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A Review on Role of Mycorrhizal Fungi in Plant Disease Management

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***Abstract*—**Plant diseases become one of the significant threats in crop production worldwide which causes billion-dollar yield losses directly. Many approaches found to suppress various disease effects on crops. Among all the options available, biotic control of crop diseases promises one and in which Mycorrhizal Fungi (MF), especially endo mycorrhizae would play a significant role. Many reviews have reported on the interface mechanisms among Arbuscular Mycorrhizal Fungi (AMF) and plant pathogens. It includes improvements in plant nutrition, competition for nutrient and photosynthates and antibiosis. Depending on the infections and the ecological conditions, all mechanisms may be involved. Studies revealed that AMF, *Glomus* sp and *Gigaspora* sp. are the best models used to control plant fungal and bacterial diseases. Further, *Rhizophagus* sp, *Funneliformis* sp and *Claroideoglomus* sp. are few of the excellent applicants of AMF shows better potential to oversee viral infections in plants. However, sufficient researches are not done so far to focus on exact stages of infection side effects of AMF when it incorporates with the crops to control pathogens. Future research on the AMF-mediated promotion of crop quality and productivity is therefore required with exploring the adverse effects of AMF, with emphasis on plant disease management. It can conclude that when biological management techniques are paired with effective AMF tactics while considering the environmental protection measures, a sustainable way of plant disease management is possible.

***Keywords*—**Arbuscular mycorrhizal fungi, Association, Mycorrhizal fungi, Pathogen, Plant disease

I. Introduction

In crop production, plant diseases play a significant role, causing a tremendous effect on earnings. It can cause annual yield losses of about 30 percent to 50 percent in developing countries, and it could cause food shortages and hunger (Shurtleff *et al*., 2020). Direct yield losses affected by pathogens, animals, and weeds are responsible for the losses running somewhere ranging from 20 to 40% of universal agronomic profitability (Oerke, 2006). For example, in annual harvests, potato losses start from 5% to 96% in France (Rakotonindraina *et al*., 2012), cotton in Thailand is about 100% (Rakotonindraina *et al*., 2012), (Castella *et al*., 2007). Primarily, phytopathogens impact plant fitness by upsetting the growth and competitive ability of the plants. These significant effects change the plant population and community structure (Latz *et al*., 2012).

Farmers usually depend on several agricultural practices and traditions, including physical, chemical, and biological approaches to manage plant diseases. Present-day horticultural practices use many kinds of artificial compounds, such as composts, insecticides, cleaners, and plant additives to deliver and protect a vast amount of first-rate food. These synthetic compounds have risky and unanticipated reactions, as harmfulness to non-intended organisms, which affects biological awkwardness (Sinha *et al*., 2009). Further, pesticide overflow is a significant supporter of surface-water defilement (Wohlfahrt *et al*., 2010).

Biological control is an "environmentally based nuisance, the chiefs that utilize one sort of living being to control another "irritation species" (Hoddle *et al*., 2009). It is a cost-effective, ecologically well-disposed method that can unravel outsider nuisance issues in different biological systems. Including horticulture and ranger service, characteristic, semi-common and urban environments, freshwater, and so forth (Wittenberg and Cock, 2001). However, many specialists' advice Integrated Pest Management (IPM) as an ideal path ahead and halfway into its 2009 Sustainable Use Instruction on Pesticides, the European Union has placed it in motion (European Parliament, 2010). IPM is a structures approach that joins diverse yield security rehearses with cautious observing of vermin and their characteristic foes (Bajwa and Kogan, 2002).

Given the vital needs of an eco-friendly and safe way to control phyto-diseases, a convincing strategy and securing plants against pathogens is established by the use of biological control of plant pathogens. In the biological approach, adopting different Mycorrhizal Fungi (MF) would be the best option to minimize phytopathogens' negative effect. The key biological components of soil ecology are Arbuscular

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Mycorrhizal Fungi (AMF) and are viewed as bio-trophic microorganisms. AMF is actively engaged in achieving plant nutrients by expanding the accessibility of various supplements (Rouphael *et al*., 2015). The degradation process of soil organic amendments could be accelerated by fungal hyphae (Paterson *et al*., 2016), plant defense against soil-borne pathogens (Cameron, 2010) and upgrading of soil structure (Tanwar *et al*., 2013). Salzer and Boller (2000) suggest the discharge of comparable chitin elicitors by Ectomycorrhizal and AMF, inducing a defensive reaction. It is used as one of the control measures adopted for plant protection (Oyewole *et al*., 2017). This review aims to understand the MF and its plant protective effects and mechanisms against plant infection-causing pathogens.

II. TYPES OF MYCORRHIZAL FUNGI USED IN PLANT DISEASE MANAGEMENT

Mycorrhiza really means "fungus-root" and A.B. Frank instituted it in 1885. Based on its penetration within the roots, it classifies Mycorrhiza into two major classes. Endomycorrhiza and Ectomycorrhiza are those.

A. Ectomycorrhiza

Ectomycorrhiza is most widespread in the Myrtaceae, Pinaceae, Fagaceae and Saliceae family of ornamental and forest species of trees (Shalini et al., 2000). Ectomycorrhizas form a Hartig net of hyphae which completely covers the plant roots. It produces metabolites to protect the plant roots against diseases (Peterson *et al*. 2004).

B. Endomycorrhiza

Endomycorrhizas, categorized by identical coil-shaped hyphae, grow intercellularly penetrate the plant cells (Slama et al., 2010). Mycorrhizas are categorized into mycorrhizal Ecto-endo; mycorrhizal Ericoid; mycorrhizal Monotropoid; mycorrhizal Arbutoid; and mycorrhizal Orchid (Tahat *et al*., 2008). Endomycorrhizal express to an assembly of fungi related with most horticultural harvests and give biological protection against soil-borne illnesses (Smith and Read 2008). Several essential plant species such as rice, mungbean, soybean, grape and floricultural species such as lilies, roses and petunia are found (Peterson et al., 2004). Generally, the endomycorrhiza group individuals recognized as AM because of the development of arbuscules (Kaur *et al*., 2014). The vesicular-arbuscular mycorrhizal (VAM) fungi have two kinds of structures, such as arbuscules that are extraordinarily extended forms found within a cell and filled in as a place for major metabolic change between the plant and the fungus and vesicles, sac-like structures that have risen out of hyphaea. The symbiotic affiliation of AMF and plant roots was considered the oldest beneficial association formed as it took more than 500 million years to advance (Redecker *et al*., 2000). About 80% of the total mycorrhizal associations among horticultural crops are represented by the endomycorrhizal association.

C. Arbuscular Mycorrhizae

Smith and Read (2008) said that AMF is a significant amount and most abundant of endomycorrhiza. In AMF affiliations, the interface among plant and fungal tissues that encourages the transfer of materials among plant and parasitic symbionts appears as arbuscules or coils. It changes arbuscules and coils fungal hyphae that give a large surface region to asset transfer. They use AMF against too many soil-borne pathogens as a biocontrol agent (St-Arnaud and Vujanovic, 2007). By using a local operating mechanism, AMF manages the root-feeding nematodes (De La Pena *et al*., 2006). Similarly, it is favored to extend in the surface zone and to advance root hairs, improving the absorptive limit of roots and compensatory tools. It reflects the aberrant commitment of AM organisms to the natural regulation of soil-borne pathogens (Tahat *et al*., 2008).

D. Monotropoid Mycorrhiza

Each one of the hyphae outgrow from the hartig net into the cortical cell. The walls of which enclose to put up the developing hypha. These interventions from the hartig net hooked on the cortical cell walls are identified as fungal pegs. The fungal peg blasting gives a flood of supplements to help seed creation (Moore, 2013).

E. Orchid Mycorrhizae

Most orchids are not photosynthetic when the orchid is in the seedling phase of its life. During this time the orchid depends on the mycorrhizal parasites to give the additives, especially sugars, required to develop the seedling. As the orchid grows, it will rely less on the Mycorrhiza for supplements like starches, yet gains phosphorous and nitrogen through the association (Moore, 2013).

F. Ericoid Mycorrhizae

Ericoid mycorrhizae are found in extreme conditions, especially acidic situations (Smith and Read, 2008). The mycorrhizae also help manage the securing of iron, manganese, and aluminium particles regularly present in profoundly accessible structures in acidic soils (Moore, 2013). Ericoid mycorrhizae vary in where they found and in form. Rather than shaping arbuscles, the growths in the family Ericaceae formation hyphal loops in the outside cells of plants' fine root hairs in the family Ericaceae. Root volume may be up to 80% parasitic tissue, and it is through these curls that supplement trade happens. These growths can be discovered free-living in the dirt, yet the harmonious connection between the parasites and plant is believed to be progressively useful to the two species (Moore, 2013).

III. MECHANISMS OF INTERACTIONS BETWEEN MYCORRHIZAL FUNGI AND PATHOGENS

The use of mycorrhizal growths for plant pathogens' biocontrol is new and is a non-synthetic strategy for disease control. AMF colonization could diminish the evil impacts of microorganisms over various tactics (Erman, 2011). Without

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a doubt, AMF it recognizes beneficial interaction for reducing the harm brought about by a broad range of soil-borne pathogens, including fungi and nematodes, which also cause incredible losses of yields (Sharma and Sharma, 2018). The mechanisms associated with this biocontrol appear to be identified with the accompanying: In comparison to phytopathogens, various defensive mechanisms are involved in mycorrhizal systems, which include the advancement of crop development, a decrease in colonization sites accessible to aggressors, alteration in root morphology, increase in damage compensation, changes in the composition of both root exudate and rhizosphere microbiome, and ultimately plant immune structure stimulation (Singh and Giri, 2017).

A. Physiological and Biochemical Changes in Plant Development

Structural and biochemical variations in the cell walls of crops occupied by AM fungi are shown by diverse evidence. AMF colonization incites striking changes in root framework morphology, adjusting pathogens' elements and altering microbial populations. Conceivable incitement of segments of microbiota with antagonistic behavior against particular root pathogens (Buarea *et al*., 2005). The microbiota arrangement can be influenced by extraordinary development of exudates in AMF roots (Lucini *et al*., 2019).

Phytoalexins are antimicrobial and regularly antioxidative substances produced once more by plants that accumulate quickly at pathogen contamination zones (Jeandet *et al*., 2013). It is authoritative to message that the regular rise of phytoalexin may be a coordinated defence method. Unaccompanied, any influence could not be able to account for the regulation of the possible pathogen (Purkayastha, 2017). Parasitic growth on new young leaves has been suggested to be limited by phytoalexins produced by hidden cells due to the dispersion of fungal metabolites from sprouting spores. (VanWees *et al*., 2003).

When all is said in fact, phytoalexins are instigated in mycorrhizal plants in the non-appearance of pathogens in plant roots that destroy the adverse impacts of pathogens. An enormous number of phytoalexins, phenylpropanoid pathway proteins, chitinases, b-1,3-glucanases, peroxidases, pathogenesis-related (PR) proteins, callose, hydroxyproline-rich glycoproteins (HRGP) and phenolics are produced by the host plant with AM colonization (Gianinazzi-Pearson *et al*., 1994). It could perform in organic control (Jung *et al*., 2012).

B. Changes in Plant Nourishment and Resistance to Pathogens

The expanded supplement take-up coming about because of AMF beneficial interaction makes the plant increasingly overwhelming and, therefore, progressively safe, making up for losing root biomass or work brought about by pathogens (Tahat *et al*., 2010). Arbuscular organisms improve plant resistance to pathogens without excessive yield losses. Also, upgrade pathogen inoculum thickness. It identifies this pay with an upgraded photosynthetic ability (Heike *et al*., 2001).

A similar finding was suggested by Declerck et al. (2002): AM fungi or extra P reduced root rot of bananas affected by *C. spathiphyylii*. It has been presumed that root pathogens need host nutrients for growth and reproduction, through competition between root pathogens, and this antagonism may be the reason for their inhibition. The enriched nutritional status of the plant was mainly due to the AM fungi, which influenced the further significant development of plants and enhanced plant life resistance to the outbreak of pathogens (Singh *et al*. 2017).

C. Competition for Survival and Photosynthates

AMF utilizes spores for survival before root contact is reached. Competition may take place for disease sites, host photosynthates and root space following root access (Smith and Read, 1997). Both the AM and root pathogens rely on photosynthates and compete for the carbon mixes that enter the root (Linderman, 1994). AM species have critical access to photosynthates, and pathogen growth can be suppressed by higher carbon demand (Azcòn-Aguilar and Barea, 1996). Competing of AMF with the pathogen makes them stifling didn't get much attention. Pathogens were often smothered even in non-colonized root parcels that were later portrayed by AMF as actuated resistance (Pozo *et al*., 1999). Irregularities regarding essentials and AMF impacts on pathogens have added to an absence of intrigue. AMF represents a competition between AMF and space pathogens. AMF might increase the plant's accretion capability that might return worthy compensation (Ma *et al*., 2019). Vigo *et al*. (2000) found that within mycorrhizal root structures and colonization, the AM fungus decreased the number of contamination spots and had no effect on the dispersal of necrosis. There may be competition for space for their growth processes if AM fungi and pathogens are colonized in similar host tissue. So, pathogen growth was suppressed by AM fungi on the root structure.

D. Antibiosis

The antimicrobial substances (unidentified) formed by the extra-radical mycelium of the AMF species. have been shown to be late. Conidial germination of *Fusarium oxysporum* f.sp. decreased intra-radice. Chrysanthemum, which is independent of changes in pH (Filion *et al*., 1999). Chrysanthemum, which is independent of changes in pH (Filion *et al*., 1999). *Paenibacillus sp*. was separated by Budi *et al*. (1999). Strain from the mycorrhizosphere of *Sorghum bicolor* plants inoculated with *G. mosseae* that displayed tremendous antagonism against *P. parasitica*. Notwithstanding the wellspring of these biocontrol exercises, the criticality of AMF in plant disease management must be recognized and used. In the management of pathogenic microbes, additional research in this field could be productive.

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Table I: List of Documented Mycorrhizal Fungi Used to manage Pathogenic Fungi in Plants.

Mycorrhizal Fungi	Targeted pathogenic fungi	Host	Mechanism	References
Glomus versiforme	*Erysiphe flexuosa*	Cowpea	Arbuscular mycorrhizal fungi improve host tolerance by increasing the intake of important nutrients such as phosphorus that are otherwise deficient in non-mycorrhizal plants	Omomowo *et al.*(2018)
Glomus fasciculatum and *Acaulospora laevis*	*Fusarium oxysporum f.* sp. lycopersici	Tomato	Aminoacids (arginine and proline) are significantly high in AM fungi inoculated crop, which advance the resistance against pathogens	Manila and Nelson (2017)
Glomus clarum and *Glomus deserticola*	*Pythium aphanidermatum*	Pawpaw	Changes in chemical constituents of plant tissues (root exudates)	Olawuyi *et al*. (2013)
Funneliformis mosseae	*Gaeumannomyces graminis*	Wheat	Host plant produces a great number of phytoalexins, enzymes of the phenyl-propanoid pathway, chitinases, b-1,3-glucanases, peroxidases, pathogenesis-related (PR) proteins, callose, hydroxyproline-rich glycoproteins (HRGP), and phenolics that can act in biological control	Falahian *et al*. (2007)
Glomus intraradices	*Fusarium verticillioides*	Maize	Mycorrhizal hyphaenetworks improve the absorption of essential nutrients such as phosphorus around the plant roots, which are otherwise readily available to non-mycorrhizal plants. Improved host nutrition is directly or indirectly linked to host resistance.	Pozo, Azc'on-Aguilar (2007)
Glomus mosseae, Glomus etunicatum, Glomus fasciculatum, Gigaspora margarita	*Phytophthora capsici*	Pepper	The tested AMF significantly increased capsidiol level in pepper. It also stimulated resistance in pepper against *Phytopthora capsici*	Ozgonen andErkilic (2007)
Glomus mosseae	*Gaeumannomyces graminis var. tritici*	Barley	*Glomus mosseae* increasing the systemic salicylic acid concentration around the barley roots creates bio-systemic protection against the *Gaeumannomyces graminis*. Significantly it reduces the number of barley's lesioned roots.	Khaosaad *et al*. (2007)
Glomus mosseae	*Fusarium oxysporum f. sp., Lycopersici (Fol.)*	Tomato	*Glomus mosseae* alters mycorrhizal plants' exudation pattern expressed as a different bioactive effect on soil-microorganisms and affects the tomato pathogen Fol.	Scheffknecht *et al*. (2006)
Glomus fasciculatum	*Fusarium oxysporum f. sp. ciceris*	Chickpea	Reduced the disease severity in chickpea	Siddiqui and Singh (2004)
Glomus clarum and *Glomus deserticola*	*Rhizoctonia solani*	Cowpea	Changes in chemical constituents of plant tissues (root exudates): Roots exhibit greater chitosanase, chitinase and b-1,3-glucanase activities	Abdel-Fattah and Shabana (2002)
Glomus etunicatum	*Rhizoctonia solani*	Potato	*G. etunicatum* increased K shoot content. Although this observation does not indicate conclusively a link between K shoot content and reduction in disease severity, adequate K supply does promote cell wall thickening that helps plants to resist disease	Yao *et al*. (2002)
Glomus boninense	*Ganoderma boninense*	Oil palm	*G. boninense* mycelium delayed the time required by the pathogen to infect and to kill the palms.	Rini (2001)
Glomus etunicatum and *Glomus monosporum*	*Phytophthora fragariae*	Strawberry	An exudate mediated mechanism expressed. Also, the tested AMF increased sporangia inhibitors against *Phytophthora fragariae*, the pathogen in strawberry.	Norman and Hooker (2000)

IV. PLANT PROTECTIVE EFFECT OF MYCORRHIZAL FUNGI IN FUNGAL DISEASE CONTROL

In dry, tropical, mild and snowcapped areas, over 10,000 forms of fungi cause plant diseases and are expected to occur in soil, air (spores) and on plant surfaces all over the world (Agrios, 2005). Pathogenic fungi lead significantly to crop damage and loss of yield. AMF possess the capacity to control different plant pathogenic fungi (Bodker *et al*., 2002). In climate change and biological corruption, misfortunes genuinely impact food security in particular parts of the world in arable land. Similarly, pests hurt economically significant yields (Sundström *et al*., 2014). The valuable microorganisms' fungi contend with plant pathogens, intended for nutrition and space, through creating anti-infection agents, parasitizing pathogens and inciting obstruction in the host. This kind of organisms have been designed for biocontrol of disease-causing microorganism (Berg *et al*., 2007). The defensive regulation of mycorrhizal symbioses against root pathogenic fungi has been tried by several scientists (Caron, 1989).

Perplexing associations between pathogen, AMF and plant increase the outcome and yield through the decline of disease

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Table II: List of Documented Mycorrhizal Fungi Used to manage Pathogenic Bacteria in Plants

Mycorrhizal Fungi	Targeted pathogenic Bacteria	Host Plants	References
AMF	*Pseudomonas solanacearum*	*Eucalyptus seedlings*	Mingqin *et al*. (2004)
Glomus mosseae	*Pseudomonas syringae*	Infection of soybean	Shalaby and Hanna (1998)
Glomus macrocarpum	*Pseudomonas lacrymans*	Eggplant and cucumber	Li *et al*. (1997)
Glomus fasciculatum or Glomus mosseae	*Pseudomonas syringae pv. mori*	Mulberry	Sharma *et al*. (1995)
AMF	*Actinomycetes*	Apple seedlings	Otto and Winkler (1995)
AMF	*Pseudomonas*	Grapevines	Waschkies *et al*. (1994)
Glomus mosseae	*Pseudomonas syringae*	Tomato	Garcia-Garrido and Ocampo (1989)

Table III: List of Documented Mycorrhizal Fungi Used to manage Viruses in Plants

Mycorrhizal Fungi	Targeted pathogenic Virus	Host Plants	References
AMF	Grape vine fanleaf virus	Grape vine	Hao, *et al*. (2018)
Rhizophagus intraradices (Syn. *Glomus intraradices* isolate BEG141)	Grapevine fanleaf virus	Grapevine rootstock	Hao *et al*. (2018)
Funneliformis mosseae (Syn. *Glomus mosseae* BEG12)	Tomato yellow leaf curl virus	Tomato (*Solanum lycopersicum* L.	Maffei, *et al*. (2014)
Rhizophagus irregularis	Potato virus Y	Potato	Thiem, *et al*. (2014)
Funneliformis mosseae (Syn. *Glomus mosseae*)	Cucumber mosaic virus (CMV-Y, yellow strain)	Cucumber cv. Tokiwa Jibai	Elsharkawy *et al*. (2012)
Funneliformis geosporum (Syn. *Endogone macrocarpa var. Geospora*)	Citrus leaf rugose virus	Alemow, Grape fruit, Sour orange	Nemec and Myhre (1984)
Rhizophagus intraradices (Syn. *Glomus intraradices*	Potato virus Y	Potato	Sipahioglu *et al*. (2009)
R. irregularis	Cucumber green mottle mosaic virus (CGMMV)	Cucumber	Stolyarchuk *et al*. (2009)
R. irregularis	Tobacco mosaic virus (TMV)	Tobacco	Stolyarchuk *et al*. (2009)
Claroideoglomus etunicatum (Syn. *Glomus tincture*)	Citrus tristeza virus	Alemow, Grape fruit, Sour orange	Nemec and Myhre (1984)
Rhizophagus intraradices (Syn. *Glomus intraradices*)	Tobacco mosaic virus (strain U1)	Tobacco	Shaul, *et al*. (1999)
Funneliformis geosporum (Syn. *Endogone macrocarpa var. Geospora*)	Arabis mosaic virus	*Petunia hybrida*, Vilmorin, var. Rose of Heaven	Daft and Okusanya (1973)
Funneliformis geosporum (Syn. *Endogone macrocarpa var. Geospora*)	Tomato aucuba mosaic virus	Tomato (*Lycopersicon esculentum* Mill. F1 hybrid, var. Eurocross A)	Daft and Okusanya (1973)
Funneliformis geosporum (Syn. *Endogone macrocarpa var. Geospora*)	Potato virus Y	Strawberry (*Fragaria* × *ananassa* Duch. var. Talisman)	Daft and Okusanya (1973)

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inside the host plants (Harrier and Watson, 2004). Various mechanisms have been taken into account to explain biological regulation through AMF, recalling biochemical variations in plant tissues, microbial variations in the rhizosphere, nutrient location and structural changes in cells, variations in the root internal structure and mitigation of stress (Hooker *et al.*, 1994). Along these lines, those systems by which AMF may reasonably regulate the soil-borne microorganisms are recorded below.

V. PLANT PROTECTIVE EFFECT OF MYCORRHIZAL FUNGI AGAINST PHYTO BACTERIAL DISEASES

Nemec (1994) identified the interaction of AMF with various bacteria, such as diazotrophs, operators of biological control and other populations of the rhizosphere. Interfaces between MF and bacteria may have impeded or beneficial impacts (Filion *et al.*, 1999; Ravnskov and Jakobsen, 1999) or have no effect at all on the pathogenic bacterium of the crop (Otto and Winkler, 1995).

VI. PLANT PROTECTIVE EFFECT OF MYCORRHIZAL FUNGI IN PLANT VIRAL DISEASES

Plant viral infectious diseases are becoming more dangerous for global food production, and also the board practice and climatic changes are aggravating this issue in crop (Kreuze and Valkonen, 2017). Viral infection has been related to an overall decrease in plant performance and hindrance of photosynthesis (Rahoutei *et al.*, 2000).

VII. Conclusions and Future Directions

Writing provides an array of evidence necessary for the AMF-intervened plant disease regulator to demonstrate. Over the years, mycorrhizae's opportunity and utilization in the agricultural division have grabbed hold in various scientific tests worldwide. Many of the research has concentrated on the benefits of host plants credited to arbuscular growths from yield and protection from biotic and abiotic strains. The AMF, through expanding crop profitability with existing assets, maintaining a strategic distance from opposition improvement to chemicals, keeping up contamination and risk-free infection regulator, and regulating to sustainable agronomic performances, give additional than simple crop disease regulations.

Despite its developing pattern, mycorrhizal fungi' current market stays a long way from its maximum capacity. Mycorrhizosphere management must get a unique workable environment for overseeing plant diseases in large scale crop cultivation. Useful AM interactions can add to improved harvest profitability through disease control. Further, data is limited to exact stages of infection side effects of AMF when it incorporates with the crops. The simple long-haul measures accomplished via inoculating plants with AM fungi must be tested one instance at a time instance in the field. A few models of AMF can impact sly outcome execution, and it requires further exploration to understand the reason for the negative effects. Such adverse claims on AMF need to sort out to use mycorrhizal fungal inocula to control future crop diseases sustainably.

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