USING RADIOGENIC AND METAL STABLE ISOTOPE RATIOS AS NEW TOOLS TO ASSESS NUTRIENT CYCLING IN AGRICULTURAL SYSTEMS

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RATIONAL

✗ Enriched isotopes ✓ Isotopes with natural abundance

Biogeochemical processes ➡ Isotope fractionation ➡ Different isotope compositions in various compartments

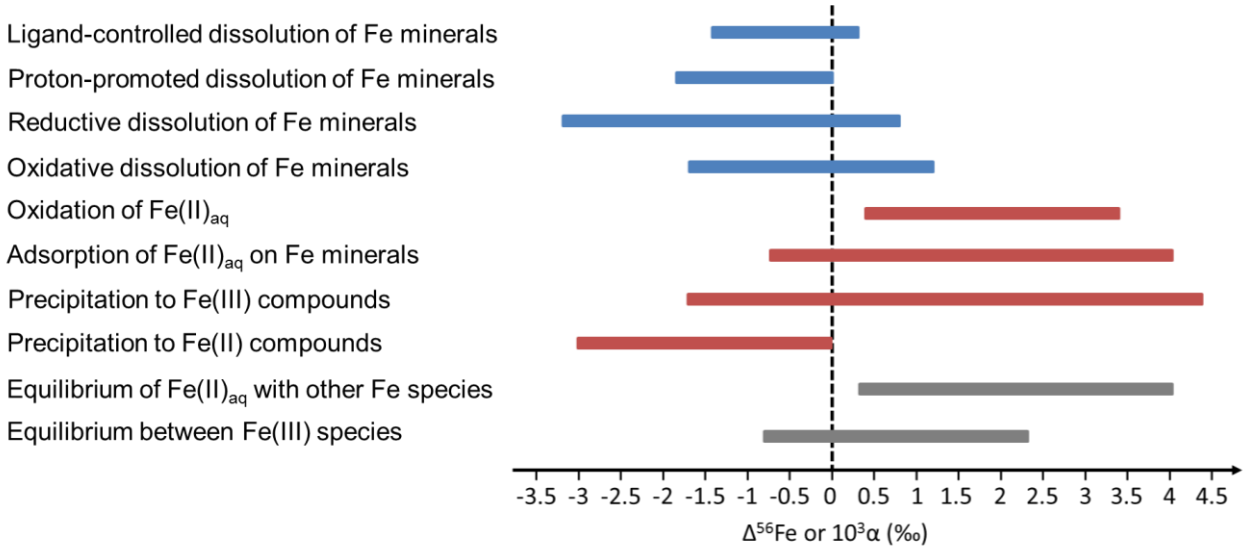


Fig. Range of Fe isotope fractionations of main processes as assessed in laboratory

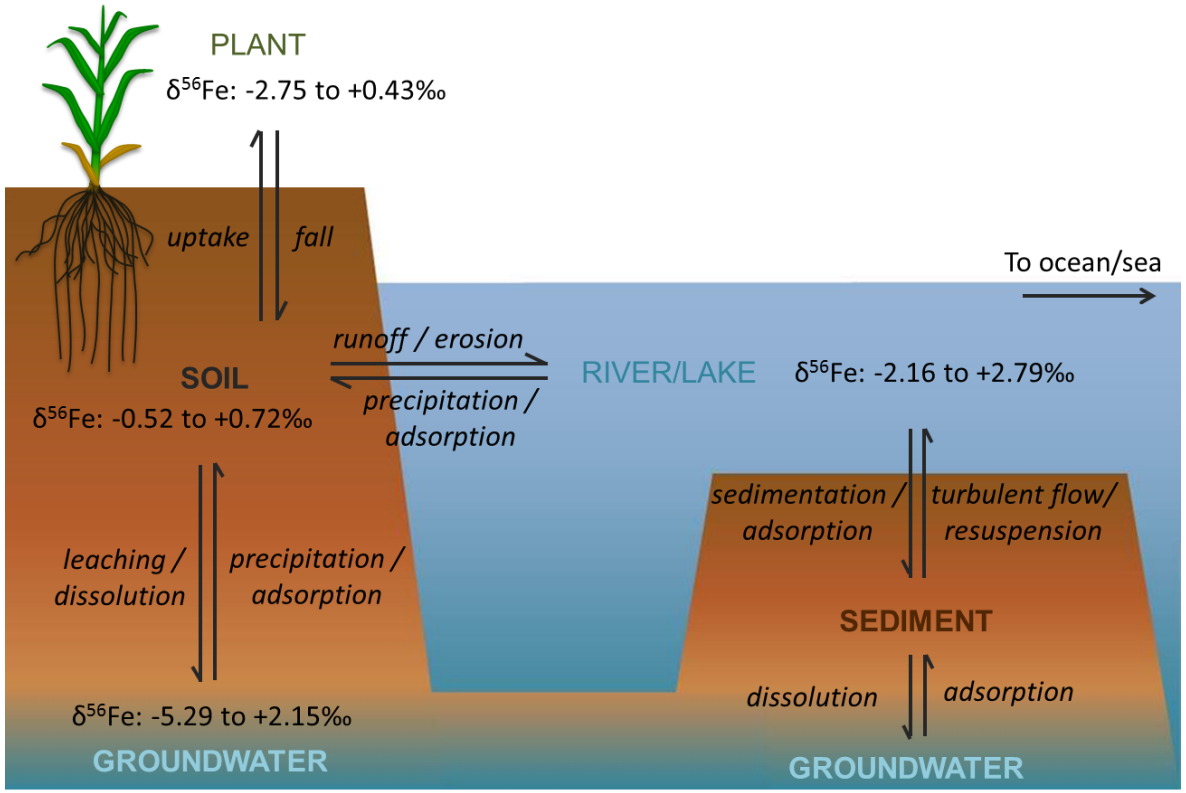


Fig. Main processes of Fe cycles in soil-plant-freshwater ecosystems

Wu et al., Earth-Sci. Rev., 2019, 190, 323–352

RATIONAL

✗ Radioactive isotopes ✓ Radiogenic isotopes

- Strontium (Sr) has four naturally occurring isotopes:

  ^{84}Sr (0.56%), ^{86}Sr (9.87%), **^{87}Sr,** ^{88}Sr (82.53%)

  primordial ^{87}Sr radiogenic ^{87}Sr

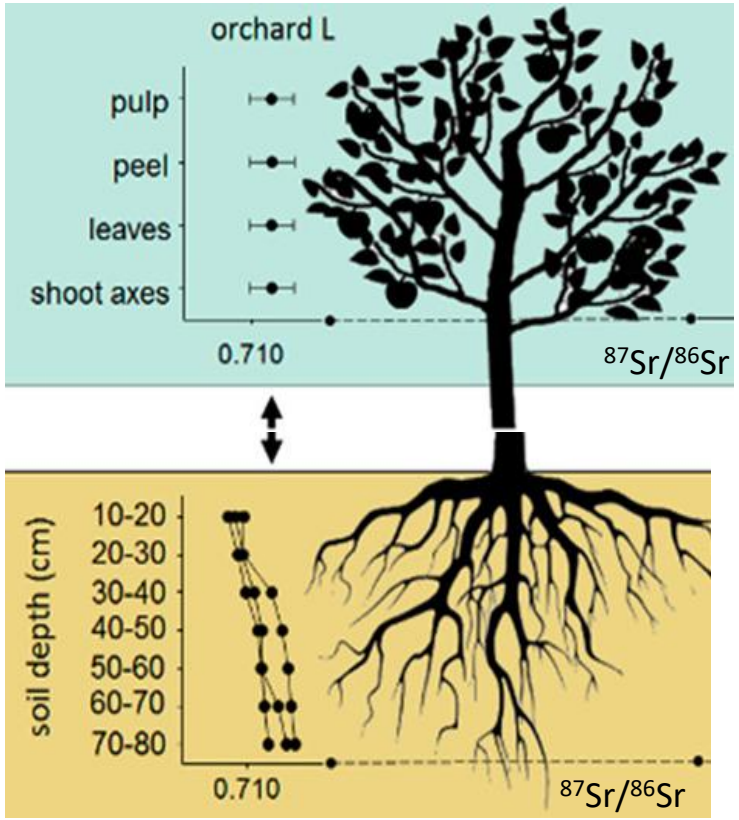
  $^{87}Rb \xrightarrow{\beta^-} {}^{87}Sr$

  Half-life 4.97×10^{10} years

No change of radiogenic $^{87}Sr/^{86}Sr$ ratio after soil formation and during the nutrient uptake

⬇

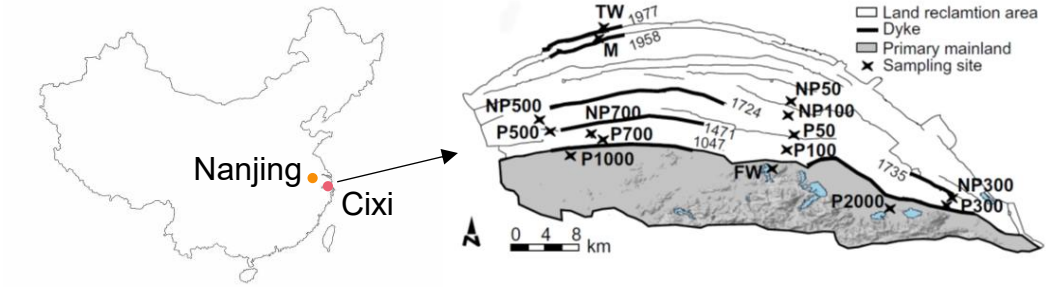
$^{87}Sr/^{86}Sr$ ratio of the plants reflects the nutrient source in soil



Modified from Aguzzoni et al., J. Agric. Food Chem. 2019, 67, 5728–5735.

Iron Isotopes for Reconstructing the Development of Paddy Chronosequence

_Cixi, China, 2000 Years of Rice Cultivation

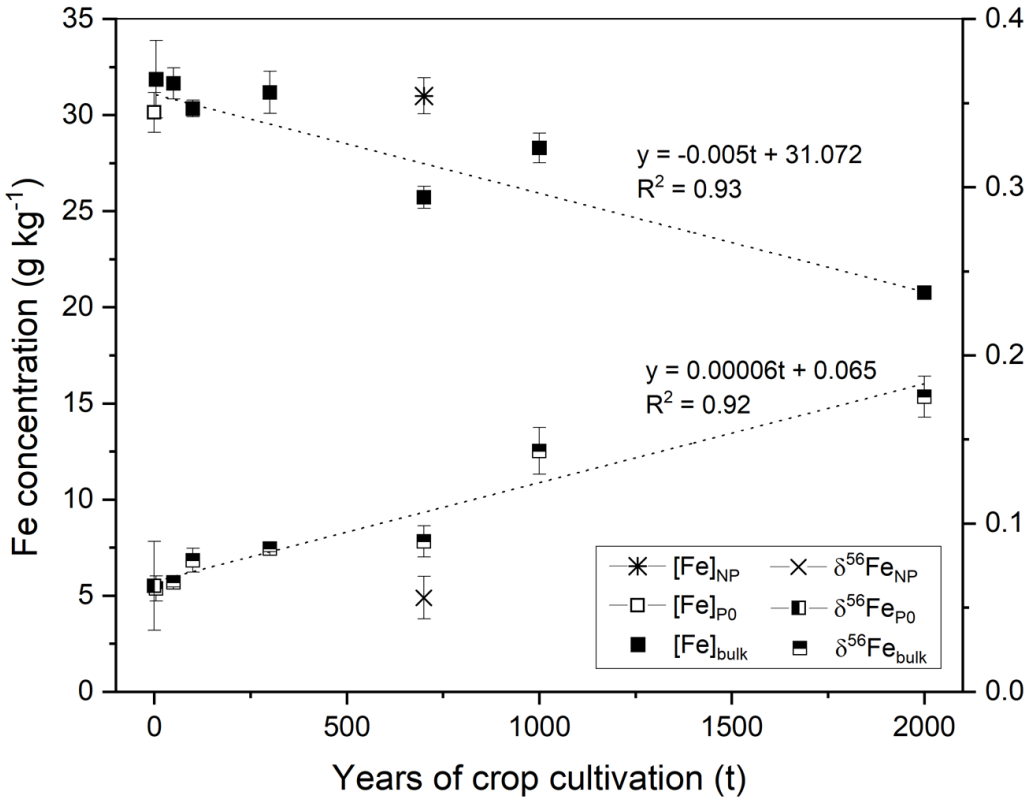


modified from Mueller-Niggemann and Schwark, Org. Geochem. 2015, 83–84, 215-226.

Radiogenic Strontium Isotope for Tracing Nutrient Source after Sustainable Subsoil Management

_Bonn & Berlin, Germany, Deep Loosening + Biocompost Incorporation

Iron Isotopes for Reconstructing the Development of Paddy Chronosequence

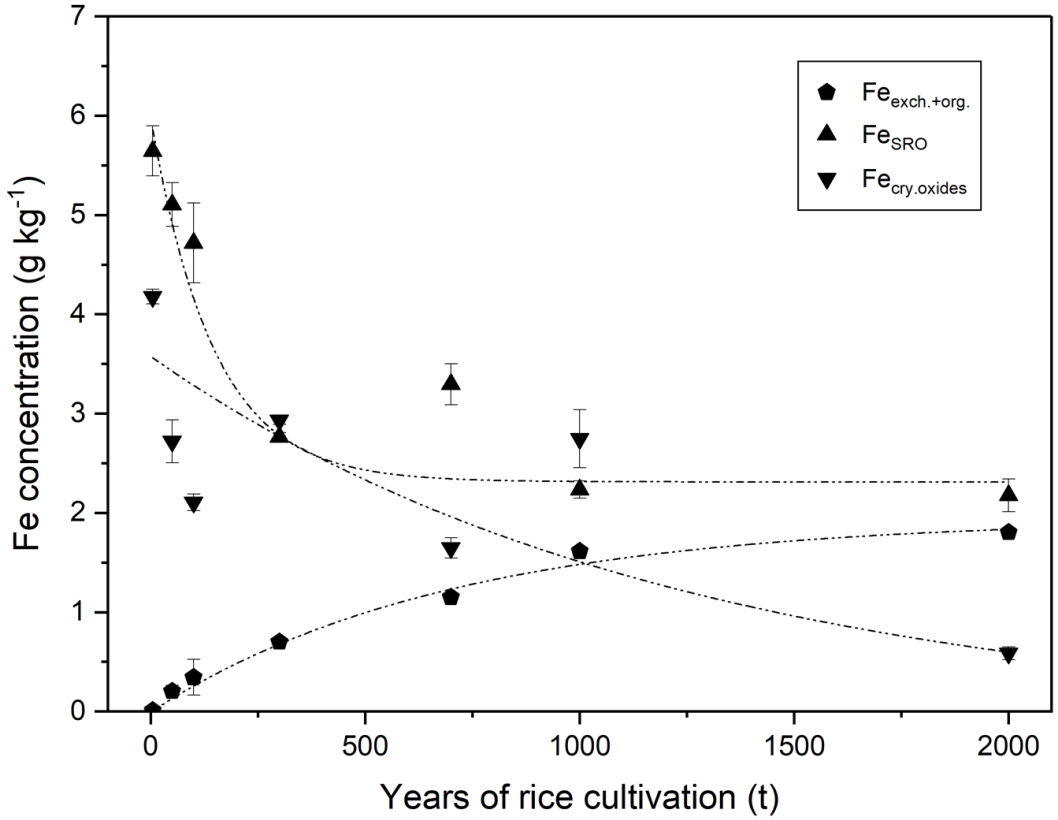


- Decrease of Fe concentration
- Depletion of light Fe isotopes

Fig. Iron concentration and isotope composition of the topsoil of the paddy chronosequence and that of non-paddy soil at the study site.
Bulk: bulk paddy topsoil of 5-, 50-, 100-, 300-, 700-, 1000-, and 2000-year-old;
NP: bulk upland topsoil of 700-year-old;
P0: parent material (tidal wetland soil)

Wu et al., Plant Soil, 2024, 495, 615–629

Iron Isotopes for Reconstructing the Development of Paddy Chronosequence

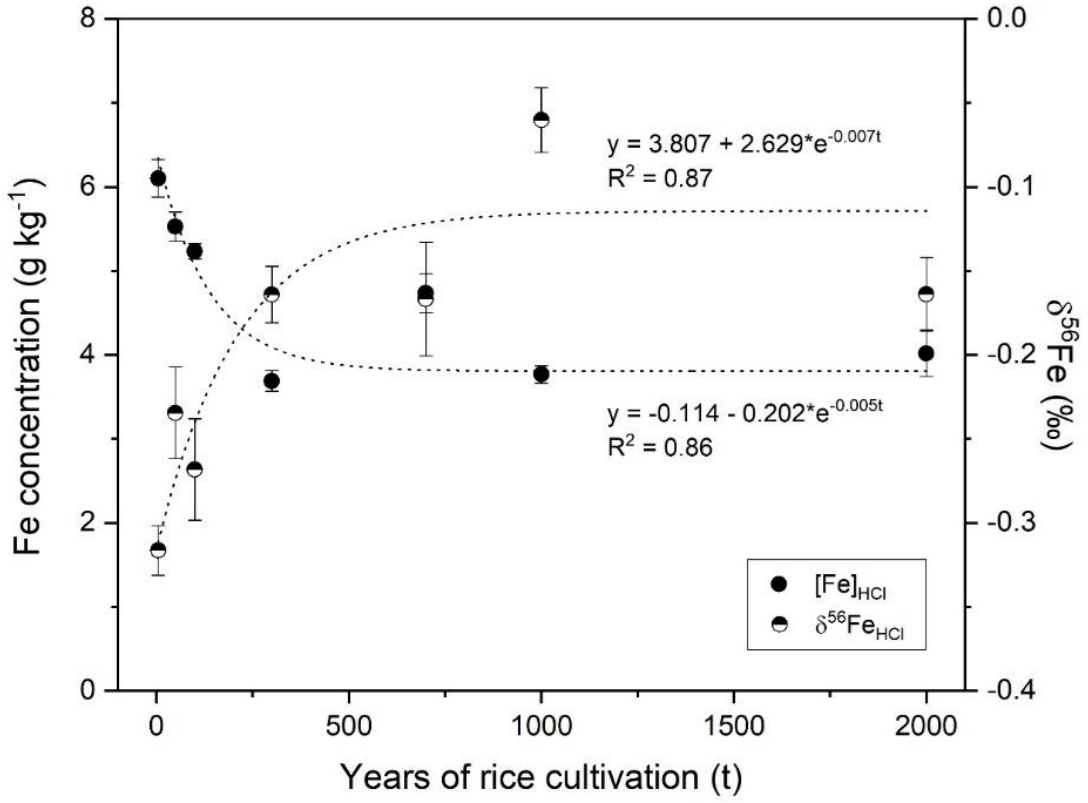


- Loss of Fe oxides with all crystallinities
- Increase of organically associated Fe

Fig. Iron concentration of exchangeable and organically sorbed or bound ($Fe_{exch.+org.}$), short-range-ordered Fe minerals (Fe_{SRO}), crystalline Fe oxides ($Fe_{cry.oxides}$), which were extracted sequentially.

Wu et al., Plant Soil, 2024, 495, 615–629

Iron Isotopes for Reconstructing the Development of Paddy Chronosequence



- Decline in plant-available Fe shortly after paddy establishment accompanied with a depletion of isotopically light Fe
- Steady state reached through replenishment by the accumulation of the organically associated Fe and the neo-formation of the short-range-ordered Fe oxides

Fig. 5. Iron concentration and isotope composition of HCl-extractable Fe (Fe_{HCl}, plant-available) in the paddy chronosequence.

Wu et al., Plant Soil, 2024, 495, 615–629

Radiogenic Strontium Isotope for Tracing Nutrient Source after Sustainable Subsoil Management

Subsoil:

- Significant nutrient reservoir

  ⇒ additional nutrient resources ⇒ possible **reduction in fertilizer use**

- Important water resources.

  ⇒ "insurance system" for plants ⇒ **enhanced crop security**

Schmittmann et al., Agronomy, 2021, 11, 1970.

Deep loosening with biocompost incorporation

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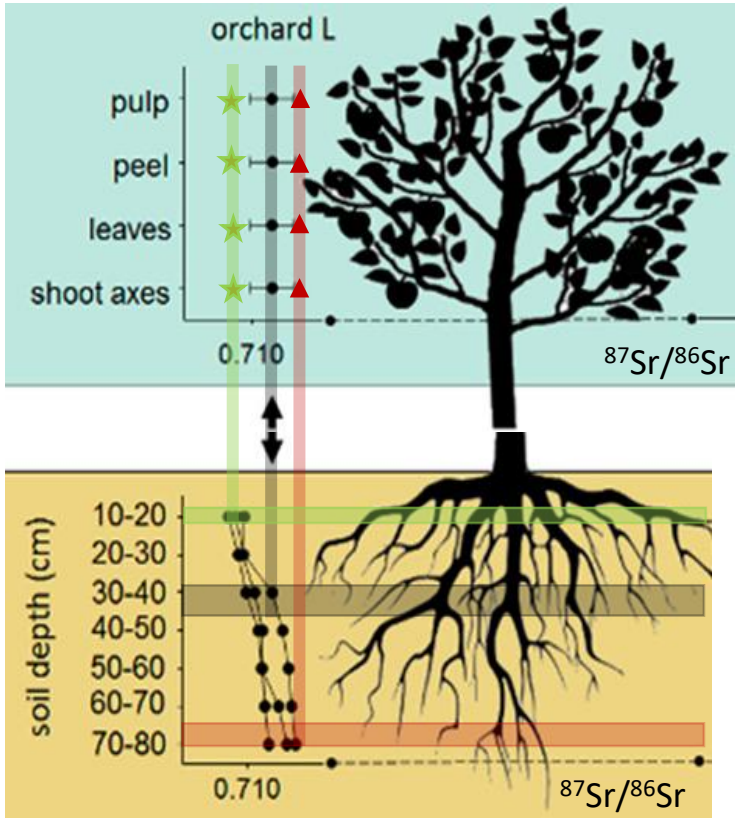
Radiogenic Strontium Isotope for Tracing Nutrient Source after Sustainable Subsoil Management



R_{plant}: radiogenic $^{87}Sr/^{86}Sr$ ratio of the plants

$R_{plant} = R_1*f_1 + R_2*f_2 + R_3*f_3 + R_4*f_4 + \ldots$

R_i: $^{87}Sr/^{86}Sr$ ratio of soil available pool in horizon i

f_i: proportion of uptake from horizon i

Mean uptake depth

≠ where the plants take up nutrients exactly
≠ where they take up the most

▲ Mean uptake depth deeper

★ Mean uptake depth shallower

Modified from Aguzzoni et al., J. Agric. Food Chem. 2019, 67, 5728–5735.

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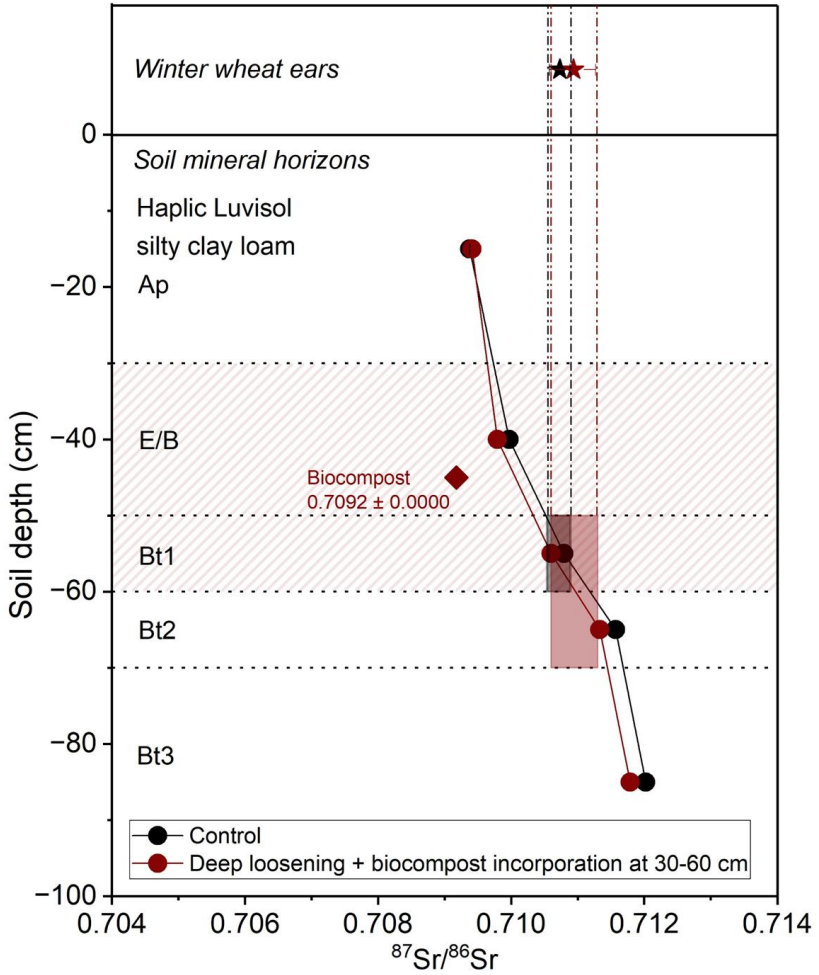


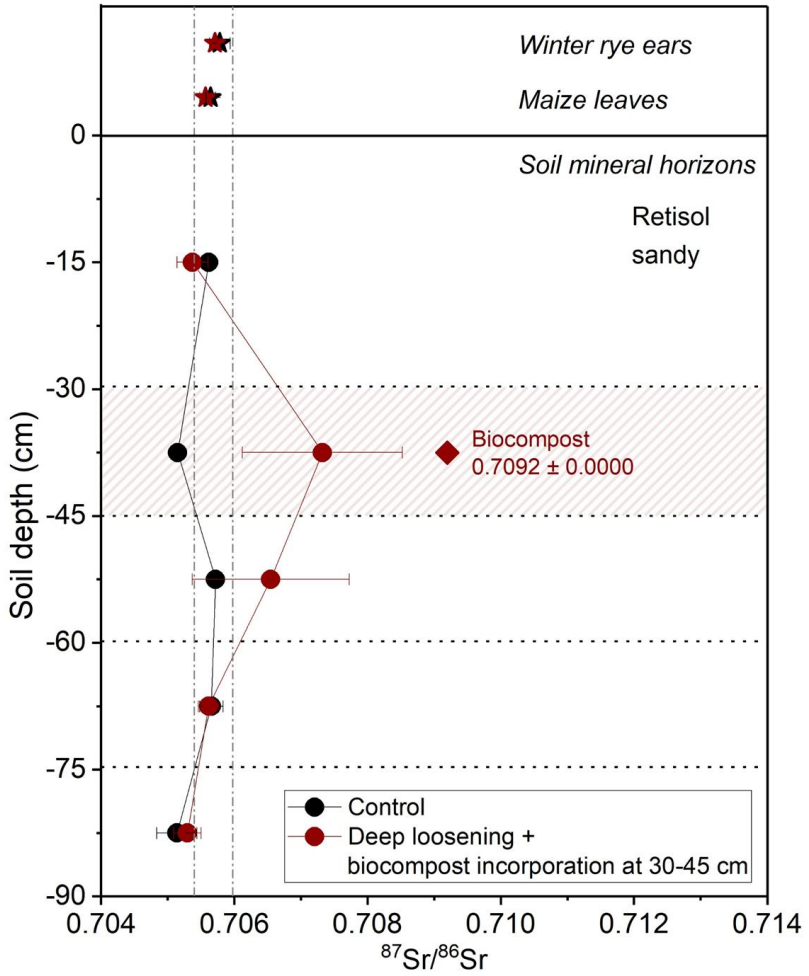
Uhlig et al., Plant Soil, 2023, 489, 613–628.

- Progressively more radiogenic $^{87}Sr/^{86}Sr$ ratios in soil profile
- Less radiogenic $^{87}Sr/^{86}Sr$ ratio of the biocompost incorporated soil
- More radiogenic $^{87}Sr/^{86}Sr$ ratio of the crops
- Deepened mean uptake depth in deep loosening with biocompost incorporation

⇒ Plants accessed the additional nutrient pool of the incorporated biocompost

Fig. Radiogenic $^{87}Sr/^{86}Sr$ ratio of winter wheat and the exchangeable fraction of Luvisol soil profiles with and without subsoil management

Radiogenic Strontium Isotope for Tracing Nutrient Source after Sustainable Subsoil Management



Liu et al., unpublished data

- Unvaried radiogenic $^{87}Sr/^{86}Sr$ ratios in soil profile
- Impossible to identify mean uptake depth by matching $^{87}Sr/^{86}Sr$ ratio
- Radiogenic $^{87}Sr/^{86}Sr$ ratio of the biocompost clearly visible
- Unvaried radiogenic $^{87}Sr/^{86}Sr$ ratios in crop

⇒ Nutrient uptake remained in the top horizon

Fig. Radiogenic $^{87}Sr/^{86}Sr$ ratio of winter rye, maize, and the exchangeable fraction of Retisol soil profiles with and without subsoil management

TAKE-HOME MESSAGE

- Isotope signature as a result of long-term agricultural land-use can be used to understand the development of the systems.
- Geological tracers can be useful in soil sciences.

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THANK YOU!

QUESTION AND SUGGESTION?