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Arbuscular Mycorrhizal Fungi (AMF) for soil fertility

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Abstract

Mycorrhizal symbiosis affects 80% of terrestrial plant species. It increases their defensive power against soil-borne pathogens by synthesising antibiotics and promoting the microbial flora in the fungal mantle. The study will analyse current knowledge of soil fertility, water and mineral nutrition, and plant growth. The study shows that the establishment of symbiosis is largely controlled by the fertilization regime. Phosphorus and nitrogen are the major elements responsible for plant growth. However, plant requirements for mineral elements are not limited to phosphorus and nitrogen. Other elements, such as Sulphur and trace elements like copper, zinc, iron and manganese, are also essential.

Key words: Mycorrhization; Soil Fertility; Phosphate; Nitrogen Nutrition

1. Introduction

Mycorrhizae are the result of a lasting union based on reciprocal exchanges between plant roots and certain soil fungi. They are essential components in the soil-plant-micro-organism relationship. Mycorrhizal fungi enter into association with a very large number of plants, and this symbiosis is beneficial to both organisms. This association can have access to the carbon fixed by the plant, thus providing better access to essential nutrients such as phosphorus, which would be difficult for the plant alone to access (Taktek, 2015). Most plant species cannot develop without the establishment of a functional mycorrhizal symbiosis within their root system (Smith & Read, 2008). The fungal component of this symbiotic association significantly improves plant development in conditions of mineral deficiency (particularly phosphorus, the main deficiency recorded in degraded Mediterranean soils, along with nitrogen) and water deficit, and also enables the plant to better resist pathogen attacks (Barea et al. 1997; Schreiner et al. 1997). The aim of this study is to analyse and present some of the current knowledge on soil fertility, water and mineral nutrition and plant growth.

2. The different types of arbuscular mycorrhizae in the rhizosphere

2.1. . The rhizosphere

Hiltner (2008) defines the rhizosphere as the volume of soil evolving under the influence of roots and characterized by intense microbial activity resulting from the diffusion or exudation of organic compounds at the root level (Grayston et al., 1997). The rhizosphere is the part of the substrate immediately in contact with the living roots and under their direct influence. The root radicles form the root hair.

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2.2. Types of arbuscular mycorrhizae in the rhizosphere

Mycorrhizae are the result of a lasting union based on reciprocal exchanges between plant roots and certain soil fungi. These are essential elements of the soil-plant-microorganisms relationship. Arbuscular mycorrhizae are the most primitive and widespread in natural and cultivated ecosystems (Tedersoo et al., 2010). Indeed, among these symbiotic fungi, arbuscular and vesicular endomycorrhizal fungi constitute the most frequently encountered group, with known beneficial effects on growth and stress tolerance (Barea et al., 1993; Smith and Read, 1997).). are known.

Endomycorrhizae (from the Greek endon: inside) are characterised by the absence of an external mycelial sleeve and by the penetration of fungal hyphae into cortical cells. Endomycorrhizae develop under the soil, inside absorbing roots. They form fungal filaments (hyphae) of microscopic size, from 3 to 15 microns (1/1,000 mm), which grow by the thousands up to a few metres from the roots.

- Orchid endomycorrhizae formed by Basidiomycetes.
- Ericaceous endomycorrhizae associated with Ascomycetes (Pezizaceae). In these two cases, the mycelium forms clumps inside the cells of the cortical parenchyma.
- Cistaceae endomycorrhizae are symbiotic fungi belonging to the hypogeous Ascomycetes (Terfeziaceae).

- Mycorrhizae with vesicles and arbuscules are associations that owe their name to the fungal structures resulting from intracellular hyphae that branch intensely within the cells of the root cortex to form structures called arbuscules. These hyphae can form vesicles (Bonfante-Fasolo, 1984).

3. Arbuscular mycorrhizal fungi and plant nutrition

3.1. Phosphorus nutrition in plants

Phosphorus is one of the major elements responsible for plant growth. A shortage of phosphorus can cause an imbalance in plant development, with yields falling or stagnating. It is therefore important to control soil phosphorus levels to ensure crop profitability. In the soil, phosphate ions are retained in colloids in the form of iron or aluminium phosphates; although present, the majority of phosphate is therefore unavailable to plants (Gaveriaux, 2012). Several authors have highlighted the importance of CMAs in phosphorus nutrition. Fritz et al (2011) have shown that plants can absorb almost 90% of the phosphorus they need in the event of phosphorus deficiency thanks to CMAs. Phosphorus is found in all plant tissues, with concentrations varying depending on the part of the plant. Plant species with high phosphorus requirements benefit greatly from MACs thanks to their multiple functions. Studies have shown that plants inoculated with CMAs solubilise natural phosphates and mobilise phosphorus, compared with non-inoculated plants (Abdelmonaim, 2013). The micro-organisms that use the organic acids excreted by the CMAs can also act as natural phosphate solubilisers. Phosphorus is one of the major plant nutrients, directly or indirectly affecting all biological processes. It is involved in all stages of plant development as an energy carrier. Phosphorus deficiency can lead to poor nitrogen and potassium utilisation (Kashchandra et al., 2005).

3.2. Nitrogen supply for plants

Mycorrhizae play a beneficial role in fixing atmospheric nitrogen. Mycorrhizal fungi are often associated with other micro-organisms that are beneficial to plants, such as nitrogen-fixing bacteria. In this way, mycorrhizal fungi encourage the infection of roots by these bacteria and the formation of nodules that allow the plant to access atmospheric nitrogen. In some Glomales, the extra-root hyphae assimilate nitrogen in the form of nitrates, nitrites and ammonium from the soil. These molecules are transformed by the fungus and stored in the cells of the extraracinar mycelium in the form of arginine. This amino acid is then transferred to the intraracinar mycelium, where it is degraded to ammonium and then transferred to the plant at the arbuscule level (Tanguay, 2014).

3.3. Nutrition of other mineral elements

Plant requirements for mineral elements are not limited to phosphorus and nitrogen. Other elements, such as sulphur, or trace elements, such as copper, zinc, iron, manganese, etc., are also essential. These substances, which are difficult to mobilise, also benefit from the help of the CMA, especially following better exploitation of the soil by extra-root hyphae (Gaveriaux, 2012).

3.4. Water supply for plants

Water is the primary factor constraining plant growth in non-aquatic continental ecosystems. Precipitation is episodic, irregular and geographically very heterogeneous, and plants must extract it from the soil where it temporarily resides before being drained or evaporated (Garbaye, 2013). In CMAs, the extra-matrix network provides a better supply of water to root cells under limited conditions. Mycorrhised plants are more resistant to transplanting and respond favourably to water stress. To explain the physiological effects, the role of improved mineral nutrition (particularly phosphate), an increase in the surface area explored by hyphae, the intervention of hormonal processes that control the opening of stomata and the maintenance of water continuity at the soil-plant interface are often put forward (Zangui, 2013).

3.5. Protection against abiotic and biotic stresses

Mycorrhised plants are more tolerant of abiotic and biotic stress factors. According to Egli and Brunner (2002), MCAs increase the defensive power of plants against soil-borne pathogens by synthesising antibiotics, inducing tannin formation and promoting microbial flora in the fungal mantle. In addition, phytohormones secreted by mycorrhizal fungi (auxin, giberelin, cytokinin, ethylene, etc.) promote plant growth. Soil contamination by various pollutants is an abiotic stress that can be alleviated by AM symbiosis. Arbuscular mycorrhizae promote plant growth in soils contaminated by heavy metals (Redon, 2009). In nature, plants are constantly under attack from bacteria, fungi, nematodes, insects and fungal diseases. It has been shown experimentally that plants inoculated with arbuscular mycorrhizal fungi are more resistant to attack by pathogenic fungi and to exposure to soil toxins (Fitter, 1991; Schtiepp et al., 1987). These mycorrhizal fungi can act in two ways and in two places to protect roots against pathogenic fungi: in the rhizosphere and in root tissue. In the rhizosphere and especially in the mycorhizosphere, the space immediately surrounding the mycorrhizal fungi, micro-organisms compete and antagonise each other, resulting in a diverse and balanced microbial flora. In this environment, the propagules of pathogenic fungi are unable to multiply and their numbers always remain relatively low. The second mechanism that enables mycorrhised plants to better resist disease is linked to changes in physiological activity in the root. Plants attacked by a pathogen react by producing antibiotic substances against these organisms (Fortin et al., 2008).

4. CMA and cropping systems

Improving soil fertility depends on a better understanding of the effects of cropping systems on this fertility. Sebillotte (1990) proposes the following definition of a cropping system: ‘All the technical methods used on plots of land cultivated in an identical manner. Each system is defined by :

- the nature of the crops and their order of succession ;
- the technical itineraries applied to these different crops ;
- the choice of varieties. The technical itinerary is defined as a logical and orderly combination of techniques used to control the environment and produce a given output. In a system experiment, many parameters change (rotation, fertilisation, etc.).

It is therefore the result of a combination of practices on the achievement of one or more objectives assigned to the system tested that is measured. Few system experiments have been described in the literature, and only a few deal with the impact of the system on the mycorrhizogenic potential of the soil. Kahiluoto et al (2009) used flax (Linum usitatissimum L.) and clover (Trifolium pratense L.) as trap plants, grown in a greenhouse, to test soils from two conventional cropping systems. The first was a low-input system (rotation: wheat + peas - barley - clover - rye / incorporation of residues / green manures / with apatite inputs for P) and the second, a high-input system (wheat - barley - rye / no legumes / with mineral fertilisation). Colonisation by CMAs was higher in the low-input system than in the high-input system and resulted in a 68% improvement in P uptake compared with a non-mycorrhizal control (sterilization), compared with 36% in the high-input system.

4.1. Impact of fertilisation on CMAs

The establishment of symbiosis is also largely controlled by the fertilisation regime in the field. Over-fertilisation with P reduces root colonisation by CMAs (Garbaye, 2013). Even a moderate application of phosphorus fertiliser, at a rate of 45 kg of mineral P per hectare per year, over a period of five years, reduces the number of spores by 50% (Martensson and Carlgren, 1994, cited by Gosling et al, 2006). Jensen and Jacobsen (1980) showed in situ that the higher the phosphorus input (0-15 and 30 kg mineral P/ha), the lower the colonisation of barley roots. In addition, this study showed, by varying N and P fertilisation together, that root colonisation and the number of CMA spores were higher in soils receiving 0 kg N/ha and 0 kg P/ha than in those receiving 75 kg N/ha and 12 kg P/ha.

4.2. Improving plant growth and nutrition

Arbuscular mycorrhizae are the most widespread plant symbiosis in the world. The fungi concerned, grouped in the phylum Glomeromycota and distributed across all ecosystems, colonise the majority of terrestrial plants. In addition to the well-known advantages of mycorrhizae for plant growth, there are a number of other benefits, notably for plant survival and biodiversity, and their potential as an agent for reducing both abiotic and biotic stress (Dalpé, 2005). With such a wide range of benefits for plants and the environment, mycorrhizae represent an ideal solution for resolving a number of problems related to plant production and protection (Dalpé, 2005).

The natural strategy for the acquisition of nutrients by terrestrial plants is symbiosis with CMAs. The external hyphal network of CMAs plays an important role in the uptake of nutrients, especially those with low mobility in the soil such as phosphorus (P). Improved nutrient uptake in mycorrhised plants usually leads to improved vegetative growth (Gilroy and Jones, 2000). MCA hyphae can absorb up to 80%, 25% and 10% of the plant's phosphorus, nitrogen and potassium requirements respectively (Marschner and Dell, 1994). Plant growth is linked to the availability of inorganic phosphorus in the plant's rhizosphere (Holford, 1997). The extra-root mycorrhizal hyphae absorb phosphorus and transport it rapidly to the mycorrhizal structures in the roots, where it is released into the periarbuscular space adjacent to the root cortical cells (Smith and Smith, 1990). The contribution of mycorrhizae to improving phosphorus uptake has been demonstrated by several authors (Fraga-Beddiar and Le Tacon, 1990; Marschner and Dell, 1994; Smith et al., 2011).

4.3. Protection against biotic and abiotic stress

Although the main function of mycorrhizal symbiosis is to improve plant mineral nutrition, it also plays a role in plant tolerance to biotic and abiotic stresses. Several studies have shown the role played by MACs in protecting plants under abiotic stresses such as salinity (Giri et al., 2008), temperature (Abdel Latef and Chaoxing, 2011), limestone (Labidi et al., 2011), drought (Ruiz-Sánchez et al., 2010) and soil compaction (Miransari et al., 2008). They are also involved in mitigating the harmful effects of pollutants such as polycyclic aromatic hydrocarbons (Verdin et al., 2006; Debiane et al., 2008, 2009), fungicides (Campagnac et al., 2010) and trace metals (Firmin et al., 2015). Other more direct actions involve the stimulation of defence mechanisms by the plant and competition between mycorrhizae and parasites for space, infection sites and nutrients (Dalpé, 2005).

5. Conclusion

The aim of this study was to analyse current knowledge of soil fertility. The results have contributed to our knowledge of mycorrhizal fungi in various respects, including their diversity and their role in phosphorus and nitrogen nutrition, as well as in plant improvement and growth. The study also highlighted the morphological diversity of CMAs living in symbiosis with plant roots. In the soil microbial community, symbiotic microorganisms form close relationships with plants, providing them with the nutrients they need for their development.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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