IMS Newsletter

The International Mycorrhiza Society quarterly e-newsletter

Ukraine stamps, 1999

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Editorial: upcoming ICOM11 and more

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With some delay, we are releasing our seventh issue of the International Mycorrhiza Society -IMS- Newsletter. Starting in 2020, we enter a third year of our increasingly read publication, which enables outreach and communication within and outside the mycorrhizologist community. We happily welcome Pedro M. Antunes, PhD, Professor and Canada Research Chair of the Department of Biology, in Algoma University, Canada, as our *Applications Editor*. His expertise will strongly enrich our Newsletter specifically dedicated to apply mycorrhiza to forestry, restoration, and for enhancing the sustainability of agroecosystems. As always, we encourage our readers to please continue give us feedback, suggestions, and/or advice in order to improve our content.

11th International Conference on Mycorrhiza (ICOM11) in Beijing, China, July 31 to August 5, 2022 (hybrid congress) – Registration and Abstract Submission

We would like to announce that the schedule of the 11th International Conference on Mycorrhiza has been announced and an exciting program with excellent speakers and workshops has been prepared (see: https://icom11.casconf.cn). This year ICOM is organized together with the 5th International Molecular Mycorrhiza Meeting (iMMM5) which complement each other very well. **Please register or submit your abstract until the 1st of May 2022 and register until the 20th of July 2022**. Note that ICOM11 is a hybrid meeting and registration as domestic visitors or online is possible. Domestic visitors attending the conference in Beijing should register at **https://icom11.casconf.cn**. For those attending online it is already possible to obtain ICOM11 virtual event tickets at: **https://mycorrhizas.org/home/join/**. Please note that if you are from outside China, there is currently a two-week quarantine period before you can enter China.

IMS awards

The International Mycorrhiza Society offers four prestigious awards at the next meeting in Beijing, China. If you know a person which you feel deserves an award or if you like to nominate yourself because you feel you made a ground breaking discover (for students and early career awards), please check out the terms of reference and register (https://mycorrhizas.org/ims-awards-icom-11/). **Deadline for nomination or application of IMS awards: 31st of May 2022**. We have four awards:

- AWARD 1: Student Award for Excellence in Mycorrhiza Research Publication (including self-nominations).

- AWARD 2: Early Career Award for Excellence in Mycorrhiza Research Publication (include self-nominations).
- AWARD 3: Mid-Career Mycorrhiza Research Excellence Award (on recommendation by colleague mycorrhizal researchers).
- AWARD 4: Eminent Mycorrhiza Researcher Award (on recommendation by colleague mycorrhizal researchers).

Applications must be submitted to Marcel G.A. van der Heijden (marcel.vanderheijden@agroscope.admin.ch).

Election for a vice President and new IMS Board members

The IMS is looking for nominations for Vice President and Director (focus social media and website communication).

Candidates are suggested by members of the mycorrhizal community and may include self-nominations (**application until 6ᵗʰ April 2022;** contact Jonathan M. Plett: J.Plett@westernsydney.edu.au). The suggested candidates are contacted by the nomination committee members. The list of candidates is then circulated within the community before and during the ICOM, and candidates can be elected until the 3ʳᵈ of August 2022. The elected new Vice President and Director will be announced at the final session of ICOM.

According to the IMS bylaw for the election of Directors and Term:
(a) Subject to the Articles, Directors shall be elected by the Members by Ordinary Resolution at an annual meeting of Members at which an election of Directors is required.
(c) One Director shall be elected to the Office of Vice-President.
(e) The terms of office of Directors shall be two years or as determined by Ordinary Resolution of the Members.

Top Ten Mycorrhizal articles and short articles

In this issue, we present a list of the Top 10 mycorrhizal articles for the last four months (September to December, 2021). We congratulate Camille S. Delavaux (University of Kansas) and co-authors for the first place with their paper "Mycorrhizal types influence island biogeography of plants" (*Commun Biol*). They found that arbuscular mycorrhizal (AM) plants have a stronger mycorrhizal filter than other mycorrhizal or non-mycorrhizal (NM) plant species when colonizing islands, i.e. lower proportions of native AM plant species were found on islands relative to mainlands. The second rank was for the study "A phosphate starvation response-centered network regulates mycorrhizal symbiosis" (*Cell*) by Jincai Shi (Chinese Academy of Sciences) and colleagues, who developed a new map of the rice mycorrhizal symbiosis transcriptional regulatory network. This network deciphers extensive regulation of mycorrhizal symbiosis by endogenous and exogenous signals and highlights co-option of the conserved P-sensing pathway for the mycorrhizal symbiosis. Carlos P. Carmona (University of Tartu) and co-authors take the third place with their *Nature* article "Fine-root traits in the global spectrum of plant form and function". The authors compiled data from different aboveground (TRY) and belowground (GRooT) global datasets, and found that that the aboveground and fine-root traits are mostly decoupled, thus, the aboveground functional strategies tell almost nothing of the fine-root strategies, and vice versa.

This issue includes two research commentaries. The first one by Matthias

J. Salomon (University of Adelaide), with a recent article entitled "Global evaluation of commercial arbuscular mycorrhizal (AM) inoculants under greenhouse and field conditions" published in *Applied Soil Ecology*. They tested several dozens of commercial inoculants in Australia, Europe, and North America. They found that most of the inoculants did not contain viable propagules and did not colonize plant roots or enhance plant yield (less than 10% mycorrhizal colonisation), especially compared to pure cultures. The article includes a series of recommendations to counteract this worrisome issue. The second commentary by Pierre-Luc Chagnon (Université de Montréal) highlights different research priorities for trait-based mycorrhizal ecology, a topic that despite being called for more than 15 years, is still in its infancy, according to Pierre-Luc. He suggests to expand culture-based work (i.e. by identifying relevant traits and measuring them in a reproducible manner) and reassess trait phylogenetic conservatism to strengthen this discipline.

Top 10 papers on mycorrhizal research*

1. Delavaux CS, Weigelt P, Dawson W, *et al.* 2021. Mycorrhizal types influence island biogeography of plants. *Commun Biol* 4: 1128.
https://doi.org/10.1038/s42003-021-02649-2

2. Shi J, Zhao B, Zheng S, *et al.* 2021. A phosphate starvation response-centered network regulates mycorrhizal symbiosis. *Cell* 184: 5527-5540.
https://doi.org/10.1016/j.cell.2021.09.030

3. Carmona CP, Bueno CG, Toussaint A, *et al.* 2021. Fine-root traits in the global spectrum of plant form and function. *Nature* 597: 683-687.
https://doi.org/10.1038/s41586-021-03871-y

4. Ward EB, Duguid MC, Kuebbing SE, *et al.* 2021. Ericoid mycorrhizal shrubs alter the relationship between tree mycorrhizal dominance and soil carbon and nitrogen. *J Ecol* 109, 3524-3540. https://doi.org/10.1111/1365-2745.13734

5. Tedersoo L, Mikryukov V, Anslan S, *et al.* 2021. The Global Soil Mycobiome consortium dataset for boosting fungal diversity research. *Fungal Divers* 111: 573-588. https://doi.org/10.1007/s13225-021-00493-7

6. Mayerhofer W, Schintlmeister A, Dietrich M, *et al.* 2021. Recently photoassimilated carbon and fungus-delivered nitrogen are spatially correlated in the ectomycorrhizal tissue of *Fagus sylvatica*. *New Phytol* 232: 2457-2474.
https://doi.org/10.1111/nph.17591

7. Caiafa MV, Jusino MA, Wilkie AC, *et al.* 2021. Discovering the role of Patagonian birds in the dispersal of truffles and other mycorrhizal fungi. *Curr Biol* 31: 5558-5570.
https://doi.org/10.1016/j.cub.2021.10.024

8. Karst J, Wasyliw J, Birch JD, *et al.* 2021. Long-term nitrogen addition does not sustain host tree stem radial growth but doubles the abundance of high-biomass ectomycorrhizal fungi. *Glob Chang Biol* 27: 4125-4138.
https://doi.org/10.1111/gcb.15713

9. Wang T, Persson P, Tunlid A. 2021. A widespread mechanism in ectomycorrhizal fungi to access nitrogen from mineral-associated proteins. *Environ Microbiol* 23: 5837-5849. https://doi.org/10.1111/1462-2920.15539

10. Högberg MN, Högberg P, Wallander H, Nilsson LO. 2021. Carbon–nitrogen relations of ectomycorrhizal mycelium across a natural nitrogen supply gradient in boreal forest. *New Phytol* 232: 1839-1848. https://doi.org/10.1111/nph.17701

Research commentaries

Global evaluation of commercial inoculants containing arbuscular mycorrhizal fungi

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Arbuscular mycorrhizal fungi (AMF) improve the sustainability of food production systems. They have the potential to reduce our reliance on agrochemicals and reduce the environmental impact of agricultural systems. They have been reported to increase plant yields and nutrition, to suppress diseases, and to improve soil ecosystem functioning through various mechanisms. The abundance and activity of AMF in soils can be promoted through specific soil management methods. For agricultural systems, positive effects of this symbiosis are mostly achieved through minimal soil disturbance and by keeping a consistent plant cover with high plant biodiversity (Bowles *et al.* 2017). However, this is not always possible, for example, when working in arid climates or due to other economic or practical requirements. Also, considerable amounts of vegetables and fruits are produced in substrates with high amounts of peat moss and composts, which are naturally free of AMF. In these cases, the use of commercial inoculants containing arbuscular mycorrhizal (AM) propagules is a logical alternative. Studies using commercial inoculants on Welsh onion (Tawaraya *et al.* 2012) and potatoes (Hijri 2016) proved the economic and ecological benefits of commercial AMF inoculants. It is not surprising that this potential resulted in an increasing number of commercial inoculants being released onto the market (Vosátka *et al.* 2008; Basiru *et al.* 2020). But what about the quality of these products?

Our most recent study (Salomon *et al.* 2022) shone some light on the quality and reliability of the global market surrounding AMF inoculants. This publication includes three individual studies, covering the Australian, European, and North American market. The idea to combine these three individual studies developed at a conference, where researchers from each group presented similar results. All three studies tested the quality and reliability of commercial AMF products which were purchased from retail stores, and then tested under greenhouse and field conditions. The Australian and European studies are greenhouse experiments which tested 25 commercial products regarding their viability and effects on plant growth in sterilized and non-sterilized soil. The North American study widens the focus by testing three commercial products in a field experiment.

Overall, the results of the greenhouse experiments were disappointing. None of the ten products in the Australian study resulted in mycorrhizal root colonization above 10%, when used with tomato plants and sterilized soil (Fig. 1).
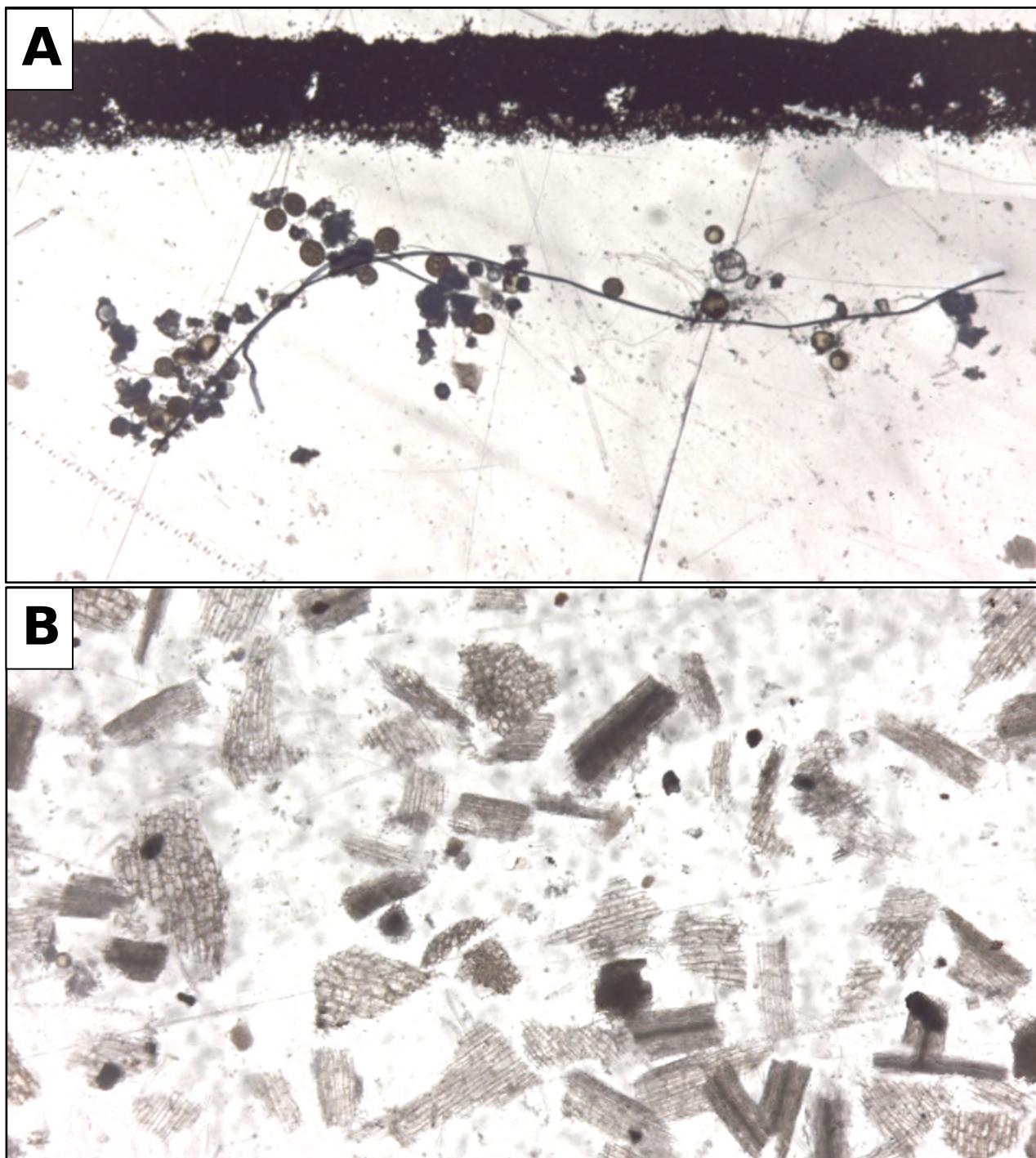
Figure 1. A. Representative microscopical photo of a commercial product which resulted in high mycorrhizal root colonization, dozens of AMF spores on hyphae, and associated to a plant root. **B.** Representative microscopical photo of a commercial product which did not result in mycorrhizal root colonization. Photo shows root fragments without visible mycorrhizal propagules. Credit: Matthias J. Salomon.

Out of the 15 products tested in the European study, only four resulted in significant root colonization when used with leek plants and sterilized soil. Both studies provided AMF-favorable conditions with low concentrations of phosphorus. This was also verified by including a well characterized laboratory strain of *Rhizophagus irregularis* as positive control treatment, which always resulted in a very high mycorrhizal root colonization. Following, the commercial products were tested in non-sterilized field soil which contained background levels of natural AMF. In the Australian study, there were some effects on plant

growth, but this was likely due to non-mycorrhizal effects or the presence of plant nutrients in the products. Further testing for plant nutrients revealed very high concentrations of mineral nitrogen and plant-available (Colwell) phosphorus in some products. This was often not labeled. In the European study and non-sterilized soil, significant positive effects on the biomass production of leek were only seen in one treatment. In non-sterilized soil, there was no strong correlation between mycorrhizal root colonization and mycorrhizal growth effect (MGR). For example, in the European study and non-sterilized soil, highest mycorrhizal root colonization was seen in the *R. irregularis* treatment (51% root colonization). However, the biomass was not significantly higher than in the control treatment (17% root colonization). This weak correlation between mycorrhizal root colonization and plant biomass production was also seen in the North American field study with soybeans. Significantly higher biomass was only seen in one treatment, which also had similar mycorrhizal root colonization to the non-inoculated control (approx. 50%). These results were supplemented by amplicon-based metagenomic analysis of the roots, using AMF-specific primers. This analysis revealed that all three commercial products resulted in reduced alpha diversity and displaced the natural AMF community to some degree. However, we do not know if this effect is only temporal or persistent.

The aim of this publication was to evaluate the quality and reliability of commercial inoculants containing AMF. This was defined as inducing mycorrhizal root colonization under AMF-favorable conditions. Ideally, the treatments

would also show positive mycorrhizal growth effects. However, given the high variability of the MGR between environmental conditions (Hoeksema *et al.* 2010), this leaves some room for discussions and further research. The question remains, why products, which were using generalist species of AMF, did not overall induce mycorrhizal root colonization? This is either caused by a lack of AMF spores, or the presence of non-viable spores. Without having further knowledge about the production method of each product, and the storage and transportation conditions between producers and consumers, it is difficult to explain why spore viability could have been reduced. However, spore extraction revealed that, for some products, spore concentrations and dosage recommendations were insufficient. After extracting and counting the spores, we could say that less than 50 spores per pot were applied in some treatments. Theoretically, this number of spores suffices to induce high mycorrhizal root colonization. But reduced spore viability and germination rates due to storage will require higher numbers in applied scenarios.

The overall results of our study painted the picture of an unregulated market, with a majority of the products not delivering on their intended purpose, which is inducing mycorrhizal root colonization. If AMF are to be established as microbial soil inoculants for food production system, their reliability needs to be improved by adhering to basic quality criteria. These quality criteria can be summarized as: "I: Transparent labelling and documentation of the inoculant's content and its production method, including expiration dates and detailed

Instructions for usage in different soil environments; II: High concentrations of viable spores or propagules that can colonize the target host within an acceptable time frame; III: A selection of microbial strains that are suitable for the proposed environment; IV: Suitable carrier material that facilitates application of inoculum; V: Any additives have beneficial or neutral impact on AMF development; VI: Tests of spore viability and germination rates; VII: Greenhouse tests showing that inoculants colonize plant roots and lead to enhanced plant growth under controlled conditions" (Salomon *et al.* 2022).

References

- Basiru S, Mwanza HP, Hijri M. 2020. Analysis of arbuscular mycorrhizal fungal inoculant benchmarks. *Microorganisms* 9: 81. https://doi.org/10.3390/microorganisms9010081

- Bowles TM, Jackson LE, Loeher M, Cavagnaro TR. 2017. Ecological intensification and arbuscular mycorrhizas: A meta-analysis of tillage and cover crop effects. *J Appl Ecol* 54: 1785–1793. https://doi.org/10.1111/1365-2664.12815

- Hijri M. 2016. Analysis of a large dataset of mycorrhiza inoculation field trials on potato shows highly significant increases in yield. *Mycorrhiza* 26: 209–214. https://doi.org/10.1007/s00572-015-0661-4

- Hoeksema JD, Chaudhary VB, Gehring CA, *et al.* 2010. A meta-analysis of context-dependency in plant response to inoculation with mycorrhizal fungi. *Ecol Lett* 13: 394–407. https://doi.org/10.1111/j.1461-0248.2009.01430.x

- Salomon MJ, Demarmels R, Watts-Williams SJ, *et al.* 2022. Global evaluation of commercial arbuscular mycorrhizal inoculants under greenhouse and field conditions. *Appl Soil Ecol* 169: 104225. https://doi.org/10.1016/j.apsoil.2021.104225

- Tawaraya K, Hirose R, Wagatsuma T. 2012. Inoculation of arbuscular mycorrhizal fungi can substantially reduce phosphate fertilizer application to *Allium fistulosum* L. and achieve marketable yield under field condition. *Biol Fertil Soils* 48: 839–843. https://doi.org/10.1007/s00374-012-0669-2

- Vosátka M, Albrechtová J, Patten R. 2008. The international market development for mycorrhizal technology. In: Varma A (Ed.), *Mycorrhiza: State of the art, genetics and molecular biology, eco-function, biotechnology, eco-physiology, structure and systematics*, pp. 419–438. Springer: Berlin-Heidelberg. https://doi.org/10.1007/978-3-540-78826-3_21

Research priorities in arbuscular mycorrhizal trait-based ecology

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Traits are the deterministic holy grail by which we can hope to predict species' distributions, responses to environmental filters, and interactions (e.g., Shipley *et al.* 2006). Arbuscular Mycorrhizal ecologists started tackling this issue by promoting the characterization of fungal traits, along with information about various aspects of their niches (e.g., Chagnon *et al.* 2013; Aguilar-Trigueros *et al.* 2015). However and to be fair, this research agenda is far from new, and begun well before the idea of "trait-based approaches" was coined (e.g., Last *et al.* 1987). But even after more than a decade of promoting mycorrhizal traits in the literature (e.g., van der Heijden and Scheublin 2007; Maherali and Klironomos 2007; Koch *et al.* 2017; Treseder *et al.* 2018), trait-based arbuscular mycorrhizal ecology remains in its infancy, and is far from being comparable to other study systems such as plants (Kattge *et al.* 2020), microarthropods (Brousseau *et al.* 2018), insects (Menezes *et al.* 2010), etc. One could argue that arbuscular mycorrhizal ecologists face a unique challenge when measuring traits: we cannot sample individuals in nature to measure traits, as even the tiniest environmental sample we can get still unavoidably comprises a "community" of individuals from different species. Yet, even protistologists (who face a similar challenge with their vials containing water samples) have made significant progress in collating data on basic protist traits into a database (Dumack *et*

al. 2020). What makes trait-based mycorrhizal ecology so slow to emerge, then? Here, I identify what I think are two major priorities to bolster research in mycorrhizal traits.

1- Expand culture-based work

In the mid 2000's, mycorrhizal community ecology has entered an era of next-generation sequencing. While the advantages of such technologies for community characterization are obvious, and certainly not a matter of debate, they rarely offer, by themselves, key deterministic insights about the mechanisms shaping mycorrhizal fungal communities. For example, our recent interpretation that extended growing seasons for arbuscular mycorrhizal (AM) fungi through the use of cover crops (sown under a cash crop) that allowed late-sporulating species to persist in the agroecosystem (Chagnon *et al.* 2021), was only possible because earlier researchers had carefully studied the life cycles of certain AM species using cultures (Boddington and Dodd 1999). Without such insights, our interpretation of results would have been much less exciting. We would have simply ended up showing that treatments differed in AM fungal assemblages, and that some AM fungi were unique to certain treatments... ordination models, α-diversity barplots, and indicator species analyses are not exciting by themselves, and probably not as likely to get our work cited. The one benefit we can get from environmental DNA studies by

Fetusca rubra roots with vesicles
Photo: Vlad Parasquive

themselves, though, is integrative work on AM fungal biogeography, either through meta-analyses using a standardized taxonomy, or through large-scale studies. Grinnellian niches are probably a useful starting point in mycorrhizal trait-based ecology. Plant phytosociological studies and the development of Ellenberg indices are a good example, and exciting progress in mycorrhizal ecology has been made in this regard over the years (Lekberg *et al.* 2007; Veresoglou *et al.* 2013; Davison *et al.* 2021).

So, what is next for culture-based research in mycorrhizal ecology? First, we must fully appreciate the seminal work conducted by key institutions and researchers: INVAM, CICG, BEG, the Guelph Long-Term Mycorrhizal Research Site (e.g., van der Heijden *et al.* 1998; Maherali and Klironomos 2012), and several individual labs that have maintained cultures for decades (e.g., Abbott and Robson 1984; Bever 2002; van der Heijden *et al.* 2003). No synthesis (e.g., Hoeksema *et al.* 2010; Chagnon *et al.* 2013) would have been possible without the cumulation of such precious resources and datasets. The upcoming challenge for trait-based mycorrhizal ecology will be, in my opinion, to transform these individual efforts into a collective, coordinated research agenda. As for any research agenda on traits, the primary goals should be to (1) identify relevant traits

to measure (De Bello *et al.* 2021) and (2) measure these in a reproducible manner (Perez-Harguindeguy *et al.* 2013). Interestingly, while our paper on Grime's CSR (competitor, stress tolerator, ruderal) strategies (Chagnon *et al.* 2013) was developed largely as a theoretical endeavor to achieve No. 1 above, it remains largely cited for our associations between strategies and AM families. These were speculations from fragmentary data, which are probably unlikely to hold true and stand the test of time and actual data. It may be time for the research community to double efforts to isolate and culture AM fungi from around the world, and think about what ecologically relevant traits to measure on such cultures (e.g., Antunes *et al.* 2011). Although basic allometry and morphology (e.g., Koch *et al.* 2017) may bear some insights into the response of AM fungi to environmental filters and their impact on ecosystem functions, they are unlikely, by themselves, to provide a complete picture of AM fungal responses to key stresses and disturbances, such as thermal stress, predation, temporal variation in C supply, competition for resource with plants and other microorganisms, etc. We should also establish standard protocols including highly controlled conditions (host, substrate, light, etc.) to measure AM traits. Databases (e.g., Zanne *et al.* 2020) will only be useful if they can be populated with traits that are reproducibly measured (e.g., Kattge *et al.* 2020).

2- Reassess trait phylogenetic conservatism

With the lack of information on traits, it is common practice to use phylogenetic diversity and dispersion as proxies for functional diversity. This is especially true when traits are known to be conserved within the phylogeny. Studies on AM fungi showing family-level conservatism in the amount of biomass produced, and its relative placement in the soil vs. the root compartment (e.g., Hart and Reader 2002; Maherali and Klironomos 2007; Koch *et al.* 2017), have gained considerable momentum in the literature, to a point where most mycorrhizal ecologists would probably not question the generality of this finding. This is in spite the fact that most data come from a single old-field, and that there are conflicting data (e.g., Jakobsen *et al.* 1992). This is at odds with the traditional 'falsificationism' with which we operate in scientific research (Popper 1963). It seems that for this particular case, we chose to accept positive inductivism and take this generality for granted. Moreover, with the uncertainty surrounding the very definition of a taxonomical unit in AM fungi (Bruns *et al.* 2018), which could have ramifications regarding the calculation of phylogenetic diversity and dispersion (Swenson 2009), it seems that AM community phylogenetics is ripe for a strengthening of its foundations. This will require (1) more cultured fungi, (2) ecologically relevant traits that serve as good proxies for key functions and strategies for AM fungi, and (3) a standardized taxonomy. With the development of reference trees on various rDNA fragments (Krüger *et al.* 2012; Delavaux *et al.* 2021), evolutionary placement of amplicon sequence variants (ASVs) will probably become the norm in the literature, which will provide more consistency than operational definitions that have been used up to now (e.g., Chagnon *et al.* 2021).

In conclusion, I think trait-based mycorrhizal ecology is at a crossroad, and the best way to move forward is to take a step backwards. While we jumped with both feet into next-generation sequencing in AM community ecology, we seemed to have forgotten that most of the insights in ecophysiology come from linking traits and environment. We will thus advance faster by keeping one foot in next-generation sequencing, and placing the other one in culture-based efforts. This will place us in a better position to identify sets of correlated traits among fungi (i.e., strategies), and correlations between fungal traits and predictable ecosystem services. The latter is key to successful use of mycorrhizal technologies for applied purposes (e.g., agriculture, restoration, nutrient and contaminant removal, etc.).

References

- Abbott LK, Robson AD. 1984. Colonization of the root system of subterranean clover by three species of vesicular-arbuscular mycorrhizal fungi. *New Phytol* 96: 275-281.
https://doi.org/10.1111/j.1469-8137.1984.tb03564.x
- Aguilar-Trigueros CA, Hempel S, Powell JR, *et al*. 2015. Branching out: towards a trait-based understanding of fungal ecology. *Fungal Biol Rev* 29: 34-41.
https://doi.org/10.1016/j.fbr.2015.03.001
- Antunes PM, Koch AM, Morton JB, *et al*. 2011. Evidence for functional divergence in arbuscular mycorrhizal fungi from contrasting climatic origins. *New Phytol* 189: 507-514. https://doi.org/10.1111/j.1469-8137.2010.03480.x
- Bever JD. 2002. Negative feedback within a mutualism: host–specific growth of mycorrhizal fungi reduces plant benefit. *Proc R Soc B: Biol Sci* 269: 2595-2601.
https://doi.org/10.1098/rspb.2002.2162
- Boddington CL, Dodd JC. 1999. Evidence that differences in phosphate metabolism in mycorrhizas formed by species of Glomus and Gigaspora might be related to their life-cycle strategies. *New Phytol* 142: 531-538. https://doi.org/10.1046/j.1469-8137.1999.00422.x
- Brousseau PM, Gravel D, Handa IT. 2018. On the development of a predictive functional trait approach for studying terrestrial arthropods. *J Anim Ecol* 87 : 1209-1220. https://doi.org/10.1111/1365-2656.12834
- Bruns TD, Corradi N, Redecker D, *et al*. 2018. Glomeromycotina: what is a species and why should we care?. *New Phytol* 220: 963-967.
https://doi.org/10.1111/nph.14913
- Chagnon PL, Bradley RL, Lafond J, *et al*. 2021. Trait-based and phylogenetic filtering of arbuscular mycorrhizal fungal communities under long-term agricultural practices. *Plant Soil* 471: 273-287.
https://doi.org/10.1007/s11104-021-05155-w
- Chagnon PL, Bradley RL, Maherali H, Klironomos JN. 2013. A trait-based framework to understand life history of mycorrhizal fungi. *Trends Plant Sci* 18: 484-491.
https://doi.org/10.1016/j.tplants.2013.05.001
- Davison J, Moora M, Semchenko M, *et al*. 2021. Temperature and pH define the realised niche space of arbuscular mycorrhizal fungi. *New Phytol* 231: 763-776.
https://doi.org/10.1111/nph.17240
- De Bello F, Carmona CP, Dias ATC, Götzenberg L. 2021. Handbook of Trait-Based Ecology From Theory to R Tools, Cambridge University Press.
- Delavaux CS, Sturmer SL, Wagner MR, *et al*. 2021. Utility of large subunit for environmental sequencing of arbuscular mycorrhizal fungi: a new reference database and pipeline. *New Phytol* 229: 3048-3052.
https://doi.org/10.1111/nph.17080
- Dumack K, Fiore-Donno AM, Bass D, Bonkowski M. 2020. Making sense of environmental sequencing data: ecologically important functional traits of the protistan groups Cercozoa and Endomyxa (Rhizaria). *Mol Ecol Resour* 20: 398-403.
https://doi.org/10.1111/1755-0998.13112
- Hart MM, Reader RJ. 2002. Taxonomic basis for variation in the colonization strategy of arbuscular mycorrhizal fungi. *New Phytol* 153: 335-344.
https://doi.org/10.1046/j.0028-646X.2001.00312.x
- Hoeksema JD, Chaudhary VB, Gehring CA, *et al*. 2010. A meta-analysis of context-dependency in plant response to inoculation with mycorrhizal fungi. *Ecol Lett* 13: 394-407. https://doi.org/10.1111/j.1461-0248.2009.01430.x
- Jakobsen I, Abbott LK, Robson AD. 1992. External hyphae of vesicular-arbuscular mycorrhizal fungi associated with *Trifolium subterraneum* L. 1. Spread of hyphae and phosphorus inflow into roots. *New Phytol* 120: 371-380.
https://doi.org/10.1111/j.1469-8137.1992.tb01077.x
- Kattge J, Bönisch G, Díaz S, *et al*. 2020. TRY plant trait database—enhanced coverage and open access. *Glob Chang Biol* 26: 119-188.
https://doi.org/10.1111/gcb.14904
- Koch AM, Antunes PM, Maherali H, *et al*. 2017. Evolutionary asymmetry in the arbuscular mycorrhizal symbiosis: conservatism in fungal morphology does not predict host plant growth. *New Phytol* 214: 1330-1337.
https://doi.org/10.1111/nph.14465
- Krüger M, Krüger C, Walker C, *et al*. 2012. Phylogenetic reference data for systematics and phylotaxonomy of arbuscular mycorrhizal fungi from phylum to species level. *New Phytol* 193: 970-984.
https://doi.org/10.1111/j.1469-8137.2011.03962.x
- Last FT, Dighton J, Mason PA. 1987. Successions of sheathing mycorrhizal fungi. *Trends Ecol Evol* 2: 157-161.
https://doi.org/10.1016/0169-5347(87)90066-8
- Lekberg Y, Koide RT, Rohr JR, *et al*. 2007. Role of niche restrictions and dispersal in the composition of arbuscular mycorrhizal fungal communities. *J Ecol* 95: 95-105. https://doi.org/10.1111/j.1365-2745.2006.01193.x
- Maherali H, Klironomos JN. 2007. Influence of phylogeny on fungal community assembly and ecosystem functioning. *Science* 316: 1746-1748.
https://doi.org/10.1126/science.1143082
- Maherali H, Klironomos JN. 2012. Phylogenetic and trait-based assembly of arbuscular mycorrhizal fungal

communities. *PLoS One* 7: e36695.
https://doi.org/10.1371/journal.pone.0036695

- Menezes S, Baird DJ, Soares AM. 2010. Beyond taxonomy: a review of macroinvertebrate trait-based community descriptors as tools for freshwater biomonitoring. *J Appl Ecol* 47: 711-719.
https://doi.org/10.1111/j.1365-2664.2010.01819.x

- Perez-Harguindeguy N, Diaz S, Garnier E, *et al*. 2016. Corrigendum to: new handbook for standardised measurement of plant functional traits worldwide. *Aust J Bot* 64: 715-716. https://doi.org/10.1071/BT12225_CO

- Popper K. 1963. Conjectures and refutations: The growth of scientific knowledge, Routledge.

- Shipley B, Vile D, Garnier É. 2006. From plant traits to plant communities: a statistical mechanistic approach to biodiversity. *Science* 314: 812-814.
https://doi.org/10.1126/science.1131344

- Swenson NG. 2009. Phylogenetic resolution and quantifying the phylogenetic diversity and dispersion of communities. *PloS One* 4: e4390.
https://doi.org/10.1371/journal.pone.0004390

- Treseder KK, Allen EB, Egerton-Warburton LM, *et al*. 2018. Arbuscular mycorrhizal fungi as mediators of ecosystem responses to nitrogen deposition: A trait-based predictive framework. *J Ecol* 106: 480-489.
https://doi.org/10.1111/1365-2745.12919

- Van der Heijden MG, Scheublin TR. 2007. Functional traits in mycorrhizal ecology: their use for predicting the impact of arbuscular mycorrhizal fungal communities on plant growth and ecosystem functioning. *New Phytol* 174: 244-250.
https://doi.org/10.1111/j.1469-8137.2007.02041.x

- Van der Heijden MG, Klironomos JN, Ursic M, *et al*. 1998. Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. *Nature* 396: 69-72.
https://doi.org/10.1038/23932

- Van der Heijden MG, Wiemken A, Sanders IR. 2003. Different arbuscular mycorrhizal fungi alter coexistence and resource distribution between co-occurring plant. *New Phytol* 157: 569-578.
https://doi.org/10.1046/j.1469-8137.2003.00688.x

- Veresoglou SD, Caruso T, Rillig MC. 2013. Modelling the environmental and soil factors that shape the niches of two common arbuscular mycorrhizal fungal families. *Plant Soil* 368: 507-518.
https://doi.org/10.1007/s11104-012-1531-x

- Zanne AE, Abarenkov K, Afkhami ME, *et al*. 2020. Fungal functional ecology: bringing a trait-based approach to plant-associated fungi. *Biol Rev* 95: 409-433.
https://doi.org/10.1111/brv.12570

YouTube interviews*

- Marcos Caiafa and Matt Smith on bird mycophagy

Camille Truong interviews Marcos Caiafa (postdoc at the University of California, Riverside) and his former PhD advisor Matt Smith (University of Florida), who chased birds in Patagonian forests to study their diet and demonstrate that they consume and disperse ECM fungi.

Interview: https://southmycorrhizas.org/reading/november-2021/

Study: Caiafa MV, Jusino MA, Wilkie AC, *et al*. 2021. Discovering the role of Patagonian birds in the dispersal of truffles and other mycorrhizal fungi. *Curr Biol* 31: 5558-5570. https://doi.org/10.1016/j.cub.2021.10.024

- Lena Neuenkamp on how light availability/demand by plants shapes their AM fungal symbionts

Guillermo Bueno interviews Lena Neuenkamp, Marie Curie Fellow at the University of Alicante, who discuss how shade, light availability, and light demand by plants affects arbuscular mycorrhizal fungi in roots and in soil.

Interview: https://southmycorrhizas.org/reading/february-2022/

Study: Neuenkamp L, Zobel M, Koorem K, *et al*. 2021. Light availability and light demand of plants shape the arbuscular mycorrhizal fungal communities in their roots. *Ecol Lett* 24: 426-437. https://doi.org/10.1111/ele.13656

*Section by:
South American Mycorrhizal Research Network
Contact/Join us: https://southmycorrhizas.org/join/

Tools

→ New dataset of worldwide fungal molecular data: *Global Soil Mycobiome*
This 15-year effort lead by Leho Tedersoo and 94 more co-authors (Tedersoo *et al.*, 2021), included the sampling of 3,200 plots in 108 countries, and consists of 722,682 fungal operational taxonomic units (OTUs) obtained from *PacBio* sequencing targeting the full-length ITS and 18S-V9. Besides the taxonomical and functional (guild) assignment of the OTUs, the dataset includes climatic and edaphic metadata for further analyses (currently on its way).

Study: Tedersoo L, Mikryukov V, Anslan S, *et al.* 2021. The Global Soil Mycobiome consortium dataset for boosting fungal diversity research. *Fungal Divers* 111: 573-588.
https://doi.org/10.1007/s13225-021-00493-7

→ AMFinder to identify and quantify AM structures
Evangelisti *et al.* (2021) developed the computer vision-based tool Automatic Mycorrhiza Finder (AMFinder) to identify and quantify AM fungal colonization and intraradical structures, based on stained root photos. The tool delivered high confidence results on roots of several hosts, and it is available on GitHub:
https://github.com/SchornacklabSLCU/amfinder

Study: Evangelisti E, Turner C, McDowell A, *et al.* 2021. Deep learning-based quantification of arbuscular mycorrhizal fungi in plant roots. *New Phytol* 232: 2207-2219.
https://doi.org/10.1111/nph.17697

→ Microdialysis technique to detect ectomycorrhizal signaling exchanges
Plett *et al.* (2021) used a novel microdialysis-based technique to detect the various signaling exchanges between an ectomycorrhizal fungus (*Pisolithus microcarpus*) and its plant host (*Eucalyptus grandis*) before physical contact. The analyses included several steps: untargeted metabolomics to screen >10,000 molecular features, prefiltering for background and artifacts, and multivariate processing.

Study: Plett KL, Buckley S, Plett JM, *et al.* 2021. Novel microdialysis technique reveals a dramatic shift in metabolite secretion during the early stages of the interaction between the ectomycorrhizal fungus *Pisolithus microcarpus* and its host *Eucalyptus grandis*. *Microorganisms* 9: 1817.
https://doi.org/10.3390/microorganisms9091817

Events

MYCORRHIZAL EVENTS:

ICOM11
Website
China National Convention Center, Beijing, China
31 July – 5 August, 2022

Organizers: Chinese Society of Mycology and IMS

III International Symposium on Mycorrhizal Symbiosis in South America
Website
Instituto SINCHI, Leticia, Colombia
24 August – 2 September, 2023
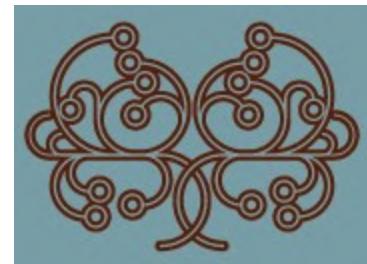
Organizers: South American Mycorrhizal Research Network and Instituto SINCHI

EVENTS POSTPONED DUE TO COVID-19:

- Soil Ecology Society Meeting
Website
Richland, Washington, United States
16 – 20 May 2022
Organizers: Soil Ecology Society

- 18th International Symposium on Microbial Ecology
Website
Lausanne, Switzerland
13 – 19 August 2022
Organizers: International Society for Microbial Ecology

- 45th *New Phytologist* Symposium: Ecological and evolutionary consequences of plant–fungal invasions
Website
Campinas, Brazil
Date not yet announced
Organizers: New Phytologist Trust and symposium organizers.

- 10th International Symposium on Forest Soils - ISFS 2022
Website
Zhijiang Hotel, Hangzhou, China
17 – 21 October, 2022
Organizers: Zhejiang A&F University and others

- **3ʳᵈ Global Soil Biodiversity Conference**

Website
Clayton Hotel, Dublin, Ireland
13 – 15 March 2023

Organizers: Global Soil Biodiversity Initiative

EVENTS AS SCHEDULED:

Microbiome Centers Consortium
Website
Scottish Event Campus, Glasgow, UK
23 – 25 March, 2022

Organizers: University of Chicago

3ʳᵈ Annual CanFunNet Fungal Biology Virtual Conference
Website
Online
23 – 25 March, 2022

Organizers: University of Chicago

***New Phytologist* next generation scientists 2022**
Website
Delta Centre, Tartu, Estonia
19 – 22 July, 2022

Organizers: New Phytologist Foundation

10ᵗʰ Congress of the International Symbiosis Society
Website
Centre des congrès, Lyon, France
25 – 29 July, 2022
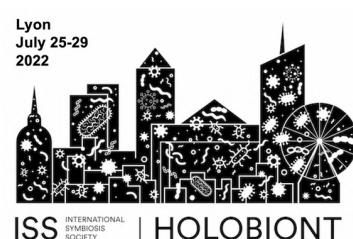
Organizers: International Symbiosis Society

22ⁿᵈ World Congress of Soil Science 2022
Website
Scottish Event Campus, Glasgow, UK
31 July – 5 August, 2022

Organizers: British Society of Soil Science

ICOM11 is scheduled for 31 July – 5 August, 2022 in Beijing, China. More details at:
https://icom11.casconf.cn/
https://mycorrhizas.org/home/icom-11/

ICOM12 will be organised in the summer of 2024 in Manchester, United Kingdom, by Prof. Dr. David Johnson (University of Manchester) and colleagues.