Review Article

Neotropical seasonally dry forests: response of soil fungal communities to anthropogenic actions

Abstract

The aim of this review was to analyze the information available on soil fungal community of Neotropical Seasonally dry forests, with special attention given to the Chaco area. This review is focused on the loss of soil fungal community due to anthropogenic actions such as forest clearing. Over the last decades, the expansion of the agricultural frontier has had a wide range of physical, chemical and biological effects on Neotropical dry forests. As these changes on the *Schinopsis* dry forests (Chaco) have rendered the ecosystem vulnerable, these areas have become some of the few protected areas in South America. After analyzing both national and international studies to find the latest research available on the topic we have noticed there is lack of specific studies on soil fungal community in the Chaco area, unlike Cerrado and Caatinga where most studies have been carried out. Therefore, we propose to conduct more in-depth studies on soil fungi in *Schinopsis* forests to revalue the Chaco fungal community to use them as potential indicators of soil health and to develop new management techniques.

Keywords: soil fungi, dry forests, land use, clearing, management

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Merlos Cristina Soledad,[1] Pelizza Sebastián Alberto,[2] Moreno María Virginia[1]

[1]Laboratory of Functional Biology and Biotechnology (CONICET-INBIOTEC-CICBA), National University of Central Buenos Aires, Argentina
[2]National University of La Plata, Argentina

Correspondence: Moreno María Virginia, Agronomy faculty, Laboratory of Functional Biology and Biotechnology, National University of Central Buenos Aires, República de Italia N°780, Tandil, Buenos Aires, Argentina,
Email vmoreno@faa.unicen.edu.ar

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Introduction

Different terrestrial ecoregions ranging from deserts to tropical forests[1] exist around the world. One of them, Neotropical dry forests (NTDFs) play an important role in the economic and cultural development[2] and according to[3] the forest is one of the main sources of carbon (C). Van der Werf et al.,[4] pointed out that the loss of C due to anthropogenic effects accounts for 12%. Becknell et al.,[5] suggested that if tropical and Neotropical dry forests were restored, they would comprise 22 Pg of carbon in aboveground biomass and in the Americas alone, the contribution of carbon could be of 8 Pg. In the last decades, the studies on NTDFs have been focused on the diversity of plants, animals and C storage.[6] This shows an increase in our awareness of biodiversity, carbon and water only in secondary forests at local scales.

Forest diversity was one of the issues of Sustainable Forest Management addressed by the General Assembly of the United Nations.[7] The loss of diversity has dramatic effects not only on the forest ecosystem services but also on science, development and knowledge. While the NTDFs are considered one of the most vulnerable forests, the existing scientific research on this habitat is scarce.[8] Over the last decades and due to the expansion of the agricultural frontier the studies on NTDFs have increased.[9] However, the studies in other areas in Central and South America are still poor or unknown. Within these areas the Neotropical seasonally dry forests (NTSDFs)[10] are relevant to socio-economic development and according to Miles et al.,[11] the NTSDFs are the most vulnerable forests in the world. The seasonally dry forest in South America is known as Gran Chaco.[10] It has favorable environmental conditions for the implantation of cultivars and technological improvements that have led to the conversion of woody vegetation into areas managed purely for agricultural crops. In addition, this region experienced a decline in the rural population.[12] The advance of agroforestry in the Chaco in the 1980s accelerated the clearing of large tracts of forests and shrublands and this is currently continuing.[13] This affects the structure and functionality of ecosystems,[14] which leads to habitat degradation, thus affecting the ecological conditions of forests.[15] The Chaco forests are a clear example of deforestation driven by the expansion of agroindustry.[16]

Soil diversity is a relevant component of ecosystem services considering that soil microorganisms play essential roles in biogeochemical cycles. Fungi are components of soil microbiota. However, little is currently known about the functioning and diversity of forest soil fungi despite the fact that they are the fundamental links of ecosystem functioning in native forests and they are relevant elements to create sustainable agriculture supply chains. The application of molecular techniques has allowed the identification of a bigger fraction of species from different substrates especially in soil.[17,18] In 2007 mycologists and scientists revealed that the Kingdom Fungi accepts one subkingdom Dikarya and seven phyla.[19] The number of species known at the moment is 1.5 million and the estimated range is from 2.2 to 3.8 million species.[20]

Soil fungal communities in different forests have been studied.[21–25] All studies have shown that deforestation alters the soil microbial community,[26] and the vegetation structure has been cited as a major source of variation on the soil community.[22,23] However, we should not overlook the environmental factors that drive the composition and abundance of soil fungal communities. In the same way, the plant community composition has been suggested as a source of variation in soil fungal diversity.[27,28]

It stands to reason that future studies should address different soil management practices to favor the biota preservation as a means of increasing production in agroecosystems. In this point, we suggest that as fungi are involved in diverse biological activities, they can act as indicators of the environmental deterioration and could provide us with information about soil health.[29,30] The diversity of soil fungal communities at different environmental levels, according to the plant species that are present, provides information about the ecological functionality of these organisms in soil.[31] Jangid et al.,[29] suggested that the soil community in modified native forest and native forest soils was similar after 50 years. This indicates that the recovery of ecosystems is noticeable to human beings although similar concentrations of C and N were detected among forests after 50 years.[32]

The information available varies noticeably across regions; for example, more studies on soil fungal diversity have been carried out in habitats like Cerrado and Caatinga than in Chaco. We observed that in the last few years and due to the development of molecular biology tools, the research work on the soil fungal community has increased considerably. We performed a review of manuscripts in the major publishers (Springer, Scielo, Wiley-Blackwell, Taylor and Francis, Elsevier) in the last ten years. We used the following as key words: fungi, soil, diversity, South America, Cerrado, Caatinga, Chaco, Neotropical dry forests. In this review, we decided to leave out the mycorrhizae since its relevance deserves a separate review.

The aim of this review is to compile the few studies available on soil fungal communities in NTDFs drawing special attention to the seasonally NDTF (NTSDFs) according to Pennington et al.,[10] Calvo-Rodriguez et al.,[7] published an interesting review about the information available which is currently available about NTDFs; however, in this manuscript the seasonally NTDFs are not taken into consideration. For this reason we have revised not only the principal international journals but also the local ones to detect the fungal diversity loss due to the expansion of the agricultural frontier in the last ten years. It is known that the soil fungal community is being modified by land use, so in agreement with Bissett et al.,[33] we consider that these changes could be used as potential soil structure and functionality indicators.

Seasonally NTDFs

The present rainfall in NTSDFs is less than 1600 mm/year and concentrated in 5-6 months a year. During the dry season the prevalent vegetation is deciduous, and in the driest areas succulent and evergreen species prevail. In South America, NTSDFs can be divided according to Pennington et al.,[10,34] and they suggested the presence of different dry-forests based on the tree-dominates composition. The first one, Cerrado, is represented by the Brazilian savanna which is known as the seasonally Neotropical dry forest according to Miles et al.,[11] The second region is Caatinga, which is considered a semiarid region of thorny woodlands in the northeast of Brazil. The last region is Chaco, which covers some areas of western Matto Grosoo and areas of Argentina, Bolivia and Paraguay. As a subtropical extension of temperate vegetation, Chaco, was described as a region with fertile soils, closed canopy, with few grasses and forests with annual frosts by Pennington et al.,[10,34] In the same way Lima et al.,[35] called this area the American Corridor of seasonally dry vegetation (SACSV). Lima et al.,[36] in agreement with other authors suggested that this area has been poorly studied compared to tropical dry forests. The main characteristics of SACSV are the harsh dry season and only one period of rainfall. During several years the studies on these areas have been developed especially in plants, soil carbon and ecosystem services.[10,34,35,37–39]

In the last years, studies on microbial ecology have increased in these areas. Their main objectives among others were a) evaluation of loss diversity, b) impact of anthropogenic management, c) forest clearance and d) functionality of soil community.

Cerrado

Among the most relevant studies, Pereira de Castro et al.,[40] studied the soil fungal composition in native and modified lands. They suggested that the anthropogenic actions reduce fungal diversity by 50%. Over the last years, Pereira de Castro et al., (2016) suggested that the main source of diversity variation was the seasonal patterns of soil water uptake. They observed that the abundance of yeast and *Agaricomycotina* decreased as soil moisture increased in Cerrado. In soybean soils and Cerradosensustricto *Basidiomycetes* showed a positive correlation with soil moisture, but a negative correlation in Cerradodenso and gallery forest. The diversity index values suggested by Ferreira de Araujo et al.,[41] were higher than the ones shown by 53. Pereira de Castro et al.,[42] and a higher fungal diversity was observed in campo graminoide than in Cerrado forests. In addition, several studies have shown that structural changes in the fungal community were in response to different soil managements. Fracetto et al.,[43] observed that the most abundant phyla were *Zygomycota* in agricultural soils and primary forest, while the *Basidiomycota* were more abundant in pasture soils. Recently, Valadares-Pereira et al.,[44] distinguished two different soil fungal communities among soybean soil and Cerrado vegetation. They suggested that these differences were due to soil chemical properties. In summary, the fungal community structure responds to different sources of variation such as vegetation, chemical and environmental conditions. The principal results obtained showed a loss of diversity in modified soils by agricultural management as a result of the expansion agricultural frontier.

Caatinga

Pennington et al.,[10] and Prado et al.,[45] suggested dividing this area in subregions according to different environmental conditions. Caatinga is an exclusive Brazilian biome having been cleared for many years, which has resulted in a decreasing plant biomass production. This has led to changes in soil interactions and biodiversity losses.[45] Few studies have been carried out on soil fungal diversity in this place.[46–51] Over the last years, Oliveira et al.,[46] and Cruz et al.,[49] have reported some results that have increased our knowledge about mycological diversity in dry environments. Cruz et al.,[49] noticed high abundance of the genus *Penicillium* and detected great richness values suggesting that a great number of species are adapted to low moisture content. Likewise, Oliveira et al.,[46] observed that *Aspergillus* and *Penicillium* are the most abundant genera and suggested that abiotic factors are the main source of variation in community structures. Moreover, the studies on soil fungal diversity allowed us to detect new fungal species isolated from Caatinga soils.[52,53] Nascimento-Barbosa et al.,[50] found that diversity and distribution of *Aspergillus* and *Penicillium* were directly affected by climate, vegetation and soil type and they pointed out that the loss of diversity was due to widespread disturbance.

In a recent study, Cruz et al.,[51] identified the genus *Aspergillus* as the most abundant isolation in some anthropic areas more than others and explained that fungal communities have changed due to anthropization.

Chaco

Schinopsis forests (Chaco forests) are a clear example of the impact of forest clearing due to the expansion of agroindustry in Argentina between 1972 and 2007.[15] At the same time, these environments are the least represented at the national system of protected areas.[54] From 6 to 12000 hectares of semiarid “Quebrachales” (*Schinopsis* forests) have been found completely dismantled, where double cultivation is under irrigation and modern technological package equipment has been developed over Salta, Chaco and Formosa.[55] The consecuence

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was the expansion of the agricultural frontier towards native forests. This damage produced soil degradation, through an increase in pH range and loss of organic carbon thus negatively affecting the microbial biomass.[56]

Over the last years, different studies on the effect of agricultural practices on soil fungi have been carried out in Argentina, especially in the agricultural core region.[57–60] Works on the *Schinopsis* forests are relevant due to the fact that they are floristically diverse.[61] However, research on the soil fungal community is scarce. We have found only two works focused on this area: Godeas[62] and Montecchia et al.,[56] In the first case, the authors used traditional tools of basic mycology and described the isolated species morphologically. They described some ascosporic forms *Emericella* sp., *Talaromyces* sp., *Sordaria* sp., among them. More recently and using molecular tools, Montecchia et al.,[56] proposed that microbial communities were more sensitive to physical-chemical parameters. They observed that microbial communities in cleared and cropped soybean soils were different from the ones in pristine soils. However, their study does not assess the fungal community structure in detail.

Despite the lack of fundamental knowledge about soil fungi in *Schinopsis* forests and their relevance in ecosystems, we decided to focus on soil fungal diversity in three different soil use types. According to our preliminary results we suggested that the genera *Humicola* and *Absidia* were only isolated from forest soils, while *Aspergillus* and *Penicillum* were most frequently isolated from cleared soils. In agricultural soils the genus *Trichoderma* and *Paecilomyces* were isolated. Besides some pathogenic genera as *Fusarium* and A*lternaria* that are typically found in agricultural soils were isolated. These results have shown that the different composition of soil fungal community depends on land use. Although it was difficult to determine any banding pattern according to land use, Montecchia et al.,[56] observed a complex banding pattern expected in these soils using Denaturing Gradient Gel Electrophoresis (DGGE) technique. However, our preliminary results showed a complex banding profile in soil fungal community using DGGE. Therefore, we suggested using a different set of primer to obtain a clear profile.[23,43,63] The DGGE provides a quick way of looking at biodiversity in a microbial sample and enables us to sequence bands of interest in order to confirm their identity.

Potential use of fungal diversity as "biological alert"

Among the major factors that modify the structure and activities of the soil microbial community could be mentioned: moisture, temperature, pH, organic soil material content, nutrient availability[64] and others that may shape them in an indirect way such as latitude, regional weather, texture and soil management, seasons and the vegetation of the place.[65] The estimations of soil fungal diversity could be used as potential indicators of disturbance or of different anthropogenic uses.[29] In rainforest soils, Vera et al.,[66] have observed that changes in land use may lead to changes in soil organic matter and consequently affect fungal community. Martínez et al.,[67] observed that the community structure allowed us to differentiate the pristine forests of *Nothofagus* in Tierra del Fuego.

Over the last decade, the PCR quantitative (qPCR) has emerged as a valuable tool for studying microbial communities in soil, water and air, opening new opportunities to investigate the changes in gene expression in response to pathogen and antagonist fungi.[68] This tool allows identifying functionality of fungal communities in different types of soil;[69] as well as community structure of *Basidiomycota*, Ascomycota and *Zygomycota* phyla.[70,71]

No studies using qPCR in *Schinopsis* forests in Argentina have been found. The only metagenomic survey in Argentinean soils was carried out by Rascovan et al.,[72] concerning how agricultural practices affect soil microbial communities in the Pampean region. In that study 27% of the Eukarya organisms identified were Fungi. Their conclusion was that water availability associated with geographic differences was the first driver that modified the microbial community and the second one was land use.

Conclusion and perspectives

Subtropical seasonally dry forests in South America have become systems under different degree of degradation and this is likely to continue because of the expansion of the agricultural frontier. The Chaco forest is regarded as a biodiversity reservoir and it is considered abiological corridor according to Admistración Argentina de Parques Nacionales.[73] However, only 9% of the Gran Chaco is protected.[74]

After analyzing the studies available we observed that the most studied areas in the SNDF are Cerrado and Caatinga in terms of structure of fungal communities, and there are more specific studies about *Aspergillus* and *Penicillium*. On the other hand, research developed in Chaco is related to the diversity of woody plant species, their distribution and the impact of patch size due to the advance of agro-industry over the past years.

This review highlights the lack of studies on the *Schinopsis* dry forests soils, so it is deemed necessary to carry out integral studies which include soil fungal communities to provide guidelines on sustainable soil management. This scenario would promote a holistic point of view of the environmental system that could demonstrate the need for new protection and conservation policies since forests are a social good. While some agricultural practices can lead to the degradation of the microbial habitat and reduction of the soil health, sustainable agriculture could be an alternative to the physical, chemical and biological alteration of soils.

Our review showed that *Schinopsis* dry forests have been scarcely studied so far. Therefore, we propose that future research should focus on the knowledge of plant diversity, soil chemical properties, among other factors, which affect the fungal community structure and function. This point reinforces the fact that only by conducting integral studies a complete understanding of dry forests will be achieved.

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Conflict of interest

Authors declare there is no conflict of interest in publishing the article.

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