Impact of human activities on mycorrhizae

L.J.C. Xavier and J. J. Germida

Department of Soil Science, University of Saskatchewan, 51, Campus Drive, Saskatoon, SK S7N 5A8, Canada

ABSTRACT

Mycorrhizal fungi form a mutualistic symbiosis with plants and play an important role in regulating community and ecosystem functioning. These plant-fungal associations are geographically widespread, being found in terrestrial ecosystems ranging from deserts to lowland tropical rain forests to high latitudes. Studies of mycorrhizal community dynamics and activity are important in that these organisms influence plant production and nutrient cycling in terrestrial biomes. Moreover, such studies are necessary to better understand how significantly human activities can affect mycorrhizal activity, functioning and succession. For example, in Canada and other developed countries, agricultural practices such as crop rotations, pesticide use and fertilizer applications can eliminate or severely reduce the incidence of mycorrhizal activity. Likewise, slash and burn production systems in the tropics and the clear cutting of forests in temperate regions can cause similar losses in mycorrhizal activity and diversity. Other anthropogenic activities such as mining, generation of air pollution, and waste disposal are also detrimental to mycorrhizae. Understanding the consequences of human activities for mycorrhizal fungi and their associations with plants can help us find ways to protect and conserve the diversity of these important soil organisms, and encourage strategies to alleviate the impacts of past disturbances.

Introduction

Mycorrhizal fungi are ubiquitous and colonize >85% of land plants, and are an important and integral component of natural ecosystems. The most common types of mycorrhizae are arbuscular mycorrhizae and ectomycorrhizae. Mycorrhizal fungi are important in agriculture and forestry as bidirectional nutrient transfer between host and fungal endophyte (i.e., drain of host carbon and uptake of soil mineral nutrients) drive many nutrient cycling processes in soil.

The advantages of a diverse and healthy mycorrhizal community include better survival and nutrition of plants in stressed environments. Of all the factors that influence mycorrhizal community dynamics and associations with plants, human activities may be considered one of the most important. This paper briefly reviews the impact of human activities that may significantly alter the diversity and activity of mycorrhizae in terrestrial ecosystems.

Agricultural activities

Agricultural practices such as soil cultivation and fallow periods, crop rotations, monoculture, non-host crops, crop breeding programs, and the indiscriminate use of fertilizers and pesticides affect the diversity and activity of mycorrhizae. The external

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mycelium of arbuscular mycorrhizal fungi (AMF) acts as an extension of host plant roots and serves as a direct link between roots and soil nutrient reserves. The cultivation of soil breaks up the AMF hyphae network leading to a significant reduction in mycorrhizal colonization of roots [28] and P absorption from soil [12, 28]. The effect of cultivation on AMF diversity is not clear. However, it is probable that cultivation of soil exacerbates the die-off of unfit AMF propagules, leading to a loss in diversity.

Continuous monoculture of a mycorrhizal host may lead to a significant reduction in mycorrhizal root colonization [39] and in the number of AMF spores [40]. Furthermore, monocultures select for ineffective AMF which drain host photosynthates [22] and cause plant stunting and yield depressions [16]. Thus, potentially beneficial AMF may be lost in monoculture systems.

Fallow periods or growing a non-mycorrhizal host have a profound effect on AMF activity and diversity [2, 43, 13]. Long fallows (>12 months) severely reduce the AMF propagule density (i.e., by up to 40%) because of the absence of a living host. This results in a reduction of the subsequent root colonization of host plants by AMF and consequently, plant P uptake [43]. Similar to other crop rotation practices, fallow periods may also cause the loss of rare and weak AMF species.

Crop breeding programs may expedite the loss of AMF diversity by selecting plant genotypes that form ineffective associations with AMF. For example, high yielding modern wheat cultivars may be non-responsive to mycorrhizae [17, 46]. Given that AMF are obligately biotrophic, this may lead to the selective proliferation of AMF which are not mutualists, but rather parasitic on the host. Hence, the selection of non-responsive host genotypes can eventually lead to the loss of AMF activity and diversity.

The indiscriminate use of fertilizers and pesticides can affect mycorrhizal activity and diversity. High rates of fertilizers are applied to obtain maximum yield. However, high soil fertility levels inhibit the formation of both ecto and endomycorrhizae [3, 32]. For example, high P levels depress mycorrhizal spore germination and spore viability [42, 31]. Furthermore, the application of high levels of fertilizers leads to the build-up of a P tolerant AMF community over time [21, 8]. This may result in a reduction in AMF-derived benefits due to unidirectional nutrient transfer. The indiscriminate use of pesticides and fungicides also leads to a reduction in spore numbers [27] and diversity [38]. In addition, high levels of some pesticides also reduce AMF colonization of roots, resulting in reduced AMF activity [34, 44]. Some pesticides inhibit hyphal elongation of ectomycorrhizae, leading to tree damage and subsequently a loss of propagule activity, density and diversity.

Non-agricultural activities

Land and air pollution, mining, deforestation caused by slash and burn strategies and accidental forest fires constitute some of the most important non-agricultural activities that impact on the activity and diversity of mycorrhizae.

Pollution

The most common industrial air pollutants emitted into the atmosphere include SO_2, NO-x and O_3. These air pollutants induce a serious loss in the viable mycorrhizae propagules [33]. Furthermore, these pollutants may cause a significant reduction in the colonization of roots [11], a severe degradation in the qualitative and quantitative aspects of mycorrhizae connections between trees, a reduction in the mycorrhizal incidence in healthy trees and a reduction in the enzyme activity of ectomycorrhizal roots [18].

Air pollutants can cause a significant reduction in root growth and mycorrhizal colonization, and a change in mycorrhizal species composition, leading to loss in mycorrhizae diversity [29, 11]. Ozone poses an indirect threat to mycorrhizae activity and diversity [5]. Ozone damage leads to lowered net photosynthesis, altered carbon allocation, and deterioration of photosynthetic pigments. The reduced level of photosynthesis leads to reduced growth and biomass of seedlings, and therefore reduces and alters mycorrhizal assemblages around roots resulting in the loss of mycorrhizal diversity [5, 11]. The deposition of excessive ammonia from the atmosphere is believed to cause physiological alterations such as cellular acidosis in plant and mycorrhizal species which are sensitive to high levels of acidity, leading to changes in mycorrhizal assemblages around roots, and therefore affecting mycorrhizae diversity [35].

Terrestrial pollutants such as heavy metals, polyaromatic hydrocarbons and industrial wastes adversely impact on mycorrhizae activity and diversity. For example, high levels of heavy metals severely decrease the number of ectomycorrhizal fruiting bodies and the number of fruiting species, resulting in a loss of viable mycorrhizae, their activity and diversity [7]. Furthermore, mycorrhizal colonization and spore germination are reduced in soils containing high concentrations of heavy metals, resulting in a reduction in spore numbers [26]. Certain heavy metals impair specific mycorrhizal functions, (e.g., indole acetic acid synthesis) which limit mycorrhizal development [24]. The presence of high levels of heavy metals and nutrients such as P and Zn in industrial sludge can suppress AMF spore germination in soil [4, 25, 45]. Hydrocarbons reduce the proportion of arbuscules in roots compared to non-polluted soils, reducing mycorrhizal activity [6].

Forestry practices

The production and survival of ectomycorrhizal fruiting bodies or spores are very limited in the absence of healthy host plant roots [37]. Therefore, clearcut harvesting may reduce the activity and diversity of ectomycorrhizae [14, 15]. However, the effect of clearcut burn on the formation of ectomycorrhizal tips is even more detrimental [14]. This is believed to be brought about by an increase in soil pH and/or available nutrients [23], which may eliminate sensitive mycorrhizae species, resulting in loss of diversity.

Aboveground burning of vegetation is known to increase biomass production, flowering and seed production, probably by stimulation of biological processes such as nitrification and mineralization [19]. However, spore production of mycorrhizal fungi associated with the root systems of plants in the burned sites is drastically depressed, which in turn reduces mycorrhizal activity and delays potential mycorrhizae-derived benefits [10, 30]. The post-fire re-establishment of mycorrhizal fungi is slow, due to the reduced viability of mycorrhizal propagules as a consequence of fire. Furthermore, by inducing changes in host physiology, burning appears to selectively depress the spore abundance of some AMF or morphotypes of some ectomycorrhizal fungi, clearly resulting in the loss of mycorrhizal diversity [9, 30].

Mining and soil disturbance

Several studies have indicated that AMF play a crucial role in the revegetation of disturbed soil [36]. However, in most cases these soils are inoculated with AMF to augment the levels of indigenous AMF in the soil. This is because the native AMF in these disturbed soils produce limited AMF colonization, and make no significant contribution to the establishment, survival or growth of plants in these soils [1]. Furthermore, mining also reduces the diversity, AMF spore numbers and mycorrhizal inoculum potential of the disturbed soil [41]. These changes in mycorrhizal ecology may be induced by alterations in the physical, chemical and biological characteristics of the soil. Alternatively, the drastic reduction in mycorrhizal infectivity may be due to the severity of disturbance on the very sensitive mycorrhizal external mycelium following mining or cultivation of soil [20].

Conclusions

Mycorrhizae are a large component of the soil ecosystem, either due to their ubiquitous nature or the benefits that can be derived from them. Mycorrhizae can contribute to and serve as indicators of plant and soil health. They are essential in the establishment and survival of plants. However, due to human oversight or lack of understanding the importance of mycorrhizae, many of our activities have resulted in the loss of mycorrhizal diversity and activity. It is important to educate the public, government regulatory agencies and industry on how human activities influence the activity and diversity of this important group of beneficial fungi.

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