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Review

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ARBUSCULAR MYCORRHIZAL FUNGI – THEIR LIFE AND FUNCTION IN ECOSYSTEM

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Arbuscular mycorrhizal fungi living in the soil closely collaborate with plants in their root zone and play very important role in their evolution. Their symbiosis stimulates plant growth and resistance to different environmental stresses. Plant root system, extended by mycelium of arbuscular mycorrhizal fungi, has better capability to reach the water and dissolved nutrients from a much larger volume of soil. This could solve the problem of imminent depletion of phosphate stock, affect plant fertilisation, and contribute to sustainable production of foods, feeds, biofuel, and raw materials. Expanded plant root systems reduce erosion of soil, improve soil quality, and extend the diversity of soil microflora. On the other hand, symbiosis with plants affects species diversity of arbuscular mycorrhizal fungi and increased plant diversity supports diversity of fungi. This review summarizes the importance of arbuscular mycorrhizal fungi in relation to beneficial potential of their symbiosis with plants, and their function in the ecosystem.

Key words: arbuscular mycorrhizal fungi, mycorrhizosphere, plant, symbiosis

Arbuscular mycorrhizal fungi (AMF) are present on the Earth about 600 million years (Redecker *et al*. 2000) and probably due to ancient symbiosis with plants they lost the ability to exist independently and its life cycle must be completed only in the presence of the host plant (Requena *et al.* 2007). About 80% of terrestrial plant species form the mycorrhizal symbiosis with AMF (Wang & Qiu 2006) and the arbuscular mycorrhizal symbiosis is the most widespread type of mycorrhizal symbiosis without host plant specificity (Klironomos 2000). On the other hand, Husband *et al*. (2002) have indicated that at least some fungi taxa are host specialists. The term “arbuscular” was derived from characteristic structures called arbuscules (lat. *arbuscula* = small tree, shrub) occurring in the cortical cells of many plant roots. These structures, together with storage vesicles, are considered diagnostic for arbuscular mycorrhizal (AM) symbiosis and these fungi belong to the phylum *Glomeromycota* (Table 1) (Schüßler *et al.* 2001). AMF are obligate symbionts dependent on the host plant and colonization of plant roots occurred through spores, hyphae, or infected root fragments (Klironomos & Hart 2002). Fungal mycelium of AMF affects the plant by extending of root systems, allowing to improve the utilization of water and minerals from the soil (Smith & Read 1997). Plants colonized by AMF have better resistance to

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environmental stresses, such as drought, cold, pollution (Juniper & Abbott 2006), and better overcome attacks of bacterial and fungal pathogens (Selvaraj & Chellappan 2006). Mycorrhizal symbiosis maintains and promotes plant growth, significantly reduces the need for synthetic fertilisers, improves quality of soil, increases soil microfloral diversity, and reduces soil erosion (Azaizeh *et al.* 1995).

Arbuscular mycorrhizal symbiosis

The arbuscular mycorrhizal symbiosis is a complex of morphological, physiological, and biochemical changes which are formed gradually in several developmental stages in both symbiotic partners. The life cycle of AMF starts with germination of fungal spores in the soil under favourable environmental conditions, spontaneously without the presence of the host plant (Gianinazzi-Pearson 1996; Requena *et al*. 2007). Fungal colonies expand several centimetres and characteristic growth structures are formed (Giovannetti *et al*. 1994). This asymbiotic phase turns into presymbiotic one characterised by extensive hyphal branching caused by presence of the host plant (Giovannetti *et al*. 1993). This is crucial stage in the AMF life cycle based on the chemotaxic abilities of AMF that allow the growth of the hyphae to the roots of host plant and repre-

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Classification of arbuscular mycorrhizal fungi according to Schüßler & Walker (2010) and Redecker *et al.* (2013)

Phylum		Class
Glomeromycota		Glomeromycetes
Orders	Families	Genera
Glomerales	*Glomeraceae*	*Glomus*
		Funneliformis (former *Glomus* Group Aa, *Glomus mosseae*)
		Rhizophagus (former *Glomus* Group Ab, *Glomus intraradices*)
		Sclerocystis (based in former *Glomus* Group Aa)
		Septoglomus
	Claroideoglomeraceae	*Clairoideoglomus* (former *Glomus* Group B, *Glomus claroideum*)
Diversisporales	*Gigasporaceae*	*Cetraspora*
		Dentiscutata
		Gigaspora
		Intraomatospora (insufficient evidence, but no formal action was taken)
		Paradentiscutata (insufficient evidence, but no formal action was taken)
		Racocetra
		Scutellospora
	Acaulosporaceae	*Acaulospora* (including the former *Kuklospora*)
	Pacisporaceae	*Pacispora*
	Diversisporaceae	*Corymbiglomus* (insufficient evidence, but no formal action was taken)
		Diversispora (former *Glomus* Group C)
		Otospora (insufficient evidence, but no formal action was taken)
		Redeckera
		Tricispora (insufficient evidence, but no formal action was taken)
	Sacculosporaceae	*Sacculospora* (insufficient evidence, but no formal action was taken)
Paraglomerales	*Paraglomeraceae*	*Paraglomus*
Archaeosporales	*Geosiphonaceae*	*Geosiphon*
	Ambisporaceae	*Ambispora*
	Archaeosporaceae	*Archaeospora* (including the former *Intraspora*)

sent a significant mechanism functional to host root location, appressorium formation and symbiosis establishment (Sbrana & Giovannetti 2005). The symbiosis phase begins by fungal hyphae connection with the plant roots through appressorium and fungi penetrate into the cortex (Giovannetti *et al*. 1993) to form morphologically distinct specialized structures – inter- and intracellular hyphae, vesicles, and arbuscules (Figure 1). The arbuscules represent the place of active bi-directional transfer of nutrients between plant and fungus (Requena *et al*. 2007) and play a major role in arbuscular mycorhizal symbiosis. The hyphae penetrate outside of the roots, into the soil, create extra-radical mycelium, and complete life cycle by the formation of new asexual spores in extra-radical mycelium (Requena & Breuninger 2004). Under this symbiosis, the AMF stimulate growth and reproduction of plants through better access to nutrients (P and N) and increased absorption of water from the soil by the extra-radical and intra-radical mycelium (Bago *et al*. 2001). Conversely, the plant provides carbon in the form of saccharides produced by photosynthesis (Pfeffer *et al*. 1999) transferred to the fungi via active or passive mechanisms (Doidy *et al*. 2012) by intra-radical fungal structures. Once AM fungi colonize the plants, they persist with the root systems and can be moved into other soil (Mishra *et al*. 2018).

Rhizosphere affected by mycorrhizas described by the term „mycorrhizosphere" has unique characteristics (Li *et al.* 1991). Mycorrhizal fungi take over the role of root hairs and expand root system of plants leading to increasing of the plant absorption area, improved absorption capacity of roots, and better utilization of hardly available nutrients. The mycorrhizosphere consists of roots, hyphae of the AMF, associated microorganisms, and the soil around them (Figure 2) (Mohammadi *et al.* 2011). Mycorrhiza also influences the colonization of roots by other microorganisms; increases resistance of roots to soil pathogens (Pozo *et al*. 2002); affects the relationship between soil, plant, and water; promotes adaptation of plants to adverse conditions such as drought and soil salinity (Giri *et al*. 2003); and has an important role in maintaining the overall soil stability (Azaizeh *et al*. 1995). AMF also detoxify the plant environment containing higher concentration of heavy metals (Hildebrandt *et al*. 1999) and induce the production of several phytohormones. Danneberg *et al.* (1993) observed in the roots and shoots of plants colonized by AMF increased amounts of several substances, such as abscisic acid, auxins, gibberellins, and substances similar to cytokinins. Simultaneously, in the plant tissues an increased ac-

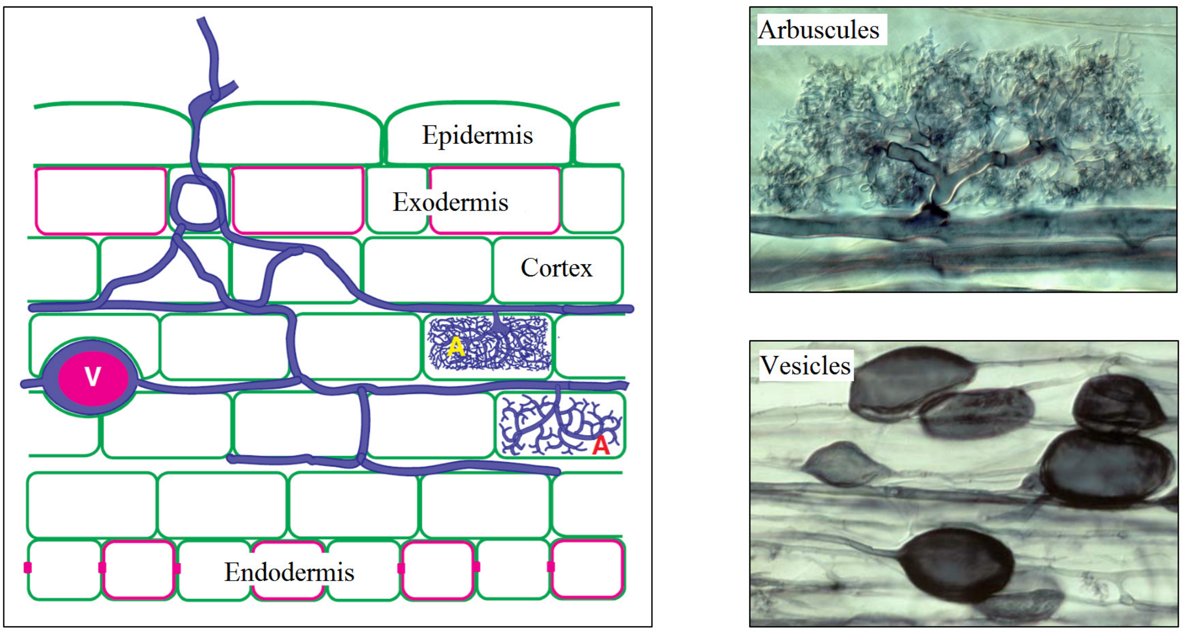

Figure 1. Typical intracellular structures (A – arbuscules and V – vesicle) of arbuscular mycorrhiza produced by *Glomus* species (left). A mature arbuscule (right up) and vesicles (right down) of *Glomus* (Brundrett 2008, photos © Mark Brundrett with permission)

tivity of some enzymes (peroxidases, phosphatases, alkaline phosphatases), enhanced photosynthesis activity, concentration of chlorophyll, and increased levels of reducing saccharides, lipids, fatty acids, amino acids, and proteins were observed (Selvaraj & Chellappan 2006).

Mineral nutrition

The extensive AMF mycelium obtains from soil nutrients such as phosphorus, nitrogen, zinc, copper, iron, potassium, calcium, magnesium, and others (Clark & Zeto 2000). In some cases, the nutrients can control the development or start the symbiosis (Ryan & Angus 2003). AMF can also cause a change in absorption of more nutrients at the same time but the effect on individual nutrients may be different. Sometimes, there may be increased and in other cases decreased intake of individual nutrients (Azaizeh *et al*. 1995; Mohammad *et al*. 2003).

Phosphorus. Phosphorus is one of the key biogenic macroelements necessary for growth and metabolism of plants (Zou *et al.* 1992). Phosphorus has an important role in the transfer of energy by the establishment of energy-rich esters of phosphoric acid, and is a basic element of macromolecules, such as nucleotides, nucleic acids, and phospholipids (Marschner 1995). A large part of inorganic phosphate applied to the soil as fertilisers is rapidly converted to the unavailable form of low solubility. The soluble phosphate is then released from the insoluble form by various reactions involving the participation of other rhizosphere microorganisms (Khan *et al*. 2007). The phosphate ions are extremely immobile in the soil due to the formation of insoluble complexes with the prevailing soil cations, such as Fe^{3+}, Al^{3+}, and Ca^{2+}. Consequently, the phosphate ions diffuse in soil very slowly but in the surrounding soil occupied by the roots (depletion zone) phosphate is exhausted very quickly. Then the rate of uptake is not defined by plant physiology but by slow diffusion of phosphate ions in the soil (Helgason & Fitter 2005). The presence of phosphate in the rhizosphere, respectively in the mycorrhizosphere, is the major factor contributing to the creation of mycorrhiza association. AMF increase intake of relatively immobile phosphate ions for their host plant due to the ability of fungal extra-radical growth (George *et al*. 1995). The depletion zone is around the host plant root, where plant roots are able to pump the necessary nutrients. AMF extra-radical mycelium grows beyond the depletion zone and acquires phosphate unavailable directly for the plant (Smith *et al*. 2003). Phosphate is then transported in

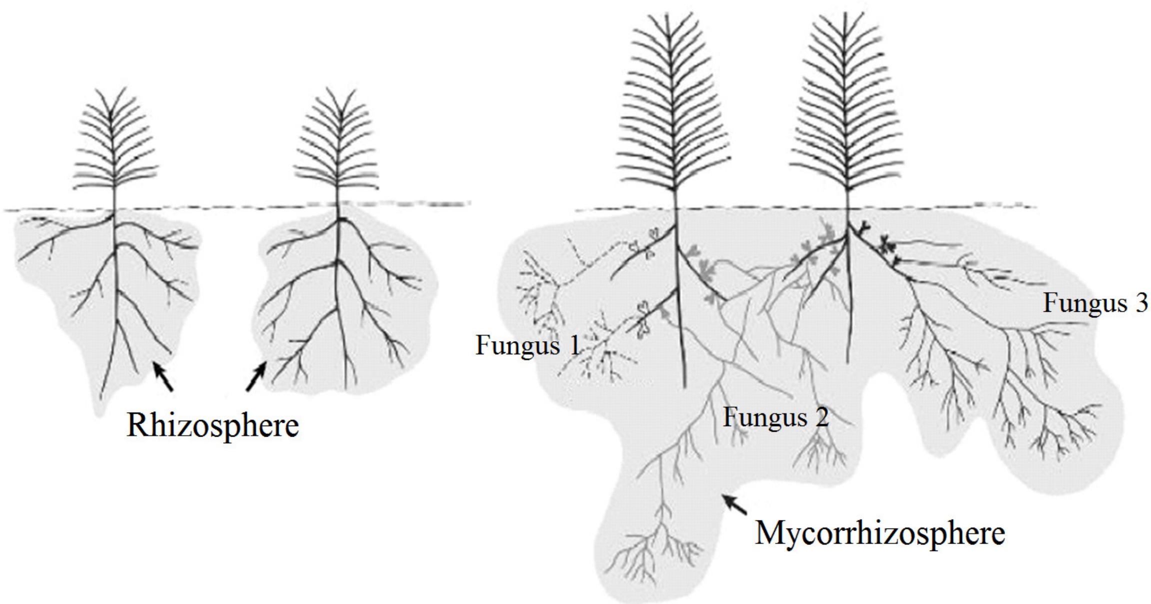

Figure 2. The area of soil occupied by plant roots only (rhizosphere, left) and by plant roots colonized by mycorrhizal fungi (mycorrhizosphere, right) (Mohammadi *et al.* 2011)

the form of polyphosphates from soil through AMF into intra-radical mycelium (Bucher 2007), already present in the roots of the host plant (Figure 3). The phosphate intake into plants is via plant phosphate transporters, which are produced during the development of AM symbiosis (Pumplin & Harrison 2009). Due to the fact that plant obtains most of the phosphorus through fungal symbiosis, it is possible to assume that the plant phosphate transporters, which partially regulate the phosphate intake, have a great importance to productivity and plant growth in most ecosystems (Smith *et al*. 2003). Increased absorption of phosphorus is generally considered as the most important contribution that AMF provided for the host plant. Simultaneously, the phosphorus level in the plants is often a major factor in regulating the relationship between plants and AMF. However, there are plants that do not respond to colonization of AMF due to high concentration of phosphorus in the soil and the colonization of plants by AMF is suppressed (Kahiluoto *et al*. 2001). Cheng *et al.* (2013) in their study confirmed that higher content of phosphorus in the soil is associated with lower mycorrhizal root colonization rates and lower AMF diversity.

Nitrogen. AMF can efficiently mediate transfer large amounts of nitrogen from the soil into the roots of host plants (Jackson *et al*. 2008). AMF extra-radical hyphae receive from the soil great amounts of nitrogen in the form of ammonium cations (NH^{4+}), nitrates (NO^{3-}) or amino acids and subsequently transfer to the plants (Johansen *et al.* 1992; Bago *et al.* 1996; Hawkins *et al*. 2000). Inorganic nitrogen is transmitted from the extra-radical mycelium to the fungal intra-radical structures in the form of amino acids which are transported to the plant in the form of the ammonium cations (Govindarajulu *et al*. 2005). AM symbiosis is involved in the process of mineralization of nitrogen in the soil, controls the recycling of plant residues in the production of biomass, and affects the structure of soil microorganisms (Atul-Nayyar *et al*. 2008; Leigh *et al.* 2009).

AMF and abiotic factors of environment

The abiotic factors affecting the composition and effectiveness of AMF community in soil are: pH, or-

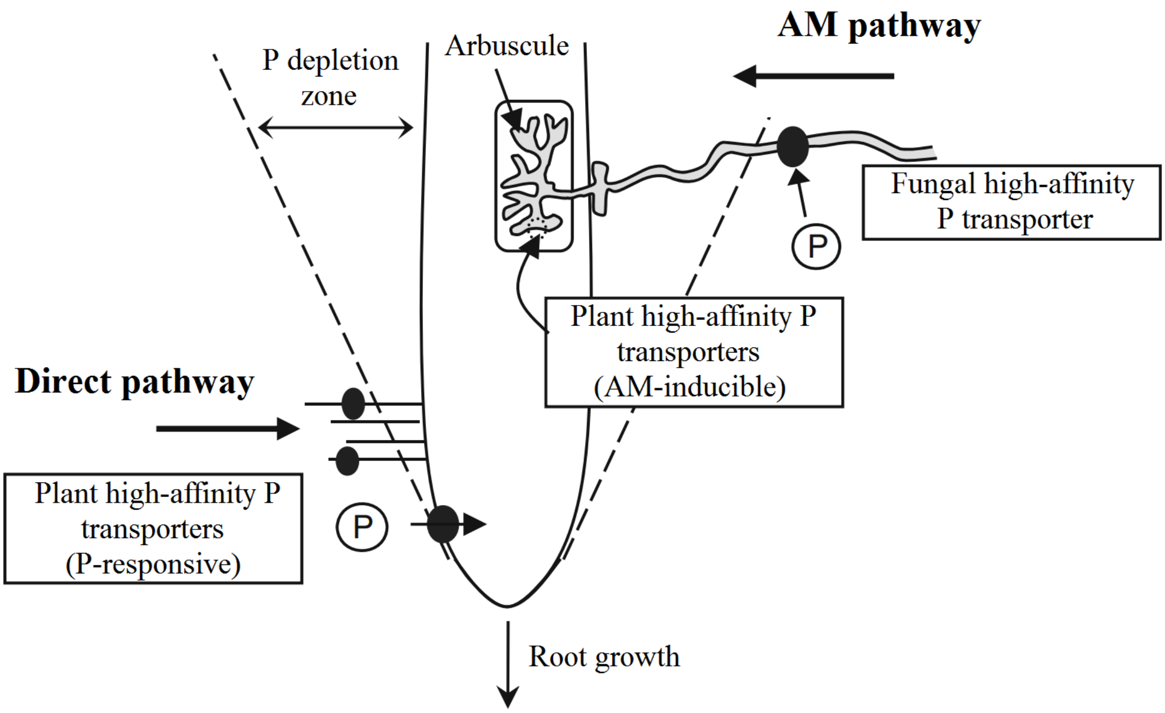

Figure 3. The scheme of phosphate direct uptake from a depletion zone through the root hair cells directly into the root and also using AMF transporters located in the extra-radical hyphae. Phosphate is transferred via the hyphae to the roots, where cortical cells are involved in the absorption of phosphate (Smith *et al.* 2010)

ganic matter, phosphorus availability, heavy metals, agricultural practice, and others. Changes in these factors can lead to differences in symbiotic efficiency and demonstrate the functional diversity among the different AMF. Mycorrhizal symbiosis can improve the physiological effectiveness of plants exposed to stress.

Soil salinity. AMF presented in the environment with increased soil salinity influence on the formation and function of mycorrhizal symbiosis (Kumar *et al.* 2010). The increased soil salinity negatively affects the plant growth through reducing nutrients uptake and increasing osmotic stress of plants (Abdel-Ghani 2009). Some studies suggest that AM fungi increase the plant's ability to cope with increased salinity (Yano-Melo *et al.* 2003; Rabie & Almadini 2005; Al-Karaki 2006; Cho *et al.* 2006; Sannazzaro *et al.* 2006). This can be achieved by increasing the intake of nutrients such as P, N, Zn, Cu, and Fe (Cantrell & Linderman 2001; Asghari *et al.* 2005; Al-Karaki 2006), inhibiting high uptake of Na and Cl and their transport to plant shoots (Daei *et al.* 2009), improving water uptake (Ruiz-Lozano & Azcon 2000), accumulating of proline and polyamines (Evelin *et al.* 2009; Ibrahim *et al.* 2011), or increasing any of enzymatic antioxidant defence system (Wu *et al.* 2010). Other arbuscular mycorrhizal mechanisms can include osmotic adaptation assisted in maintaining the leaf turgor pressure, influence the photosynthesis, transpiration, stomatal conductance, and water use efficiency (Juniper & Abbott 1993).

Plant-water relationship. AMF have an impact on the plant-water relationship, thereby increasing the host plant resistance to drought. Plants colonized by AMF are able to absorb more water from the soil in comparison with not colonized plants (Khalvati *et al*. 2005) and the amount of received water is dependent on the fungal species (Marulanda *et al.* 2003). Furthermore, AMF affect the efficient use of water and root conductivity (Auge 2001). An increased tolerance to water stress relates to the fact that endophytes have an impact on the increased conductivity of the leaves, transpiration, and intake of phosphorus and potassium. Potassium plays a key role in plants exposed to water stress when the free cations are responsible for the activity of leaf stomata. The specific physiological (CO_2 fixation, transpiration, water use efficiency) and nutritional (P and K) mechanisms of the AMF are involved in the symbiosis to contribute to the alleviation of the drought stress (Ruiz-Lozano *et al*. 1995).

Climatic changes. The most commonly considered global and regional climatic changes affecting mycorrhiza are elevated atmospheric CO_2, increased tropospheric ozone, ultraviolet radiation, temperature, and drought (Mohan *et al*. 2014). However, it is not just one factor that has implications on the AM association but the influence of several factors must be taken into account. For example, AM colonization of grass roots decreased with warming and in combination with elevated CO_2 decreased even more (Olsrud *et al.* 2010). Treseder (2004) confirmed that increased atmospheric CO_2 contributes to improved activity of mycorrhizal associations and has a beneficial effect on the mycorrhizal abundance. Other studies have shown that increased atmospheric CO_2 can affects differently on AMF and it is important to consider what plant species create an association with AMF. Garcia *et al.* (2008) founded that the increased atmospheric CO_2 not affected the length of hyphae and root colonization in a desert environment. Similarly, in a warm temperate forest the increased CO_2 have no effect on AMF (Garcia *et al.* 2008). On the other hand, in the chaparral ecosystem the amount of AM hyphae and the glomalin protein increased with increasing of CO_2 (Allen *et al.* 2005) and also in a sandstone grassland the length of the AM hyphae and root colonization were increased (Rillig *et al.* 1999). Most studies examined the combined effect of temperature on the AMF and host plant. Generally, internal colonization increases with temperature between 10°C and 30°C (Wang *et al*. 2002) but temperature below 15°C may decrease the colonization (Zhang *et al.* 1995). At temperatures above 15°C the AMF provide to the plants increased amount of phosphorus in comparison with the non-mycorrhizal plants (Wang *et al.* 2002; Karasawa *et al.* 2012).

Heavy metals. Nowadays, soil contamination with heavy metal is a global problem caused mainly by anthropogenic activities such as mining, agriculture, smelting, electroplating, and other human activities (Gomez-Sagasti *et al.* 2012). Heavy metals are heavily degraded in the soil, accumulate in the soil, and affect the microbial biomass, activity, and diversity (Alguacil *et al.* 2011; Margesin *et al.* 2011). Community of AMF is sensitive to the presence of metals in the soil. The long term application of sludge with increased amount of heavy metals in the soil can significantly reduce the total number of spores and diversity of AMF (Del Val *et al.* 1999). However, symbiosis of AMF with plants could be a potential biological solution to increase plant resistance to heavy metals and to improve fertility of contaminated soil (Vivas *et al*. 2005). The immobilization of metals through the fungal biomass is one of the possible mechanisms. The beneficial use of AM fungi is through improved nutrient acquisition and increased growth by arresting metal uptake in different mycorrhizal structures (Kaur & Garg 2017). Also, plant roots colonized by AMF can form and strengthen a root barrier against the transfer of heavy metal and reduce their transmission (Andrade & Silveira 2008). This effect is ascribed to the absorption of metal by chitin in the cell walls of the hyphae, which has a significant ability to bind metals (Joner *et al*. 2000). Glomalin, a glycoprotein produced abundantly on hyphae and spores of AMF in soil and in roots, has also a chelating effect, thereby decreases the availability of metals to plants (Gonzalez-Chávez *et al*. 2004). Another possible mechanisms are the dilution of concentrations of metals in plant tissues as a result of plant growth promoting by AMF (Andrade & Silveira 2008) and increased exclusion of metals by precipitation or chelation in the rhizosphere (Kaldorf *et al*. 1999).

Soil pH. The soil pH is an important factor affecting the AMF community in the soil. The different AMF have various claims and sensitivity to the pH (Hayman & Tavares 1985). Soil acidity affects the number of AMF spores in the soil (Mohammad *et al.* 2003) and species composition (Porter *et al.* 1987; Sharma *et al.* 2009). Changes of soil pH may affect the availability of nutrients for the plant, e.g. inorganic P is more easily available in the soil with pH ≈ 6.5. Lower pH decreases the solubility of Fe and in high pH solubility of Ca phosphates decreases (Marschner 1995).

AMF and biotic factors of environment

Plants. There were found 5–30 AMF species at a given locality (Douds & Millner 1999) and 8 various AMF species were found colonizing a single 5 centimetres root segment in field experiments (Tommerup 1988). Increasing of plant diversity could increase the AMF species diversity and also affects the production of spores. Some plant species may support individual AMF species, which may lead to increasing in species richness. Moreover, root exudates of different plant species can affect the germination and growth of AMF species (Douds *et al.* 1996). It appears that AMF have benefit from increased plant diversity due to number of possible host-fungal pairings and elevated density of plant roots available for colonization, AMF growth and sporulation (Burrows & Pfleger 2002). De León *et al*. (2018) observed that roots of soybean plants were colonized by diverse communities of AM fungi and composition of AMF community in roots was primarily driven by host plant identity.

Plant pathogens. Plants in their natural environment interact with a large number of harmful herbivorous insects and pathogenic microorganisms. AMF directly do not ensure the protection of plants against phytopathogens, but they induce the ability of plants to respond more quickly to the pathogen attack (Whipps 2004). In some cases, the apparent plant resistance to pathogens and diseases may be the result of improved nutrition (Karagiannidis *et al*. 2002). Probably one of the most important cases is the elimination of pathogens from the area where the colonization of root cells by AMF occurs. The advantage is when the AMF colonize the plant before pathogen (Slezack *et al*. 1999). Another factor may be related with changes in the root exudates composition (Filion *et al*. 1999), which can cause changes in the rhizosphere microbial community structures (Hassan Dar *et al*. 1997). Also changes in the root structure of host plant or biochemical changes associated with protective mechanisms of plant may cause the putative plant resistance to pathogens (Gianinazzi-Pearson 1996; Vigo *et al*. 2000).

Other soil microorganisms. Bacterial communities and individual species support the germination of AMF spores and may increase the rate and extent of fungal colonization of plant roots (Johansson *et al*. 2004). Once the arbuscular symbiosis is developed, AMF hyphae affect the surrounding soil leading to the development of different microbial communities (Linderman 1988). AMF communicate with beneficial rhizosphere microorganisms in the mycorrhizosphere, including bacteria involved in the nitrogen fixation and rhizobacteria (Biró *et al*. 2000). In the concept called mycorrhiza helper bacteria (MHB) the bacteria directly assist in the formation of mycorrhiza and positively affect symbiosis. MHB mechanisms stimulate spore germination, growth of AMF mycelium, improve the soil conditions and chemistry via alteration of phytohormones level (Frey-Klett *et al*. 2007). AMF and *Pseudomonas fluorescens* (rhizosphere bacteria) have gained considerable attention among soil microorganisms due to their positive effect on plant growth (Smith & Smith 2011). Gamalero *et al.* (2004) studied the effect of the interaction between the AMF and *P. fluorescens* on root morphology and the resulted effect was synergistic or neutral, respectively. Similar study was carried by Cosme & Wurst (2013). Their results indicated that the positive interactions between AMF and *P. fluorescens* on the root morphology were depended on the nutrient status in the rhizosphere and the root hormonal balance. Their result also indicate that the *P. fluorescens* belongs to MHB, even if it is not isolated from the rhizosphere of mycorrhizal plant (Glenn *et al.* 1985). This means, that the MHB mechanisms are independent of the rhizobacteria origin (Frey-Klett *et al.* 2007).

AMF and agriculture

Fertilising, plowing, biocides, and other agricultural practices may have a negative impact on the AMF community (Jansa *et al*. 2002) and soils can be depleted about the AMF diversity (Helgason *et al*. 1998). Changes in the composition of the AMF can be caused by various factors, such as the disruption of AMF hyphal networks, changes in the soil nutrient content, and in the microbial activity (Jansa *et al*. 2003). Application of fertilisers containing phosphorus may leads to less dependence of plants in AMF colonization, reduced colonization of roots by AMF, or less spore density of AMF in soils (Kahiluoto *et al*. 2001). Also, fertilisers with a high content of nitrogen may have negative effects on the colonization and diversity of AMF (Egerton-Warburton *et al*. 2007). The soil tillage may significantly disrupt the mycorrhizal network, delay or reduce root colonization and the soil volume usable for AMF. Simultaneously, it may reduce intake of necessary nutrients by plants, plant growth and production (Evans & Miller 1990). In some cases, the effects on growth and nutrient intake are temporary and the effect of tillage on the AMF community also may depends on the soil type (Kabir 2005). Säle *et al*. (2015) demonstrated that AMF communities were affected by land use, farming and tillage system, and fertilisation. Other studies showed that community structure and diversity of AMF in soils differs between tilled, reduced, and no-tilled soils (Jansa *et al.* 2002; Köhl *et al.* 2014; Maurer *et al.* 2014; Wetzel *et al.* 2014). Some fungicides significantly inhibited the ability of AMF to colonize plants, phosphorus uptake (Schweiger & Jakobsen 1998), and affect sporulation. Indirect effect of herbicides is due to elimination of weeds, the potential hosts of AMF (Ryan *et al*. 1994). Some biocides may have a negative, neutral (herbicides) or positive (nematicides) effect on the AMF community (Pattinson *et al*. 1997).

CONCLUSIONS

Arbuscular mycorrhizal fungi are microorganisms with very important and valuable functions in growing systems of agricultural crops. Mycelia of arbuscular mycorrhizal fungi assist in uptake of nutrients from soil to the plants, such as phosphorus, nitrogen, zinc, copper, and other elements. Mycorrhizal symbiosis can improve the physiological response of plants to abiotic and biotic stresses, increase biomass yield, and retain productivity of plants. Also, they are useful in decreasing of pollutants in the biosphere, including heavy metals, organic compounds, and radionuclides. However, conventional agricultural practices such as fertilising, tillage, and application of chemical pesticides acting as biocides, may have a negative impact on their communities. This can results to depletion of arbuscular mycorrhizal fungi from agricultural soils, especially from the genetic diversity point of view, followed by reduction of intake of necessary nutrients by plants and decreasing of plant growth and crop productivity. However, the potential of AMF have to be exploited for the sustainability of agricultural production. Utilization of mycorrhizal symbiosis can reduce external inputs into agriculture, while the crop productivity can remains or may be even higher. Ecological impacts of particular importance are associated with the bellow-ground ecosystem affected also by AMF and AMF-plant interactions. To meet the challenge of exploitation of arbuscular mycorrhizal symbiosis in agricultural practice can contribute studies of qualitative and quantitative analysis of AMF diversity in soil.

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