Chapter 12
Arbuscular Mycorrhizal Fungi in Organic Versus Conventional Farming

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Abstract Arbuscular mycorrhizal fungi (AMF) establish symbiotic relationships with plant roots, enhancing nutrient uptake and promoting plant growth. This chapter discusses various factors that influence AM fungal populations under different farming systems. These factors include soil management routines such as tillage intensity, pesticide usage, fertilizer application, and crop rotation strategies. The aim is to compare the effects of organic farming practices that prioritizes sustainable approaches with those employed in conventional agriculture. The chapter looks at how organic farming methods differ from conventional farming in terms of AM fungal communities, diversity, and functionality. It describes practical strategies for improving mycorrhizal associations through inoculation techniques or by implementing specific agronomic practices that promote a favorable environment for these beneficial microorganisms. Overall, this chapter illuminates the role of AMF in influencing soil health and plant productivity across various agricultural approaches. It emphasizes the importance of taking these symbiotic relationships into account when designing sustainable farming systems that maximize yields while minimizing environmental impacts.

Keywords AMF · Monoculture · Crop rotation · Soil management · Beneficial microorganism · Symbiosis

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12.1 Introduction

Frank (1885) first used the term “mykorhiza” (mycorrhiza) and noted that nutrients and water were transported to plant roots by endophytic hyphae through mutualistic symbiotic relationships (Frank 1885). Arbuscular mycorrhizal fungi (AMF), as one of the utmost earliest obligate symbioses, are considered the most important soil organisms for agroecosystem sustainability (Martin et al. 2017).

Mycorrhizal symbiosis benefits plants in several ways, including improving their access to immobile nutrients (Basu et al. 2018; Hodge and Fitter 2010; Javot et al. 2007), tolerance to abiotic stress (Aroca et al. 2007; Chourasiya et al. 2021), and protection against pathogens (Morris et al. 2019). Meanwhile, they can play a key role in soil aggregation (Rillig and Mummey 2006), nutrient cycling (Lanfranco et al. 2018), and soil stability (Morris et al. 2019) and have prodigious potential for improving agricultural sustainability (Basu et al. 2018; Bender et al. 2016; Lehmann et al. 2020). As a result of their implications to plant performance and soil health, they play a crucial role in sustaining ecosystem productivity (Castillo et al. 2016; Ma et al. 2021).

More importantly, extensive hyphae networks could be produced by AMF, thereby enhancing water and nutrient uptake by the roots (Smith and Smith 2011). Mycorrhizae can increase the effective root absorption area of the host plants by producing mycelium and forming a mycelial network. Mycorrhizae can also enhance the environmental adaptability and stress resistance of host plants to cope with constraint from an adverse environment. Additionally, AMF are more important in terms of their potential to improve plant growth and health in future climate change scenarios (Wahdan et al. 2021; Johnson et al. 2013). The significance of AMF in improving plant nutrition (especially phosphorus (P)) and improving plant stress tolerance to both biotic and abiotic stress in natural ecosystems or low-input organic agriculture has been widely recognized (Jeffries et al. 2003).

12.2 AMF and Agroecosystem

12.2.1 Plant Growth and Productivity

Although the “high investment and high production” mode of conventional agriculture in the past has significantly increased the yield of crops, with the development of modern agriculture, the “low investment and high production” mode of intensive agriculture is becoming a key strategy of sustainable agricultural development (Shen et al. 2013). To meet the increasing demands of global food production, conserve environmental quality, and respond to more hostile environmental changes, agriculture management is more complex than ever, and simultaneously accomplishing high nutrient utilization efficiency and increasing crop yields have appeared key challenges (Cassman et al. 2003).

AMF provide multiple advantages to plant hosts because they are in direct contact with crop roots (Zhang et al. 2017). AMF are not only important for improving plant resistance to stress and sustaining biogeochemical cycling and ecological functions (Wu et al. 2018) but also for increasing crop yields (Cavagnaro et al. 2015; Rillig et al. 2016). Mounting evidences have suggested that mycorrhizal inoculation can promote the accumulation of grains and aboveground biomass (Ren et al. 2019; Zhao et al. 2015a, b), which being considered to be an effective agronomic measure (Pellegrino and Bedini 2014). The potential mechanism of increased crop yield after inoculation with AMF has received more attention (Bowles et al. 2016; Ren et al. 2019; Zhao et al. 2015). Several studies proved that AMF colonization promotes crop yields and can be a critical factor in making agroecosystems more sustainable (Bender et al. 2016; Thirkell et al. 2017). Recently, much discussion has been devoted to whether AM symbiosis is appropriate for agricultural production (Ryan and Graham 2018; Rillig et al. 2019). AMF symbionts can enhance the water absorption capacity of roots by producing hyphal structures (Zhao et al. 2015a, b) and increase host plant nutrient availability, directly contributing to increased crop yields (Hestrin et al. 2019). Besides, inoculation with AMF can boost the root biomass of host plants and thus produce more root exudates, which may facilitate microbial-driven nitrogen (N) mineralization, and further increase nutrient availability (Mo et al. 2020).

Despite numerous data on the benefits of inoculation of the host plants by AMF, the role of AMF on host plant yield is still under debate. It is known that the respiration rate is increased upon mycorrhization of plants that consumes part of the photosynthetic products (Mortimer et al. 2008). Thus, the enhanced carbon (C) assimilation observed in the mycorrhizal plants is most likely offset by higher respiratory consumption, and the crop yield did not change significantly (Xavier and Germida 2003). Some other studies have revealed that root colonization with AMF reduces crop productivity, crop biomass production, and yield (Berruti et al. 2016; Ryan and Graham 2018; Jayne and Quigley 2014). Divergent influences of AMF on crop productivity might be relevant to experimental conditions, AMF species identity, climate, soil moisture, and soil fertility (Gosling et al. 2016; Jayne and Quigley 2014; Roger et al. 2013; Thirkell et al. 2017). Therefore, further studies are required to elucidate how inoculation with AMF differs in plant production and physiological properties under various conditions.

12.2.2 Quality of Crops

AMF can enhance plant uptake of nutrients and promote plant health (Gonzalez-Dugo 2010). After colonization of plant roots with fungi, AMF can significantly promote the acquisition of soil mineral nutrients, especially P. The ^{14}C tracking experiment found that the translocation of carbohydrates from plant to AM symbiotic structures (from root cells to AM mycelium) can promote the uptake of P by the fungi and its further transport to the plant (Bücking and Shachar-Hill 2005).

Additionally, inoculation of date palms with *Albahypha drummondii*, *Pervetustus simplex*, *Septoglomus xanthium*, *Claroideoglomus etunicatum*, *Rhizoglomus irregular*, and *Funneliformis mosseae* resulted in a higher shoot length and stem diameter as compared with control plant (El Hilali et al. 2022). Inoculation of tomato (*Solanum lycopersicum* L.) with *Rhizophagus intraradices*, *R. irregularis*, *Funneliformis mosseae*, *and Glomus iranicus* resulted in a higher growth index and P content in AMF-treated plants as compared with the control group (Shafiei et al. 2022). Furthermore, the growth rate and consumption index of *Tuta absoluta* larvae feeding AMF tomato leaves were much lower than that on plants without AMF (Shafiei et al. 2022).

Moreover, AMF promote plant water uptake; increase water use efficiency, especially under drought stress conditions; and enhance plant drought resistance (Birhane et al. 2012). In wheat plants, AMF inoculation induces an increase in plant biomass accumulation under long-term growth conditions under drought stress (Al-Karaki et al. 2004).

12.2.3 AMF as Biocontrol Agent

AMF play a vital role in boosting the plant resistance to above- and/or belowground pests and diseases (Whipps et al. 2008). AMF-plant symbiosis has been revealed to profoundly alter plant primary and secondary metabolism, including the salicylic acid (SA) and jasmonate (JA) signaling pathways that are critical to plant defenses (Cameron et al. 2013). Plants that have been colonized by AMF prior to pest or pathogen attacks may be systemically primed through defense compound reallocation (Jung et al. 2012), thus allowing rapid and increased expression of defense genes compared with non-AMF plants (Song et al. 2015). AMF can enhance the ability of host plants against fungal, bacterial, viral, and nematode diseases. AMF can significantly inhibit the dispersal of root-knot nematodes and decrease gall numbers and the infection rate and the damage caused by nematodes (Lax et al. 2011). *Glomus mosseae* increased the resistance of different tomato varieties to *Fusarium*, but the extent of resistance was not consistent (Steinkellner et al. 2012). Cucumber, bent grass (*Agrostis stolonifera*), and tomato were inoculated with *Phoma* sp. GS8-2 and *Glomus mosseae*, respectively. *Glomus mosseae* reduced *Rhizoctonia*-caused cucumber root rot and *Fusarium oxysporum*-caused tomato root rot but aggravated bent grass brown spot (Saldajeno et al. 2012). Cosme et al. (2011) explored the effect of inoculation of *Glomus intraradices* on the oviposition of *Lissorhoptrus oryzophilus* and found that this insect prefers to lay eggs on mycorrhizal plants. The possible explanation is that AMF colonization improves the root N and P contents; thus, the mycorrhizal plants with better growth were preferred to lay eggs; however, the harm of adults did not increase.

From the agricultural point of view, however, trade-offs that reduce yields may occur between AMF, crops, and pests. In addition to benefiting crop nutrition, AMF colonization also enhances the attraction, quantity characteristics, and quality measures of plants against herbivores (Hartley and Gange 2009) and therefore improves capabilities of herbivores (Kempel et al. 2010). Moreover, phloem-feeding insects frequently outperform non-AM controls on AMF-colonized plants (Hartley and Gange 2009). AMF management strategies should consider these trade-offs and balance them accordingly.

12.2.4 Contribution of AMF to Soil Health

Arbuscular mycorrhiza can directly affect the cycle of inorganic elements such as N, P, K, Ca, and Mg through chemical, physical, and biological activities and play an important role in the biogeochemical cycling of soil nutrients. The impact of arbuscular mycorrhiza on inorganic N is mainly through the hyphae absorbing N from the substrate and transferring it to the host plant and improving the rate of N fixation in N-fixing host plants by alleviating various stresses. The impact of AMF on promoting plant growth is closely associated with the improvement of plant P nutrition by mycorrhizal colonization. In soils with insufficient P supply, the inoculation of AMF can greatly improve the absorption and use of P by the symbiotic partner plants and alleviate the phenomenon of P deficiency in the rhizospheric zone (Recorbet et al. 2013).

AMF improve soil health through external hyphae too, thereby sustaining the constancy of the soil food web and increasing the stability of the soil structure (Finlay 2008), which provides numerous benefits to the host plants, such as defense against pathogens, enhanced salinity tolerance, decreased pH and heavy metals, and biofortification with trace elements in the crops (Ryan and Graham 2018). The huge mycelial network formed by the symbiosis of AMF and crops can extend to deeper and wider soils beyond the rhizosphere trophic zone of plants, thus improving the utilization of elements by plants (Lehmann et al. 2014). Besides facilitating host plant uptake of nutrients and water, AMF expand nutrient entrapment through their mycelial network, increasing soil aggregation through mycelium and glomalin, thereby improving soil nutrient storage and retention (Rillig and Mummey 2006) as well as reducing soil erosion and the risk of nutrient leaching.

12.2.5 Abiotic Stress Alleviation

Abiotic stress (e.g., drought, high temperature, salinity, heavy metal stress, and unfavorable soil pH) leads to degradation of soil and poses a serious threat to agricultural production. Therefore, abiotic stress is considered to be one of the main reasons for crop yield reduction worldwide (Singh et al. 2011). AMF can enhance the tolerance of plants to abiotic stress. The extracellular hyphae of AMF can promote the uptake and consumption of nutrients and water by plants, and it is one of the critical factors in facilitating plants to avoid drought damage (Tyagi et al.

2017). Increased drought resistance and better crop performance can be due to the abundance of antioxidative enzymes (superoxide dismutase, catalase, peroxidase) and soluble sugars symbiotically produced by AMF (Huang et al. 2011). AMF also improve plant drought tolerance by improving soil structural stability. It has been reported that AMF hyphae have a rich filamentous hyphae network, which can enhance soil structure and also change soil structure by producing glycoproteins to form aggregates (Singh et al. 2013). Therefore, AMF symbiosis can enhance the drought tolerance of plants by enhancing the stability of soil structure, thereby increasing soil water-holding capacity (Ruiz-Lozano 2003).

The occurrence of AMF greatly enhanced the tolerance of plants to extreme temperature. Under the condition of high temperature stress, root colonization with AMF can enhance the activity of antioxidant enzymes and increase the content of soluble protein and proline in maize (*Zea mays* L.). Plants inoculated with AMF increased the activity of SOD, POD, and CAT by 50%, 40%, and 21%, respectively, indicating that AMF can resist high temperature stress damage by improving the antioxidant capacity of plants, thereby promoting plant growth (Mathur et al. 2018). In addition, low temperature or high temperature induces excessive ROS production under stress, causing oxidative stress response to damage plants. Usually, AMF can effectively promote the production of SOD, POD, CAT, and GR after colonizing host plants and relieve the damage caused by reactive oxygen species. Specifically, they reduce peroxidation of membrane lipids as well as membrane permeability and increase osmotic adjustment substance accumulation in response to temperature stress (Ahanger and Agarwal 2017; Hajiboland et al. 2019).

Under heavy metal stress, AMF change the growth pattern of plants by exploiting and exploring unstressed parts of the environment, alleviating the toxicity of heavy metals through various pathways (Gonzalez-Guerrero et al. 2008). The roots of AMF-inoculated plants can greatly contain heavy metals, which can inhibit the transport of heavy metals from the root system to the aboveground tolerance to adapt to heavy metal stress (Słomka et al. 2011; Zhang et al. 2010). However, mycelia have limited uptake potential of heavy metals, and in highly polluted places, the possibility of mycelium avoiding the hazards of toxic metals is very limited. Therefore, mycorrhizae have developed different strategies to resist heavy metal stress: AMF can secrete glomycin (Ferrol et al. 2009); glomycin participates in heavy metal inactivation by chelating heavy metals in soil. Audet and Charest (2007) revealed that AMF shift from "enhanced uptake" at soil with low concentrations of heavy metals to "metal binding" at soil with high concentrations of heavy metals. The remediation effect of AMF on heavy metals is also reflected in the ability to induce host plants to produce antioxidant enzymes, upregulate the expression of related peroxidase genes, and reduce the detrimental effects of ROS on plants under heavy metal stress (Rozpądek et al. 2014).

Salt stress can negatively affect plant photosynthetic capacity, enzyme activity, protein synthesis, and mineral nutrition and produce osmotic stress and ion stress on plants, thereby affecting the physiological and biochemical balance of plants (Hashem et al. 2016; Iqbal et al. 2015). Salt stress can promote ROS production, cause plant oxidative damage, and interfere with the normal metabolism of plants

(Akyol et al. 2020). AMF can improve the antioxidant capacity of host, reduce H_2O_2 content, inhibit lipid peroxidation, and enhance the salt stress of plants by inducing plants to produce and accumulate osmotic adjustment substances such as glycine betaine, proline, and soluble sugar tolerance (Akyol et al. 2020; Porcel et al. 2015; Zhu 2003). Hidri et al. have found that AMF can improve nutrient (P) acquisition; reduce sodium absorption; enhance water absorption; and improve photosynthesis, chlorophyll content, and availability of antioxidant molecules under saline conditions. Hajiboland et al. (2010) reported that improved salt stress tolerance in tomato plants inoculated with AMF was associated with increased uptake of P, potassium (K), and calcium (Ca) and reduced sodium (Na) toxicity.

12.3 Response of Arbuscular Mycorrhizal Fungi to Agricultural Management Practice

AMF develop symbiosis with most plant species and can assist the host plant in many ways, including better nutrient uptake, drought and salt tolerance, and disease resistance (Smith and Read 2008). These fungi are crucial to the preservation of the soil and the sustenance of plants. The development and survival of fungal propagules, including spores, hyphae, and colonized roots, are necessary for AM fungus to persist in various ecosystems. In the presence of host plants and no soil disturbance, hyphae are considered to be the primary source of inoculum, but spores are thought to be a relatively resistant fungal structure that may be viewed as “long-term” propagules when no viable host plants are present. For agricultural crops, there are management techniques that are widely acknowledged. Numerous agricultural management practices, such as soil tillage, fertilization, and plant protection techniques, have deleterious impact on mycorrhizal symbioses in agroecosystems (Säle et al. 2015; Jansa et al. 2002; Gryndler et al. 2006) (Fig. 12.1). These traditional management techniques can decrease soil biodiversity, especially AMF (Tsiafouli et al. 2015). The technique of organic agriculture, in contrast, can enhance soil quality in terms of boosting the diversity and biomass of soil microbiome (Mäder et al. 2002; Verbruggen et al. 2010) (Fig. 12.1). This section focuses on the discussion of the effects of agricultural management practices on AMF.

12.3.1 Agrochemical Management Practice

Agrochemicals are chemical formulations used in industrial agriculture. It refers to chemical fertilizers and biocides, which are substances used for control of hazardous organisms. A biocide can be (1) pesticides including insecticides, herbicides, fungicides, and nematicides; (2) antimicrobials including antibacterials, antifungals, antiviral, antiprotozoals, and antiparasites; and (3) synthetic fertilizers. In addition to

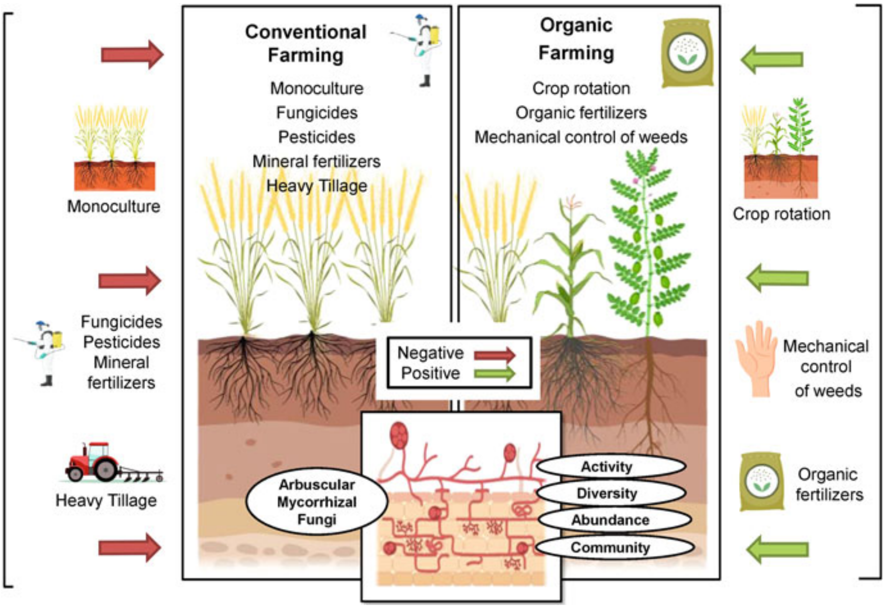

Fig. 12.1 Impact of different agricultural management practices on arbuscular mycorrhizal fungi

potentially contaminating the soil, the application of agrochemicals may have detrimental effects on AMF community (Kurle and Pfleger 1994; Abd-Alla et al. 2000; Lekberg and Koide 2005; Pasaribu et al. 2011; Mathimaran et al. 2007) leading to a decline in AMF spore diversity and abundance (Oehl et al. 2004).

12.3.1.1 Pesticides

Insecticides, fungicides, nematicides, and herbicides are the four major categories of pesticides. Pesticides that are applied in agricultural systems could harm both human and environment when used in an unrestrained manner. The quantity of pesticides used and, consequently, their presence in food depend on the farming system which is generally higher in conventional integrated pest management (IPM) than that in organic systems (Atkinson 2009). Therefore, agricultural production has been referred to as “the ghost of conventional agriculture past” (Riedo et al. 2021). Consequently, the application of beneficial soil organisms like AMF contrasts with previous and present conventional agricultural procedures because of the deleterious effects of excessive levels of pesticides on soil microbial communities (Dodd 2000; Montesinos 2003; Jacobsen and Hjelmsø 2014). Such unfavorable outcomes are caused not only by the direct harm of pesticides to soil life, but it also alters the soil ecosystem by favoring weeds and some specific crops through the emergence of pesticide resistance (Baek et al. 2021). When active compounds (pesticides) are administered as a soil drench, seed treatment, and foliar spray or when these substances exist in runoff from leaf application or drift to the soil, they affect the viability and functionality of AMF structures like spores and hyphae in soil. Additionally, variations in the physiology of the host plant may have indirect impacts on AMF symbiosis.

12.3.1.1.1 Fungicides

It is not surprising that fungicides might have a deleterious impact on AMF. There is a varied sensitivity of AMF to fungicides that explains why negative, neutral, and positive impacts of fungicides have been recorded. Some fungicides target specific families of fungi (e.g., Ascomycota, to which the majority of fungal diseases belong). However, some fungicides, including thiazoles (benomyl and carbendazim), have a substantial adverse impact on Glomeromycota, the phylum of fungi to which AMF belongs. Thus, benomyl causes a reduction in AMF activity in the field (Allison et al. 2007; Chiocchio et al. 2000; Hartnett and Wilson 2002; O'Connor et al. 2009). Additionally, benomyl has a negative effect on nutrient mineralization and decomposition by reducing the diversity and abundance of saprotrophic soil fungus. An alternative fungicide, Topsin M (also known as topsin), was described for use in ecological study including the reduction of AMF (Wilson and Williamson 2008). The dosage used, as well as the fungicide's interactions with the soil matrix (such as adsorption on organic matter or solubility in soil solution), influences how well fungicides work.

12.3.1.1.2 Herbicides

Because the majority of current efforts are focused on aboveground control, herbicide impact on soil biota has got little attention (Kremer 2014). The three herbicides that are most frequently used are paraquat, oxyfluorfen, and glyphosate. The herbicide oxyfluorfen was found to have a negative or indifferent effect on AMF. Recently, genetically modified crops (such as cotton, maize, soybean, and canola) have been released onto the market and include a gene that renders such plants resistant to glyphosate; its use is probably going to grow. Consequently, glyphosate usage as a weed control method was increased particularly in no-till or conservation agriculture (Watrud et al. 2011; Baek et al. 2021). Due to its alleged quick decomposition in soil and minimal toxicity to vertebrates, glyphosate has been viewed as a reasonably advantageous foliar-acting herbicide (Duke and Powles 2008; Weidenhamer and Callaway 2010). Studies examining the effects of glyphosate on AMF reveal a suppression of AM fungal spore germination as well as germ tube growth and a reduction of mycorrhizal count in soil (Zaller et al. 2014) but only at concentrations higher than those advised for usage in the field. When used at acceptable concentrations, glyphosate has no effect on mycorrhiza (Baumgartner et al. 2010; Pasaribu et al. 2011). Although sublethal doses of herbicides may not cause the plant to die, they can diminish photosynthetic rates to the point where the symbiosis is compromised.

12.3.1.1.3 Insecticides and Nematicides

The effects of fungicides and herbicides on AMF are far greater than the effects of insecticides and nematicides. Insecticides and nematicides, according to earlier evaluations, had either no adverse effects or moderately positive effects on AMF (Trappe et al. 1984; Hamel and Strullu 2006). However, differential impact of systemic and contact insecticides was documented, just as they were in the case of fungicides (Sarr et al. 2013; Deliopoulos et al. 2008). For example, phoxim, an insecticide/acaricide, was reported to prevent AMF colonization in carrot (*Daucus carota*); however, it was not the case in green onion (*Allium fistulosum*) (Wang et al. 2011a, b). Aldicarb, a nematicide, had no impact on mycorrhizal colonization of potato (*Solanum tuberosum*) (Goulson 2013). Currently, neonicotinoid insecticide class is one of the most popularly used globally due to their broad spectrum of action on many pests of various crops. Numerous civilizations use neonicotinoids extensively. They have drawn a lot of attention because of their extremely detrimental effects on insect diversity, which also have major repercussions for ecosystem services like pollination (Hladik et al. 2018; Malfatti et al. 2023). Neoicotinoid effects on AMF have just recently been the subject of studies. For instance, two neonicotinoids, imidacloprid as well as thiamethoxam, were evaluated on the spore germination of two AMF species, *Rhizophagus clarus* and *Glomus albida*. The results showed that both neonicotinoids dramatically decreased spore germination of AMF in a dose-dependent way (Malfatti et al. 2023).

12.3.1.2 Fertilizers

Due to the critical symbiotic interaction between hyphae of mycorrhizal fungi and host plants, AMF might be sensitive to alternations in soil nutrients (Hack et al. 2019). Numerous earlier researches have demonstrated that modifying the soil microenvironment with the addition of mineral fertilizer can have (positive, negative, or inconsequential) impacts on the proliferation of AMF. A field study revealed that while P application increased AMF abundance, N application predominantly changed the species composition of AMF (Chen et al. 2014). Nevertheless, according to Xiao et al. (2019), the application of N had an impact on AMF abundance, while the addition of P had an impact on AMF diversity, and the augmentation of N and P had no discernible impact on the AMF community composition. Besides, high soil nutrient levels, such as N and P, can promote AMF sporulation, so adding organic fertilizer helps the soil flora thrive (Qin et al. 2015). Furthermore, soil pH and K have a significant impact on the AMF community structure (Qin et al. 2015).

12.3.2 Soil Tillage

Rotary soil tillage is regarded as a traditional farming method. Rotary tillage is important because it breaks up and softens the soil while also equally distributing organic materials and nutrients. No-till farming, on the other hand, is a method of crop production in which the soil is not tilled. Crop growth and yield have been observed to be lowered (Huynh et al. 2019), unchanged (Büchi et al. 2017), or increased (da Silva et al. 2022) when compared to rotary tillage cultivation. As previously mentioned, tillage is a factor that influences soil hardness and the alterations in root growth which can either improve or decrease yield (Ren et al. 2018). Additionally, it has been proposed that variations in the species of soil microbes may have an impact on crop yield, which is another element that may change crop growth and yield during plowing (Ma et al. 2020). AMF produce exterior hyphae that provide the host with P that could not be taken up through plant roots (Smith and Read 2008). Intensive soil tillage may have a deleterious impact on AMF biomass and community composition. The disruption of the AMF mycelial network has been proven to be the primary reason why traditional farming generally diminishes the quantity of AMF when compared to no-tillage systems (Gu et al. 2020; Jansa et al. 2006; Castelli et al. 2014). Additionally, substantial research has been done to show how tillage techniques and AMF colonization can change AMF communities in soil and plant roots (Tatewaki et al. 2021; Liu et al. 2022a, b; Lu et al. 2018; Gu et al. 2020; Tatewaki et al. 2021).

12.3.3 Crop Rotation

Crop rotation is a popular agronomic soil management technique that aims to manage nutrient requirements, maintain healthy soil, reduce pest and disease pressure, and reduce reliance on agricultural chemicals in order to produce high yields that are sustainable (Angus et al. 2015). Crop rotation slows the growth of weeds and plant diseases (Krupinsky et al. 2002; Liebman and Dyck 1993). It also hastens the buildup of soil organic C and soil N (Havlin et al. 1990; Van Eerd et al. 2014). Additionally, a system with a greater variety of rotating crops is linked to a greater diversity and richness of soil microbial life (Venter et al. 2016). The benefits of crop rotation systems are influenced by the plant species chosen and the order in which they are planted (Yang and Kay 2001; West and Post 2002). Despite its significance, it can also impact soil microbial communities, particularly AMF, which are imperative for plant growth. The existence of nonhost crops in the rotation has been proven to have an impact on root colonization and spore abundance (Arihara and Karasawa 2000). Extremely little AMF variety has reportedly been found in monoculture (Burrows and Pfleger 2002; Oehl et al. 2003). Crop rotations appear to be a simple and low-cost farming technique associated with increased AMF sporulation in many upland farming systems. AMF sporulation increased in a maize-common bean crop rotation system compared to a maize monoculture, and AMF sporulation correlates with the crop previously planted on the site (Oruru and Njeru 2016). Similarly, crop rotation with mycorrhizal plants and AMF inoculation both improve maize growth performance in limed, acid sulfate soil (Higo et al. 2010). Crop rotation also aids plant nutrient absorption. Improved N uptake by maize plants in a maize-common bean crop rotation system is one example (Oruru and Njeru 2016). Similarly, Ratnayake et al. (2017) revealed that rotations of crops can boost nutrient availability in soil and stocks of C compared with monocultures.

12.4 Comparing Arbuscular Mycorrhizal Fungi in Organic and Conventional Farming

12.4.1 Benefits and Limitations of Organic and Conventional Farming

Organic and conventional farming both have advantages and disadvantages. Although conventional farming is frequently associated with higher yields and lower costs, it is harmful to the environment, reduces biodiversity, and poses potential health risks. In addition, traditional farming controls synthetic inputs (such as pesticides, chemical fertilizers, and amendments) consistently, disregarding the naturally occurring spatial-longitudinal heterogeneity of soil and crop conditions within fields. As a result, organic farming is emerging as a viable option for productive and sustainable agriculture although it is characterized by high cost and relatively unstable yield (Jaacks et al. 2022). Organic farming relies on the use of organic fertilizers, biofertilizers, and organominerals, which helps to avoid the negative environmental effects and toxicities associated with chemicalized farming. In addition, organic agriculture increases the agroecosystem's resistance to the negative effects of climate change by enhancing the sequestration and conservation of C in soil systems (Gamage et al. 2023).

12.4.2 Influence of Organic and Conventional Farming on Arbuscular Mycorrhizal Diversity and Community Composition

Agricultural management strategies and differences in land-use types can have a significant impact on AMF populations (Martinez and Johnson 2010; Zhao et al. 2015a, b). Understanding the effects of organic and conventional agricultural practices on the diversity and community composition of mycorrhizal symbiosis is essential for agricultural production and sustainable soil utilization. Several studies have been undertaken in agricultural contexts for comparing the effect of organic and

Table 12.1 Recent studies comparing the effect of organic and conventional management approaches on arbuscular mycorrhizal fungi

Studied plants	Major findings	Applied techniques	References
Maize root	The colonization intensity, operational taxonomic unit, and taxonomic diversity were all greater on conventional farms compared with that on organic farms	Sequencing of V4–V5 hypervariable regions of the fungal 18S rRNA gene	Chen et al. (2022)
Wheat	Conventional agriculture had a substantial impact on the AMF population but led to a decline in AMF diversity	Sequencing of 18S rRNA gene amplicons	Wahdan et al. (2021)
Cereal crops	Organic farming had a positive effect on the AMF diversity, which influenced plant productivity	Sequencing of the LSU region of ribosomal DNA	Manoharan et al. (2017)
Apple	AMF abundance was substantially greater in organically managed than in conventionally managed orchards. Also, organic orchards harbored significantly different AMF communities	454 pyrosequencing of SSU rRNA gene amplicons	van Geel et al. (2015)
Maize and potato	A decline was observed in the diversity of mycorrhizal taxa in conventionally maintained fields	T-RFLP of 25S rRNA gene fragments	Verbruggen et al. (2012)
Maize and potato	The average number of AMF taxa was greater in areas treated organically. In addition, AMF abundance significantly increased after transition to organic agriculture	Terminal restriction fragment-length polymorphism (T-RFLP) of PCR-amplified large subunit rRNA gene fragments	Verbruggen et al. (2010)
Onion	Farming systems did not influence AMF diversity	Sequencing of the partial 18S-ITS1–5.8S-ITS2 rDNA region	Galván et al. (2009)
Potatoes, winter wheat, and beetroots	Mycorrhizal spore abundance and species diversity were considerably greater in organic systems than that in conventional ones	Morphological identification	Oehl et al. (2004)

conventional management approaches on AMF diversity (Table 12.1). Almost all studies indicated that organic farming is capable of sustaining greater diversity of AMF than conventional farming and showed the necessity of an improved diversity for long-term crop productivity (Manoharan et al. 2017).

12.5 Digging Deeper: Factors to Consider When Applying Arbuscular Mycorrhizal Fungi in Organic Farming

The environmentally benign, innovative, and sustainable method of organic farming increases agricultural output and the quality of life for many farmers. The role of AMF in helping soil fertility, sustainability, and crop production improvement is one of the most researched and well-known topics in agronomy. When incorporating AMF into organic farming practices, several factors need to be taken into consideration.

Firstly, arbuscular mycorrhizal fungal communities can be influenced by the identity of the host plant. Furthermore, plant traits, such as root exudates and morphological characteristics, play a critical role in determining the specificity of AM symbiosis (Ramana et al. 2023). Hence, various studies have shown that the presence of suitable AMF species is required in a given soil system. For instance, Gao et al. (2020) reported a high specificity between roots of cotton plant and the mycorrhizal fungus, *Rhizophagus irregularis* CD1. They also reported an increase in growth and yield, boll number per plant, as well as the maturity of the fiber cotton when inoculated with *Rhizophagus irregularis* CD1 as compared with non-inoculated plant. After mycorrhizal inoculation, both the expression of particular P transporter family genes and the P concentration in cotton biomass were dramatically increased.

Secondly, the presence of other soil microorganisms should also be considered. Some microorganisms, such as certain bacteria and fungi, may cooperate with AMF to facilitate the host plant growth (Feng et al. 2023). Therefore, it is essential to maintain a balanced microbial community to support the symbiotic relationship between AMF and plants. For instance, a recent study revealed that some isolates of AMF (e.g., *Gigaspora* sp.) and bacteria (e.g., *Sphingomonas*) assisted their host plants thrive in the native soil (Feng et al. 2023). The combined use of *Bacillus subtilis* and AM fungi resulted in superior yield-related indexes and biofortification in wheat grains (Yadav et al. 2020).

Thirdly, combining AMF with suitable sustainable agronomic practices can maximize the expected benefits from plant-arbuscular mycorrhizal symbiosis. For instance, the use of biofertilizers to agricultural soils has a positive impact on crop productivity and soil fertility. Combining the exogenous AMF *Rhizoglomus irregulare* (DAOM) with phospho-compost resulted in considerably increased shoot and root dry weights as well as yield in lettuce plants compared to control plants (Anli et al. 2022). In addition, soil characteristics, particularly soil total organic C, N, P, and GRSP content, were considerably enhanced in soils treated with biofertilizers and *Rhizoglomus irregulare* (DAOM) after 2 months of field testing compared to the control (Anli et al. 2022).

Finally, regular monitoring and evaluation of AMF colonization and effectiveness are essential. This can be accomplished by sampling and analysing roots, and assessing plant growth and nutrient acquisition. To maximize the benefits provided by AMF, management practices may need to be adjusted based on the results.

12.6 Arbuscular Mycorrhizal Fungi and Climate-Smart Organic Agriculture

Climate change is one of the most significant concerns influencing the way of life of people worldwide. Climate change and some agricultural management practices, such as tilling and excessive chemical use, have all led to land degradation and crop output decline. AMF are capable of mitigating future environmental disturbances. Field investigations and greenhouse tests under simulated climate warming indicate that temperature increases may have a positive effect on AM symbiosis (Hu et al. 2015). Furthermore, it has been suggested that the stimulation of AMF by elevated atmospheric carbon dioxide (CO_2) is a key mechanism for promoting soil C sequestration by boosting C inputs to soil and by shielding organic C from degradation via aggregation (Cheng et al. 2012). In a unique field experiment that simulates future climate, Wahdan et al. (2021) found that organic agricultural practices significantly increased total richness of AMF under future climate conditions compared to all other treatments, indicating that organic farming not only mitigates the effects of climate change but also increases richness of AMF under future climate conditions (Wahdan et al. 2021).

12.7 Future Directions in Sustainable Forestry: AMF Response to Management Practices in Forests

AMF play a major role in the establishment and succession of plant communities, driving the restoration process of degraded land (Manaut et al. 2015; Karthikeyan and Krishnakumar 2012). AMF is one of the pivotal factors determining species diversity, community structure, and productivity in terrestrial ecosystems, and they regulate the resource allocation among adjacent plants through the underground mycelial network, thereby affecting the coexistence and competition among plants (Smith et al. 2010). Zobel and Öpik (2014) stated that the inherent relationships between AMF and the plant community can be explained by "driver" and "passenger" hypotheses, which illustrated the driving effect of AMF on the plant. Generally, AMF will govern the plant community structure of a certain successional stage, and the specific plant community of this successional stage will affect the colonization of the AMF communities, and the varied AMF communities will further affect the plant community in the next successional stage (Renker et al. 2004). In addition, plant-soil feedback is also a manifestation of AMF-driven plant community succession. Positive feedback can promote community development in the early stage, while negative feedback can facilitate plant species replacement and drive community succession (Kikvidze et al. 2010).

The influence of AMF on plant fitness can be attributed to improved seedling establishment, plant growth, a higher tolerance to belowground plant pathogens, better water acquisition, and improved soil structure and stability in forest ecosystems (Newsham et al. 1995). Through the removal of nutrients, disturbance of soil or forest floor, and altered microclimates, intensive forest management practices can negatively affect AMF biodiversity (Sharmah and Jha 2014). It has been suggested that intensive forest clearcutting may affect the distribution and composition of AMF communities (Moora et al. 2014; Mummey et al. 2010), favoring some AMF taxa and disfavoring others (Gottshall et al. 2017). Intensive management practices can significantly decrease AMF biomass in soil and glomalin-related soil protein (GRSP) content, of which understory removal, mineral fertilization, and soil tillage are major practices with profound negative effects on AMF (Qin et al. 2017). AMF can produce glomalin, which plays the role of "super glue" in the formation of stable soil structure, which can significantly increase the water percolating capacity and stability of soil (Burrows 2014).

In addition, the abundance of AMF taxa may be correlated with the level of management, and AMF diversity varies depending on management techniques as seen by the high AMF biodiversity in non-managed fields and low diversity in intensively managed fields (Sharmah and Jha 2014). In Moso bamboo forests, AMF abundance and community composition are altered by long-term intensive management, leading to a decrease in soil aggregation (Qin et al. 2017). Moreover, when AMF communities are strongly altered, Moso bamboo forests have been intensively managed for long-term experience soil erosion and organic C decomposition. Because of intensive management practices, AMF communities differ from those of old stands, but the ecosystem can still provide a "symbiotic service" needed to restore old-growth understory plant communities (Uibopuu et al. 2009).

In abandoned slash-and-burn forests, which have been disturbed for 2 or 3 years, AMF communities were similar to those in mature forests (de León et al. 2018). Studies indicate that AMF communities and forest regeneration may be threatened by clearcutting tropical rain forests (Stürmer and Siqueira 2011), whereas slash-and-burn management may have relatively minor effects (Rillig 2004; Stürmer and Siqueira 2011). According to Aguilar-Fernández et al. (2009), slash-and-burn maintained similar levels of species richness in forest and pasture plots. AMF communities that develop after forest conversion to pasture seem to be defined more by the persistent effects derived from conversion and management which can be manifested by variations in composition of plant species, soil quality, and microclimates than by the slash-and-burn process (Sharmah and Jha 2014).

The composition of AMF communities was significantly affected by land use, with communities in the clearcut region being the most distinct (de León et al. 2018). Under various land-use regimes, changes in AMF communities may be caused by both biotic and abiotic interactions. Host plants assist AMF establishment via different types of propagules that arrive at a location of interaction (Fonseca et al. 2017), although abiotic factors filtering environment are more significant components in community development than AMF competition (Bouffaud et al. 2016). According to Oehl et al. (2010), soil type and land-use intensity are the primary factors determining the composition and richness of AMF, and different agricultural practices including monoculture and narrow cereal mono-crop rotations can significantly reduce the biodiversity and richness of AMF in comparison to grasslands.

In terms of plant community structures and production, the biological and functional variety of AMF is crucial to forest ecosystems (Jiang et al. 2017). AMF populations in differently managed forests had distinct effects on the development of various forest plant species; in general, the old growth inoculum had a greater beneficial impact than the inoculum from the young forest. The response of plant communities to the severity of forest management may be mediated by mycorrhizal interactions since land use influences the composition of AM fungus populations (Uibopuu et al. 2012). Thinning is a crucial silvicultural strategy that has an impact on a variety of forest features, including overstory, understory, soil properties (Trentini et al. 2017; Zhou et al. 2016), and microbial communities (Dang et al. 2018). In comparison with the late successional species, the early successional species considerably increased the rate of AMF colonization (Zangaro et al. 2003). The findings of Lu et al. suggested that the expansion of Chinese fir may have reached a turning point in the 32-year period as the number of shared OTUs continuously climbed from 9-year, 17-year, and 23-year to 32-year while decreasing in 45-year (Lu et al. 2019). The colonization, biomass, and diversity of AMF considerably increased with the emergence of *Cunninghamia lanceolata*, and the biomass contribution of AMF to glomalin-related soil protein (GRSP) showed a strong association with soil organic C (Liu et al. 2022a, b). Zhou et al. found that the topsoil C storage was significantly enhanced by in-forest planting of *Sarcandra glabra*, while the diversity and composition of the related AMF community were not significantly affected (Zhou et al. 2022). In-forest planting of *Sarcandra glabra* was beneficial for the forest and ecologically safe for the *C. lanceolata* AMF (Zhou et al. 2022). Wang et al. found that the rate of AMF colonization was substantially and negatively linked with soil P, suggesting that low P soil would be a better choice for using AMF in afforestation (Wang et al. 2019).

12.8 Conclusions

AMF play a vital role in ecosystem function, soil structure maintenance through C sequestration, and water retention. As a result, whether farmers use organic or conventional methods has an impact not only on agricultural productivity but also on overall environmental sustainability. This chapter investigated the impact of organic vs. conventional farming practices on AMF using existing research and empirical evidence.

For starters, organic farming has been found to be more conducive to promoting AMF diversity and abundance due to its emphasis on sustainable and eco-friendly practices. The absence of synthetic fertilizers and pesticides promotes a more balanced and natural ecosystem, which promotes the sporulation and activity of AMF. As a result, organic farming systems have the potential to significantly improve soil fertility, nutrient cycling, and plant health. Conventional farming, on the other hand, has been shown to have negative effects on AMF populations because of its heavy reliance on agrochemical inputs. Synthetic pesticides and fertilizers can disrupt the symbiotic association between AMF and plant host, resulting in a reduction in AMF diversity and activity. This, in turn, can have deleterious impacts on soil health and nutrient availability.

More research is needed in the future to gain a better understanding of the mechanisms that govern interactions between farming practices and AMF communities. This knowledge will be extremely useful in directing agricultural policies and practices toward more environmentally sound and sustainable approaches. Efforts should also be made to educate farmers, policymakers, and consumers about the significance of AMF and the potential benefits of organic farming in promoting their growth.

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