Chapter

Mycorrhizal Fungi and Sustainable Agriculture

Soibam Helena Devi, Ingudam Bhupenchandra, Soibam Sinyorita, S.K. Chongtham and E. Lamalakshmi Devi

Abstract

The 20thcentury witnessed an augmentation in agricultural production, mainly through the progress and use of pesticides, fertilizers containing nitrogen and phosphorus, and developments in plant breeding and genetic skills. In the naturally existing ecology, rhizospheric soils have innumerable biological living beings to favor the plant development, nutrient assimilation, stress tolerance, disease deterrence, carbon seizing and others. These organisms include mycorrhizal fungi, bacteria, actinomycetes, etc. which solubilize nutrients and assist the plants in up taking by roots. Amongst them, arbuscular mycorrhizal (AM) fungi have key importance in natural ecosystem, but high rate of chemical fertilizer in agricultural fields is diminishing its importance. The majority of the terrestrial plants form association with Vesicular Arbuscular Mycorrhiza (VAM) or Arbuscular Mycorrhizal fungi (AMF). This symbiosis confers benefits directly to the host plant's growth and development through the acquisition of Phosphorus (P) and other mineral nutrients from the soil by the AMF. They may also enhance the protection of plants against pathogens and increases the plant diversity. This is achieved by the growth of AMF mycelium within the host root (intra radical) and out into the soil (extra radical) beyond. Proper management of Arbuscular Mycorrhizal fungi has the potential to improve the profitability and sustainability of agricultural systems. AM fungi are especially important for sustainable farming systems because AM fungi are efficient when nutrient availability is low and when nutrients are bound to organic matter and soil particles.

Keywords: Actinomycetes, Bacteria, Mycorrhizal fungi, Vesicular Arbuscular Mycorrhiza

1. Introduction

The productivity of agriculture has increased steadily since the middle of the last century in temperate regions and, more recently, in tropical areas [1] mainly due to improved varieties, machinery, fertilizers, and pesticides. However, recently agricultural yields have plateaued [2], largely because of land degradation often associated with unsustainable farming practices [3, 4]. To meet future demand, food production must rise significantly through this century, utilizing less cultivable land in a sustainable manner [5]. Many factors have contributed to making this increase in crop production essential, including population increases worldwide, food shortages in developing countries, the importance of agricultural products for trade in many countries, the competition between urbanization and agriculture for land, and the competition that is likely to develop between food and non-food production [6]. However, the mechanism available for producers to increase yields tends to increase input costs, the number of operations in the field, and the financial risks of failure. At the same time environmental degradation linked to the use of chemical inputs (i.e., water pollution from nitrates, phosphates, and pesticides) is increasingly widespread and sometimes irreversible. Moreover, secondary effects on biogenesis and soil impoverishment have weakened cropping systems to make them increasingly dependent on chemicals [7]. Thus, there is growing demand for clean agriculture, high-quality food, and more information on how food is produced are finally having an effect on decreasing the level of chemical inputs used in developed countries [8]. However, in developing countries the great need for food implies a trend towards intensification, mainly through the use of more fertilizers [9] as plant nutrition has played a key role in the dramatic increase in meeting the demand for and supply of food. The consumption of Nitrogenous (N) fertilizer has increased almost nine-fold and that of Phosphorus (P) more than four-fold. The tremendous increase of N and P fertilizers in addition to the introduction of highly productive and agricultural systems has allowed these developments to occur at relatively low costs [10]. But the increasing use of fertilizers and highly productive system have also created environmental problems such as deterioration of soil quality, surface water and ground water as well as air pollution, reduced biodiversity and suppressed ecosystem function [10, 11]. Environmental pollution resulting from greater nutrient availability can be either direct or indirect. Directly, misuse and excessive or poorly managed use of fertilizers can result in leaching, volatilization, acidification and denitrification. Indirectly, the production (use of fossil fuel in Haber-Bosch process) and transport (combustion of fossil fuel) of fertilizer result in air- borne carbon dioxide and nitrogen pollution, which will be eventually deposited into terrestrial ecosystems.

The most limiting nutrients for plant growth are N and P. Most of N is tied into soil organic matter. Even after fertilization, plants have to compete with soil microbes for easily available soluble N but problem with P are different. In acidic soils, even when phosphorus fertilizer is added in substantial quantities, it becomes non available as fertilizers P precipitates with iron or aluminum whereas in alkaline soils P precipitates as calcium phosphates [12]. Accordingly, P limitation may be a difficult problem to overcome through the addition of P-containing fertilizers. So, the recent increase in crop yields and food production in developed countries have been achieved by intensive agricultural practices. This increase, however have not come without tremendous environmental costs. In developing countries, the problems are different. The lack of fertilizers and adequate agricultural practices do not allow intensive crop production and a vast segment of the population remains undernourished. Clearly, there is an urgent need for sustainable agricultural practices on a global level. In the developed world a reduction of energy and environmental costs is necessary. In developing countries, efficient, sustainable practices are needed to allow cost efficient production of adequate nutrition for the growing populations. To overcome the ecological problems resulting from the loss of plant nutrients and to increase crop yields in the absence of resources for obtaining costly fertilizers, microscopic organisms that allow more efficient nutrient use or increase nutrient availability can provide sustainable solutions for present and future agricultural practices. Therefore, a better knowledge of the processes and factors that govern the bioavailability of soil nutrients to plants, thus including the root-soil interactions understanding of microorganisms in the rhizosphere [12, 13] is necessary. As Samuil [14] mentioned, organic farming promotes sustainable production systems, diversified and balanced crop, to prevent pollution and the environment damages. Moreover, the importance of the mycorrhizal arbuscular fungi in organic farming and farmers' potential to increase the benefits of arbuscular mycorrhizae (AM) associations in such systems represented interesting subjects as it was synthesized by Gosling *et al.* [15]. Symbiotic soil organisms, such as mycorrhizal fungi, may be the source of many of these beneficial effects and thereby be key components of agricultural 'sustainable intensification' [5].

2. Arbuscular mycorrhizae symbiosis

The term 'Mycorrhiza' was first introduced by Frank [16] and comprises of all symbiotic associations of soil-borne fungi with roots or rhizoids of higher plants. Allen [17] described the fungal-plant interaction from a more neutral or microbially oriented aspect stating that 'Mycorrhiza is a mutualistic symbiosis between plant and fungus localized in a root or root-like structure in which energy moves primarily from plant to fungus and inorganic resources move from fungus to plant'. The group of fungi and plants, which are involved in the interaction, determines the type of mycorrhiza they form [18]. Recently, there have been significant advances in the understanding of physiological processes and taxonomy of these fungi [19, 20]. They are obligate symbionts belonging to the phylum Glomeromycota [21]. Their activity in agricultural ecosystems is well documented [22–24]. The distribution of ectomycorrhizal (ECM) fungi is also widespread, but they form associations with only 3% of terrestrial plant families [25]. ECM fungi are members of the phyla Ascomycota and Basidiomycota [26, 27]. Unlike the ECM fungi, AM fungi are dependent on plants for their carbon (C) and when a symbiosis is formed, both ECM and AM fungi can demand 20–40% of photosynthetically fixed plant C [28] (**Figure 1a** and **b**). Soil microorganisms have significant impact on soil fertility and plant health.

Microbial symbionts including arbuscular mycorrhizal (AM) fungi form an essential component of the soil microbial community playing a key role in overall plant growth and development (**Figure 1c**). Arbuscular mycorrhizal (AM) fungi form symbiotic relationships with over 80% of terrestrial plant species [32]. Arbuscular mycorrhizas are ancient and ubiquitous symbioses formed between a relatively small group of soil fungi and higher plant roots which has been traced back 460 million years [21]. During AM symbiosis, the fungal hyphae penetrate the root cortical cell walls by formation of aspersoria leading to the development of intra-radical hyphal colonization and formation of arbuscules or coils that interface with the host cytoplasm [33]. The highly branched arbuscules aid in metabolic exchanges between the plant and the fungus. AM fungi also produce vesicles, which function as storage organs [33]. It has been estimated that in natural ecosystems plants colonized with AM fungi may invest 10–20% of the photo-synthetically fixed carbon in their fungal partners [34].

AM fungi not only can promote via directs effects, but there are also a number of indirect effects such as a stimulation of soil quality and the suppression of organisms that reduce crop productivity (**Table 1**) [35]. AM fungi also interface directly with the soil by producing extra-radical hyphae that may extend several centimeters out into the soil thereby helping the host plants in uptake of nutrients especially P [36]. The extra-radical mycelium of AM fungi can also enhance mobilization of organically bound nitrogen (N) from plant litter [37]. Hyphae of AM fungi have been shown to play an important role in soil stabilization through formation of soil aggregates by secretion of glomalin [38]. Glomalin is a glycoprotein produced on hyphae of AM in the soil. It is discovered by [39] and termed as glomalin, after the source organism of phylum "Glomeromycota." It is apparently insoluble in water;

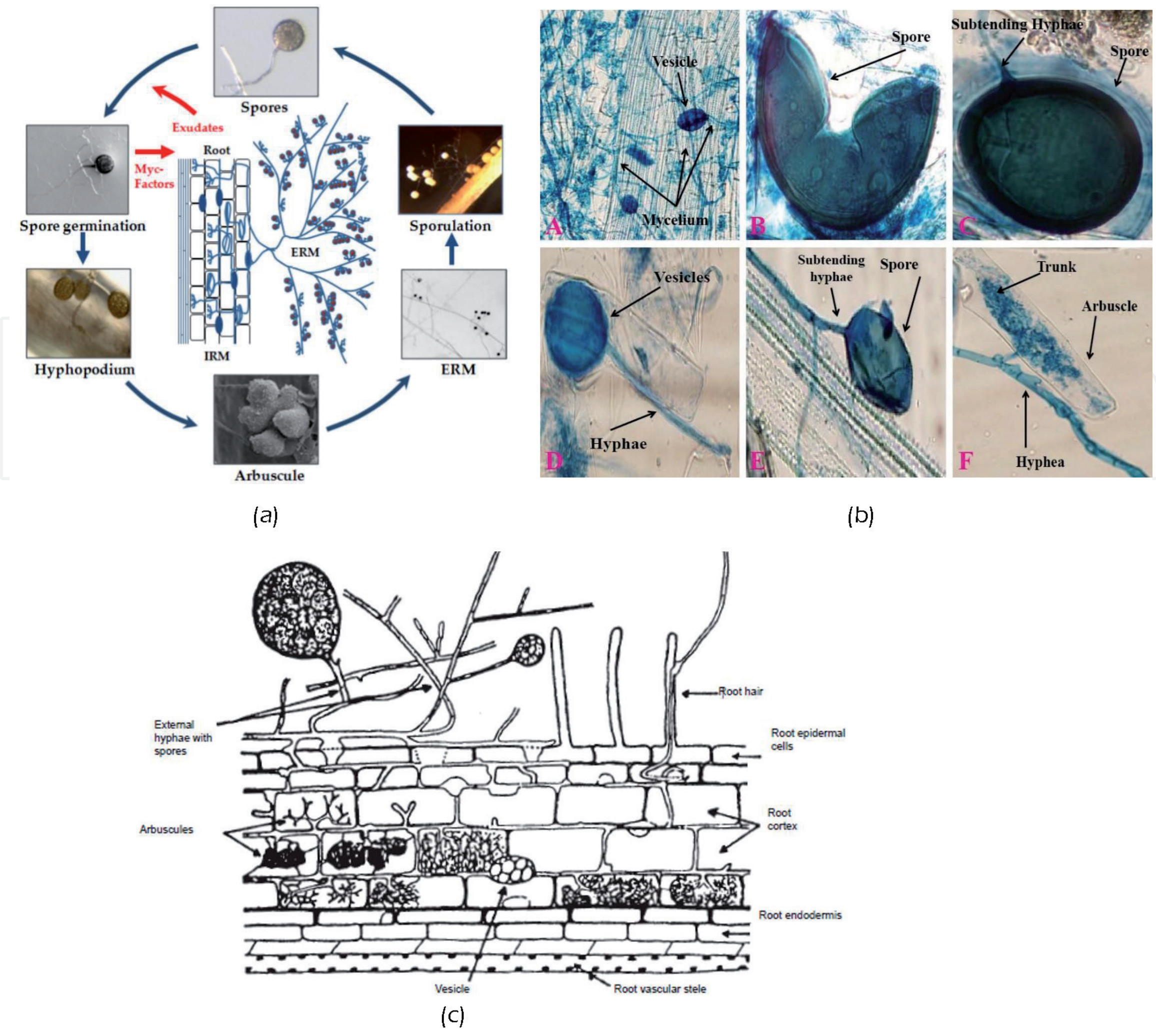

Figure 1.
(a) Life cycle of an AM fungus and the different steps during AM development (Adated from Bücking et al. [29]). (b). A-F: The structural colonization of AMF in roots [a]: Vesicle and mycelium occurrence of the AMF-colonized root sections (arrow), [B]: Spore morphology of AMF (arrow), [C]: Intact mycorrhizal spores and subtending hyphae (arrow), [D]: Vesicles and subtending hyphae of AMF (arrow), [E]: Vesicles and subtending hyphae (arrow), [F]: Trunk, arbuscle and hyphae of AMF (arrow). (adapted from Abeer [30]. (c) Diagram of a root colonized by AM fungi (adapted from Habte, M., and R.L. Fox. [31].

Direct effects on crops	*Indirect effects*
• Stimulation of plant productivity of various crops • Nutrient acquisition (P, N, Cu, Fe, Zn) • Enhanced seedling establishment • Drought resistance • Heavy metal resistance	Weed suppression Stimulation of nitrogen fixation by legumes (green manure) Stimulation of soil aggregation and soil structure Suppression of some soil pathogens Stimulation of soil biological activity Increased soil carbon storage Reduction of nutrient leaching

Table 1.
Direct and indirect effects of mycorrhizal fungi on crop productivity in organic farming systems [35].

extremely persistent glycoproteinaceous compound [40] thus remains in soil after the death of the hyphae [41]. It improves soil physical properties, carbon sequestration, mineral elements, microbes' activities, stabilizes pollutants, and ultimately helping in restoration of soil ecosystem. This kind of beneficial effect of glomalin may be through its existing impact on soil; by serving as a substrate for microbial population, a gluing mediator for aggregate formation, chelation of heavy metals and toxic pollutants, and enhancing carbon sequestration via long-term persistence in soil [42]. The indirect or 'secondary' impacts of glomalin on the formation and stabilization of soil aggregates further improved the efficiency of the symbiotic relationship and the growth environment [43, 44].

In addition to increasing the absorptive surface area of their host plant root systems, the extra-radical hyphae of AM fungi provide an increased area for interactions with other microorganisms, and an important pathway for the translocation of energy-rich plant assimilates to the soil. The symbiosis is primarily characterized by its association with phosphorus (P) uptake by host plants and the enhancement of water uptake through the extra radical fungal hyphal networks. This symbiosis can also trigger physiological and molecular signals at subcellular levels, alter plant community structure and increase plant tolerance to various abiotic and biotic stresses. Mycorrhizal hyphal networks link plants of the same and different species below ground and are able to transfer resources between plants and release signal molecule defense-related proteins, lipochito oligosaccharides and strigolactones. Molecules like strigolactones secreted by the roots help fungi identify their host plants. Strigolactones also stimulate AM fungal growth and its branching. The fungi reciprocate to this signal by secreting a set of hypothetical factors known as Mycorrhizal Factors (Myc). These factors also play a major role in communication between AM fungi and nitrogen-fixing bacteria. The AM interactions are established further with the induction of seven genes (SYM genes) [45].

3. Application of AMF in agriculture

3.1 AMF enhances soil fertility

Microbes inhabiting in the rhizospheric region interact with the plant root system and generate a nutrient-rich situation improving crop development [46]. At the same time such microorganisms also protect the plant root from harmful chemicals either by repelling them or by diluting their impacts in rhizosphere. Symbiotic association between a particular group of fungus with the plant root system enhances the availability of essential mineral elements principally those elements which are less mobile (phosphorus, copper, zinc etc.) in soil thus allowing crop roots system to access them at ease, which are otherwise difficult to uptake because of their less mobility [47, 48]. Such association also helps crops to establish even in soil with poor fertility, as the microbes will help in uptake of essential nutrients, both major and minor [49]. Studies reported that the amount of fertilizer (particularly phosphatic) used can be decreased with the appliance of mycorrhizae [50, 51].

3.1.1 Uptake of phosphorous

P is a critical and macro essential element (**Figure 2**). It performs an important function in all biological system as it is involved in all energy transfer processes in the form of ATP. Moreover, it also acts as an indispensable constituent for various biological molecules like nucleotides, phospholipids and sugar phosphates [52]. One of the significant advantages of mycorrhizal application is the augment in the P nutrition to the crop. The normal mechanism of P uptake may be discussed in these following ways-; (i) AMF hyphae will absorb it (P) from the rhizosphere, (ii) the absorbed P will be translocated along the hyphae from outside to inner (root cortex) mycelium, (iii) ultimately the absorbed phosphorous is transferred to cortical region of the roots [53].

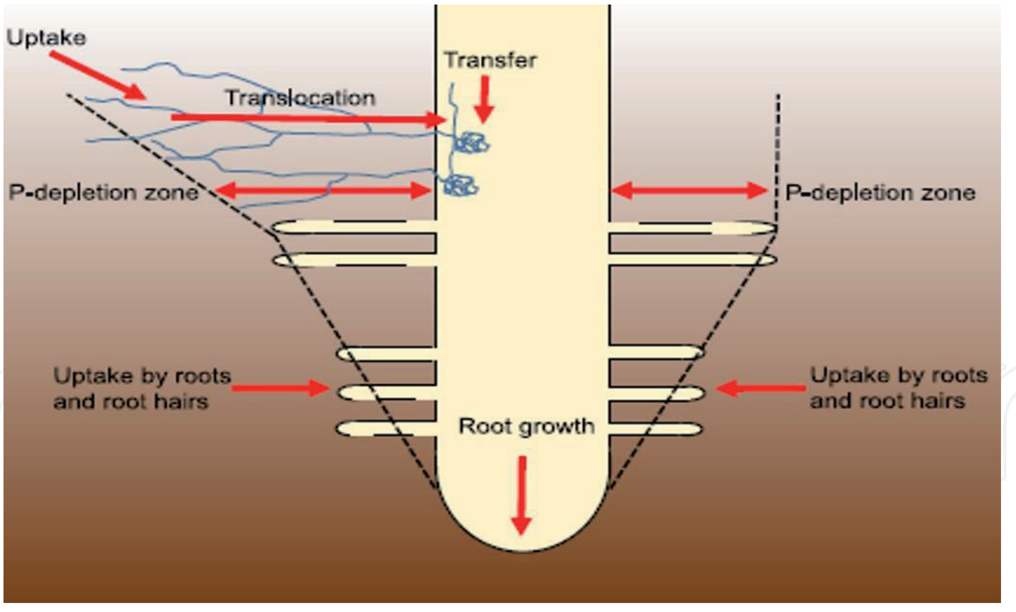

Figure 2.
Mycorrhizal and non-mycorrhizal phosphorous uptake pathways. In mycorrhizal roots, the P-depletion zone is extended by extraradical fungal hyphae beyond that of the non-mycorrhizal root and root hairs (adapted from smith and smith [52]).

A variety of techniques were anticipated in order to increase the accessibility to essential elements such as (i) enhanced assessment of soil; (ii) better movement of phosphate into roots via arbuscules; (iii) alteration of root growing region; (iv) proficient exploitation of phosphate inside crops; (v) proficient transportation of Phosphorous to crop root systems; and (vi) improved storing of captivated Phosphorous. Bhat and Kaveriappa [54] reported that the uptake of PO_4^{-3} by root systems occur more rapidly as compared to the rate at which the ions diffuse to absorbing the site the root system. Thus, it may result in a PO_4^{-3} exhaustion region in the roots surroundings. However, the vast expanded mycorrhizal hyphae lengthen into the surroundings region of plant roots scaffoldingPO_4^{-3} exhaustion region. Consequently, improves the ability of the crop to venture their growing region farther than the nutrient exhaustion region where rootlets and root hair cannot grow [55]. An enzyme known as phosphatase is responsible for converting organic Phosphorous into absorbable form and the action of this enzyme is used by mycorrhizae in order to metabolized PO_4^{-3} in the soil. This enzyme is found inside polyphosphate granules residing in the vacuoles of the fungus. The action of this enzyme will break the polyphosphate granules in fine branches of ultimately the mineralized are released in the protoplasm.

The AMF possibly will give a P uptake route; however, AMF colonization can lower the crop acquisition of PO_4^{-3} via their root PO_4^{-3} transporter [56]. If this reduction is not compensated via AMF pathway of PO_4^{-3} acquisition then it may result in lowering the ultimate cropPO_4^{-3} uptake in AMF-colonized crops [56]. Dissimilarity in the proportionate contributions of these PO_4^{-3} delivery routes can be accountable for the differences in P absorption amongst crop cultivars. In some crop families the AMF has lately been exposed to give a large enhancement on their development example *Alliaceae, Fabaceae* and the *Solanaceae* [57], however the response of other plants, particularly grass family, are ambiguous [58]. Additionally, dissimilarity in growth due to AMF colonization too occurs amongst cultivars within species [59].

3.1.2 Uptake of nitrogen

N is an essential component of amino acid and nitrogenous bases therefore, it is necessary though in direct for protein and nucleic acid bio-synthesis. AMF colonized crops shown to have improved N content in their above ground part. Various processes may be implied for this improvement, viz. (i) enhancement of symbiotic fixing of atmospheric N; (ii) direct acquisition of combined N by mycorrhiza; (iii) crops without nodule are also benefited as a portion of N fixed by the plants with nodule is transferred towards the former; (iv) activity enzymes viz. pectinase, xyloglucanase and cellulose which are necessary for N metabolism as well as decomposing soil organic matter where enhanced [53]. AMF hyphae have the capacity to extort N from the soil and transporting it to crops. They possess the enzymes to facilitate breaking of organic nitrogen and have N reductase that transform the N present in the rhizosphere. AM not only promotes growth, nodulation and N fixing process in legume-*Rhizobium* symbiosis but also enhances acquisition of ammonia easily from soil which represent the major contribution of accessible N in numerous innate environments. Bacteria which can fix N thus distinctly have the capacity to impact AM fungi. Minerdi *et al.* [60] reported the occurrence of genes responsible for fixing of N in endosymbiotic *Burkholderia* sp., however, significant expression of this genes so that it can impact the growth of the fungal association has not been confirmed. *Rhizobium spp*. might perform collegially with AM fungi on their plant hosts. Nodulation as well as fixing of N are normally augmented in legumes subsequently after AM colonization, possibly for the reason that the fungus provides access of P to the plant and the rhizobacteria, which is necessary for the enzymes essential in the fixing of N. Supplementary fixing of N also improves growth of mycorrhizae [61]. In soils where major fraction of N is available in the form NO_3^-, AMF have a mere impact in uptake of N by legumes [62]. AMF hyphae enhance translocation of N in crop colony, as the connection of AM mycelia joins varied crops species thriving close by and helps pooling and enhancing availability of nutrients for these crops. McFarland *et al.* [63] reported that above 50% of N required by the crop is by associating with mycorrhizal.

3.2 Plant growth hormones

Fungi associated with a pants produced crop growth regulators [64]. Arbuscular mycorrhizae develop a reciprocal and advantageous symbiosis with the majority land plants as their association is not species specific. The existence of host plant at the time of beginning and during the progress of symbiosis is essential, as their symbiotic relation is obligatory in nature. However, AM fungal spores have the capacity to germinate even if the host plant is not present [65]. The fungal counterpart can sense the incidence of the host plant via some signal transduction. Amongst the signaling compounds, that can influence mycorrhizal associations are plant hormones, which might definitely or negatively influence the associations [66]. Plant hormones can manage the intensity and therefore specificity of mycorrhizal associations. Consequently, it might be probable to improve the effectiveness of mycorrhizal association during stresses by regulating the amount of stress hormones [67, 68].

3.3 Uptake of water

AMF may also have a vital position in the improving water economy. The AMF symbiosis either augments the hydraulic conductivity of the roots thereby improving water absorption by the crops or modifies the crop physiology so as to decrease the stress response to soil drought [69]. In severe arid situation, crops associated with mycorrhizae have superior endurance than those crops without the association. It was revealed that mycelial complex may lengthen beneath and broader the soil profile in explore of water and essential mineral elements. Mycorrhizal association might also adjust the selectivity of plasma membrane to water, with enhanced P nourishment thus these AMF association could enhance the drought resistance of crops [70, 71]. During the situation of water stress, AMF apply their impact by enhancing the transpirational rate and enhancing stomatal conductance or by modifying the equilibrium of plant hormones [72]. The alteration in leaf flexibility owing to AMF association improve H_2O and turgor pressure of leaves and also enhance root growth and extension [73] thus they might affect H_2O relations and consequently, the water stress resistance of the crops. The possible basis for the improved moisture and nutrient absorption by mycorrhiza-crops association may be owed to improved allocation of absorbing hyphal system, more constructive ideotype of hyphae as compared to roots, superior absorbing area and rapid expansion rate, improved serviceable longevity, chemical modification in soil rhizosphere thus modifying microorganism inhabiting in the sphere, uptake kinetics, superior hydraulic conductivities, reduce transportation rates per unit leaf area, withdrawal of moisture from soil towards less Ψ_w and more swift revival form moisture stress.

3.4 Improvement of soil texture and structure

Interruption in ecology may influence the physical and bio-chemical activities in the soil. AMF assist in the fastening of soil particles and improving aggregation of soil and thus aiding conservation of soil [74]. Mycorrhizal fungi also enhance soil quality, because they generate glomalin subsequently when this molecule get accumulated in soil, then with fungal hyphae they produce micro aggregate and ultimately macro aggregates thereby, acting directly as a skeleton for soil aggregation and stabilization. It also produces discharge in the soil consequently improves and stabilizes soil and boosting the growth of microbes [34].

3.5 AMF in plant defense

AMF association can improve host plant endurance to pests and pathogens both above- and below-ground (**Figure 3**) [75–77]. Although the clear-cut biological and chemical reasons are uncertain, their colonization is identified to stimulate subtle modifications in plant metabolic process, like jasmonate and salicylic acid signaling routes, which are vital constituents of crop defense mechanism [78]. Mycorrhizal colonization of a plant before they are attacked by pathogen or pest may have a systemic priming effect via defense molecules/signal re-allocation [79]. So, crop defense related DNA can be expressed more rapidly and extensively than in non-colonized plants [80]. Mycorrhizal colonization may promote crop nutrients uptake and growth; however, this improvement may result in making the plant more attractive, enhance quantity and more nutritive to herbivores [81], thus promoting herbivore action [82]. In fact, phloem-feeding insect normally have enhanced performance on AMF-colonized crops than non-AM crops [81, 83]. Therefore, stabilizing these compromises ought to represent a key module of every farming management tactic associating AMF. Some plants may perhaps display a nonspecific method of defense against phloem-feeding herbivore, facilitated by AMF symbionts. Aphid-infested crops can interact signals via common mycelial networks (CMN) to an uninfected plant (**Figure 3**) [84], therefore a quick flux can be elicited for aphid-repellent volatiles compounds prior to the attack of the plant, this can check the widening or severity of invasion and consequent reduction in productivity [85].

Organic management of crop diseases is one of the important mechanisms for improving crop productivity either by repressing or killing the disease-causing microbes, thus augmenting the capability of crops to endure pathogens or by defending crops against disease causing microbes. In this context mycorrhizal

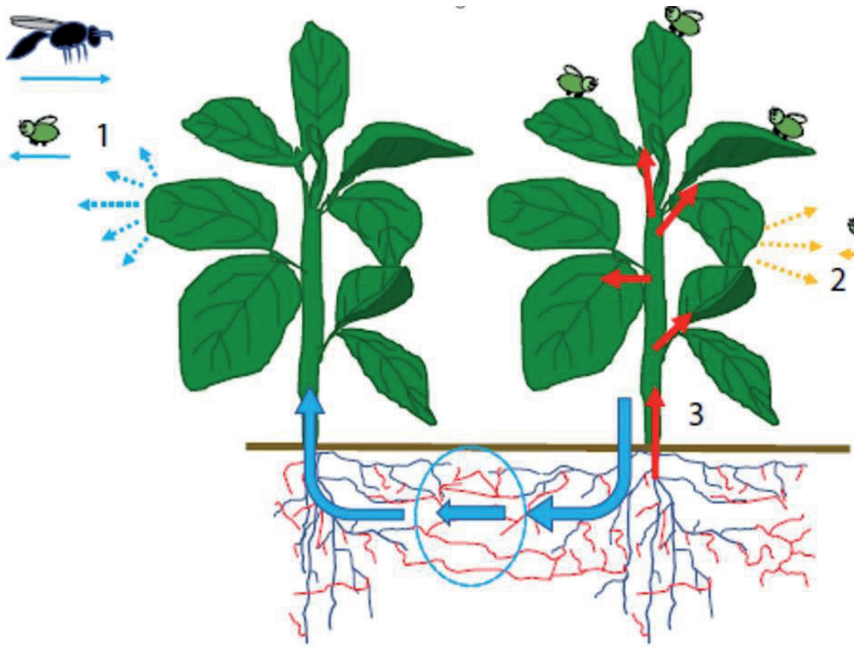

Figure 3.
Mechanisms by which arbuscular mycorrhizal fungi (AMF) may influence agroecosystem physiological ecology. (1) Common mycelia network transmits signal, altering volatile organic compounds (VOCs) in neighboring plants, repelling herbivores and attracting parasitoids (blue arrows), (2) AMF induce VOCs, repelling herbivores (yellow arrows), and (3) AMF elicit systemic plant defense priming (red arrows). (Adapted from Thirkell et al. [73]).

association proves to be the organisms which may serve as bio protectors of crops [86]. Several mechanisms might be involved in mycorrhizal symbiosis in regulating plant pathogens:

I. Generating a physical fence and obstructing the infiltration and successive expansion of disease-causing microbes [87].

II. Making the cell wall thicker via deposition of lignin and by producing many complex carbohydrates which consecutively hamper the penetration of root pathogen [88].

III. Activating host plants specially in the roots to synthesize and concentrate adequate amount of biochemical compounds (alkaloids etc.) which improve the host ability to resist against microbes invasion in their tissue [89].

IV. Promoting flavonoid wall infusions eg. *Laccaria bicolor*, subsequently preventing lesion development by the pathogen *Fusarium oxgsporum* in roots of *Douglas fir* [90].

V. Augmenting the amount of orthodihydroxy phenols in roots, which discourage the infestation of microbes [91].

VI. Synthesizing antifungal and antibacterial antibiotics and toxins function against disease causing microbes [92].

VII. Augmenting competitive advantage to host root for nutrients element in the root zone than the microbes [93].

VIII. Increasing microbial functioning and competition in the rhizosphere consequently forbidding the pathogens to acquire entrance to the roots [94].

Roots associating with VAM/AM fungi might serve as a site for actinomycetes accumulation thus opposing root pathogens [95].

IX. Balancing the trade-off in nutrient uptake mechanism of roots caused due to damage by microbes attacked [96].

X. Altering the quantity and nature of chemical produces by plant root and this would be difficulty for that pathogen which depends on specific type plant roots exudates [97].

Reduced pathogen growth in mycorrhizal and non-mycorrhizal portions of infected roots is connected with aggregation of phenolic and plant cell resistance mechanism. It has been observed that mycorrhizal infected crops were shown to be more lenient to fungal root pathogen in the presence of the root modulating symbiont viz. *Rhizobium leguminosarum*. Thus, indicating that interaction between mycorrhizae and other microorganism thriving in the rhizoplane is more effective in warding off the soil-borne pathogens than the mycorrhizae alone. Therefore, it is essential to understand of the mechanisms of plant disease resistance in mycorrhizae inoculated plants so as to get improved guidelines for developing an efficient plant production and sustainable agriculture. The compositions with mycorrhizae are extremely essential to produce novel groups of biocides which can also give a reduction in risk to both humane healthiness and the ecology [98].

4. AM fungi and sustainable agriculture

For sustainability in agriculture sector, it is essential to exploit the innate mechanisms so as to realize an adequate level of yield and food quality at the same time reducing chemicals inputs, reducing input overheads and obviate ecological contamination and its impact [27, 99]. However, it must be viable in the existing ecosystem and socially accountable. Edaphic factors have numerous contributions towards achieving sustainability in agricultural system such as controlling of pathogen in rhizosphere and augmenting the growth of soil microbes and their activeness which enhanced antagonistic and parasitic interaction in the crop root growing region [100, 101]. Plant and microbe interactions were the intriguing events contributing in agricultural sustainability. Mycorrhizal fungi are native to soil and crop rhizoplane thus making them as an essential mechanism for sustainability in agricultural. In sustainable agricultural systems specially when there are shorts supply for essential elements the mycorrhizae association turn out to play a vital role. In these conditions AM extra-radical mycelium have a vital position for mobilizing the nutrient components into usable form. Hamel and Strullu [102] stated analyzing an AM fungi have been a tough job, however nowadays they are identified as vital ingredients of edaphic environments rather than only crop root constituent. AM fungi can impact plant development, nutrient supply and production even in P-riched soils [103, 104] but the positive response of AM fungi will be more pronounced when the crop is grown in less fertile soil agro ecosystem and also resulting in reduced environmental nutrient loss.

Therefore, attention in AM fungal proliferation for sustainable agricultural system is escalating owing to its function in the encouragement of plant vigor, and enhancement in soil quality and structural stability. These fungal associations could be used efficiently for escalating productivity whilst decreasing the utilization of chemical inputs such as insecticides, fertilizers etc. To enhance crop productivity in soil with low fertility, inorganic fertilizers have been extensively employed, organic matter is included and techniques like keeping the soil fallow or incorporation leguminous crops have been practiced to improve soil ecosystem, boost soil microbial growth and functioning and augment nutrient re-cycling in order to decrease external inputs and make the most of their utility [105]. This mechanism has been initiated for managing soil ecosystem using earthworms and micro-symbionts [106, 107]. These soil organisms might contribute above 90% of soil organic activity consequently aiding the courses like nutrient cycling, soil fertility and symbiotic association in the plant root zone. Soil fungal multiplicity and functions have not been sufficiently investigated and inferred [108]. Mycorrhizae serve as a significant faction since they have an extensive dissemination and might have significant contribution to biomass of soil microbes and to soil nutrient cycling processes in crops. For sustainable improvement in crop yield more dependence should be on natural and organic mechanism by acclimating on germplasm favorable to plants [109]. They advance absorption of essential elements, particularly phosphorous, and minor nutrients like Zn, Cu; they influence the production of growth material and may lessen both biotic and abiotic stresses [33, 71, 110].

5. Conclusion

In order to have sustainability agricultural system, administration of appropriate nutrient supply represents necessary condition and in this situation mycorrhizae involvement cannot be ignored. Native mycorrhizae spores attack the plant roots and contribute in sustainability nutrients management, moisture, soil properties and productivity [48]. With increasing concern and demand on the requirement to augment sustainability in agricultural development, mycorrhizae fungi possess a significant part to perform in decreasing the detrimental consequent of chemical inputs of agriculture viz. pesticides, synthetic nutrients for promoting plant growth and regulating numerous pathogens. It is an economic and non-detrimental way of acquiring higher yield which may leads to development of a feasible, minimum-input cropping system. It is expected that, in the coming days, limitation in crop cultivation in the globe may be bypassed by using the techniques based on organic processes like mycorrhizae fungi. In the circumstance of existing limitation associated to large population, food requirement and ecological changes, it is obvious that the recent development and progress in arbuscular mycorrhiza field research and those in the future should be considered on maximizing production, improving its quality, enhancing cost effectiveness and profit return, conserving biodiversity and protection of environment. These limitations can be attained by interacting different discipline in particular ways to generate an interdisciplinary connection and association of all researchers in the field [111]. Mattoo and Teasdale [112] stated that sustainable agriculture systems be likely to meet the common necessities in terms of, productivity efficiency and management by confined appliance of the principles as per the climate, soil and existing markets.

Presently, it is probable the beneficial effect of AMF colonization is not nutritional, through their effect on soil aggregates and activity and on plant defenses. Therefore, research in the coming days must focus on improving AM effects on nutrient acquisition so that productivity is continued at the same time as optimizing the sustainability of production. By recognizing and improving those character linked with AMF accessibility, functionality and climate resilience (e.g. water stress tolerance) in new cultivars, considerable development can be made towards acquiring food supply in coming days in more sustainable agricultural system.

Author details

Soibam Helena Devi[1], Ingudam Bhupenchandra[2]*, Soibam Sinyorita[2], S.K. Chongtham[3] and E. Lamalakshmi Devi[4]

1 Department of Crop Physiology, Assam Agricultural University, Jorhat, India

2 ICAR-KVK Tamenglong, ICAR-RC for NEH Region, Manipur Centre, India

3 Multi Technology Testing Centre and Vocational Training Centre, CAEPHT, CAU, Gangtok, Sikkim, India

4 ICAR-RC for NEH Region, Sikkim Centre, Gangtok, Sikkim, India

*Address all correspondence to: ibhupenj@gmail.com

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