Soil weathering degree controls silicon bioavailability by increased pH after biochar application

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Background

Crop harvesting disturbs the turnover of BSi (biogenic Si) in the topsoil because large amounts of phytolith can be exported. Phytolith removal may promote silicon (Si) depletion in the long-term (Vandevenne et al. 2012). Through soil development, desilication implies that the source of dissolved Si (DSi) from lithogenic (LSi) and pedogenic (PSi) silicate minerals decreases, while the source of DSi from phytolithic (PhSi) silicates increases (Figure 1). The Si accumulation and recycling rates depend on plant species and increase in highly weathered soils (Cornelis and Delvaux 2016) which are depleted in weatherable LSi and PSi. Therefore, in such soils, a Si supply should be best be continuously applied to sustain a cropping system.

Since plants accumulate Si in the form of phytolith, the pyrolysis of plant material produces biochar containing PhSi (Xiao et al., 2014). PhSi dissolution from biochar could thus supply DSi in the soils amended with biochar (Houben et al., 2014). In this regard, biochar can be a promising cost-effective and environmentally friendly alternative to conventional Si amendments in agro-ecosystems with Si high-accumulator crops.

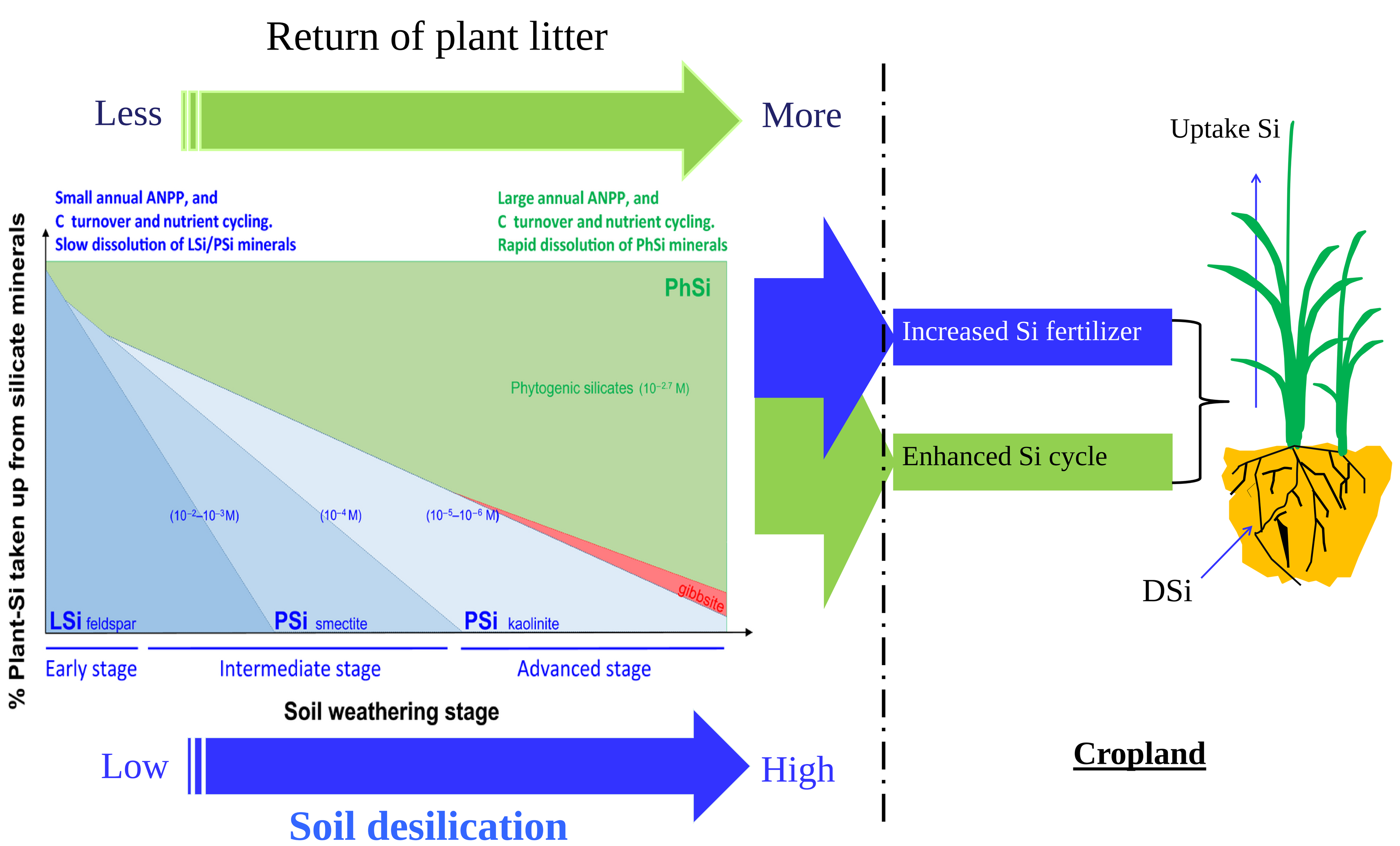

Figure 1. Soil weathering increases the proportion of phytolithic Si (PhSi) in plant Si uptake which could be further increased by cultivation practices. (Modified from *Cornelis and Delvaux, 2016*).

References

Houben D., Sonnet P., Cornelis J.-T. (2014. *Plant and Soil* 374:871-882.

Cornelis, J. T., & Delvaux, B. (2016). *Functional Ecology, 30*(8), 1298-1310.

Vandevenne, F., Struyf, E., Clymans, W., & Meire, P. (2012). *Frontiers in Ecology and the Environment, 10*(5), 243-248.

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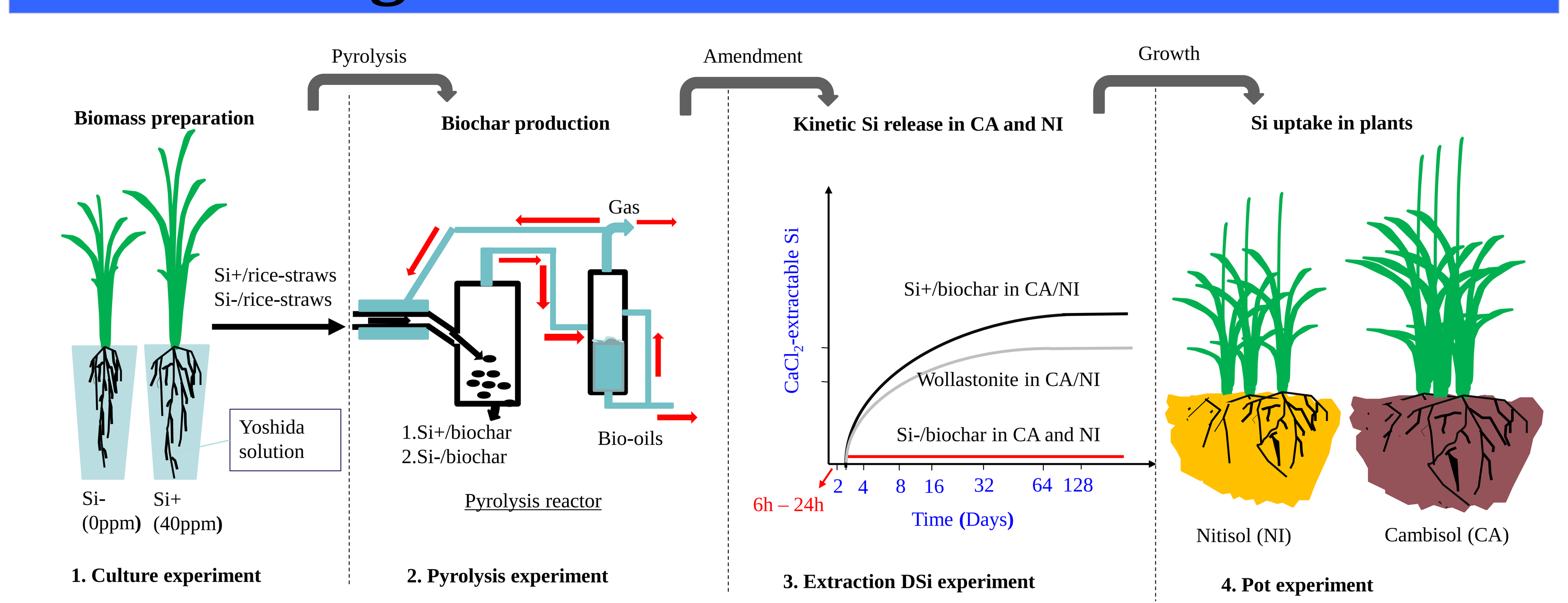
Objective:

Question-1, Does Si-enriched rice-straw biochar contribute to the often-observed increase of bioavailable Si?

Question-2, Can Si-enriched biochar amendment serve as an alternative to $CaSiO_3$-wollastonite amendment in short and long-terms?

Question-3, Does an increase of bioavailable Si result in an increase plant growth and Si uptake in a given soil?

Methodologies and materials



Results and Discussion

1. *Properties of rice-straws and its biochars*

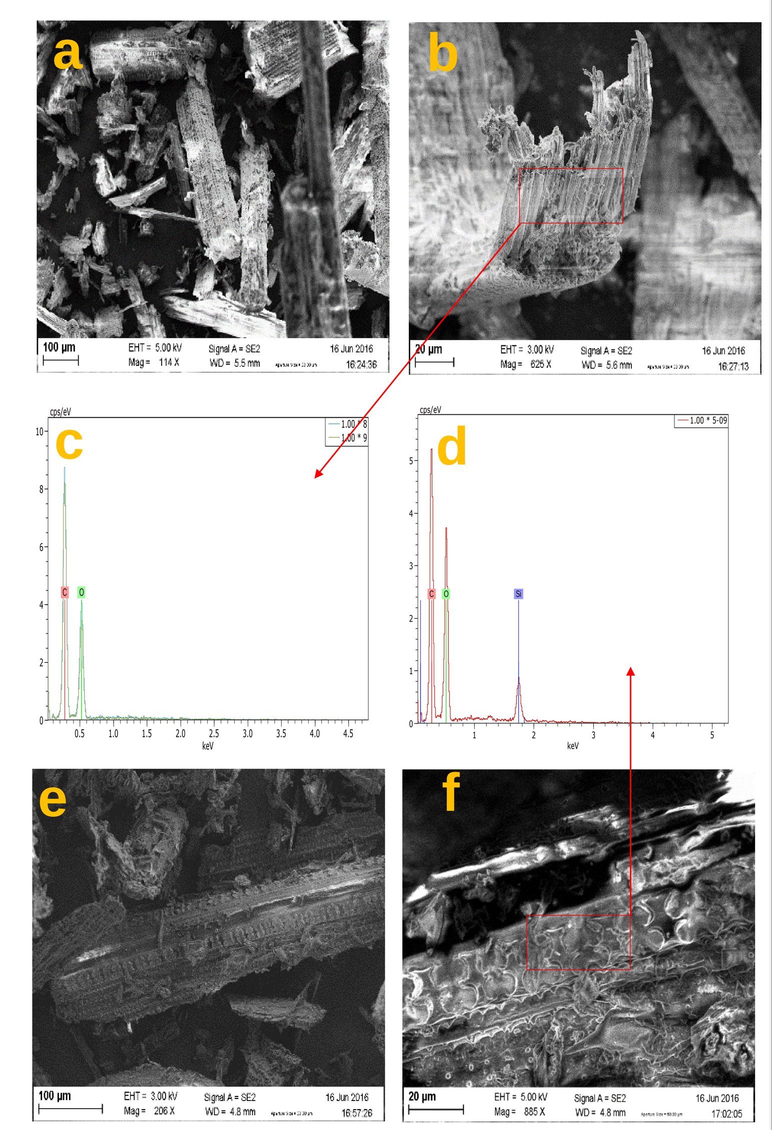


Figure 2. Scanning electron micrograph (SEM) images of particles from (**a**, **b**) Si-/rice straw, (**e**, **f**) and Si+/rice straw. The energy dispersive X-ray spectra (EDX) (**c** and **d**) collected from **b** and **f**, respectively, which are used to prove the presence of phytoliths.

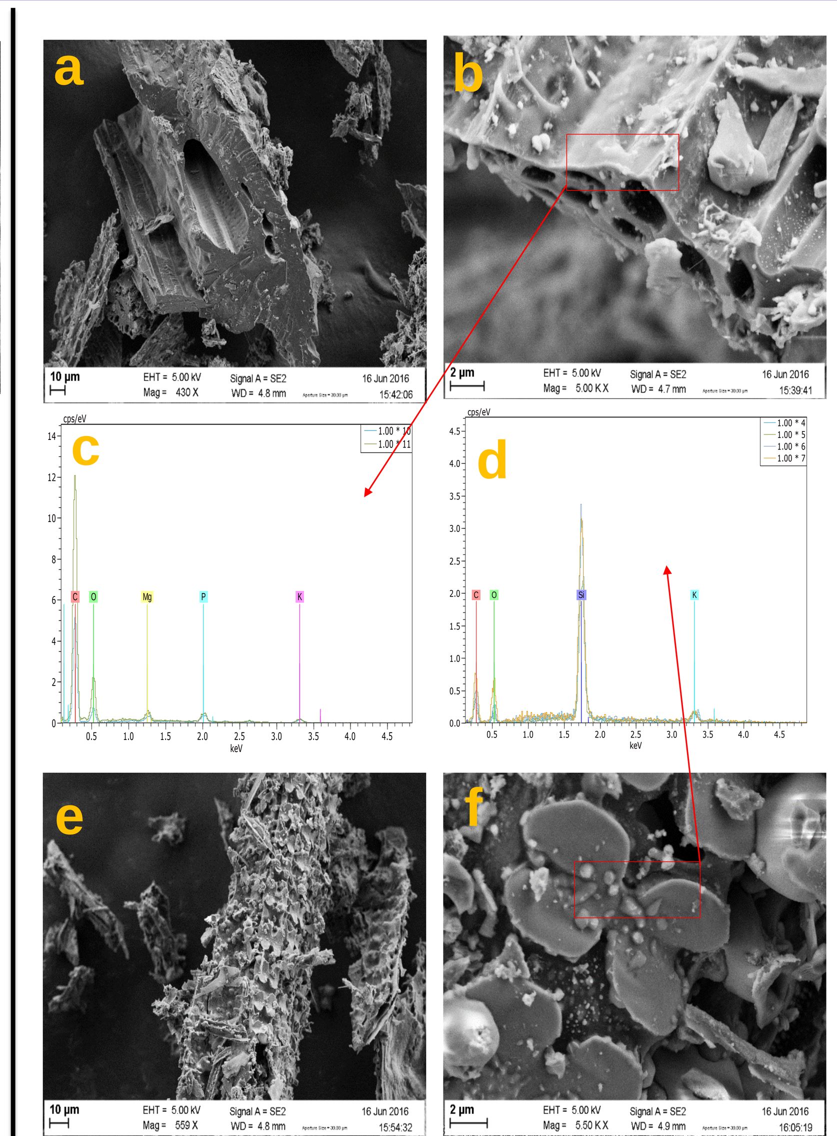


Figure 3. Scanning electron micrograph (SEM) images of particles from (**a**, **b**) Si-/rice-straw biochar, (**e, f**) and Si+/rice-straw biochar. The energy dispersive X-ray spectra (EDX) (**c** and **d**) collected from **b** and **f**, respectively, which are used to prove the presence of phytoliths.

Figure 2 shows that Si+/rice straw accumulates phytoliths in abundance while Si-/rice straw does not.
Figure 3 shows that pyrolysis did not damage the morphology of phytoliths in Si+/biochar. In addition, the concentration of phytoliths in Si+/biochar is more than in initial rice straw. Thus, our data suggest that biochar concentrates PhSi minerals.

2. *Biogenic AlkExSi (alkaline extractable Si)*

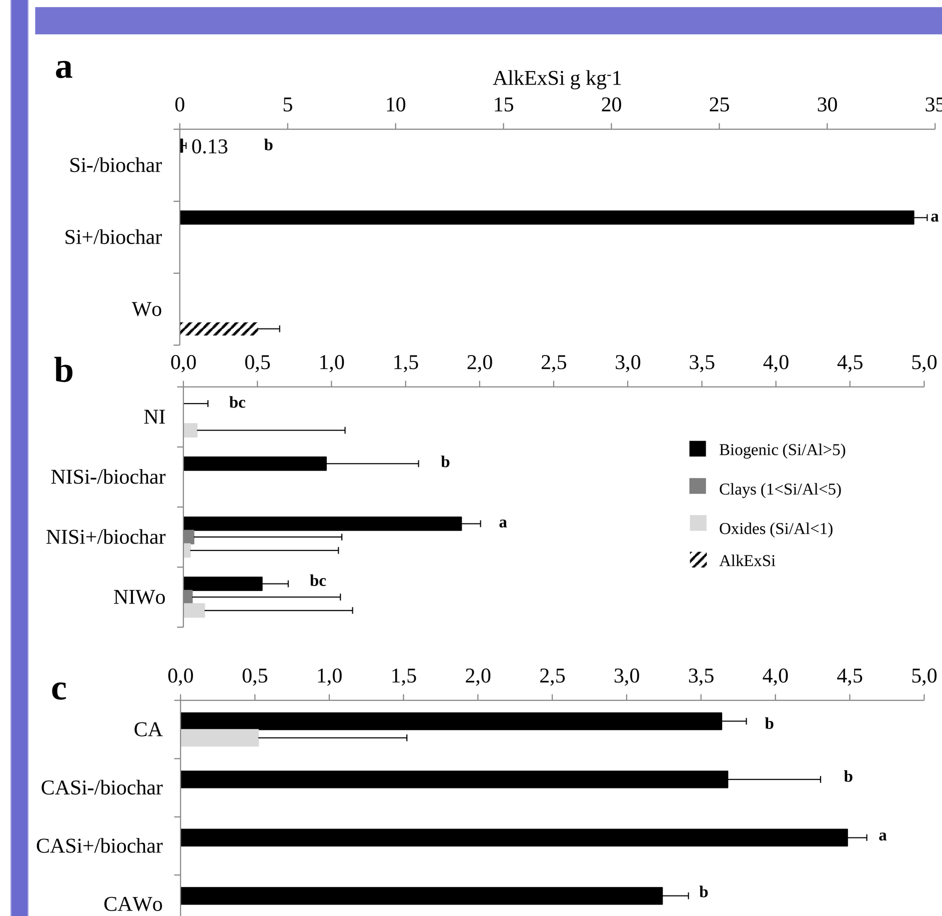


Figure 4. Alkaline extractable Si (AlkExSi, g kg^{-1}). **a**: Amendments: biochars (Si- and Si+) and wollastonite (Wo). **b**: CA, CASi-/biochar, CASi+/biochar and CAWo **c**: NI, NISi-/biochar, NISi+/biochar and NIWo. In NI, the origin of the alkaline-extractable Si is not defined.

Figure 4 shows that the addition of Si+/biochar significantly increases the BSi pool in NI and CA. The addition of Si-/biochar significantly increases the BSi pool in NI but not in CA. No significant effect is measured after wollastonite application in both soils.

Out data indicate that Si+/biochar provides huge quantities of biogenic Si with respect to Si-/biochar and wollastonite.

3. *Kinetic release of bioavailable Si ($CaCl_2$ extractable Si)*

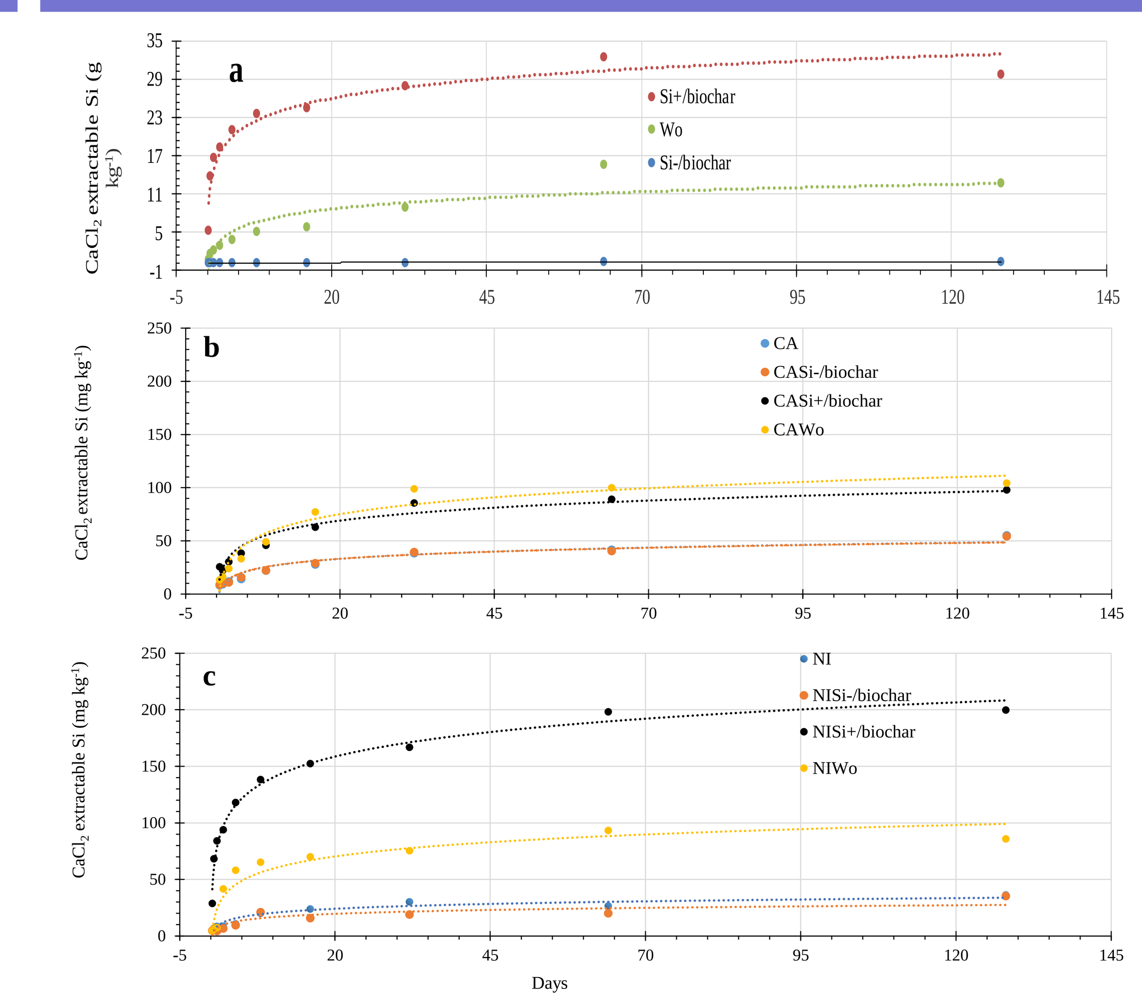


Figure 5. The kinetic release of $CaCl_2$ extractable Si over the time at 6h, 12h, 1, 2, 4, 8, 16, 32, 64 and 128 days. **a:** Si-/biochar, Si+/biochar and wollastonite (Wo); **b**: Cambisol (CA) and Cambisol amended by Si-/biochar (CASi-/biochar), Si+/biochar (CASi+/biochar) and wollastonite (CAWo); **c.** Nitisol (NI) and Nitisol amended by Si-/biochar (NISi-/biochar), Si+/biochar (NISi+/biochar) and wollastonite (NIWo). Note that the units for the amendments extractions in a) are g kg^{-1}.

Figure 5a shows that after the 128th day, the cumulative $CaCl_2$ extractable Si is two times larger in the Si+/biochar than in wollastonite (30 and 13 g kg^{-1} for the Si+/biochar and the Wo respectively). In contrast, Si-/biochar shows a negligible release of $CaCl_2$ extractable Si (below 0.3 g kg^{-1}).

Figure 5b and c show after 128-days kinetic extraction, the cumulative $CaCl_2$ extractable Si (mg kg^{-1}) is 200 in NISi+/biochar and much larger than that in CASi+/biochar (98), CAWo (104) and NIWo (86).

Our data thus highlights that rice-straw biochar enriched phytoliths can serve as an alternative to $CaSiO_3$-wollastonite amendment to supply bioavailable Si, especially in highly weathered soils.

4. *Effect of biochar amendment on wheat biomass and Si mineralomass*

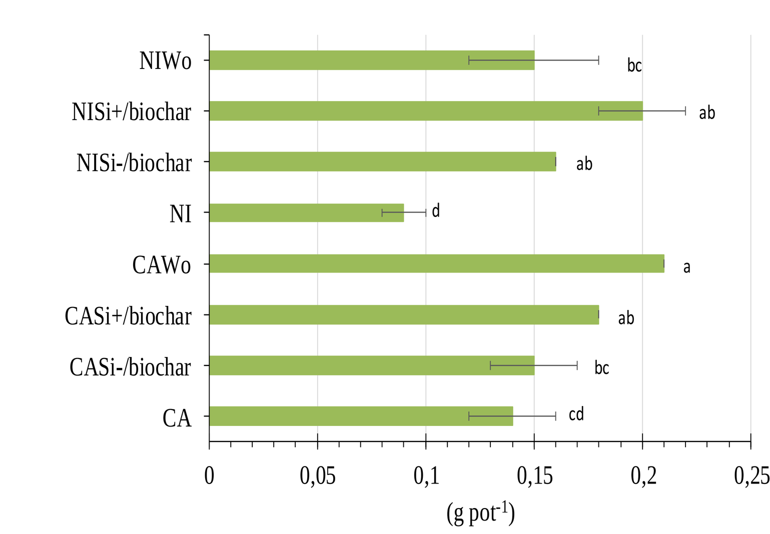


Figure 6. Dry weight in wheat plants grown in CA, NI, CASi-/biochar, CASi+/biochar, CASi-/biochar, CAWo; NI, NISi-/biochar, NISi+/biochar, NIWo).

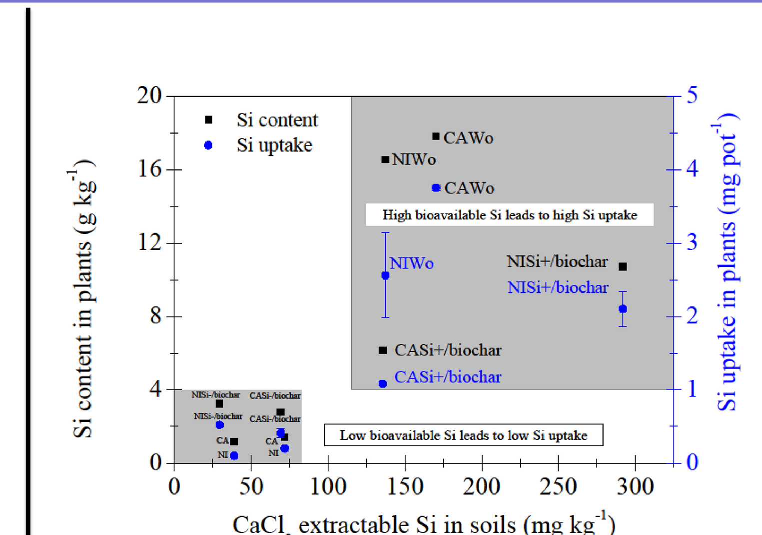


Figure 7. Plot of Si uptake by wheat plants against the total $CaCl_2$ extractable Si (bioavailable Si, i.e., readily taken up by plant roots) in the Cambisol (CA) and Nitisol (NI).

Figure 6 shows that Si+/biochar and Wo significantly increase the wheat biomass grown in both CA and NI. The wheat biomass significantly increases only in NISi+/biochar.
Figure 7 shows that Si+/biochar and Wo applications largely increase the Si content of plants in both CA and NI, which, in turn, substantially increases respective Si uptake. But Si-/biochar does not have a significant effect on Si uptake in both CA and NI.

Our data thus suggest that Si+/biochar holds, to a certain degree, the ability to supply bioavailable Si into the soil solution in the same order than Wo, that in turn, directly affecting the Si absorption by roots and possibly enlarging the Si deposition in plant tissues.
Our data also highlights that plant roots can readily take up bioavailable Si released from phytolith in biochar.

Conclusion and Outlook

Our data highlight that phytolith-rich biochar readily contributes to the pool of bioavailable Si over time (***Question-1***), further taken up by plant roots, and increases Si mineralomass in plants as well as plant growth (***Question-3***). Thus it provides an alternative to wollastonite application (***Question-2***). The effect is particularly large in the highly weathered Nitisol depleted in BSi, LSi and PSi.