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Simulated acid rain changed the proportion of heterotrophic respiration in soil respiration in a subtropical secondary forest

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ABSTRACT

Acid rain is a matter of concern in southern China. We explored how soil respiration (R_s) and heterotrophic respiration (R_h) rates changed when subjected to simulated acid rain (SAR) environment for 3 years (from March 2010 to February 2013) in a secondary forest in subtropical China. The field experiment was arranged in a split-plot design, with 4 main blocks. Each block was split into un-trenched (R_s) and trenched (R_h) treatments. Four SAR treatments of CK (control, deionized water), A1 (pH 4.0), A2 (pH 3.0), and A3 (pH 2.0) were randomly assigned in each of the R_s and R_h treatments. Soil CO_2 fluxes as well as soil temperature and moisture at a depth of 5 cm were measured weekly. Different SAR treatments exhibited similar seasonal patterns of R_s and R_h. Mean annual R_s rates in CK, A1, A2, and A3 plots were 878.2 ± 100.8, 919.4 ± 33.1, 865.6 ± 62.5, and 925.2 ± 20.5 g C m^{-2} yr^{-1}, respectively, over 3 years; SAR had no significant effects on R_s. R_h, however, was significantly ($P < 0.05$) affected by the lowest SAR pH level (A3). On overage of 3 years, annual R_h rates in CK, A1, A2 and A3 plots were 606.7 ± 52.4, 663.5 ± 35.5, 728.2 ± 60.7, and 760.1 ± 42.2 g C m^{-2} yr^{-1}, respectively. Statistical analysis showed that SAR significantly ($P < 0.05$) increased the proportion of R_h in R_s. The relationship between residual R_s (or R_h) based on soil temperature and observed R_s (or R_h) and soil moisture could be well fitted in a quadratic model.

1. Introduction

On combustion of fossil fuels, sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are released. These gases are transformed in the atmosphere to cause acid rain (Driscoll et al., 2001). Acid rain includes deposition of wet and dry acidic components. Wet deposition occurs when precipitation clears acids from the atmosphere, while dry deposition occurs in the absence of precipitation. Acid rain is a serious environmental hazard in China (Bian and Yu, 1992), and is particularly serious in the southern part of China where most of the soil is acidic in nature. Southern China was reported as the third largest area affected by acid rain after Europe and the United States (Wang and Xu, 2009). Since mid-1990s, there is no decrease in the area affected by acid rain in China (Xie et al., 2009; Tang et al., 2010; Zhang et al., 2012).

R_s is one of the largest CO_2 fluxes in the global carbon cycle, contributing 68–98 Pg C to the atmosphere annually (Schlesinger, 1977; Raich et al., 2002; Bond-Lamberty and Thomson, 2010; Gomez-Casanovas et al., 2013). R_s generally results from two respiratory processes, namely autotrophic respiration (R_a) and heterotrophic respiration (R_h) (Hanson et al., 2000). Separating autotrophic and heterotrophic contributions to R_s is important, as in a specific ecosystem R_h and R_a may respond differently to various environmental factors (Hanson et al., 2000; Trumbore, 2000; Giardina et al., 2004; Ryan and Law 2005; Selsted et al., 2012). R_h is important in carbon cycle because it is an ecological indicator of the decomposition rates of soil organic carbon (SOC) and carbon storage (Ryan and Law, 2005).

Acid rain can potentially disrupt nutrient cycling by leaching nutrients from plant foliage and soils, interference with decomposition of organic matter, and disruption of processes such as nitrogen fixation (Turner and Tingey, 1990; Wright et al., 1990; Aber et al., 1998; Zhang et al., 2007; Lovett et al., 2009; Ling et al., 2010). It has direct and indirect effects on plants in forests. These effects may reflect in changed forest productivity and respiration (Tamm and Cowling, 1977; de Vries and Breeuwsma, 1987; Falkengren-Grerup, 1987; Nygaard and Abrahamsen, 1991). The leaching of sulfate and nitrate results in acidification of soil, and in some cases mobilizes aluminum. Aluminum is a natural component of soil, but under acidic conditions it becomes more soluble

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compared with neutral conditions. This results in high concentrations of aluminum in water in the soil, which may in turn be toxic to plant roots and microorganisms (Kuperman, 1996).

Influences of acid rain on R_s in forests are an increasing concern (Salonius, 1990; Vanhala et al., 1996; Liang et al., 2013), because acid rain changes the conditions of soil and plant roots. However, previous reviews have found mixed results of the effects of simulated acid rain (SAR) on R_s (Vanhala et al., 1996). Studies have shown positive (e.g., Salonius, 1990), neutral (e.g., Will et al., 1986), and negative (e.g., Fritze, 1992) effects of SAR. One reason for the differences between the reported observations may be attributed to the varying time periods over which the artificial acidification studies were carried out (Vanhala et al., 1996). Field studies in which SAR is applied over a long time period may reflect the long-term effects of acid rain on CO_2 emissions of the soil (Liang et al., 2013). To our knowledge, such field studies are rare. Little is known about the effects of acid rain on heterotrophic and autotrophic components of R_s. Soil enzymes can be considered as sensitive indicators of ecological change and used to identify microbial activity (Caldwell, 2005). The effect on enzyme activities in the soil under different SAR pH levels is unclear. Moreover, little is known on the effect of temperature and moisture content of soil on R_s or R_h under various SAR pH levels.

In this study, we report on the R_s and R_h rates in a subtropical soil environment with 3 years of artificial acidification. We explore how R_s and R_h may change in a SAR environment, particularly during the relatively long experimental period (3 years), in a subtropical secondary forest. We address 4 important questions for predicting how SAR contributes to soil carbon balance in forested ecosystems:

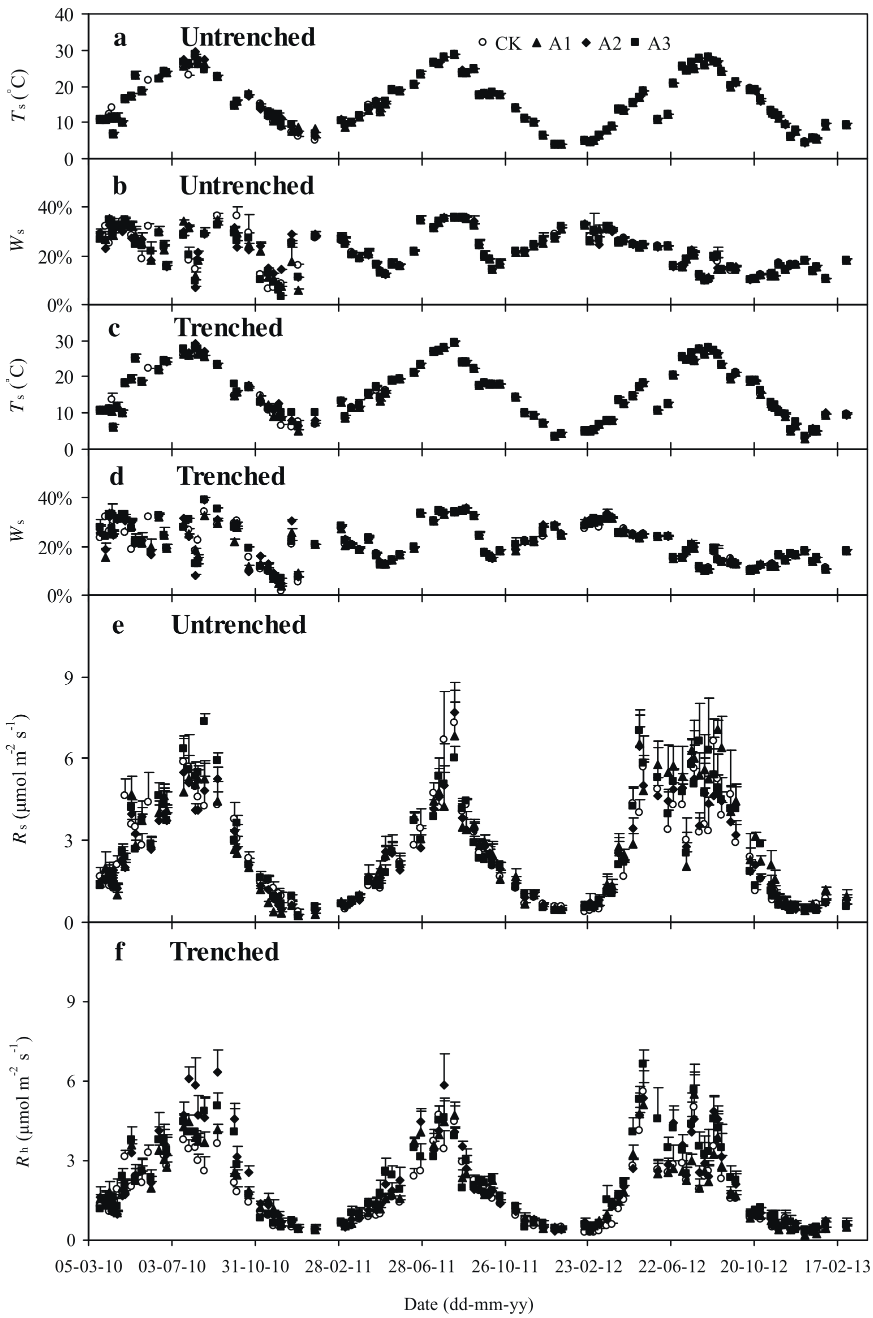

Fig. 1. Seasonal variability in soil temperature (T_s) (a), soil moisture (W_s) (b), and soil respiration (R_s) (e), in un-trenched plots and that in soil temperature (T_s) (c), soil moisture (W_s) (d), and heterotrophic respiration (R_h) (f), in trenched plots. Error bars are standard error of the mean (n = 4).