The significance of mycorrhizal fungi for crop productivity and ecosystem sustainability in organic farming systems

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Abstract

Mycorrhizal fungi are widespread in agricultural systems and are especially relevant for organic agriculture because they can act as natural fertilisers, enhancing plant yield. Here we explore the various roles that mycorrhizal fungi play in sustainable farming systems with special emphasis on their contribution to crop productivity and ecosystem functioning. We review the literature and provide a number of mechanisms and processes by which mycorrhizal fungi can contribute to crop productivity and ecosystem sustainability. We then present novel results, showing that mycorrhizal fungi can be used to suppress several problematic agricultural weeds. Our results highlight the significance of mycorrhizal fungi for sustainable farming systems and point to the need to develop farming systems in which the positive effect of these beneficial soil fungi is optimally being utilized.

Introduction

The 400 million year old symbiosis between the majority of land plants and arbuscular mycorrhizal (AM) fungi is one of the most ancient and abundant mutualisms on Earth. AM fungi form extensive hyphal networks in soil and provide plants with nutrients in return for assimilates (Smith & Read 1997). AM fungi can act as support systems for seedling establishment, provide resistance against drought and some pathogens, and AM fungi can enhance biological diversity in grassland (van der Heijden et al. 1998). Several studies have shown that AM fungi contribute to up to 90% of plant P demand (Jakobsen et al. 1992; van der Heijden et al. 2006).

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AM fungi are especially important for sustainable farming systems because AM fungi are efficient when nutrient availability is low and when nutrients are bound to organic matter and soil particles. Many important agricultural crops can benefit from AM fungi, including maize, potato, sunflower, wheat, onion, leek and soybean, especially under conditions where nutrient availability is limiting plant growth. Moreover, AM fungi not only can promote via directs effects, but there are also a number of indirect effects such as a stimulation of soil quality and the suppression of organisms that reduce crop productivity (see Table 1 for an overview).

Table 1: Direct and indirect effects of mycorrhizal fungi on crop productivity in organic farming systems

Direct effects on crops
Stimulation of plant productivity of various crops
Nutrient acquisition (P, N, Cu, Fe, Zn)
Enhanced seedling establishment
Drought resistance
Heavy metal resistance
Indirect effects
Weed suppression
Stimulation of nitrogen fixation by legumes (green manure)
Stimulation of soil aggregation and soil structure
Suppression of some soil pathogens
Stimulation of soil biological activity
Increased soil carbon storage
Reduction of nutrient leaching

Until now, most studies have investigated the effects of AM fungi on plant growth using pot experiments with single plants. However, in the field crops co-occur with weeds and some crops are grown together with other crops in mixtures. Hence, it is necessary to use a “system” approach in order to assess the significance of AM fungi for the functioning of agricultural ecosystems. Using such a system approach we explore in this paper whether AM fungi can suppress growth of several highly problematic agricultural weeds that coexist with crops.

Methods

42 microcosms simulating a sunflower cropping system were established in the greenhouse under controlled conditions. Sunflower and six weed species were grown together in microcosms (sunflower-weed mixtures) or weeds and sunflower were grown alone (weed and sunflower monocultures respectively). Half of the microcosms of each treatment were inoculated with a mixture of three AM fungal species and the other half of the microcosms received sterilized inoculum as a control. The microcosms were harvested after 14 weeks. Dry weights of sunflower and weeds were determined in each treatment and used to calculate the competitive balance index according to Wilson (1988). It was tested whether AM fungi reduce weed growth and alter competitive interactions between weeds and sunflower.

Results & Discussion

It is well known that AM fungi enhance plant growth. However, AM fungi are not only beneficial and interactions between plants and AM fungi can range from mutualistic to parasitic (van der Heijden 2002; Klironomos 2003). Studies performed with plants from natural communities show that AM fungi have a negative impact on several ruderal plants (Francis & Read 1995). Many important weeds have a ruderal lifestyle, suggesting that AM fungi have the potential to suppress weed growth. To test this we established microcosms in which sunflower was grown together with weeds (see methods). We observed a reduction in weed biomass when AM fungi were present in the microcosms supporting our expectations. Moreover, the presence of AM fungi significantly enhanced the competitive ability of sunflower relative to the weeds (Figure 1). Thus, our results show that AM fungi alter the interaction between weeds and sunflower, promoting sunflower and suppressing weeds.

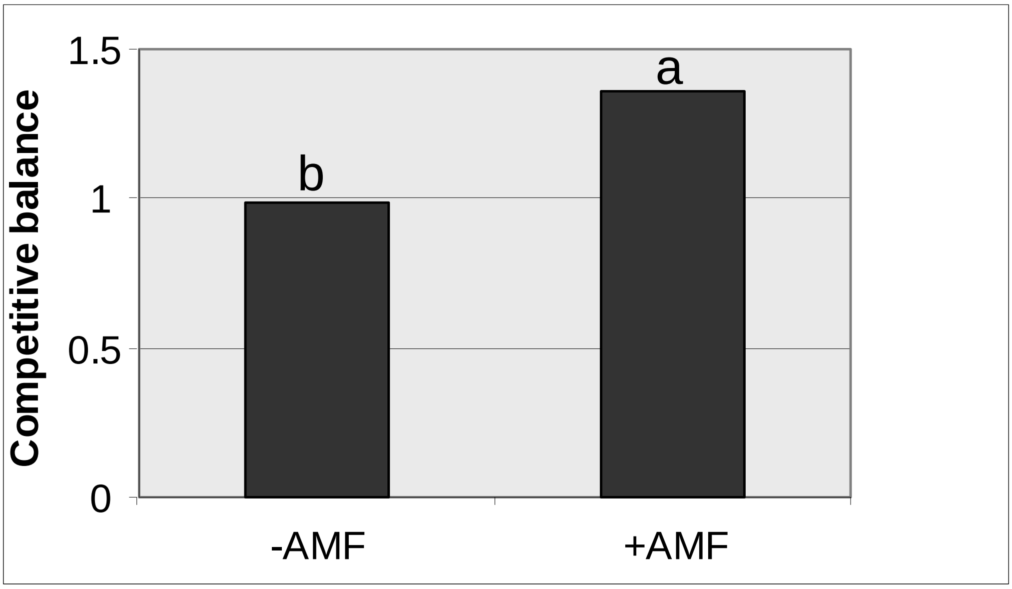

Figure 1: Competitive balance between sunflower and weeds in microcosms with AM fungi (+AMF) or without AM fungi (-AMF). A higher competitive balance indicates a higher competitive ability of sunflower. A competitive balance of > 0 indicates that sunflower is more competitive than weeds.

Conclusions

Our results show that mycorrhizal fungi can contribute to weed control because they suppress the competitive ability of weeds relative to sunflower. Moreover, mycorrhizal fungi can directly and indirectly contribute to plant productivity in organic farming systems. Mycorrhizal effects include enhanced nutrient uptake, enhanced seedling establishment and stimulation of soil structure. Additional research is needed to develop farming systems that optimize the use of natural resources such as mycorrhizal fungi for sustainable agricultural production.

References

Jakobsen I., Abbott L.K., Robson A.D. (1992): External hyphae of vesicular-arbuscular mycorrhizal fungi associated with *Trifolium subterraneum* L. I: Spread of hyphae and phosphorus inflow into roots. New Phytol., 120, 371-380.

Francis R., Read D.J. (1995). Mutualism and antagonism in the mycorrhizal symbiosis, with special reference to impacts on plant community structure. *Can. J.Bot.* 73, S1301-S1309.

Klironomos J.N. (2003): Variation in plant response to native and exotic arbuscular mycorrhizal fungi. Ecology 84: 2292-2301.

Smith S.E., Read D.J. (1997): Mycorrhizal symbiosis, 2nd ed. Academic Press, London, UK.

van der Heijden M.G.A., Klironomos J.N., Ursic M., Moutoglis P., Streitwolf-Engel R., Boller T., Wiemken A., Sanders I.R. (1998). Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. Nature 396: 72-75.

van der Heijden MGA. 2002. Arbuscular mycorrhizal fungi as a determinant of plant diversity: in search for underlying mechanisms and general principles. In: van der Heijden MGA, Sanders IR. ed. *Mycorrhizal Ecology*. Ecological Studies 157. Springer Verlag, Heidelberg, Germany.

van der Heijden M.G.A., Streitwolf-Engel R., Riedl R., Siegrist S., Neudecker A., Ineichen K., Boller T., Wiemken A., Sanders I.R. (2006): The mycorrhizal contribution to plant productivity, plant nutrition and soil structure in experimental grassland. New Phytol. 172: 739-752.

Wilson J.B. (1988) Shoot competition and root competition. J. Appl. Ecol. 25: 279-296.