Guest Article

Arbuscular Mycorrhizal Fungi – Down To Earth Friends of Plants

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Summary

At present, agriculture is challenged with meeting the global food demands for the growing population, while maintaining environmental quality and reducing the input of chemical fertilizers and pesticides. In this context, the article gives insights on the beneficial soil microorganisms "arbuscular mycorrhizal fungi" that play key roles in sustainable agriculture and promote plant nutrition and produce safe and high-quality food.

Introduction

Microbes are ubiquitous tiny organisms that are too small to be seen with the unaided eye. Both plants and animals are closely linked with microbes that make nutrients more available, provide protection from diseases, and contribute to development of immune/defense system. Furthermore, microbes are indispensable for making various foods that people enjoy such as cheese, bread, and wine. It is also worth mentioning that without the microbial decomposers, life on earth would have been smothered by dead organisms. Unfortunately, microorganisms are often brought into limelight in negative terms. The recent COVID pandemic has woken awareness to microbes in people from all walks of life, and are considered synonym to organisms that cause diseases. Although reduction of disease transmission is important for maintaining individual as well as community health, it is equally imperative for people to understand the constructive contributions provided by microbes. They are much more than their repute as causal agents of diseases.

Microbes display an enormous amount of diversity and complexity too. They are largely of five types namely; bacteria, virus, algae, fungi, and protozoa. They are present almost everywhere, from oceans on coral reefs to permafrost at high altitudes. Of all the living organisms that exist in soil, microorganisms are the most abundant and are essential for life on earth. They are responsible for driving organic matter and nutrient cycling and bring about soil fertility and restoration, maintaining plants' health, and modulating primary productivity of the ecosystem. Although a lot of these organisms are present naturally in the soil, in some conditions it is favorable to surge their populations either through direct introduction of the microbes or by adopting agricultural management techniques that enrich their abundance as well as their activities, to harness more benefits. Such beneficial microorganisms encompass those that build mutually beneficial associations (called symbiosis) with plant roots, such as mycorrhizal fungi that essentially aid in acquisition of mineral nutrients from soil andbacteria

that convert atmospheric free nitrogen gas into ammonia; a biological functional form.

Mycorrhizal Fungi - What they are and why they're important

The word 'Mycorrhiza' means fungus-root in the Greek language and is characterized as the nutrient transferring association that exists between plant roots and a group of soil fungi. There are several forms of mycorrhizal interactions; among them, the most recognized and conceivably the most common mycorrhizal symbioses include arbuscular mycorrhiza (association with vast majority of agricultural and horticultural crops) and ectomycorrhizae (association with only woody species; mostly shrub and tree species). These are the two economically and ecologically significant ones. The fungi make essential mineral nutrients and water from the soil available to the host plant, in-return of sugar that plant synthesizes as a result of photosynthesis.

Arbuscular mycorrhiza (AM) is the most widespread and successful symbiotic association of terrestrial plants with fungi displaying fascinating relationships with approximately 80% of terrestrial plants. Interestingly, they have been existing together with plants for more than 500 millions of years (much before Dinosaurs!!). A group of fungi belonging to Glomeromycotina only, take part in this association. It is known that plants first originated in water and this symbiotic association helped plants to successfully establish in land, and since then has been serving their host plants with various benefits.

In arbuscular mycorrhiza, the thin tubular hyphae of fungi enter the root cells and form highly branched tree-like structures called as arbuscules in root cells

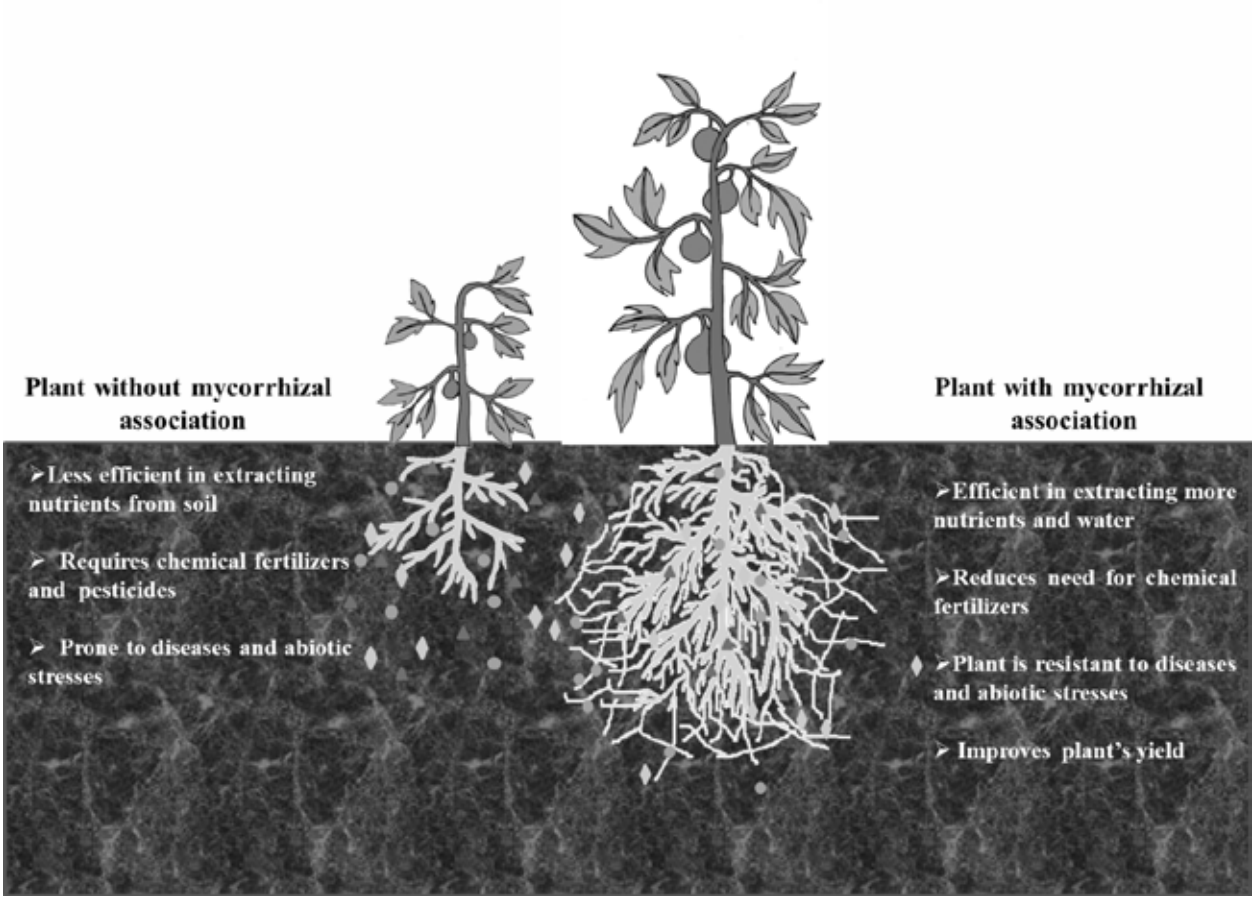

Figure 1: Comparative illustration of non-mycorrhizal and mycorrhizal plant

(cortex). The tubular external hyphae of AM fungi facilitates uptake of mineral nutrients that is present in soil in unavailable form or physically inaccessible to plant roots. Arbuscules are essentially the sites where the give-and-take of nutrients takes place and the repeated branching in arbuscules facilitate larger surface area for exchange between the roots and fungi. In later stage of life, they produce other membrane-bound sac-like structures called vesicles that have different color, shape, and diameter exterior to or within the root cells. The main function of vesicles is to provide facility for material storage and they can act as multiplication organ when fully developed. These vesicles develop thick walls and are released in to the soil with decay of the roots, and are then called as spores. Vesicles, arbuscules, and spores are the characteristic features of arbuscular mycorrhiza.

The world is on the edge of a new agriculture that requires the amalgamation of agroecology with plant biology under the umbrella of biotechnology and improvement of propagating agent (genetic resources such as seeds or other tissues). Developing countries such as India face tremendous problems with respect to food shortage. Hence, food security becomes a basic issue in the developing countries, at local, regional, and global levels. As a result, the urgency is to counter balance the problems linked with food inadequacy, for which maintaining or increasing productivity of agriculture and soil resources management is required. Agro-ecosystems should practice sustainable agriculture, both from environmental and economic view point. Hence, better awareness of the system and factors governing soil nutrients bioavailability to plants, that include root-soil interactions and understanding of microorganisms in their soil habitat is a requisite.

Arbuscular Mycorrhiza and Sustainable Agriculture

From the biological view point, AM fungi shape sustainable agriculture in two ways; soil quality and plant productivity. Their beneficial effects on soil physical conditions and plants performances are vital for sustainably managing agricultural ecosystems. AM fungi are considered natural bio-fertilizers as they provide host plants with nutrients, water, and pathogen protection. They represent a key link between plants and soil mineral nutrients by allowing effective utilization of mineral elements such as phosphorus and nitrogen by plants. Plants require phosphorus in significant amount and its deficiency leads to reduced plant development. This symbiotic relation is primarily important for plants that grow in phosphorus deficit environments as it increases plant growth and phosphorus level in plants.

Stresses (both biotic and abiotic) have negative impact on plant productivity. Abiotic stresses such as drought, salinity, and pollutants (for instance heavy metal, trace elements, petroleum, and crude oil) have pernicious effects on plant growth and productivity at a time when there is a constant increase in food needs globally. Mycorrhizal plants (that have AMF in their roots) abate abiotic stresses through mechanisms such as improved plant nutrition, tolerance to induced oxidative stress, modification in plant physiology, and entrapment of pollutants in roots and fungal cells and inactivation of pollutants/contaminants. In addition, AMF exert control against biotic stresses (pests and pathogens) directly by competing with the pests/pathogens for nutrients and space. Indirectly, they bring about boosted tolerance by enhancing production of antimicrobial compounds and chemicals that contribute to plant immunity. The competition for nutrients and space suggests that higher colonization of the root by AMF results in higher level of bio-control.

Besides their role in improving plant productivity, their role in improving soil quality is also well recognized. They improve soil structure and aggregation and thereby drive plant communities and regulate their productivity. For years humans have tilted the soil so much that it is actually drained off of everything that is required to make it the perfect womb to nurture a young seed that germinates. A germinating seed fights the odds in the soil, and emerges as a seedling. The fibrous roots of plants and the mycorrhizae appear to be like a “sticky-string bag” that holds the soil particles together and builds macroaggregates that form the basis of soil structure. Glomalin, a compound produced by AMF, also acts as glue and binds soil particles together to form aggregates. Later, these soil aggregates facilitate diffusion of water and

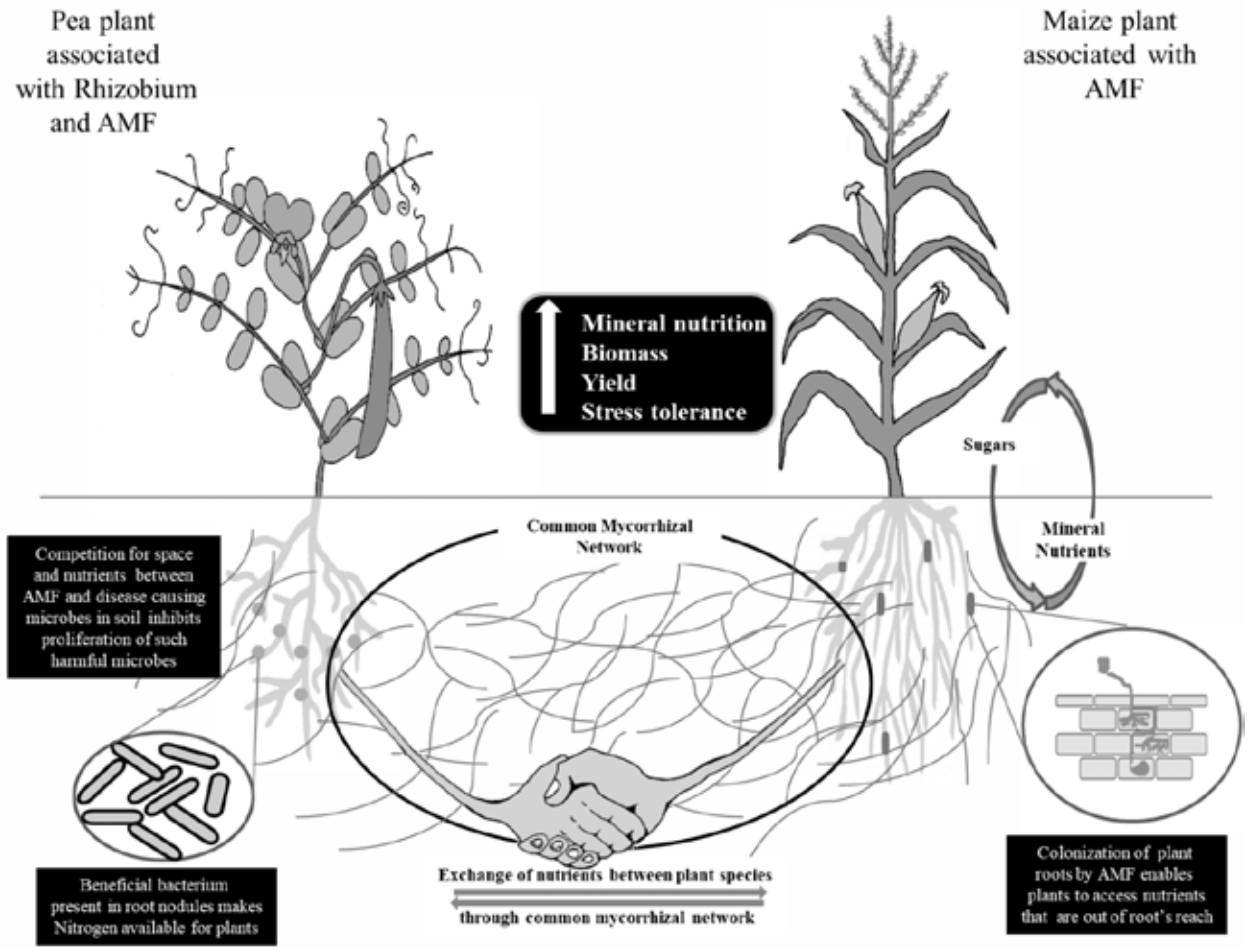

Figure 2: Common mycorrhizal network: a means of social networking of plants at belowground level

air that provide conducive environment for the plant roots to breathe.

Arbuscular mycorrhizal fungi mediated social-networking underneath the soil

Extent of fungal hyphae in soil is enormous and the mutualism between host plants and fungal species usually disperse, thereby resulting in the establishment of mycorrhizal networks. These networks comprise of extended fungal hyphae connecting two or more plants belonging to same or different species. Thus, the network integrates numerous plant species with various fungal species and promotes their interaction and provides feedbacks to one another, thereby forming a complex adaptive social network. Different plant species benefit differently from this network, depending on the AMF species involved, and these differences affect plant co-existence significantly. The network is regarded as evolutionarily and ecologically significant because due to its constructive effects on the fitness of the member fungi and plants. Communication among the members of these networks takes place through biochemical signaling (release of compounds) and resource transfers. For instance, interconnecting legumes with cereal crops through the network in mixed cropping benefits the cereals with nitrogen supply from legumes (capable of fixing atmospheric nitrogen). Nitrogen translocation mediated by the fungal network from legumes to cereals prevents the loss of nitrogen, for which nitrogen is generally applied to a field before cultivation of cereal crops. It is worth mentioning that this network renders the same nitrogen benefit from less legume plants in comparison with rotating cereals like corn

and legume crops in field, thus providing maximum benefits in less time and space. Also, less utilization of nitrogen fertilizers impact groundwater quality and soil health as well, thereby rendering the farmers an economic benefit that is ecologically sound too.

Future Prospects and Challenges of AMF

At present, it is anticipated that by 2050 world's population will exceed nine billion. As a result, global agriculture will take charge of nearly doubling food production and also face the task of reducing the dependence on agrochemicals by the producers, so as to safeguard human as well as environmental health. Thus, now more than ever, there is need to execute or invigorate eco-friendly practices, such as use of mycorrhizae based biofertilization. Regardless of its colossal potential, farmers have not flatteringly embraced AMF application so far, owing to challenges that come together with AMF usage.

The extensive exploitation of mycorrhizal inoculants in agro-ecosystems has been held back, however, by the complexity in propagation of arbuscular mycorrhiza and producing adequate and efficient inocula at affordable prices. Nevertheless, enrichment of naturally-occurring mycorrhizal population in agricultural fields is likely and beneficial effects can arise via the implementation of several management practices that enhance mycorrhizal populations and activity such as reduced tillage, crop rotations and lower nitrogen and phosphorus applications.

Arbuscular mycorrhiza promotes many aspects of plants' life; particularly by improving nutrition, promote growth, and mediates stress tolerance, and disease resistance. Furthermore, their hyphal networks improve characteristics of soil, such as soil aggregation, thereby improving soil resistance towards erosion by water and wind. In addition, AMF reduce leaching of nutrients from the soil, thereby contributing to nutrient retention in the soil, and subside the risks of groundwater contamination. Thus, the multiple benefits AMF render translate into significant ecological services.

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