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Review Article
Significance of Arbuscular Mycorrhizal Fungi for Acacia: A Review

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Abstract
Microbes play a vital role in ecosystem stability. Here, microbes-Acacia association is discussed with particular reference to Arbuscular Mycorrhizal Fungi (AMF) which help in the establishment of crop-plants, especially in arid and semi-arid areas. The association helps to restore the structural composition of soil from the hazardous impact of agrochemicals, increase resistance against various pathogenic attack as well as several abiotic stresses. Further, a comparative account of microbes found in the rhizosphere of Acacia is illustrated. Among these, *Rhizobia*, *Acetobacter*, *Bradyrhizobium*, *Bacillus*, *Pseudomonas* and *Trichoderma* were described in detail. All these microbes can be regarded as Plant Growth Promoting Rhizospheric Microbes (PGPM), some of PGPM are Phosphate Solubilizing Microbe (PSM). Both of them help AMF for infecting mycorrhizal hyphae inside the plant cell. Overall, microbes can be used as biofertilizers along with other organic compounds, that can compensate for the nutrient's availability.

Key words: Arbuscular Mycorrhizal Fungi (AMF), microbes, agroforestry, *Pseudomonas*, *Trichoderma*

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Acacias are the members of the legume family (Fabaceae) and include plants with many distinctive growth styles with a profusion of white or yellow flower clusters. The genus Acacia has been well represented. It's among probably the most abundant genera of shrubs and trees in the planet, with almost 800 species[1]. Acacias are usually cultivated throughout temperate, tropical and desert regions and also include many distinctive growth styles with a profusion of white or yellow flower clusters. Acacias also supply us with numerous helpful items, from hardwoods to water-soluble gums used as a thickening agent in your preferred frozen dessert. This feature of the crown top allows the trees to record the optimum volume of sunlight. The cultivation of wheat and rice produce CH_4 and CO_2 emission and as compared to that tree plantation is carbon sequester[2]. Acacia is a significant multipurpose tree that is used in plantation forestry as traditional agrosilvopastoral management. Agroforestry with *Acacia* spp. leads to a diverse community with time (15-20 years) and can able to diminish the impact of man on natural processes. In this direction, *Acacia nilotica* has been used as a pollution-resistant species[3,4].

Moreover, important members of genus Acacia, i.e., *A. nilotica*, *A. catechu*, *A. auriculiformis*, *A. senegal* and *A. tortilis* are virtuous in improving the carbon, nitrogen and phosphorus content of the soil. Moreover, these species are also used in wasteland management[5]. Due to the high cover canopy of *A. tortilis* and *A. nilotica*, they can be used as resistance to high wind and act as shelterbelts. Soil ecosystem has a vast diversity of microbes that interact with roots that influences ecosystem productivity. This interaction with roots and microbes, especially mycorrhizal fungi significantly help in nutrient mineralization, chiefly phosphate and also works against pathogenic fungi[6]. There is a two-way association where plants give carbon to the mycorrhizal colonized fungal partners and in return, provide nutritional benefits to the host. This also increases the niche overlapping in the forest ecosystem. Moreover, microbial diversity is being affected by the traditional agricultural practice and that's why plantation forestry is vital so that the microbes withstand their natural habitat for long. Whereas, the use of chemical fertilizers has an adverse effect on soil[7].

Introducing mycorrhization with micropropagation can become a tool to impart viability to the cultivation and production of propagated species. This increases their growth as well as survival chance. In the 1990s many workers had used *in vitro* mycorrhization for micropropagation of fruit trees. This gives the idea to do this technique for plantation crops[8]. It has been found that plant biomass, phosphatase enzyme activities, available leaf phosphorus, etc., are more in mycorrhizal inoculated plants than non-mycorrhizal inoculated plants, whether they are in polyhouse trial or open field trial[9,10]. Understanding the molecular aspects of nutrient exchange potential by AMF can contribute to agroforestry practice in the future application. To develop an efficient production system of mycorrhizae colonized seedlings for agroforestry, a substantial attempt has been undertaken. Problems like the specificity of host and AMF, survival up to hardening step and biotic and abiotic factors have to be faced. Environmental factors at mycorrhizosphere mediate AMF functioning. Compatible AMF strain and proper levels of inoculation should follow. Otherwise, seedlings survival proportion decreases[11,12]. Therefore, morphological, physiological and phenological characteristics of AMF symbiont describe the functioning of mycorrhization. In this review article, an attempt was made to represent the economical role, mycorrhization importance, on the *Acacia* spp.

Rhizomicrobiome of Acacia (arbuscular mycorrhizal fungi): Arbuscular Mycorrhizal Fungi (AMF) is an obligate, beneficial, ubiquitous and non-specific collaboration between roots of more than 80% of higher plants with fungi belonging to phylum Glomeromycota through arbuscules (and sometimes vesicles) forming unique structure within the cortical cells. Mycorrhizal roots anchorages a diverse group of microbes around mycorrhizosphere which are widely distributed. AMF has a role in plant stress management[13]. They encourage the host to become stress-tolerant. Mycorrhizal hyphae begin with a single spore which is of many kinds, some have a different shape, color, ornamentations, etc., that are the basis of identification. In the beginning, the hyphae are unbranched and straightforward that sustained on glycogen and triglycerides reserves. The hypha then marched towards the root exudates like Strigolactones (iron-chelator) produced by the host in the vicinity and enters inside. This chemotropic moment is responsible for signaling that initiates mycorrhizal infection. After contact with the root, the hyphae form hyphopodium that allows entering the cortex and start branching vigorously where they form arbuscules[14]. Strigolactones can sense P deficiency in plants that systematically run several signaling pathways for AMF colonization for the absorption of P in the form of orthophosphate (Pi). Mycorrhization does not only depend on mycelial growth but also a recalcitrant glycoprotein compound, "glomalin" produced by mycorrhizal fungi themselves and keep it depositing on their hyphal walls. Glomalin has high cementation capability and can be better called as "Glomalin Related Soil Protein" (GRSP). GRSP remains

Table 1: Microbes present in the rhizosphere of Acacia

Microbe	Size	Type of flagella	Shape	Gram staining	Respiration mode	Genome size (Mb)
Bacillus	0.5-2.5×1.2-10 μm	Peritrichous	Rod	Gram-positive	Aerobic or facultative	4.2-5.4
Acetobacter	0.6-0.8×1-4 μm	Peritrichous	Rod	Gram-negative	Aerobe	3
Bradyrhizobium	0.5-0.9×1.2-3 m	Monoflagellate	Rod	Gram-negative	Facultative anaerobe	7-9
Rhizobium	0.5-0.9×1.2-3 m	Several flagella on polar ends	Rod	Gram-negative	Aerobe	7
Sinorhizobium	NA	Peritrichous	Rod	Gram-negative	Aerobe	7.14
Pseudomonas	1-5×0.5-1 μm	Single unsheathe polar flagella	Rod	Gram-negative	Anaerobe	5.5-7
Rhodococcus	0.5-1 μm	Flagella present	Spherical	Gram-positive	Obligate aerobe	3.9-10
Paenibacillus	0.3 μm	Flagella present	Rod	Gram-positive	Aerobic and facultative anaerobe	6.7
Paraburkholderia	1.6-3.2 μm	Flagella present	Rod	Gram-negative	Obligate aerobe	2.4
Herbaspirillum	1.6-2×0.5-0.6 μm	Unipolar flagella with hook	Rod	Gram-negative	Facultative anaerobe	5.3
Mesorhizobium	-	Polar or subpolar peritrichous flagella	Rod	Gram-negative	Aerobic	7.2
Serratia	0.5-0.8×0.9- 2 μm	Peritrichous flagella	Rod	Gram-negative	Facultative anaerobe	5.2
Burkholderia	1.6×3.2 μm	Single or multiple polar flagella	Rod	Gram-negative	Obligate aerobe	2.4
Actinobacteria	10 μm	Flagella present	Cuboidal, oval	Gram-positive	Aerobic and anaerobic (few)	4.2
Azospirillium	2.1-3.8 μm	Polar flagella	Straight rods, slightly curved	Gram-negative	Microaerophilic	7.6
Trichoderma (fungi)	3-5 μm			-	Aerobic and anaerobic	33-41

within the soil particles for a much longer time interval (6-42 years) than hyphal roots (several days to months only), consequently, help in soil aggregates stabilization. AMF directs the clay particles to come closure and promote soil micro- and macroaggregates through polysaccharides secretion that causes the 'packing effect' of dispersed soil particles[15]. The stimulation of soil aggregates is guided by the transfer of carbon from plant to soil. Particles of GRSP are present in mycorrhizosphere in a huge amount. On the other side, bacterial may also produce compatible polysaccharides that communicate with AMF[16].

It has been found that the water holding capacity of mycorrhizal roots is more than non-mycorrhizal roots. This means that the hydraulic conductivity and xylem efficacy of mycorrhizal roots become advanced. Even under drought conditions, mycorrhizal roots survive more than non-mycorrhizal roots. For example, if the colonization of AMF starts first, they will suppress the growth of pathogenic fungal mycelia. This means that early colonizers would utilize the habitat and nutrients. These beneficial colonizers have the property to reduce the pathogenic infections through the production of antibiotics or antifungal compounds, creating hurdles for later arriving pathogens[17]. Therefore, AMF inoculation can prove beneficial agricultural practices. Important microbes present in the rhizosphere of Acacia based on the information provided elsewhere[18] are presented in Table 1.

ACACIA AND AMF

AM fungi in early-successional environments maybe limited due to reduced abundance and infectivity in disturbed soil (Abbott and Robson 1991, Jasper *et al.* 1991) and restricted propagule dispersal, potentially selecting for plants with lower mycorrhizal responsive-ness (Seifert *et al.*, 2009).

Many symbioses, whether they are positive or negative influence ecosystem stability. Positive symbiosis like mutualism is very crucial for the forest ecosystem. Like, Lichens, a perfect example of mutualism that is a vital step for succession on bare rocks. Succession leads to a complex stable ecosystem comprises of several abiotic and biotic interactions. These interactions may be herbivory, pollination, mycorrhization, root nodulation (nitrogen-fixation rhizobacteria), allelopathy, amensalism, pathogenicity, parasitism, inter- and intraspecific competition. The primary interaction studied in this paper is the association of microbes, mycorrhizal fungi and rhizobia with roots of Acacia. Acacia is an excellent example of plantation forestry that shows allelopathy, mycorrhization nitrogen-fixation rhizobacteria and other mutualisms altogether[19].

Any plant including Acacia release some root exudates 5-deoxy-strigol which are Sesquiterpenes that work as a chemoattractant for the mycorrhizal hyphae[20]. The hyphae make the roots grow deeper to capture nutrients that leached below the rooting zone. This can act as a 'safety net' for the vegetation and able to recycle nutrients back into agroforestry systems. Utilizing plantation forestry-based intercropping can ameliorate the undesirable influence on AM fungi by normal agricultural practices[21]. Incorporation of different species of trees can influence AMF diversity. By this technique, AMF diversity would be more in agricultural fields than in the woodlands. The adoption of plantation forestry in agricultural fields in arid regions is minimal, which might be due to lack of knowledge to poor farmers and/or attributed to the financial costs as well as subsequent loss of cultivated land. This leads to sustainable development. Earlier it has been acknowledged that AMF quantitatively absorbs nitrogen and phosphorus from the soil. AMF is now accredited to access organic N and P, qualitatively. AMF symbiosis has increased the quality of absorbing nutrients from organic sources or directly from insoluble mineral resources through the excretion of organic acids[22]. AMF is a strong influence in the agroforestry system where plants showed a multifunctional role. The number of pollinators gets increased when they are inoculated with AMF. This also helps in the dispersal of fruit and seeds and helps in achieving the forest ecosystem. It can be said the intercropping practices by Acacias work as a festivity for the AMF and other microbial strains. Contrarily, AMF also helps Acacia plants to colonize. Presence of *Acacia* spp. and AMF increases the diversity and quality of soil to decomposed for litter, consequently, decrease the cellulase activity[23]. As we know, cellulase decomposition is hard to process and is dominant in green plants, having high C/N and C/P ratios. But, with AMF collimation litter decomposition is fast, that released many hydrolytic enzymes, described further in this paper. Hence, it proves that translocation of P and N from soil to roots become much faster than non-colonized roots. Further, it is noticed that acid phosphatase and alkaline phosphatase enzymes promoted during the intercropping system of Acacia and AMF[24].

The AMF status of Acacia tree (*A. raddiana* and *A. aneura*) and found 41 species of AM fungi belonging to Glomus, Acaulospora, Funneliformis, Gigaspora, Dentiscutata, Scutellospora, Rhizophagus, Claroideoglomus, Ambispora, Entrophospora, Diversispora and Racocetra genera. Among these 12 genera, Glomus showed maximum diversity with ten species followed by Acaulospora and Funneliformis with species count 6 and 4, respectively. They also summarized that frequency of Claroideoglomus with species *C. etunicatum* was 12% more than another AMF spores[25]. Understanding the role of AMF in doing agroforestry practice is very important and is useful in navigating the biodiversity and composition of nutrients[26]. AMF concerning the host plant has been related to many edaphic factors. AMF association improves the nutrient status, particularly P and water uptake in Acacias that make them able to establish in arid regions and also contribute to drought stress[27]. AMF symbiosis makes Acacias withstand in nutrient-deprived area, high acidity and alkalinity with or without metal toxic soil that make the soil less fertile. Subsequently, Acacia involved in agroforestry for the fast rehabilitation of threatened and marginalized agro-ecosystem. Acacia belongs to leguminous trees which form one of the largest groups of woodland in arid and semi-arid regions. Many investigations have been carried out to examine the diversity and density of AMF on fruit trees, timber trees or shade trees in tropical areas, studies on leguminous plant and AMF relationship is limited to the co-inoculation of Rhizobia and AMF[28].

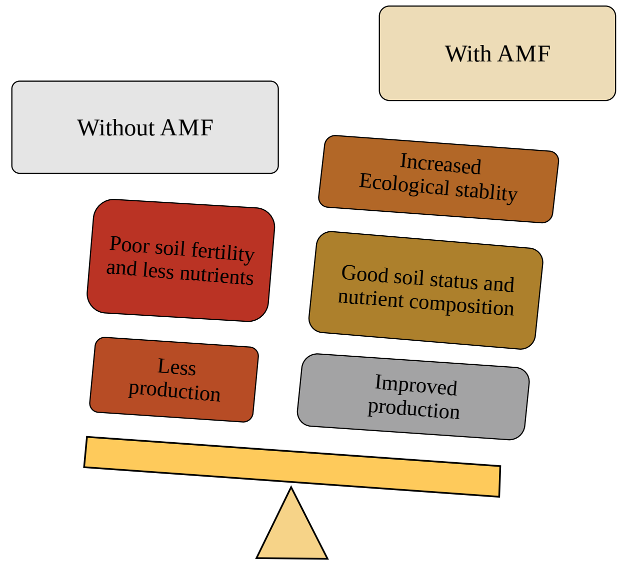

Fig. 1: Balanced sheet showing the importance of Arbuscular Mycorrhizal Fungi (AMF)

Extracted AMF from the rhizosphere of Acacia, mainly belonging to genera Glomus and Gigaspora, respectively. The 9 species of Acacia (*A. nilotica*, *A. saligna*, *A. seyal*, *A. sieberiana*, *A. tortilis*, *A. senegal*, *A. abyssinica*, *A. robusta* and *Faidherbia albida*) and extracted *Funneliformis*, *Scutellospora*, *Paraglomus*, *Diversispora*, *Claroideoglomus*, *Sclerocystis*, *Gigaspora*, *Glomus*, *Entrophospora*, *Acaulospora*, *Racocetra*, *Pacispora* and *Rhizophagus*[29,30]. The role of Acacias in maintaining the diversity of AMF and sustaining the growth of mycelial networks for the intercropping system is very well documented. As the intercrops are short-lived or seasonal so the roots of Acacias can provide the host until the next crop is planted. The problem of low fertility in nutrient and moisture-deprived areas can be circumvented by the use of mycorrhizal fungi[31,32]. AMF-Acacias interaction plays an imperative role in the below-ground and above-ground ecosystem. *Acacia* spp. proved to the establishment of sustainability of plant communities and AMF symbiosis is required for long-term sustainability in agricultural fields[33,34].

Inoculation of AMF at large-scale is difficult, but trees like Acacias have to be recognized which can be best suited in the particular environment, has a pivotal role in mineralization, nutrient cycling, maintaining plant growth and can become a barrier for wind, water-runoff, pathogens and pests should be planted[35]. The study at the molecular and genetic level are going on to recognize the key regulatory genes so that gene editing strategies can be improved and use wisely[36]. Last but not least, to study the co-inoculation effect with other microbes for soil restoration Fig. 1.

CONCLUSION

It can be concluded that AMF symbiosis is beneficial for Acacia studies are indicating a functional and consistent AM symbiosis with acacia roots. This symbiosis might be utilized efficiently in restoration programs as Acacia is generally grown on the marginal lands. Interaction with much more diverse AMF communities may improve its development as well as adaptation to in the harsh ecosystems.

SIGNIFICANCE STATEMENT

This study provides valuable information regarding Acacia association with Arbuscular Mycorrhizal Fungi (AMF) assists in the acquisition of water as well as growth nutrients like N and P which help in the successful development of Acacia, particularly in semi-arid and arid areas. AMF also brings the structural changes in soil, increases resistance against the different pathogens and several abiotic stresses. Among these, *Bacillus*, *Bradyrhizobium*, *Acetobacter*, *Rhizobia*, *Trichoderma* and *Pseudomonas* could be regarded as plant-growth-promoting-rhizospheric-microbes. Overall, microbes could be utilized as biofertilizers along with various other natural compounds, which may compensate for the availability of the nutritional requirements.

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