Soil Biology & Biochemistry 75 (2014) 1–10

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

journal homepage: www.elsevier.com/locate/soilbio

Effects of experimental nitrogen and/or phosphorus additions on soil nematode communities in a secondary tropical forest

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ARTICLE INFO

Article history:
Received 3 January 2014
Received in revised form
18 March 2014
Accepted 21 March 2014
Available online 13 April 2014

Keywords:
Nitrogen fertilization
Phosphorus fertilization
Soil nematodes
Soil food web
Tropical forest
Nitrogen-rich and phosphorus-poor soils

ABSTRACT

In tropical forest ecosystems, highly weathered soils are often considered as relatively nitrogen-rich but phosphorus-poor. Nutrient availability greatly regulates ecosystem processes and functions of tropical forests. However, little is known about how nitrogen and/or phosphorus additions affect the conditions of soil food web which is an important component of belowground ecosystems. In the present study, soil nematode communities were monitored and served as indicators of soil food web conditions under experimental nitrogen and phosphorus additions in a secondary forest in tropical China. The principal response curves of soil nematode community structure revealed same tendency of changes under nitrogen and/or phosphorus additions compared with control, in terms of nematode functional guild compositions: apparent successions from communities dominated by He_3 and Ba_1 to communities dominated by Ba_2 and Fu_2 occurred after nitrogen and/or phosphorus additions. The diversity of soil nematode genera was not sensitive to either nitrogen or phosphorus addition. Phosphorus addition significantly suppressed total nematode density, density of omnivore-predators, and four nematode faunal indices (i.e. MI25, EI, SI, and SFI), but increased two faunal indices (i.e. CI and BaI). However, nitrogen addition did not induce remarkable changes of these variables in the present study. Our results suggest that nitrogen and/or phosphorus additions suppress soil nematodes in tropical secondary forests, which was inconsistent with our expectation that nitrogen addition was detrimental to and phosphorus addition was conducive to soil nematodes in this nitrogen-rich but phosphorus-poor soil. Furthermore, the effects of phosphorus addition are more powerful than the effects of nitrogen addition. Moreover, phosphorus addition degrades the structure and trophic links of the soil food web, reduces the carbon utilization of soil nematodes, and leads to a more fungal dominated decomposition pathway. The alterations of soil food web conditions might result in altered ecosystem functioning. Our findings could provide a better understanding of the responses of soil food web to nitrogen and phosphorus additions in nitrogen-rich but phosphorus-poor soils.

1. Introduction

Tropical forests possess great biodiversity (Myers et al., 2000; Sala et al., 2000), contain up to 40% of global terrestrial biomass carbon (Dixon and Brown, 1994; Cleveland and Townsend, 2006) and 30–50% of terrestrial productivity (Grace et al., 2001). Therefore, they are considered as one of the most important ecosystems on earth. Their highly weathered soils are often considered as relatively nitrogen-rich but phosphorus-poor. Soil phosphorus level plays a key role on ecosystem functions such as net ecosystem production (NEP) and litter decomposition in those ecosystems (Vitousek, 1984; Hobbie and Vitousek, 2000; Wardle et al., 2004; Cleveland et al., 2006; Kaspari et al., 2008). In addition, global atmospheric nitrogen deposition is accelerating through time due to anthropogenic activities such as fossil fuel burning and agriculture

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http://dx.doi.org/10.1016/j.soilbio.2014.03.019
0038-0717/

fertilization (Lu et al. 2010a; Fang et al. 2011). Chronic elevated nitrogen depositions impact many aboveground and belowground ecosystem functions such as NEP, biodiversity or richness, and global carbon cycling (Vitousek, 1984; Alison et al., 2000; Nadelhoffer, 2000; Matson et al., 2002; Lu et al., 2010a, 2010b).

Nematodes are the most abundant soil mesofauna, occupy key positions at most trophic levels in the soil food web, and correlate with ecosystem processes and functions such as soil nutrient cycling, litter decomposition, net ecosystem production (NEP), and ecosystem succession (Van der Putten et al., 1993; De Deyn et al., 2003; Neher et al., 2012; Zhao et al., 2012; Zhao and Neher, 2013b). They are sensitive to various disturbances (e.g., agriculture management, pollution, land-use change) and it is well documented that soil nematodes can be useful ecological indicators (Neher, 2001; Todd et al., 2006; Zhao and Neher, 2013; Zhao et al., 2013a, 2013b). Soil nematode communities are quite susceptible to the changes in soil nitrogen and/or phosphorus levels (Todd, 1996; Sarathchandra et al., 2001; Coyne et al., 2004; Wang et al., 2006; Liang et al., 2009). Therefore, the additions of nitrogen and phosphorus may lead to alteration in soil nematode communities. Addressing the effects of nitrogen and phosphorus additions on soil nematodes can improve our insights of how nitrogen and phosphorus additions alter soil food web structure and ecosystem processes (e.g., nutrient mineralization) in tropical forest ecosystems. However, soil nematode communities are usually overlooked in studies of nitrogen and phosphorus additions, particularly, the phosphorus addition.

Only few studies have monitored the effects of simulated nitrogen deposition on soil nematode communities. The main findings of these studies are that high levels of nitrogen addition ($>$80 kg N ha^{-1} yr^{-1}) suppressed soil nematode communities but low levels of nitrogen deposition ($<$50 kg N ha^{-1} yr^{-1}) did not induce significant changes of soil nematode communities in both alpine tundra soils in Wyoming, USA (Lokupitiya et al., 2000) and in grassland soils in Inner Mongolia, China (Ruan et al., 2012; Wei et al., 2012; Li et al., 2013). Many previous studies monitor the effects of nitrogen fertilization on soil nematode communities in agriculture, forest and grassland ecosystems. However, there are conflicting observations of the same monitored variables even in similar ecosystems. For examples, mineral N fertilization increased total nematode abundance of a boreal forest in southern British Columbia (Forge and Simard, 2001) but decreased that of a boreal forest in central Sweden (Sohlenius and Wasilewska, 1984), respectively. Nitrogen fertilization significantly increased the relative abundance of herbivores and decreased that of omnivores in a subtropical farm in Florida, US (Wang et al., 2006) but had no significant impact on soil nematode communities in a temperate farm in northeast China (Liang et al., 2009). Moreover, chronic nitrogen fertilization significantly increased the abundances of herbivorous and microbivorous nematodes in a tallgrass prairie in Kansas, US (Todd, 1996) and significantly reduced the abundance of omnivores in a grass sward in British Columbia (Forge et al., 2005). In addition, 3-yr application of nitrogen fertilizer increased the abundances of total nematodes and herbivores and decreased the abundances of fungivores and carnivores in a pasture in New Zealand (Sarathchandra et al., 2001). However, long-term applications of different types and levels of nitrogen fertilization did not significantly influence the abundances of total nematodes or trophic groups in a Kentucky bluegrass (*Poa pratensis*) turf in Ohio, US (Cheng et al., 2008).

Compared with nitrogen, studies focused on the effects of mineral phosphorus fertilization on soil nematode communities are rare. The effects of phosphorus fertilizer on soil nematode community composition and structure are poorly known. Sarathchandra et al. (2001) reported that the abundances of total nematodes, bacterivores, fungivores and omnivores increased slightly (statistically insignificant) but nematode maturity index values did not change after phosphorus fertilization in pasture soils in New Zealand. Todd (1996) reported that the effects of phosphorus fertilization on soil nematodes were limited. Some other studies focused on how phosphorus fertilization affects specific nematode species. For example, Coyne et al. (2004) reports that phosphorus fertilization decreases the abundance of cyst nematode (*Heterodera sacchari*) in soils with both upland and lowland rice in Ivory Coast of Africa. In contrast, Simon and Rovira (1985) and Price et al. (1995) report that phosphorus fertilization increased abundances of *Heterodera avenae* and *Heterodera glycines*.

In the present study, we test the effects of experimental nitrogen and/or phosphorus additions on soil nematode communities in soils of secondary forests in tropical China where soils are nitrogen-rich but phosphorus-poor and face increasing deposition of atmospheric nitrogen depositions (Lu et al., 2010a; Fang et al., 2011). Therefore, we expected the additional nitrogen application might aggravate nitrogen-saturation which might be detrimental to soil nematode communities. Phosphorus application might improve the available phosphorus levels which was conducive to soil nematode communities. We hypothesize that: 1) nitrogen addition may have negative effects on the abundance, diversity, and/or community complexity of soil nematodes and 2) phosphorus addition may have positive effects on these variables of soil nematodes.

2. Materials and methods

2.1. Study site

This study was conducted at the Xiaoliang Tropical Coastal Ecosystem Research Station (110°54′E, 21°27′N), Chinese Academy of Sciences (CAS), Guangdong Province, China. The climate is tropical monsoon with a distinct wet (from April to September) and dry season (from October to March). The mean annual temperature is 23 °C and the annual precipitation is 1400–1700 mm, respectively. The soil is lateritic, formed from highly weathered granite (Table 1).

Our experiment was conducted in a secondary mixed forest. The forest started as *Eucalyptus exserta* plantation in 1959, then 312 species were introduced between 1964 and 1975 (Ding et al., 1992; Ren et al., 2007). Now, the most common tree species are: *Castanopsis fissa*, *Cinnamomum camphora*, *Carallia brachiata*, *Aphanamixis polystachya*, *Ternstroemia pseudoverticillata*, *Acacia auriculiformis*, *Cassia siamea*, *Albizia procera*, *Albizia odoratissima*, *Leucaena leucocephala*, *Aquilaria sinensis* and *Chukrasia tabularis*.

2.2. Experimental design

A nitrogen and phosphorus addition experiment was designed as a randomized complete block ($n = 5$) and established in August

Table 1
Means (standard error, $n = 5$) of soil physical and chemical properties (0–10 cm depth) in Control (CK), N fertilization (+N), P fertilization (+P), and NP fertilization (+NP) plots at the study site at the initiation of the experiment in 2009.

Soil properties	Treatments			
	CK	+N	+P	+NP
Moisture (%)	25.0 ± 1.3	24.5 ± 1.2	24.1 ± 1.1	25.0 ± 1.4
SOC (g/kg)	33.8 ± 0.7	33.8 ± 0.9	32.3 ± 0.7	33.4 ± 0.8
TN (g/kg)	2.60 ± 0.15	2.23 ± 0.21	2.54 ± 0.10	2.57 ± 0.19
TP (g/kg)	0.38 ± 0.04	0.36 ± 0.02	0.40 ± 0.02	0.41 ± 0.03

SOC, soil organic carbon; TN, soil total nitrogen; and TP, soil total phosphorus.