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PhytOC stock in forest litter in subtropical forests: Effects of parent material and forest type

Yuqi Ying[a,b], Kangyi Lou[c], Tingting Xiang[a,b], Peikun Jiang[a,b,**], Jiasen Wu[a,b], Weilei Lin[a,b], Zhangting Huang[a,b], Scott X. Chang[c,*]

[a] School of Environmental and Resource Sciences, Zhejiang A&F University, Lin'an, Zhejiang, China
[b] Zhejiang Provincial Key Laboratory of Carbon Cycling in Forest Ecosystems and Carbon Sequestration, Zhejiang A & F University, Lin'an 311300, China
[c] Department of Renewable Resources, University of Alberta, 442 Earth Sciences Building, Edmonton, AB T6G 2E3, Canada

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ABSTRACT

Organic carbon (C) occluded in phytolith (PhytOC) is stable in the soil for millennia and can be an important contributor to long-term C storage in forest ecosystems. In order to understand the effect of parent material and vegetation type on the production of PhytOC in plant litter in subtropical forests in China, we investigated the PhytOC concentration and stock in plant litter in four forest types, moso bamboo (*Phyllostachys edulis* Moso), Chinese-fir (*Cunninghamia lanceolata*), evergreen broadleaf and mixed conifer-broadleaf forests, established on three parent materials (rhyolite, sandy shale and tuff). This study showed that: 1) both parent material and forest type significantly affected phytolith concentrations in litter, and there was a significant interaction between parent material and forest type. Plant litter in the moso bamboo forest developed on rhyolite and tuff had the highest phytolith concentrations followed by moso bamboo forest on sandy shale; 2) forest type but not parent material affected PhytOC concentrations in litter, with the highest in the moso bamboo forest; 3) both parent material and forest type significantly affected PhytOC stock in litter, without a significant interaction between the two factors. The moso bamboo forest had the highest PhytOC stock in its litter; and 4) the PhytOC stock returned to the soil in moso bamboo, Chinese-fir, evergreen broad-leaf and mixed coniferous forests was (mean ± SD) 14.66 ± 4.69, 2.87 ± 2.19, 6.22 ± 2.46 and 4.84 ± 1.82 kg ha^{-1}, respectively. Considering the area of the four respective forest types, the amount of C that can be entered into the soil in the form of PhytOC in litter was 2.08×10^5, 1.19×10^5, 5.68×10^5 and 2.75×10^4 t CO_2-e, respectively, and therefore it indicates a great potential in long-term C storage.

1. Introduction

Plants absorb monosilicic acid from the soil and the monosilicic acid can be deposited within the intra- and extracellular structures in plant cells as amorphous silica to form phytolith (Parr and Sullivan, 2005). During the process, organic carbon (C) can be occluded in the phytolith to form phytolith occluded organic C, or PhytOC (Wang and Lv, 1993). PhytOC may be highly resistant to decomposition and represents a significant amount of C in the soil, contributing to long-term storage of organic C in ecosystems (Parr and Sullivan, 2005, 2011) even though some literature consider PhytOC to have a turnover rate similar to that of bulk soil organic matter (Alexandre et al., 1997; Blecker et al., 2006). The 1–3% of phytolith concentration in most soils can be a significant sink for organic C (Blecker et al., 2006; Reyerson, 2004; Clarke, 2003). In a forest ecosystem, the forest floor is the result of the accumulation of detritus or dead organic material consisting of undecomposed, partially decomposed and fully decomposed leaves and other debris on the soil surface. Litter fall is the main pathway for phytolith or PhytOC accumulation from plants to the soil. Phytolith is released to the soil when plant litter decomposes while PhytOC contained within the phytolith is preserved and sustained in the soil over the long-term (Chen and Zhang, 2011). Quantifying phytolith and PhytOC contents in litter fall has been shown to be the most reliable and direct approach to estimate PhytOC storage potential in forest soils (Huang et al., 2014b).

The bioavailable silicon (Si) or dissolved Si in the soil (Wang and Lv, 1993) and the bioaccumulation capacity of Si by plants (Li et al.,

* Corresponding author.
** Corresponding author at: School of Environmental and Resource Sciences, Zhejiang A&F University, Lin'an, Zhejiang, China.
E-mail addresses: jiangpeikun@zafu.edu.cn (P. Jiang), scott.chang@ualberta.ca (S.X. Chang).

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2014) directly impact the phytolith concentration in plant tissues. The bioavailable Si in the soil is determined by two factors including parent material (inherited Si) and chemical weathering which liberates dissolved Si by hydrolysis or complexation (Conley et al., 2006). Additionally, parent material as one of the soil formation factors will also affect a range of soil properties, which indirectly affects bioavailability of Si within the soil (Cai et al., 2013; Li et al., 2014). For instance, the bioavailable Si in the soil is found to be influenced by soil acidity and concentrations of soil organic C and other nutrients (Tian and Chen, 2007).

Most previous studies on PhytOC have focused on herbaceous species with a large potential for Si uptake and accumulation (Parr et al., 2010; Zuo and Lu, 2011; Li et al., 2013a; Huang et al., 2014a) in the subtropical region in China. The subtropical region in China has diverse parent materials that support a variety of forest covers such as Chinese-fir (*Cunninghamia lanceolata*), evergreen broadleaf and mixed conifer-broadleaf forests besides bamboo forests, and yet the effects of parent material and stand type on PhytOC concentration in forest litter have not been studied. It is therefore essential to investigate the PhytOC concentration in forest litter of different forest types as affected by parent material to gain a better understanding of the size of the PhytOC stock in forest litter that can be returned to the soil in subtropical forests in China.

The specific objective of study was to evaluate the PhytOC storage potential in forest litter of four common forest stand types including moso bamboo (*Phyllostachys edulis* 'Moso'), Chinese-fir, evergreen broadleaf and mixed conifer-broadleaf forests that were developed on three parent materials including rhyolite, sandy shale and tuff. The results from this study will have implications for forest management through selecting for specific plant species or planting on soil developed on a specific parent material to achieve the highest PhytOC sequestration and the greatest associated ecological goods and services including the mitigation of climate change.

2. Material and methods

2.1. Experimental sites

The study area was located in Zhejiang Province, China that features a typical subtropical-monsoon climate with four distinct seasons. This area had abundant precipitation with an annual rainfall that ranges between 980 and 2000 mm between 1949 and 2004 (same below). The mean annual temperature was between 15 and 18 °C, and the maximum and minimum temperatures were 43 and −17.4 °C, respectively. The mean annual sunshine hours were between 1710 and 2100. Specifically, the study sites were located at Qingyuan County within the municipality of Lishui (27°43′ N, 118°58′ E), Deqing County within the municipality of Huzhou (30°33′ N, 120°04′ E), and Town of Linlong within the municipality of Lin'an (30°14′ N, 119°42′ E) (Fig. 1). The parent materials in the study sites were rhyolite, sandy shale or sandshale and tuff, and the soils were Orthic Acrisols in all sites based on the soil classification system of Food and Agriculture Organization of United Nations (World Reference Base for Soil Resources, 2006).

Three study sites were selected and the three sites had rhyolite, sandy shale or tuff as the parent material. Within each study site, the forest stand type and their understory vegetation studied were: 1) Moso bamboo stands, with mainly grass as the understory vegetation; 2) Chinese-fir stands, with shrubs including *Dicranopteris dichotoma* and *Phoebe sheareri* as the dominant understory vegetation; 3) Evergreen broadleaf stands with *Cyclobalanopsis glauca*, *Castanopsis sclerophylla,* and *Schima superba* as dominant tree species, and *Litsea cubeba* and *Lindera glauca* as dominant shrub species; and 4) Mixed conifer-broadleaf stands, with *Castanopsis sclerophylla, Schima superba* and *Pinus massoniana* as dominant tree species, and *Loropetalum chinense*, *Eurya hebeclados*, and *Rhododendron simsii* as dominant shrub species.

2.2. Experimental design and sample collection

The experiment in this study used a 3 (three parent material types) x 4 (four forest stand type) factorial design with four replications. Within each site, we established four experimental blocks with each containing four experimental units, and each unit represents one forest type. Within each block, moso bamboo forest, Chinese-fir, evergreen broadleaf and mixed conifer-broadleaf forests were randomly selected.

Four litter samples were randomly collected in each experimental unit using a 1 × 1 m quadrat. The litter samples were stored in fabric bags, and the total biomass of litters was weighed immediately. The litter samples were then washed with deionized water and enzymes were deactivated by drying the litter samples at 105 °C for 10 min. After deactivation, the litter samples were oven-dried at 70 °C, weighed, ground and stored in plastic bags for use. Soil samples were collected from the top 10 cm in each experimental unit and air-dried. After removing rocks and visible roots, the soil samples were ground and passed through a 2-mm sieve and stored for further analysis.

2.3. Sample analysis

To measure the Si concentration in leaf litter, the samples were cut into small pieces (< 5 mm in size) and were then ashed at 500 °C with lithium metaborate to remove organic matter. The ash was dissolved in dilute nitric acid and analysed for Si concentration using inductively coupled plasma-optical emission spectroscopy (ICP-OES) (Optima 7000 DV, Perkin Elmer, Massachusetts, USA) (Chinese Society of Soil Science, 2000). Soil pH was measured with a solution to solid ratio of 2.5 to 1 (v:w), and hydrolysable nitrogen (N) was determined by the alkaline hydrolysis method using a diffusion dish (Chinese Society of Soil Science, 2000). Briefly, 2 g of air-dried soil (<2 mm) was evenly placed into a pan outside the diffusion chamber, and 2 mL boric acid (2%) was added into the chamber. After adding 10 mL of 1 M sodium hydroxide onto the soil, the diffusion dish was gently shaken to mix the soil and the sodium hydroxide solution and placed into a 40 °C incubator for 24 h. Boric acid was used to absorb the liberated ammonia and was subsequently titrated with 0.005 M sulfuric acid to calculate soil hydrolysable N.

Available phosphorus (P) content was determined by the Bray method (Chinese Society of Soil Science, 2000). Total soil organic C (SOC) was analysed using an elemental analyser (Elmemtar Vario MAX CN, Germany). Plant phytolith was isolated from plant material by the microwave digestion method described in Parr et al. (2001) and separated by a flotation method using a heavy liquid with a specific gravity of 1.7 (Wang and Lv, 1993). The floating material was discarded, and the recovered phytolith that sinks to the bottom of the container was digested by the Walkley and Black method (1934) to remove extraneous organic C. If those extraneous organic C is not removed, the phytOC content in phytoliths could be overestimated (Corbineau et al., 2013). The extracted phytolith was then oven-dried and weighed. The PhytOC concentration in the phytolith was determined by an alkali dissolution-spectrophotometry method (Yang et al., 2014). Briefly, a sodium hydroxide solution was used to dissolve silicon compound and isolate the organic C, and a potassium dichromate (Cr^{6+})-sulfuric acid solution was added to oxidize the organic C, while Cr^{6+} was reduced to Cr^{3+} and measured by spectrophotometry at the wavelength of 590 nm. Based on the amounts of potassium dichromate consumed, organic C concentration was obtained. Available Si in the soil was determined by extracting the soil sample with