Science of the Total Environment 577 (2017) 413–417

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Short Communication

Phytolith-occluded organic carbon as a mechanism for long-term carbon sequestration in a typical steppe: The predominant role of belowground productivity

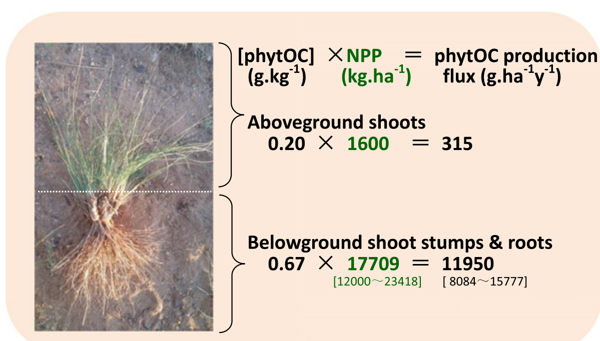
Limin Qi [a], Frank Yonghong Li [a,*], Zhangting Huang [b], Peikun Jiang [b], Taogetao Baoyin [a], Hailong Wang [b]

[a] School of Ecology and Environment, Inner Mongolia University, 235 University West Road, Hohhot, Inner Mongolia 010021, China
[b] School of Environmental and Resource Sciences, Zhejiang A & F University, Lin'an, Zhejiang 311300, China

HIGHLIGHTS

- Occlusion of organic carbon in phytolith (phytOC) is a mechanism for long-term C sequestration.
- PhytOC content and production in the above and belowground parts of steppe plants were determined.
- PhytOC concentration was significantly higher in below than above ground plant parts.
- PhytOC production was at least one order of magnitude greater from below than above ground parts.
- Belowground part plays a dominant role in biogeochemical silica cycle and C sequestration.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 9 September 2016
Received in revised form 23 October 2016
Accepted 27 October 2016
Available online 3 November 2016

Editor: Ajit Sarmah

Keywords:
Carbon sequestration
Grassland
phytOC production
ANPP
BNPP

ABSTRACT

Phytolith-occluded organic carbon (phytOC) has recently been demonstrated to be an important terrestrial carbon (C) fraction resistant to decomposition and thus has potential for long-term C sequestration. Existing studies show that plant leaves and sheath normally have high phytOC concentration, thus most of phytOC studies are limited to the aboveground plant parts. Grassland communities comprise herbaceous species, especially grasses and sedges which have relatively high concentrations of phytoliths, but the phytOC production from grassland, especially from its belowground part, is unknown. Here we determined the phytOC concentration in different parts of major plant species in a typical steppe grassland on the Mongolian Plateau, and estimated the phytolith C sequestration potential. We found that the phytOC concentration of major steppe species was significantly ($p < 0.05$) higher in belowground (0.67 g kg^{-1}) than aboveground biomass (0.20 g kg^{-1}) and that the belowground net primary productivity (BNPP) was 8–15 times the aboveground net primary productivity (ANPP). Consequently, the phytOC stock in belowground biomass (12.50 kg ha^{-1}) was about 40 times of that in aboveground biomass (0.31 kg ha^{-1}), and phytOC production flux from BNPP (8.1–15.8 kg ha^{-1} yr^{-1}) was 25–51 times of that from ANPP. Our results indicate that BNPP plays a dominant role in the biogeochemical silica cycle and associated phytOC production in grassland ecosystems, and suggests that potential phytolith C sequestration of grasslands may be at least one order of magnitude greater than the previous estimation based on ANPP only. Our results emphasize the need for more research on phytolith and phytOC distribution and flux in both above and below ground plant parts for quantifying the phytolith C sequestration.

* Corresponding author.
E-mail address: lifyhong@126.com (F.Y. Li).

http://dx.doi.org/10.1016/j.scitotenv.2016.10.206
0048-9697/

1. Introduction

Terrestrial biogeochemical carbon (C) sequestration is among the most promising approaches to reduce the speed of rapidly rising atmospheric carbon dioxide (CO_2) concentrations and thus mitigate impacts of climate change (IPCC, 2014; Lal, 2004). Occlusion of C within phytoliths has been recently shown to be an effective biogeochemical mechanism for long-term C sequestration (Parr et al., 2009, 2010; Parr and Sullivan, 2011; Song et al., 2012; Street-Perrott and Barker, 2008). Phytoliths are highly resistant to decomposition and phytolith-occluded organic carbon (PhytOC) may be preserved in the environment for several thousands of years after plant decomposition (Blecker et al., 2006; Parr and Sullivan, 2005; Wilding, 1967). Phytoliths are present in most plants and range in concentration from 0.5% or less in most dicotyledons, 1–3% in typical dryland grasses, and may comprise 10–15% in Cyperaceae and wetland Poaceae species (Epstein, 1994). Phytoliths contain 0.2–5.8% of PhytOC (Parr and Sullivan, 2005, 2011; Parr et al., 2010; Zhang et al., 2016; Zuo and Lü, 2011), and although the phytOC concentration in plants is low, its long residence time in soil after plant decomposition implies it an important C sink (Blecker et al., 2006). In addition, the carbon to nitrogen (C:N) ratio in phytoliths is around 41, which indicates that unlike other forms of C, phytOC does not lockup a significant amount of nitrogen (Hodson et al., 2008). Biogeochemical cycling of silica and the associated phytOC production has been increasingly studied to quantify the potential of various plant species/communities to sequester atmospheric CO_2 (Blecker et al., 2006; Conley, 2002; Parr et al., 2010; Song et al., 2012).

Grassland covers more than one fifth of the world's land surface (Scurlock and Hall, 1998), and holds nearly one-fourth of the global terrestrial C stock (Jones and Donnelly, 2005; Lal, 2004), playing a crucial role in the process of the global terrestrial C cycle. Grassland vegetation comprises mainly herbaceous species, especially Poaceae and Cyperaceae species which have been shown to have relatively high concentrations of phytoliths (Epstein, 1994; Marschner, 1995), and thus have potential for C sequestration (Blecker et al., 2006; Song et al., 2012). However, phytOC concentration in grassland species, especially in the different plant parts of different species are largely unknown. The few existing studies evaluating the potential of grasslands for phytolith C sequestration did not determine PhytOC content in phytoliths of grassland plants directly, but rather used the mean phytOC content in phytoliths and phytolith content in plants to estimate the phytOC production flux and rate; and only the aboveground part of plants was considered (Blecker et al., 2006; Song et al., 2012; Zhao et al., 2016).

PhytOC production flux in a terrestrial ecosystem is the product of plant dry matter production (i.e., net primary productivity, NPP) and the phytOC content in the dry matter. In arid and semi-arid steppe grasslands, belowground NPP (BNPP) is usually 8–15 times of the aboveground NPP (ANPP) (Chai et al., 2014; Chen and Huang, 1988; Hou et al., 2014; Ma et al., 2010). To include the belowground biomass and BNPP is essential for estimating phytOC stock and phytOC production flux in grassland ecosystems. This requires the information of plant biomass production and phytOC content in the biomass in both the above- and belowground parts of grassland plants, but this information is unavailable. Phytoliths are non-crystalline minerals in living plants through silica deposition of cell wall, fillings of cell lumen and intercellular spaces of the cortex near evaporating surfaces within plant tissue when soluble silica is absorbed by the roots (Piperno, 2006). Plant leaves and sheath normally have high phytOC concentration (Marschner, 1995). For example, a few recent studies showed that phytOC concentration was lower in roots than shoots of rice (Li et al., 2013), and is lower in culm than leaves of bamboo (Yang et al., 2015). Thus we hypothesized that grassland plants have higher phytolith and phytOC concentration in the above- than belowground parts, but we also hypothesized that BNPP plays an important role in phytolith C sequestration in grassland ecosystems, as BNPP is much greater than ANPP, even though phytOC concentration might be lower in the former. The objective of present study was to test the above two hypotheses, that is, (1) to determine the phytOC concentration in the above- and belowground parts of the major plant species in a typical steppe grassland on the Mongolian Plateau, and (2) to estimate the phytolith C sequestration potential of the grassland, with an emphasis on quantifying the contribution of above versus below ground plant production.

2. Materials and methods

2.1. Sampling site

The study was conducted in a typical steppe grassland located around 50 km northeast of Xilinhot city, Inner Mongolia, China (latitude 44°101′N–44°128′N and longitude 116°101′E–116°127′E). The region experiences a temperate–semiarid climate, with mean annual temperature of 2.6 °C and mean annual precipitation of 267 mm. The precipitation has a large inter-annual variation from 121 to 512 mm, and 60–80% of which falls during the summer season of June to August. The soil is a sandy-loam chestnut soil (or Calcic-orthic Aridisol in the US soil taxonomy classification system). The soil has a humus layer of 20–30 cm and a calcic layer at about 40 cm in depth. The dominant vegetation is typical steppe, with dominant species *Leymus chinensis* Tzvel, *Stipa grandis* Smirn., *S. krylovii* Roshev and *Cleistogenes squarrosa* Keng.

2.2. Sampling of plant materials

Three undisturbed natural grassland sites were selected to sample plants. These three sites are located about 15 km apart but are covered with the same grassland type, dominated by *L. chinensis, S. grandis, S. krylovii, C. squarrosa, Carex korshinskyi* Kom, and *Agropyron cristatum* (L.) Gaertn. These grass and sedge species were sampled for determination of their phytolith and PhytOC content at peak plant biomass time (early September 2015). A semi-shrub species *Artemisia frigida* Willd., which is dominant in grazing-degraded grassland in the typical steppe region, was also sampled at this time.

The seven species were collected by digging up each individual plant to a depth of 20 cm below ground level at the three plots. The plant individuals were cut into three parts: aboveground parts (shoots), belowground shoot stumps (shoot stumps buried below the soil surface) and belowground roots (including rhizomes). Many plant individuals were collected at each plot to make up approximately 300 g DM (Dry Matter) for each part of each plant species. Each sample was washed three times with deionized water, dried to a constant weight at 65 °C and cut into pieces (<5 mm) for phytolith analysis.

Five quadrats of 1×1 m^2 were placed at the center and four corners of a delineated 20×20 m^2 at each plot, and all standing live and dead (that was obviously produced in current season) vascular plants in these quadrats were cut at ground level species by species, dried to a constant weight at 65 °C and weighed. The dry mass of all plant species per quadrat averaged over the five replicates was used to estimate the aboveground plant biomass at peak biomass time, and this was also used to approximate the annual ANPP of the grassland (Scurlock et al., 2002). The belowground biomass and its depth distribution (0–70 cm) during the plant growing season (May to October 2011) were measured using the soil coring method. The BNPP of grassland was calculated as the sum of increments in belowground biomass from the beginning to the end of the season and was reported by Chai et al. (2014).

2.3. Sample measurements

The phytoliths within plants were extracted with a microwave digestion process (Parr et al., 2001), followed by a Walk-Black type digestion (Walkley and Black, 1933) to ensure that extraneous organic materials in the extracted phytoliths were removed. Two duplicates were analyzed for each plant sample. The extracted phytoliths were oven-dried at 75 °C to a constant weight, and the phytolith content