Chapter 17

Impact of Arbuscular Mycorrhizal Fungi (AMF) in Global Sustainable Environments

Sanjeev Kumar and Joginder Singh

17.1 Introduction

The arbuscular mycorrhizal (AM) association is a symbiosis between soil-borne fungi with more than 80% of the terrestrial land plants. Colonization of AM fungi with host roots resulted in increased growth and development of plants. This association further improved nutrient uptake and increased protection against soil-borne pathogenic fungus (Smith and Read 1997; St-Arnaud and Vujanovic 2007). Arbuscular mycorrhizal fungi are important components of soil microbiota and form mutual interactions with other microorganisms of rhizospheric soil (Bowen and Rovira 1999; Mathur et al. 2011; Yadav et al. 2019a). These interactions are mainly confined to the mycorrhizosphere region of plant that leads to changes in the physical and chemical structures of the soil. Furthermore, associations change in root exudation pattern (composition and quantity) and fungal exudates, and mycorrhizal formation can affect the microbial population present in rhizosphere. This also affects the colonization pattern by soil microorganisms, and it is known as mycorrhizal effect (Gryndler 2000). Mycorrhizosphere is known as a zone which influences the mycorrhiza (fungus roots) in the soil (Oswald and Ferchau 1968). Moreover, the mycorrhizosphere consists of two components as shown in Fig. 17.1. One is a thin layer of soil that surrounds the root, known as rhizosphere. The other is a zone of AM hypha–soil interaction (Marschner 1995) called hydrosphere. Hydrospheric zone consists of AM soil mycelium, and this is not affected by plant roots. Therefore, mycorrhizosphere region affects soil fertility and quality. Current application of chemical fertilizers and pesticides with

S. Kumar (✉)
Department of Genetics and Plant Breeding, Lovely Professional University, Jalandhar, India

J. Singh
Department of Biotechnology, School of Bioengineering and Biosciences,
Lovely Professional University, Jalandhar, Phagwara, Punjab, India

A. N. Yadav et al. (eds.), *Recent Advancement in White Biotechnology Through Fungi*, Fungal Biology, https://doi.org/10.1007/978-3-030-25506-0_17

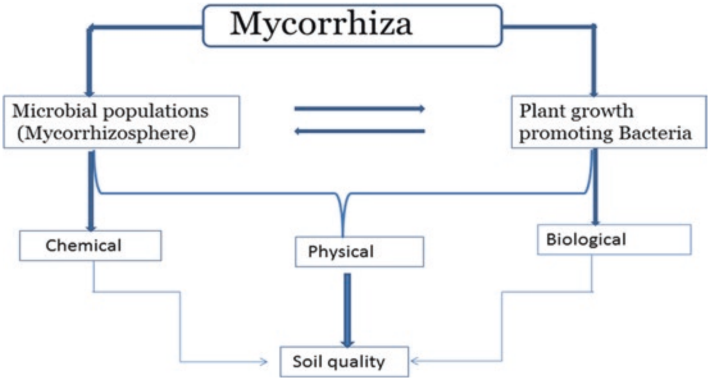

Fig. 17.1 Arbuscular mycorrhizal fungi interacted with plant growth-promoting bacteria (Beneficial microorganism) in the mycorrhizosphere affecting soil properties and quality. (Modified from Jeffries et al. (2003))

continuous husbandry of single crop may affect the community composition pattern of AM fungi in different soil types.

Describing the diversity of AM communities at sites becomes, therefore, an important step in determining the effect of different agricultural practices. Mycorrhizal communities are site-specific, and each species can be affected in several ways by different agricultural management practices. Agricultural practices such as tillage, fertilization, and crop rotation affect the structure of AMF communities. There are a number of reports that have described AM community composition in differently managed ecosystems, as briefly shown in Table 17.1. In recent years, organic farming practices have gained importance in many industrialized countries for the conservation of natural resources and reduction of environmental degradation (Maider et al. 2002; Yadav et al. 2017, 2018, 2019b). Several reports concluded significantly greater AMF colonization in organically managed soil which further enhances microbial activity and biodiversity (Maider et al. 2002; Kumar and Adholeya 2016). In contrast, very few studies have dealt with structural and functional differences among AM fungi in different land-use systems. The screening and identification, and multiplication of diverse AMF species occurring over a broad range of land-use intensity will contribute to meeting the future need for sustainable development.

17.2 Extraction and Propagation of AMF

The obligate symbiotic nature of AM fungi has greatly hindered their use in agriculture, agroforestry, and the commercialization of inocula. Additionally, biodiversity of AMF species is measured mainly by extracting, counting, and identifying their field-collected asexual spores containing limited taxonomic characters. To overcome this limitation, new methodologies have been required that allow studies of different aspects of life cycle of AM fungi. For this purpose, in the last few decades,

Table 17.1 A summary of number of AMF species reported in different land-use system

Habitats	Number of AM species	Trap culture used	References
Bamboo Forest, Taiwan	14	–	Wu and Chen (1986)
Old meadow, Quebec	13	–	Hamel et al. (1994)
Grassland, North Carolina, USA	23	+	Bever et al. (1996)
Tallgrass prairie, Kanas, USA	14	–	Bentivenga and Hetrick (1992)
Sonoran deserts crub, Arizona, USA	7-–9	+	Stutz and Morton (1996)
Sand dune, Rhode Island, USA	6	–	Koske and Halvorson (1981)
Sao Paulo, Brazil	19	–	Trufem (1995)
Santa Catarina, Brazil	12	–	Stürmer and Bellei (1994)
Sandy soil, Hel Peninsula, Poland	34	–	Blaszkowski (1994)
Native vegetation, Cultivated Soil, Poland	46	–	Blaszkowski (1993)
Native woodland, Florida, USA	10	+	Schenck and Kinloch (1980)
Malus domestica orchards, USA	3–6	+	Miller et al. (1995)
Wheat monoculture, Cultivated	24	–	Schalamuk et al. (2006)
Amazon forest, Colombia	18	–	Peňa-Venega et al. (2007)
Western Brazilian, Amazon	54	–	Stümer and Siqueira (2011)
Changins, Canton Vaud, Switzerland	26	+	Mathimaran et al. (2005)
Native forest and grassland in southeast Tibet	08		Xu et al. (2017)
Cr contaminated site of Jajmau, Kanpur, India	07	+	Akhtar et al. (2017)

Modified from Douds and Millner (1999)

a number of reports are available (Schenck 1982; Brundrett et al. 1994; Clapp et al. 1996; Verma and Adholeya 1996) that deal with isolation and enumeration of AM fungal propagules, propagation of AM propagules in greenhouse pot culture, and finally, storage of fungal material for germplasm collection, which required thorough understanding of AM fungal life cycle and growth pattern.

17.2.1 *Pot-Culture Inoculum*

The most intensively used pot-culture technique consisted of growing bait plants in field-collected soil. It allows the sporulation and multiplication of AM fungal propagules (spores and colonized roots) present in the collected soil sample. The collected soil sample was frequently diluted with a variety of inert substrates (Feldman and Idczak 1994; Lilly and Santhanakrishnan 1999), sterilized sand (Bragaloni et al. 1998; Gaur and Adholeya 2002), vermiculite, or Terra green (Baltruschat 1987). This propagation approach multiplies AM species of unknown composition.

17.2.2 Trap Culturing

Field-collected AM spores are found to be low in numbers, parasitized with microbes and fungi, lacking suitable information for taxonomic characters, and hindering a more accurate identification. Trapping is necessary to obtain healthy AM spores for identification as well for using as inoculum to establish monospecific culture. Trap cultures are helpful in unveiling AM community that is undetected in initial extraction of spores from field soil (Morton et al. 1995). Beaver et al. (1996) and Koske et al. (1997) observed that trap cultures tended to encourage preferential sporulation of some species when different conditions are applied. Miller et al. (1985) recovered 14 AMF species in *Sorghum* and *Coleus* trap cultures that were not previously present in field sampling of apple orchards. Trap culture has been extensively used to investigate AM biodiversity and isolates of indigenous fungi (Morton et al. 1995). Beaver et al. (1996) established *Sorghum* trap cultures and also transplanted intact plants from the field to microcosms in order to complement their diversity estimates based on field-collected spores from mown grassland. Successive generation of trap cultures using the same soil sample often allows the initiation of nonsporulating dormant species (Stutz and Morton 1996). Establishment of trap cultures greatly improves the assessment of species composition in an ecosystem, and in some cases, it can promote the sporulation of cryptic AMF species that were not sporulating in field conditions (Stürmer 2004). AMF biodiversity studies from 30 sites in Arizona, USA, were compared to determine the impact of urbanization on AMF communities by Bills and Stutz (2009). In this study, they used trap cultures for AM spores propagation collected from the field soil of nonindigenous and indigenous plants at urban sites and from indigenous plants at desert sites.

17.2.3 Single-Spore Culture

It is well known that pot culture established from multiple spores setup from field soil may contain more than one species/isolate of AM fungi. Establishment of a single-spore culture is the same like pot culture but, as their name implies, it is initiated using single spore. Single-spore culture of AM fungi constitutes valuable resource, not only for plant growth experiment but also for taxonomic and biochemical studies. Several techniques were reported for establishing monosporic culture from germinated and ungerminated spores by Hepper (1984) and Brundrett and Juniper (1995). Later, more improved methods for hypha and single-spore propagation were described by Fracchia et al. (2001). Single-spore culture using healthy-looking AM spores was collected from pot culture and originated from field soil usually with high success rate (80%) particularly for ‘aggressive’ species of Glomeromycota (Walker 1999). However, the success rate for the development of monosporic culture using field-collected spore is only 1%. This may be due to contamination of (1) fragment of hyphae, (2) other species sporulating inside dead spores, and (3) production of a culture of a species other than the one thought to have been used for inoculation.

17.3 Biodiversity of AMF

17.3.1 Subtropical Agricultural Soil

Many soils of tropics are low in soil biodiversity and prone to degradation because of soil moisture stress, low nutrient capital, high erosion, low pH, high P fixation, and low amount of soil organic matter (Sanchez et al. 2003; Kour et al. 2019; Rana et al. 2019a, b). In the last decade, intensive use of inorganic fertilizers and pesticides along with introduction of new high-yielding cultivar had overcome these constraints (Dalgaard et al. 2003). However, at the same time, decline in quality and fertility of soils leads to gradual decline in household food production in tropic and subtropic ecosystems. Several recent studies have demonstrated that AM fungi are common and ecologically important in tropical ecosystems; and they co-occur with mixture of plant species; maintain soil fertility; guard against erosion; and fully utilize soil resources (Alttieri 2004).

Almost all tropical plants have mycorrhizal association. There are 102 AM fungi reported in diverse tropical habitats from India (Ragupathy and Mahadevan 1993; Manoharachary et al. 2005). The occurrence of AM fungi in a forest and also coastal regions of Andhra Pradesh was reported by Manoharachary and Rao (1991); distribution and identification of AM fungi in the rhizosphere soils of the tropical plains were done in Tamil Nadu, India, by Ragupathy and Mahadevan (1993); and from natural forest regions in the Old Delhi Ridge, Saraswati Range of Haryana, by Thapar and Uniyal (1996). Diversity of AM fungi has also been studied in the coastal sand dunes of the west coast of India (Beena et al. 2000); in deciduous forests in Dharwad district of Karnataka (Lakshman et al. 2001); in the Western Ghats of Goa (Khade and Rodrigues 2003); and in coastal saline soils of Kerala, South India, (Karthikeyan and Selvaraj 2009).

The AM biodiversity in rhizospheric soil of plant *Leucaena leucocephala* was studied from the agricultural field of Bangalore and reported by Nalini et al. (1987). Diversity of AM fungi was studied in the pot-culture setup from the agricultural field soil of different wheat-growing regions of India by Singh and Adholeya (2002). A subsequent study by Sunil Kumar and Garampalli

(2010) reported AM fungal diversity in agricultural soils of maize, wheat, Pigeon pea, and chickpea plants; and soil samples were collected from Gwalior and Hassan districts, India. AM fungi were collected from the tannery effluent-polluted soil of Tamil Nadu, India, by Sambandan et al. (1991). Raman et al. (1993) described and identified *Glomus* and *Gigaspora* spp. in the mycorrhizospheres of 14 plant species collected from a magnesite mine spoil in India. Later studies by Raman and Sambandan (1998), and in soils of Kanpur, Uttar Pradesh, by Khade and Adholeya (2009), described AM community from tannery-contaminated soils.

17.3.2 Inorganically Managed Agricultural Soil

Arbuscular mycorrhiza is an association between plants and fungus and must be studied as a dynamic system, not as an individual organism. This dynamic system leads to hypotheses for a number of investigations, and also edaphic properties influence both plants and mycorrhiza diversity. An earlier study by Hayman (1975) found that crop rotation and fertilizer's treatment caused changes in spore population in soil. Abbott and Robson (1991) observed that more of AM community is in the top 8 cm of zero-tilled soil as compared with tilled soil. Later studies by McGonigle and Miller (1993) observed that less tillage of soil is better for mycorrhizal population, and that reduced disturbance of soil with ridge tillage resulted in more induced mycorrhizal population. Subsequent studies by Johansen et al. (1993) observed that application of inorganic fertilizers increased the abundance of specific mycorrhizal fungi, for example, *Rhizophagus intraradices* and *Funneliformis mosseae,* whereas, other species like *Gigaspora gigantea*, *Gigaspora margarita*, *Scutellospora calospora,* or *Paraglomus occultum* significantly decreased in abundance. In a subsequent report, Treseder et al. (2004) show that conventional agricultural practices such as application of inorganic fertilizers and tillage tend to decrease AMF spore abundance and alter community composition. Similar findings by Hijri and Sanders (2005) observed AMF species diversity to be low in agricultural field and also found that low-input agricultural land with crop rotation practices induces relatively high AMF species richness. Jasper et al. (1989) observed that soil disturbance decreases AM colonization of plants via destruction of AM fungal network. Tillage practices reduce AMF spore density and species richness (Hendrix et al. 1990; Altieri 1999). Galvez et al. (2001) observed negative impact on AMF spore numbers and on the density of AMF hyphae in tilled soil. Higher AMF infection potential, as well as faster development of AMF colonization, was observed in soils under reduced tillage conditions by McGonigle and Miller (1996). By contrast, Jansa et al. (2002) found no significant effect of tillage on diversity indices of the AMF community structure. Jansa et al. (2002, 2003) found that *Rhizophagus* species is generally predominantly present in tilled soil. On the contrary, *Scutellospora* sp. was observed in minimum-tilled soil.

17.3.3 Organically Managed Agricultural Soil

Arbuscular mycorrhizal fungi are important members of soil microbial community and can exert beneficial effect by application of low-input organic agricultural practices. Many agricultural practices can negatively affect AM fungal population while organic agricultural practices may be the sustainable practices and increase the number of AM spores in soil. This may be due to increased pore volume of soil which has a beneficial effect on AM colonization, the mycorrhizal growth response, and AM spore density (Giovanetti and Avio 1985). The addition of organic matter also decreases the mechanical soil resistance to the growth of AM hyphae (Joner and Jakobsen 1995). AM sporulation was found to be enhanced when soil rich in organic amendments was investigated by Douds et al. (1997) and Johnson and McGraw (1988). Application of farmyard manure overall reduced AM density in rhizospheric soils of corn, millet, and sunflowers as reported by Harinikumar and Bagyaraj (1989); however, other field studies have observed negative effects of farmyard manure on mycorrhizal colonization (Jensen and Jokobsen 1980). Subsequent studies by Muthukumar and Udaiyan (2000) found that organically managed soil improves colonization of roots with mycorrhizal fungus. Additionally, application of organic matter can have a beneficial effect on the growth of indigenous AM fungi in nutrient-limited soils (Caravaca et al. 2002; Gaur and Adholeya 2002). Overall, higher biomass and diversity of soil animals and a higher microbial activity were noted in organically managed soil (Maider et al. 2002). Recent study by Gosling et al. (2010) examined 11 sites to test the hypothesis that organic management increases AM fungal number and colonization potential of tilled agricultural soil. They concluded overall spore number to be significantly higher in organically managed soil with no overall difference in soil physicochemical properties. However, it was also found in the study of Eason et al. (1999) that organic farming not necessarily resulted in large numbers of AM spores in absolute terms.

17.3.4 Industrial Wasteland Soil

Wastewater discharged from textile and dye industries is the major cause of serious environmental hazards. Many physical and chemical methods have been used to detoxify the wastewater, but unfortunately, due to high operating costs and complex operational process, a suitable alternative will be required; also, these methods do not take away dyes completely. In contrast, introduction of biological organism, arbuscular mycorrhizal fungi (AMF), has enormous potential to enhance phytoaccumulation process of heavy metal by naturally grown plant species in

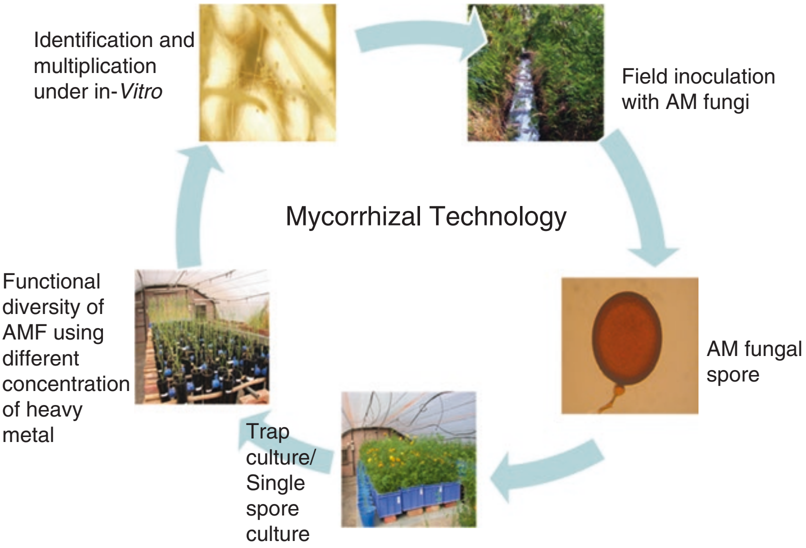

Fig. 17.2 Mycorrhizal-based technology use as a bioremediation of polluted soil

contaminated soils as shown in Fig. 17.2. However, very limited information is available about community composition of tolerant mycorrhizal species/strains associated with heavy metal accumulator plant grown naturally under tropical soil. Study suggested that consortia of *Rhizophagus* species from metal polluted soil contribute to higher uptake and transportation of heavy metals, as well as tolerance of heavy metals toxicity than single AMF species. This study also suggested different AM fungi to differ in their susceptibility and tolerance to heavy metals, and being responsible for uptake of specific metals only constitutes some limitation. It was also suggested that roots of some plant are species-specific and sporulate differently in the presence specific AMF species/strains. Many reports described that the presence of AMF increases the efficiency of plants for the removal of heavy metals from toxic environment (Regvar et al. 2003; Turnau and Mesjasz-Przybylowicz 2003). The study by Kumar and Adholeya (2016, 2018) recorded that *Rhizophagus fasciculatus* obtained from trap culture originated from sludge-contaminated field used for the clean-up of multi–metal-contaminated tannery sludge. More recent report by Nazir and Bareen, (2011) investigated the synergistic effect of *Rhizophagus fasciculatus* and *Trichoderma pseudokoningii* on *Heliathus annuus* for decontaminating toxic metals from tannery sludge. They showed that consortia of AM fungi could be exploited for decontamination of heavy metals from tannery sludge.

17.4 Life Cycle of AMF, and Economic and Ecological Significance

Arbuscular mycorrhizas are mainly symbiotic with herbaceous plants in temperate areas, but are also found frequently in tropical trees (Smith and Read 2008). 80–90% of terrestrial plant species form association with AM (Smith and Read 2008). In a recent survey of 3617 plant species, Wang and Qiu (2006) showed that 92% of the families (80% of the species) potentially form at least one mycorrhiza type. A very detailed review about mycorrhizal associations was most recently published (by Brundrett 2009). AM fungi enhance mobilization and transportation of nutrients to roots (Smith and Read 1997). AM fungi improved nutrient uptake, especially nitrogen and phosphorus, by increasing the abilities of the host plants to explore a larger volume of soil than plant roots alone would have been able to cover, and to mobilize phosphate from a greater surface area (Joner et al. 2000). It also reduces water stress and improves soil aggregation in eroded soils (Caravaca et al. 2002). There are three different phases of AM fungal interaction: (1) the asymbiotic phase, when AM fungal spores germinate and hypha grow in the absence of plant signals; (2) the presymbiotic phase, during which AM fungal hyphal growth and differentiation occur in the presence of signal exuded by host roots; and (3) the symbiotic phase, following colonization of roots, during which there is formation of intraradical structures and an exchange of nutrients between host and fungus. The formation of AM symbiosis is a complex developmental event leading to the coordination of gene expression of both partners. The fungus life cycle starts with germination of hyphae from resting spores. The spores are able to germinate in the absence of host plants, but the growth of the hyphae is restricted after days or weeks, depending on the species/isolate of AM fungi (Tamasloukht et al. 2003). Germination of AM spores need not necessarily be in the presence of plant host root, although the percentage of germination is sometimes increased in their presence. *Gigaspora* spores germinated directly through the spore wall, *Acaulospora* and *Scutellospora* through germination shields, and *Glomus* (Siqueira et al. 1985) through the hyphal attachment. On the other hand, germinating spores produce diffusible factors that lead to an expression of specific genes in the host plant root cells even in the absence of direct physical contact (Kosuta et al. 2003). Furthermore, several reports confirm plant–microbe interaction and show that root exudates also produce primary plant signal that triggers a complex cascade of signals from both the plant and the AM fungus (Morandi 1996; Vierheilig et al. 1998). Root exudates of AM host plants stimulate spore germination (Gianinazzi et al. 1989; Schreiner and Koide 1993) and hyphal growth (Mosse and Hepper 1975; Graham 1982; Balaji et al. 1995; Pinior et al. 1999). It is known that in the absence of roots or root exudates, the hyphae have very slow metabolic rates, and all attempts at long-term culture have failed (Azcón-Aguilar et al. 1999; Giovannetti 2000; Bécard et al. 2004). The presence of a root or root exudates stimulates growth and branching of the mycelium and apparently converts it into an 'infection-ready' state.

The chemical nature of diffusible factors of plants and of fungi is not yet known. First observation by Akiyama et al. (2005) suggested that strigolactones are known to stimulate the germination of seeds of root parasite in the genera *Striga* and *Orobanche* and their role as general signaling molecule for establishment of AM symbiosis. Furthermore, Besserer et al. (2006) investigated and observed that strigolactones are responsible not only for spore germination but also for stimulating the growth of hypha of AMF. Several other phenolic compounds produced by roots or seeds are known to influence symbiotic development between *Rhizobium* and *Agrobacterium* and their hosts. Ex Flavonoids have stimulatory effects on the growth and branching of germ tubes of *Gigaspora margarita* and some *Glomus* species (Gianinazzi-Pearson et al. 1989; Tsai and Phillips 1991; Bécard et al. 1992; Buee et al. 2000) and can also lead to increased colonization of roots by the fungi (Nair et al. 1991; Siqueira et al. 1991; Akiyama et al. 2002). Oldroyd and Downie (2004) confirmed rhizobial symbioses, and AM fungi utilize the same factor (at least seven proteins) of a common signaling (Sym) pathway in legumes. Therefore, it is likely that different rhizobial and mycorrhizal signals (Nod factors and Myc factors) result in a common signaling pathway, whereas the output is unique in both symbioses (Oldroyd and Downie 2006; Kosuta et al. 2008). In AM, Myc factors are thought to induce calcium oscillations in root epidermal cells (Kosuta et al. 2008) and activate plant symbiosis-related genes (Kosuta et al. 2003).

The second step in the root–AM fungus interaction prior to colonization is the formation of aspersorium on the root surface. Genre et al. (2005) observed that AM fungi on the root surface involve changes in the plant cells, encompassing wall alterations, nuclear movements, alterations in cytoskeletal activity, and membrane proliferation and modification, including the formation of a complex prepenetration apparatus (PPA). Using a plant mutant of *Lotus japonicus* affected in the symbiosis genes SYM15 or SYMRK, Demchenko et al. (2004) found that the plant actively allows the fungus to penetrate the rhizodermis. They observed three steps in the interaction that were differentially impaired in the mutants: (1) the surface opening, where the anticlinal cell walls of two adjacent epidermal cells separate from each other in the vicinity of fungal hyphae: (2) the intracellular passage of hyphae through an exodermal cell and an adjacent cell of the outermost cortical layer; and (3) the arbuscule formation in cells of the two innermost cortical layers. Gallaud (1905) identified two different morphological growth patterns of AMF on the root surface. First, *Arum* type is characterized by fast-growing hyphae spreading through intercellular air spaces and penetrating cortical cells by side branches, in which arbuscules are formed. Smith and Read (2008) show that Arum type in particular is typical for fast-growing crops. Second, *Paris* type is characterized by hyphae growing intracellular from cell to cell in which coils are formed. This type of growth pattern is found in Gentianaceae (Sýkorová et al. 2007).

Subsequently, AM fungus forms tree-like structures, called arbuscules, inside inner cortical cells of host roots. On the other hand, genera belonging to *Paraglomus*, *Scutellospora,* and *Gigaspora* form intra-and intercellular storage organs called vesicles in the late stage of the symbiosis (Smith and Read 1997; Morton and Redecker 2001). Sander et al. (1977) reported that arbuscules in AM fungi are the central place for nutrient exchange. This structure is degraded by plant cells after 4 to 10 days, and then plant regains its original morphology (Jacquelinet-Jeanmougin et al. 1987). Consequently, plant cells form new colonization. The life cycle is completed by the formation of new spores by the AM fungus.

17.5 Role of AMF for Global Sustainable Environments

Climate change and food security have now become major problems mainly in developing countries. Therefore, there is need to fulfill demand of growing population of developing countries by increasing food production through high-input agricultural practices and at the same time by minimizing negative environmental impact (Foley et al. 2011; Rillig et al. 2016). Holistic use of several beneficial microorganisms may lead to minimization of environmental pollution and conservation of soil ecosystem. Moreover, many microbes symbiotically associated in soil life play a role as major pillars in conservation agriculture. Among these symbioses, a well-known player is mycorrhiza, the extensive symbiotic association of fungi with roots of higher plant (Smith and Read 2008). AM fungi offer several benefits to the plants: (1) improved nutrient uptake, (2) faster growth, (3) greater drought resistance, (4) protection from pathogens, (5) increased seedling survival, (6) improved soil structure, and (6) greater resistance to invasion by weeds. Colonization of the root system by AM fungi confers benefits directly to the host plant growth and development, through the acquisition of phosphate and other mineral nutrients from the soil. In addition, colonization may also enhance the plant's resistance to biotic and abiotic stresses (Newsham et al. 1995). AM fungi also develop an extensive hyphal network out with the plant root system, which makes a significant contribution to the improvement of soil texture and water relationship (Bethlenfalvay and Schuepp 1994). Mycosorption using AM fungi in heavy metal-contaminated soil showed significantly greater accumulation as compared with plant noncolonized with AM fungi (Utomo et al. 2014). Therefore, AM fungi constitute an integral and important component of ecosystems and may have significant applications in sustainable agricultural system (Schreiner and Bethlenfalvay 1995). Current production technique of mycorrhizal inocula presents with certain limitations with regard to purity and quality. Moreover, Cardoso and Kuyper (2006) suggested that side by side with mycorrhizal technology, mycorrhizal management practices may increase crop production through intensive use of agroforestry. They also concluded that sustainable conservation of soil ecosystem may be possible through mycorrhization, multi cropping, and crop rotation practices.

17.6 Conclusions and Future Prospect

This chapter suggests that the presence of AMF increases the efficiency of plants for the removal of heavy metals from toxic environment. Study revealed that plant species diversity would increase the diversity of AMF in soil and contribute to the efforts to restore degraded lands. Review dealt with selection and multiplication of AMF from wasteland sites and the manner in which we can use them for future revegetation programs. The characterization and identification of AMF adapted from harsh conditions of soils/area affected by industrial effluents can be put to use for future utilization of the reclaimed areas for the successful management of revegetation programs.

Acknowledgments The authors wish to thank financial contributions from Department of Biotechnology, Government of India and The Energy and Resource Institute (TERI), New Delhi, India. We thank Dr. R K Pachauri, Director General, TERI, for providing the necessary infrastructure for carrying out the research work.

References

Abbott LK, Robson AD (1991) Factors influencing the occurrence of vesicular-arbuscular mycorrhizas. Agric Ecosyst Environ 35:121–150

Akhtar O, Mishra R, Kehri HK (2017) Arbuscular Mycorrhizal Association Contributes to Cr accumulation and tolerance in plants growing on Cr contaminated soils. Proc Natl Acad Sci India Sect B Biol Sci 89(1):63–70

Akiyama K, Matsuoka H, Hayashi H (2002) Isolation and identification of a phosphate deficiency-induced C-glycosylflavonoid that stimulates arbuscular mycorrhiza formation in melon roots. Mol Plant-Microbe Interact 15:334–340

Akiyama K, Matsuzaki K, Hayashi H (2005) Plant sesquiterpenes induce hyphal branching in arbuscular mycorrhizal fungi. Nature 435:824–827

Altieri MA (1999) The ecological role of biodiversity in agroecosystems. In: Paoletti MG (ed) Invertebrate biodiversity as bioindicators of sustainable landscapes. Elsevier, Amsterdam, pp 19–31

Altieri MA (2004) Linking ecologists and traditional farmers in the search for sustainable agriculture. Front Ecol Environ 2:35–42

Azcón-Aguilar C, Bago B, Barea JM (1999) Saprophytic growth of arbuscular mycorrhizal fungi. Mycorrhiza:391–408. Springer, Berlin/Heidelberg

Balaji B, Poulin MJ, Vierheilig H, Piché Y (1995) Responses of an arbuscular mycorrhizal fungus, Gigaspora margarita, to exudates and volatiles from the Ri T-DNA-transformed roots of non mycorrhizal and mycorrhizal mutants of *Pisum sativum* L Sparkle. Exp Mycol 19:275–283

Baltruschat H (1987) Field inoculation of maize with vesicular-arbuscular mycorrhizal fungi by using expanded clay as carrier material for mycorrhiza. JPDP 94:419–430

Bécard G, Douds DD, Pfeffer PE (1992) Extensive *in vitro* hyphal growth of vesicular-arbuscular mycorrhizal fungi in the presence of CO2 and flavonols. Appl Environ Microbiol 58(3):821

Bécard G, Kosuta S, Tamasloukht M, Séjalon-Delmas N, Roux C (2004) Partner communication in the arbuscular mycorrhizal interaction. Can J Bot 82:1186–1197

Beena KR, Raviraja NS, Arun AB, Sridhar KR (2000) Diversity of arbuscular mycorrhizal fungi on the coastal sand dunes of the west coast of India. Curr Sci 79:1459–1466

Bentivenga S, Hetrick B (1992) The effect of prairie management practices on mycorrhizal symbiosis. Mycologia 84(4):522–527

Besserer A, Puech-Pagès V, Kiefer P, Gomez-Roldan V, Jauneau A, Roy S, Séjalon-Delmas N (2006) Strigolactones stimulates arbuscular mycorrhizal fungi by activating mitochondria. PLoS Biol 4(7):226

Bethlenfalvay GJ, Schüepp H (1994) Arbuscular mycorrhizas and agrosystem stability. In: Impact of arbuscular mycorrhizas on sustainable agriculture and natural ecosystems. Birkhäuser, Basel, pp 117–131

Bever JD, Morton JB, Antonovics J, Schultz PA (1996) Host-dependent sporulation and species diversity of arbuscular mycorrhizal fungi in mown grassland. J Ecol 84(1):71–82

Bills RJ, Stutz JC (2009) AMF associated with indigenous and non-indigenous plants at urban and desert sites in Arizona. In: Mycorrhizas-functional processes and ecological impact. Springer, Berlin/Heidelberg, pp 207–220

Blaszkowski J (1993) Comparative studies on the occurrence of arbuscular fungi and mycorrhizae (Glomales) in cultivated and uncultivated soils of Poland. Acta Mycol 28:93–140

Błaszkowski J (1994) Arbuscular fungi and mycorrhizae (Glomales) of the Hel Peninsula, Poland. Mycorrhiza 5(1):71–88

Bowen GD, Rovira AD (1999) The rhizosphere and its management to improve plant growth. Adv Agron 66(1):102

Bragaloni M, Rea E, Pirazzi R (1998) Problems and perspectives in the inoculum production of vesicular– arbuscular fungi isolated from sand dunes. Micol Ital 27:61–67

Brundrett MC (2009) Mycorrhizal associations and other means of nutrition of vascular plants: understanding the global diversity of host plants by resolving conflicting information and developing reliable means of diagnosis. Plant Soil 320:37–77

Brundrett M, Juniper S (1995) Non-destructive assessment of spore germination of VAM fungi and production of pot cultures from single spores. Soil Biol Biochem 27:85–91

Brundrett M, Melville L, Peterson L, (Eds.) (1994) Practical methods in mycorrhiza research : based on a workshop organized in conjunction with the ninth North American Conference on mycorrhizae, University of Guelph, Guelph, Ontario, Canada. Mycologue Publications

Buee M, Rossignol M, Jauneau A, Ranjeva R, Bécard G (2000) The pre-symbiotic growth of arbuscular mycorrhizal fungi is induced by a branching factor partially purified from plant root exudates. Mol Plant-Microbe Interact 13:693–698

Caravaca F, Hernandez T, Garcıa C, Roldan A (2002) Improvement of rhizosphere aggregate stability of afforested semiarid plant species subjected to mycorrhizal inoculation and compost addition. Geoderma 108(1–2):133–144

Cardoso IM, Kuyper TW (2006) Mycorrhizas and tropical soil fertility. Agric Ecosyst Environ 116(1–2):72–84

Clapp JP, Fitter AH, Merryweather JW (1996) Arbuscular mycorrhizas methods for the examination of organismal diversity in soils and sediments. CAB International, New York, pp 145–161

Dalgaard T, Hutchings NJ, Porter JR (2003) Agroecology, scaling and interdisciplinarity. Agric Ecosyst Environ 100:39–51

Demchenko K, Winzer T, Stougaard J, Parniske M, Pawlowski K (2004) Distinct roles of Lotus japonicus SYMRK and SYM15 in root colonization and arbuscule formation. New Phytol 163:381–392

Douds DD, Millner P (1999) Biodiversity of arbuscular mycorrhizal fungi in agro ecosystems. Agic Ecosyst Environ 74:77–93

Douds DD, Galvez L, Franke-Snyder M, Reider C, Drinkwater LE (1997) Effect of compost addition and crop rotation point upon VAM fungi. Agric Ecosyst Environ 65:257–266

Eason WJ, Scullion et al (1999) Soil parameters and plant responses associated with arbuscular mycorrhizas from contrasting grassland management regimes. Agric Ecosyst Environ 73:245–255

Feldman F, Izsak E (1994) Inoculum production of VA mycorrhizal fungi. In: Techniques for mycorrhizal research. Academic Press, San Diego, pp 799–817

Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M et al (2011) Solutions for a cultivated planet. Nature 478:337–342

Fracchia S, Menendez A et al (2001) A method to obtain monosporic cultures of arbuscular mycorrhizal fungi. Soil Biol Biochem 33:1283–1285

Gallaud I (1905) Études sur les mycorrhizes endophytes. Revue General de

Galvez L, Douds DD, Drinkwater LE, Wagoner P (2001) Effect of tillage and farming system upon VAM fungus populations and mycorrhizas and nutrient uptake of maize. Plant Soil 228:299–308

Gaur A, Adholeya A (2002) Arbuscular mycorrhizal inoculation of five tropical fodder crops and inoculum production in marginal soil amended with organic matter. Biol Fertil Soils 35:214–218

Genre A, Chabaud M, Timmers T, Bonfante P, Barker DG (2005) Arbuscular mycorrhizal fungi elicit a novel intracellular apparatus in *Medicago truncatula* root epidermal cells before infection. Plant Cell 17:3489–3499

Gianinazzi S, Gianinazzi-Pearson V, Trouvelot A (1989) Potentialities and procedures for the use of endomycorrhizas with special emphasis on high value crops. Cambridge University Press, Cambridge, pp 41–45

Giovanetti M, Avio L (1985) VAM infection and reproduction as influenced by different organic and inorganic substances. In: Molina R (ed) Proc. 6th N. Amer. Conf. Mycorrhizae. For. Res. Lab, Corvallis, p 400

Giovannetti M (2000) Spore germination and pre-symbiotic mycelial growth. In: Arbuscular mycorrhizas: physiology and function. Springer, Dordrecht, pp 47–68

Gosling P, Ozaki A, Jones J, Turner M, Rayns F, Bending GD (2010) Organic management of tilled agricultural soils results in a rapid increase in colonisation potential and spore populations of arbuscular mycorrhizal fungi. Agric Ecosyst Environ 139:273–279

Graham JH (1982) Effect of citrus root exudates on germination of chlamydospores of the vesicular-arbuscular mycorrhizal fungus, *Glomus epigaeum*. Mycologia 74(5):831–835

Gryndler M (2000) Interaction of arbuscular mycorrhizal fungi with other soil organisms. In: Kapulink Y, Douds DD Jr (eds) Arbuscular mycorrhizas: physiology and function. Kluwer Academic, Dordrecht, pp 239–262

Hamel C, Dalpé Y, Lapierre C, Simard RR, Smith DL (1994) Composition of the vesicular- arbuscular mycorrhizal fungi population in an old meadow as affected by pH, phosphorus and soil disturbance. Agric Ecosyst Environ 49(3):223–231

Harinikumar K, Bagyaraj D (1989) Effect of cropping sequence, fertilizers and farmyard manure on vesicular-arbuscular mycorrhizal fungi in different crops over three consecutive seasons. Biol Fertil Soils 7:173–175

Hayman DS (1975) The occurrence of mycorrhiza in crops as affected by soil fertility. Endomycorrhizas. Academic Press, London, pp 495–509

Hendrix PF, Crossley DA Jr, Blair JM, Coleman DC, Edwards CA, Lal R, Madden P, Miller RH, House G (1990) Soil biota as compounds of sustainable agroecosystems. Sustainable agricultural systems. Stlucie Press, Delray Beach, pp 637–654

Hepper CM (1984) Isolation and culture of VA mycorrhizal (VAM) fungi. CRC Press, Boca Raton

Hijri M, Sanders IR (2005) Low gene copy number shows that arbuscular mycorrhizal fungi inherit genetically different nuclei. Nature 433:160–163

Jacquelinet-Jeanmougin J, Gianinazzi-Pearson V, Gianinazzi S (1987) Endomycorrhizas in the Gentianaceae. II. Ultrastructural aspects of symbiont relationships in *Gentiana lutea* L. Symbiosis (USA) 3:269

Jansa J, Mozafar A, Anken T, Ruh R, Sanders IR, Frossard E (2002) Diversity and structure of AMF communities as affected by tillage in a temperate soil. Mycorrhiza 12:225–234

Jansa J, Mozafar A, Kuhn G, Anken T, Ruh R, Sanders IR, Frossard E (2003) Soil tillage affects the community structure of mycorrhizal fungi in maize roots. Ecol Appl 13:1164–1176

Jasper DA, Abbott LK, Robson AD (1989) Soil disturbance reduces the infectivity of external hyphae of vesicular—arbuscular mycorrhizal fungi. New Phytol 112:93–99

Jeffries P, Gianinazzi S, Perotto S, Turnau K, Barea JM (2003) The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. Biol Fertil Soils 37(1):1–16

Jensen A, Jakobsen I (1980) The occurrence of vesicular-arbuscular mycorrhiza in barley and wheat grown in some Danish soils with different fertilizer treatments. Plant Soil 55:403–414

Johansen A, Jakobsen I, Jensen ES (1993) Hyphal transport by a vesicular-arbuscular mycorrhizal fungus of N applied to the soil as ammonium or nitrate. Biol Fertil Soils 16(1):66–70

Johnson NC, McGRAW AC (1988) Vesicular-arbuscular mycorrhizae in taconite tailings. II. Effects of reclamation practices. Agric Ecosyst Environ 21(3–4):143–152

Joner EJ, Jakobsen I (1995) Uptake of 32 P from labelled organic matter, by mycorrhizal and non-mycorrhizal subterranean clover (*Trifolium subterraneum* L.). Plant Soil 172:221–227

Joner EJ, Briones R, Leyval C (2000) Metal-binding capacity of arbuscular mycorrhizal mycelium. Plant Soil 226:227–234

Karthikeyan C, Selvaraj T (2009) Diversity of arbuscular mycorrhizal fungi (AMF) on the coastal saline soils of the west coast of Kerala, Southern India. World J Agric Sci 5:803–809

Khade S, Adholeya A (2009) Arbuscular mycorrhizal association in plants growing on metal contaminated and noncontaminated soils adjoining Kanpur tanneries, Uttar Pradesh, India. Water Air Soil Pollut 202:45–56

Khade SW, Rodrigues BF (2003) Occurrence of arbuscular mycorrhizal fungi in tree species from Western Ghats of Goa, India. J Trop Forest Sci 15:320–331

Koske R, Halvorson W (1981) Ecological studies of vesicular-arbuscular mycorrhizae in a barrier sand dune. Can J Bot 59(8):1413–1422

Koske RE, Gemma JN, Jackson N (1997) A preliminary survey of mycorrhizal fungi in putting greens. J Turfgrass Sci 73:2–8

Kosuta S, Chabaud M, Lougnon G, Gough C, Dénarié J, Barker DG, Bécard G (2003) A diffusible factor from arbuscular mycorrhizal fungi induces symbiosis-specific MtENOD11 expression in roots of *Medicago truncatula*. Plant Physiol 131:952–962

Kosuta S, Hazledine S, Sun J, Miwa H, Morris RJ, Downie JA, Oldroyd GED (2008) Differential and chaotic calcium signatures in the symbiosis signaling pathway of legumes. Proc Natl Acad Sci U SA 105(28):9823–9828

Kour D, Rana KL, Yadav N, Yadav AN, Singh J, Rastegari AA, Saxena AK (2019) Agriculturally and industrially important fungi: current developments and potential biotechnological applications. In: Yadav AN, Singh S, Mishra S, Gupta A (eds) Recent advancement in white biotechnology through fungi, Volume 2: perspective for value-added products and environments. Springer International Publishing, Cham, pp 1–64. https://doi.org/10.1007/978-3-030-14846-1_1

Kumar S, Adholeya A (2016) Impact of land use and soil types on arbuscular mycorrhizal fungal diversity in tropical soil of India. Afr J Microbiol Res 10(38):1595–1606

Kumar S, Adholeya A (2018) Congruence of morphology and fatty acid methyl ester profile (FAME profile) revealed low Mycorrhizal diversity in soil contaminated with tannery sludge. Pollut Res 37(May Suppl):S71–S81

Lakshman HC, Rajanna L, Inchal RF, Mulla FI, Srinivasulu Y (2001) Survey of VA- mycorrhizae in agroforestry and its implications on forest trees. Trop Ecol 42:283–286

Lilly SS, Santhanakrishnan P (1999) Coir pith compost a suitable medium for mass multiplication of *Glomus fasciculatum*. Madras Agric J 85:240–242

Maider P, Fliessbach A, Dubois D, Gunst L, Fried P, Niggli U (2002) Soil fertility and biodiversity in organic farming from clover (*Trifolium repens*) roots. J Appl Environ Microbiol 57(2):434–439

Manoharachary C, Rao PR (1991) Vesicular–arbuscular mycorrhizal fungi and forest trees. In: Soerianegara I, Supriyanto (eds) Proceedings of the second Asian conference on Mycorrhiza, p 39

Manoharachary C, Sridhar K, Singh R, Adholeya A, Suryanarayanan TS, Rawat S, Johri BN (2005) Fungal biodiversity: distribution, conservation and prospecting of fungi from India. Curr Sci 89(1):58–71

Marschner H (1995) Mineral nutrition of higher plants, 2nd edn. Academic Press, Amsterdam, The Netherlands

Mathimaranhe N, Ruh R, Vullioud P, Frossard E, Jansa J (2005) *Glomus intraradices* dominates arbuscular mycorrhizal communities in a heavy textured agricultural soil. Mycorrhiza 16:61–66

Mathur N, Vyas P, Joshi N, Choudhary K, Purohit DK (2011) Mycorrhiza: a potent bioinoculant for sustainable agriculture. In: Pathak H, Sharma A (eds) Microbial technology “the emerging era” lap lambert. Academic Publishing Ag & Co. Kg, Dudweiller Landstr, pp 230–245

McGonigle TP, Miller MH (1993) Mycorrhizal development and phosphorus absorption in maize under conventional and reduced tillage. Soil Sci Soc Am J 57(4):1002–1006

Mcgonigle TP, Miller MH (1996) Development of fungi below ground in association with plants growing in disturbed and undisturbed soils. Soil Biol Biochem 28:263–269

Miller DD, Domoto PA, Walker C (1985) Mycorrhizal fungi at eighteen apple rootstock plantings in the United States. New Phytol 100:379–391

Miller MH, McGonigle TP, Addy HD (1995) Functional ecology of vesicular-arbuscular mycorrhizas as influenced by phosphate fertilization and tillage in an agricultural ecosystem. Crit Rev Biotechnol 15:241–255

Morandi D (1996) Occurrence of phytoalexins and phenolic compounds in endomycorrhizal interactions, and their potential role in biological control. Plant Soil 185:241–251

Morton JB, Redecker D (2001) Two new families of Glomales, Archaeosporaceae and Paraglomaceae, with two new genera Archaeospora and Paraglomus, based on concordant molecular and morphological characters. Mycologia 93(1):181–195

Morton JB, Bentivenga SP et al (1995) Discovery, measurement, and interpretation of diversity in arbuscular endomycorrhizal fungi (Glomales, Zygomycetes). Can J Bot 73:25–32

Mosse B, Hepper C (1975) Vesicular-arbuscular mycorrhizal infections in root organ cultures. Physiol Plant Pathol 5:215–218

Muthukumar T, Udaiyan K (2000) Arbuscular mycorrhizas of plants growing in the Western Ghats region, Southern India. Mycorrhiza 9:297–313

Nair MG, Safir GR, Siqueira JO (1991) Isolation and identification of vesicular-arbuscular mycorrhiza-stimulatory compounds. Fertil Soils 31:150–156

Nalini PA, Byra Reddy MS, Bagyaraj D J (1987) VA mycorrhizal spore types present in the root zone of *Leucaena leucocephala* (LAM) de. Mycorrhiza round table proceedings of workshop, JNU, New Delhi, pp. 129–136

Nazir A, Bareen F (2011) Synergistic effect of Glomus fasciculatum and Trichoderma pseudokoningii on Heliathus annuus to decontaminate tannery sludge from toxic metals. AJB 10(22):4612–4618

Newsham KK, Fitter AH, Watkinson AR (1995) Arbuscular mycorrhiza protect an annual grass from root pathogenic fungi in the field. J Ecol 83:991–1000

Oldroyd GE, Downie JA (2004) Calcium, kinases and nodulation signalling in legumes. Nat Rev Mol Cell Biol 5(7):566

Oldroyd GE, Downie JA (2006) Nuclear calcium changes at the core of symbiosis signalling. Curr Opin Plant Biol 9(4):351–357

Oswald ET, Ferchau HA (1968) Bacterial associations of coniferous mycorrhizae. Plant Soil 28(1):187–192

Peña-Venegas C, Cardona GI et al (2007) Micorrizas arbusculares del sur de la amazonia colombiana y su relación con algunos factores fisicoquímicos y biológicos del suelo. Act Amazon 37(3):327–336

Pinion A, Wyss U et al (1999) Plants colonized by AM fungi regulates further root colonization by AM fungi through altered root exudation. Can J Bot 77:891–897

Ragupathy S, Mahadevan A (1993) Distribution of vesicular-arbuscular mycorrhizae in the plants and rhizosphere soils of the tropical plains, Tamil Nadu, India. Mycorrhiza 3:123–136

Raman N, Sambandan K (1998) Distribution of VAM fungi in tannery effluent polluted soils of Tamil Nadu, India. Bull Environ Contam Toxicol 60:142–150

Raman N, Nagarajan S, Gopinathan SK (1993) Mycorrhizal status of plant species colonizing a magnesite mine spoil in India. Biol Fertil Soils 16:76–78

Rana KL, Kour D, Sheikh I, Dhiman A, Yadav N, Yadav AN, Rastegari AA, Singh K, Saxena AK (2019a) Endophytic fungi: biodiversity, ecological significance, and potential industrial applications. In: Yadav AN, Mishra S, Singh S, Gupta A (eds) Recent advancement in white biotechnology through fungi: Volume 1: diversity and enzymes perspectives. Springer International Publishing, Cham, pp 1–62. https://doi.org/10.1007/978-3-030-10480-1_1

Rana KL, Kour D, Sheikh I, Yadav N, Yadav AN, Kumar V, Singh BP, Dhaliwal HS, Saxena AK (2019b) Biodiversity of endophytic fungi from diverse niches and their biotechnological applications. In: Singh BP (ed) Advances in endophytic fungal research: present status and future challenges. Springer International Publishing, Cham, pp 105–144. https://doi.org/10.1007/978-3-030-03589-1_6

Regvar M, Vogel K et al (2003) Colonization of pennycresses (Thlaspi spp.) of the Brassicaceae by arbuscular mycorrhizal fungi. J Plant Physiol 160:615–626

Rillig MC, Sosa Hernández MA, Roy J, Aguilar-Trigueros CA, Vályi K, Lehmann A (2016) Towards an integrated mycorrhizal technology: harnessing mycorrhiza for sustainable intensification in agriculture. Front Plant Sci 7:1625

Sambandan K, Raman N, Kannan K (1991) Association of VAM fungi with *Casuarina equisetifolia* at different soil types in Tamil Nadu, India. In: Soerianegara I, Supriyanto (eds) Proceedings of second Asian conference on Mycorrhiza, pp 61–65

Sanchez PA, Palm CA, Buol SW (2003) Fertility capability soil classification, a tool to help assess soil quality in the tropics. Geoderma 114:157–185

Sanders FE, Tinker PB, Black RLB, Palmerley SM (1977) The development of endomycorrhizal root systems: I. Spread of infection and growth-promoting effects with four species of vesicular-arbuscular endophyte. New Phytol 78(2):257–268

Schalamuk S, Velazquez S, Chidichimo H, Cabello M (2006) Fungal spore diversity of arbuscular mycorrhizal fungi associated with spring wheat: effects of tillage. Mycologia 98(1):16–22

Schenck NC (1982) Methods and principles of mycorrhizal research. Am Phytopathol Soc 244:2

Schenck N, Kinloch R (1980) Incidence of mycorrhizal fungi on six field crops in monoculture on a newly cleared woodland site. Mycologia 72(3):445–456

Schreiner RP, Bethlenfalvay GJ (1995) Mycorrhizal interactions in sustainable agriculture. Crit Rev Biotechnol 15(3–4):271–285

Schreiner RP, Koide RT (1993) Stimulation of vesicular-arbuscular mycorrhizal fungi by mycotrophic and nonmycotrophic plant root systems. Appl Environ Microbiol 59(8):2750–2752

Singh R, Adholeya A (2002) Biodiversity of arbuscular mycorrhizal fungi (AMF) in different agroclimatic regions of India. IMC7-conference on mycological advances, 11–17, Norway. Mol Biol Evol 4:406–425

Siqueira JO, Sylvia DM, Gibson J, Hubbell DH (1985) Spores, germination, and germ tubes of vesicular-arbuscular mycorrhizal fungi. Can J Microbiol 31:965–972

Siqueira JO, Safir GR, Nair MG (1991) VA-mycorrhizae and mycorrhiza stimulating flavonoid compounds reduce plant herbicide injury. Plant Soil 134:233–242

Smith SE, Read DJ (1997) Growth and carbon economy of VA mycorrhizal plants. In: Mycorrhizal symbiosis. Academic Press, London, pp 105–125

Smith SE, Read DJ (2008) Mycorrhizal symbiosis. Elsevier Academic Press, New York

St-Arnaud M, Vujanovic V (2007) Effect of the arbuscular mycorrhizal symbiosis on plant diseases and pests. In: Mycorrhizae in crop production. Haworth, New York, pp 67–122

Stürmer SL (2004) Effect of different fungal isolates from the same mycorrhizal community on plant growth and phosphorus uptake in soybean and red clover. Rev Bras Cienc Solo 28:611–622

Stürmer SL, Bellei MM (1994) Composition and seasonal variation of spore populations of arbuscular mycorrhizal fungi in dune soils on the island of Santa Catarina, Brazil. Can J Bot 72:359–363

Stürmer SL, Siqueira JO (2011) Species richness and spore abundance of arbuscular mycorrhizal fungi across distinct land uses in Western Brazilian Amazon. Mycorrhiza 21(4):255–267

Stutz JC, Morton JB (1996) Successive pot cultures reveal high species richness of arbuscular endomycorrhizal fungi in arid ecosystems. Can J Microbiol 74:1883–1889

Sunilkumar CP, Garampalli HR (2010) Diversity of arbuscular mycorrhizal fungi in agricultural fields of Hassan District. World J Agric Sci 6:728–734

Sýkorová Z, Ineichen K, Wiemken A, Redecker D (2007) The cultivation bias: different communities of arbuscular mycorrhizal fungi detected in roots from the field, from bait plants transplanted to the field, and from a greenhouse trap experiment. Mycorrhiza 18(1):1–14

Tamasloukht MB, Séjalon-Delmas N, Kluever A, Jauneau A, Roux C, Bécard G, Franken P (2003) Root factors induce mitochondrial-related gene expression and fungal respiration during the developmental switch from asymbiosis to presymbiosis in the Arbuscular Mycorrhizal fungus *Gigaspora rosea*. Plant Physiol 131:1468–1478

Thapar HS, Uniyal K (1996) Effect of VAM fungi and Rhizobium on growth of Acacia nilotica in sodic and new forest soils. Indian Forester 122(11):1033–1039

Treseder KK, Mack MC, Cross A (2004) Relationships among fires, fungi, and soil dynamics in Alaskan boreal forests. Ecol Appl 14:1826–1838

Trufem S (1995) Ecological aspects of arbuscular mycorrhizal fungi from coastal sand dunes community of Ilha do Cardoso, SP, Brazil. Revta Brasil Bot 18:51–60

Tsai SM, Phillips DA (1991) Flavonoids released naturally from alfalfa promote development of symbiotic Glomus spores *in vitro*. Appl Environ Microbiol 57:1485–1488

Turnau K, Mesjasz-Przybylowicz J (2003) Arbuscular mycorrhiza of Berkheya coddii and other Ni-hyperaccumulating members of Asteraceae from ultramafic soils in South Africa. Mycorrhiza 13(4):185–190

Utomo WH, Suntari R, Arfarita N, Handayanto E (2014) Rehabilitation of artisanal small- scale gold mining land in West Lombok, Indonesia: 3. exploration of indigenous plant species and the associated mycorrhiza for phytomycoremediation of mercury contaminated soils. Am Eurasian J Sustain 8(1):34–41

Verma A, Adholeya A (1996) Cost-economics of existing methodologies for inoculum production of vesicular-arbuscular mycorrhizal fungi. In: Concepts in mycorrhizal research. Springer, Dordrecht, pp 179–194

Vierheilig H, Bago B, Albrecht C, Poulin MJ, Piche Y (1998) Flavonoids and arbuscular-mycorrhizal fungi. Adv Exp Med Biol 439:9–34

Walker C (1999) Methods for culturing and isolating arbuscular mycorrhizal fungi. Mycorrhiza News 11:2–4

Wang B, Qiu YL (2006) Phylogenetic distribution and evolution of mycorrhizas in land plants. Mycorrhiza 16:299–363

Wu CG, Chen ZC (1986) The Endogonaceae of Taiwan: I. A preliminary investigation on Endogonaceae of bamboo vegetation at Chi-Tou areas. Central Taiwan Taiwania 31:65–88

Xu M, Li X, Cai X, Li X, Christie P, Zhang J (2017) Land use alters arbuscular mycorrhizal fungal communities and their potential role in carbon sequestration on the Tibetan Plateau. Sci Rep 7(1):3067

Yadav AN, Kumar R, Kumar S, Kumar V, Sugitha T, Singh B, Chauhan V, Dhaliwal HS, Saxena AK (2017) Beneficial microbiomes: biodiversity and potential biotechnological applications for sustainable agriculture and human health. J Appl Biol Biotech 5:45–57

Yadav AN, Verma P, Kumar V, Sangwan P, Mishra S, Panjiar N, Gupta VK, Saxena AK (2018) Biodiversity of the genus Penicillium in different habitats. In: Gupta VK, Rodriguez-Couto S (eds) New and future developments in microbial biotechnology and bioengineering, penicillium system properties and applications. Elsevier, Amsterdam, pp 3–18. https://doi.org/10.1016/B978-0-444-63501-3.00001-6

Yadav AN, Mishra S, Singh S, Gupta A (2019a) Recent advancement in white biotechnology through fungi Volume 1: diversity and enzymes perspectives. Springer International Publishing, Cham

Yadav AN, Mishra S, Singh S, Gupta A (2019b) Recent advancement in white biotechnology through fungi. Volume 2: perspective for value-added products and environments. Springer International Publishing, Cham