The Importance of Mycorrhizal Fungi in Agriculture Technologies

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Abstract: ***Arbuscular mycorrhizal fungi are fundamental in field stress management and agricultural yield. In general, the rhizosphere microbiome holds enormous potential to increase crop yields and mitigate both diseases and abiotic stress factors through rhizobacteria and mycorrhizae Modern inoculum-based biotechnology will be increasingly incorporated into common practice. Our perspective is that new inoculum consortia applications will be developed every year. In addition to increasing the productivity of agricultural systems, these innovations are important for sustainability, to reduce agriculture's polluting environmental impact. However, traditional substrate-based techniques focus on the isolation, purification, and cultivation of AMF spores, thereby enabling the establishment of pure cultures. As the demand for sustainable agriculture increases, the application of AMF in agroecosystems has gained prominence. This review discusses the implementation of these techniques in conventional and organic farming systems. In conclusion, this review synthesizes the diverse methodologies employed in AMF propagation, from traditional spore-based techniques to cutting-edge approaches. This paper discusses is important of mycorrhiza in agriculture and different technologies and need to research.***

Keywords: Arbuscular mycorrhizal fungi, Agriculture Technologies and need to research

1. Introduction

The focus in applied research on mycorrhiza in sustainable agriculture could be circumscribed as developing mycorrhizal technology. Clearly most easily recognized as a mycorrhizal technology is the production and application of mycorrhizal fungal inoculum (Gianinazzi et al., 2002; Vosatka et al., 2012; Solaiman et al., 2014), directly addressing the decline in mycorrhizal abundance in agricultural fields. Inoculation can have demonstrable yield benefits, powerfully documented by the recent, very in-depth study by Hijri (2016) analyzing 231 potato field trials. Nevertheless, we argue here that this should not be the exclusive focus of next-generation mycorrhizal technology. A recent analysis concluded that one of the most striking aspects of sustainable agricultural intensification is an "increase in knowledge per hectare" (Buckwell et al., 2014), i.e., a better understanding of how to achieve resource-efficient agroecosystems with minimal environmental impacts in any given location. This is a very useful conceptualization that helps frame what mycorrhizal technology could or should increasingly mean.

2. Mycorrhizal Technology: Components

Components of an Inclusive Mycorrhizal Technology

We propose some key elements of an inclusive mycorrhizal technology monitoring, agricultural management, database tools, plant breeding and ecological engineering of communities of mycorrhizal fungi ("myco-engineering") and their associated microbiota. *Monitoring* refers to assessment of the abundance (in roots and soil) and diversity of mycorrhizal fungal abundance in the field. *Management* represents a complex set of tools that can impact abundance and diversity of mycorrhiza, including agronomic practices with known effects on mycorrhiza (e.g., crop rotations, tillage, fertilizer and other additions), and also more directly targeted approaches, such as inoculation with fungal strains or mycorrhization helper-bacteria. *Databases* serve as dynamic repositories of site-specific information linking site parameters with mycorrhizal abundance and functioning. *Plant breeding* is an important component, since mycorrhizal fungi require suitable hosts. And *myco-engineering* denotes an approach grounded in community ecology with the goal to promote members of the mycorrhizal fungal community with desirable traits.

Abiotic Factors through Rhizobacteria and Mycorrhizae.

Soil quality degradation and disturbance to natural ecosystem functionality are evident and therefore threaten environmental sustainability; furthermore, they could be a warning for future food security (Velten, et al., 2015 and Thirkell, et al., 2017). In general, the rhizosphere microbiome holds enormous potential to increase crop yields and mitigate both diseases and abiotic stress factors through rhizobacteria and mycorrhizae modern inoculum-based biotechnology will be increasingly incorporated into common practice. AMF induce morphological, biochemical, and physiological alterations, including changes at the gene expression level in the plant to intensify plant productivity (Rosendahl, 2008, and Caruso, et al., (2012). Most approaches discussed herein are based on their ability to enhance plant nutrient and water uptake by means of fungal mycelium extension. Mycorrhiza is mainly located on the roots of the plants but associations are also observed in bryophytes. The symbiotic relationship is established when fungal spores germinate developing thread-like structures called hyphae that enter the epidermis of plant roots (Meyer, 2007). The fungus sends out a large network of hyphae across the soil after colonisation of the root to shape a greatly improved absorptive surface area. This leads to improved acquisition and absorption of nutrients by plant roots, especially elemental phosphorus (P), zinc (Zn), manganese (Mn) and copper (Cu) and water. The plant supplies nutrients for the fungus in exchange (Ramasamy et al., 2020).

Abiotic stresses include drought, soil salinity, flooding, extremes of temperature, and contamination with organic pollutants and heavy metals, while biotic factors include the effects on agricultural production caused by plant pathogens, such as insects, fungi, bacteria, viruses, and nematodes. However, the same soil, and in particular, those that inhabit the rhizosphere, may contain beneficial microorganisms, whose associations with plants facilitate plant growth. The rhizosphere may be defined as the part of the soil that is directly influenced by root exudates, which include metabolites, amino acids, or vitamins that can serve as nutrients and stimulate the growth of microbial populations (Olanrewaju et al., 2019; Vives-Peris et al., 2020).

In rhizospheric soil, multiple interactions that are essential to stimulate the growth, health, and development of plants take place among the microorganisms (Trivedi et al., 2020). Two of the main players in this ecosystem are mycorrhizal fungi and plant growth-promoting bacteria (PGPB). These microorganisms play a key role in sustainable agricultural production, and can enable growers to lessen or avoid the use of chemical fertilizers and pesticides. Mycorrhizae (a combination of mycelium of the fungus and the roots of the plant) form networks that capture water and nutrients from the soil, which facilitate the acquisition of the plant. PGPB can also solubilize various nutritional resources or produce antimicrobial compounds that antagonize potential phytopathogens. Interestingly, some bacteria can modulate mycorrhizal symbiosis with the plant. Thus, the tripartite interaction between mycorrhizae, bacteria and plants can be an excellent strategy for sustainable agricultural production (Glick, 2020; Phour et al., 2020), particularly in regions where abiotic stresses decrease the quality of crops.

3. Mycorrhiza Agriculture Technologies

Agricultural management, database tools, plant breeding and ecological engineering of communities of mycorrhizal fungi ("myco-engineering") and their associated microbiota. *Monitoring* refers to assessment of the abundance (in roots and soil) and diversity of mycorrhizal fungal abundance in the field. *Management* represents a complex set of tools that can impact abundance and diversity of mycorrhiza, including agronomic practices with known effects on mycorrhiza (e.g., crop rotations, tillage, fertilizer and other additions), and also more directly targeted approaches, such as inoculation with fungal strains or mycorrhization helper-bacteria. *Databases* serve as dynamic repositories of site-specific information linking site parameters with mycorrhizal abundance and functioning. *Plant breeding* is an important component, since mycorrhizal fungi require suitable hosts. And *myco-engineering* denotes an approach grounded in community ecology with the goal to promote members of the mycorrhizal fungal community with desirable traits.

Agricultural management practices, for example, offer a rich opportunity for interventions affecting mycorrhizal fungi. The AM symbiosis responds sensitively to nutrient ratios (Johnson, 2010), and since AM fungal phylotypes associated with certain N:P ratios may be preferentially lost upon cultivation (Verbruggen et al., 2015), tightly managing nutrient stoichiometry in agricultural systems, including the amount, timing and element ratios of nutrient additions will be an important priority—of course always with a view toward ensuring yield. Easy monitoring of the abundance (and functioning) of AM fungi, ideally in real time, possibly the biggest bottleneck at the moment, would allow detection of deleterious management practices, permitting precise responses at the farm level. These data, when combined over many fields and over time, can feed databases to iteratively fine-tune local management interventions. Microbial community engineering (Mueller and Sachs, 2015) is a rapidly developing field in microbial ecology. This technique relies on the selection over multiple microbial generations of entire communities that outperform in a particular function. It has already been used in the selection of bacterial communities, thus similar techniques can be brought to bear on communities of AM fungi, or, perhaps even more importantly, AM fungi and the microbes associated with their extraradical mycelium. Engineering entire consortia, with AM fungi as a part of this larger system, may be very promising, since it is clear that AM functionality may depend on interactions with many other soil organisms.

4. Research Needs

Development of new mycorrhizal technologies needs to be supported by research, and specific research needs for the various components of technology, addition to these, there are some general research needs that are crucial, which we discuss here.

1) First, we need a better understanding of the *relative contribution* of mycorrhiza to any aspect of sustainability. That is, achieving a comprehensive view of all major hypothesized causal pathways by which mycorrhiza influence sustainability, including their interactions with other soil biota. For example, this means measuring also other organism groups, especially if those are also typically important in a given process, for example for nutrient cycling (symbiotic and non-symbiotic diazotrophs, phosphate mobilizers, nitrifiers, ammonia oxidizers) or for soil aggregation (soil animals, roots, bacteria, saprobic fungi). The same also applies to assessing other causal influences (site factors) in order to assess mycorrhizal contributions to yield increase, soil aggregation, crop quality or other parameters. The use of statistical tools such as variance partitioning or structural equation modeling is required to attribute relative effect sizes of mycorrhiza given all the other causal pathways.
2) A second research priority relates to defining which parameters influence mycorrhizal effectiveness. This will help prevent other agricultural management approaches from interfering with the mycorrhizal-mediated benefit. Data demonstrating that mycorrhizas are not as important as previously believed in some circumstances (e.g., Ryan and Kierkegaard, 2012) or for some processes are ultimately very useful in providing realistic expectations for stakeholders and for setting management priorities.
3) Third, there is a need to expand the response variables for documenting mycorrhizal effects. For example, plenty of data exist for direct plant growth responses, but dramatically less knowledge exists for nutrient and

micronutrient contents in the relevant (consumed) tissues (e.g., Lehmann et al., 2014; Lehmann and Rillig, 2015). When considering multiple mycorrhizal-influenced parameters it may also become evident that there are conflicts, i.e., mycorrhiza may positively influence some plant traits and others negatively (e.g., pollination and nutrient uptake; Barber et al., 2013). Carefully documenting such tradeoffs and understanding their mechanistic basis would be crucial and could advance mycorrhizal technology.

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