

**Knowledge of biodiversity and ecosystem services of South
American mycorrhiza through research networking**

César Marín^{1, 2}*

¹Instituto de Ciencias Agroalimentarias, Animales y Ambientales, Universidad de O'Higgins, Chile.

²Center of Applied Ecology and Sustainability, Pontificia Universidad Católica de Chile, Chile. cesar.marin@uoh.cl

Abstract summary

The South American Mycorrhizal Research Network originated in Chile in 2017, as an horizontal scientific community directed towards the progress of mycorrhizal applications, research, and outreach in South America. By conducting a scientific literature review, and experimental settings, the state of knowledge of mycorrhizal fungi diversity, types, and ecosystem services is shown. The continent host 186 morphospecies of arbuscular mycorrhizal fungi, representing the 60 percent of the global diversity. Patagonian Nothofagaceae forests present the highest species richness of ectomycorrhizal fungi compared to other biogeographic regions of the continent. In the temperate rainforests of the continent, arbuscular mycorrhizal fungi associate with 85 percent of vascular plants, while ectomycorrhizal fungi associate with less than 3 percent. The roles of mycorrhizal associations in the bedrock' biogenic weathering and in increasing the tolerance of cereals to high aluminum concentrations are shown as examples of the ecosystem services provided by this symbiosis. Research and geographic gaps in plants, soil, and mycorrhizal fungi of entire biomes/countries of South America are caused by monetary, linguistic, geographic, technical, and political barriers, and also by different research interests. These limitations can be overcome through collaborative and horizontal networking aimed at integrate the biodiversity and ecosystem services of mycorrhiza in South America.

Keywords: biodiversity-ecosystem functioning, community structure, knowledge gaps, mycorrhiza, networking, South America.

Introduction, scope and main objectives

Vast regions of South America remain unstudied in terms of their soil biodiversity and ecosystem services, despite the great ecosystem diversity of this continent (Guerra *et al.*, 2020). Although the emergence of new and more efficient molecular and macroecological approaches in the last decades has boosted global soil biodiversity studies, geographical data gaps are still large in South America because of monetary, linguistic, geographic, and political barriers (Amano and Sutherland, 2013). Thus, many regions, biomes, soil organisms, and soil functions have now been assessed in the continent (Guerra *et al.*, 2020).

Mycorrhizal fungi, a crucial symbiosis for 92 percent of terrestrial plants (Brundrett and Tedersoo, 2018), are involved in many soil ecosystem services as food production and nutrient cycling (Van der

Heijden *et al.*, 2015). The geographic and research gaps regarding the biodiversity and ecosystem services of mycorrhiza in South America have limited the ability of scientists to address many ecological and evolutionary questions. These limitations are caused by an historic shortage of connections between researchers in and out of the continent, and also by different research interests (Marín and Bueno, 2019).

In this context, research networks are a necessary tool to surpass local constraints (Richter *et al.*, 2018). The South American Mycorrhizal Research Network (SAMRN; <https://southmycorrhizas.org/>) was established in 2017, as a horizontal scientific community directed towards the progress of mycorrhizal research and knowledge, along with applications and public outreach in South America. In its short existence, the SAMRN has reinforced scientific interactions between researchers, stakeholders, and students from the continent, organizing two symposia: in Valdivia, Chile, in 2017 (Bueno *et al.*, 2017; Godoy *et al.*, 2017), and in Bariloche, Argentina, in 2019 (Mujica *et al.*, 2019). The cooperative effort of our members has also resulted in the first book on mycorrhizal fungi in South America (Pagano and Lugo, 2019).

This work aimed at highlighting the main findings of the SAMRN regarding the biodiversity and ecosystem functions of mycorrhizal fungi in South America.

Methodology

Three areas of research were explored regarding the biodiversity and ecosystem functions of mycorrhizal fungi in South America: i. Biodiversity of arbuscular mycorrhizal and ectomycorrhizal fungi in the continent; ii. Mycorrhizal types of plant species in a biodiversity hotspot of the continent -its southern temperate rainforests; and iii. Ecosystem services provided by mycorrhiza.

Biodiversity of mycorrhizal fungi

A detailed compilation of published studies was made in Google Scholar for arbuscular mycorrhizal fungi (Cofré *et al.*, 2019) and ectomycorrhizal fungi (Nouhra *et al.*, 2019).

Mycorrhizal types

In order to determine the mycorrhizal types of the plant species in southern temperate rainforests of South America, 17 plots (30 m × 30 m) in southern Chile were selected. The mycorrhizal type was determined by analysis of the mycorrhizal colonization of roots (i.e. fixation, root staining, and microscope quantification) (Godoy and Marín, 2019).

Mycorrhizal ecosystem services

One year *in situ* experiments with phyllosilicates (muscovite and biotite) contained in bags buried at a 15 cm soil depth, and analysed by confocal laser microscopy, were implemented to evaluate the bedrock' biogenic weathering in southern Chile (Marín, 2018). The effects of high aluminum concentrations on the community structure of the arbuscular mycorrhizal fungi associated with six cereal species (*Avena sativa*, *Hordeum vulgare*, *Triticum durum*, x. *Triticosecale Wittmack*, *Secale cereale*, and *Triticum aestivum*) were studied in southern Chile by morphological analyses of spores, roots' mycorrhizal colonization, and glomalin related soil protein quantification (Aguilera et al., 2017).

Results

Biodiversity of mycorrhizal fungi

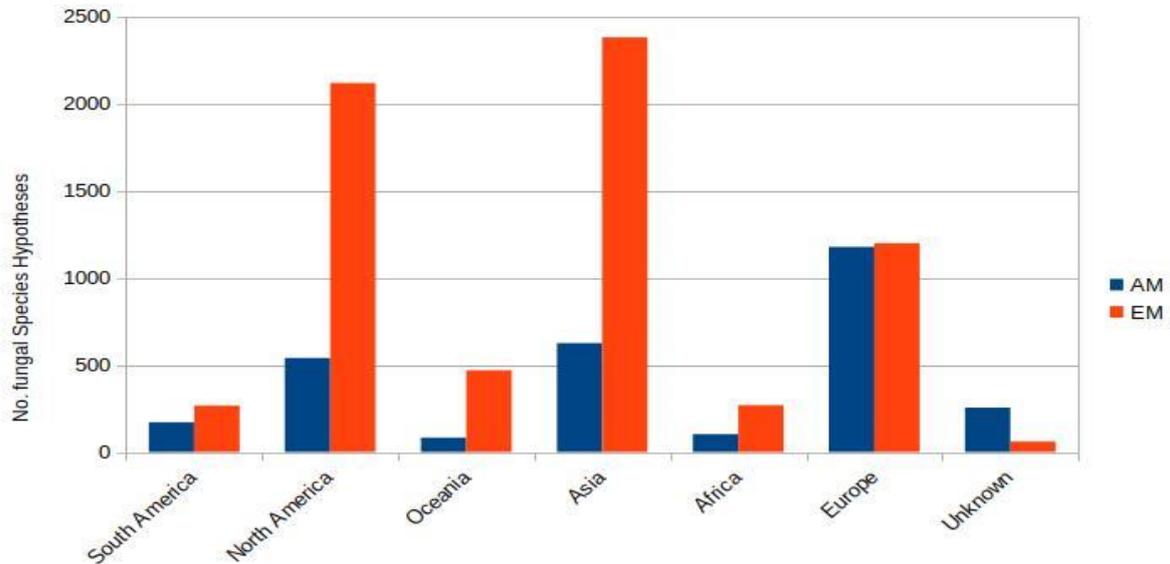
Cofré et al. 2019 compiled a total of 110 articles identifying a total of 186 morphospecies of arbuscular mycorrhizal fungi in South America, approximately the 60 percent of the global biodiversity of these fungi. Brazil (158) and the Atlantic Forest (120), were the country and biogeographic region, respectively, with most arbuscular mycorrhizal fungi species (Cofré et al., 2019). Though, this may be explained by a geographic bias as much of South America has not been studied (Figure 1). Nouhra et al. (2019) compared morphological and molecular methods regarding ectomycorrhizal fungi richness, finding very similar results with both methods: the most abundant ectomycorrhizal lineages were *cortinari*, *russula-lactarius*, *amanita*, and *inocybe*; and the Patagonian Nothofagaceae forests showed the higher diversity.

Mycorrhizal types

In the temperate rainforests of southern Chile, from a total of 245 vascular plant species, 208 species (85 percent) have mycorrhizal associations (Table 1) (Godoy and Marín, 2019). A total of 187 plant species associated with arbuscular mycorrhizal fungi, 10 with ericoid mycorrhizal fungi, seven with ectomycorrhizal fungi, four with orchid mycorrhizal fungi, and 37 plant species did not form any mycorrhizal association (Table 1) (Godoy and Marín, 2019).

Mycorrhizal ecosystem services

Ecosystem age was related to the degree of biogenic weathering in southern Chile, showing also a higher degree on forests dominated by ectomycorrhizal fungi (Nothofagaceae) (Marín, 2018). Furthermore, hyphae channels were seen on phyllosilicate minerals (Figure 2) (Godoy and Marín, 2019). The alpha diversity of arbuscular mycorrhizal fungi was higher in aluminum-tolerant *Triticum aestivum* compared to the other species; overall, the cereal species had significant effects on the number of spores and the glomalin related soil protein produced



by arbuscular mycorrhizal fungi, while both cereal species and aluminum stress affected the roots' mycorrhizal colonization and the hyphal length (Aguilera *et al.*, 2017).

Figure 1: Number of fungal mycorrhizal Species Hypotheses for the different continents, from the database FungalTratis (Pölme *et al.*, 2020).

Mycorrhizal types: arbuscular mycorrhizal (AM), ectomycorrhizal (EM)

Table 1: Proportion of mycorrhizal types by different plant groups in temperate rainforests of southern Chile

Plant/Mycorrhizal type	AM	EM	ER	OR	NM	Total
Ferns	23 (74.19%)	0 (0%)	0 (0%)	0 (0%)	8 (25.81%)	31
Conifers	7 (100%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	7
Angiosperms	157 (75.85%)	7 (3.38%)	10 (4.83%)	4 (1.93%)	29 (14.01%)	207
Total	187 (76.33%)	7 (2.86%)	10 (4.08%)	4 (1.63%)	37 (15.10%)	245

Mycorrhizal types: arbuscular mycorrhizal (AM), ectomycorrhizal (EM), ericoid (ER), orchid (OR), and non-mycorrhizal (NM). Adapted from: Godoy and Marín (2019).

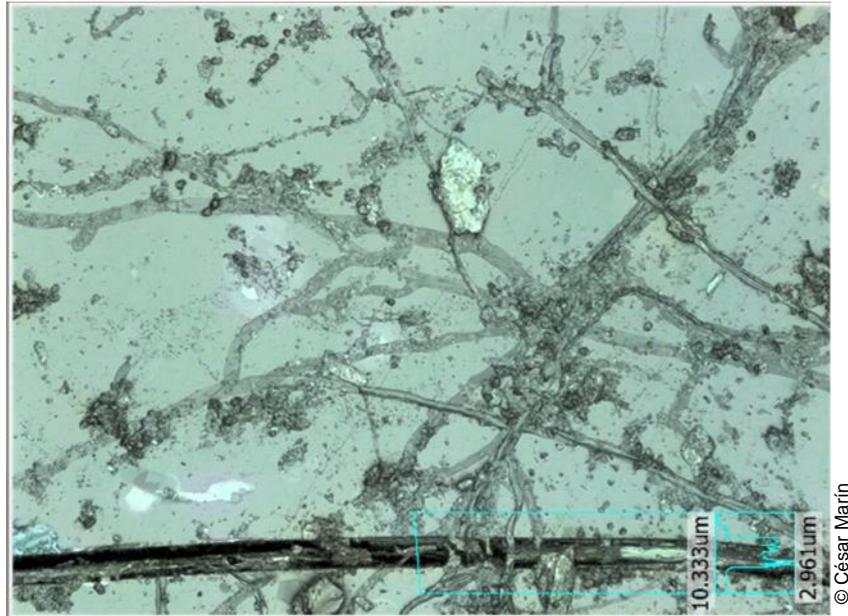


Figure 2: Channels formed by mycorrhizal fungi on Biotite after one year in a Nothofagus dombeyi forest, Nahuelbuta National Park, Chile

Photo with a Confocal Laser Microscope at 5000x.

Discussion

Despite its modest scientific productivity in comparison to other regions or continents as Europe (Marín and Bueno, 2019), mycorrhizologists in South America have developed a general baseline of mycorrhizal research, but there are still important geographic and research gaps. For example, large plant and mycorrhizal fungi trait databases are fundamental to address biogeographic, ecological, or evolutionary questions, where South American studies and datasets are scarce (Mujica *et al.*, 2019). Overall, the formation of the SAMRN 2.5 years ago - with significant scientific, technical, and funding limitations in the continent - has already started to fill these knowledge gaps through networking and collaboration. In fact, South American mycorrhizal researchers are becoming more integrated into global-scale monitoring of soil biodiversity and ecosystem services. Thus, activities such as exchanges, partnerships, and future events (e.g. a third Symposium in Leticia, Colombian Amazon, in 2022), are on the immediate horizon to face current and future South American mycorrhizal research challenges.

Conclusions

The plants, soil, and mycorrhizal fungi of entire biomes/countries of South America are understudied (e.g. underrepresentation on molecular databases). Solid knowledge on the distribution of mycorrhizal fungi/types is missing on many (highly diverse) ecosystems. This is partially explained as no continental or multilateral funding is available, but also because training on sampling and molecular,

bioinformatic, and statistical methods is missing. As in a global context (Guerra *et al.*, 2020), there is not a full experimental and conceptual integration of mycorrhizal diversity and its ecosystem services. And despite some initiatives, a full picture of the mycorrhizal applications on productive systems in the continent is missing, and also how to transfer and fund this knowledge.

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References

- Amano, T. & Sutherland, W.J.** 2013. Four barriers to the global understanding of biodiversity conservation: wealth, language, geographical location and security. *Proceedings of the Royal Society B*, 280(1756): 20122649.
- Aguilera, P., Marín, C., Oehl, F., Godoy, R., Borie, F. & Cornejo, P.E.** 2017. Selection of aluminum tolerant cereal genotypes strongly influences the arbuscular mycorrhizal fungal communities in an acidic Andosol. *Agriculture, Ecosystems and Environment*, 246: 86-93.
- Bueno, C.G., Marín, C., Silva-Flores, P., Aguilera, P. & Godoy, R.** 2017. Think globally, research locally: contrasting patterns of mycorrhizal symbiosis in South America. *New Phytologist*, 215(4): 1306-1309.
- Brundrett, M.C. & Tedersoo, L.** 2018. Evolutionary history of mycorrhizal symbioses and global host plant diversity. *New Phytologist*, 220(4): 1108-1115.
- Cofré, M.N., Soteras, F., del Rosario Iglesias, M., Velázquez, S., Abarca, C., Risio, L., Ontivero, E., Cabello, M.N., Domínguez, L.S. & Lugo, M.A.** 2019. Biodiversity of Arbuscular Mycorrhizal Fungi in South America: A Review. *Fungal Biology*: 49-72. https://doi.org/10.1007/978-3-030-15228-4_3
- Godoy, R., Silva-Flores, P., Aguilera, P. & Marín, C.** 2017. Microbial Interactions in the plant-soil continuum: Research results presented at the Workshop "Mycorrhizal Symbiosis in the Southern Cone of South America". *Journal of Soil Science and Plant Nutrition*, 17(4): 1-3.
- Godoy, R. & Marín, C.** 2019. Mycorrhizal studies in temperate rainforests of Southern Chile. In: M. Pagano & M. Lugo, eds. *Mycorrhizal Fungi in South America*, pp. 315-341. Cham, Springer.
- Guerra, C.A., Heintz-Buschart, A., Sikorski, J., Chatzinotas, A., Guerrero-Ramírez, N., Cesarz, S., Beaumelle, L., et al.** 2020. Blind spots in global soil biodiversity and ecosystem function research. *Nature Communications*, 11(1). <https://doi.org/10.1038/s41467-020-17688-2>
- Marín, C.** 2018. *Fungal biodiversity associated to bioweathering processes in a chronosequence of temperate rainforests in southern*

Chile. Faculty of Sciences, Austral University of Chile. (PhD dissertation).

Marín, C. & Bueno, C.G. 2019. A systematic review on South American and European mycorrhizal research: is there a need for scientific symbiosis? In: M. Pagano & M. Lugo, eds. *Mycorrhizal Fungi in South America*, pp. 97-110. Cham, Springer.

Mujica, M.I., Bueno, C.G., Duchicela, J. & Marín, C. 2019. Strengthening mycorrhizal research in South America. *New Phytologist*, 224(2): 563-567.

Nouhra, E.R., Palfner, G., Kuhar, F., Pastor, N. & Smith, M.E. 2019. Ectomycorrhizal fungi in South America: their diversity in past, present and future research. In: M. Pagano & M. Lugo, eds. *Mycorrhizal Fungi in South America*, pp. 73-95. Cham, Springer.

Pagano, M. & Lugo, M., eds. 2019. *Mycorrhizal fungi in South America*. Cham, Switzerland, Springer.

Pölme, S., Abarenkov, K., Nilsson, R.H., Lindahl, B.D., Clemmensen, K.E., Kauserud, H., Nguyen, N., et al. 2020. FungalTraits: a user-friendly traits database of fungi and fungus-like stramenopiles. *Fungal Diversity*, 105: 1-16.

Richter, D.D., Billings, S.A., Groffman, P.M., Kelly, E.F., Lohse, K.A., McDowell, W.H. & Zhang, G. 2018. Ideas and perspectives: Strengthening the biogeosciences in environmental research networks. *Biogeosciences*, 15(15): 4815-4832.

Van Der Heijden, M.G., Martin, F.M., Selosse, M.A. & Sanders, I.R. 2015. Mycorrhizal ecology and evolution: the past, the present, and the future. *New Phytologist*, 205(4): 1406-1423.