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Mycorrhizosphere as a hub of microbial interactions: Implications for nutrient cycling and plant health

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Abstract
In sustainable, low-input cropping systems as opposed to conventional agriculture, where their importance has been diminished by high inputs of agrochemicals, the natural roles of microbes in maintaining soil fertility and biocontrolling plant diseases may be more relevant. The largest category, known as vesicular-arbuscular mycorrhizal (VAM) fungus, is primarily connected to agricultural crops. Through the host plasma membrane and the fungal cell wall, these fungi enter the host cytoplasm and produce distinctive haustoria-like structures (arbuscules or coiled hyphae) that come into contact with the host cytoplasm. The cortex's fungal structures increase the surface area available for metabolic interactions between the host and the fungal partners. For the construction of a sustainable management system for crop production and soil fertility, a deeper understanding of the interactions between arbuscular mycorrhizal fungi and other microorganisms is necessary. AM fungi are constantly interacting with a variety of soil microbes, including harmful bacteria, rhizobacteria that promote plant growth, and mycorrhizal helper bacteria. Their interactions might significantly affect agriculture. Numerous studies have examined the effects of mycorrhizal colonisation on associated bacterial communities, although the mechanisms of interaction are still not fully understood. The review includes current state of knowledge on the interactions between bacteria and arbuscular mycorrhizal fungi, along with the potential advantages of VAM in sustainable agriculture.

Keywords: Sustainable agriculture, bio control, colonisation, arbuscular mycorrhizal, rhizobacteria, interactions

Introduction
One important factor influencing soil health, quality, and productivity is soil biological behaviour. The evaluation of such consequences can improve agricultural and ecological efficiency. For instance, maximising the applications of agrochemicals to enhance soil biological properties, such as the interactions between various soil microbes, have considerable effects on the environment and crops production (Artursson *et al.* 2006) [5]. This is critical for biotechnology in particular because interactions like this could alter the pace of input necessary for an effective and long-lasting production (Barea *et al.* 2005) [10]. Plant health and soil fertility are significantly influenced by soil microbes (Gianinazzi and Schuepp, 1994) [28]. The surrounding plant roots in the rhizosphere of the soil are interesting and complex. There are so many different kinds of microorganisms interacting with plant roots and other soil microbes in the rhizosphere of the soil. The characteristics of the soil rhizosphere make it a distinct and dynamic region. Rhizotrhophic microbe activity and interactions can affect soil conditions, which in turn affect plant development and microorganism activity (Zaidi *et al.*, 2003) [83]. AM fungus, one of the most prevalent and influential soil microbes, has a significant impact on the growth of plants and other soil microorganisms. The term "mycorrhizosphere" refers to the area of soil surrounding plant roots and AM hyphae where AM fungi and soil bacteria interact (Linderman, 2000) [2]. Different species of soil bacteria interact with AM fungus in the soil, especially in the rhizosphere. The interactions are typically beneficial (Smith and Read 2008) [70]. Mycorrhizal fungi that live in symbiotic relationships with plants, including arbuscular mycorrhizal (AM) fungi, are an important part of the microbial communities that affect plant development and nutrient intake. These symbiotic fungi's hyphae enhance the area available for interactions with other microorganisms, which serve as a vital pathway for the transportation of energy-rich plant assimilates to the soil, and increase the absorptive surface area of the root systems

of their host plants. The confined region of soil surrounding living roots known as the rhizosphere has historically been used to describe how plant assimilates affect microbial ecosystems (Hiltner, 1904) [33]. Increased microbial activity in the rhizosphere is caused by the leaking and exudation of organic materials from the root (Grayston *et al.*, 1997) [30]. The term "mycorrhizosphere" has been coined since the rhizosphere concept has been expanded to incorporate the fungal component of the symbiosis because plant roots in natural and semi-natural habitats tend to be mycorrhizal. More specifically, the term "hyphosphere" exclusively refers to the area around specific fungal hyphae. The mycorrhizosphere is the area that is affected by both the root and the mycorrhizal fungus. It might be claimed that the word "mycorrhizosphere" could apply to every soil because fungal hyphae and mycorrhizas are more or less ubiquitous in natural soils. Due to ploughing (Sturz *et al.*, 1997) [7] and excessive inorganic fertiliser, herbicide, and pesticide inputs (Gianinazzi *et al.*, 2002) [29] have altered microbial communities in typical agricultural systems, it is possible that the natural roles of mycorrhizosphere species have been marginalised in intensive agriculture (Fig.I). The microbial diversity in these systems has decreased (Meader *et al.*, 2002) [43], and it is still unknown what functional effects this loss of diversity will have. Agriculture and ecology may benefit significantly by taking into account rhizotrophic interactions and how they affect the soil's characteristics and, in turn, plant growth. Such interactions may change the structural characteristics of the soil (Rillig and Mummey 2006) [59] and increase the availability of nutrients (Marschener and Dell 1994) [44].

The phylum Glomeromycota comprises arbuscular mycorrhizal (AM) fungi, which are soil-dwelling fungi essential for many terrestrial plants (Schußler *et al.*, 2001) [66]. Evidence from fossil records and DNA sequencing suggests AM fungi and plants co-evolved over 400 million years ago (Parniske, 2000) [55]. These fungi can establish non-specific symbiotic relationships with most terrestrial plants (Feddermann *et al.*, 2010) [24]. During symbiosis, AM fungi invade the root cortex, forming haustoria-like structures called arbuscules that interact with the host's cytoplasm (Smith and Read, 1997) [71]. In exchange for phosphorus, the fungi provide the plants with hydrocarbons (Hause *et al.*, 2002) [32]. While AM fungi are generally non-specific in their associations, certain combinations of AM fungi and host plants may be more effective, especially under stress conditions (Feddermann *et al.*, 2010) [24].

As the symbiosis progresses, fungal hyphae develop arbuscules and vesicles that store nutrients. Arbuscules facilitate nutrient exchange between fungi and roots, and it is estimated that AM-associated plants may allocate 10-20% of their fixed carbon to these symbionts, significantly influencing the soil ecosystem (Johnson *et al.*, 2002) [36]. AM fungi also enhance soil stability by forming soil aggregates (Tisdall and Oades, 1979) [78] and can mitigate the impacts of plant diseases (St-Arnaud *et al.*, 1997) [72] and hazardous metal concentrations (Khan *et al.*, 2000). Vesicles act as specialized storage organelles that can help plants cope with stress by storing salt ions and heavy metals, thus reducing stress effects on growth (Smith and Read, 2008) [70]

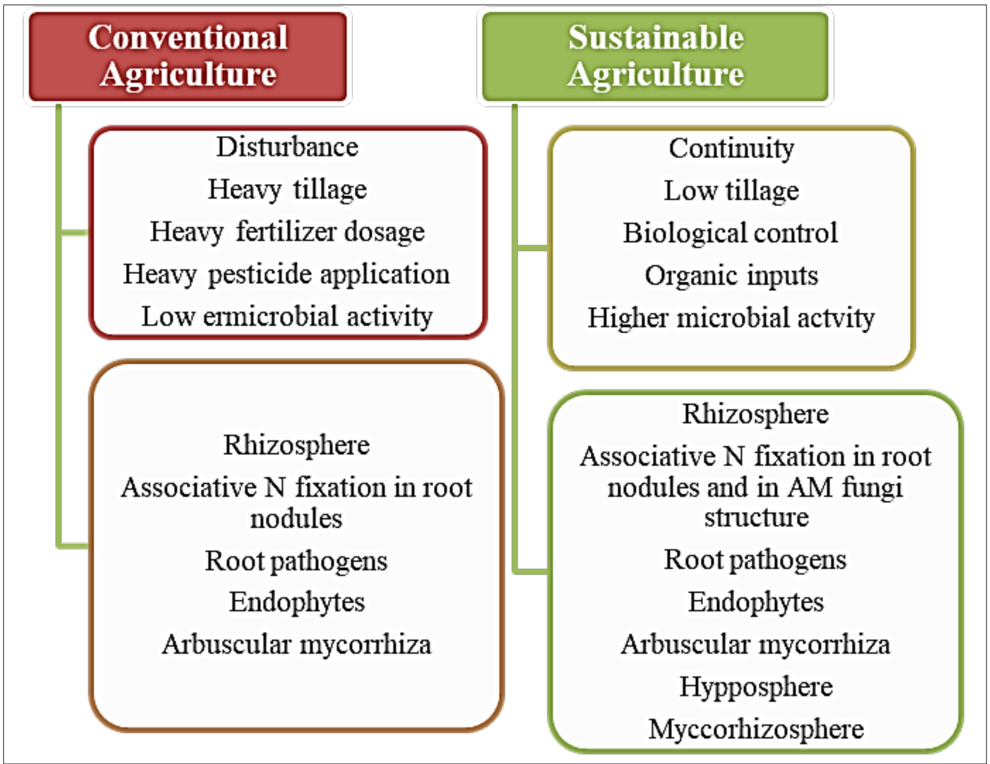

Fig 1: Schematic representation of different interactions in conventional and sustainable agriculture

Interactions of AM fungi and mycorrhizosphere bacteria

The colonisation of plant roots by AM fungi can have both direct and indirect effects on bacterial communities associated with those roots. Direct interactions include the transmission of high-energy carbon compounds from host assimilates transported to the mycorrhizosphere by fungal hyphae, alterations in the pH of the mycorrhizosphere brought on by the fungus, competition for nutrients, and fungal exudation of additional inhibitory or stimulatory compounds. Examples of indirect interactions include the effects of mycorrhiza on host plant development, root exudation, and soil structure. As a result, in comparison to a plant that is not mycorrhizal, root exudates are also modified by AM symbiosis due to the creation of some novel biochemicals. This alters the microbial populations in the rhizosphere. Although at a much lower rate than the rhizosphere, AM hyphae can create C products as an energy source for soil bacteria in the mycorrhizosphere (Andrade *et al.*, 1998) [2]. Microorganisms in the soil can create products that improve the quantities of root exudates causing activation of a greater rate of root colonisation as a result of AM hyphae (Baraa *et al.*, 2005) [10]. Furthermore, soil microorganisms create plant hormones that may have an impact on AM establishment, and spore and hyphal development. The interactions between soil bacteria and AM fungus are influenced by multiple factors. Additional pertinent factors include AM species, bacterial strains, plant species, rhizosphere, and climatic factors (Sanon *et al.* 2009) [62]. The significance of bacterial adhesion on AM activities has not yet been discussed in depth (Artursson *et al.* 2006) [5]. Future research should therefore concentrate on this effect as well as if these interactions and attachments can affect soil productivity. Furthermore, it has been demonstrated that root exudates may be more advantageous to bacteria than hyphal products since bacterial genera are more prevalent in the rhizosphere than hyphosphere (Artursson *et al.*, 2006) [5]. Examples of improved associations have been observed between several bacterial strains, such as *Bacillus*, *Paenibacillus*, *Pseudomonas*, and *Rhizobia*, and various AM species, such as *G. calrum*, *G. intraradices*, *G. mosseae*, and *G. versiforme*. These encouraging outcomes include pathogen suppression, root colonisation by AM fungi, phosphate solubilization, and the growth and germination of fungus and spores, respectively (Artursson *et al.*, 2006) [5]. Plant growth-promoting rhizobacteria (PGPR) are the most important soil bacteria for enhancing plant development and crop output. They have the ability to: (1) lessen the negative impacts of soil stressors on plant growth; (2) produce plant hormones; (3) increase the solubility of different nutrients by producing diverse enzymes and siderophores; (4) manage diseases; and (5) engage in interactions with AM fungus. (Zabihi *et al.*, 2010) [82]. The hyphae themselves and the organic chemicals they create play a part in the aggregation of soil particles (Tisdall and Oades, 1979) [78] which could provide microsites for microbial colonisation and proliferation. After analysing the microbiological makeup of these aggregates, Forster and Nicolson (1981) [26] discovered a variety of bacteria, actinomycetes, and algae. Andrade *et al.* (1998) [2] employed compartmented systems in which roots and hyphae were split by fine mesh in order to evaluate the qualitative and quantitative impacts of AM on microbial communities in the mycorrhizosphere and the stability of soil aggregates associated with it. They found that as compared to the unstable fraction, the water-stable soil-aggregate (WSA) fraction typically had larger numbers of total bacteria and P-solubilizing bacteria. The bacteria in the hyphosphere and mycorrhizosphere of the AM fungi *Glomus etunicatum*, *G. intraradices*, and *G. mosseae* were studied by Andrade *et al.* (1998) [2]. The composition and growth of rhizobacteria are more reliant on the qualitative effects of the fungal species on the hyphosphere (such as the composition of exudates) than on the quantitative development of AM mycelia in the soil, as shown by the observed changes in the bacterial community in the hyphosphere not being caused by the quantity of AM mycelium per se. The underlying mechanisms are currently unknown, despite the fact that multiple studies have demonstrated that AM fungi have both qualitative and quantitative effects on bacterial communities. There are currently little or no studies on the overall amount or variety of compounds produced by AM mycelium.

AM fungi's relationship with fungal pathogens and N-transforming bacteria

Other root-associated microorganisms, such as pathogenic fungus, may interact with AM fungi. The potential interactional mechanisms are the same as those discussed in the section above. Filion *et al.* (1999) [25] studied the differential impacts *in vitro* of a crude extract from the growth medium of the AM fungus *G. intraradices* on the sporulation of two species of pathogenic fungi. They claimed that the growth of *Pseudomonas chlororaphis* and *mycoparasitic* conidial germination of the fungus Trichoderma harzianum were promoted while conidial germination of the plant root pathogen *Fusarium oxysporum* was suppressed. Growth of *Clavibacter* is unaffected. The authors reached to the conclusion that the principal cause of the dissimilar growth of the organisms under examination was the release of unknown compounds into the growth substrate by AM fungus. Many researchers have proposed that an improved nutritional status in the host plant brought on by the presence of the AM fungus which leads to better ablility of AM colonised plants to survive an attack from root diseases. There are researches that dispute this theory, though. The annual grass *Vulpia ciliata's* seedlings were transplanted into a natural population in field trials by Newsham *et al.* (2005) [50], who showed that AM inoculation had no effect on the plants' phosphorus concentrations. Further, the mycorrhiza shielded the plants against *Fusarium oxysporum* infection's negative effects on shoot and root growth. It appears that the AM prevented pathogen growth in the roots. This idea was also put forth by Read and Moreno (2003) [57], who investigated whether the AM fungus *G. intraradices* could stop the tuber dry rot (*Fusarium sambucinum*) in potato minitubers (*Solanum tuberosum*). This medium produced minitubers that had substantially lower tuber dry rot (20-90%). They were able to demonstrate these benefits in a high-input commercial greenhouse even when AM colonisation was extremely low and there was no proof of better plant P nutrition. Additionally, Hodge *et al.* (2001) [34] showed that the co-cultivation of non-mycorrhizal carnations (*Dianthus caryophyllus*) with *Tagetes patula* plants infected by the AM fungi *G. intraradices* can lower the degree of disease by preventing the growth of root pathogens in soil. It is well known that legumes' nodulation and N fixation are enhanced by the presence of AM fungus. The rates of infection, mineral nutrition, and plant growth are synergistically influenced in a positive way by mycorrhizal and nodule symbioses (Lagopodi *et al.*, 2002) [40]. The nitrogenase enzyme of the bacterial symbiont benefits from the enhanced P intake provided by the AM symbiosis, which increases N fixation and, in turn, promotes mycorrhizal and root development (Wamberg *et al.*, 2003) [79]. Amora-Lazcano *et al.* (1998) [1] investigated how two different types of *Glomus* affected other N-transforming microorganisms. Autotrophic nitrifying bacteria populations were much greater in cultures colonised by the AM fungus G. mosseae and G. fasciculatum than in non-mycorrhizal cultures, but ammonifying and denitrifying bacterial populations were substantially reduced in pot cultures of mycorrhizal sweet corn. Although the impacts of AM fungus on fungal pathogens are qualitative but despite numerous demonstrations of pathogens, little is known about their direct effects on such pathogens. Since there are few to no studies on the interactions of AM fungus with bacterial pathogens, it may be difficult to distinguish between direct effects on the pathogens and indirect effects brought on by the mycorrhizal plants' improved nutritional condition.

Benefits of mycorrhizal interactions

1. Mycorrhiza as biofertilizer: Among the many positive aspects of Mycorrhiza, its usefulness as a natural biofertilizer is of utmost significance and always occupies the top spot on its list of merits. Mycorrhiza's innate ability to colonise plant roots and establish a symbiotic relationship with them solidifies its function by supplying vital nutrients in challenging situations (Syafruddin *et al.*, 2016) [75]. A number of mycorrhizal species exist, however due to their broad occurrence, particularly in relation to agriculture and horticulture crops, endomycorrhiza, or AM (*Arbuscular Mycorrhiza*) fungi, are perfect for use as biofertilizers. Following its separation from Zygomycota, it was assigned to a new phylum named Glomeromycota, which included three families with over 150 species each: Archaeosporales, Paraglomerales, and Diversisporales (Schubler *et al.* 2001) [66]. This was done in light of its variety in comparison to other fungal species at the morphological, molecular, and ecological levels.AM fungus can drastically boost the host plant's root's ability to absorb water by up to ten times while also assisting their hyphe in spreading infection to neighbouring plants (Sadhana 2014) [60]. The most basic goal of AM fungus is to absorb immobile phosphorus from soil before finally transporting it into the host plant. This is due to the fact that PSM dissolves immobilised phosphorous into a available form that is readily assimilated by AM fungus. Additionally, they reported that AM fungus inoculation reduced the application of phosphatic fertilizer by 50% in field conditions, which is a highly encouraging development. In addition to phosphorus, Hodge *et al.* (2001) [34], reported that the AM fungus Glomus hoi proved its capacity to absorb more nitrogen from organic matter and has accelerated the rate at which organic matter decomposes. Mycorrhiza enhanced both macro and micronutrients such Ca, K, S, and Zn as well as Ca, Si, Ni, and Co (Mirzakhani *et al.* 2009) [47]. The presence of the organic material also promoted the hyphal development of the fungal symbiont. The mobilisation of nutrients from the soil can also be helped by bacteria related to the AM. This frequently occurs in tripartite bacterial-AM-legume symbiotic associations, when diazotrophic bacteria also supply fixed N to the fungus and the plant. As previously mentioned, AM establishment and legume nodulation by N-fixing bacteria typically occur simultaneously and collaboratively. Minerdi *et al.* (2001) [45] stated that presence of N fixation genes in endosymbiotic Burkholderia bacteria in AM hyphae raises the possibility of enhancing the availability of N to mycorrhizal plants by atmospheric N fixation. Tripartite symbiosis research is still in its infancy, and further study is required to determine whether mycorrhizal fungus could interact with the decomposition processes. Exploiting nutrient resources that naturally reside in the environment is becoming more and more important when fertilizer inputs are reduced. On both a temporal and spatial basis, these resources are dispersed unevenly, but it is still unclear what potential functions mycorrhizosphere organisms may play in the recycling of these nutrients to plants.

Table 1: Effect of Mycorrhiza as a biofertilizer in different crops

Crop	Mycorrhizal species	Effect	References
Rice	*Rhizophagus intraradices*	Reduced production costs by a factor of 18.5-16.3%	Orona-Castro *et al.* (2013) [54]
Maize	*Glomus intraradices*	Increased cell membrane stability and relative water content	Naghashzadeh (2014) [49]
Safflower	*Glomus intraradices*	Enhancement in grain yield	Mirzakhani *et al.* (2009) [47]
Tobacco	*Glomus intraradices*	Combining AMF and bacteria that dissolve potassium increased P and K availability and improved leaf quality.	Subhashini (2016) [74]
Cowpea	*Glomus etunicatum and Gigasporaalbida*	Elongation of the grain and the shoots	Andrade *et al.* (2013) [3]
Black gram	*Glomus mossae*	Increase in leghemoglobin levels and seed germination	Bharti and Kumar (2016) [14]
Potato	*Glomus sp.*	Decreases the use of synthetic fertilizer	Nurbaity *et al.* (2016) [52]
Barley	*Glomus intraradices*	Increased phosphorus uptake	Zhu *et al.* (2003) [86]

2. Mycorrhiza as biocontrol agent: Mycorrhiza has been suggested as a potential biocontrol agent for soil-borne diseases as a result of the failure of various tactics, including both biological and chemical ones, for controlling these diseases. Vesicular Arbuscular Mycorrhizal (VAM) fungi provide a number of different benefits for defending plants against diseases in addition to being economical and environmentally benign (Dar and Reshi, 2017) [21]. As a result, they contribute to sustainability and stability in multifunctional agriculture systems. Mycorrhiza was considered an alternative due to its powerful root colonisation ability and symbiotic nature, which covers the majority of the rhizosphere. Caron (2009) [18] emphasised the importance of vesicular arbuscular mycorrhiza (VAM) in controlling soil borne diseases, especially those brought on by nematodes and fungi. Waschkies *et al.* (1994) [80] investigated the anti-bacterial action of *Glomus mosseae* on fluorescent pseudomonads, reducing the incidence of replant disease in grapevine. Pinochet *et al.* (1996) [56] showed that mycorrhizal fungus can successfully control the nematode *Pratylenchus vulnus* when introduced at the early stages of plant development. Mycorrhizal fungi have not, however, yet demonstrated a high level of biocontrol activity against viruses (Xavier and Boyetchko 2004) [81]. In their experiment, Cordier *et al.* (1996) [19] discovered that tomato plants that had previously received treatment from the mycorrhizal fungus Glomus mosseae experienced less root invasion from Phytophthora nicotianae var. parasitica. In the fight against soil-borne infections. Further, it is also critical to appreciate the significance of rhizobacteria and their close association with mycorrhizal fungi. The effectiveness of AM fungus preferentially promotes the growth of rhizobacteria in and around the mycorrhizosphere, which eventually has an antagonistic effect on soil-borne diseases (Lioussanne 2013) [42]. Kamal *et al.* (2014) [38] reported on the beneficial interactions between several microorganism groups, such as mycorrhizal fungi, actinomycetes, and plant growth-promoting rhizobacteria, for the reduction of plant illnesses through enhancement of plant defence mechanisms. The following are some of the defence mechanisms used by mycorrhizal fungi against soil-borne pathogens: (a) an increase in nutrient uptake; (b) several changes to the anatomical and morphological root structure (c) compensating for the biomass loss; d) modifications to soil microbial interactions (d), (e) competition for photosynthesis and colonisation in the host, and (f) alterations to the chemical makeup of host tissues. Schouteden *et al.* (2015) [64] provided a thorough explanation of the methods that mycorrhiza fungi use to combat plant harmful nematodes. During the formation of mycorrhiza, it has been observed that the plant immune system becomes systemically active throughout the entire plant (Jung *et al.* 2012 [37]. The effects on AM fungal hyphae, however, were not examined. In addition to producing antifungal compounds, bacteria's ability to quickly colonise root surfaces and interact closely with pathogens may help in preventing infections (Lagopodi *et al.*, 2002) [40]. Since roughly 30 years ago, researchers have been studying AM fungi as possible pathogen defence mechanisms. Despite several published studies, the fundamental mechanisms remain poorly understood. Improved plant nutrition and competition for photosynthates have been cited as some basic reasons (Azcon-Aguilar and Barea, 1996) [8] but other potential mechanisms include AM-induced saprotroph stimulation, decrease of root infections, and activation of plant-growth-promoting microbes (Bolwerk *et al.*, 2003) [16]. Few research have examined the practical application of AM fungi as inoculants to boost plant resistance to root-rotting diseases because it is challenging to produce large volumes of pure culture AM inoculum. Combining AM fungus with bacteria that promote growth may help with inoculum production (Sakai *et al.*, 2001) [61]. Some AM fungi have been shown to have biocontrol abilities (Niemira *et al.*, 1996) [51] against root infections in a number of investigations. It is unknown if AM fungi may serve as practical biocontrol agents or if they could operate as vectors for related bacteria with biocontrol abilities.

Table 2: Mycorrhiza as a biocontrol agent against Fungal pathogen

Mycorrhizal Species	Fungal Species	Crop	References
Glomus etunicatum Glomus leptotichum Rhizophagus intraradices	*Fusarium oxysporum f. sp. lycopersic*	Tomato	Muhsen *et al.* (2015) [48]
Glomus hoi Glomus fasciculatum	*Fusarium oxysporum f. sp. ciceris*	Chickpea	Singh *et al.* (2010) [69]
Piriformospora indica Sebacina vermifera	*Gaeumannomyces graminis var. tritici*	Wheat	Ghahfarokhy *et al.* (2011) [27]
Glomus mosseae Glomus intraradices Glomus clarum Glomus gigantean Glomus margarita	*Fusarium solani*	Bean	Askar and Rashad (2010) [6]
Glomus aggregatum	*Sclerotium cepivorum*	Onion	Leta and Selvaraj (2013) [41]

Table 3: Mycorrhiza as a biocontrol agent against Nematodes

Mycorrhizal Species	Nematode	Crop	References
Glomus mossae	*Meloidogyne incognita*	Cowpea	Odeyemi *et al.* (2010) [53]
Glomus intraradices	*Meloidogyne incognita*	Tomato	Sharma and Sharma (2015) [67]
Glomus intraradices	*Xiphinema index*	Grape	Hao *et al.* (2012) [31]
Glomus mossae Glomus versiforme	*Meloidogyne incognita*	Cucumber	Zhang *et al.* (2008) [84]
Scutellospora heterogama	*Meloidogyne incognita*	Sweet Passion Fruit *(Passiflora alata)*	Anjos *et al.* (2010) [4]
Scutellospora castanea and Glomus spp.	*Pratylenchus penetrans*	Dune grass *(Ammophila arenaria)*	de la Pena *et al.* (2006) [22]

Potential of Mycorrhiza for Sustainable Agriculture

When agriculture is viewed as a job for a poor farmer, its savage conflict with sustainability is a potentially hidden issue that is mostly hovering over the industry. To solve this problem, a root cause analysis that passionately advocates a deeper understanding of the interactions between soil microbes and their surroundings (the rhizosphere) is required. Mycorrhiza is a far more real and diverse microbial relationship, but it has been slow to reach its full potential, which has the capacity to fundamentally alter the story of agricultural sustainability. It serves as an outstanding example of how plants and fungi can coexist in harmony and serves as a reminder of how crucial mutualistic relationships are in nature. Mycorrhizal associations are found in 336 plant groups, 99% of which are flowering plants (Brundrett, 2009) [17]. Mycorrhizae are widely known for being beneficial phosphorus absorbers, but in addition, they are also suitable for giving plants micronutrients, properly establishing themselves as Natural biofertilizers (Berruti *et al.* 2016) [12]. To validate its status as a bio-control agent, it is crucial to take into account its capacity to shield plants against soil-borne illnesses (Tahat *et al.* 2010) [76]. Mycorrhiza is known to have prevented weed growth in addition to suppressing infections, as was successfully proved by Bethlenfalvay *et al.* (1996) [13]. However, Mycorrhiza's importance in the successful reduction of heavy metal contamination (Tamayo *et al.* 2014) [77] and the reduction of water stress in drought conditions (Auge *et al.* 2015) [7] cannot be understated (Farahani *et al.* 2008). Under the influence of mycorrhizal treatment, a rise in photosynthetic levels and improved water use efficiency were found in Boswellia papyrifera seedlings (Brihane *et al.* 2012) [15]. Sheng *et al.* (2008) [68] also reported a similar finding in maize plants in salt stress conditions. With the addition of some more teeth, it is also a powerful soil aggregator and so has an invisible hand at work improving soil structure and reducing soil erosion, both of which are yet mostly uncharted territory (Schreiner and Bethlenfalvay 1995) [13]. Arbuscular mycorrhizal fungi participate in the carbon cycle by regulating the amount of carbon that is transferred back and forth between the atmosphere and the biosphere (Zhu and Miller, 2003) [86]. In reality, a more varied interaction takes place in the mycorhizosphere, where a galaxy of microorganisms almost has its own world of existence and influences the growth of the plant. Arbuscular mycorrhiza is essential for the creation of sustainable agriculture since it largely colonises the roots of crop plants, whereas Ectomycorrhizal fungi colonise forest plants and perform their function for phytoremediation. Looking at the situation from a much wider angle, mycorrhiza can combat climate change by storing carbon. A highly extensive and in-depth hypothesis addressing the anticipated impact of mycorrhizal diversity due to continued climate change is presented by Bellgard and Williams (2011) [11]. Numerous other aspects of the mycorrhiza, such as its role in the food chain, bio-geochemical cycling, and the interactions between or within certain plant species, can teach us more about the impact of the mycorrhiza on natural ecosystems (Jha and Kumar, 2011) [35]. Because 75-80% of the phosphatic fertiliser applied here gets fixed right away, unlike in temperate regions, their role in the tropics is essential and indispensable (Bagyaraj, 2014) [9]. Knowing that Mycorrhiza can easily alter any narrative of sustainable agriculture, especially in the tropics, this reality even lends more weight to their enormous relevance and stature. It is evident from a brief description of Mycorrhiza and knowledge of its several uses that greater knowledge on its two most potent naturally occurring hideous forms as a biofertilizer and a biocontrol agent is required to position it as a dominant force in the area of sustainable agriculture

Conclusions

The interactions in soil between AM fungus and bacteria are quite crucial. These interactions need to be explained in detail because they may have important repercussions for environment and agriculture. These interactions, are carried out in many ways like bacterial adhesion to the hyphae and fungal spore, the bacteria's transmission of chemicals into the fungal spore, fungus cell wall breakdown and synthesis of volatiles that affect the expression of fungal genes. Therefore, the productivity of the ecosystem is also impacted by the symbiosis between the fungi and the host plant. We have just recently come to understand how common it is for microbes to associate with plant roots and other microbes in natural ecosystems. Sustained crop yield in disturbed environments, like the agroecosystem, is now only viable with significant inputs to offset the consequences of the disturbance. In natural ecosystems, sustained plant development is feasible because of the balance that has developed through the period of evolution between the host plants, their microbial associates, and the macroenvironment. Any prospect of sustainability without human intervention is reduced when that balance is disturbed. Establishing suitable populations of mycorrhizal fungus and as many of their beneficial partners as possible should be the first step in reconstruction. To encourage early colonisation, mycorrhizal fungi and bacterial and fungal biocontrol agents that are compatible with and competent in the rhizosphere should be planted. Although the efficacy of such combinations has not been established, it makes sense to employ them as a crop management technique in sustainable agriculture.

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