Meetings

Strengthening mycorrhizal research in South America

The II International Symposium of Mycorrhizal Symbiosis in South America, 6–8 March 2019, Bariloche, Argentina

South America is a vast region of exceptional biodiversity that, in over 60° of latitude, encompasses an extraordinary range of ecosystems and ecological gradients. From the World's driest climate in the Atacama Desert, to one of the wettest in the Chocó biogeographic region; and from the World's largest drainage basin, the Amazon, to the World's longest mountain range, the Andes. Despite this impressive range of ecological conditions that can be seen as natural laboratories, many groups of organisms are not well studied in South America. Soil microorganisms are particularly under-studied (Cameron *et al.*, 2019), especially mycorrhizal fungi (Bueno *et al.*, 2017a; Marín & Bueno, 2019), which are crucial for many ecosystem services, as nutrient cycling and food production (van der Heijden *et al.*, 2015).

These knowledge gaps have limited the ability of scientists to address ecological and evolutionary questions related to the distribution and role of mycorrhizal fungi in the face of current environmental changes. The overall limitations for the development of such biodiversity studies in South America lie in an historic shortage of connections between the human and technical research resources (Marín & Bueno, 2019). In this context, ecological research networks are increasingly used tools to overcome these and related constraints (Richter *et al.*, 2018). The South American Mycorrhizal Research Network (SAMRN; https://southmycorrhizas.org/) was established in 2017 (Bueno *et al.*, 2017a; Godoy *et al.*, 2017) as an horizontal and cooperative effort integrating researchers from the five continents (Fig. 1), which aims to assess the continent's mycorrhizal biodiversity and its role in reducing the impact of current environmental changes.

In its short existence, SAMRN has reinforced scientific interactions between researchers, stakeholders, and students from the continent. The cooperative effort of our members has also resulted in the first book centered on mycorrhizal fungi in South America (Pagano & Lugo, 2019). As a further step, the 'II International Symposium of Mycorrhizal Symbiosis in South America', organized by Universidad Nacional del Comahue, took place in Bariloche, Argentina, held on 6–8 March 2019, gathering *c.* 90 participants from 16 countries. The Symposium focused on the developments and opportunities for mycorrhizal research in South America, hosting several debates, which helped to identify the most critical research questions, along with a first round of potential future directions (Table 1). Several themes emerged at this meeting that traversed the ecological levels of organization (Fig. 2), with a strong focus on the diversity of ectomycorrhizal (ECM) fungi, and the potential application of arbuscular mycorrhizal (AM) fungi in agricultural and sustainability/conservation contexts.

The ecosystem roles of ectomycorrhizal fungi on Patagonian temperate forests

The current understanding of the ecosystem roles of ECM fungi on temperate forests comes mainly from conifer studies in the Northern Hemisphere (Fernandez & Kennedy, 2016). By contrast, Southern Cone native conifers associate with AM fungi, displaying a very localized distribution (Godoy & Marín, 2019). In fact, most South American temperate forests are represented by ECM *Nothofagaceae* species, showing a broad latitudinal and altitudinal distribution (Godoy & Marín, 2019). These forests have the highest ECM fungi diversity in South America (Pagano & Lugo, 2019), but are highly prone to anthropogenic disturbances. For example, María Jose Dibán from Universidad de Chile (winner of the Symposium's *New Phytologist* poster prize) showed that regenerating *Nothofagus obliqua* forests had lower ECM fruiting body diversity than nonintervened forests. Similarly, *Nothofagaceae* forests have also been shown to be susceptible to Pine invasions driven by suilloid fungal symbionts (Policelli *et al.*, 2019).

In a study presented by Dr Camille Truong from Universidad Nacional Autónoma de México, the roles of ECM fungi in nitrogen cycling on large elevation gradients (100–800 m above sea level (asl)) of monospecific *Nothofagus pumilio* forests in southern Patagonia were analyzed (Truong *et al.*, 2019). This pioneer study established relationships between ECM fungal taxonomic (alpha diversity and community structure) and functional (enzymatic activities) diversity, with carbon and nitrogen cycling in South American temperate forests. This study revealed that the total soil fungal and ECM fungal communities were mainly shaped by soil pH, followed by elevation, whilst enzymatic activities were minimally influenced by elevation, but rather correlated with the amount of total carbon and nitrogen in soil organic matter (Truong *et al.*, 2019).

Despite these recent efforts, the research on the ECM symbiosis in the Neotropics is still emerging (Roy *et al.*, 2017). Further studies may need to incorporate other measures of diversity (as phylogenetic diversity), community structure (as co-occurrence networks), and mycorrhizal types, to fully understand the role of this symbiosis in the continent's ecosystem processes.

The use of arbuscular mycorrhizal fungi for agricultural sustainability

A major issue discussed during the Symposium was the need to focus on soil health and biodiversity across farmers, major

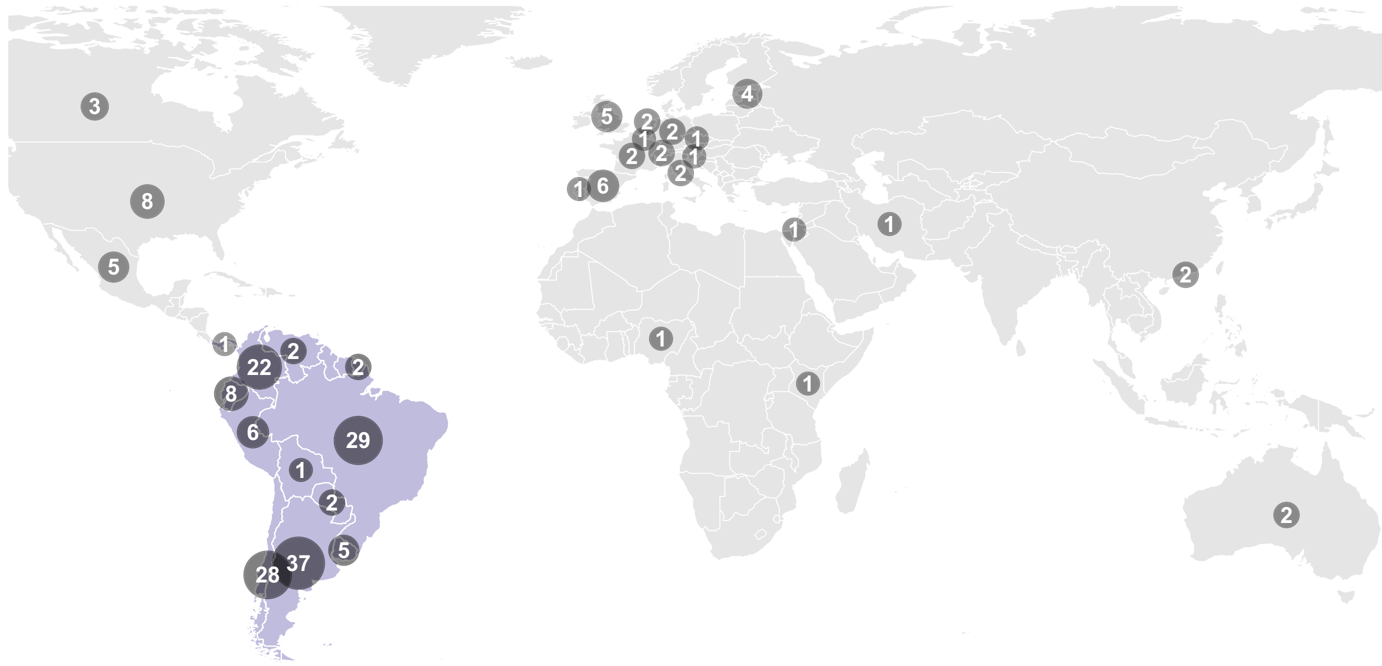

Fig. 1 Distribution of the members of the South American Mycorrhizal Research Network (https://southmycorrhizas.org/) in South America (purple background) and outside South America (gray background). From the 196 total members of the Network (in July 2019), 142 are based in 11 South American countries, whilst 54 are based in 22 countries outside South America.

agricultural companies, and policymakers, complementing the current productivity paradigm with sustainability and conservation goals. Dr Luis Gabriel Wall from Universidad de Quilmes, in Buenos Aires, Argentina, challenged the chemical paradigm of soil management in agriculture, which focuses on the application of fertilizers, lime, and pesticides (Wall *et al.*, 2019). He highlighted the need to describe the development of the rhizosphere microbiome in crops, as the microbial communities are deeply affected by agricultural management.

An example of mycorrhizal applications was the study presented by Marcela Ruscitti, from Instituto de Fisiología Vegetal (CONICET) in Buenos Aires, Argentina, which showed a

Table 1 Major questions and possible solutions for strengthening mycorrhizal research in South America raised during the II International Symposium of Mycorrhizal Symbiosis in South America.

Questions	Possible solutions
Weaknesses in South American mycorrhizal ecology	
How can data collection on plant mycorrhizal traits and environmental factors be effectively enhanced at ecosystem, biome, or continental scales?	Developing standardized protocols to foster the comparison of plant mycorrhizal traits and environmental data at different scales.
How can insufficient funding – leading to nonrepresentative sampling at ecosystem, biome, or continental scales – be overcome?	Networking, bilateral agreements, and integration into global soil biodiversity initiatives.
How can the training on sampling, molecular, statistical, and bioinformatic methods be improved?	Promoting the availability of self-training tools, and the exchange of graduate students and researchers.
Current tools and methods for studying the mycorrhizal symbiosis	
How to classify and use the large amount of hidden fungal biodiversity resulting from environmental samples?	Isolating strains from the most common unknown fungal sequences in environmental samples.
What is the distribution of mycorrhizal fungi in the continent?	Building continental georeferenced databases of plant and mycorrhizal fungal traits, and also contributing to current global databases (Chaudhary *et al*., 2016; Bueno *et al*., 2017b).
How to integrate different measures of mycorrhizal biodiversity and traits to ecosystem processes?	Establishing causal models for mycorrhizal biodiversity and ecosystem functions.
Management and sustainable production involving mycorrhizal fungi	
Which is the current state of knowledge on mycorrhizal applications in agricultural and forestry systems?	Reviewing the known mycorrhizal benefits on the most common crops in the continent.
How to efficiently and safely apply mycorrhizal technology to specific environmental or productivity problems?	Assessing the mycorrhizal inoculation needs, evaluating its ecological consequences and risks.
How to test and monitor the applications of mycorrhizal inoculum in the continent?	Working together with stakeholders and policymakers to demonstrate the effectivity and innocuity of mycorrhizal applications.

reduction of up to 93% in egg production of the nematode *Nacobbus aberrans* on pepper plants inoculated with different strains of the AM fungus *Rhizophagus intraradices*. When *R. intraradices* was absent, pepper root damage, phenolic compound content, and water stress increased, whilst the content of chlorophyll, proline, sugars, and soluble proteins decreased. Thus, mycorrhizal inoculation of pepper plants resulted in clear physiological and organoleptic improvements. Also, John Felipe Sandoval from Universidad Nacional de Colombia, Bogotá, showed that AM fungi grown under high cadmium concentrations enhanced plant growth (dry biomass and leaf area) of certain Andean *Cocoa* genotypes, where high contents of soil cadmium and zinc are otherwise toxic to *Cocoa* plants. Such research efforts suggest the potential effective use of mycorrhizal applications that would consider the dynamics of mycorrhizal microbiomes, and its direct effects on crop growth, yield, and alleviation of stressful environmental conditions.

However, the general effectiveness of AM fungal inoculation remains unclear in many cases, and many knowledge gaps should be targeted in the future. One clear consideration is associated with the use of exotic inoculum, since its use can trigger the risks of invasive and/or co-invasive plants and fungi (Hart *et al.*, 2017, 2018). Consequently, the use of local inoculum has been strongly prioritized (Hart *et al.*, 2018). In this context, initiatives using native inoculum are a promising approach, for example, Dr Paula Aguilera (Universidad de La Frontera, Temuco, Chile) showed the success of local-commercial AM fungal inoculum to alleviate high aluminum and low phosphorous soil conditions in southern Chilean cereals (Aguilera *et al.*, 2017).

Fig. 2 Word cloud showing major themes from the meeting, generated from the most common words in 72 abstracts presented at the II International Symposium of Mycorrhizal Symbiosis in South America. Only the words that appeared 10 or more times are shown (148 words overall, common conjunctions and verbs were excluded).

Future directions

Despite its modest scientific productivity in comparison to other regions, mycorrhizologists in South America have developed a general baseline of mycorrhizal research, but there are still important knowledge gaps (Marín & Bueno, 2019). For example, large plant and mycorrhizal fungi trait databases are fundamental to address biogeographic or evolutionary questions, where South American studies and datasets are scarce. One exception is the work presented by María Isabel Mujica from Universidad Católica de Chile (awarded the *New Phytologist* prize for oral presentation), who found a positive relationship between the diversity of mycorrhizal types and diversification rates in plant families, pointing out that having diverse mycorrhizal types has strong evolutionary effects on plant biodiversity. Overall, the formation of the SAMRN two years ago – which faces scientific isolation as well as technical and funding limitations in the continent – has already helped in starting to fill these knowledge gaps through networking and collaboration. In fact, South American mycorrhizal researchers are becoming more integrated into global-scale monitoring projects that will contribute to the study and understanding of global soil biodiversity and ecosystem functions. Thus, activities such as exchanges, partnerships, this Symposium, or 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.

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