Review on Symbiotic Synergy: Mycorrhizal Diversity and its Role in Sustainable NPK Management in Agroecosystems

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Abstract: **Agroecosystems' long-term production and environmental sustainability depend heavily on managing nitrogen, phosphorus, and potassium. A viable strategy for long-term NPK control is mycorrhizal diversity, which develops symbiotic relationships with plant roots. These fungi decrease reliance on outside inputs like chemical fertilizers, improving nutrient absorption, especially for phosphate and micronutrients. It is possible to maximize nutrient retention and optimize resource use by utilizing the diverse range of access and mobilization capacities exhibited by mycorrhizal fungus species. Crop nutrient availability can be improved and environmental impact can be decreased by fostering mycorrhizal variety in agroecosystems. Increased crop growth and production result from its improvements to soil fertility, structure, and efficiency of nutrient use. Moreover, it helps agroecosystems remain resilient and stable by protecting crops from abiotic stressors like drought and temperature extremes. Incorporating mycorrhizal diversity in sustainable NPK management strategies offers a sustainable and ecologically friendly approach to agroecosystem sustainability and resilience.**

Keywords: **Mycorrhiza, plants, symbiosis, nutrients, soil.**

1. Symbiotic Synergy: An Overview

Symbiotic cooperation known as a mycorrhiza occurs when a fungus and vascular plant roots work together. In this relationship, the fungal species either extracellularly, as in the case of ectomycorrhizal fungi, or intracellularly, as in the case of arbuscular mycorrhizal fungi, colonizes the roots of the host plant. They have a significant role in the chemistry and life of the soil. Arbuscular mycorrhiza is the most common symbiotic relationship between plants and *Glomeromycota* fungi, which inhabit various habitats and invade the roots of majority of the plant species, including angiosperms, gymnosperms, pteridophytes, and bryophytes, thrive in stressful conditions, including grasslands, woods, and agricultural fields(Sadhana, 2014).

Background: A mycorrhiza (from Greek, **mykos: fungus** and **Rhiza: root**) is a particular symbiotic association between a higher plant and a fungus that is located in the plant root apparatus and extends into the rhizosphere and the surrounding soil(Ganugi et al., 2019). Frank termed this interaction "mycorrhiza" in 1885(B. Frank, 1885). An ectomycorrhiza and an endomycorrhiza are two common categories for mycorrhizas. The ectomycorrhizal fungus' hyphae do not enter individual cells within the root, whereas the endomycorrhizal fungus' hyphae do enter cell walls and invade the cell membrane, distinguishing the two types (Harley & Smith, 1983).

Arbuscular Mycorrhizal Fungi (AMF): An endomycorrhizae penetrates the cortical cells of the roots of a vascular plant forming arbuscules, sometimes, globular storage structures called vesicles are encountered. A subphylum of fungi called *Glomeromycotina* forms arbuscular mycorrhizae. As a sister clade to the more well-known and varied dikaryan fungus, this subphylum is part of the phylum *Mucoromycota*, associated with the *Mortierellomycotina* and Mucoromycotina (Spatafora et al., 2016). Symbioses, once known as vesicular arbuscular mycorrhiza (VAM), consist of both vesicles and arbuscules in some connections. While some *Glomeromycota* members do not produce arbuscules, not all associations form vesicles either (Sally E. Smith, n.d., 2008).

Ectomycorrhizal Fungi (EcMF):

Ectomycorrhizas, or EcMs, are symbiotic relationships that occur between the roots of around 10% of plant families. These relationships are primarily woody, including orchids, fungi from the Basidiomycota, Ascomycota, and Zygomycota, as well as birch, dipterocarp, eucalyptus, oak, pine, and rose (Wang & Qiu, 2006) families.

2. Understanding Mycorrhizal Diversity

According to the study, which looks at the coevolution of mycorrhizal fungi and roots, endophytic relationships between early Devonian land plants and vesicular-arbuscular mycorrhizas were comparable. Endophytic hyphae gave rise to balanced interdependent relationships in mycorrhizal associations, while certain plants still display exploitative mycorrhizas. Rhizomes gave rise to roots, which are now used as appropriate environments for mycorrhizal fungi and plants that require water and nutrients through their branches and foliage. Due to selection pressures, roots developed differently; mycorrhizal plants have bigger roots and suberized exodermis(Brundrett, 2002).

3. The Role of Mycorrhizae in Agroecosystem Sustainability:

AM fungi assist plants in the uptake of nutrients, including macro- and micro-nutrients, such as sulphur, phosphorus, and nitrogen from the soil. It is thought that the emergence of an AM symbiosis was essential to the first plant colonization of land and the subsequent evolution of vascular plants (Brundrett, 2002).

Arbuscular mycorrhizal fungi (AMF) are a significant part of terrestrial ecosystems, but their impact at the plant community level has been less studied. Human-induced disturbances and agroecosystem management significantly affect AMF functioning, making ecosystem studies crucial. This paper discusses four interacting routes through which AMF can influence ecosystem processes: indirect pathways through changes in plant and soil microbial community composition, direct pathways via effects on host physiology, resource capture, and mycelium effects, and a case study of carbon cycling. However, the integration of AMF ecology into ecosystem studies is limited due to scale mismatches or ill-adaptation to the "pools and flux" paradigm. The paper concludes with an assessment of available tools for studying mycorrhizae at the ecosystem scale(Rillig, 2004).

Plants and soil mineral nutrients are mostly mediated by soil microorganisms, such as arbuscular mycorrhizal fungi (AMF or AM fungi) (Berruti et al., 2016).

4. Case Studies: Mycorrhizal Impact on Crop Yield and Soil Health:

Gigaspora calospora, a vesicular-arbuscular mycorrhizal fungus, and its impact on NPK Gerdemann and Trappe studied the root colonization, dry biomass, and spore production, shoot mineral content of onions (*Allium cepa* L. cv. *Autumn spice*). All combinations of the presence and absence of N, P, K, and inoculum were examined. Nitrogen fertilization promotes root colonization, whereas potassium fertilization increases spore formation. Phosphorus fertilization slows root colonization and spore generation. Endomycorrhizal plants have more biomass than non-mycorrhizal plants. Yield improvements from P are greater when plants are not treated with extra N. When plants are fertilized with N, P, or K, they absorb more of those nutrients. Tissue and calcium content are impacted by certain interactions involving N, P, and K. For the host plant-VAM fungal system to function as efficiently as possible, the ratio of available nutrients in the soil must be optimal (Furlan V., Cardou M., 1989).

The effectiveness of biofertilizer, soil fertility, and weed control measures on the growth and yield of chickpeas planted late in the growing season was investigated in Varanasi during an empirical field research conducted in 2003–2004. According to the results, the application of VAM caused weed dry matter to accumulate more than other biofertilizer sources. However, maximum seed and straw yields were obtained when Rhizobium and VAM were applied together. This was similar to Rhizobium inoculation but much greater than VAM alone. The recommended NPK dose of 125% produced the maximum yields of chickpea seed and straw, whereas the recommended NPK dose of 75% had the lowest dry weight of weeds. Pendimethalin applied before emergence decreased the weeds' dry weight, increasing seed yields (Kumar R. & Mukiierjee, 2009).

The usefulness of *Glomus moseae* (Arbuscular Mycorrhizal Fungus) cultivation as a "Phosphofert" bio-fertilizer in a mulberry garden was assessed by research. The experiment involved the S1635 mulberry variety and five treatments, including organic and inorganic fertilizers. The results showed that Phosphofert bio-fertilizer reduced the rate of phosphorus chemical fertilizer usage, potentially saving up to 75% in expenditure. The study also highlighted the role of arbuscular mycorrhizal fungi (AMF) in maintaining leaf productivity without compromising quality. The study provided information on the mass culture of AMF for Phosphofert bio-fertilizer preparation and application techniques(Patton et al., 2014).

In grapevine (Vitis vinifera L.) roots, the study investigated the impact of bioproducts on arbuscular mycorrhizal fungi (AMF). Results showed that bioproducts like Ausma, Bioilsa, manure, and BF Ekomix increased mycorrhizal frequency. Mineral fertilization limited AMF colonization, but when combined with bioproducts, it mitigated the negative effect. The study also identified several species of AM fungi. Soil moisture, fertility, pH, and phosphate content also influenced mycorrhizal frequency. The study suggests bioproducts counteract the negative effects of mineral fertilization on AMF colonization, suggesting potential for sustainable wine-growing methods. Further research is needed to explore bioproducts' impact on grapevine microbiome and plant growth and yield(Paszt et al., 2019).

A two-year field experiment examined the effects of biofertilizers, fertility levels, and weed management practices on weed growth and chickpea yield under late-sown conditions. Results showed that vesicular arbuscular mycorrhiza (VAM) led to higher weed dry matter accumulation than other biofertilizers. Combining Rhizobium and VAM resulted in higher seed and straw yields, while applying 75% of the recommended NPK dose resulted in the lowest weed dry weight. The highest chickpea seed and straw yields were achieved with 125% of the recommended NPK dose. Pre-emergence application of pendimethalin and hoeing reduced weed dry weight, resulting in increased seed yield(R. Kumar & Mukiierjee, 2009).

5. Exploring Mycorrhizal Diversity

Arbuscular Mycorrhizal Fungi (AMF)

Arbuscular mycorrhizal fungi (AMF) are found in diverse environments and form symbiotic relationships with plants. They provide about 20% of photosynthate to host plants in exchange for inorganic minerals and environmental protection. AMF plays a crucial role in phosphorous absorption, nitrogen circulation, tolerance to heavy metals, and enhancing protection against nematodes and root diseases in the rhizosphere. Rhizospheres with AMF have dense hyphal networks that act as extended roots, occupying significant biomass. Despite their low host specificity, AMF species diversity is low, but molecular evidence suggests greater diversity in ecosystems than previously expected. Differences in functionality between AM fungal isolates can complement species diversity, potentially changing functional units interacting with plants. This suggests the need for a novel ecological concept of AMF as not just decomposers but also producers or assistant producers of plants, enhancing productivity and fitness in ecosystems(Lee et al., 2013).

AM inoculants have context-dependent effects on plant development that can differ depending on soil fertility and plant cultivar. For five months, the grapevines (*Vitis vinifera* L.) were housed in pots within a greenhouse. Cultivars differed in their responsiveness to treatments in terms of growth. Vine 'Merlot' responded more strongly than 'Chardonnay' to the mycorrhizal inoculant product, particularly in cases where no P fertilizer was applied. For "Merlot," the co-amendment of AM fungus and P fertilizer increased root biomass, but had no impact on "Chardonnay." There was no difference in tissue P between 'Chardonnay' and 'Merlot' vines cultivated with the AM fungal inoculant product and uninoculated vines. Evidence of grapevine cultivar-specific reactions to an AM fungal inoculant product in a greenhouse is provided by this study, which may be helpful when planning nursery management strategies for incorporating biological amendments into grapevine production (Cifizzari et al., 2023).

6. Identifying drawbacks and environmental implications

According to the study, nematode parasitic plants with mycorrhizae produce more than non-mycorrhizal plants with worms, but less than mycorrhizal plants without nematodes. However, non-mycorrhizal plants with nematodes outperformed those with mycorrhizae and nematode parasites. Arbuscular mycorrhizal fungi (AMF) did not improve yam (*Dioscorea rotundata ‘cv’ ewuru*) tuber weight compared to the control. NPK mineral fertilizer had a greater impact on suppressing nematodes and enhancing yam tuber yield compared to AMF. The combined application of NPK fertilizer and AMF on yam tuber weight in nematode-infested soil did not have an additive or synergistic effect. NPK fertilizer reduced the negative effect of nematodes on yam tuber weight, significantly reducing nematode populations in the roots, soil, and tuber. Nematodes did not reduce yam tuber weight but did reduce tuber quality(Kolawole et al., 2018).

7. Facilitated nutrient uptake mechanism :

- **Addressing phosphorus solubilization and transfer**

Phosphorus (P) concentration in soil solutions negatively impacts arbuscular mycorrhizal fungi (AMF) root colonization in plants. Higher P levels decrease mycorrhizal association, spore production, and secondary external hyphae formation. Mycorrhizal plants can absorb more P in lower P-concentration soil solutions. The diameter of AMF hyphae may be a mechanism for this process. High phosphorus status in plant root tissue reduces signal molecules responsible for hyphal branching and mycorrhizal association, impacting membrane permeability and essential carbon compounds released for mycorrhizal colonization. Application of higher P levels can hamper mycorrhizal formation, and in some cases, the benefits of mycorrhizal associations can be annulled. Recommendations for minimum P levels to promote mycorrhizal colonization are limited, but higher P fertilizer application can reverse this effect in crops like barley, maize, and soybean(Naher et al., 2013).

The effect of intraradicular rhizobia inoculation and phosphorus fertilizer interaction on the development and production of secondary crops in Cerveria, Mato Grosso do Sul, Brazil was studied. Phosphorus is important for corn production but can be difficult to manage in dry soils. This study used a randomized block design that included phosphate application at planting and secondary treatment of mycorrhizal inoculum. The results showed that inoculation and phosphorus fertilization increased the yield of maize crops in the first year of the experiment; This indicates the potential for increased efficiency. This suggests that symbiosis with arbuscular mycorrhizal fungi can increase the absorption of phosphorus from the soil that does not directly reach the roots (Souza Buzo et al., 2023).

- **Nitrogen fixation & assimilation.**

The study found that nitrogen (N) rate significantly influences AM fungal operational taxonomic unit (OTU) richness, but not N form. N additions, except for two specific types, increased AM fungal richness and Shannon diversity index. The results showed that N addition had positive effects on AM fungal richness and diversity. Moderate N addition increased AM fungal OTU richness compared to control treatment and high N addition in another alpine meadow ecosystem. The study suggests that moderate N addition can increase soil microbial diversity, while high N input may reduce it. Overall, moderate N addition (1.5-7.5 N m^2 year^−1) can increase AM fungal richness in alpine meadow ecosystems(Zheng et al., 2014).

Arbuscular mycorrhizal symbiosis, found in over 60% of plant species, is crucial for nutrient acquisition, stress tolerance, and pathogen resistance in plants, especially agricultural crops. AM fungi (AMF) facilitate phosphorus, zinc, and copper uptake, but their impact on nitrogen (N) nutrition is less pronounced. In low soil mineral N availability, competition for N can reduce N uptake by AMF, but may positively affect phosphorus uptake. AMF relies on other microorganisms to mineralize organic nutrients, such as N from organic sources like plant litter or manure. Microbial grazers release N to the soil solution, which can be absorbed by AMF hyphae and transported to the host plant. Understanding these processes is essential for improving agricultural practices and global sustainability(Jansa et al., 2019).

The influence of nitrogen fertilizer and arbuscular mycorrhizal fungus (AMF) on the early development of coconut plants has been examined in this study. Nitrate reductase activity (NRA), colonization, and root surface area were all considerably enhanced by the combination of AMF and NPK fertilizer, with the largest effects being shown at dosages of 2/seeds and 4 g/seeds. AMF alone also led to significant increases in NRA and root surface area(Sulistiono et al., 2019).

8. Case studies demonstrating improved nutrient utilization

The effects of arbuscular mycorrhizal fungi on the development and absorption of macro and micro components in date palm (*Phoenix dactylifera L. cv Bartomouda*) plantlets were investigated in research carried out between 2008 and 2009. Mycorrhizal fungi were used to inoculate the plantlets, and NPK (Krestalon) complete fertilizers were applied in varying amounts. The growth and mineral content were shown to be positively influenced by mycorrhizal fungi, with the greatest significant values at 2.5 g/l NPK treatment. A network of hyphae around roots was also seen in mycorrhizal fungi, which may have increased nutritional and water absorption. There were notable variations seen in the mineral contents and growth metrics of the different NPK treatments. According to the study, using mycorrhiza in soil may reduce the demand for large amounts of fertilizer, which might have a positive financial impact on farming methods(Abo- Rekab, 2010).

Onion growth and mineral content have been evaluated in relation to nitrogen, phosphorus, potassium, and *Gigaspora calospora*. According to the findings, phosphorus fertilization decreased root colonization and spore formation in plants fed with potassium, while nitrogen fertilization increased these traits. Endomycorrhizal plants had higher biomass than non-mycorrhizal ones. The optimal soil nutrient ratio was crucial for the efficient host plant-VAM fungus system, with interactions affecting tissue nitrogen and calcium content (Furlan V. & Cardou M., 1989).

To promote plant development and lessen dependency on chemical fertilizers like NPK in vegetable farming, a study conducted in Indonesia investigates arbuscular mycorrhizal fungus (AMF) as a biological fertilizer. The research found that AMF application increased nutrient uptake, growth, and yield, especially at a 50% NPK dosage. The study also demonstrated that AMF can reduce NPK use by up to 50%, demonstrating its effectiveness in sustainable agricultural systems. AMF thrives in acidic soils, improving nutrient availability, yields, and symbiosis with host plants. The findings support the use of AMF as a biofertilizer for sustainable agriculture and reducing chemical fertilizer environmental impact (Mbusango et al., 2019).

The productivity of zeolite growing media was increased, and bok choy (*Brassica rapa* L.) plant development was encouraged by the use of rhizobacteria, vesicular-arbuscular mycorrhizal fungus (VAM), and graded dosages of NPK fertilizer. The experiment involved a factorial design with two treatments: NPK doses ranging from 0% to 100% and microbial biostimulants. Results showed that MIXN1(NFB + PSB + VAM + NPK 25%) and MIXN2 (NFB + PSB + VAM + NPK 50%) treatments effectively enhanced growth media fertility and optimized bok choy plant growth, with high levels of rhizobacteria and significant VAM root colonization (Widawati & Suliasih, 2020).

Using AMF and *Bradyrhizobium japonicum* strains, the study explores the application of biofertilizers in soybean (*Glycine max* L.) plants to reduce the impacts of drought stress. In comparison to water-stressed plants, the results indicate that unstressed plants had higher biomass, leaf chlorophyll content, nodulation, and grain production. Biofertilizers improve bacterial counts, enzyme activities, and gene expression, leading to increased soybean tolerance to drought stress(Sheteiwy et al., 2021).

With *Claroideoglomus* being the most prevalent species, the study examines the effects of eleven mycorrhizal species on wheat development. The introduction of mycorrhizal consortia increased tillers per plant by 49.5%, resulting in nutritional enrichment and increased protein content in wheat grains. This suggests mycorrhizal inoculation can reduce dependence on synthetic fertilizers in sustainable agriculture. Biofertilizers containing mycorrhizal fungi and PGPR strains improved wheat seedling growth (Akbar et al., 2023).

9. Influencing plant resilience and stress tolerance in varied agroecosystems.

In a Mediterranean agroecosystem, the study examined the effects of moderate fertilization and arbuscular mycorrhizal fungi (AMF) on tomato (*Solanum lycopersicum* L.) plant development and production. The results showed that mycorrhizal inoculation increased root colonization, height, biomass, total yield, and fruit number. Conversely, NPK fertilizer decreased root colonization but enhanced tomato growth and yield. The study suggests that combining AMF and moderate fertilization in low phosphorus soil with low to medium mycorrhizal potential can improve tomato growth and yield, potentially improving agricultural sustainability and mitigating the environmental impact of conventional practices in Mediterranean agroecosystems (Ziane et al., 2021).

10.Success stories in diverse agricultural settings (Implementing Sustainable Practices and Applications)

The study found that the bio intervention of arbuscular mycorrhizal fungi (AMF) and potassium mobilizing bacteria (KMB) in soil significantly increased nutrient bioavailability and uptake in tobacco (*Nicotiana tabacum L.)* plants. The addition of chemical fertilizer led to increased biomass yield, indicating the importance of available phosphorus and potassium in soil for biomass production. Co-inoculation of AMF and KMB showed significant increases in biomass yield, possibly due to solubilization of P and mobilization of K from soil to plant through biological processes. When NPK was added to the treatments, soil inoculation with AMF or KMB led to significant increases in leaf nitrogen, phosphorus, and potassium content. The study confirmed the role of AMF and KMB in enhancing P and K acquisition by tobacco plants. The integration of bio-inoculation with NPK improved mineral nutrient uptake in nutrient-deficient soils(Subhashini, 2016).

In research done during the rabi seasons, the effects of biofertilizers on the development and production of chilis (*Capsicum annuum L. cv. Beldanga*) were assessed using graded levels of inorganic fertilizers. Different biofertilizers and potassium, phosphorus, and nitrogen (NPK) dosages were used in the experiment. The results showed that the combined application of NPK (100%) with *Azospirillium,* VAM, and *Fraturia aurantea* led to the highest number of primary and secondary branches per plant, earliest flower initiation, number of fruits per plant, yield per plant, and projected yield. The best treatment for yield maximization was found to be NPK (100%) combined with *Azospirillum*, VAM, and KM. These findings align with previous studies that reported growth and yield increases with combined biofertilizer inoculation in chili(Kumbar et al., 2017). In combination with *Azotobactor*, PSB, and KM, NPK (75%) produced the highest plant height.

The effects of vermicompost, biofertilizers, and trichoderma on strawberry (*Fragaria x annanasa Duch.*) cv. were investigated in a study conducted at SHUATS, Allahabad. The nitrogen-phosphorous (NPK) residue and fruit quality of Sweet Charlie. The experiment involved twelve treatments and three replications. The study found that the treatment T11, which included Trichoderma, vermicompost, Azotobactor, PSB, and VAM, resulted in the highest total soluble solids, acidity, ascorbic acid, and total sugars in strawberries. T11 also showed the highest residual nitrogen, phosphorous, and potash content in the soil. These findings are consistent with previous research (A. Kumar et al., 2018).

The influence of biological and NPK fertilizers on the function of mycorrhizae in the production of maize (*Zea mays* L.) was evaluated in Indonesian research. Results showed that the combination of NPK fertilizer, biofertilizer, and mycorrhizae significantly affected crop height, highlighting the importance of fertilization in maize growth. The addition of mycorrhizal fertilizer increased the total soil spores. Mycorrhizae improved mycorrhizal colonization and spore formation (Prayogo et al., 2021).

The excessive use of mineral fertilizers in maize cultivation leads to soil contamination and increased production costs. To reduce over-fertilization, Arbuscular Mycorrhizal Fungi (AMF) can be used as a partial replacement. A pot experiment and two field experiments showed that AMF inoculation with 50% NPK fertilization significantly increased maize growth, root colonization, leaf chlorophyll content, and nitrogen, phosphorus, and potassium content. In the field, AMF inoculation reduced chemical fertilizer application by half and improved soil chemistry. The results suggest that AMF inoculation can be used in integrated soil fertility management strategies, providing an economical, environmentally friendly, and sustainable way to increase soil fertility and yields. Further studies are needed to determine the presence of multiple AMF strains in the field and if the introduced AMF species persists in the field (Fall et al., 2023)

11.Challenges and Future Directions

Recent research on mycorrhizal fungi has focused on their role in plant nutrient absorption, water retention, and stress resistance. Wheat, a crucial global food crop, has been extensively studied for its mycorrhizal inoculation. Genetic characterization has revealed significant variations in wheat genotypes' susceptibility and responsiveness to arbuscular mycorrhizal fungi (AMF), suggesting the potential for selecting wheat varieties with effective mycorrhizal symbiosis for sustainable agricultural systems. Molecular markers associated with mycorrhizal symbiosis could be useful tools for selecting high-performing plants and developing wheat varieties suitable for low-impact agricultural systems. Identifying and selecting the most infectious and efficient mycorrhizal fungi could lead to the development of biofertilizers that mitigate soil fertility loss, reduce chemical inputs, and alleviate biotic and abiotic stress (Ganugi et al., 2019).

12.Current Limitations and Knowledge Gaps

The effect of fertilizers on tomato plants' mycorrhizal-conferred resistance was investigated in this study. The plants' biomass was shown to be boosted by mycorrhizae at low levels of fertilization and reduced at high ones. They also increased resistance to herbivores at medium fertilization levels, especially with phosphorus-rich organically derived fertilizer. However, mycorrhizae did not provide simultaneous growth and resistance benefits, suggesting potential for improved crop growth or pest resistance under lower fertilizer conditions (Getman-Pickering et al., 2021).

With an emphasis on arbuscular mycorrhizal fungi, this work explores the interaction between soil microbes and plants in agriculture. It discovered that in stress-free growth circumstances, farmers' young olive cuttings had very modest advantages. According to the study, particular goals should be the focus of commercial biofertilizers, which should also take environmental factors, plant and microbe combinations, and other factors into account. The agronomic effectiveness of commercial biofertilizers is uncertain, and most studies take place under artificial conditions. The study found no significant differences in dry matter yield, plant performance, or nutritional stress among fertilizer treatments (Rodrigues et al., 2021)

13. Advocacy for Sustainable Agricultural Practices

The role of arbuscular mycorrhizal (AM) fungi in agricultural sustainability. These fungi have a symbiotic relationship with host plants, aiding in the absorption of nutrients and water. The hyphal network of AM fungi has a high absorbing capacity and surface volume, aiding in the uptake and translocation of water and essential nutrients like phosphorus and nitrogen. Additionally, the extraradical hyphae can enter and procure nutrients and water from finer soil crevices beyond the entry of roots, helping retain soil moisture and ensuring quick absorption from beyond the root depletion zone. This symbiosis plays a vital role in sustainable intensification of agriculture (Kuila & Ghosh, 2022).

Conclusively, in the natural nutrition network of plants, fungi known as mycorrhizal fungi are essential. By spreading the roots of the plant, they increase the amount of vital nutrients that are released from the soil, such as potassium, phosphate, and nitrogen (NPK), which enhances the health of the plant. Despite external obstacles, this diversified society maintains a steady flow of nutrients, much like a healthy ecosystem. Our reliance on artificial fertilizers, which may harm the environment and decrease soil health, can be reduced by making use of this natural symbiosis. In addition to supporting plant development, mycorrhizal fungi also nourish the soil environment. To completely harness the potential of mycorrhizal variety and incorporate them into farming methods, more study is necessary. A viable route to long-term NPK management is to embrace mycorrhizal variety, which fosters soil enrichment, better crops, and sustained planet.

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