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REVIEW ARTICLE

The use of Arbuscular mycorrhizal fungi to maximize the function of organic fertilizer on soil properties and nutrient uptake in plant production

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Abstract
The use of chemical fertilizer can be harmful for envionments and threaten a sustainability agriculture. One of the alternative to overcome the problem is using organic fertilizer which is eco-friendly. However, another problem comes when organic fertilizer cannot meet nutrients sufficiency due to low nutrients and slow-release effect, while the use of Arbuscular Mychorrizal Fungi (AMF) has been widely used around the world to provide nutrients for plants, even allows plants to survive in severe conditions. This study explores the potency of AMF combined with organic fertilizer in soil properties and enhancing plant nutrient uptake. Besides, AMF also can be used as biocontrol agen. Data collection from researchers' database were obtained to fulfill the critical analysis. This study found that the potential synergism between organic fertilizer and AMF is crucial to complement the effects of each other, such as increasing nutrient availability and improving soil health. However, the effects of their combination might be positive or negative depending on environmental factors, including nutrients status in the soil and strains of AMF used. Therefore, the use of organic fertilizer and AMF combination should consider some aspects to avoid negative effects, such as unbalanced soil fertility setting and to obtain the advantages from both of them.

Keywords: Arbuscular mychorrizal Fungi, Organic Farming, Manures, Soil Nutrients.

INTRODUCTION

To enhance the yield of crops, fertilizers are needed to be added into soils, especially chemical fertilizers. Farmers have proven that the crop production increase considerably, but the use of NPK in a long term is harmful for sustainability of crop production due to soil degradation (Menšík et al., 2018). Moreover, the application of fertilizer also can represent 20 to 25% of the production cost (Calvin et al., 2013), so to reduce or eliminate the utilization of mineral fertilizer, organic fertilizers can be used as a promising alternative. The other advantages of organic fertilizer are to preserve natural resources, avoid water contamination due to leaching from residues of chemical fertilizer, recycle materials and wastes available in the farm to create circular economy, and allow environment sustainability (Vidigal et al., 2010).

Many studies show that organic fertilizer affected soil chemical, physical, and biological properties, such as increase soil fertility, improve soil structure, and enhance microbial activity to provide more nutrients (Elshony et al., 2019; Mažeika et al., 2021; Guo et al., 2019). Preparation of making organic fertilizer is low cost because the raw materials are very abundant around farmland, including agricultural residues, animal wastes, household wastes, etc. Gao et al., 2015 stated that long-term application of green manures can improves soil fertility through biogeochemical cycle driven by the shifts in bacterial functional groups and microbial communities in red paddy soil.

On the other hand, as time goes by, the decrease in the content of organic matter and native fertility have occured in the soil all over the world. Many researchers pay special attention to adopting appropriate and sustainable strategies, not only using organic fertilizers, but also using bio-organic fertilizers or integrating microorganisms (mycorrhizal fungi), to compensate for nutrient deficiency and its effect on plant growth and to reduce the use of chemical fertilizers (El Amerany et al., 2020).

Mycorrhiza can be used as an example of a symbiotic association between plants and fungi which shows the mutualism effect. Mycorrhizal associations enable the host plants to deal with stress conditions, such as in infertile soils and drought situations by increasing the root surface and nutrient absorption ability. Environmental threats like increased temperature due to global warming can affect unstable conditions for plant productivity. Moreover, pests and diseases will develop and mutate to adapt to the environment. These challenges have to be controlled and be mitigated to ensure global food supply. In this context, mycorrhiza-based crop production is one of the key components of sustainable agriculture practices which is more adaptable to face the effects of climate change (Barman et al., 2016). Previous studies by Srivastava et al., 2010 reported that the mycorrhizal fungi can reduce the incidence and severity of disease and improve the yield of tomato plants. Besides, other research has shown the higher colonization of root system and decreased pathogen infection sites in apple plants inoculated with AMF (Hare Krishna et al., 2010).

The use of organic fertilizer combined with mycorrhizal can maximize the configuration and efficiency of the AMF symbiosis. Another researcher has shown an improvement of root dry weight on tomato plant growth using the green waste biochar and AMF complex. Although the root colonization was not enhanced, the combination of biochar and AMF had a bio-protective effect against Fusarium oxysporum (Akhter et al., 2015). Also, Akhzari et al., 2015 have revealed the efficiency of vermicompost and AMF on nutrient acquisition, e.g. total nitrogen and potassium, where the increase of shoot and root dry weight occured across all vermicompost treatments. To maximize the benefits reported, the application of the fertilizer was necessary, with a positive synergistic effect of mycorrhizal and organic fertilizer. Soils with sufficient fertilizer doses are known to favor AMF efficiency. Therefore, it is necessary to investigate the potential synergism in plant production between AMF and other organic fertilizers.

MATERIALS AND METHODS

This study uses a literature review approach, which aims to examine the use of Arbuscular mycorrhizal fungi to maximize the function of organic fertilizers on soil properties and nutrient absorption in the plant production.

RESULTS AND DISCUSSION

The Role of Arbuscular Mycorrhizal Fungi for Nutrient Cycling

Arbuscular mycorrhizal fungi (AMF) can play a key role in the absorption of nutrients (Fig. 1) in natural and agricultural ecosystems, in particular for biofortication micrinutrients (Ercoli et al., 2017). Furthermore, AMF can stimulate the growth of other microorganisms in the rhizosphere, such as Pseudomonas fluoerescens which can be used as potential bicocontrol agents producing antibiotics (Siasou et al., 2009). Arbuscular mycorrhizal symbiosis allows plants to survive in severe conditions, including water stress and improves total biomass, N content, and N2 fixation. Also, contributing in the early growth phase, when nutrient uptake is limited by the relatively poorly developed plant root system (Saia et al., 2014). However, the scale of these advantages depends on the edaphic and climatic background in which symbiosis occurs, the involved AMF and plant species, and the practices of agricultural management (fertilisation, tillage, etc.).

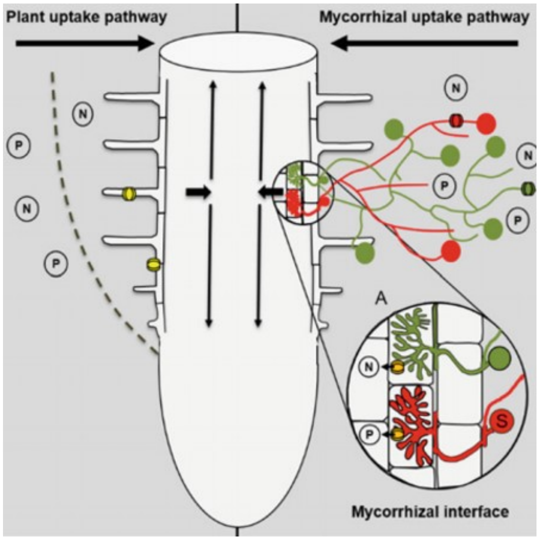

Figure 1. Nutrients transportation by direct (plant) uptake pathway (DP) and mycorrhizal uptake pathway (MP) (Varma et al., 2018).

Mycorrhizal infection may affect the mineral nutrition of the host plant directly by enhancing plant growth through nutrient acquisition by the fungus, or indirectly by modifying transpiration rates and the composition of rhizosphere microflora (Marschner and Dell, 1994). It has been reported that AMF contribution to host plant N varied widely, but in the low N systems, the competition for N between symbionts occured (Hodge and Storer, 2015). However, AMF can maintain and improve P/N uptake, water use efficiency, and growth of plants both at high/low P levels, although plant growth response to AMF was not related to the percentage of AMF root colonization (C. Liu et al., 2018). Arbuscular mycorrhiza symbiosis can enhance the supply of water and nutrients, such as phosphate and nitrogen to the host plant through roots and root-external AM mycelium in the soil. In return, up to 20% of plant-fixed carbon is transferred to the AM fungus (AMF) (Parniske, 2008).

Mycorrhizal inoculation allows plant to survive in a wide range of environmental stresses, including plants in saline environment by reducing Na and Cl uptake to alleviate toxic ions effects (Varma et al., 2018). Many researchers also have reported that AM fungi isolated from areas affected by salinity can be a powerful tool to enhance the tolerance of crops to saline stress conditions (Estrada et al., 2013). The mechanisms used by AMF to boost the salt tolerance of plants to grow and develop in saline environments (Fig. 2) include the synthesis and accumulation of compatible solutes to avoid cell dehydration and maintain root water uptake, the regulation of ion homeostasis to control ion uptake by roots, compartmentation and transport into shoots, the fine regulation of water uptake and distribution to plant tissues by the action of aquaporins, the reduction of oxidative damage through improved antioxidant capacity and the maintenance of photosynthesis at values adequate for plant growth (Lozano et al., 2012).

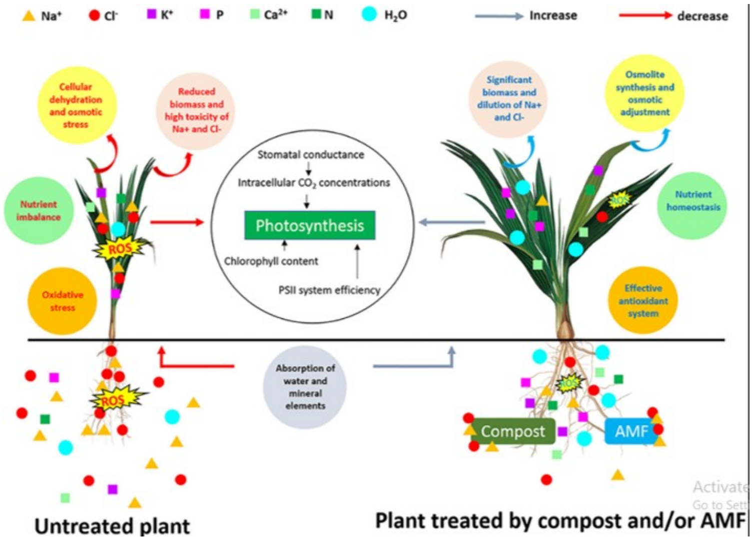

Figure 2. Schematic representation of various mechanisms induced by AMF and compost application in date palm plants under salt stress (Mokhtar et al., 2020).

The Role of Organic Fertilizer to Improve Soil Properties

Numerous studies show the advantages and disadvantages of long-term fertilization on soil properties and crop yields. M. Wang and Yang, 2003 found that chemical fertilizer played a significant role in governing the maize and rice yields, but it did not significantly contribute to the improvement of some soil quality attributes. On the other hand, the soil amended by organic fertilizer improved soil structure. J. Wang et al., 2017 observed that the soil microorganisms respond differently to the inputs of inorganic and organic fertilizers in paddy soil. Compared with organic fertlizer, the chemical fertilizer treatment had lower richness of bacteria, but higher richness of fungi. Moreover, the organic fertilizer also had the sparsest and most discrete network indicated that soil microbes tended to be less interacted with each other after organic fertilizers inputs.

Organic manure derived from animal waste has been used to improve crop production and repair soil damage. The application of organic manure has multiple benefits due to the balanced supply of both macro and micronutrients. It also has a large stock of carbon and nutrients, a diverse soil microbial community, and a high cation exchange capacity (Biratu et al., 2019). Furthermore, manure fertilization has slow-release effects on nutrient availability, so the residue of manure fertilization can be used for crop growth and development in the next season.

The use of organic fertilizer improved soil properties in ways that had beneficial impacts on bacterial diversity and plant health. Gu et al. 2019 observed that soil samples with organic fertlizer (OF) treatment had higher microbial diversity than other samples. The microbial community in soils with OF treatment had a more organized and diverse communities with a greater number of functionally interrelated modules (14) than that in soils with chemical fertilizer (CF) treatment (10 modules).

Soil parameters, such as soil organic carbon, NO3, and available phosporus has also been proven to be a key factor affecting the change in the soil bacterial community (J. Liu et al., 2018). Long-term use of organic fertilizer boosts the quantity and quality of soil organic matter by increasing microbial biomass and enzyme activity. A study on peanuts cultivated in red earth soil with low fertility revealed that the vegetable biomass increased by 27.6%-85.7% after application of organic fertilizer or mixed application of functional bacteria (Xiong et al., 2014).

The average soil organic carbon (SOC) storage over the years in organic manure with mineral fertilizer was significantly greater than those applying mineral fertilizers only in red paddy soil (Huang et al., 2015). Unlike continous chemical fertilizer, long-term organic fertilization in surface soil is successful in preserving the organic carbon fraction to increase the distribution rate of soil macroaggregates,improve organnic matter of soils,concentrations of total N and alkali-N,and increase the activity of soil enzymes (H. Wang et al., 2019). Organic fertilizer also is more beneficial to soil carbon and nitrogen accumulation compared to conventional fertilizers because nitrogen and organic fertilizer mainly contribute to active organic carbon as the cause of greenhouse gases.

Correlation Between AMF and Organic Fertilizer to Enhance Nutrient Uptake on Supporting Plant Production

The problem with organic fertilizers is their low nutrient content and slow-release effect to meet nutrients sufficiency in a short time cultivation, hence the sole application of manure could not meet the demand of agriculture product. On the other hand, over the last decades, plants have evolved many traits to optimize nutrient acquisition, including the formation of arbuscular mycorrhizas (AM), associations of plant roots with fungi that acquire soil nutrients. There is emerging evidence that AM have the ability to reduce nutrient loss from soils by enlarging the nutrient interception zone and preventing nutrient loss after rain-induced leaching events (Cavagnaro et al., 2015). However, as the advantages of mutualism differ greatly depending on the AMF strains, the use of sufficient AMF, either individually or in combination, still remains a major challenge.

Combination of organic fertilizer and mychorriza is expected to overcome the problem. J. Liu et al., 2018 revealed that adding biochar together with AM inoculant significantly promoted fungal populations compared to a control. Amending soil with AM inoculant and biochar together produced the largest increase in maize growth and decrease in tissue Cd concentrations (Fig. 3). The combined treatment also had a synergistic effect on inducing soil alkalinization and causing Cd immobilization, and decreasing Cd phytoavailability and post-harvest transfer risks. Moreover, El Amerany et al., 2020 showed the application of the three bio-fertilizers together looks more efficient than being separated. The use of three bio-fertilizers chitosan, AMF, and compost was proven to be very beneficial for the growth of tomato plants.

AMF colonization frequency was reached 86% indicating that the use of a complex of AMF may help to promote growth of tomato. In addition, AMF colonization was changed in the presence of other bio-fertilizers (Ch+ and compost). When Ch+ applied alone with AMF, the frequency and intensity of AMF root colonization were significantly increased to reach 47% and 97%, respectively; however, chitosan did not show an enhancement of growth of mycorrhizal plants (El Amerany et al., 2020). Chitosan application did not inhibit AM colonization or AM infectivity in the microbial inocula, indicating chitosan may be non-toxic to AM fungi. This confirmed that chitosan had no phytotoxic or fungicidal effects (F. Y. Wang et al., 2007) and can be used as a combination with AMF application. On the contrary, Lino et al., 2019 explained that manure application had significant effects on maize grain and straw yields, while mycorrhizal inoculation affected plants when manure was not supplied.

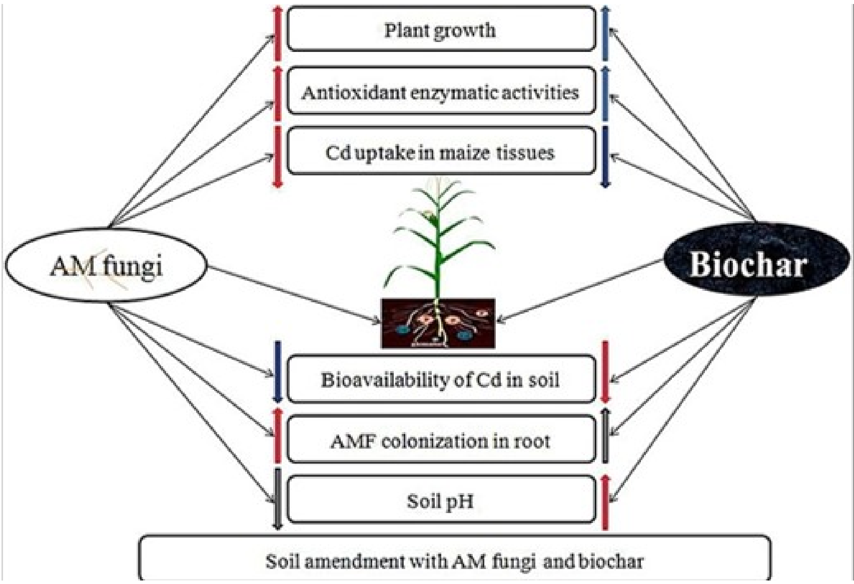

Figure 3. Effects of arbuscular mycorrhizal (AM) inoculation and biochar application on maize growth, antioxidant enzyme activities, cadmium uptake, soil pH, AMF colonization and soil cadmium bioavailability under Cd-contaminated soil. Red, blue and grey arrows represent the strong, moderate and slight effects on the corresponding parameters, respectively.

Interaction of Mychorrizal and Organic Fertilizer Under Different Nutrients Status in The Soil

Organic fertilizer, such as compost using locally available recycled organic materials is a partial alternative to chemical fertilizers. The decrese of 50% NPK could be done by adding 20 or 30 ton h-1 compost (Rady et al., 2016) which means no dose at which compost becomes toxic to plants. In contrast, the addition of compost had a substantial impact on plant growth, increasing significantly, and linearly, with increasing rates of compost application (Cavagnaro, 2014). However, the inhibition of growth under excessive compost application could be explained by the fact that hugely uptake of some nutrients by plants could interrupt the absorption of others based on Liebig's law (law of the minimum). A study showed that the excess supply of N resulted in poor growth in the second year of cultivation due to small potassium (K) and magnesium (Mg) uptakes (Chang et al., 2012).

Unbalancing nutrients in fecund soils due to the application of organic fertilizer together with AMF might be show negative effects to nutrients uptake in plants. For instance, Hernández et al., 2020 revealed that the effects of mychorriza to maize plant growth response depends on the soil P status resulting in growth depression and promotion in high and low P soil, respectively. Surprisingly, in the high P soil experiment fertilization both mineral (NK and NPK) and organic (Bokashi) mitigated the plant growth suppression caused by the AMF. This occurs when there are enough nutrients in soils for the host plant, especially P, and occurs frequently in the early AMF root colonization process, where the host plant is investing in the external mycelium development, without obtaining any nutrients in return. According to de Assis et al., 2020 treatments with AMFs and organic fertilizer, and without AMFs and with manure, did not record significant difference, because soil with organic fertilizer showed the highest P concentration (17.2 mg dm^{-3}), which interfered in colonization (Fig 4.).

Figure 4. Plants of M. officinalis L. grown under the influence of arbuscular mycorrhizal fungi (AMFs) and organic manure (OM).

As expected, in the low P soil experiment, the AMF induced plant growth promotion in the vegetative plant growth phase without fertilization, as well as with both NPK and Bokashi fertilization. On the contrary, the observed AMF plant growth suppression with NK fertilization with P limitation suggests a possible competition for P between AMF and the host plant, under such unbalanced soil fertility settings. It is important to note that the observed AMF-induced maize growth responses during the vegetative plant growth phase were not reflected in the final yield where no AMF effects were observed (Hernández et al., 2020).

CONCLUSIONS

The use of chemical fertilizer face some environmental problems that can be fixed by the use of organic fertilizer which is eco-friendly. The application of organic fertilizer has multiple benefits due to enhanced soil microbial activity, improving soil physical and chemical properties. Furthermore, organic fertilizer can be enriched by using bio-fertilizer, such as arbuscular mychorriza fungi. AMF can play a key role in natural and agricultural ecosystems affecting plant nutrition, particularly P and other poorly mobile nutrients, increasing soil biological activity, modifying the availability of nutrients by plants, and improving resistance to biotic stresses and abiotic stresses. The application of AMF, either individually or in combination with organic fertilizer shows different effects to plant production depending on environmental factors, including the soil NP status and the AMF strains as well.

Author contributions

Ari Kurniawati, Evans Duah Agyemang, Sándor Hoffmann, Angéla Anda, Zoltán Tóth: Conceptualization, analysis, writing draf, and editing.

Conflict of Interest

There is no conflict of interest in this study.

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Data availability

Data related to the findings of this study are available at the corresponding author.

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