

# Enhancing phytolith carbon sequestration in rice ecosystems through basalt powder amendment

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**Abstract** Global warming as a result of rapid increase in atmospheric CO<sub>2</sub> emission is significantly influencing world's economy and human activities. Carbon sequestration in phytoliths is regarded as a highly stable carbon sink mechanism in terrestrial ecosystems to mitigate climate change. However, the response of plant phytolith-occluded carbon (PhytOC) to external silicon amendments remains unclear. In this study, we investigated the effects of basalt powder (BP) amendment on phytolith carbon sequestration in rice (*Oryza sativa*), a high-PhytOC accumulator. The results showed that the contents of phytolith and PhytOC in rice increased with BP amendment. The PhytOC production flux in different rice plant parts varied considerably (0.005–0.041 Mg CO<sub>2</sub> ha<sup>-1</sup> a<sup>-1</sup>), with the highest flux in the sheath. BP amendment can significantly enhance flux of phytolith carbon sequestration in croplands by 150 %. If

the global rice cultivation of  $1.55 \times 10^8$  ha had a similar flux of PhytOC production in this study,  $0.61 \times 10^7$  to  $1.54 \times 10^7$  Mg CO<sub>2</sub> would be occluded annually within global rice phytoliths. These findings highlight that external silicon amendment such as BP amendment represents an effective potential management tool to increase long-term biogeochemical carbon sequestration in crops such as rice and may also be an efficient way to mitigate the global warming indirectly.

**Keywords** Phytolith · Carbon sink · Carbon sequestration · Basalt powder amendment · Rice

## 1 Introduction

The increase of global CO<sub>2</sub> emissions has become an increasingly urgent environmental problem as it may cause climate warming [1–4]. Carbon sequestration in terrestrial ecosystems has been considered as an important process to mitigate global climate warming [5–8]. However, some organic carbon temporarily fixed in terrestrial vegetation will be rapidly oxidized into CO<sub>2</sub> and dissolved into water to form water-soluble organic carbon after plant litter decomposition. Therefore, long-time biogeochemical carbon sequestration mechanisms in terrestrial ecosystems remain to be investigated.

Phytoliths, also known as plant opals, are amorphous silica deposited in plant tissues during plant growth [9–11]. Phytoliths are found in most plant species, and their content varies greatly, mostly 0.3 %–12 % [10–16]. Generally, phytolith content in Poaceae and Cyperaceae is much higher than that in other plants [17]. Some organic carbon may be occluded within phytoliths as a result of phytolith

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formation during plant growth, and the carbon content of phytoliths ranges 0.5 %–6 % [7, 15, 16, 18–21]. Although the annual phytolith carbon sequestration was small relative to the terrestrial vegetation carbon sequestration [22, 23], phytolith-occluded carbon (PhytOC) may be preserved in soils for several thousand years when dead plant materials decompose and the phytoliths are released into the soil [9, 24]. In some soils and sediments after 2,000 years of PhytOC accumulation, PhytOC can even represent up to 82 % of the total organic carbon [9, 15]. Therefore, the potential of phytolith carbon sequestration in soil–plant ecosystems is significant and stable at century time scales.

Cereals (e.g., rice, wheat and maize) and other Si-rich crops (e.g., sugarcane) [18] can produce a large amount of PhytOC and may play a crucial role in the long-term terrestrial carbon sequestration [9, 15, 19, 25–27]. For example, Song et al. [26] indicated that the potential of phytolith carbon sink in the global cropland was  $2.6 (\pm 1.0) \times 10^7 \text{ Mg a}^{-1}$  that may represent about 22 % to 58 % of the global net carbon sequestration in crop soil during 1961–2100. Recent researches on phytolith carbon sequestration in crops mainly focused on sugarcane [18], millet [21], wheat [19] and rice [15], based on analytical data of phytolith and PhytOC contents. For example, Li et al. [15] indicated that PhytOC content in biomass depends not only on the C content of phytoliths but also on phytolith content, implying that external silicon (Si) amendment may also improve PhytOC production through enhancing phytolith production during growth of crops, especially rice. Basalt is widely distributed in the world. Although the content of total  $\text{SiO}_2$  is lower, minerals such as augite and anorthose in basalt are more abundant and more rapidly weathered, releasing more dissolved silicon than other igneous rocks (such as granite). Although mulching organic matter (e.g., rice straw) has been suggested to increase soil PhytOC accumulation in bamboo forests [28], the total amount of PhytOC does not increase and the regulation mechanisms of phytolith carbon sink through external silicon amendment have not been demonstrated. The objective of this study is to investigate the response of rice phytolith carbon sequestration to basalt powder amendment, to offer references for management of phytolith carbon sequestration in agricultural ecosystems.

## 2 Materials and methods

The pot experiment was carried out at Zhejiang Agricultural and Forestry University, Lin'an, Zhejiang Province, eastern China ( $29^\circ 56' - 30^\circ 27' \text{N}$ ,  $118^\circ 51' - 119^\circ 52' \text{E}$ ), during April to July, 2012. The site has a subtropical and monsoonal climate, with a mean annual precipitation of

1,000–2,000 mm and a mean annual temperature of  $15.8^\circ \text{C}$ . There are 234 frost-free days.

### 2.1 Pot experiment

Fresh basalt was sampled from Xinchang County, Zhejiang Province, in July 2011 ( $29^\circ 28' \text{N}$ ,  $120^\circ 59' \text{E}$ ). The basalt consists of  $\text{SiO}_2$   $48.15\% \pm 2.84\%$ ,  $\text{Al}_2\text{O}_3$   $13.53\% \pm 0.48\%$ ,  $\text{Fe}_2\text{O}_3$   $13.59\% \pm 1.23\%$ ,  $\text{P}_2\text{O}_5$   $0.61\% \pm 0.42\%$ ,  $\text{K}_2\text{O}$   $1.31\% \pm 0.17\%$ ,  $\text{CaO}$   $8.48\% \pm 0.71\%$  and  $\text{MgO}$   $6.53\% \pm 1.36\%$ . Basalt blocks were crushed by hammer and machine, and then passed through a 0.85-mm mesh stainless steel sieve. The experimental soil (Gleysols) was taken from a paddy field of an agricultural testing base of Zhejiang Agricultural and Forestry University. The basic physical and chemical properties of the soil were as follows: pH  $5.34 \pm 0.02$ , soil organic matter  $30.26 \pm 4.28 \text{ g kg}^{-1}$ , available Si (silicon that could be easily absorbed and utilized by plant)  $155.59 \pm 22.73 \text{ g kg}^{-1}$ , available phosphorus (phosphorus that could be easily absorbed and utilized by plant)  $113.87 \pm 1.35 \text{ mg kg}^{-1}$ , available potassium  $10.33 \pm 1.11 \text{ mg kg}^{-1}$  and available nitrogen  $87.15 \pm 2.47 \text{ mg kg}^{-1}$ . The analytical methods were after Lu [29].

Jiayu 253, a widely distributed and high yielding rice (*Oryza sativa*) cultivar, was selected in this study. BP amendment was applied at levels of 0 (non-amendment control), 50, 100, 250 and 500  $\text{g pot}^{-1}$  (CK-0, CK-1, CK-2, CK-3 and CK-4, respectively) with three replicates. Each pot had a diameter of 0.24 m and a height of 0.28 m. Each pot contained 8.5 kg soil, and rice was grown in each pot under the same irrigation condition and accurate fertilizer control.

### 2.2 Sample collection and analysis

Plant and surface soil (0–10 cm) samples were collected after 102 days on 26 July, 2012. Soil was removed from the roots. Plant samples were divided into sheath, leaf, flag leaf and stem. Rice samples were washed three times with distilled water, three times with deionized water and oven-dried at  $75^\circ \text{C}$  to a constant weight. Finally, each rice tissue sample was divided into two subsamples: one subsample was ground thoroughly for analysis of rice Si content and the other subsample was cut into small fragments ( $< 5 \text{ mm}$ ) for the extraction of phytoliths [15].

The analysis of Si content in plant and soil samples was described by Song et al. [11] and Li et al. [15]. Microwave digestion [30] in combination with Walkley-Black digestion [31] was used to extract phytoliths from all rice samples. The purity of phytoliths was checked using the method of Li et al. [15]. The extracted phytoliths were thoroughly dried at  $75^\circ \text{C}$  for 24 h and weighed to obtain the phytolith content of samples. The phytolith sample was

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