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Mechanisms and potential of terrestrial phytolith carbon sequestration: A case study of China

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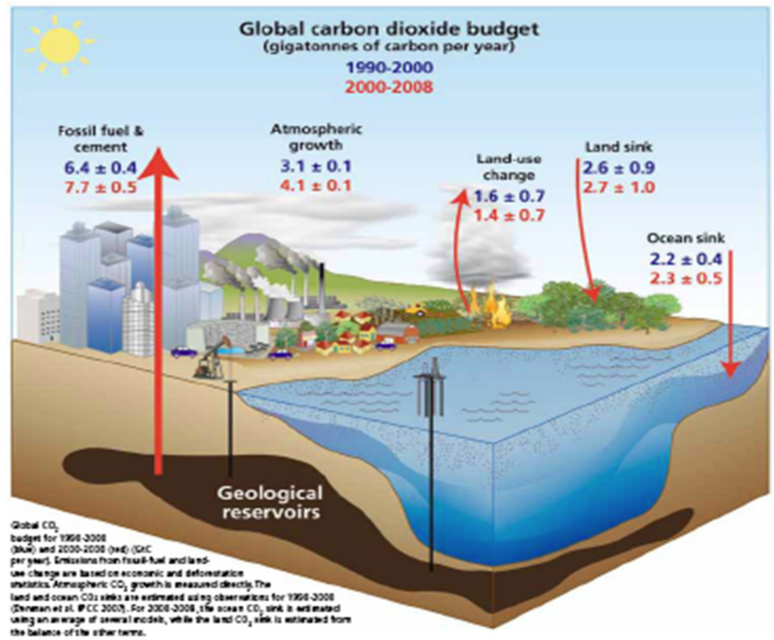
Outline

1. Terrestrial biogeochemical cycles of Si and C
2. Characteristics of phytoliths
3. Storage and stability of phytoliths in soil profiles
4. Phytolith C sequestration in ecosystems of China
5. Conclusions and perspectives

1. Terrestrial biogeochemical cycles of Si and C

1.1 Biogeochemical C cycle

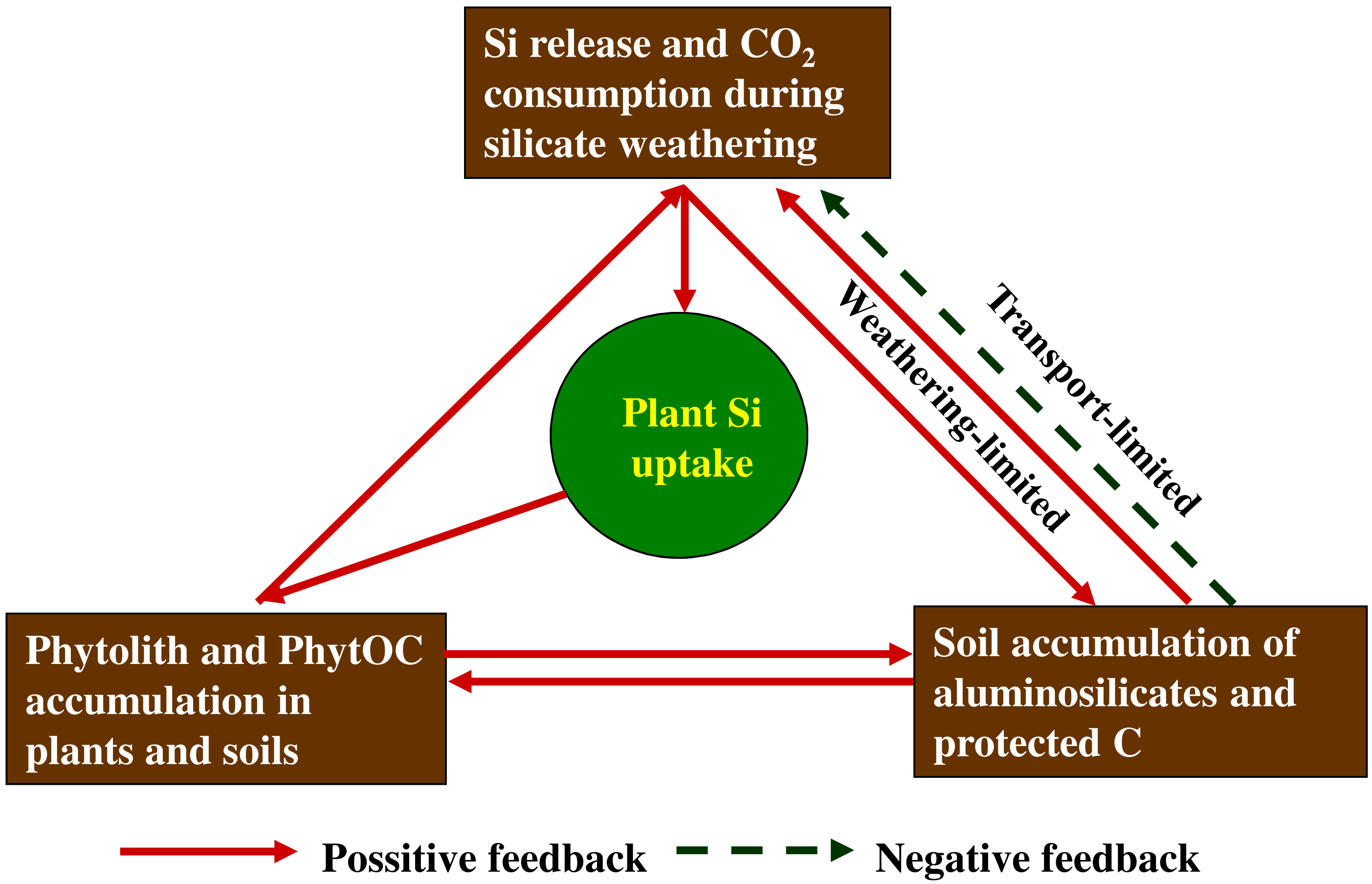
- **Carbon cycle plays an important role in the regulation of global climate change**
- **There are many limits in current global C cycle models**
  - ✓ **Based on carbon itself**
  - ✓ **Lack of impacts from silicon and other elements**



Global C cycle and its change

Le Quere, Global Biogeochemical Cycles, 2010

1.2 Interactions of silicate weathering, phytolith dynamics, and aluminosilicate accumulation



Feedback among processes of terrestrial biogeochemical Si and C cycles

Song et al,. Earth-Science Reviews, 2012

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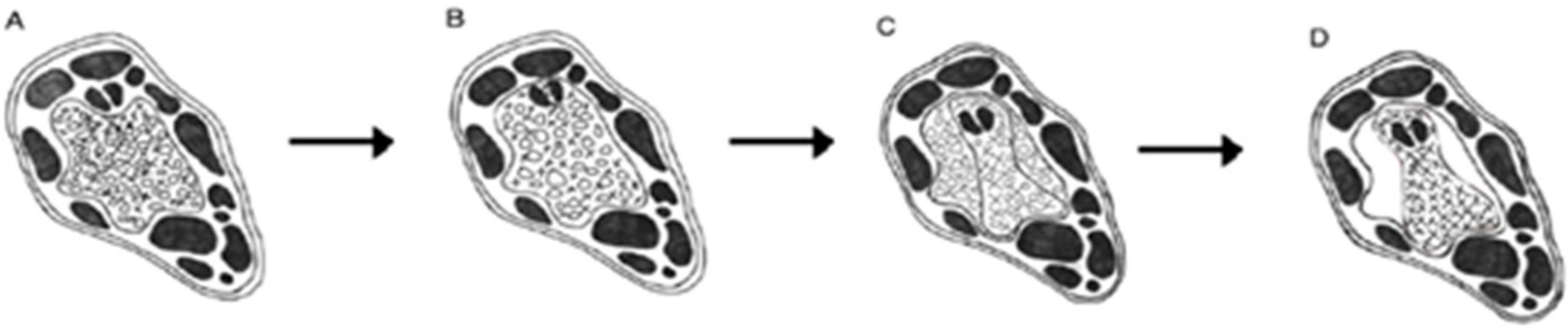
2. Characteristics of phytoliths

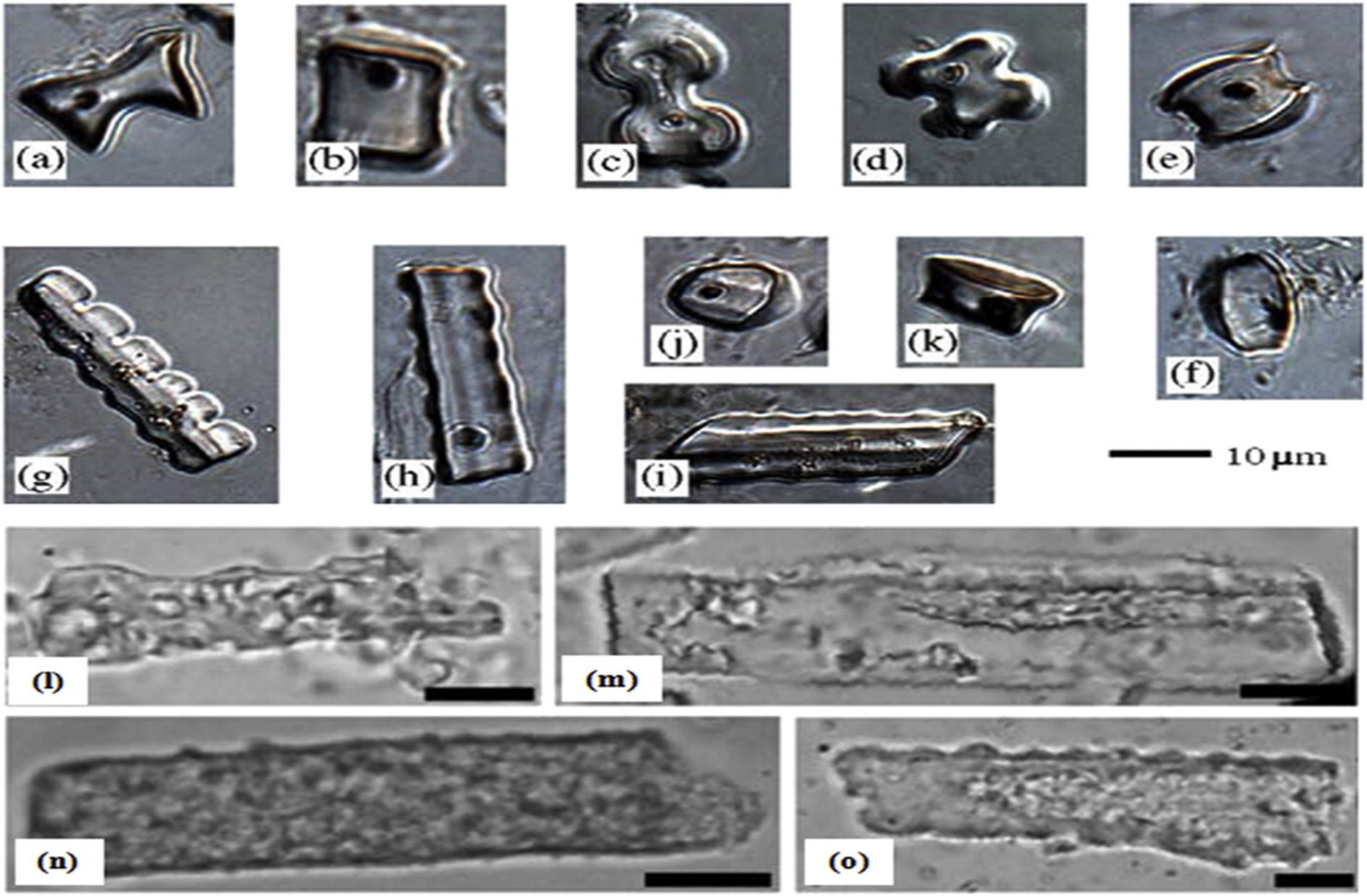
2.1 Formation and morphotypes of phytoliths

Dissolved silicon in soil solution is taken up by plant roots and eventually deposited within cell or between cells to form phytoliths (Piperno, 1988).



A hypothetical model of how C becomes occluded during phytolith formation

Carter, Quaternary International, 2009

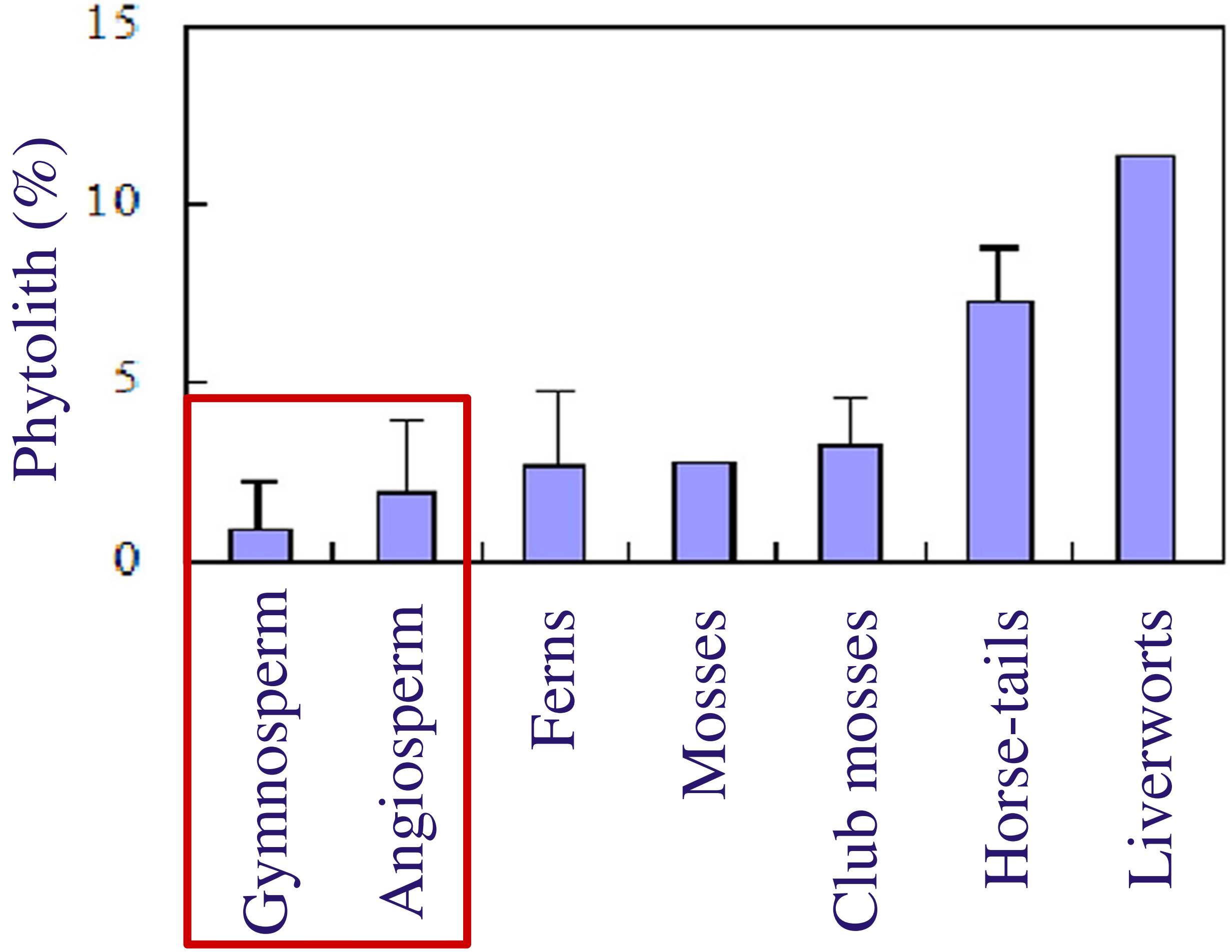


Selected phytoliths from modern grasses (a)–(k) and phytoliths in soils with different weathering degrees (l)–(o).

Lü et al., Quat. Sci. Rev. 2016; Borrelli et al., J. Soils Sediments, 2010

2．Characteristics of phytoliths

2.2 Distribution of phytoliths in different plants

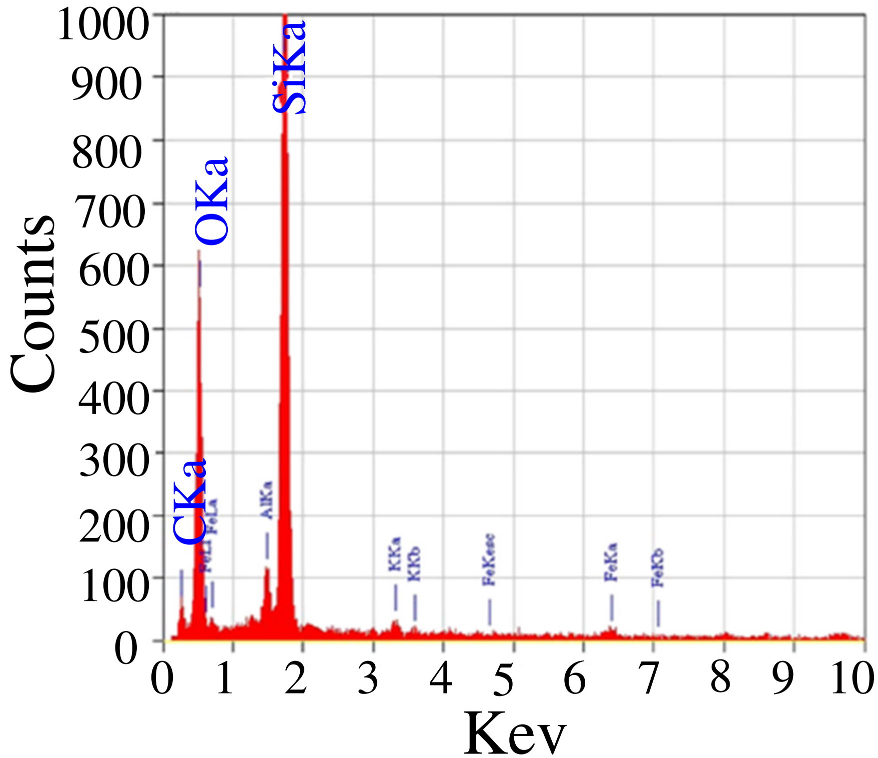


Contents of phytoliths in different plant groups

Hodson, et al., Ann. Bot. 2005; Song et al., Earth-Science Reviews, 2016

2. Characteristics of phytoliths

2.3 Elemental composition of phytoliths



Si, O, C in phytolith (SEM-EDS)

- **Phytoliths consist mainly of SiO_2 (66 to 91%) with minor amounts of other elements such as C, Fe and Al.**
- **Phytoliths can occlude 0.2–6% of organic C.**

Anala, et al., Paddy Water Environ. 2015

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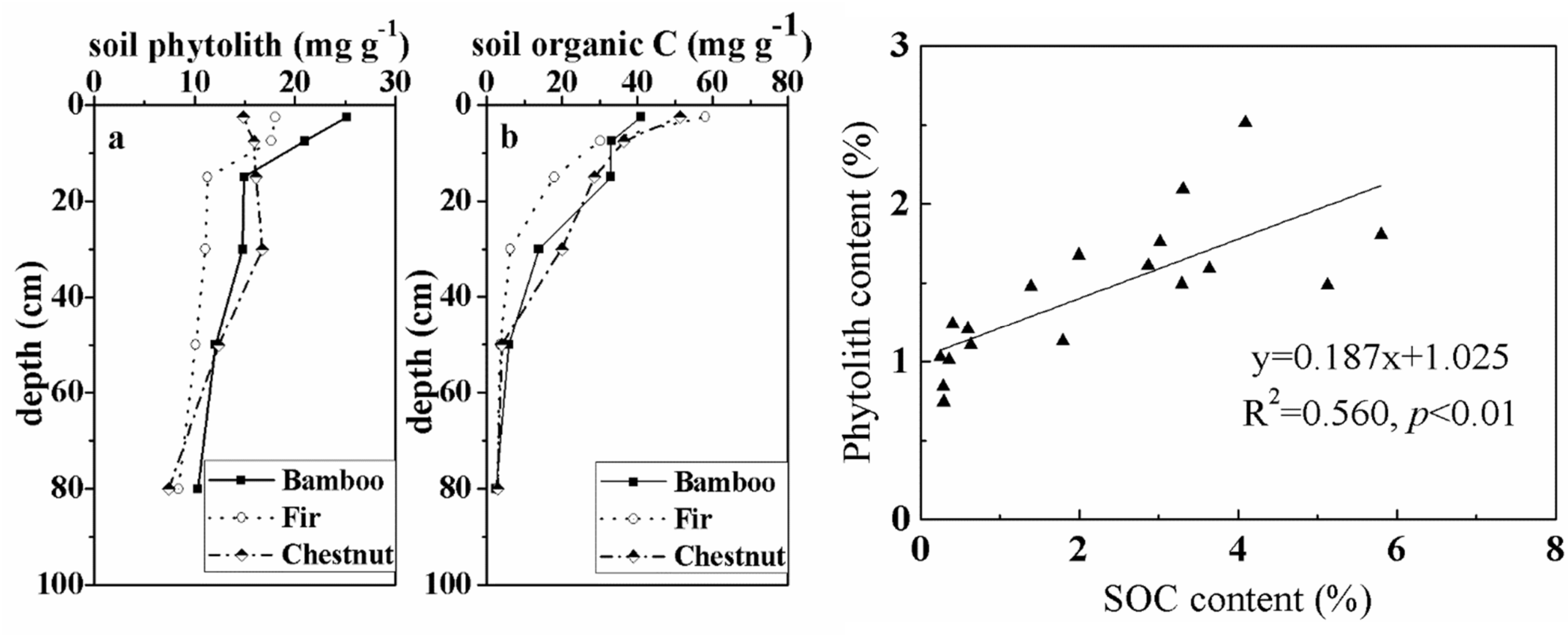
3. Storage and stability of phytoliths in soil profiles

- **Phytoliths accumulate near surface and decrease with depth.**
- **Significant positive correlation between phytolith content and SOC content in bamboo, fir, chestnut forest soils**



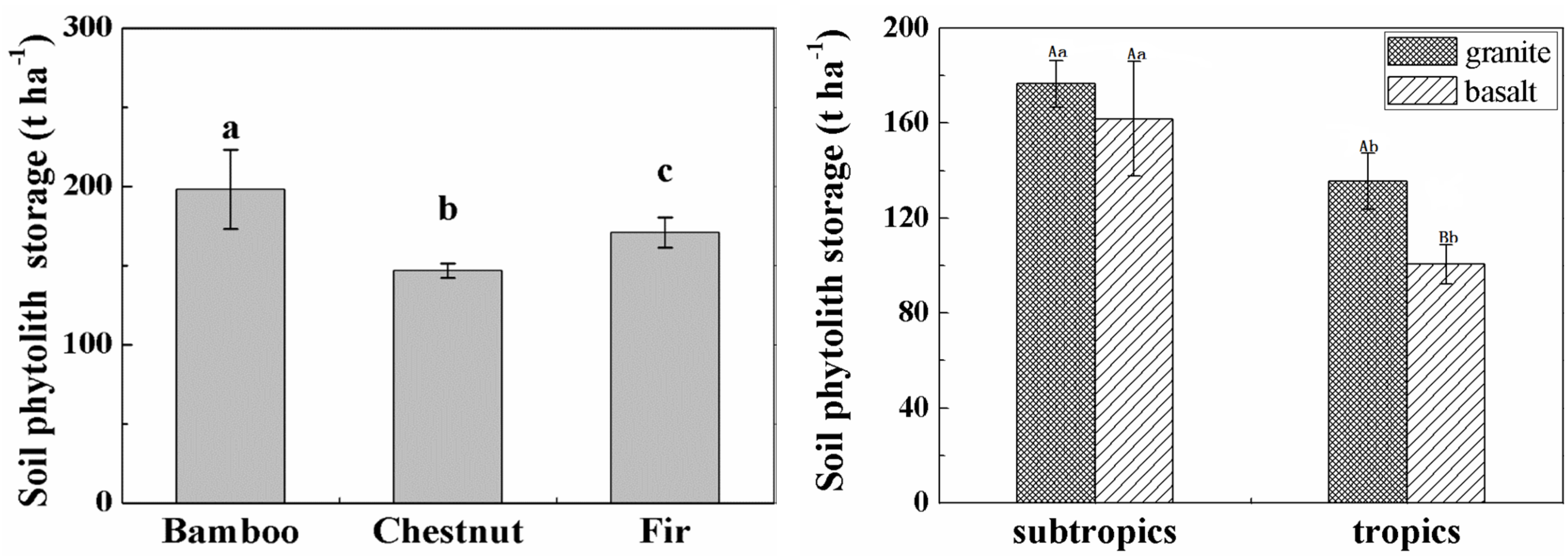
The distribution and correlation of phytolith and SOC in soil profiles

(Zhang et al., Journal of Soils and Sediments, 2015)

3. Storage and stability of phytoliths in soil profiles

3.1 Storage of phytoliths in soil profiles

Soil phytolith storage depends on plant phytolith input flux and soil stability of phytoliths.



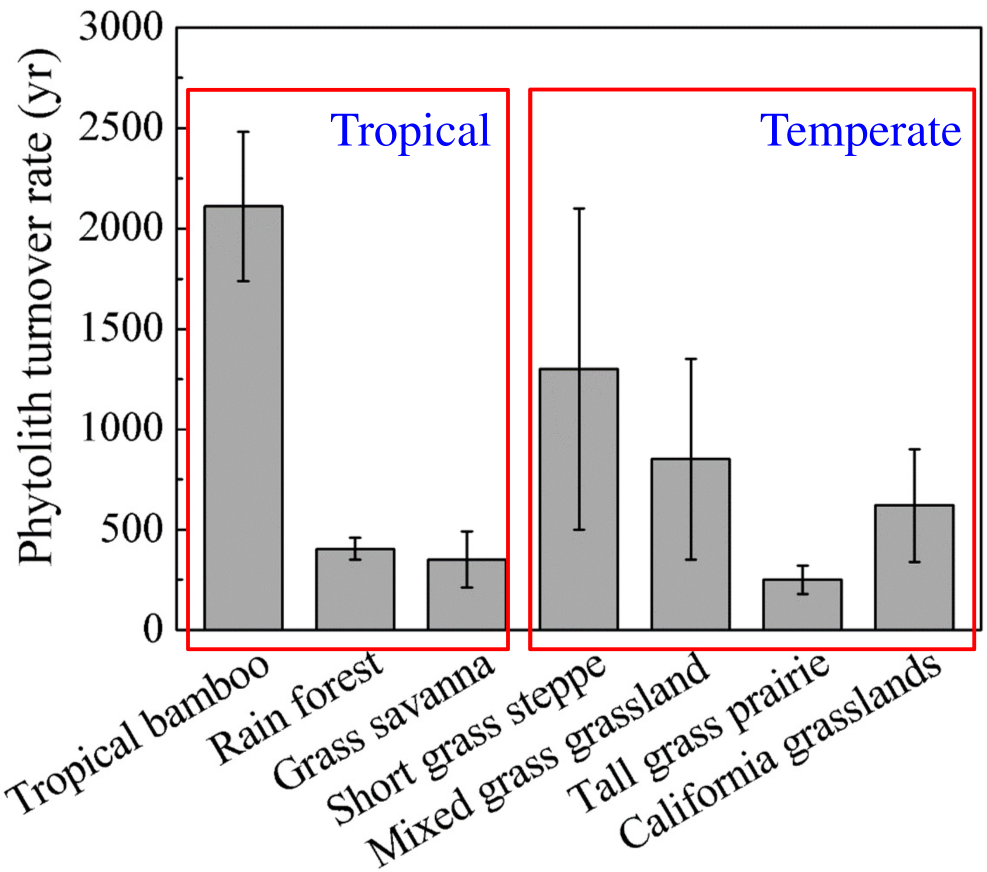
The storages of phytolith in different climate zones

Zhang et al., Journal of Soils and Sediments, 2015, 2016

3.Storage and stability of phytoliths in soil profiles

3.2 Stability of phytoliths in soils depends on:

- **Phytolith properties, e.g. water content and element composition.**
- **Soil properties, e.g. soil pH, moisture.**
- **Climate, e.g. precipitation and temperature.**



Phytolith turnover rate in soils

Song et al., Earth-Science Reviews, 2016; Reference cited

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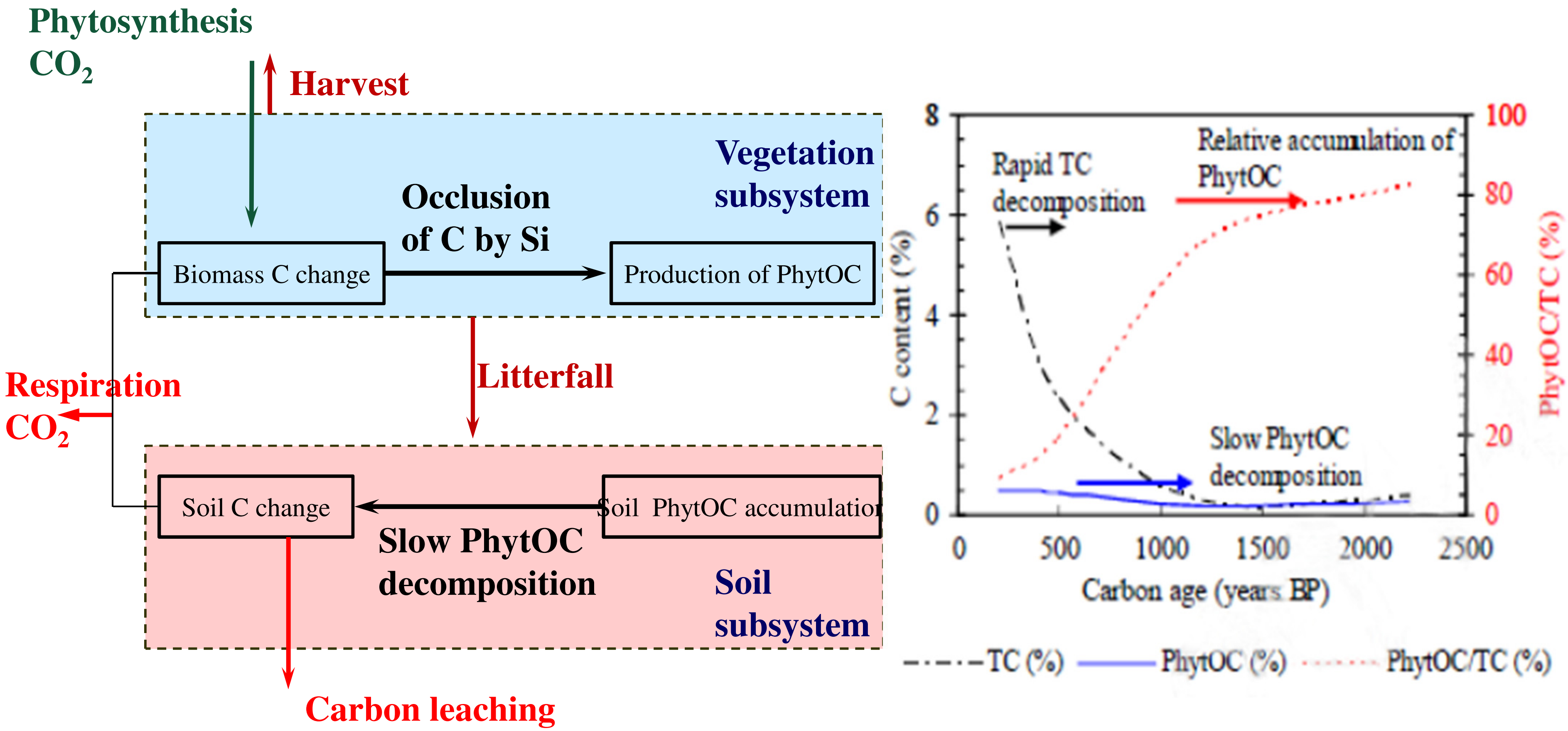
5 Conclusions and perspectives

4. Phytolith C sequestration in ecosystems of China

4.1 Mechanisms of PhytOC formation and accumulation

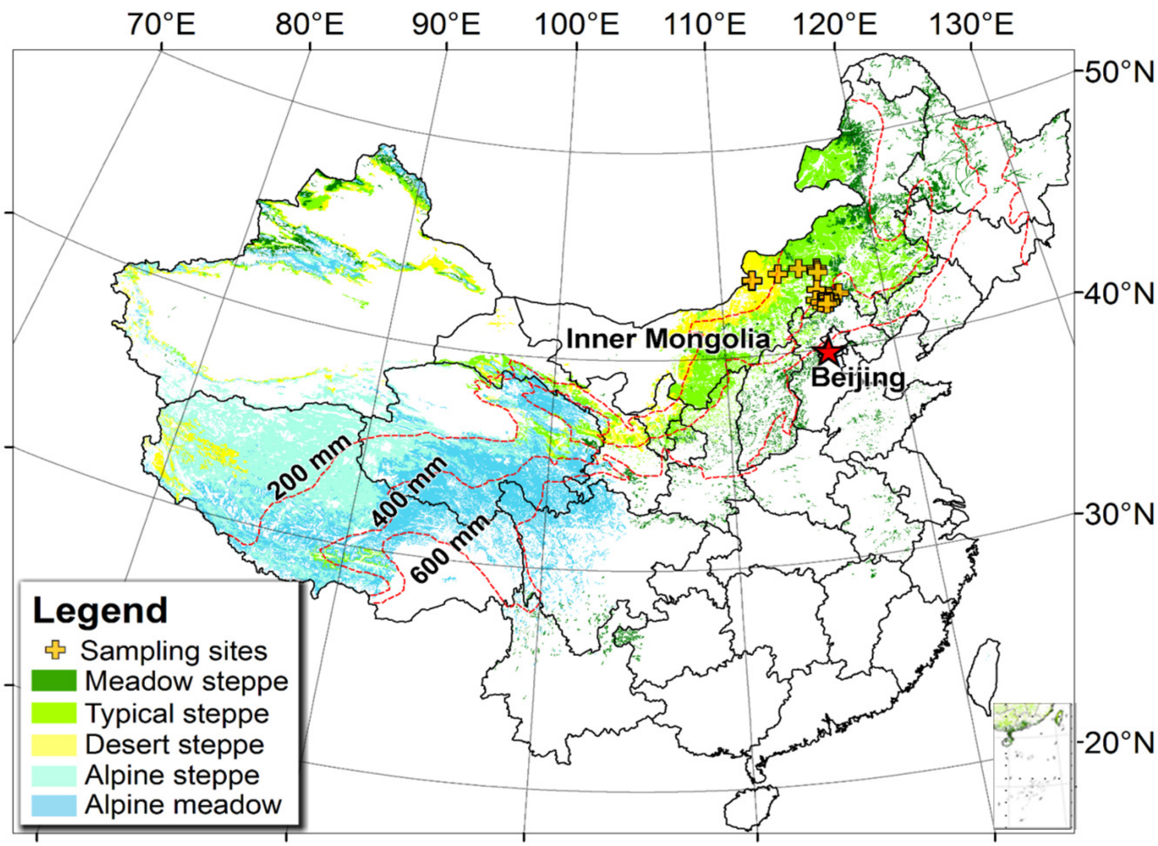


The mechanism and stability of PhytOC sink

Parr et al., Soil Biol. Biochem, 2005; Song et al., Global Change Biology, 2013

4. Phytolith C sequestration in ecosystems of China

4.2 Phytolith C sequestration in grasslands



Grasslands in China:

- cover nearly one third of the country's area
- Show different degree of degradation from human activities

Distribution of the five grassland types of China at a scale of 1 : 1 000 000

Song et al., Global Change Biology, 2012

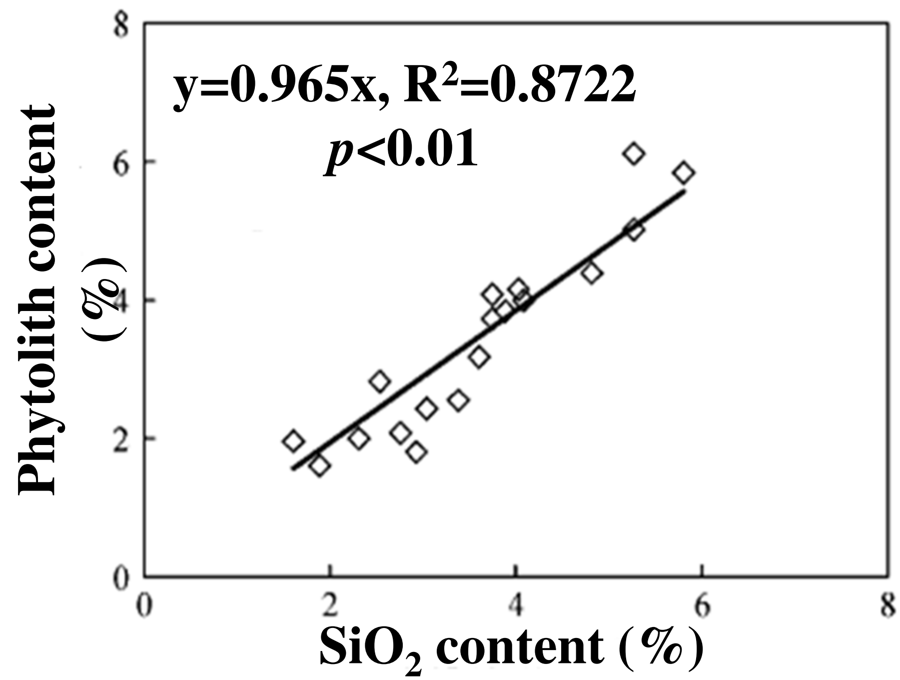
PhytOC production flux of grassland plants can be estimated as:

PhytOC production flux = PhytOC content × SRO production flux

where PhytOC content is estimated from C content of phytolihts (1-4%) and phytolith content. SRO represents Si-rich organs.

Silica-phytolith content transfer function for grassland plants:

Phytolith content = 0.965 × silica content



Correlation of phytolith and SiO_2 in different grasses

Song et al., Global Change Biology, 2012

- **There is significant difference in phytolith production flux among the five types of China's grasslands.**
- **Phytolith production flux in meadow steppe and typical steppe is higher than other grasslands.**

Estimated grassland phytolith production flux and rate

Grassland type	ANPP ($g\ m^{-2}\ yr^{-1}$)	Phytolith production flux ($g\ m^{-2}\ yr^{-1}$)	Phytolith production rate ($10^6\ t\ yr^{-1}$)
Desert steppe	58.6	1.6	0.3
Typical steppe	109.2	3.8	1.5
Meadow steppe	218.6	9	0.7
Alpine steppe	46	1.6	1.1
Alpine meadow	105	2.9	1.7

Song et al., Global Change Biology, 2012

The PhytOC production flux of China's grasslands is much lower than that in other areas mainly due to its lower ANPP.

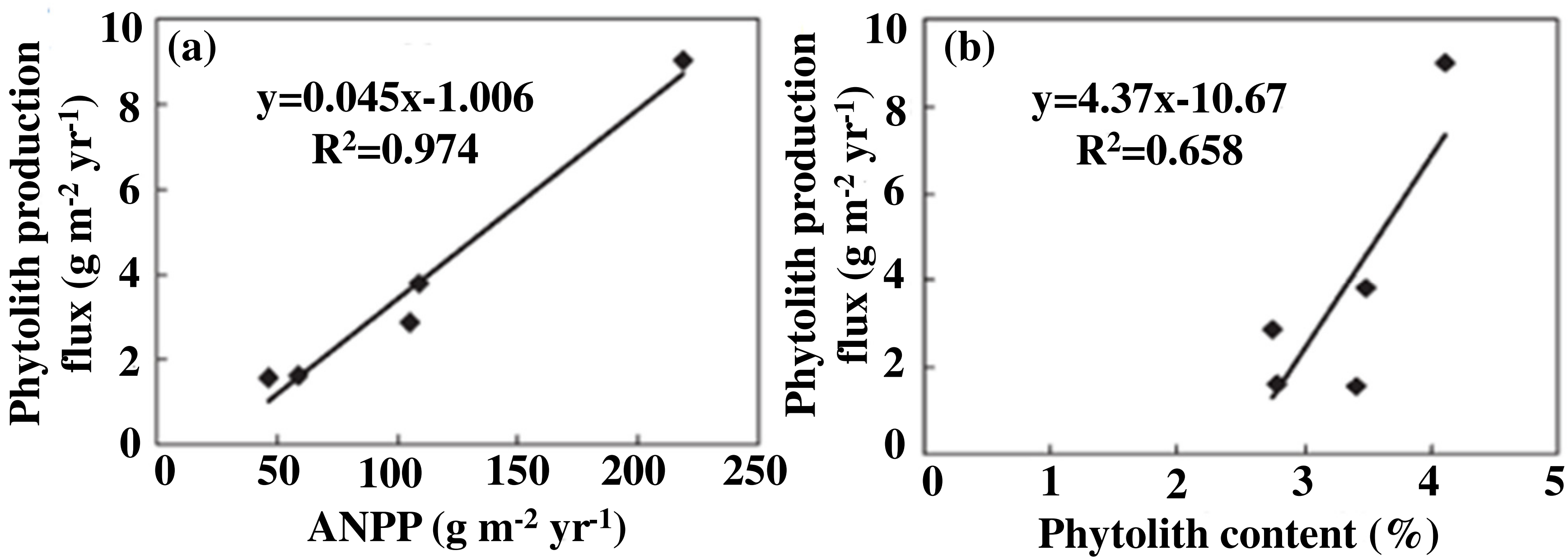
Aboveground phytolith C sequestration flux and rate in grasslands

Region	SRO production flux (t ha^{-1} yr^{-1})	Phytolith C sequsetration flux (kg CO_2 ha^{-1} yr^{-1})	Phytolith C sequsetration rate (Tg CO_2 yr^{-1})	Reference
China	1	1.8(0.3)	0.6(0.1)	Song et al. 2012
North America	2.5	8.2(2.6)	1.0(0.3)	Blecker et al. 2006
World	6.5	11.8(1.8)	41.4(6.3)	Song et al. 2012

*SOR: Si-rich organs.

Song et al., Global Change Biology, 2012

Management to maximize ANPP has great potential to enhance phytolith C sequestration in China's grasslands.

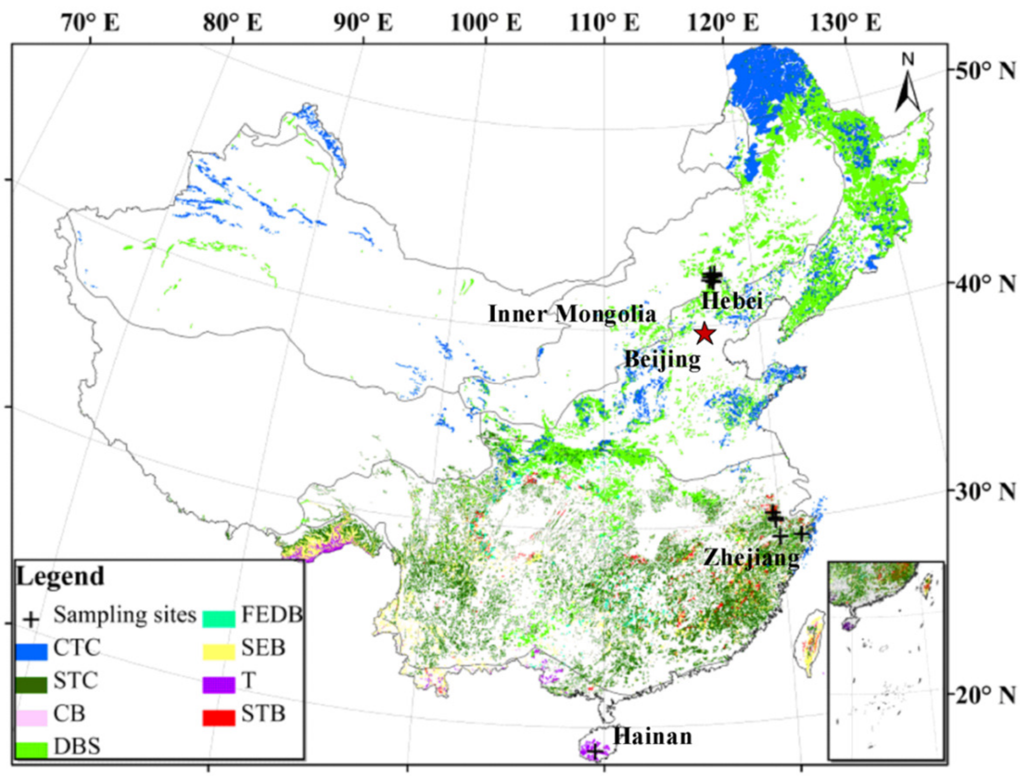


Correlation of grassland phytolith production flux with: (a) above-ground net primary productivity (ANPP), (b) phytolith content.

Song et al., Global Change Biology, 2012

4. Phytolith C sequestration in ecosystems of China

4.3 Phytolith C sequestration in forest



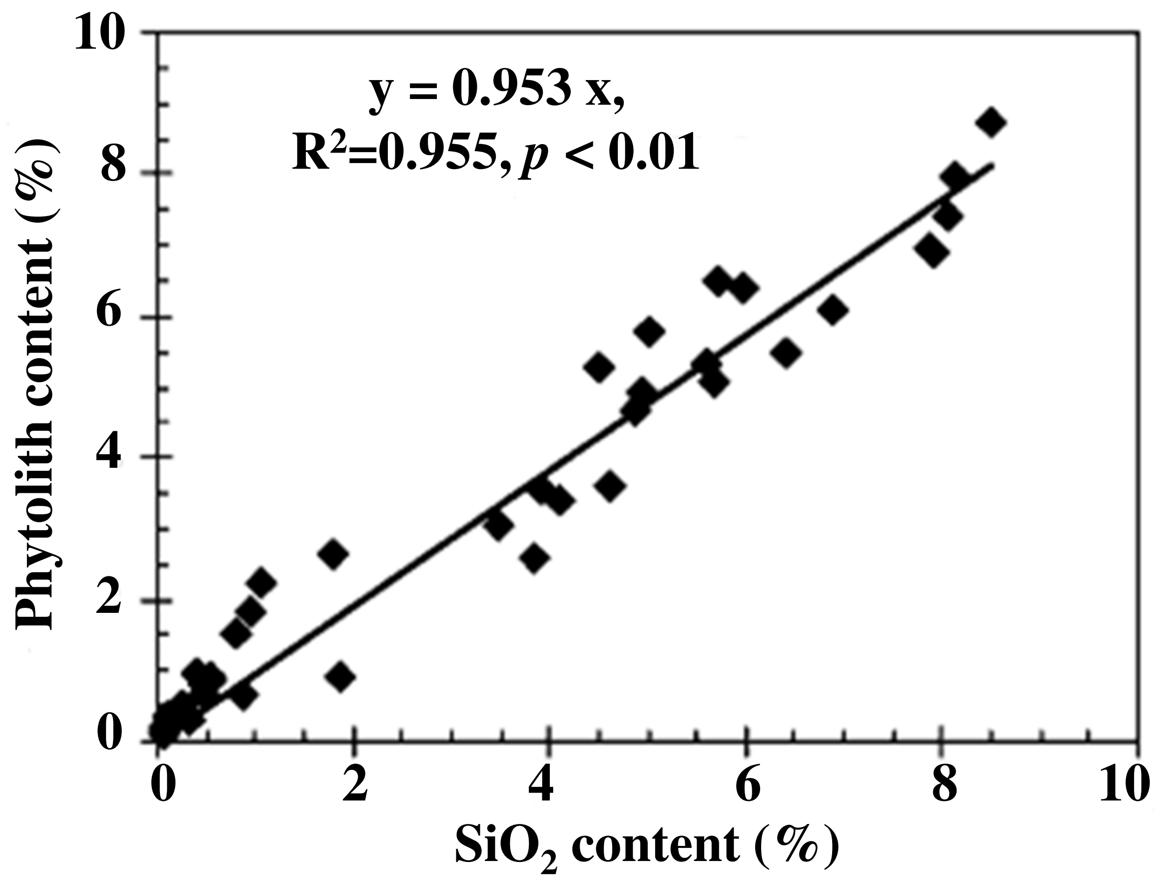
Distribution of the eight Chinese forest types at a scale of 1 : 1000000

- China has 142.8 million ha of forested land including 7.2 million ha of bamboo.
- China's forests range from boreal forests in the north to tropical forests in the south.

Song et al., Global Change Biology, 2013

Silica content-phytolith content transfer function in forests:

Phytolith content=0.953×silica content



Correlation of phytolith and SiO_2 in different plants of forests

Song et al., Global Change Biology, 2013

Subtropical and tropical bamboo (STB) has much higher phytolith production flux than other forests.

Estimated phytolith production in China's forests

Forest type	ANPP ($t\ hm^{-1}\ yr^{-1}$)	Phytolith production flux ($Kg\ CO_2\ hm^{-1}\ yr^{-1}$)	Phytolith production rate ($Tg\ CO_2\ yr^{-1}$)
CTC	5.19	7.54	0.18
STC	5.06	6.6	0.19
CB	6.6	9.01	0.04
DBS	6.03	8.55	0.36
SEDB	8.05	21.7	0.27
SEB	8.6	12.89	0.28
T	10.89	30.06	0.03
STB	7.37	81.63	0.59

CTC, cold-temperate and temperate coniferous forest; STC, (sub)tropical coniferous forest; CB, coniferous and broad-leaf mixed forest; DBS, deciduous broad- or small-leaf forest; SEDB, subtropical evergreen and deciduous broad-leaf forest; SEB, subtropical evergreen broad-leaf forest; T, tropical forest; and STB, subtropical and tropical bamboo.

Song et al., Global Change Biology, 2013

30% of the phytolith C sink in China's forests is from bamboo which occupies only 5% of the area for China's forests.

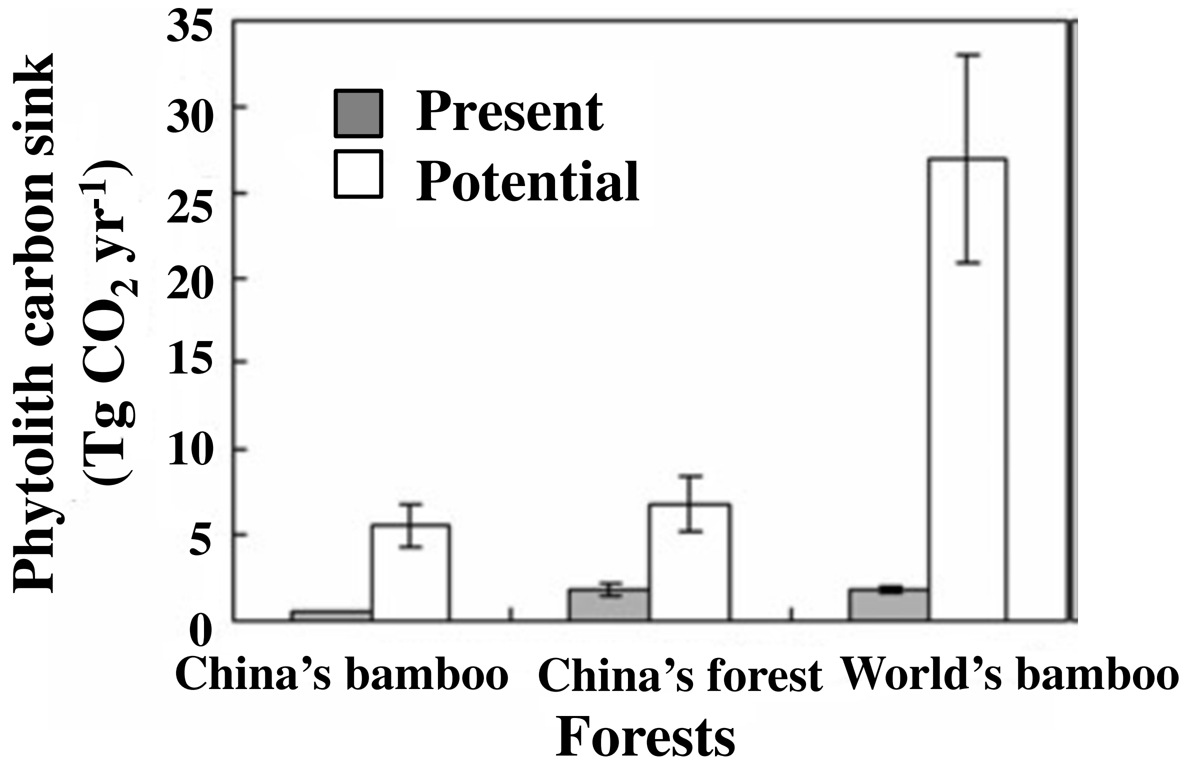
Aboveground phytolith C sequestration flux and rate in forests

Region	SRO production flux (t ha^{-1} yr^{-1})	Phytolith C sequestration flux (kg CO_2 ha^{-1} yr^{-1})	Phytolith C sequestration rate (Tg CO_2 yr^{-1})
China forest	6.4	13.6(3.1)	1.94(0.44)
China bamboo	7.37	81.63(7.11)	0.59(0.05)
World bamboo	7.37	81.63(7.11)	2.05(0.17)

*SOR: Si-rich organs.

Song et al., Global Change Biology, 2013

Management practices such as bamboo afforestation and reforestation may significantly enhance phytolith carbon sink.

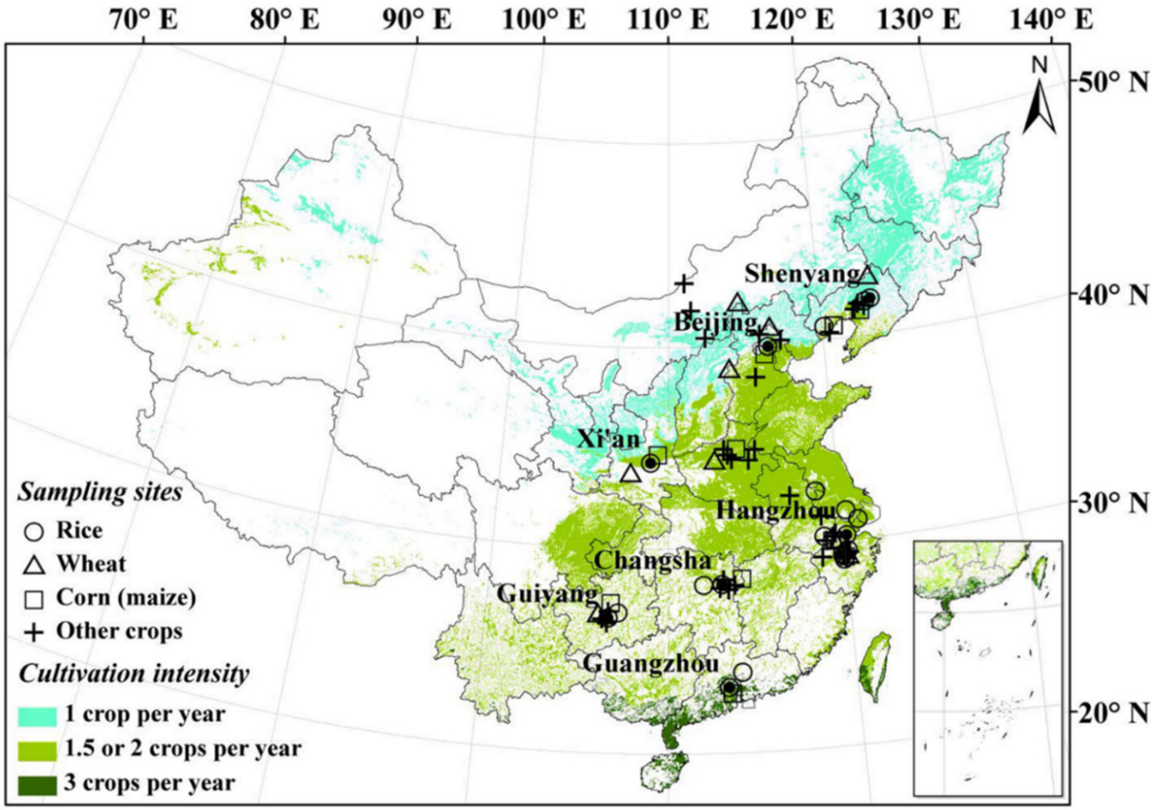


Phytolith C sink in China's bamboo, China's forests, and world's bamboo

Song et al., Global Change Biology, 2013

4．Phytolith C sequestration in ecosystems of China

4.4 Phytolith carbon sequestration in croplands



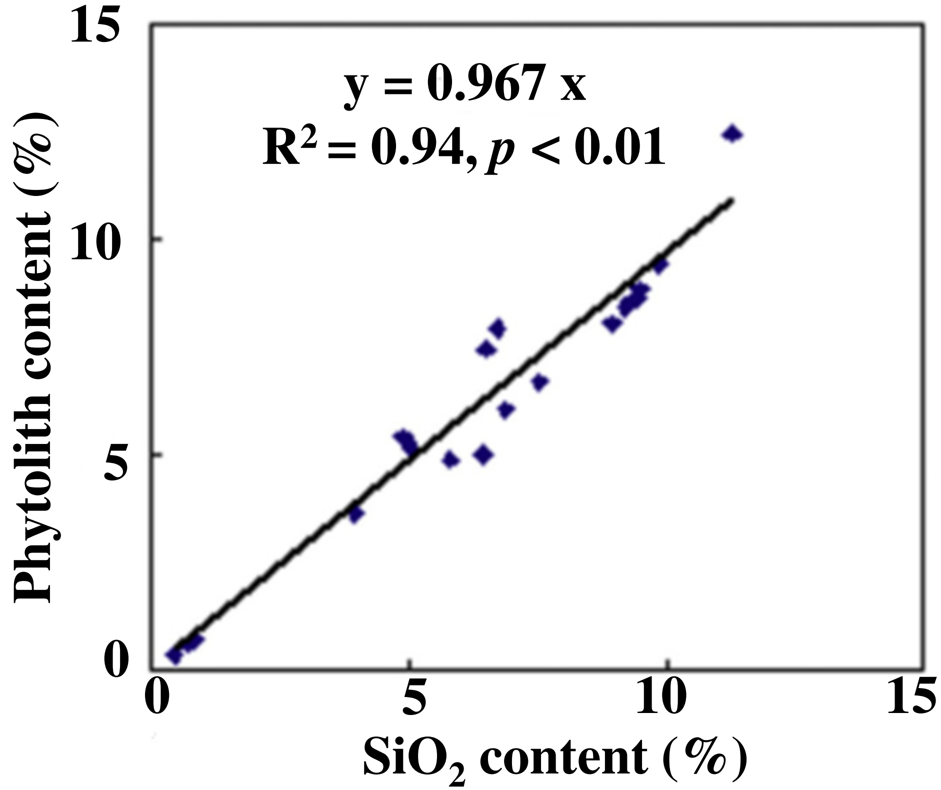
- China has 160 million ha croplands including 91 million ha cereal croplands (e.g., rice, wheat and corn).
- Cultivation intensity decreases from south to north in China.

Distribution of arable crops across China and sampling sites

Song et al., European Journal of Agronomy, 2014

Silica content-phytolith content transfer function in crops:

Phytolith content (wt %) = silica content (wt %) × 0.967



Correlation of phytolith content and SiO_2content in different crops

Song et al., European Journal of Agronomy, 2014

4. Phytolith C sequestration in ecosystems of China

The predominant crop species for PhytOC production are rice (40%), wheat (18%) and corn (30%).

Estimated PhytOC production by Chinese crops

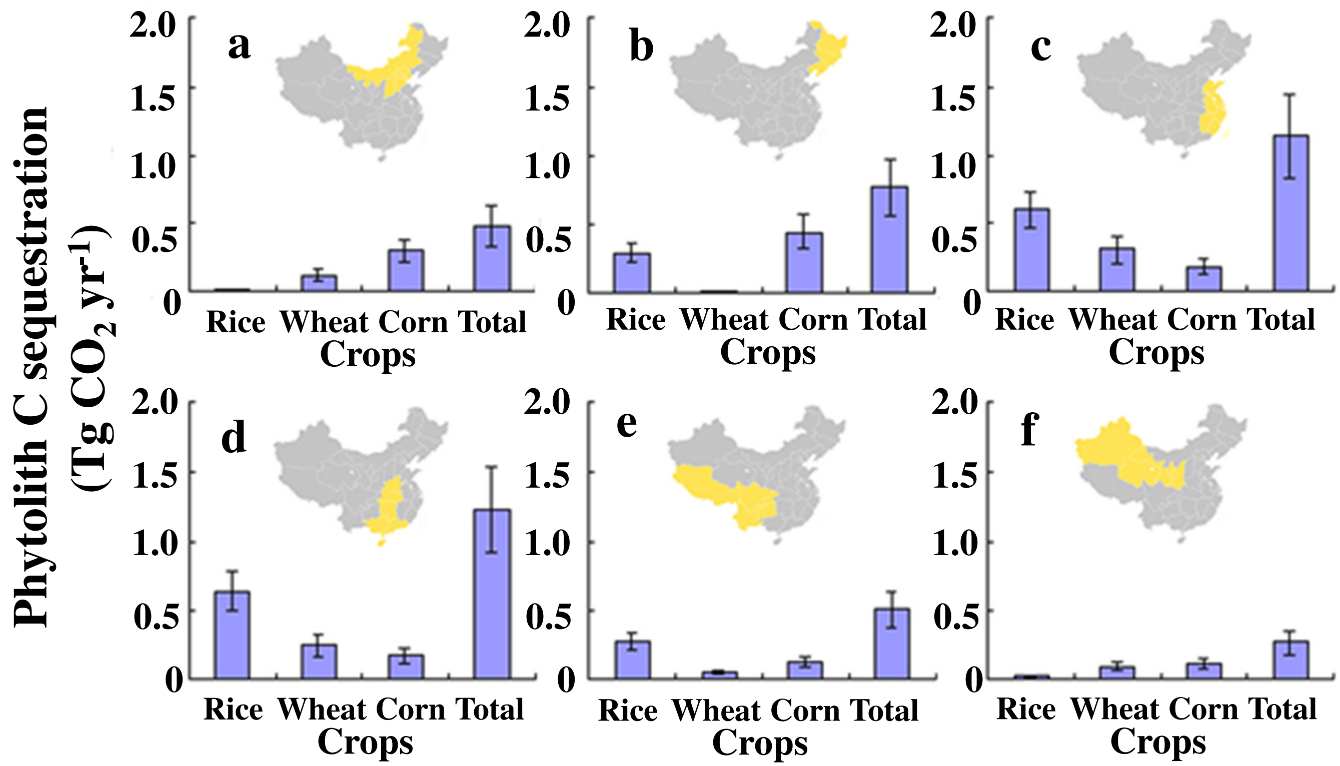
Farm crops	SRO production flux ($kg\ ha^{-1}\ yr^{-1}$)	PhytOC production flux ($kg\ CO_2\ ha^{-1}\ yr^{-1}$)	PhytOC production rate ($Tg\ CO_2\ yr^{-1}$)
Rice	**7356**	**68（19）**	**2.04（0.58）**
Wheat	**6225**	**38（17）**	**0.91（0.41）**
Corn	**7771**	**44（17）**	**1.49（0.57）**
Other cereal	**2329**	**14（8）**	**0.09（0.05）**
Cotton	**19101**	**17（6）**	**0.08（0.03）**
Sugarcane	**10575**	**96（26）**	**0.19（0.05）**
Total	**6144**	**36（13）**	**4.88（1.73）**

*SOR: Si-rich organs.

Song et al., European Journal of Agronomy, 2014

4. Phytolith C sequestration in ecosystems of China

The largest crop phytolith C sequestration in China occurs in the midsouthern, and northeastern regions due to intensive rice production with frequent fertilization and irrigation.

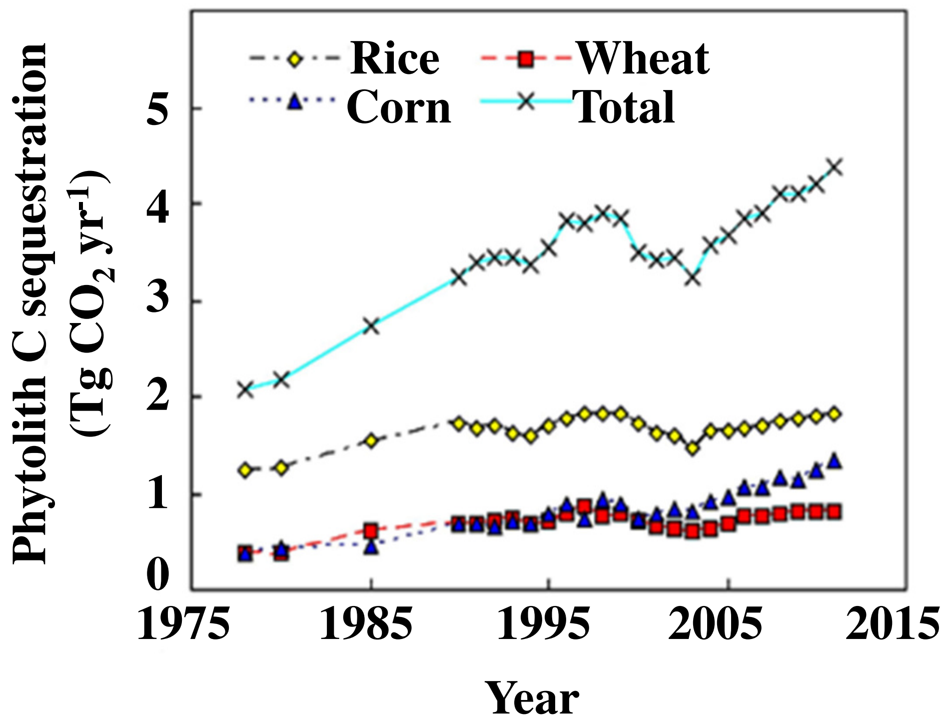


Phytolith C sink rate of arable crops in different regions of China in 2011

Song et al., European Journal of Agronomy, 2014

4. Phytolith C sequestration in ecosystems of China

- Phytolith C sink of China's croplands has doubled since 1978.
- Cropland phytolith C sink can be enhanced by cropping system optimization, rational fertilization and irrigation.



Cropland phytolith C sequestration change with time

Song et al., European Journal of Agronomy, 2014

4. Phytolith C sequestration in ecosystems of China

4.5 Comparison of different ecosystems

- **Cropland phytolith C sink contributes about one half of terrestrial ecosystems in China.**
- **The increasing potential of phytolith C sink in forests and grasslands are also large.**

PhytOC production of different ecosystems in China

	Area (10^6ha)	PhytOC production fluxes (kg CO_2 ha^{-1} a^{-1})	PhytOC production rate (Tg CO_2 a^{-1})
Shrubland	215	4.77–7.13	1.28(0.25)
Croplands	134.5	23–49	4.88(1.73)
Forests	142.8	10.5–16.7	1.94(0.44)
Grasslands	331	1–2	0.60 (0.17)

Song et al., Global Change Biology, 2012, 2013; Song et al., European Journal of Agronomy, 2014; Ru et al., Silicon, 2016

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Conclusions

- **Phytolith C sequestration in terrestrial ecosystems is a promising biogeochemical C sequestration mechanism and may contribute to the mitigation of global climate warming.**

- **Management practices that can significantly enhance phytolith C sequestration include:**
  - ✓ **Grassland management to maximize ANPP**
  - ✓ **Forest management practices (e.g. bamboo afforestation)**
  - ✓ **Optimizing crop structures, rational fertilization and irrigation.**

Perspectives

- **Understanding factors controlling the turnover and stability of phytoliths in different environment is necessary.**
- **Contribution of grasslands and other ecosystems to the global phytolith C sequestration needs to be quantified.**
- **Cost and potential of each measure deserve investigation to enhance terrestrial biogeochemical C sequestration.**
- **Phytolith C sequestration and related biogeochemical C sequestration processes should be incorporated into carbon-climate feedback models.**


Thank you for your attention!