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Soil acidity reconstruction based on tree ring information of a dominant species *Abies fabri* in the subalpine forest ecosystems in southwest China

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Tree ring information of Abies fabri is suitable to reconstruct soil acidity caused by acid deposition.

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ABSTRACT

To assess the suitability of dendrochemistry as an indicator of soil acidification, soil chemistry and tree ring information of *Abies fabri* were measured at two distinct sites (severe acid deposition site-Emei Mountain and clean site-Gongga Mountain) of the subalpine forest ecosystems of western Sichuan, southwest China. The actual soil acidity (pH) was significantly correlated with some of the recent xylem cation (Ca, Mg, Mn, Al, Sr and Ba) concentrations and their molar ratios. Xylem Ca/Mg and Ca/Mn of *A. fabri* were ultimately selected to reconstruct the historical changes of soil pH in Emei Mountain and Gongga Mountain, respectively. The validity of those rebuild was also verified to a certain extent. We conclude that xylem cation molar ratios of *A. fabri* were superior to the single cation concentrations in soil acidity rebuild at the study sites due to normalizing for concentration fluctuations.

1. Introduction

Tree growth is strongly influenced by environmental and climatic variables. For the advantages of accurate dating, high resolution, strong continuity and wide distribution, tree rings can be used as sensitive biomonitors to record local and global environmental changes. Compared to many other types of data, the information presented by tree rings are larger in quantity and stronger in reliability (Barrelet et al., 2008; Cutter and Guyette, 1993). Thus, dendro-analysis has become one of the key techniques to obtain the past environmental changes, and there is important significance on scientific research. Used widely in many fields like climatology, archaeology, hydrology, ecology and environmental sciences, dendro-analysis has become a comprehensive discipline of rapid development (Barrelet et al., 2008; D'Arrigo and Jacoby, 1999; Linderholm et al., 2004). Coniferous species have become the main materials for dendro-analysis because of their broad distribution and clear texture. They have been frequently used to monitor the effects of environmental changes on forest health and to investigate the responses of trees to those changes (Battipaglia et al., 2009; Fernandez et al., 2005; Sass-Klaassen et al., 2008). Coniferous and some other deciduous species have been widely used to reveal the impacts of pollution on forest health (Berger et al., 2004; Houle et al., 2002), and have been frequently selected as proxies for reconstructing the history of environmental pollution, such as the loss of base cations (Tomlinson, 2003; Wang et al., 2005), the element deposition of sulfur and nitrogen (Penninckx et al., 1999; Struis et al., 2008), the emission of heavy metals (Aznar et al., 2008; Padilla and Anderson, 2002) and the changes in soil chemistry (Dai et al., 1998; Demchik and Sharpe, 2000; Watmough et al., 1999). Among all of them, using the temporal variation of dendrochemistry to indicate the historical changes in soil chemistry has provided rich scientific information for evaluating the past long-term changes and predicting the future evolution trend of soil environment, and it has important practical significance in exploring temporal reconstruction of soil chemistry (Berger et al., 2004; Kuang et al., 2008).

Acid rain arose as a global environmental problem in United Nations Conference on the Human Environment in 1972. Since then, there have been several concerns in the properties and the effects of acid rain on environment, especially in soil, which is

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presented as the breeding sites of plants and microorganisms and the main bearer of acid rain (Dai et al., 1998; Porebska et al., 2008). Soil acidification is a natural biogeochemical process in soil formation underlying forest ecosystems (Schoenholtz et al., 2000), but acid deposition aggravate it by accelerate the base cation loss and increase the phytotoxic element emission, ultimately causing the decline and mortality of forest species (Miller and Watmough, 2009; Tomlinson, 2003). Metals may enter tree xylems through roots, foliage and bark, but uptake from soil solution via roots is considered the major pathway for most elements to become incorporated in tree rings (Watmough, 1999). The concentrations of these elements are influenced by the changes of soil acidity (Demchik and Sharpe, 2000; Tomlinson, 2003; Watmough and Dillon, 2003). Although there is lack of historical monitoring data for evaluating the long-term changes in soil pH in most areas, we can overcome it by virtue of the radial variations in base cations in tree rings which offer the potential to detect the historical changes in soil chemistry.

The subalpine forest ecosystems of western Sichuan, located in Sichuan province of southwest China, is a tourist attraction noted for its natural and cultural sights. The industrialization and urbanization of adjacent areas have been rapidly rising along with the steady increase in population and vehicles and the significant development of service industry since China's opening and reforming policy from 1980's. It has caused persistent attention focused on environmental pollution and ecosystem deterioration in this region (Zhu et al., 1997). *Abies fabri* is an endemic and dominant species of Sichuan province, distributed across the subalpine region with an elevation of 1900 ~ 3800 m at the western edge of Sichuan Basin, which is bounded on the east by Emei Mountain and on the west by the eastern slope of Gongga Mountain. *A. fabri* plays a vital role in ecological research as the constructive and timberline tree species of subalpine dark coniferous forest (Shen et al., 2004). The *A. fabri* forest in Emei Mountain has undergone large areas of decline and mortality since 1975. It has caused a serious destruction on ecological environment and natural landscape. The long-term effects of acid deposition have been considered the primary cause of the forest decline (Lu et al., 1996). As a consequence, *A. fabri* could be used as a strong indicator for dendrochemical analysis due to its high sensitivity to acid deposition.

It has been well documented that local forest has been declining in the subalpine forest ecosystems of western Sichuan during the last several decades, which is mainly caused by the continuous input of acidic agents (Lu et al., 1996; Zhuang et al., 1995). However, long-term changes in soil chemistry have not been reported until recently. The specific objectives of the present study were to: (1) reconstruct soil pH using dendrochemistry of *A. fabri* in the subalpine forest ecosystems of western Sichuan; (2) verify the reconstruction results indirectly based on physiological indices of tree ring width, and test the validity and accuracy of dendrochemistry as the indicator of soil acidification; (3) provide an effective method for detecting soil chemistry changes in the external environment and give an early warning signal for forest health.

2. Materials and methods

2.1. Sites description

Two forest stands located at *A. fabri* distribution zone in the subalpine forest ecosystems of western Sichuan are chosen for this study. Emei Mountain (103°21′E, 29°34′N) is located at western edge of Sichuan Basin in Sichuan province, where huge amounts of pollutants from Sichuan Basin are deposited and cause severe acid deposition (Jiang, 1991). The sampling sites are at elevations between 1700 m and 3098 m. The annual mean air temperature and average annual precipitation are 6.5 °C and 2300 mm around 2210 m altitude (Tang and Ohsawa, 2002). It is strongly influenced by southeasterly monsoon winds during summer (Tang, 2006). The dominant species are *A. fabri* in the upper canopy, and *Rhododendron calophytum* and *Bashania fangiana* in the understory of Emei Mountain. On the contrary, as an experimental control, Gongga Mountain (101°53′E, 29°36′N) represents clean site which lies in the southeast of Tibetan Plateau of western Sichuan. The altitude variation of sampling sites ranges from 2200 m to 3650 m. The annual mean air temperature and average annual precipitation are 4.0 °C and 1938 mm at 3000 m altitude (Shen et al., 2004). The dominant species and the climatic factor are similar to Emei Mountain (Lu and Cheng, 2009). Soils are classified as mountain brown dark coniferous forest soils derived from basalt, crystalline rock in both sampling sites, which is slow at mineral weathering rate and susceptible to acid deposition.

2.2. Sampling and analytical methods

Six mature trees in Emei Mountain and five mature trees in Gongga Mountain were selected from similar microhabitat for sampling. The sampling trees were equally distributed by altitude at each site, which were all healthy-looking at similar size (age) and open-grown without suppression by shading. Soil which developed normally without animal damage or factitious destruction was collected from the east, south, west and north directions 1 m away from each selected tree, and the litter layer was removed before soil sampling. Soil sample of 0–30 cm depth was collected, in which the roots of the trees were mainly distributed. Soil samples were stored in labeled plastic bags, brought to the laboratory, and were air-dried and sieved through a 2-mm sieve for chemical analysis. Soil pH was then measured in distilled, deionized water with a soil/solution ratio of 5 g: 25 mL. The soil and solution were stirred thoroughly for about 1 min, and again after 15, 30 min. Then the pH meter (Thermo Scientific, Orion 3-Star) was used to measure the pH of the supernatant settled after 5 min, with 3 replicates. Exchangeable base cations (Na, Mg, K, Ca, Mn and Al) in the soil samples were extracted using 1 mol L^{-1}, pH 7.0 ammonium acetate (CH_3COONH_4) approximately 14 h with a shaker at room temperature, the mass to volume ratio was 3 g: 50 mL, then the 1:5 dilution of extracted solution were determined by inductively coupled plasma mass spectrometry (ICP-MS, PerkinElmer Inc., Elan DRC-e). The effective cation exchange capacity (CECe) of soil was determined as the sum of the exchangeable base cations and the exchangeable acidity. Base saturation percentage of soil (BS) was determined as the ratio of exchangeable base cations on CECe, expressed as a percentage. A paired sample *t*-test was used to evaluate the difference between two sampling sites for soil chemistry at the confidence level of 95%.

After soil collection, three tree ring cores were extracted from each tree at breast height using a stainless steel increment corer with diameter of 5 mm, and damaged cores were eliminated during sampling. The cores were labeled and mounted on sample holders, then brought to the laboratory for dendrochronological and chemical measurements. In the laboratory, all the cores were air-dried and polished using sandpaper. Annual growth rings of each core were dated by the WinDendro system (Regent Inc., V2008a) and ring widths were measured at an accuracy of 0.01 mm. After that, the cores were split into 5-year increments from the pith to the outer using a manual chisel. For the most recent xylems, 6-year growth intervals (2001–2006) were split as one sample. The wood chips were cut into small pieces and dried at 65 °C for 24 h. The wood pieces (weight ranging from 40 to 150 mg) were placed into the digestion vessels, mixed with 5 mL concentrated HNO_3, and digested in microwave digestion system (CEM Inc., Mars-V). The solution was finally diluted to certain volume with distilled, deionized water. The xylem cations (Ca, Mg, Mn, Al, Sr and Ba) were analyzed by ICP-MS. The half-decadal means of cation concentrations in tree ring for *A. fabri* per site were calculated during the reconstruction of soil pH according to Smith and Shortle (1996).

2.3. Calculation of soil pH from tree ring chemistry

According to the method described by Berger et al. (2004) and Kuang et al. (2008), we obtained the linear correlations for all cations and their molar ratios (log_{10}-transformed) of the last six-year xylem with actually observed soil pH data. Secondly, stepwise regressions were performed to select the best indicator of soil pH, of which the input variables were the parameters chosen in significant linear correlation coefficients. Finally, based on those parameters in the tree rings, soil pH values of all time series were computed by the regression equations.

3. Results and discussion

3.1. Soil chemistry characteristics at the forested sites

Soil chemistry characteristics at the two sites were shown in Table 1. No significant difference in soil pH between Emei Mountain and Gongga Mountain was observed. However, BS and CECe in Emei Mountain were significantly lower than those in Gongga Mountain. BS and cation exchange capacity (CEC) are widely considered as efficient indices for evaluating the acidification process (Derome and Lindroos, 1998). Dai et al. (1998) conducted a study in