Redox-driven colloidal mobility and its effects on carbon cycling in temperate paddy soils

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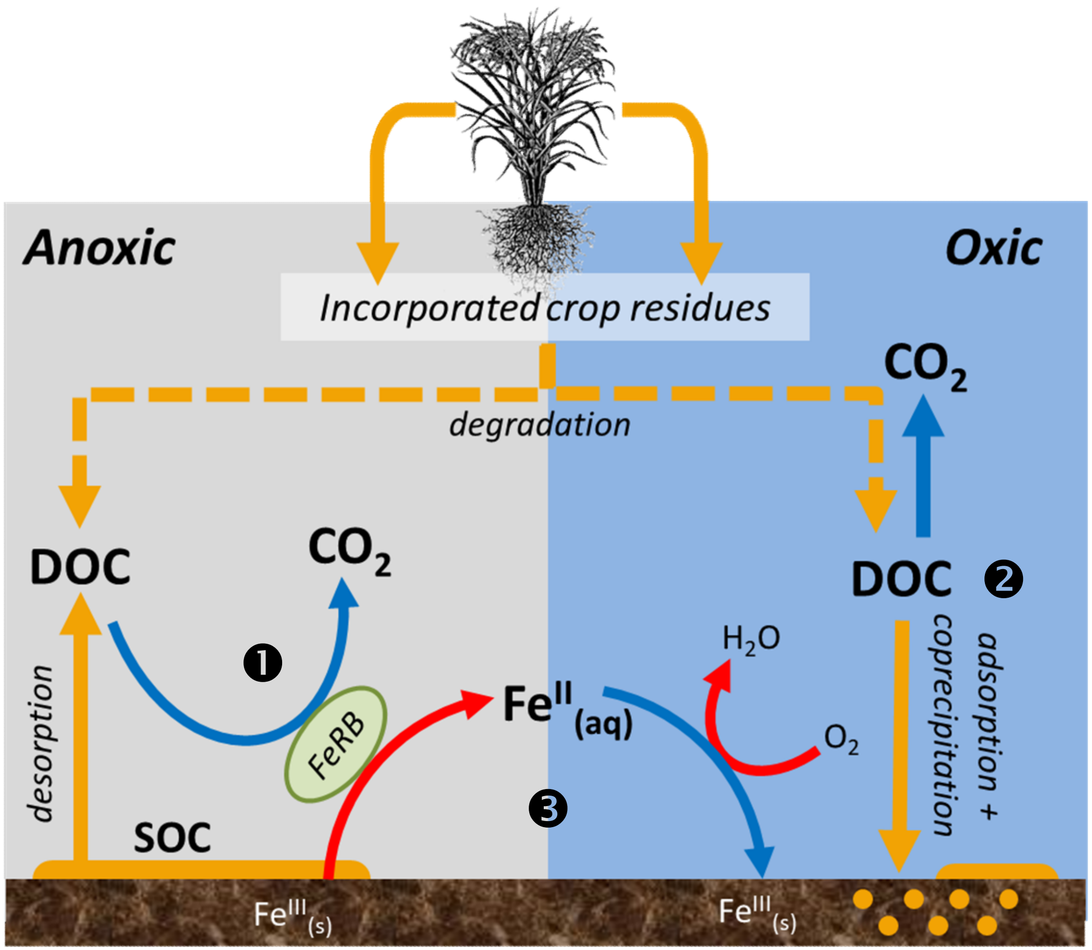
Rice paddies are important global C sinks

- Rice is cultivated in flooded paddies with one, two or even three consecutive cropping seasons per year.
- Rice paddies represent a large proportion of global terrestrial carbon (C) stocks (ca.10 Pg) which partly offsets their significant contribution to global methane emissions.
- Substantial OM inputs with crop residue incorporation and limited mineralization of SOM under anoxic soil conditions are generally assumed to contribute to their C sink functions.

Organic C stabilization in redoximorphic soils

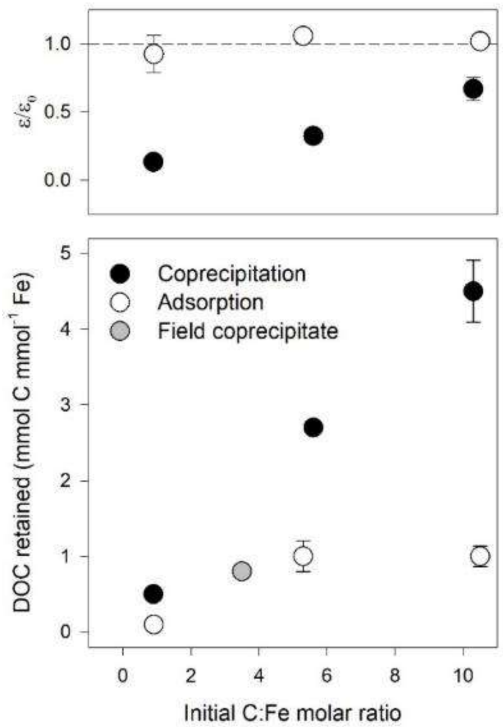


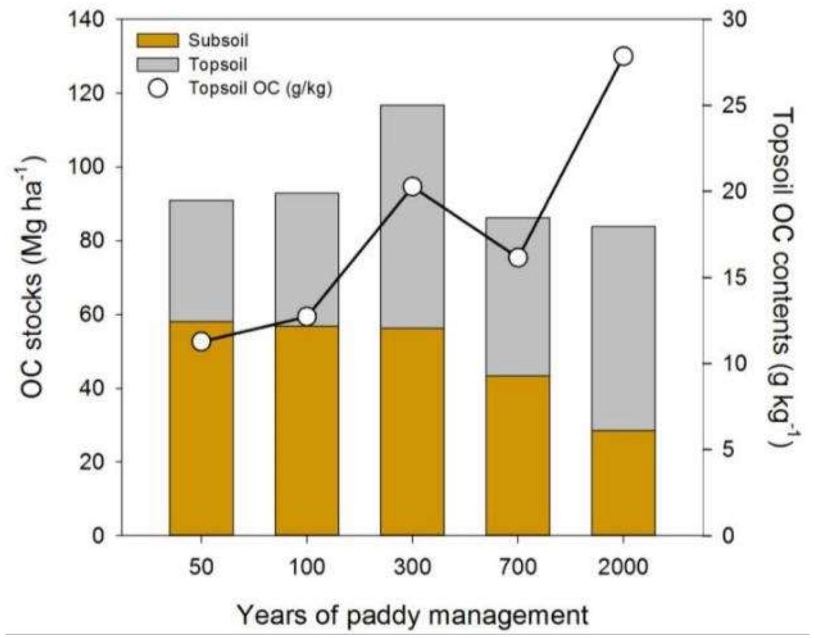
❶ Under anoxic conditions the reductive dissolution of Fe oxides may release Fe(II) and associated DOC in solution. This DOC can be transported into deeper mineral horizons through percolation.

❷ Under oxic conditions DOC may be re-adsorbed by coprecipitation during the precipitation of Fe(III) phases. These processes are further enhanced with the input of fresh OM through crop residue addition.

❸ Dynamic interactions between C and redox-active minerals particularly Fe oxides, together with the transport of organic C to deep mineral horizons can contribute to C accrual in paddy soils.

Coprecipitation and DOC transport



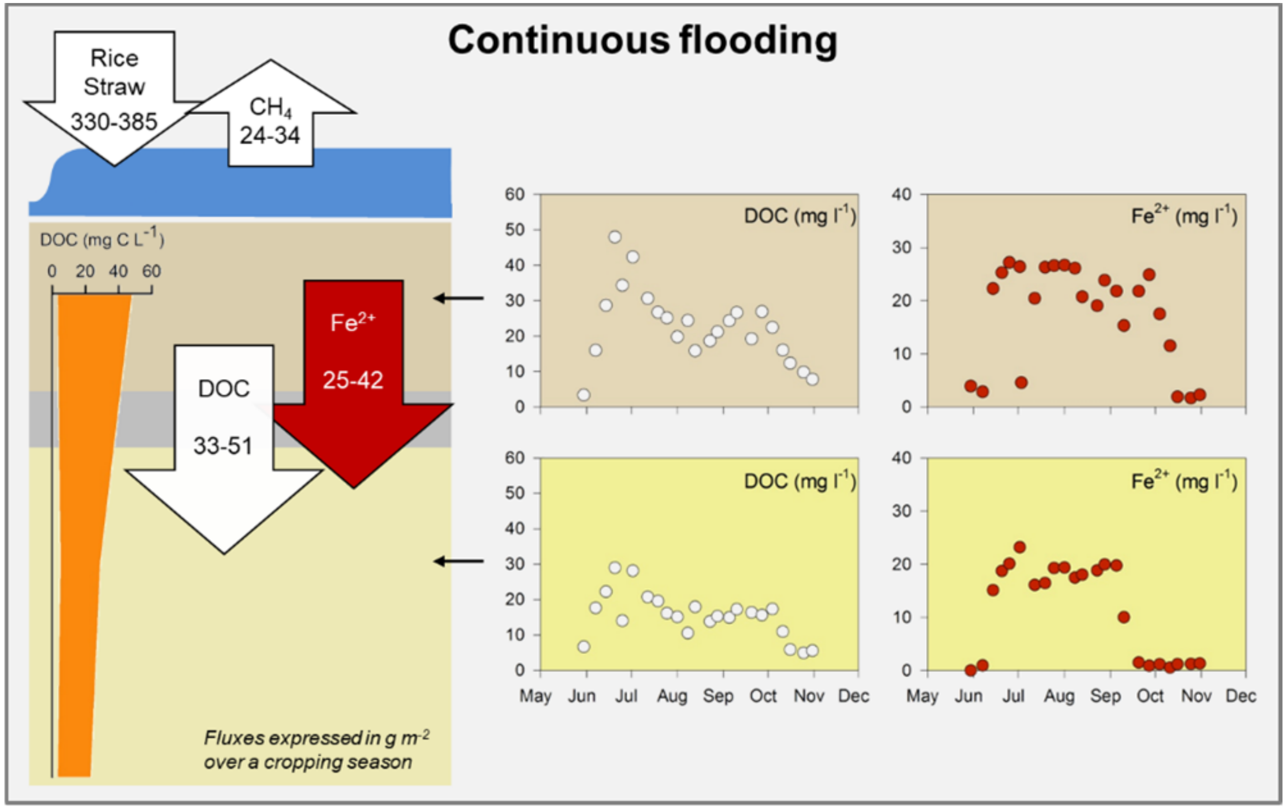


❶ We have previously shown that coprecipitation can retain substantially more OC with respect to surface adsorption, with a stronger preferential retention of aromatic constituents

❷ Wissing et al., and Kalbitz et al. have shown that long-term OC accrual is limited to the topsoil as the dense plough pan can serve as a transport barrier limiting C input into the subsoil.

Sodano et al., 2017 (Geoderma); Wissing et al., 2011 (Catena); Kalbitz et al., 2013 (Global Change Biol)

DOC and Fe transport from topsoil to subsoil



❶ However, in temperate rice paddies we found that high topsoil DOC and Fe(II) concentrations during field flooding and the substantial water percolation fluxes in coarse textured soils, can actually contribute substantial DOC and Fe(II) fluxes into the subsoil, potentially contributing to increasing deep soil OC stocks.

Said-Pullicino et al., 2016 (Plant and Soil)

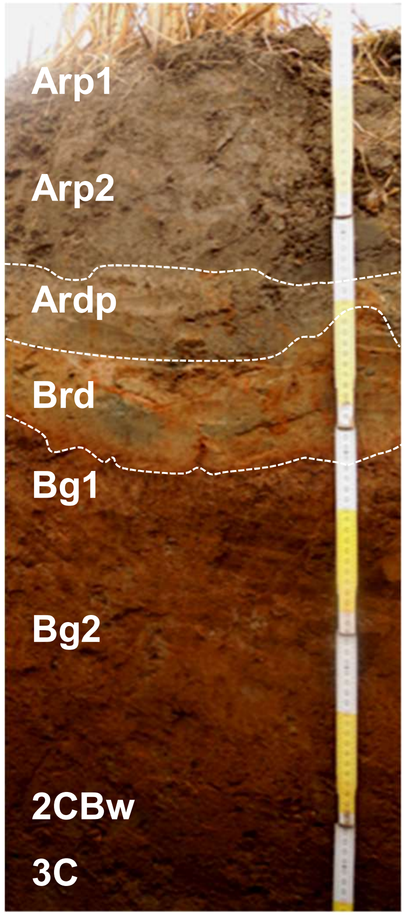
How much 'DOC' is really dissolved?

We hypothesized that:

- Redox fluctuations in paddy soils may lead to an overall increase in colloid dispersion.
  - » Reductive dissolution of Fe oxides that bind mineral particles
  - » Changes in soil pH under reducing conditions may affect the surface charge and colloidal stability
  - » Neoformation of colloidal organo-mineral associations
- Colloidal mobility may represent an important C input to paddy subsoils.

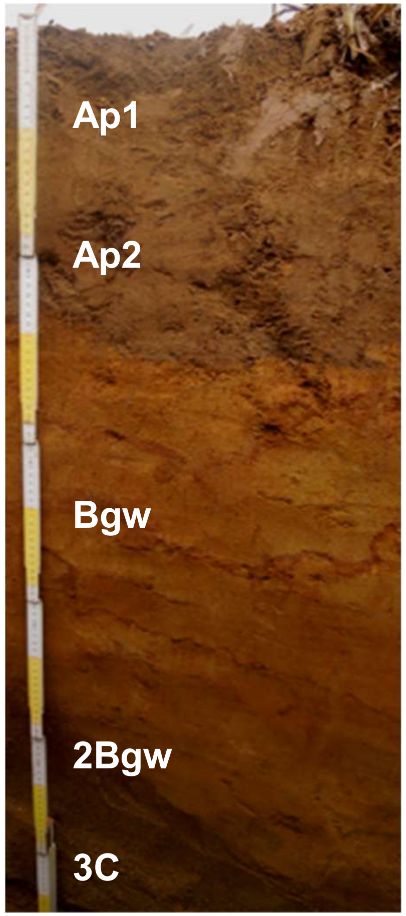
Study site and experimental work

Paddy - Rice



Haplic Gleysol

Non-paddy - Maize



Endogleyic Fluvisol

Topsoil horizons
(0-30 cm)

Anoxic incubation

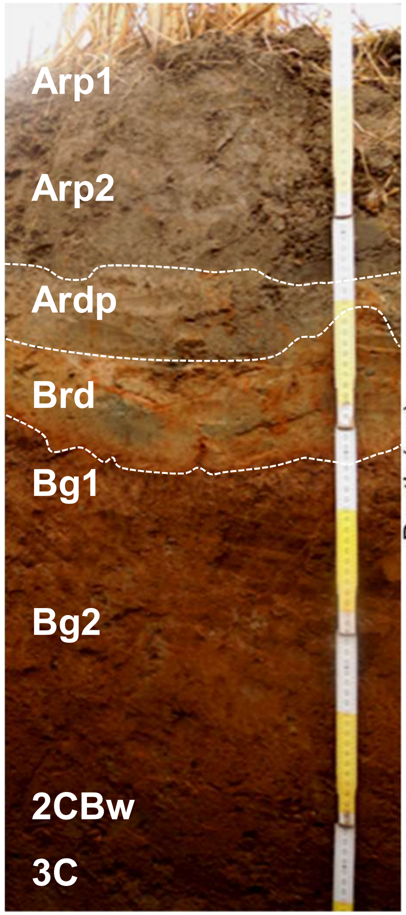
WFDC* extraction
AF4-OCD / AF4-ICP-MS**

Subsoil horizons
(30-100 cm)

*WDFC, water-dispersible fine colloids
**AF4, asymmetric flow field-flow fractionation

Soil development under paddy management.

Paddy - Rice



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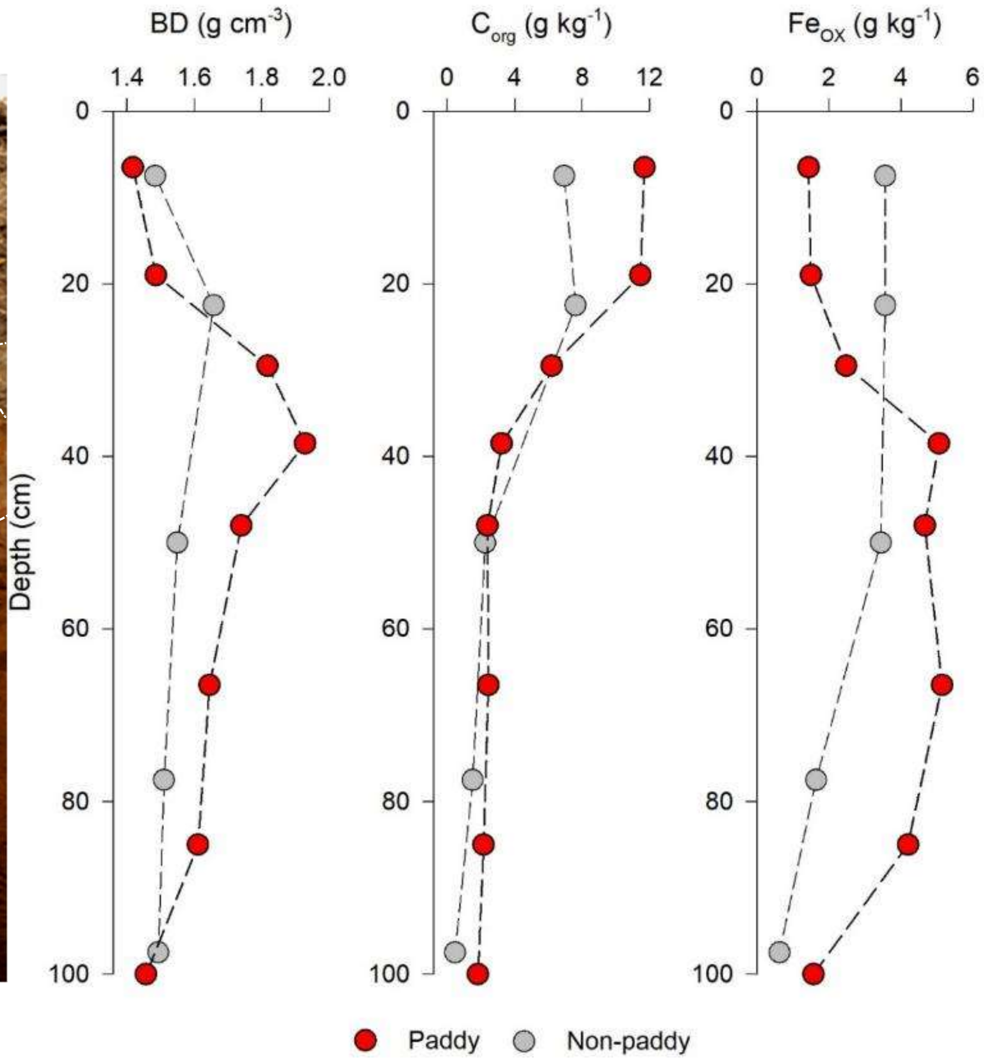
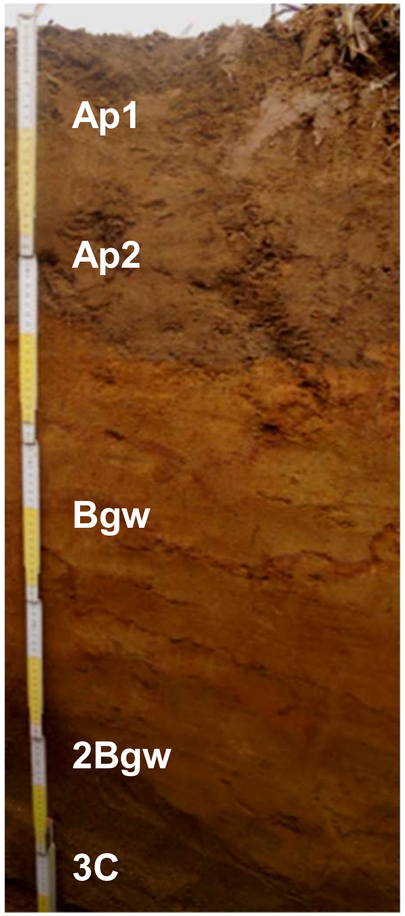
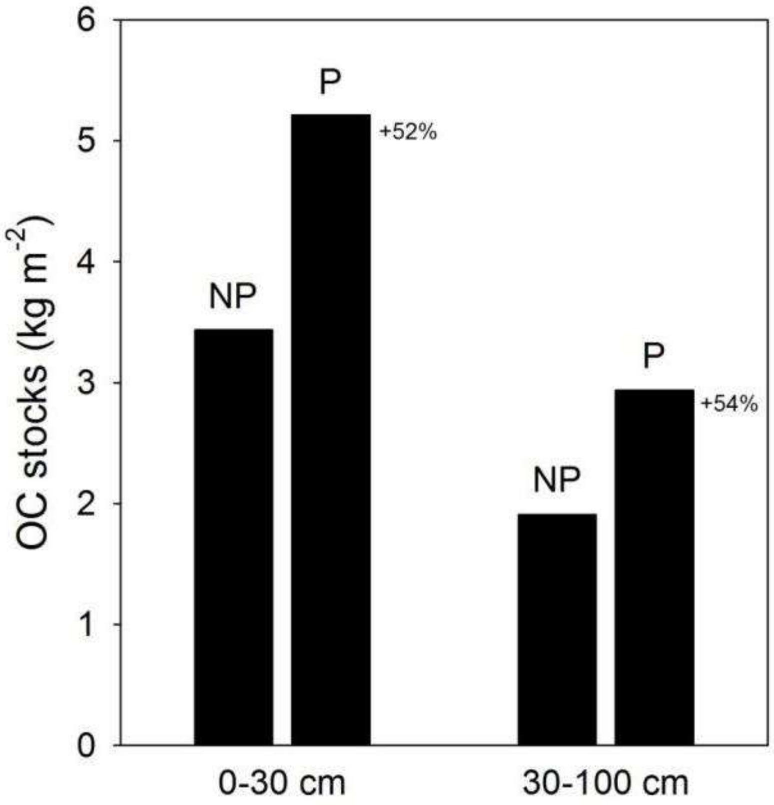


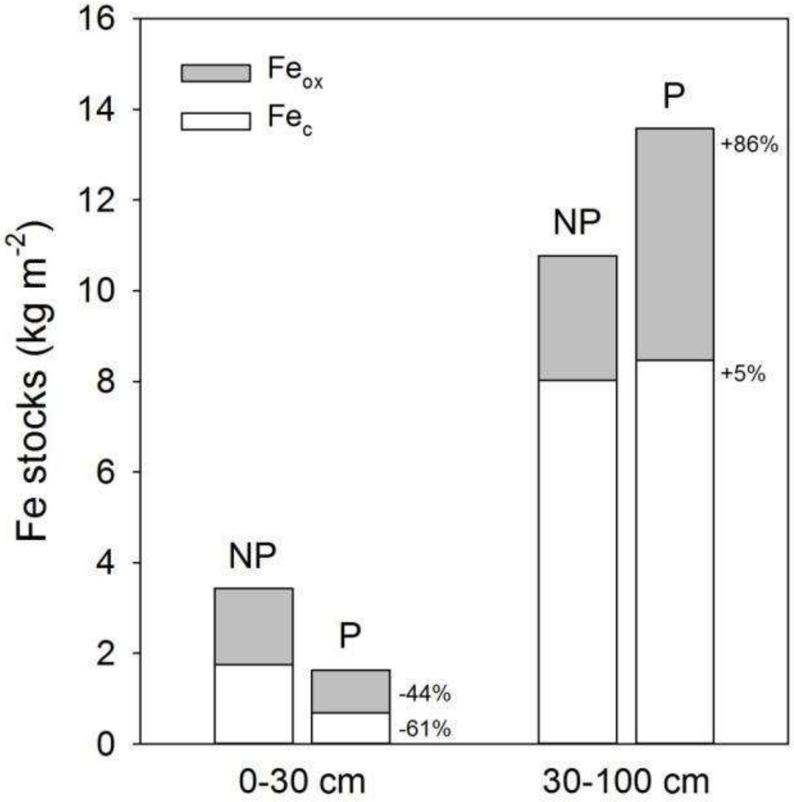
Non-paddy - Maize



Endogleyic Fluvisol

Management-induced changes in C and Fe stocks

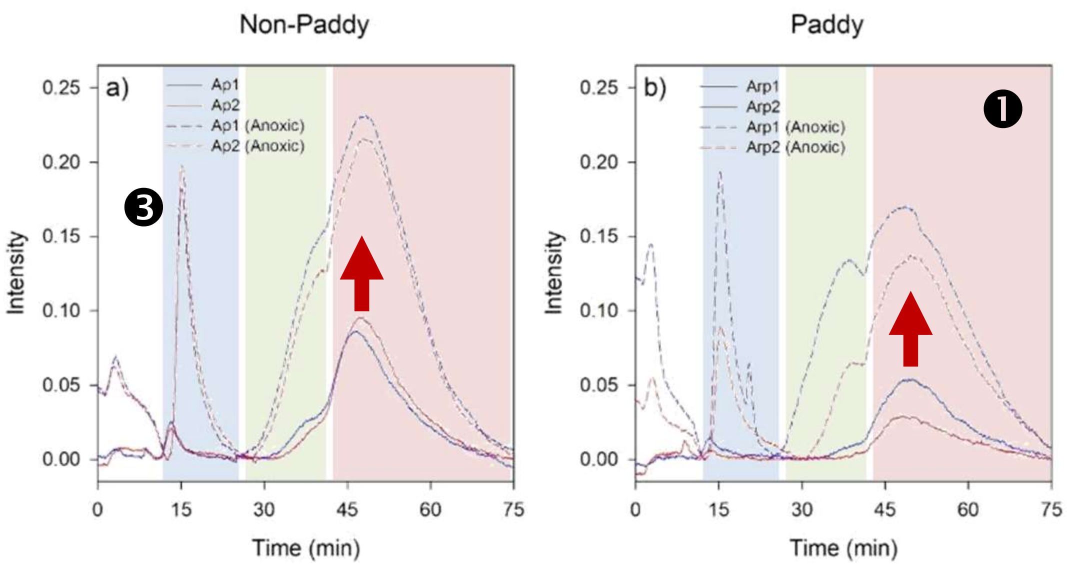


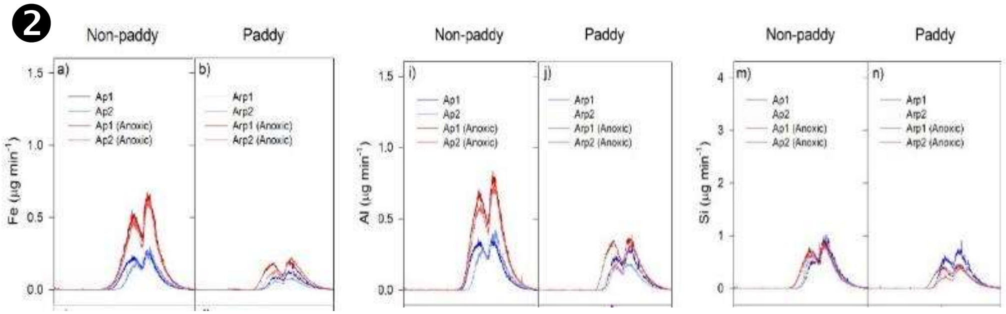


❶ Results showed a 52-54% increase in OC stocks in both topsoil and subsoil of the paddy soil with respect to the non-paddy soil.

❷ Redox cycling led a depletion in both SRO (Fe_o) and crystalline (Fe_c) Fe oxides in paddy topsoils, while subsoils were enriched in SRO oxides.

Topsoil water-dispersible fine colloids





❶

Fractograms showed the presence of three colloid size-fractions. OC in the WDFC was predominantly associated with the larger colloids >240 nm (49%), while truly dissolved DOC constituted around 43%.

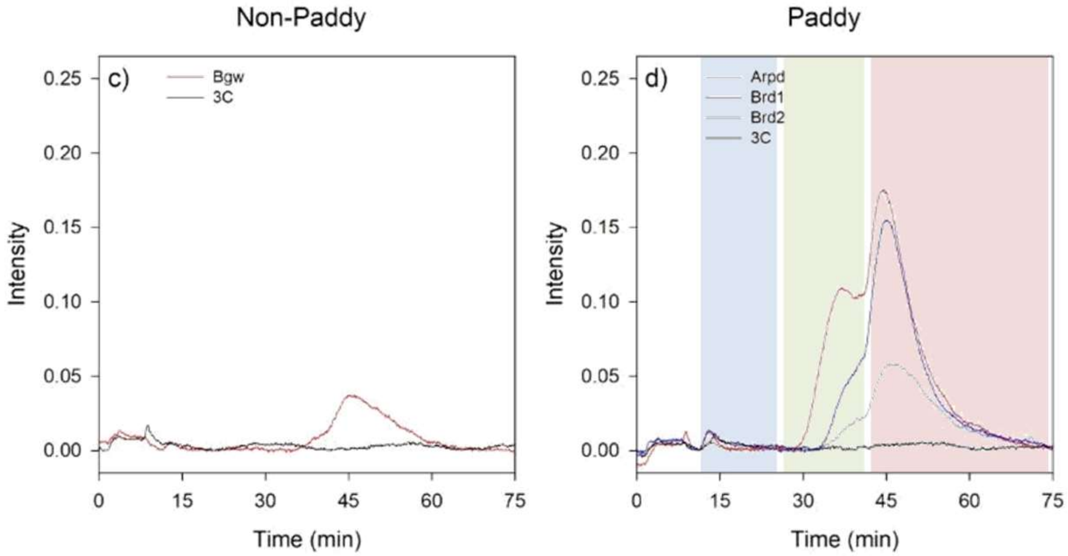
❷

Nanoparticles <30 nm were mainly composed of OM while larger colloids contained important amounts of Fe, Al and Si suggesting the presence of Fe and Al hydroxides, associated with 2:1 type phyllosilicate minerals.

❸

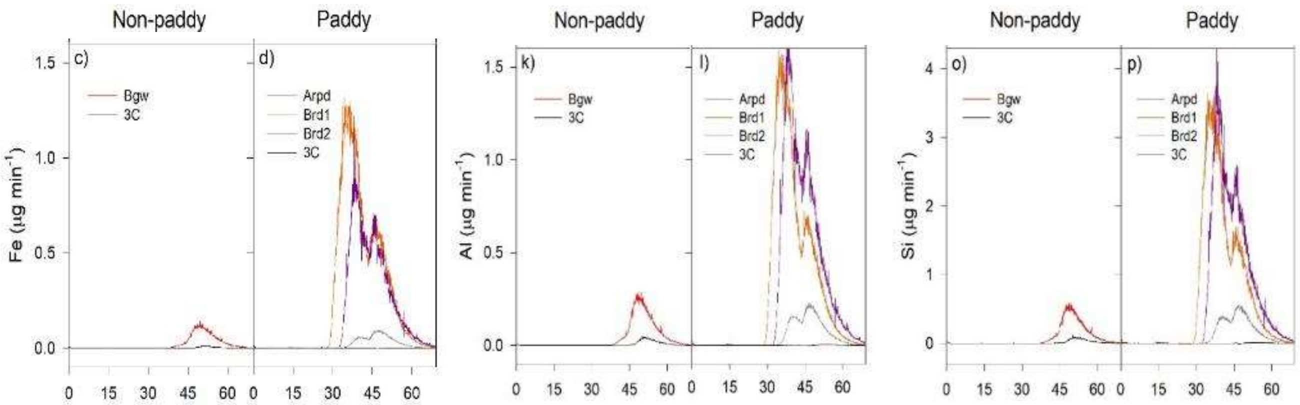
Anoxic conditions resulted in an increase in WDFC with a preferential dispersion of nanoparticles and finer colloidal C, as well as a substantial increase in colloidal Fe and Al. This was more evident in non-paddy soils that experienced less redox cycling.

Accumulation of WDFC in the subsoil



❶ In paddy soils, subsoil horizons just beneath the plough pan were particularly enriched in WDFC, unlike the non-paddy soil.

❷ Although anoxic conditions favoured the release of OC associated with finer colloidal fractions in the topsoil, subsoils showed higher contents of larger size-fractions.



❸ Paddy subsoils also showed substantial accumulation of Fe, Al and Si in fine colloids, indicating the mobilization of colloids along the profile combined with the neoformation of colloidal associations in these oxic horizons.

“Take-home” messages

- Redox cycling favours colloid dispersion in paddy topsoils, with a preferential release of finer colloidal fractions.
- Together with DOC, organo-mineral colloid mobility can represent an important input of OC into the subsoils with percolating water.
- Paddy subsoils are also important zones of colloid neo-formation through the (co-)precipitation of SRO oxides responsible for the retention of OC in deeper soil horizons.

Thank you for your attention

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Photo courtesy of Jean Paul Said Pullicino