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Phytolith carbon sequestration in China's croplands

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ABSTRACT

A relatively recent found persistent component of the carbon (C) sink is C occluded within plant phytoliths. We constructed a silica–phytolith content transfer function and used crop production data to explore the phytolith C sink within China's croplands. The purposes of the study are to offer references for agricultural management and contribute to mitigating climate change. The Chinese cropland phytolith sink represented approximately 18% of world's croplands ($24.39 \pm 8.67\,Tg\,yr^{-1}$) and sequestered $4.39 \pm 1.56\,Tg\,yr^{-1}$ of carbon dioxide (CO_2); more than the USA or India. The predominant crop species were rice (*Oryza sativa* L., 40%), wheat (*Triticum* sp., 18%) and corn (*Zea mays*, 30%), while the main contributing areas were the midsouthern (28%) and eastern (26%) Chinese regions. The sink has doubled since 1978 owing to fertilizer application and irrigation. Therefore, fertilizer application and irrigation in conjunction with other management practices (such as crop pattern optimization) may further enhance the cropland phytolith C sink and thereby mitigate climate change.

1. Introduction

As a long-term carbon (C) sink, biogeochemical C sequestration in terrestrial ecosystems mediates long-term global C cycle (Lackner, 2003; Piao et al., 2009; Parr et al., 2010; Song et al., 2012a,b). Phytoliths, silica opals formed in plant tissues, usually occlude 1–6% of C (phytolith-occluded carbon, PhytOC) (Parr and Sullivan, 2005; Song et al., 2012a). Cereal crops (Parr et al., 2009; Parr and Sullivan, 2011; Zuo and Lü, 2011; Rajendiran et al., 2012; Li et al., 2013b), bamboo (Meunier et al., 1999; Parr et al., 2010), and grassland and wetland grasses (Song et al., 2012a; Li et al., 2013a) are found to be PhytOC accumulators. Protected by silica, the PhytOC is highly resistant to decomposition (Wilding, 1967; Wilding et al., 1967; Mulholland et al., 1992; Parr and Sullivan, 2005). For example, it has been reported that the age of phytoliths in soils and sediments can be older than 8000 aBP and phytoliths can contribute 15–37% of long term biogeochemical C sequestration (Parr and Sullivan, 2005).

As one of the largest crop-producing countries of the world, China has approximately 160×10^6 ha of croplands, of which 91×10^6 ha are cereal croplands (Piao et al., 2009). Quantifying the PhytOC production in China's croplands is essential so that the magnitude of phytolith C sink may be established. In addition, quantifying PhytOC yields would guide the management of cropland ecosystems and contribute to mitigating climate change. In this study, we constructed a silica–phytolith content transfer function and calculated the magnitude of the phytolith C sink within China's croplands. Calculations were performed using relevant crop data such as the land productivity, the Si-rich organ ratio, silica and PhytOC content, and the PhytOC stability factor.

2. Materials and methods

2.1. Construction of silica–phytolith content transfer function

We collected various mature crop samples (including 11 rice samples, 8 wheat samples, 10 corn samples and 20 other crop samples) from China to construct silica–phytolith content transfer function (Fig. 1). The sampling locations were selected randomly within each defined plot where representative and healthy crop plants were sampled. Each sample of rice, wheat and other small crops was made up of approximately 300 g of composite plant

Abbreviations: C, carbon; PhytOC, phytolith-occluded carbon; SOC, soil organic carbon; FAO, Food and Agriculture Organization of the United Nations; SRO, Si-rich organs.

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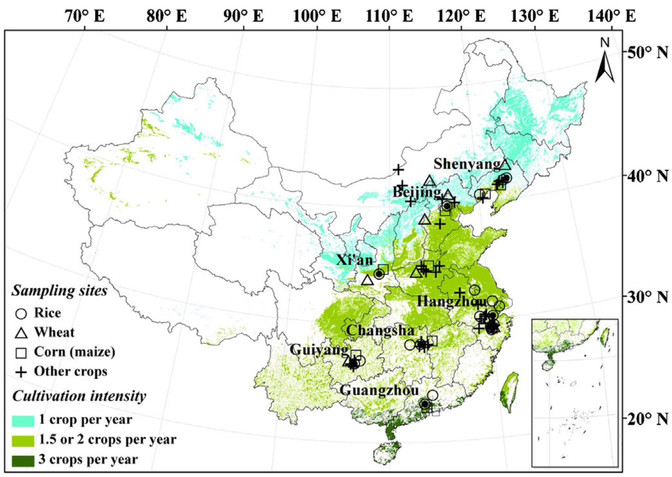

Fig. 1. Distribution of arable crops across China and sampling sites in this study.

materials including leaves, stems and sheath. Each sample of corn was made up of 300–600 g above-ground parts of a plant.

Crop samples were cleaned, oven-dried at 75 °C, and cut into small pieces (<5 mm). They were fused with Li-metaborate at 1000 °C and analyzed for silica content by inductively coupled plasma-optical emission spectroscopy (ICP-OES, Optima 7000 DV Series, Perkin Elmer) (Song et al., 2012a). Plant phytoliths were separated with a microwave digestion process followed by a Walkley–Black digest to remove extraneous organic materials (Parr et al., 2010). The isolated phytoliths were then dried in a fan-forced oven at 75 °C for 24 h and weighed to calculate plant phytolith content (Parr et al., 2010; Li et al., 2013b). Modified from methods of Kroger et al. (2002), the dried phytoliths samples were dissolved in 1 mol/L HF at 45 °C for 100 min to remove phytolith–Si. The exposed organic C from phytoliths after HF treatment was dried at 45 °C and analyzed for C content with classical potassium dichromate digestion method (Li et al., 2013b).

The silica–phytolith content transfer function was derived from Fig. 2:

$$\text{Phytolith content (wt\%)} = \text{silica content (wt\%)} \times 0.9671\,(R^2 = 0.9442,\ p < 0.01) \quad (1)$$

2.2. Data collection and estimation of phytolith and PhytOC content

Crop production data was obtained from China Statistical Yearbook (National Bureau of Statistics of China, 2012), FAO: Statistics

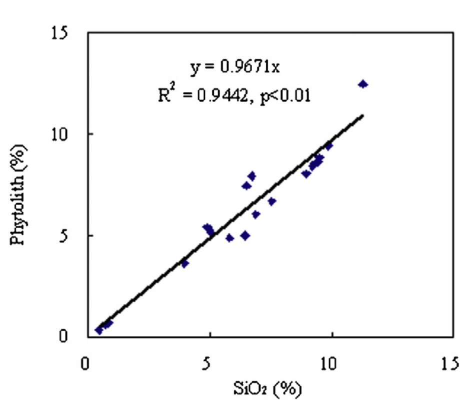

Fig. 2. The correlation of phytolith content to the SiO_2 content in different crop species (p < 0.01).

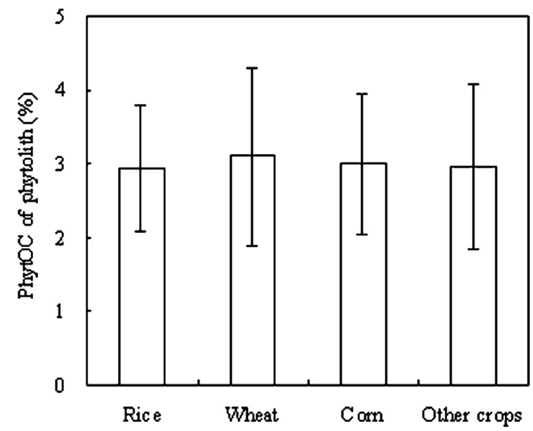

Fig. 3. The average and variation of PhytOC content in phytolith of rice, wheat, corn and other arable crops. The sample numbers for rice, wheat, corn and other crops are 11, 8, 10 and 20, respectively.

(FAO, 2012) and China Agriculture Statistical Report (Ministry of Agriculture of PRC, 2011). Silica and phytolith data were from published monographs (Hou, 1982; Xu et al., 1998), papers (Ding et al., 2008; Parr and Sullivan, 2011; Zuo and Lü, 2011) and determined in this study. The phytolith content was estimated from silica content of a crop species using a transfer coefficient of 0.9671 (Eq. (1)). Phytolith content data was used to estimate the PhytOC content in plant organs using a PhytOC content in phytolith of 3 ± 1% (Fig. 3).

2.3. Estimation of PhytOC production flux and rate

The PhytOC production flux was estimated as (Song et al., 2013):

$$\text{PhytOC production flux} = \text{PhytOC content} \times \text{SRO Production flux} \times 44/12 \quad (2)$$

where PhytOC production flux is the annual PhytOC production by crop's Si-rich organs (kg CO_2 ha^{-1} yr^{-1}) and PhytOC content is the PhytOC concentration in crop's Si-rich organs (SRO) (wt%). The SRO production flux is the above-ground production of Si-rich crop organs of unit area (kg ha^{-1} yr^{-1}), which is estimated from the crop output of unit area and mass ratios of the Si-rich organ: crop output (Tables 1 and 2). 44/12 is the mass transfer coefficient of CO_2/C.

The PhytOC production rate was estimated from PhytOC production flux and crop area (Song et al., 2013):

$$\text{PhytOC production rate} = \text{PhytOC production flux} \times \frac{\text{area}}{1000} \quad (3)$$

where PhytOC production rate is the total PhytOC production of an area (Tg CO_2 yr^{-1}), PhytOC production flux (kg CO_2 ha^{-1} yr^{-1}) can be estimated from Eq. (2) and area is expressed as 10^6 ha.

2.4. Estimation of phytolith C sink flux and rate

The flux at which the PhytOC is conserved in croplands can be estimated from phytolith stability factor and the PhytOC production flux for a particular crop (Song et al., 2013):

$$\text{Phytolith C sink flux} = \text{phytolith stability factor} \times \text{PhytOC production flux} \quad (4)$$

where phytolith C sink flux is the net phytolith C sink flux, the stability factor of phytoliths is assumed to be 0.9 ± 0.05 as soils contain approximately 10,000 times more phytolith than the aboveground biomass (Blecker et al., 2006), and most phytoliths have been proved stable for hundreds to thousands of years though a few