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# Effects of simulated acid rain on soil fauna community composition and their ecological niches☆

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## ABSTRACT

Acid rain is one of the severest environmental issues globally. Relative to other global changes (e.g., warming, elevated atmospheric [$CO_2$], and nitrogen deposition), however, acid rain has received less attention than its due. Soil fauna play important roles in multiple ecological processes, but how soil fauna community responds to acid rain remains less studied. This microcosm experiment was conducted using latosol with simulated acid rain (SAR) manipulations to observe potential changes in soil fauna community under acid rain stress. Four pH levels, i.e., pH 2.5, 3.5, 4.5, and 5.5, and a neutral control of pH 7.0 were set according to the current pH condition and acidification trend of precipitation in southern China. As expected, we observed that the SAR treatments induced changes in soil fauna community composition and their ecological niches in the tested soil; the treatment effects tended to increase as acidity increased. This could be attributable to the environmental stresses (such as acidity, porosity and oxygen supply) induced by the SAR treatments. In addition to direct acidity effect, we propose that potential changes in permeability and movability of water and oxygen in soils induced by acid rain could also give rise to the observed shifts in soil fauna community composition. These are most likely indirect pathways of acid rain to affect belowground community. Moreover, we found that nematodes, the dominating soil fauna group in this study, moved downwards to mitigate the stress of acid rain. This is probably detrimental to soil fauna in the long term, due to the relatively severer soil conditions in the deep than surface soil layer. Our results suggest that acid rain could change soil fauna community and the vertical distribution of soil fauna groups, consequently changing the underground ecosystem functions such as organic matter decomposition and greenhouse gas emissions.

## 1. Introduction

Acid rain has been regarded as one of the three severest environment disasters around the world. Following Europe and North America, China is the third biggest acid rain region (Rodhe et al., 2002) and about 40% of the terrestrial area is receiving acid rain at present. Unfortunately, the area of territory in China under acid rain remains increasing with economic and technological developments. Referring to the latest Bulletin of Environment Status in China (Ministry of Environmental protection of the People's Republic of China, 2015), 44.3% of the 470 cities under weather monitoring received acid rain pollution in the past year. Therein, 26.6% of the monitored cities were under acid rain pollution with a frequency of more than 25% of precipitation event; in these cities, at least one fourth of precipitations were acid rain in the last year. More than three fourths of precipitations were acid rain in 9.1% of the cities with weather monitoring (Ministry of Environmental protection of the People's Republic of China, 2015). In 2014, 29.8% of cities received precipitations with annual average pH lower than 5.6, the threshold to define a precipitation as an acid rain (Ministry of Environmental protection of the People's Republic of China, 2015); that is to say, around one third of cities in China are enveloped by acid rains. Acid rain can result in lots of ecological consequences, such as water and soil acidity, forest declines, loss of biodiversity, soil degradation, and damage of buildings. As a result,

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economy loss originated from acid rain pollution was estimated up to 110 billion RMB each year in China. Therefore, effects of acid rain on ecosystems received much attention in recent years.

The aboveground parts of ecosystems (such as leaves and twigs of plants) are initially affected by the acid rain, because natural acid rains precipitate from the air to land. Previous studies showed that acid depositions could damage cuticular structure of plant leaves, reduce mesophyll conductance to $CO_2$, limit photosynthesis and transpiration, and raise cation leaching and water loss of foliages (Hogan, 1992; Mena-Petite et al., 2000; Neufeld et al., 1985), therefore lessening aboveground productivity (Chen et al., 2013; Shukla et al., 2013). Plants can change a variety of physiological processes and metabolic pathways to mitigate damages under acid rains (Mena-Petite et al., 2000; Wang et al., 2012). Such changes in aboveground components of ecosystems probably give rise to alterations of belowground ecosystems, as mutual feedbacks exist between the both (Wardle et al., 2004). Moreover, impacts of acid rain on plant individuals might be amplified by other coinstantaneous environmental stresses such as drought and heavy metal pollution, and vice versa (Mena-Petite et al., 2000; Wang et al., 2014b).

Soil is the final receptor of acid rains in terrestrial ecosystems and thus the belowground ecosystem is probably more sensitive to acid rain, relative to its aboveground counterpart of terrestrial ecosystems (Chen et al., 2013). Taking into account of extreme complexity of the belowground system, observations of acid rain effects on soil systems are most difficult and obscure, making the acid rain impacts below ground far less understood than its impacts above ground (Bokhorst et al., 2012). Previous studies reported that acid rain depositions could change cation adsorptions and solution chemistry in soils (Calace et al., 2001; Qiu et al., 2015), raise cation leaching and aluminum toxicity (Zhang et al., 2007, 2014), alter soil microbial community composition and function (Chen et al., 2013; Liu et al., 2014; Wang et al., 2014a) and depress activities of soil animals such as earthworms (Zhang et al., 2013, 2015). These decline the ability of soil to provide a suitable physiochemical environment and essential nutrients to maintain soil biota and could therefore change soil biota community composition and functions. Such adjustments resulted from acid rains may lead to significant changes in several important soil ecological processes such as soil carbon (C) and nitrogen (N) cycling under acid rain stress (Liang et al., 2013; Stemmer et al., 2007; Wang et al., 2010).

Soil biota plays a critical role in maintaining the regular ecosystem functions below ground (Birkhofer et al., 2011; Bokhorst et al., 2012; Chen et al., 2013). Therein, soil microbial community has received more attention in comparisons with soil fauna, although the importance of the latter to ecosystem functions has been highlighted (Brennan et al., 2009; Garcia-Palacios et al., 2013; Heneghan and Boglger, 1996). For instance, Wall et al. (2008) found that soil animals stimulated C decomposition in temperate and tropical ecosystems. Recent studies also demonstrated that soil fauna could potentially affect soil $N_2O$ emissions and promote the efficiency of rain gardens in urban ecosystems (Kuiper et al., 2013; Mehring et al., 2015). However, the role of soil fauna in ecosystem functions might be altered under current global changes (Haimi et al., 2005; Kardol et al., 2011; Wall et al., 2008). Previous literature noted that several species of soil invertebrate responded obviously to acid rain stress (Felten and Guerold, 2006; Hågvar, 1990). Nevertheless, how acid rain affects soil fauna community composition and their ecological niches remains far less studied. More attempts are still needed to bridge our knowledge gaps on the topic, taking into account of asymmetric responses of soil fauna with various traits to environmental changes (Bokhorst et al., 2012; Hågvar, 1990).

In this study, we conducted a microcosm experiment for two months to explore the effects of simulated acid rain (SAR) on soil fauna community. Five pH levels were set to simulate acid rain with different acidities and soil samples in different depths were collected for the identification of soil fauna periodically. We expected that soil fauna community composition, as well as their ecological niches, would be altered in response to the SAR treatments. Previous studies showed that different groups of soil fauna could respond variously to environmental changes, depending on their physical or physiological traits (Bokhorst et al., 2012). The SAR treatments could be beneficial to acidophilic soil animals but adverse to basophilic soil fauna (Hågvar, 1990). Moreover, we expected that soil animals would move downwards as a mitigation of soil fauna to the SAR stress since surface soil layer would be affected the most by acid rain.

## 2. Material and methods

### 2.1. Site descriptions and experimental design

Soil used in this study is garden soil which was collected from an experimental farm (113°21′ E, 23°9′ N) of South China Agricultural University in Guangdong province of southern China. Three layers of soil (i.e., 0–5, 5–10, and 10–15 cm) were collected separately and delivered back to laboratory for the following experiment. The soil is acidic latosol, with a pH value being 5.29. It contains 24.2 and 2.5 g $kg^{-1}$ of soil organic C (SOC) and total N (TN), respectively.

The acid solutions were prepared by mixing $H_2SO_4$ and $HNO_3$ with a ratio of 3:1 and then diluted with deionized water to certain pH levels. The SAR was set four pH levels of 2.5, 3.5, 4.5 and 5.5, referring to the current acidity and acidification trend of natural precipitations in the study area. In this region, Huang et al. (2010) observed that pH in natural rainfalls from 2005 to 2009 varied from 3.61 to 6.89, with a 5-year average being 4.56. An extremely low pH level (i.e., pH 2.5) was counted in this study since we expected pH of precipitations would turn lower with the developments of economy and technologies in southern China (Zhang et al., 2015). The ratio of $H_2SO_4$: $HNO_3$ in our SAR treatments was determined according to the $SO_4^{2-}$: $NO_3^-$ ratio in natural precipitations in this region (Cao et al., 2009; Huang et al., 2009, 2010). Moreover, a control was set using deionized water with the pH of 7.0.

In this study, uniform plastic cylinders (with the height being 40 cm and the inner diameter 15 cm) were used as experimental containers. The same amount of fresh soils was filled in the containers accordingly at the three soil layers (i.e., 0–5, 5–10, and 10–15 cm) in the same order as soil collection. For all the experimental units, soil was packed slightly to make the final soil depth 15 cm for the following incubation. Glass fibers were covered upon the surface soil in all the cylinders to prevent soil from splashing out and disrupting when the SARs were sprayed. Soils were incubated under room temperature for 60 days, starting at 27th September 2012. The SARs were sprayed once every five days. An influent of 250 mL SAR solutions was slowly sprayed at a rate of approximate 6 $cm^3$ $min^{-1}$ in each incubation container each time (Xu et al., 2015). This amount (250 mL) of the SAR solution sprayed each time is equivalent to 14 mm precipitation, a rainfall intensity frequent occurrence in the study site. Therefore, totally 3000 mL of acid solutions or deionized water were sprayed into each of the incubated soils. This corresponds to 1020 mm of acid rain per year, a figure close to the average annual amount (around 1080 mm) of acid rain in this region. For each SAR treatment or the control, twelve containers were set with three experimental replicates at each of the four sampling occasions. Soil samples were collected from 0–5, 5–10, and 10–15 cm, respectively, at the 15th, 30th, 45th, and 60th days after treatments conducted. At each sampling