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Review

Diversity and ecology of soil fungal communities in rubber plantations

Jutamart MONKAI[a,b,c], Kevin D. HYDE[d,e], Jianchu XU[a,b,c], Peter E. MORTIMER[a,c,*]

[a]Centre for Mountain Ecosystem Studies, Kunming Institute of Botany, Chinese Academy of Sciences, Kunming 650201, Yunnan, China
[b]University of Chinese Academy of Sciences, Beijing 100049, China
[c]World Agroforestry Centre, East and Central Asia, Kunming 650201, China
[d]School of Science, Mae Fah Luang University, Chiang Rai 57100, Thailand
[e]Center of Excellence in Fungal Research, Mae Fah Luang University, 57100 Chiang Rai, Thailand

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ABSTRACT

Monoculture rubber cultivation and its intensive associated human activities are known to have a negative impact on the biodiversity, ecology, and biological conservation of the ecosystems in which they occur. These negative impacts include changes to the biodiversity and function of soil fungal communities, which contribute towards nutrient cycling and interact with other organisms in belowground ecosystems, and may be pathogens. Despite the important role of soil fungi in rubber plantations, these communities have been poorly studied. In this paper, we review the existing literature on the diversity and ecology of belowground fungi in rubber plantations. Various groups of soil fungi, including saprobes, symbionts, and pathogens are discussed. Additionally, the role of plantation management is discussed in the context of both pathogenic soil fungi and the promotion of beneficial soil fungi. Management practices include clone selection, tree age and planting density, application of chemicals, and intercropping systems. Our review shows the strong need for further research into the effects of monoculture rubber plantations on soil fungal communities, and how we can best manage these systems in the future, in order to create a more sustainable approach to rubber production.

1. Introduction

The rubber tree, *Hevea brasiliensis* (Willd.) Muell.Arg., a deciduous perennial tree of the family Euphorbiaceae, is the main producer of commercial natural rubber (Priyadarshan *et al.*, 2009). Although the rubber tree is indigenous to the tropical rain forests in the Amazon Basin of South America, it is cultivated in tropical regions worldwide (Rao *et al.*, 1990; Priyadarshan *et al.*, 2009). With the introduction of the rubber tree to the world market, consumption of natural rubber in

* *Corresponding author*. World Agroforestry Centre, East and Central Asia, Kunming 650201, China.
E-mail address: P.Mortimer@cgiar.org (P. E. Mortimer).
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global markets has increased dramatically, leading to further expansion of rubber plantations (Fox and Castella, 2013). Today, rubber plantations are rapidly expanding throughout non-traditional environments in montane areas of mainland Southeast Asia, including China, Laos, Thailand, Vietnam, Cambodia, and Myanmar (Ziegler et al., 2009; Ahrends et al., 2015).

The introduction of monoculture rubber plantations has led to the spread of pathogens and diseases and resulted in a number of negative environmental impacts (Jacob and Liyanage, 1992; Jayasinghe, 1999, 2001; Ziegler et al., 2009; Xu et al., 2014; Liyanage et al., 2016). These environmental impacts include the loss of natural forests, a decline in biodiversity, a depletion of natural carbon (C) stocks, and soil degradation (Zhang et al., 2007; Li et al., 2008; De Blé court et al., 2013; Warren-Thomas et al., 2015). Reference to soil degradation includes factors such as the loss of soil organic matter and nutrients, increase in surface run off of water, a reduction in the soil water holding capacity, and a decrease in soil biological activity (Zhang and Zhang, 2003, 2005; Guardiola-Claramonte et al., 2010; Clermont-Dauphin et al., 2013; Sreekanth et al., 2013; Puttaso et al., 2015).

Soil is a complex system comprising both abiotic and biotic factors, including macro- and meso-fauna, and microorganisms (Lavelle and Spain, 2001). Fungi comprise a crucial functional component of the belowground ecosystem in terms of nutrient acquisition and cycling, C turnover, soil formation, and the formation mycorrhizal associations with plants (Fontaine et al., 2007; Van Der Heijden et al., 2008). In addition, certain species of soil fungi are known to be pathogenic, resulting in the spread of disease both above and below ground (Narayanasamy, 2011).

It was estimated that the total number of fungi worldwide is around 1.5 million species with only 70,000 species presently described (Hawksworth, 1991, 2001). Soil fungal diversity is still underestimated and the function and relationship between fungi, soil, and plants remains unclear (Bridge and Spooner, 2001; Van Der Heijden et al., 2008). The majority of below ground studies conducted in rubber plantations have focused on soil quality in terms of physical and chemical characteristics, ignoring the role of the soil microbial communities (Cheng et al., 2007; Zhang et al. 2007; Orimoloye et al., 2010; Oku et al., 2012). Despite the fact that fungal activity in soil has direct consequences for soil quality and fertility, fungi have received little attention to date (Peries et al., 1979; Deka et al., 1998; Guo et al., 2013, 2015; Krashevska et al., 2015). This review therefore highlights the significance and influence of soil fungi on rubber plantations.

2. Soil fungal communities in rubber plantation

Saprotrophic fungi

Given that *H. brasiliensis* is a deciduous tree, a large amount of litter is generated, which accumulates on the plantation floor throughout the year (Verghese et al., 2001). It has been reported that, annually, rubber plantations produce approximately 7 tonnes of litter per hectare. However, this litter has been shown to decompose at a slow rate, with 16–21 % leaf weight loss in 120 d (Jacob, 2000; Verghese et al., 2001).

It is well-established that the conversion of natural forests to rubber plantations results in a decline of litter decomposition rates (Zheng et al., 2006; Zhang et al., 2013). The slow decomposition of rubber litter has been attributed to the greater amounts of recalcitrant compounds such as alkyl C and methylated hydrocarbon *cis* polyisoprene in comparison to forest litter (Abraham and Chudek, 2008; Zhang et al., 2013). In a study conducted by Abraham and Chudek (2008), rubber had the lowest soil microbial activity compared to pueraria, mucuna, teak and natural forest. This was attributed to the greater alkyl-C: O-alkyl-C ratio of the rubber litter. The greater microbial activity of teak soil might be due to the increased understory layer and longer planting cycles (up to 100 y) of teak, resulting in a build-up of soil organic matter (Abraham and Chudek, 2008). Thereby, this study suggested that rubber plantations should be cropped with leguminous species during the initial years.

There have been few studies investigating the fungal communities associated with rubber litter (Osemwegie et al., 2010; Seephueak et al., 2010, 2011a, 2011b). The studies of fungal diversity in the rubber litter layer, conducted by Seephueak et al. (2010, 2011a, 2011b), found 447 species of saprotrophic fungi on leaves, 497 species on branches, and 461 species on logs. These studies also established that the diversity and composition of fungal communities on rubber litter varied according to differences on decomposition stages and seasonality. Rubber litter also supported high species richness and fungal diversity. Many factors can affect the changes in fungal communities such as the physical and chemical properties of trees, tree ages, microclimate, biological interaction, substrate preference, host preferences and geographical characters (Lodge, 1997; Kodsueb et al., 2008). Therefore, more studies on fungal diversity of rubber litter in other regions should be carried out to evaluate these effects. It would also be of value to investigate the function of these decomposer fungi.

A study of mushroom diversity related to rubber agroforestry systems and secondary forests in south western Nigeria revealed a total of 435 fruiting bodies, belonging to 93 fungal species (Osemwegie et al., 2010). The greatest number of fungal taxa recorded was wood-inhabiting mushrooms, comprising 70 % of the total fungal community. Compared to secondary forest, rubber agroforestry systems had lower macrofungal diversity, whilst the young rubber plantation supported greater fungal species richness and diversity of macrofungi than the old rubber plantations. In conclusion, the conversion of secondary forest into rubber agroforestry systems has a negative impact on mushroom diversity (Osemwegie et al., 2010).

Mycorrhizal fungi

Arbuscular mycorrhizal fungi (AMF) were first described on the roots of *H. brasiliensis* by D'Angremond and Van Hell (1939). They recorded intra and extracellular hyphae as well as vesicles and arbuscules. This AMF was suggested to be *Rhizoctonia bataticola* (*Macrophomina phaseoli*) (Taub.) Butl., nevertheless, the correct identity has not yet been confirmed (D'Angremond and Van Hell, 1939). The AMF species which