization, population of *Trichoderma*, and wilt disease severity in pigeon pea (*Cajanus cajan* L Mill sp.). Co-inoculation of Th and Myc gave highest growth and reduced severity of wilt disease of pigeon pea significantly. Myc alone was sufficient to promote growth and was effective in terms of disease suppression before pathogen inoculation. The shoot length, dry weight, phosphorus (P) uptake of plants, AMF colonization, spore density, and population of *Trichoderma*. Significant physiological changes take place in the host plant upon root colonization by AMF affecting the interactions with a wide range of organisms. Protective effects of the symbiosis against pathogens, pests, and parasitic plants have been described for different plant species, including agriculturally important crop varieties (Jung et al. 2012). A possible biological control alternative to reduce the damage caused by *N. aberrans* may be the use of arbuscular mycorrhizal fungi. The effect of *Glomus intraradices* on tomato plants inoculated with the nematode at transplanting and three weeks later was tested. AMF colonization was higher in the presence of the nematode. The use of AMF favoured tomato biomass and reduce the number of galls and RF on the plants inoculated with the nematode at transplanting (Marro et al. 2014).

10.6 Conclusions

The minimal and no use of synthetic fertilizers in agriculture and the use of organic manure, to replenish the soil of its lost nutrients is known as organic farming. The research oriented towards use of AMF for control of pathogens or plant defence induction may replace pesticides and fertilizers in near future. The improvement in crop productivity and disease resistance is an indication for the same. The control of plant nematodes with the help of AMF will prevent losses arising due to various nematode pathogens. Changes in architecture, ability to increase the uptake of phosphorous by plant, metabolic profile fluctuations and defence compound accumulation occurrence makes AMF exceptionally different from other organic manures. In sustainable and organic agricultural systems, the role of AMF in maintaining soil fertility and bio-control of plant pathogens may be more important than in conventional agriculture where their significance has been marginalized by high inputs of agrochemicals. Therefore, the management and planned applications of AMF to improve growth of beneficial and important crops particularly in developing world with an understanding of exploiting AMF payback towards sustainable agricultural development is very important. It is believed that farming with AMF will be helpful in developing eco-friendly and cost effective plant disease management practices, will open and establish new avenues in the field of agriculture and industry.

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