Role of Mycorrhizae in Nutrient Acquisition in Relation to NPK Fertilizers: A Review

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Abstract- Although AM is known to increase the uptake of phosphorus in plants, they are also beneficial for other minerals. As a result, it's becoming clearer that they promote the uptake of other nutrients. To increase the nutritional value of the food we consume; some cultures can form an AM symbiont. Whether or not some AM fungal isolates can obtain nutrients from their hosts or which nutrients are affected by AM symbiosis is still unknown. Because they enable plants to grow and develop in harsh mineral environments, AMFs are advantageous to plants. They can also increase the amount of soil nutrients due to the AMF ability that plants can use compared to the roots alone. The effects of AMF are examined in this article on increasing/decreasing the uptake of nitrogen, phosphorus, and potassium in nutrient cycling, mineral acquisition, uptake of nitrogen, and additional phosphorous to improve crop nutrient quality and increase plant nitrogen uptake by soil communities and mycorrhizal fungi. Our studies show that AM fungal identity can be influenced by many nutrients in addition to phosphorus, but the direction and magnitude of this response are the characteristics of the host plant and soil nutrients. The host plant's characteristics and the soil's nutrient status also have an impact. This review is the first ever record that no such work is still available so far on the role of mycorrhizae in nutrient acquisition under the NPK fertilizers.

Index Terms- AM fungi, nutrients acquisition, nitrogen, host plants, microbial activity, and symbiosis

I. Introduction

1.1 Arbuscular mycorrhizal (AM) associations in Nutrients cycling

Numerous interactions involving soil microbial populations have an impact on the transport of macronutrients and micronutrients in ecosystems. The Arbuscular mycorrhizal community (AM) plays a significant role in the distribution of this nutrient by participating in microbial activity and acquiring phytonutrients (1,2). Arbuscular mycorrhizal fungi and many plant roots often form a beneficial symbiosis, allowing them to survive and grow well under severe mineral stress (3,4). A plant's root is connected to the microhabitats around it by radical extra mycelium, increasing the amount of soil used by host plants (5). Plants can survive in areas depleted of water and nutrients. Compared to roots mycorrhizal hyphae carry mineral nutrients across longer ways from exhausted regions. Therefore, roots that colonized AM may have higher uptake of immobile micro and macro nutrition under situations of under nutrition conditions (6). Moreover, the roots of mycorrhiza not only grow in length but also change the structure of the root. However, under nutrient-rich conditions, less mineral accumulation was observed in AM plants (7).

1.2 Mineral acquisition by arbuscular mycorrhizal plants

Arbuscular mycorrhizal fungi (AMF) are beneficial to plants because they enable them to produce and survive in mineral-heavy environments. This is mainly due to AMF ability to increase the amount of soil that makes mineral nutrients available to plants compared to those in contact with the root. The effect of AMF can decrease/ increase the intake of nitrogen (N), phosphorus (P), and potassium (K) in plants. N, Zn, P, and Cu are the most enriched nutrients for host plants growing in many soils (e.g., high and low soil pH) whereas K, Ca, and Mg are enriched when plants grow in acidic soils. Many AMFs also can enhance Al and Mn toxicity in acidic soils grown plants (3). As a result, three species of arbuscular mycorrhizal fungi were studied by Clark and Zeto (3) in acidic and alkaline soil at various concentrations of (N, P, and K). The study revealed that nitrogen and potassium are present in high amounts in *Glomus etunicatum* while phosphorous content is reduced in *G. etunicatum* in acidic soil, followed by *Glomus diaphanum* in which N and K are improved but no effect of P. In *Glomus intraradices* concentration of K is abundant, N concentration was enhanced and no effect of P in acidic soil. Similarly in alkaline soil, it was reported that P concentration was present in high amounts, N and K were enhanced in *G. etunicatum*, and there is no effect of NPK in *Glomus diaphanum* in alkaline soil and *Glomus intraradices* showed a significant result as only N was enhanced, P was present in abundant amount and no effect of K alkaline soil as shown in Table 1.

Table 1. A detailed summary of reduced (-) increased (+), or no effect (0) acquisition of NPK by AM in alkaline and acidic soils (3).

Mineral	Acidic soil			Alkaline soil		
	AM Fungal species			Fungal species		
	Ge	Gd	Gi	Ge	Gd	Gi
N	++	+	++	+	0	+
P	-	0	0	++	0	+++
K	++	+	+++	+	0	0

Keys: Ge-*Glomus etunicatum***, Gd-** Glomus diaphanum**, Gi-** Glomus *intraradices.*

(+)- enhanced

(++)- Present in a high amount

(+++)- Abundant

(-)- reduced

(0)- No effect

As demonstrated in Table 2, Eight AMF isolates are used to cultivate switch grass in a pH 4.0 acidic soil that had shoot mineral concentrations of N, K, and P per colonized root length. N concentrations were highest in *Glomus etunicatum* (4.89 µg m^{-1}) followed by *Glomus diaphanum* (1.70 µg m^{-1}) and *Glomus Intraradices* (1.66 µg m^{-1}) while the lowest amount was found in *Gigaspora rosea* (1.17 µg m^{-1}). The concentration of P is highest in *Glomus etunicatum* (216.3 µg m^{-1}) followed by *Gigaspora albida* (86.6 µg m^{-1}) and *Acaulospora morrowiae* (43.6 µg m^{-1}) and lowest in *Gigaspora rosea* (20.6 µg m^{-1}). The concentration of K was found maximum in *Glomus etunicatum* (3.52 µg m^{-1}), leading to *Gigaspora albida* (1.44 µg m^{-1}) and the lowest concentration was found in *Gigaspora rosea* (0.32 µg m^{-1}).

Table 2. The shoot mineral concentrations of N, K, and P per colonized root length of switchgrass grown with eight AMF isolates in acidic soil (pH 4) were measured 3).

S. No	AMF isolate	N (mg m^{-1})	K (mg m^{-1})	P (µg m^{-1})
1.	*Glomus Intraradices*	1.66	0.41	28.7
2.	*Gigaspora rosea*	1.17	0.32	20.6
3.	*Gigaspora albida*	1.59	1.44	86.6
4.	*Glomus etunicatum*	4.89	3.52	216.3
5.	*Gigaspora margarita*	1.30	0.55	38.5
6.	*Acaulospora morrowiae*	1.50	0.84	43.6
7.	*Glomus diaphanum*	1.70	0.84	40.2
8.	*Glomus darum*	1.56	0.78	39.8

1.2.1 Nitrogen (N)

AM plants frequently report enhanced N acquisitions in addition to their frequently reported enhancements in P acquisition. The increasement of nitrogen in AM plants is explained by the high nitrogen demand due to the increase in P. However, studies show that even when a plant has sufficient phosphorus, AM plants support nitrogen acquisition. The acquisition of ammonium-N by AM plants was more significant. Both forms of nitrogen can be easily acquired and transported in AM due to NH_4-N's lower soil mobility than NO_3-N's (8). The hyphae of arbuscular mycorrhizal fungi can move nitrogen from the soil to the roots. Studies in which compartments were used to separate hyphae from roots provided data on the separation of hyphae from root N acquisition. The mesh screen is placed in the soil so that the hyphae can penetrate the compartment rather than the roots, or a thin screen is placed so that the hyphae cannot penetrate the compartment (9). To study N movement (typically 15N) and accumulation in plant tissues, N sources are typically introduced to hyphal or non-hyphal compartments. Early research with G. mosseae (*Apium graveolens*) celery demonstrated that AM plants were more organic or inorganic from N sources than non-AM plants, even though AM and non-AM plants had the same amounts of P. It was shown that 15 many Ns were obtained. It might be effective. Host plant N demand appears to regulate Soil NH_4 and NO_3-N depletion, and hyphal uptake and translocation of N (10).

1.2.2 Phosphorus (P)

Arbuscular mycorrhizal fungi are particularly beneficial for plants that grow in soils where plant growth is limited by phosphorus. This is mostly because AMF hyphae explore a greater quantity of soil than non-AMF plants' root hair does. Decreased colonization efficiency of AMF roots often occurs with elevated soil-soluble phosphorus levels (11,12). Arbuscular mycorrhizal mycorrhizas usually transport P, which is farther from the roots than non-AM roots. For instance, Glomusmosseae plants had a zone of soil P depletion around their roots that was about 20 mm larger than non-AM white clover (*Trifolium repens*) (3,13,14). The uptake of P into hyphae also depends on the propagation and rate of hyphae (12). For example, after four weeks, the mycelium of *A. Laebis* had spread 81 mm into the soil, whereas the other two fungi (*Glomus sp.*) spread 31 mm (11). The hyphae of *Glomus sp*. Compared to *A. laevis*, the spread was lower. At the route distance (between 0 and 10 mm), it performed more effectively than *A. Laevis*. Additionally, if root utilization is restricted, it was estimated that AMF hyphae could feed 80 percent of P plants at distances of up to 100 mm (3).

1.3.3 Potassium (K)

There was a lot of conflicting information regarding AM plants' acquisition of key nutrient cations, with reports of increased, no effects, and decreased levels. In contrast to non-AM plants, different plants colonized with different AMFs isolated showed improved K acquisition. K acquisition is significantly better in AM maize grown in acidic soils than in alkaline soils when colonized by the same AMF isolate (*G. etunicatum, G. diaphanum*, and *G. intraradices*). These nutrients were also acquired differently by the AMF isolates. It has been demonstrated that plants growing in acidic soils absorb more K when there is volatility in other AMF isolates (15). Studies of AM plants grown in acidic soil or under acidic conditions frequently revealed improvements in the acquisition of K, Ca, and Mg. These cationic bases are usually absent from acid soils, so only plants grown in them can thrive (16). The major active AMF species that are associated with plants and the effectiveness of AMF isolates in acquiring major nutrient cations may also be altered if acidic soils are depleted. Potassium uptake was particularly enhanced in AM grasses with soil changes grown at pH 4 compared to Ca and Mg (15). Significant differences were observed between AMF isolates with K acquisition along colonized roots compared to the relatively small differences in K acquisition along roots (17).

1.3 Arbuscular mycorrhizal fungi and nitrogen uptake

Nitrogen (N) is the most significant major nutrient that has a significant influence on plant yield and growth production. Therefore, you do not need to procure properly to get the best yield. There are various methods of feeding plants, including the use of organic and chemical fertilizers. N is very easy to move because of its chemical composition, especially in humid conditions. Therefore, nitrogen should not be over-fertilized economically and ecologically (18,19). Soil microorganisms like diazotrophs and plant growth-promoting rhizobia (PGPR), including rhizobia, can be used for biological fertilization (18, 19,20). Arbuscular mycorrhizal fungi (AM) can also be used as a source of organic fertilizer source. AM fungi, also known as soil fungi, form a symbiotic relationship with the majority of land plants. In this symbiotic relationship, the fungi exchange carbon for water and nutrients from the host plant. The fungus and the host plant have not been specifically found to be in a symbiotic relationship; however, certain fungal and host plant combinations may be more effective in certain situations (21,22). AM fungi can reduce the effects of various stresses on plant growth and yield production by significantly increasing the host plant's uptake of nutrients like nitrogen and water (22). N uptake by host plants may be affected by the three-way symbiosis between AM fungi, diazotrophic rhizobia, and host plants. In this kind of symbiosis, the host plant microsymbiosis receives N and P. As a result, the effects of the host plant-microsymbiotic interaction and the impact of the micro-symbionts interaction have an impact on each microsymbiont's association (18). The plant's requirement for inorganic nitrogen may influence the AM fungi's rate of nitrogen mineralization. This is because AM hyphae's growth and development in organic patches can be slowed down by high nitrogen levels in the soil. This is due to the uptake of nitrogen (23,24). In the presence of AM, the following factors affect the development of nitrogen mineralization: (1) AM hyphae swelling (2) production of hydrolases like xyloglucanase, cellulose, and pectinase, which may cause organic matter to decompose in the soil and (3) the impact that AM fungi have on the activity of other soil microorganisms. Increased plant growth, induction of plant resistance, changes in root leachate, and consequently signaling pathways can all be mediated by AM pole effects on soil microorganisms. Additionally, AM hyphae provide soil microorganisms with a significant supply of organic C (18,25,26). The N-uptake by AM bacteria is important in the following ways: (1) the influence that AM bacteria have on the process of nitrogen cyclization, (2) whether AM bacteria can slow the rate of NO_3 leachation that, (3) Plant nitrogen sources are limited under limited conditions where AM fungi can be considered, e.g., dry and semi-dry conditions in the care of nutrient absorption by plants, and (4) suitable fertilizers. Use and use of organic fertilizers (24).

1.4 AMF for improvement of the nutrient quality of crops in addition to phosphorus (P)

Although soil microorganisms known as arbuscular mycorrhizal fungi (AM) have long been employed as organic fertilizers, however, their potential to increase the nutritional value of crops has been mostly ignored (27). However, interest in these microbial inoculums may be rekindled in light of recent advertisements for better food quality and agricultural practices (28). Improved phosphorus nutrition is the main advantage AM fungus provides to host plants. On the other hand, there is a growing body of evidence that AM bacteria may be crucial for several of nutrients (29). Differences in AM fungi may also be the cause of fluctuations in plant micronutrients. AM fungi show an increasing degree of functional specialization (30). Additionally, even though a specific taxon cannot be assigned a function, some fungi protect the pathogen from nutrient acquisition. There is evidence that it is more suitable (31).

It has not yet been shown whether the observed differences between AM fungi are consistent with the evidence of AM fungi’s multifunctionality in plant nutrition. In other words, certain fungi constantly improve certain nutrients in all plants (32). However, corn and wheat have higher P, Fe, Mn, and Zn concentrations. Hart and Forsythe, (29) showed that inoculated leeks had more P, Zn, Cu, and N than uninoculated controls. Kim et al. (33) discovered that pepper contained high levels of Ca, Zn, Cu, N, P, K, and Fe (*M. oryzae*) when inoculated with AM and rhizobacteria. Based on what is already known about the uptake of nutrients mediated by AM bacteria in plants, we ask about the number of phytonutrients increased by AM bacteria and whether AM fungus exhibits functional specificities (34). Arbuscular mycorrhizal fungi (AM) are known to increase plants’ phosphorus uptake, but there is increasing evidence that AM is essential for promoting other minerals’ uptake. These fungi may be able to enhance the nutritional value of the foods we eat because the majority of cultures can form AM symbiosis. However, it is currently unknown which additional nutrients are affected by AM symbiosis or whether or not different AM fungal isolates are capable of obtaining the host's nutrients in different ways. This study demonstrates that AM bacteria's identity can affect other nutrients in addition to phosphorus. However, the host plant's characteristics and the state of the affected soil nutrients also influence the magnitude and direction of this response (29). Studied nutrient concentration (nitrogen, phosphorous, and potassium) in shoots of *Allium* and *Plantago* (Table 3-4) inoculated with 5 different arbuscular mycorrhizal fungi (*Etrophospora colombiana*, *Acaulospora lacunosa*, *Scutellospora calosporai Glomus constrictum*, *Glomus intraradices*,) by Hart and Forsythe (29).

1.5 Soil microbial communities and mycorrhizal fungi boost plant nitrogen uptake.

The primary productivity of terrestrial ecosystems is frequently limited by the availability of nitrogen. Arbuscular myrmecophytes are common terrestrial myrmecophytes that have limited access to organic nitrogen but can help plants to absorb more nitrogen. Other bio phases of the soil mineralize organic nitrogen into forms that can be used in biology, but at the same time, they may compete for nitrogen, which may have unanticipated effects on plant nutrition (35). Here, we demonstrate that the model grass *Brachypodium distinctyon* acquires nitrogen in a very non-additive manner due to the synergistic effect microbial community of the soil and the mycorrhizal fungus *Rhizophagus irregulis.* Mycorrhizal plants gain twice as much nitrogen from organic matter and absorb 10 times as much nitrogen as non-mycorrhizal plants grown without soil microbial communities because of the synergistic effect of these multiple components (36). The annual assimilation of nitrogen by plants above 70 Tg may be influenced by this previously unquantified multi-part relationship, which may have a significant impact on the functioning of ecosystems and the global nutrient cycle (37). Here we explain that the multi-division synergistic effect of soil microbial communities and AM fungi significantly enhances the acquisition of plant nitrogen and fungi from organics and the acquisition of microorganisms in plant photosynthesis. Long-term nitrogen enrichment disrupts these synergies and reduces the acquisition of mycorrhizal nitrogen from organic matter. These findings influence models of understanding the ecosystem's response to terrestrial nutrient cycles, agricultural management, and global change (Treseder 2008).

Using soil microbial communities collected from plant mesocosms, AM fungi, stable isotopes, and nitrogen gradient experiments, how multi-component interactions affect plant nitrogen absorption and these relationships are long-term N enrichments. Autoclaved sand and double gravel were used to sow *Brachypodium distachyon* seeds with or without the spores of the AM fungus *Rhizophagus irregulis* (previously Glomus intraradices). The spore-inoculated plant's root system became infested with the fungus a month later. After that, AM and non-AM plants were transplanted into a mesocosm with a patch of organic matter rich in 15N/13C and a gravel mixture that had been twice autoclaved (Figure 1a). Inoculum from fresh pasture soil (annual addition of 0, 28, or 196 kg N ha-1; Kellogg Biological Station Loc Hickory Corners, MI) Organic matter that was exposed to the N concentration gradient and contained the entire soil microbial community was added to a subset of the mesocosms. Six mesocosmic treatments include plants cultivated without the addition of AM fungi or soil inoculum [control], plants cultivated only in microbial communities in unfertilized fields [+ microorganisms (N0)], AM fungi only includes plants cultivated in [+ AM fungi], Plants grown in AM fungal and microbial communities in fields fertilized at 196 kg N ha -1 per year [+ AM fungi + microbial community (N196)], grown in fungal AM and microbial communities in fields fertilized at 28 kg Nha Plants-A plant grown once a year with [+ AM fungi + microbial (N28)] and microbial communities [+ AM fungi + microbial (N0)] from AM fungi and unfertilized fields. Each of these six processes was repeated seven times. Double-autoclaved soil from unfertilized fields was added to AM and non-AM mesocosms that were not microbially inoculated from fresh soil to control the abiotic properties of the soil. A low-N improved Hoagland solution is added weekly, reducing the amount of non-N nutrient competition between plants and microorganisms and providing enough N to keep the plant alive for the same amount of time as the natural growing season. Each mesocosm received a total of 15.75 mg of inorganic nitrogen during the experiment. This experimental design examines plant interactions and the inheritance of environmental nitrogen enrichment in nutrient acquisition strategies as well as the individual contributions of AM fungi and the remaining soil microbial communities to the acquisition of plant nitrogen from organics. As expected, I was able to determine the relationship between plants, AM fungi, and free-living soil microorganisms may be associated with higher nitrogen uptake from organic plant material. Surprisingly, the synergistic effects of these interactions far exceeded the additive effects on plant nitrogen acquisition. Plants grown with soil microorganisms or AM fungi obtain 10-12 times more organic matter than control plants, and plants are grown with soil microbes or AM fungi obtain twice as many Ns. While the plant grows, either soil microorganisms or AM fungi obtain 2 and 3 times more N from organic matter than control plants, respectively. (Fig. 1b). Plant N uptake has increased by 10 to 12 times, which is more than twice the expected increase in nitrogen uptake. It is determined by the amount of nitrogen absorbed by plants grown solely on AM fungi or free-soil microorganisms (Fig. 1c). This synergistic effect on plant N acquisition is a new characteristic of biological plant relationships, highlighting how complex multi-component interactions affect mycorrhizal ecology and nutrient acquisition (37).

Table 3. Mean nutrient concentration in shoots of *Allium* inoculated with different AM fungi

Nutrients	AM Fungal species				
	Al	**Ec**	**Gc**	**Gi**	**Sc**
N	1.35±0.10*	0.78±0.40	0.20±0.09*	0.22±0.09	0.30±0.09*
P	0.20±0.01*	0.23±0.03	0.24±0.01	0.27±0.04	0.21±0.01
K	2.21±0.30	2.5±0.33	2.15±0.19	2.01±0.26	2.12±0.15

Table 4. Mean nutrient concentration in shoots of *Plantago* inoculated with different AM fungi

Nutrients	AM Fungal species				
	Al	**Ec**	**Gc**	**Gi**	**Sc**
N	0.81 ± 0.07	0.84±0.02	1.00±0.18	0.92±0.14	0.88±0.12
P	0.13 ±0.02	0.13±0.02	0.17±0.02	0.16±0.01	0.15±0.04
K	1.58±0.49	1.39±0.46	1.86±0.35	1.33±0.11	1.45±0.12

II. CONCLUSION

Some of the most recent findings regarding how AM fungi influence the process by which the fungi or host plant uptake N were discussed. As a result, the significance of AM fungi's N uptake may be obscured by a few intriguing findings. The effect of AM fungi on the dynamics of nitrogen in plant and soil N uptake may have an impact on plant growth, and N cycling, ecosystem function. To control the abiotic properties of the soil, double-autoclaved soil from unfertilized fields was added to AM and non-AM mesocosms that were not microbially inoculated from fresh soil. This was done to control plant N uptake. This suggests that more research is required into how AM fungi influence the process of N uptake. We analyzed some of the more recent advances about how AM fungi affect the fungus itself or how the host plant absorbs nitrogen. Therefore, some interesting discoveries may indicate the importance of N uptake by AM bacteria. The effects of AM fungi on the dynamics of soil nitrogen and plant nitrogen absorption may have an impact on plant growth, the nitrogen cycle, and ecosystem function. This suggests that further research is needed on the effect of AM bacteria on the nitrogen absorption process.

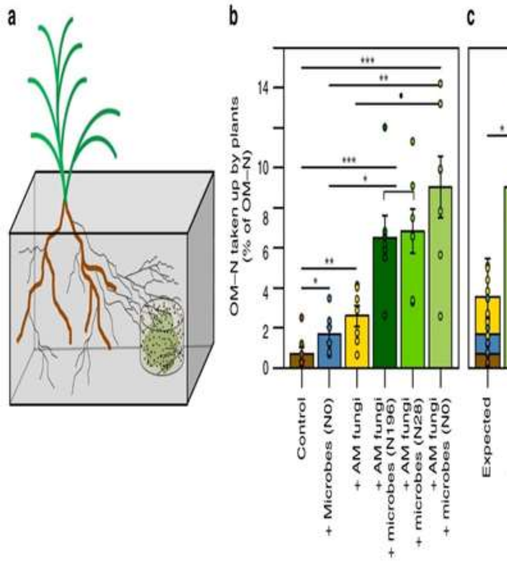

Fig. 1 Plant biomass and N acquisition from organic matter is increased as a result of multipartite synergies between AM fungi and soil microbial communities. a plan for a Mesocosm. b When AM fungi and soil microbial communities were present, plants obtained more nitrogen from organic matter. c Based on the sum of N acquired by control plants and those grown with AM fungi or soil microbes alone, plants grown with AM fungi and soil microbes acquired more N than anticipated.

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