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Fungi Boost Up Plant Growth by Improving Nutrient Uptake: A Review

Rajendra Kumar, R. K. Meena, Yamini Tak, Praveen Kumar Chachaiya

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ABSTRACT

Microbial populations play a very important role to optimize the turnover and recycling of nutrients. Mutualistic symbionts like arbusular mycorrhizal fungi living at the root-soil interfaces, rhizosphere, or may be in the plant-associated soil, are acknowledged as crucial drivers of nutrient cycling. Arbuscular mycorrhizal fungi (AMF), as natural root symbionts, supply essential plant inorganic nutrients to host plants, enhancing plant growth and yield under both normal and stressed conditions. AMF colonize the roots of agricultural crops and act as 'biofertilizers and bioprotectors' in environmentally friendly farming. Ectomycorrhizal fungi colonize a smaller number of plant species but play an important role in forest ecosystems as symbiotic partners of tree and shrub species.

Keywords Mycorrhizal fungi, Nutrient, Plant, Uptake, Soil.

INTRODUCTION

Trend to rise in population needs to rise in crop production and productivity, so application of pesticides is enhances in farmers field without concerns about the accessibility and environmental impact of fertilizer and the potential harmful impacts on climate change. Farmer and scientist are arduous to increase agricultural production by keeping the concept of environment protection and sustainable agriculture in their mind. Integrated plant nutrition management is a most effective technique for sustainable agriculture, because it is more relevant, cost-effective and environmentally friendly to control plant disease. By using of beneficial microbial symbionts can improve agricultural productivity and can limit the hazardous effect to the environment. Plant-microbe symbiosis improves not only plant growth and health, but also agricultural traits such as soil quality and nutrient cycling (Vishwakarma *et al.* 2020). Different ecofriendly microbes including fungi such as endophytic, ectomycorrhizal, arbuscular, gives strength to plant by increasing the mineral uptake and mobilization. Plants have symbiotic relationship with endophytic

Rajendra Kumar[1], R. K. Meena[2], Yamini Tak[3]*, Praveen Kumar Chachaiya[4]

[1]Assistant Professor
College of Agriculture, Hindoli, Bundi, Rajasthan 323023, India
[2]Assistant Professor, [4]Lab Assistant

[2,4] College of Agriculture, Ummedganj, Kota, Rajasthan 324001, India

[3]Assistant Professor
Agricultural Research Station, Ummedganj, Agriculture University, Kota, Rajasthan 324001, India

Email: yaminitak1992@gmail.com
*Corresponding author

and mycorrhizal fungi from 400 million years ago. This is thunderbolt, as mycorrhizal fungi are associated with more than 90% of terrestrial plant species (Lanfranco *et al.* 2016). This symbiotic association helps to plant for better survival in soil ecosystem from benefited them by various aspects. Fungi are also known as 'naturopathy for plants' because they maintain ecological distractions, helps to balance C:N ratio, decreasing minimizing ecological disturbances, lowering dependency on fertilizers results increasing crop production and productivity (Begum *et al.* 2019). By the interactions with other positive environmental factors fungi play crucial role for better survival of plant. Here we discuss the important roles of fungi in plant growth and development by assisting them in various ways like mineral uptake and mobilization, enhancement of nitrogen fixation, solubalization of phosphorus, increasing the systemic resistance and biosynthesis of plant growth promoting hormones. Role and proper mechanism of micorrhizae in cropping system need to be studied so it will be useful to improve the plant growth and development.

Arbuscular mycorrhizal fungi and nutrient uptake

In this whole earth ecosystem association of arbuscular mycorrhizal (AM) fungi mainly members of *Glomeromycota* with angiosperms, bryophytes, pteridophytes and gymnosperms is one of the acient and well liked type of terrestrial symbiotic association (Strullu-Derrien *et al.* 2018). AM fungus is obligate biotrophs and to complete their life cycle and to produce the next generation of spores depends on their autotrophic host. These spores can germinate without host, but these spores react with an increase in hyphal branching and metabolic activity to root exudates. Strigolactones are steroidal hormone which is secreted from plant roots and able to induce pre-symbiotic growth of AM fungal spore (Besserer *et al.* 2006). Agricultural crop related to family *Gramineae, Palmae, Leguminosae* and *Rosaceae* are habituate to associate with AM fungi. Due to extensive occurrence of AM symbiotic relationship with crop plants, they ease nutrient such as C, P, N, exchange and movement, plays a critical role in soil biogeochemical recycling of inorganic and organic matter (Berruti *et al.* 2016). Due to laborious multiplication and maintenance of AM fungi, during initial stage scientists were not so much interested but in the last decade, some novel techniques have come in light to maintain AM fungi in pot culture. AM fungi are beneficial for soil habitat because they sequester the bound nutrients from low-nutrient soil and deploy beneficial impact to various agricultural crops such as maize, potato, sunflower, onion, wheat, soybean, Jatropha, AM fungi directly or indirectly provide minerals to the plants; they can facilitate the degradation of organic matter and deliver nutrients to host plants (Jansa *et al.* 2019). Inside the cytoplasm of plant cell perifungal membrane is surrounding the arbuscule. The extra-radical mycelium assembles nutrition from expansive space and provide to the plant cell through cortical cells and perifungal membrane (Bonfante and Genre 2010).

Minerals which have less solubility and low mobility are up taken easily by help of the AM fungi. In this symbiotic relationship AM fungi supply adequate amount of P by transporters to host plants and clutch C in the form of sugar such hexoses or glucoses from plant. Pi intake by AM fungi occurs distance from the depletion zone which is near to the root and root hairs (Chibucos and Tyler 2009). Perifungal membrane of AM fungi comprises Pi and NH_4+ transporter, helps to uptake Pi from soil easily which boost up plant growth and development. Studies have shown that the AM fungi help plant to absorb Pi and in turn receive C from plant (Wang *et al*. 2017). AM fungi are appraised to be one of the effective soil microbes which absorb P very effectively than an NM plant root. Smith and Read (2008) revealed that in low P soils, AM-infected plant roots absorb and accumulate more P as compared to NM roots of plant. Mycorrhizal association enhanced biomass of roots, root length and boost up uptake up P, Fe, Zn in wheat plants (Ingraffia *et al.* 2019). Mycorrhiza-inducible NO_3^- or NH_4^+ transporters help to uptake of N sources from the mycorrhizal soil habitat. Uptake and mobilization of P and N are mainly depends on colonization in rhizosphere and feedback responses of nutrients. If there is P and N starvation in plant, so it will induces a nutrient stress transcriptome that is chargeable alarm AM colonization (Bücking and Kafle 2015). Under nursery conditions, AM fungi, *Gigaspora decipiens* and *Glomus clarum* inoculated with *M. paniculatus* and *A. saman* seedlings showed that shoot dry weight and shoot N and P concentra-

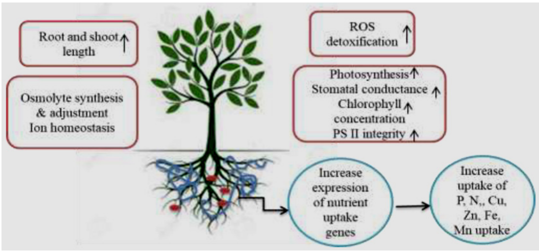

Fig. 1. Fungi enhancing plant growth by increasing nutrient uptake.

tion were increased (Wulandari *et al.* 2014). AMF can have a direct impact on nitrogen recycling by increasing the uptake of both organic and inorganic nitrogen. Glomalin contains 30–40% C and related organic compounds that protect soil from dehydration by enhancing soil water retention capacity. AMF inoculation affects stomatal conductance, leaf water potential, relative water content, photosystem efficiency, and CO_2 assimilation (Xu *et al.* 2016). Inoculation with AMF increases the accumulation of dry matter and the uptake of water moisture, improving plant tolerance to abiotic stresses such as drought and salinity. Under drought stress, mycorrhizal symbiosis increased the uptake of N, P, and Fe in *Pelargonium graveolens* L. Under drought stress, AMF-inoculated Pistachio plants revealed high levels of P, K, Zn, and Mn (Fig. 1) (Bagheri *et al.* 2012).

Ectomycorrhizal fungi and nutrient uptake

An ectomycorrhiza has a mutualistic symbiotic relationship defined by a root-fungus association in which the fungus expands on the root surface and intercellularly penetrates the cortex to build a network within the cell. During association, there are three key features: (1) the formation of a mantle or sheath of fungal hyphae, (2) the expansion of hyphae between root cells to form a Hartig net, and (3) the growth of hyphae into the surrounding soil (Bonfante and Genre 2010). Hartig net is the main interface of nutrient exchange in ECM, and it aids in bidirectional nutrient movement. Toxic metals can be bound to polyphosphates and other vacuolar deposits in the mantle, inhibiting their uptake into roots, while lipids, protein, and/or phenolics and polyphosphates compounds can accumulate in the mantle hyphae. Mantle interacts with the soil and may control the transport of water and nutrient ions into the root. The Hartig net facilitates nutrient exchange, and fungal hyphae absorb the majority of the sugars, minerals, and water. The mobilization, absorption, and translocation of mineral nutrients and water from the soil to plant roots is the most important role of fine hyphae (Liu *et al.* 2020).

Mycorrhizal fungi play a critical role in ecosystem functioning by cycling nutrients, increasing plant diversity, and gaining access to nutrient sources. Mycorrhizal infection improves nutrient uptake by increasing the absorbing surface area, mobilizing available nutrient sources, or excreting chelating compounds or ectoenzymes, which in turn improves plant growth (Bowles *et al.* 2018). ECM fungi secrete extracellular enzymes capable of acquiring P in organic form, allowing the host plant access to organic P. ECM fungi can use organic N sources by producing extracellular acid proteinases (Pritsch and Garbaye 2011). Mycorrhizal fungi provide host plants with N sources that would otherwise be unavailable to non-mycorrhizal roots. Because fungi can assimilate ammonia via the glutamate dehydrogenase and glutamine synthetase enzymatic reactions, proteolytic capacity varies among all fungal isolates. However, a smaller number of species can effectively reduce nitrate. Ammonia and nitrate are frequently assimilated by extraradical hyphae and transferred to the host in the form of glutamine N. The analysis of ECM genomes revealed that free-living mycelium has the ability to import organic and inorganic N sources from the soil, such as nitrate, ammonium, and peptides. There is little known about the role of mycorrhiza in the uptake of K, Ca, Mg, and S. Maximum studies on ECM and micronutrient uptake shed light on the protection from excessive Cu and Zn uptake on heavy metal-rich soils. Many ECM fungi mobilize and use amino acids and amides such as glutamine, glutamate, and alanine, which can represent a significant N pool, especially in acid-organic soils. Some amino acids can be taken up intact and directly incorporated into assimilation pathways, forming a significant carbon pool for ECM fungi (Bücking and Kafle 2015). Fungi and their positive effects on growth of plants reported by various researchers is depicted in Table 1.

Table 1. Fungi, nutrient uptake and their effect on growth of plants.

Fungi	Nutrient uptake	Effect on plant	Reference
Funneliformis mosseae and *Diversispora versiformis*	Increase nitrogen uptake	Increased root length, shoot and root dry weight and root N concentration in the mycorrhizal plants	Wang *et al*. 2018
Rhizophagus irregularis	Increase in nitrogen acquisition	Mycorrhizal fungi and free-living soil microbes on N acquisition from organic matter	Hestrin *et al*. 2019
Rhizophagus irregularis	Carbon and Nitrogen uptake	AM symbiosis enhanced dry weights of leaves, stems and roots.	Zhu *et al*. 2016
Pinus sylvestris L.	Phosphorus uptake	Aluminum reduced P uptake in non-mycorrhizal plants but had no effect on P uptake in mycorrhizal plants.	Ahonen-Jonnarth *et al*. 2003
Pisolithus tinctorius (Pers.) Coker & Couch. and *Descolea antartica* Sing	Nitrogen & Phosphorus uptake	GS/GOGAT, GDH, NR activities are closely interlinked and ensure sustained N and P uptake	Alvarez *et al*. 2009
Glomus mosseae and *Glomus etunicatum*	Phosphorus and zinc	Increased plant growth and yield	Ortas 2010
Rhizophagus irregularis CD1	Phosphorus	Increased photosynthesis, boll number per plant and maturity of the fiber	Gao *et al.* 2020

CONCLUSION

The biological market dynamics drive the C to P exchange mechanism in the AM symbiosis, and both partners reciprocally reward beneficial partners with more resources. AM fungi are carbon-dependent on their host plant, and high mycorrhizal dependency improves carbon allocation to the root system, resulting in more carbon available for the fungus and more P and N transport in the AM symbiosis. AMF-mediated growth and productivity is also beneficial for farmers and also it is ecofriendly approach so it should be widespread use. There is a need for more research into the identification of genes and gene products that control AMF-mediated growth and development regulation. Understanding the AMF-induced changes in tolerance mechanisms and crosstalk can aid in the regulation of plant productivity.

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