Chapter

Arbuscular Mycorrhizal (AM) Fungi as a Tool for Sustainable Agricultural System

Kavita Chahal, Vaishali Gupta, Naveen Kumar Verma, Anand Chaurasia and Babita Rana

Abstract

A sustainable agriculture is a type of agriculture that focuses on producing long-term crops and livestock without having any adverse effect on the environment. However, agricultural malpractices like excessive use of chemical fertilizers and pesticides, as well as climate change have aggravated the effects of biotic and abiotic stresses on crop productivity. These led to the degradation of ecosystem, leaving bad impacts on the soil qualities and water body environment. As an alternative to the rising agricultural energy, the use of Vesicular– Arbuscular Mycorrhizae (AM) may be a better option. Being natural root symbionts, AM provide essential inorganic nutrients to host plants, thereby improving its growth and yield even under stressed conditions. AM fungi can also potentially strengthen the adaptability of a plant to the changing environment, as a bio-fertilizer. The chapter provides a comprehensive up-to-date knowledge on AM fungi as a tool for sustainable agricultural system. Thus, further research focusing on the AM -mediated promotion of crop quality and productivity is needed.

Keywords: vesicular–arbuscular mycorrhizae, sustainable, symbionts, productivity

1. Introduction

A potential solution to enable agricultural systems to feed a growing population within the changing environmental conditions is a sustainable agriculture, that is based on an understanding of the society's present food and textile needs, as well as on the ecosystem services. A special attention must be needed towards the study of the ability of symbiotic relationship among the actinorhizal plants and microbes, so as to overcome the problems of deforestation and the increasing cost of nitrogenous fertilizers [1].

For increasing the sustainability of agriculture, among various other methods, the better option is the use of natural root symbiont, Arbuscular Mycorrhizae (AM). As compared to conventional agriculture, the soil conditions are likely to be more favorable to AM fungi in a sustainable agriculture [2–4].

The AM fungi have been found to be associated with more than 80% of land plants, liverworts, ferns, gymnosperms, angiosperms and grasses, and are widely distributed in natural and agricultural environments. Hence, for crop and biomass production, these symbiotic associations are very important, and they are receiving considerable attention in forestry and agriculture. Therefore, AM fungi are commonly known as bio-fertilizers. Moreover, these natural root symbionts help their host plants to grow vigorously under stressful conditions like drought, salinity, metals, and extreme temperatures. The mechanism behind is a series of complex communication events between the plant and the fungus that lead to increased photosynthetic rate and increased water uptake [5–7]. The AM fungi also assists in the regulation of metabolic pathways in plants.

2. Sustainable agricultural system and its benefits

The best agricultural system is the one that find a good balance between the need for food production and the preservation of the ecological system within the environment. Also, the agriculture that focuses on producing long-term crops and livestock with minimum adverse effects on the environment is called as sustainable agriculture [8]. Besides the production of food, some of the various objectives of sustainable agriculture include reducing the use of fertilizers and pesticides, promoting biodiversity in crops grown and the ecosystem, and conserving water. It also aimed at maintaining the economic stability of farms and improving farming techniques and quality of a farmer's life [9].

The various benefits of sustainable agriculture can be divided into human health benefits and environmental benefits. Regarding human health, crops grown through sustainable agriculture are better for people. People are not becoming ill by consuming synthetic materials present in chemical pesticides and fertilizers. In addition, these crops are also more nutritious because of their more natural production. Its positive impacts of the environment include use of less percentage of energy per unit of crop yield as compared to industrialized agriculture [10, 11]. This minimizes the release of harmful chemicals and thereby reduces pollution of environment. Other benefits to the environment are maintenance of soil quality, reduction in soil degradation and erosion, and saving water. It also increases biodiversity of the area by providing a variety of organisms surrounded with a healthy and natural environment (**Figure 1**) [12–14].

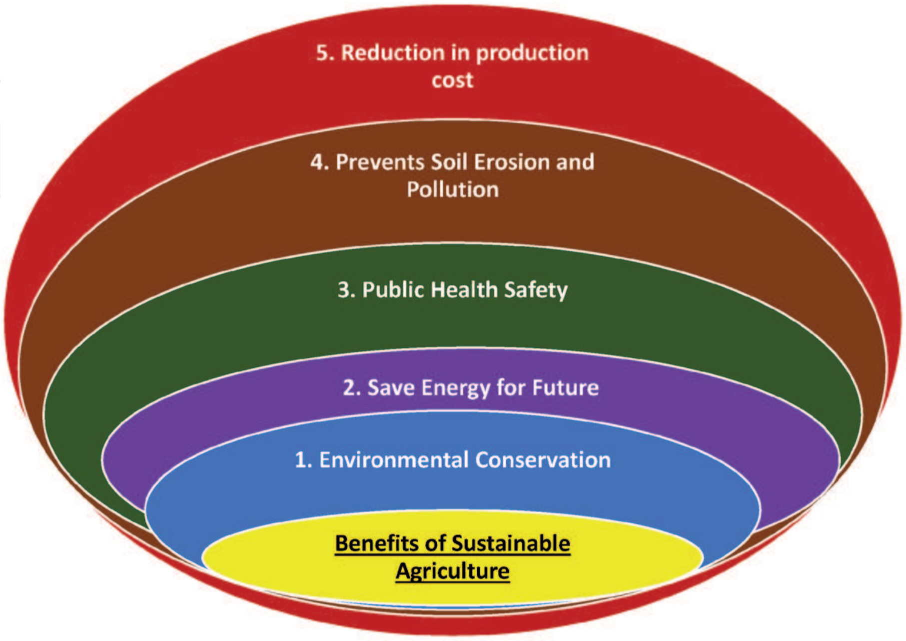

Figure 1.
Benefits of sustainable agriculture

3. Mycorrhizal association

The symbiotic association between a fungus and a root of higher plant is called as Mycorrhiza [15]. From this association, both of the partners, the host plant and the fungal member are benefited potentially [16]. There are several benefits provided by the Mycorrhizal fungi to the host plant species. Some of them are increased nutrient uptake, production of growth promoting substances, tolerance to drought, salinity and synergistic interactions with other beneficial microorganisms [17, 18].

4. Arbuscular mycorrhizae

Endomycorrhiza i.e. Arbuscular Mycorrhizal (AM) symbiosis is formed by approximately 80% of all terrestrial plant species. Even the roots of some aquatic plants are colonized by AM fungi [19, 20]. AM fungi belong to the class Zygomycetes, order Endogonales, family Endogonaceae, and phylum Glomeromycota. The mycorrhizal associations are formed by the six genera of fungi belonging to Endogonaceae. These are Glomus, Gigaspora, Acaulospora, Entrophospora Sclerocystis and Scutellospora. Their common characteristic are spores and sporocarps which are formed mostly in the soil surrounding the roots and rarely inside the roots [21].

The most visible AM structure is the hyphal network. Hyphae are thin from 2 μm in diameter to >20 μm, hollow tubes of fungi having only few cross walls and distinct angular projections [22]. In search of the roots of host plants, these tubes originally grow from fungal spores, extending short distances into the soil.

Hyphae that penetrates a host root form a structure called an appressorium. It penetrates the cell wall of the root by mechanical pressure or through the enzymes that degrade the cell wall. Hyphae that enter host roots through these infection points can form networks both inside the root and throughout the soil surrounding the root. As the name suggests, the AM fungus colonizes the root cortex forming a mycelial network and characteristic bladder-like structures called as vesicles and branched finger-like hyphae called as arbuscules. Arbuscules are short-lived structures meant for nutrient transfer and absorptive function. The hyphal branch that penetrates the plant cell wall forms the arbuscules trunk. This arbuscule trunk branches repeatedly and is surrounded by the plasma membrane. The terminal swellings of the hyphae forms vesicles on both intercellular and intracellular surfaces, and have storage as function [23, 24].

4.1 As a tool for sustainable agriculture

4.1.1 Benefits from tripartite relationship

In the mutualistic association, the plant provides the fungus with photosynthetically derived carbohydrate, while the fungus supplies the plant roots with nutrients. Also, in this symbiotic association, there is a third component i.e., a bacterium that seems to be having a loose or tight association with the plants and the mycorrhizal fungi and play an important role in mycorrhizal function. So, there is a tripartite relationship among host plant, AM fungi and bacteria. This bacterium has been termed as ‘helper bacteria’ because it supports mycorrhizal establishment [25].

For the establishment of a symbiotic relationship with the nitrogen fixing rhizobium bacteria, the AM fungi releases a 'myc factor' which is a diffusional factor responsible for activating the nodulation factor's inducible gene MtEnod11. This gene is involved in establishing symbiotic relationship with the nitrogen fixing rhizobial bacteria [26–28]. Under natural conditions, this bacterium live in the cytoplasm as endobacteria or colonize the surface of extraradical hyphae [29].

4.1.2 Natural growth regulators

AM fungi are used as bio-inoculants, and as prominent natural growth regulators in sustainable crop productivity. Also, the stomatal conductance, leaf water potential, relative water content, photosystem II efficiency, and carbon dioxide assimilation are improved by AM inoculation that contribute greatly to organic culturing for growth promotion and yield maximization [30–32].

4.1.3 Bio-fertilizer

For fulfilling the fertilizer requirements of plants in areas of marginal fertility and to reduce the harmful effects of chemical fertilizer, AM have a potential use as a biofertilizer. Bio- fertilizers are a mixture of naturally occurring substances for improving soil fertility [33]. Various problems and damaging impact on the quality of food products, soil health, and air and water systems are associated with the continuous use of inorganic fertilizers, herbicides, and fungicides. Reports showed the AM can possibly lower down the use of chemical fertilizers up to 50% for best agricultural production [34].

4.1.4 Plant yield

AM Fungi can also have potential to enhance the dietary quality of crops and to increase the levels of secondary metabolites and production of carotenoids and certain volatile compounds. There are reports that showed beneficial effects of AM fungi *Glomus versiforme* on the increased contents of sugars, organic acids, vitamin C, flavonoids, and minerals resulting in enhanced citrus fruit quality. It enhances plant yield for a healthy food production chain by increasing the accumulation of anthocyanins, chlorophyll, carotenoids, total soluble phenolics, tocopherols, and various mineral nutrients. The field production of maize, yam, and potato, has been significantly increased using AM fungi [34–36].

4.1.5 Mineral nutrition cycle

The performance of most agricultural crops becomes better and is more productive in the presence of AM fungi. Mycorrhiza develops symbiosis with roots to obtain essential nutrients from the host plant and consequently provide mineral nutrients in return, for example, N, P, K, Ca, Zn, and S. This symbiosis increases the micronutrient uptake and growth of their plant host [37]. It has an important function in promoting the mineral cycling by maintaining an efficient and closed nutrient cycle of natural ecosystems, thereby changing the ecology of surrounding environment. An increase in the accumulation of biomass is also observed by the inoculation of AM fungi. This is because AM fungi increases the concentration of various macro-nutrients significantly, leading to increased photosynthate production [38, 39]. Thus, even under inappropriate conditions it provides nutritional support to the plants.

4.1.6 Transport of phosphorus and nitrogen to plants

The AM fungi are important to their hosts as they enhance the ability of plants to absorb phosphorus from soil, which is relatively inaccessible to the plants. The arbuscules of the fungi assist in exchange of inorganic minerals and the compounds of carbon and phosphorus imparting a considerable strength to host plants. Therefore, it significantly boosts the phosphorus concentration in both root and shoot systems. Also, under phosphorus-limited conditions, the association improves phosphorus supply to the infected roots of host plants. For phosphorus uptake, the crops that are poor at seeking out nutrients in the soil are dependent on AM fungi. It has significant effects on different plant communities, particularly on invasive plants and the fungal-mediated transport of phosphorus and nitrogen to plants [40–42].

4.1.7 Phyto-availability of micronutrients

A part from the macronutrients, AM fungi association has been reported to increase the phyto-availability of micronutrients like zinc and copper. Also, it helps the plants to take up nutrients from the nutrient-deficient soils. It is also responsible for the uptake of almost all essential nutrients, specifically phosphate, in plants. It was also reported to increase the absorption of trace elements, such as boron and molybdenum [43–45].

On the other hand, it also decreases the uptake of sodium and chlorine thereby stimulating the plant growth. Increased nitrogen content in plants evidently results in higher chlorophyll contents that can effectively trap nitrogen. Maintenance of calcium ion and sodium ion ratio helps improve the overall plant performance. It also improves the surface absorbing capability of host roots [46–48].

Some examples of enhancement of mineral nutrition:

- In mycorrhizal chickpea, improved growth and levels of protein, iron, and zinc were found [49].

- In the mycorrhizal roots of *Lotus japonicus*, an enhanced activity of a potassium transporter was reported [50].

- AM fungi when inoculated in tomato plants have shown increased leaf area, and nitrogen, potassium, calcium, and phosphorus contents, showing an increased plant growth [51, 52].

- In *Pelargonium graveolens* L., mycorrhizal symbiosis increased the concentrations of Nitrogen, Phosphorus, and Iron under drought stress [53].

- In *Euonymus japonica,* improved levels of P, Ca, and K under salinity stress due to instant fungus attachment were reported. In another study, AMF-inoculated Pistachio plants exhibited high levels of P, K, Zn, and Mn under drought stress [54].

- In *Chrysanthemum morifolium* plant tissues, improvement in P and N contents were reported [55].

- In *Leymus chinensis*, an increased seedling weight by improving water content and intercellular CO2, P, and N contents was reported [56].

- *Glomus mosseae* and *Rhizophagus irregularis* showed improved heavy metal translocation in the shoot [57, 58].

4.1.8 Quality of soil

Mycorrhizal symbiosis can be further increased by agricultural practices like reduced tillage, low phosphorus fertilizer usage, and perennialized cropping systems [59, 60]. In the agroecosystems the quality of the soil and the productivity of the land can be enhanced by colonization of AM fungi. It enhances the constant masses, soil aggregate stability, rapidity of soil recovery, and significantly increases extra-radical hyphal mycelium in the soil. This is due to a soil protein known as glomalin, that is thought to be of AM fungal origin. Glomalin is responsible for improving soil aggregate water stability and for decreasing soil erosion [61].

4.1.9 Water stress tolerance

By physiological alteration of the above-ground organs and tissues, it enhances water stress tolerance, accumulation of dry matter and water moisture uptake, thereby improving plant tolerance against stresses like salinity and drought. Glomalin-related soil protein (GRSP) is maintain water content in soils exposed to different abiotic stresses and enhances the soil water holding capacity, which later on regulates water frequencies between soil and plants, thereby enhancing plant development [62–64].

4.1.10 Plant tolerance to stressful circumstances

Plant tolerance against various biotic and abiotic stressful circumstances like alkalinity and toxicity resulting from mining operations, heavy metals and mineral imbalance are reported to be increased by AM symbiosis. This is because of the communal nutrients' relocation from fungi to the plant, along with other related effects such as changes in their morpho-physiological traits [65–72].

4.1.11 Disease control

Apart from increasing the availability of macro and micronutrients, AM provides the plant with necessary strength to resist disease germs and unfavorable conditions. They also increase host tolerance to pathogen attack and compensate for the loss of root biomass or function caused by pathogens including Root-knot nematodes and fungi [73, 74]. The presence of AM fungi showed consistent reduction of disease symptoms for fungal pathogens such as *Phytophthora, Fusarium, Chalara, Pythium, Rhizoctonia, Sclerotium, Verticillium, Aphanomyces.* Several hypotheses have been put forwarded to explain the mechanisms of plant disease control by mycorrhizal fungi [75–77].

Some of them include creating a mechanical barrier for the pathogen penetration, thickening of cell wall through lignification and polysaccharide production that stops the entry of root pathogen, stimulation of the host roots to produce and accumulate sufficient concentration of metabolites like terpenes and phenols, imparting resistance to the host tissue against pathogen invasion, stimulating flavonolic wall infusions to prevent lesion formation by the pathogen, producing antifungal and antibacterial antibiotics, competing with the pathogens for the uptake of essential nutrients in the rhizosphere and at the roots surface, competitions in the roots and thus preventing the pathogen to get access to the roots. Harboring more actinomycetes antagonistic to root pathogen [78–81].

5. Conclusion and future prospect

Modern sustainable agriculture demands for a low-input and more nature-based system having role of soil loving microorganisms that are able to accelerate plant nutrition, health and soil, quality, also under stressful environments. All of these demands are being fulfilled by AM fungi. Its use in increasing food production is far and wide; therefore, is a better tool for modern sustainable agriculture particularly as biocontrol agent. Encouragement of AM as a tool for sustainable agriculture usage is of immense importance. Exploitation of AM for promoting a bio-healthy agriculture can significantly reduce the use of synthetic fertilizers and other chemicals resulting in agricultural improvement. Hence, using AM fungi as a biocontrol agent in modern sustainable agriculture, in terms of various parameters like reduction of damage caused by various pathogens, cost effectiveness, energy saving and also as an environment friendly, is a promising perspective for a sustainable agricultural system. The primary focus of future research should be on the identification of genes and gene products controlling the AMF mediated growth and development regulation under stressful cues. Identification of both host as well as AMF specific protein factors regulating symbiotic association and the major cellular and metabolic pathways under different environmental stresses can be hot areas for future research in this field.

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