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Effect of iron oxides on CO_2 emission under conditions of low and high microbial biomass in anoxic paddy soil

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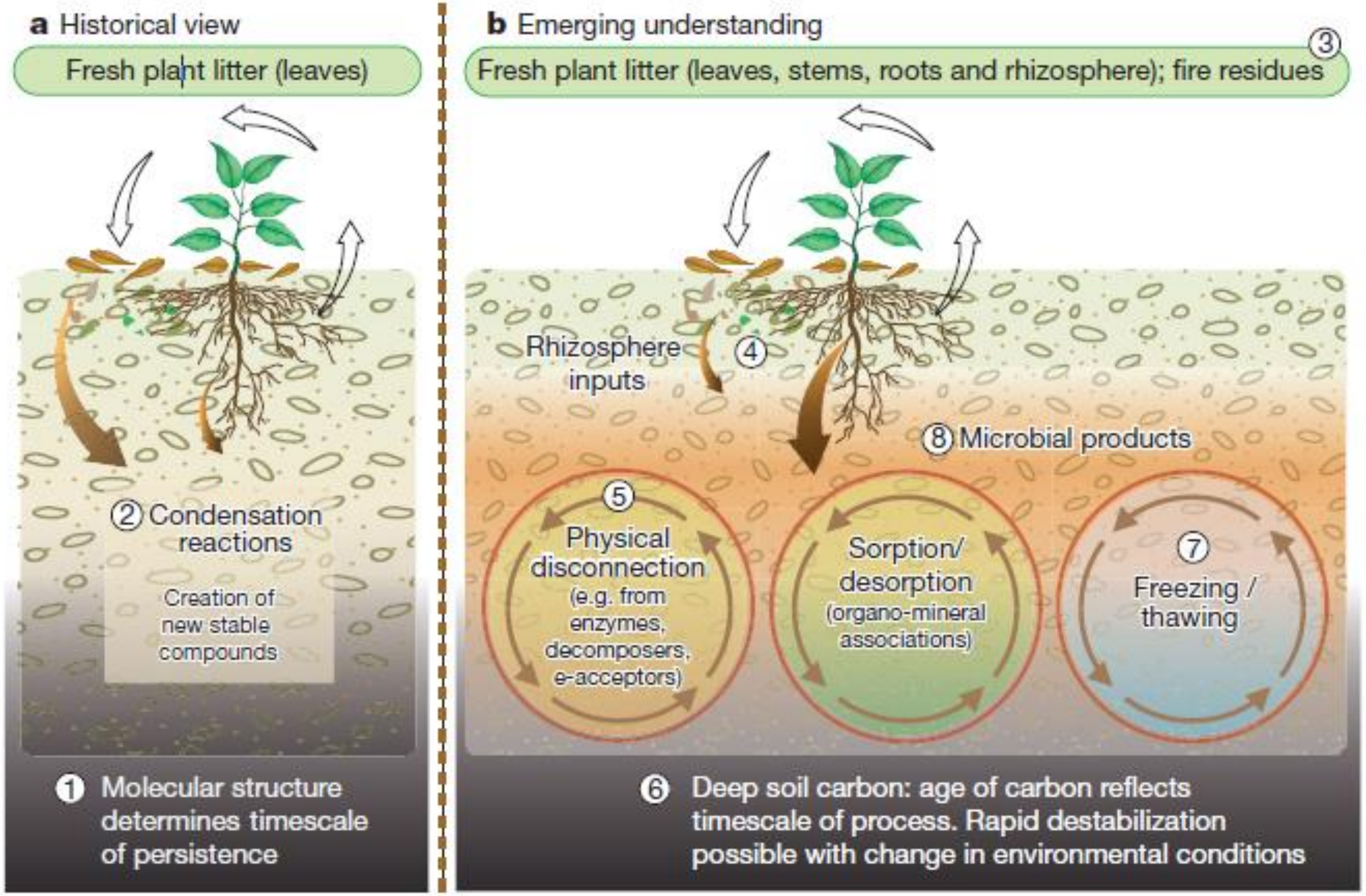
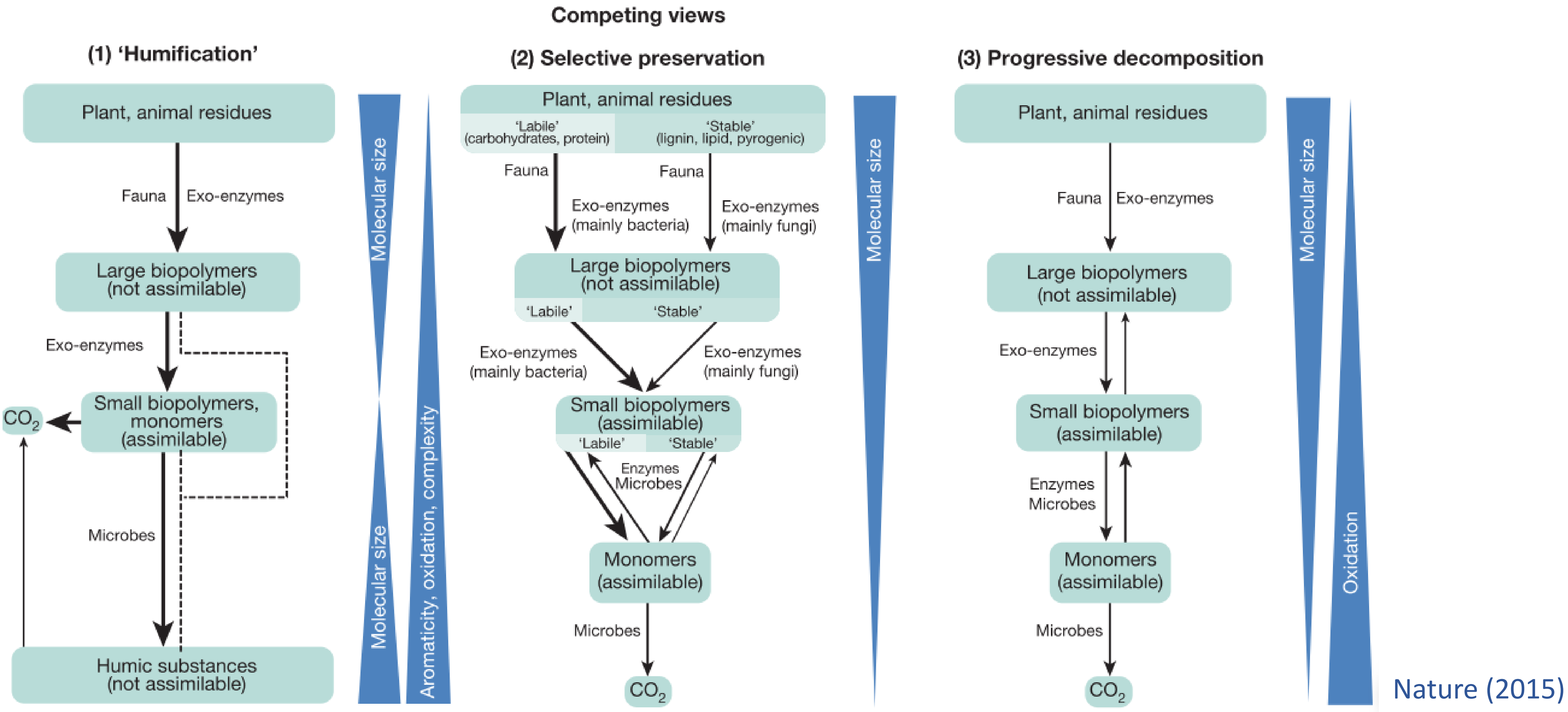
Soil organic carbon



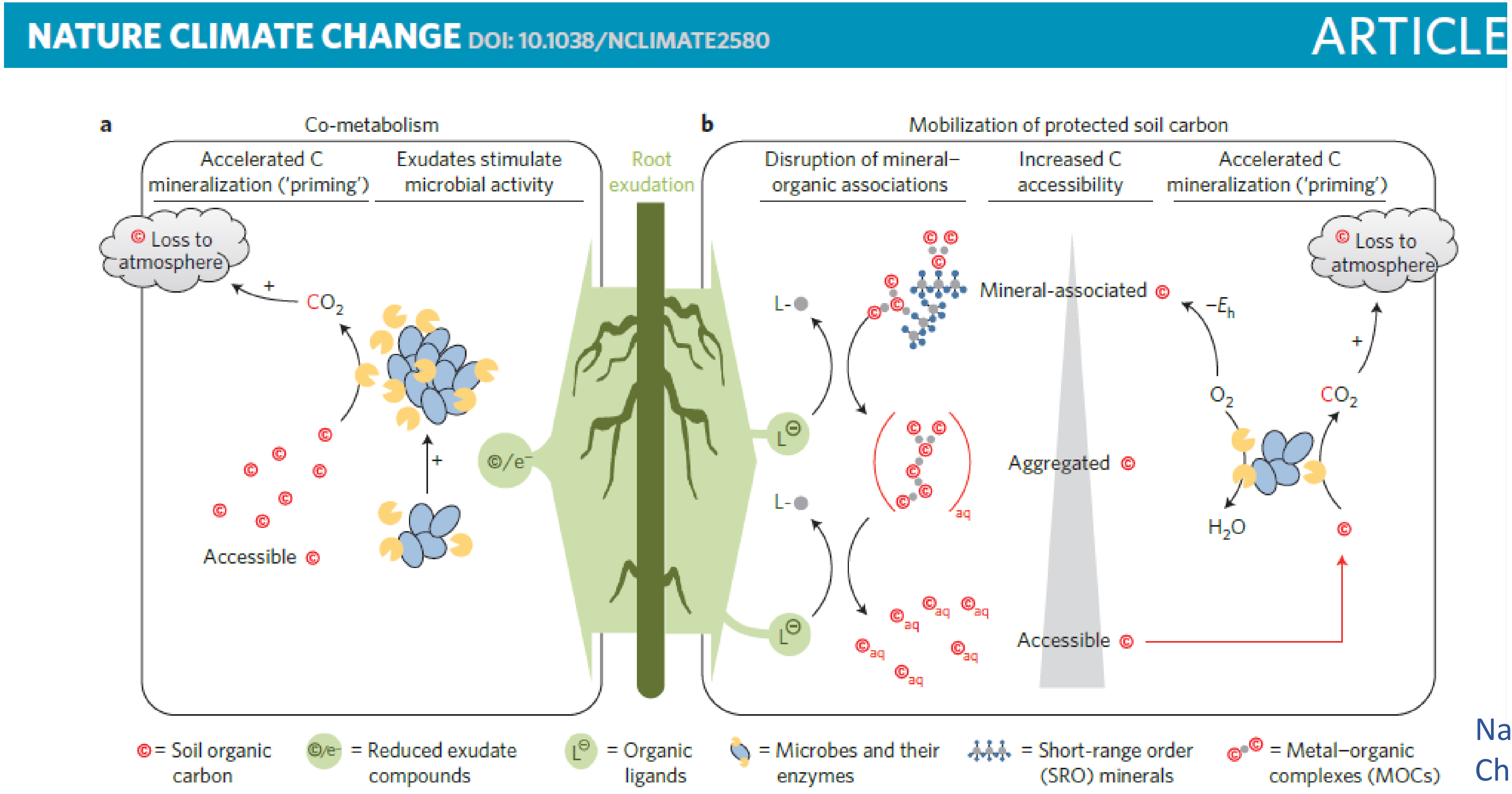
Nature (2011)

Soil organic carbon



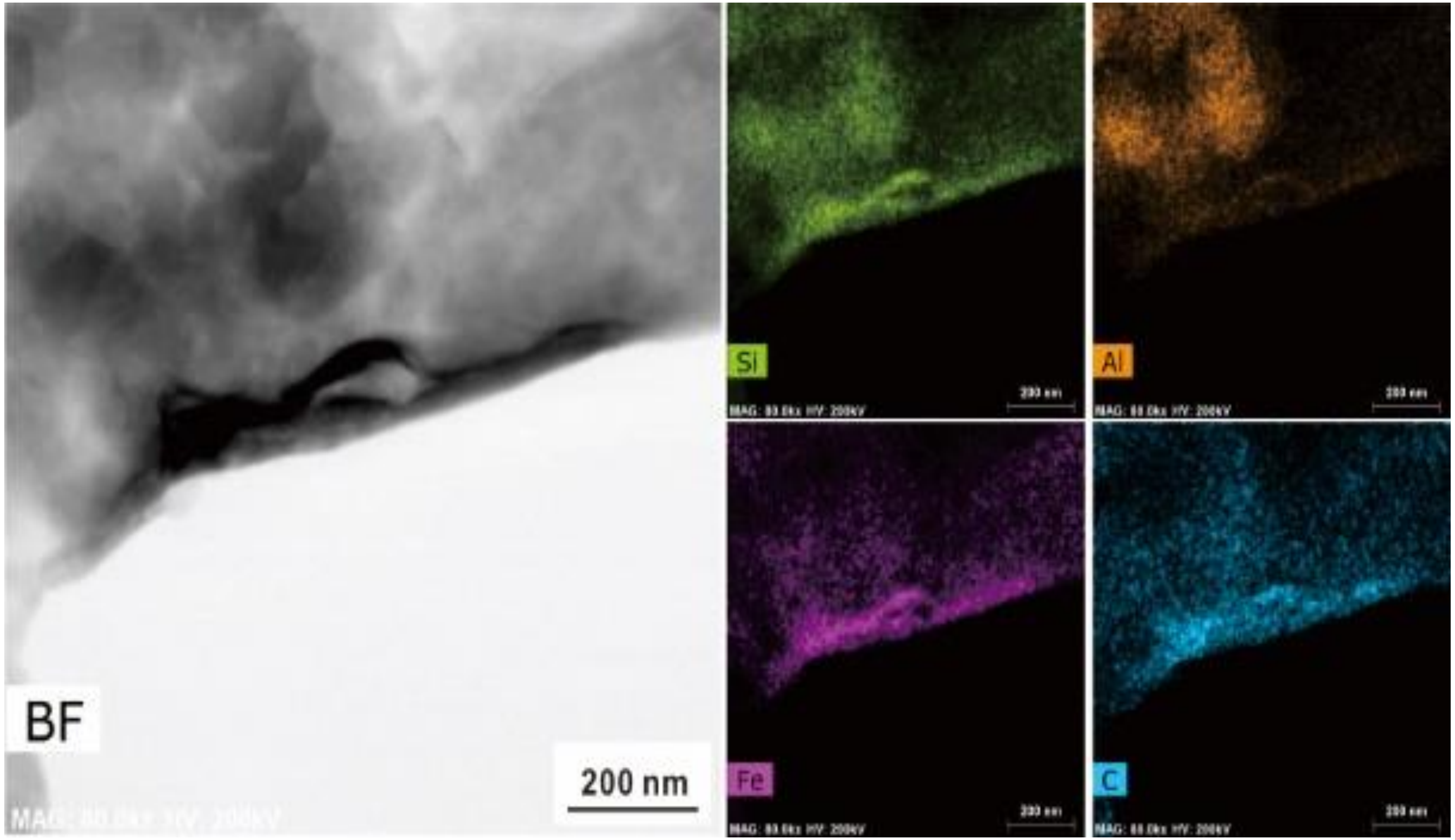
Nature (2015)

Soil organic carbon


NATURE CLIMATE CHANGE DOI: 10.1038/NCLIMATE2580 ARTICLE

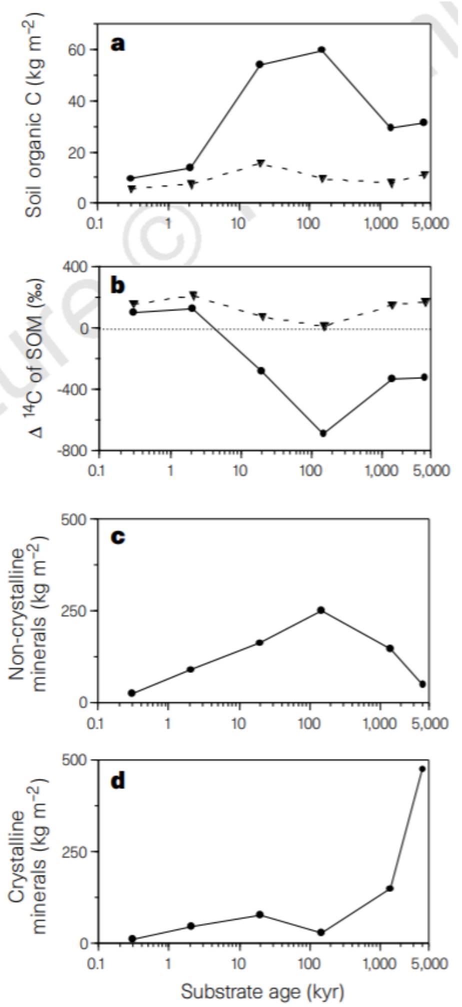
Nature Climate Change (2016)

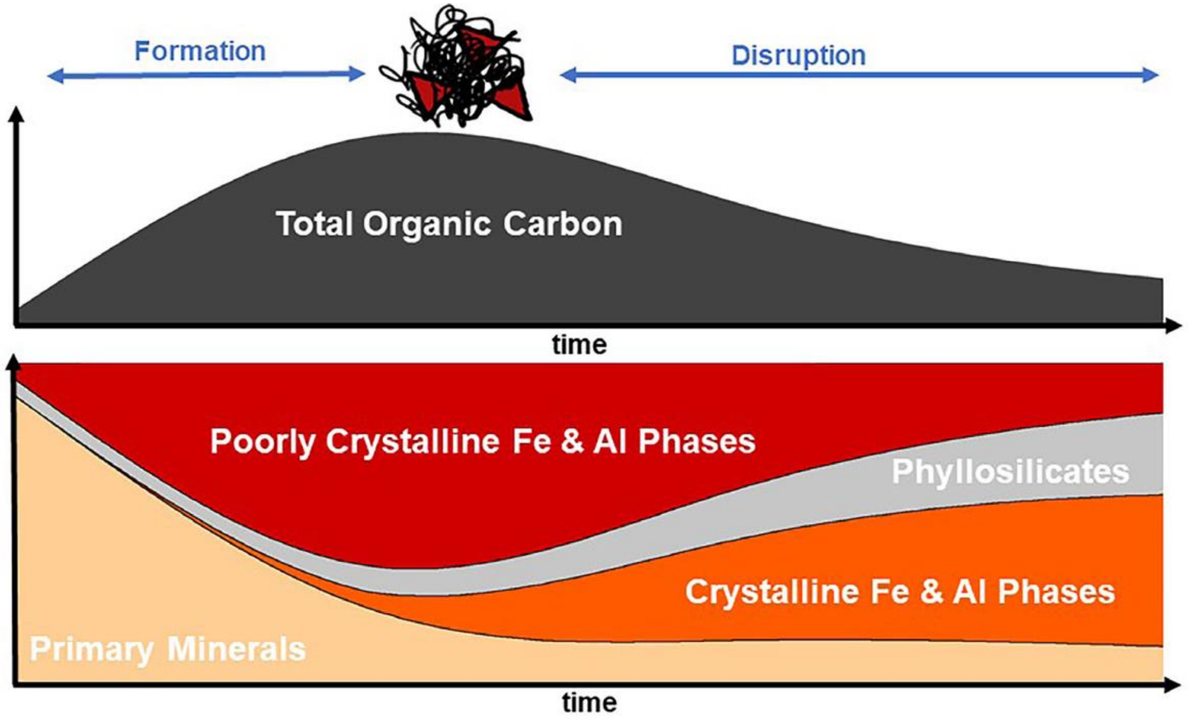
Role of iron in SOC protection



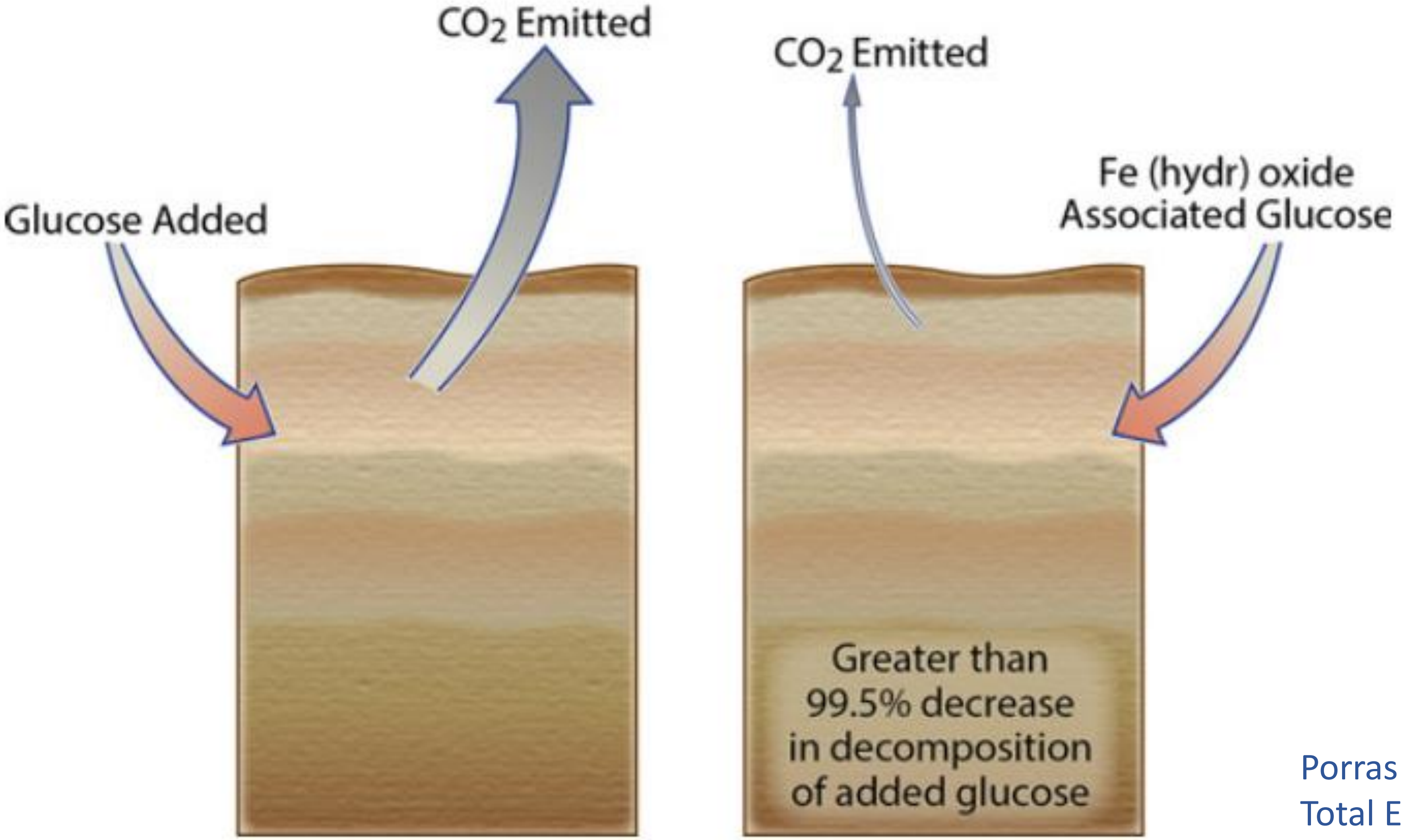
Distribution of photosynthesized assimilated carbon in soil with distribution of Fe (HRTEM-EDS analysis)

Relationship between SOC stock and turnover with crystallinity of Fe oxides





Torn et al., Nature, 1997; Arredondo et al., GCA, 2019

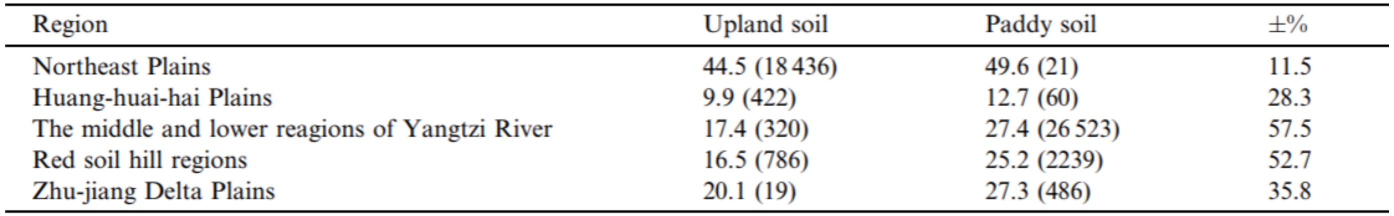


Porras et al., Science of Total Environment, 2018

Upland

Paddy

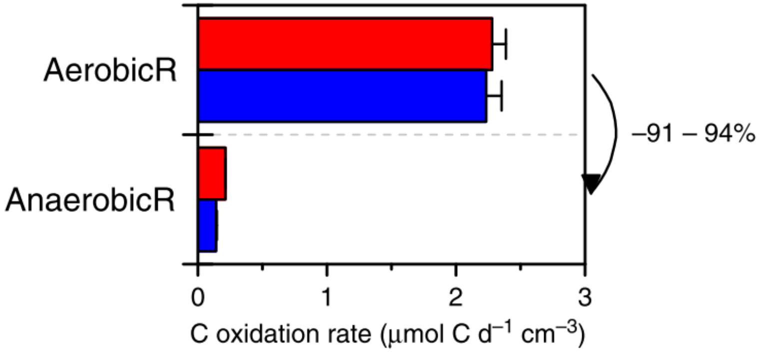
Soil organic matter content（g kg^{-1}） in China



Region	Upland soil	Paddy soil	±%
Northeast Plains	44.5 (18 436)	49.6 (21)	11.5
Huang-huai-hai Plains	9.9 (422)	12.7 (60)	28.3
The middle and lower reagions of Yangtzi River	17.4 (320)	27.4 (26 523)	57.5
Red soil hill regions	16.5 (786)	25.2 (2239)	52.7
Zhu-jiang Delta Plains	20.1 (19)	27.3 (486)	35.8

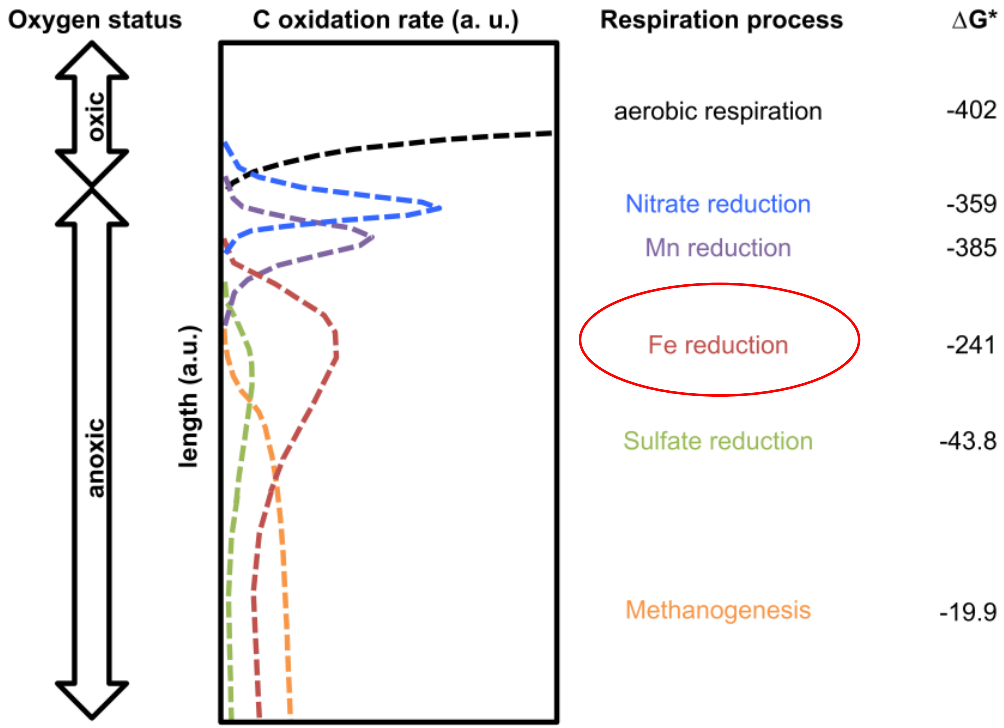
Yan et al. (2011)

- C stock of paddy soil is higher than upland by 12–58%
- Oxidation rate of organic C under aerobic is much faster than anaerobic condition

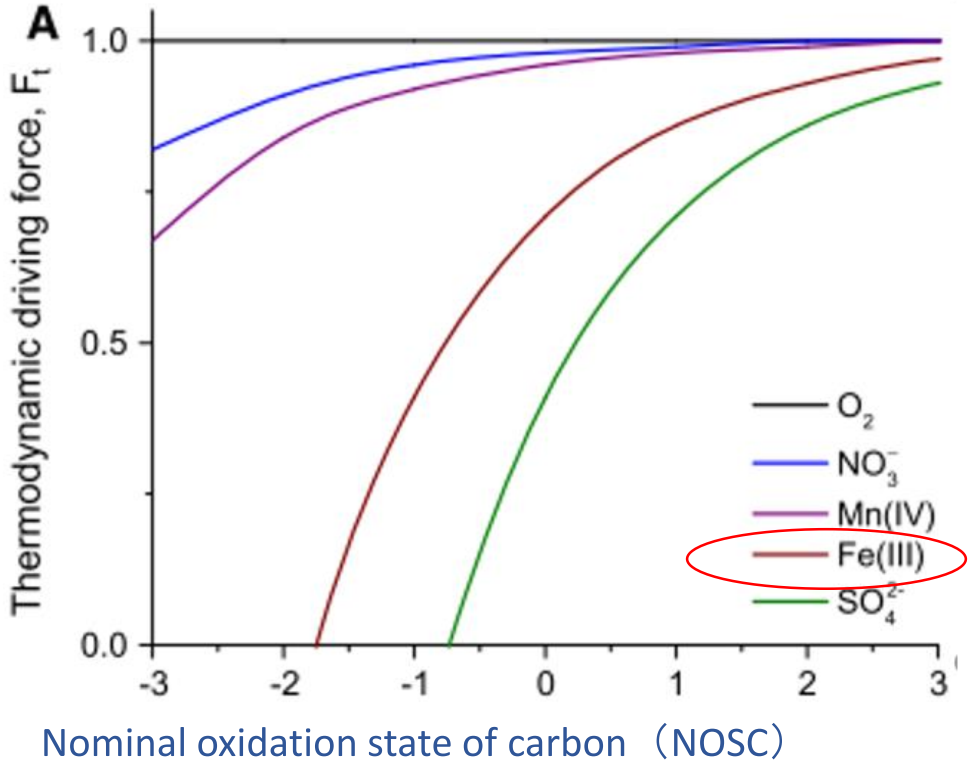


Keiluweit et al., 2017

Role of iron in organic carbon decomposition

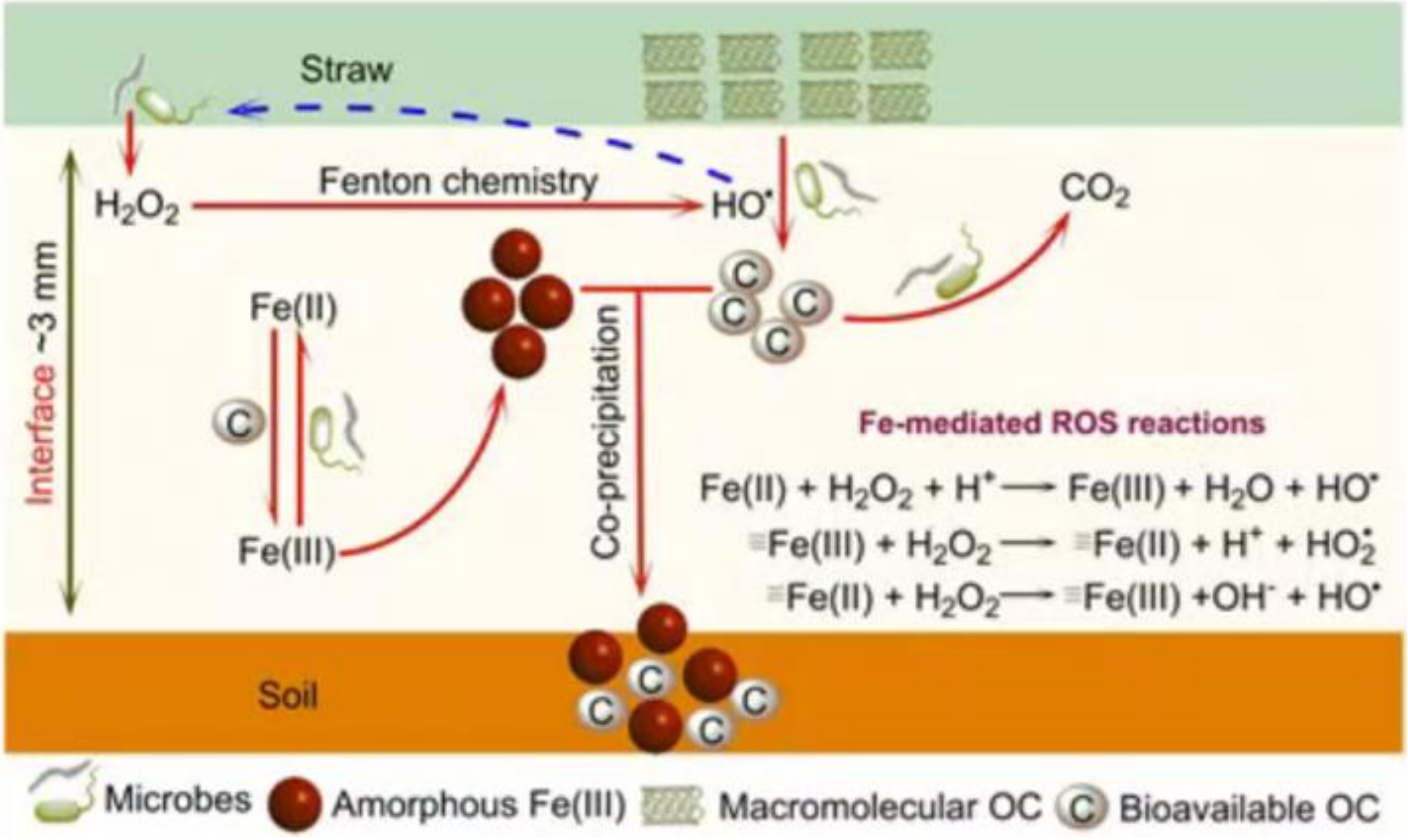


*Standard Gibbs free energy with acetate as an electron donor (kJ per reaction, ΔG)



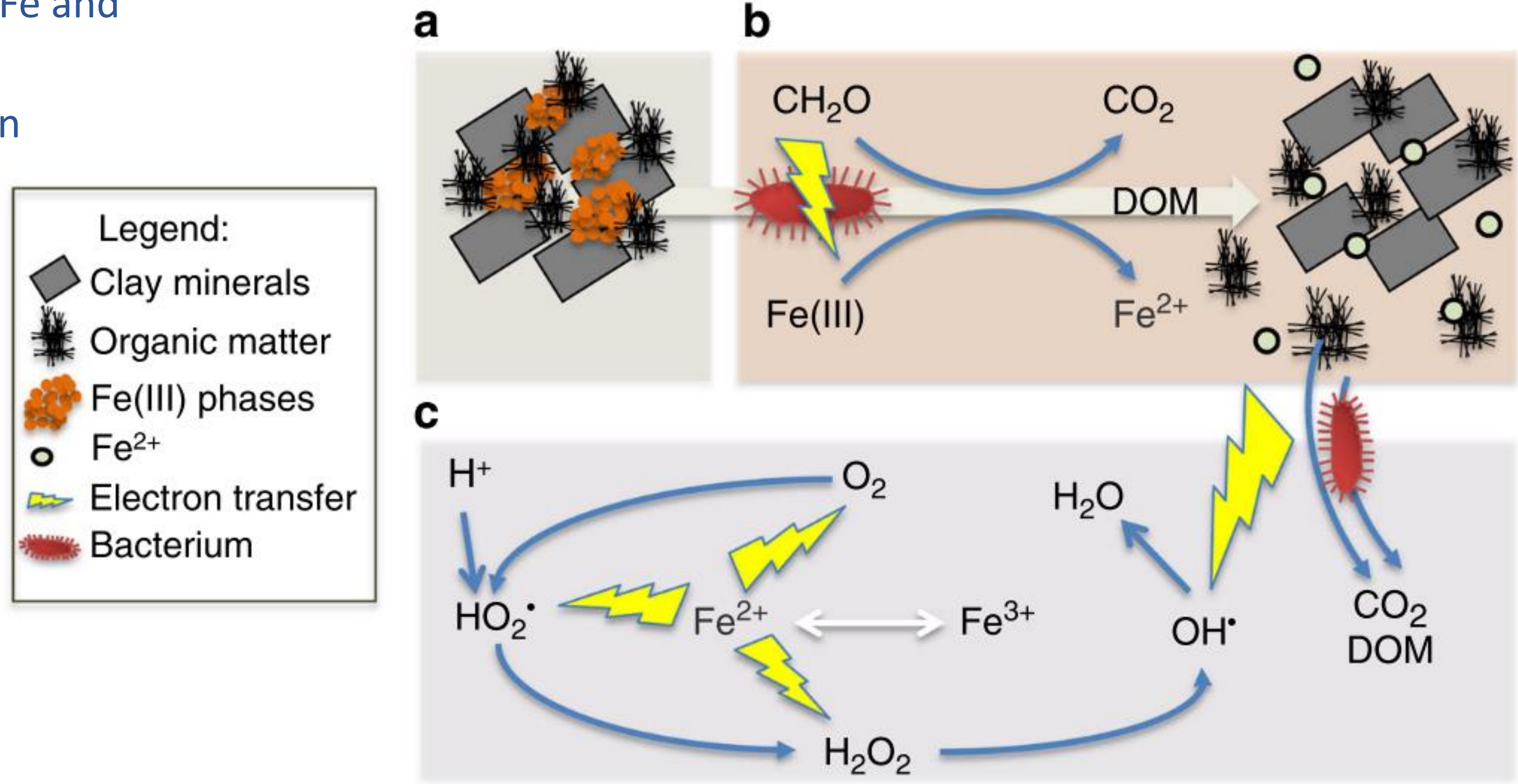
Keiluweit et al., 2016

Ferrous oxidation produces hydroxyl radical which can decompose soil organic carbon

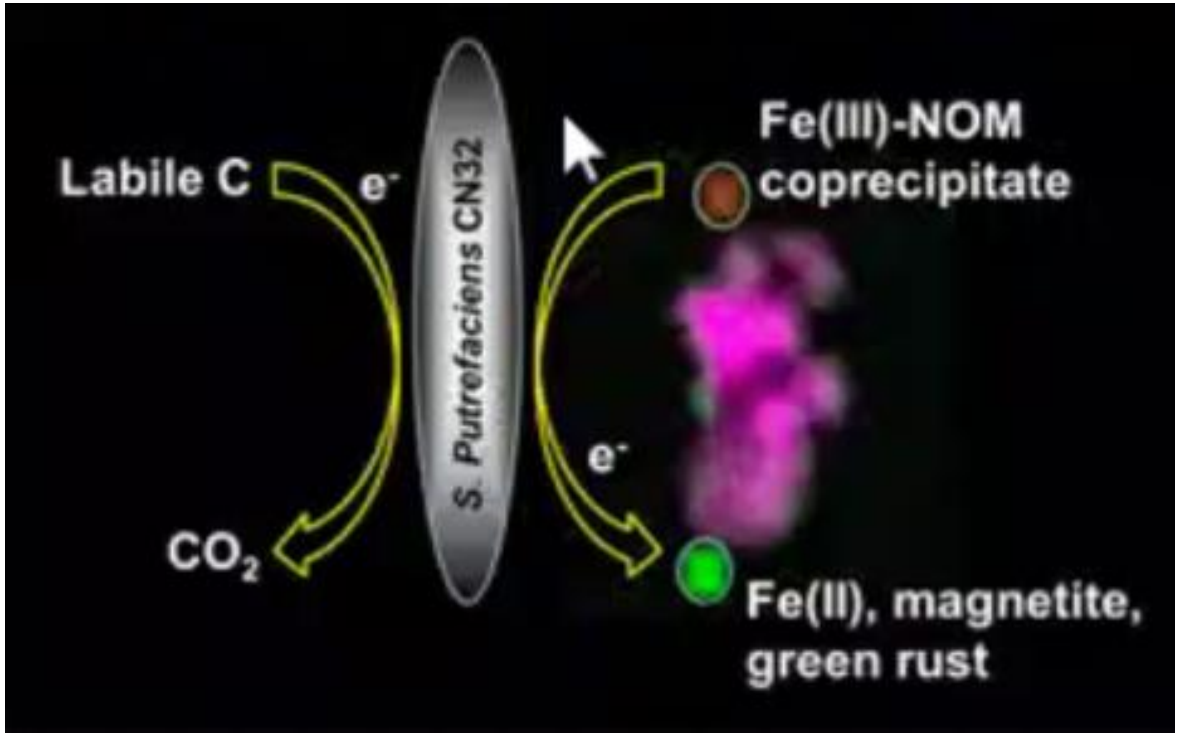


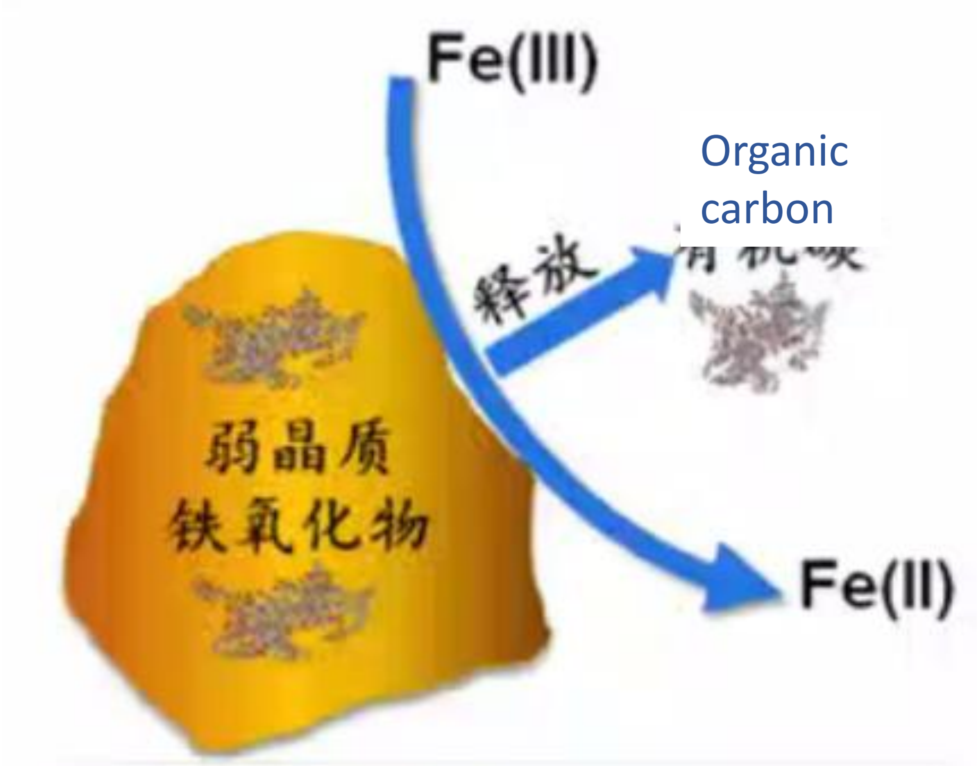
Role of iron oxides
Carbon sequestration vs organic carbon mineralization

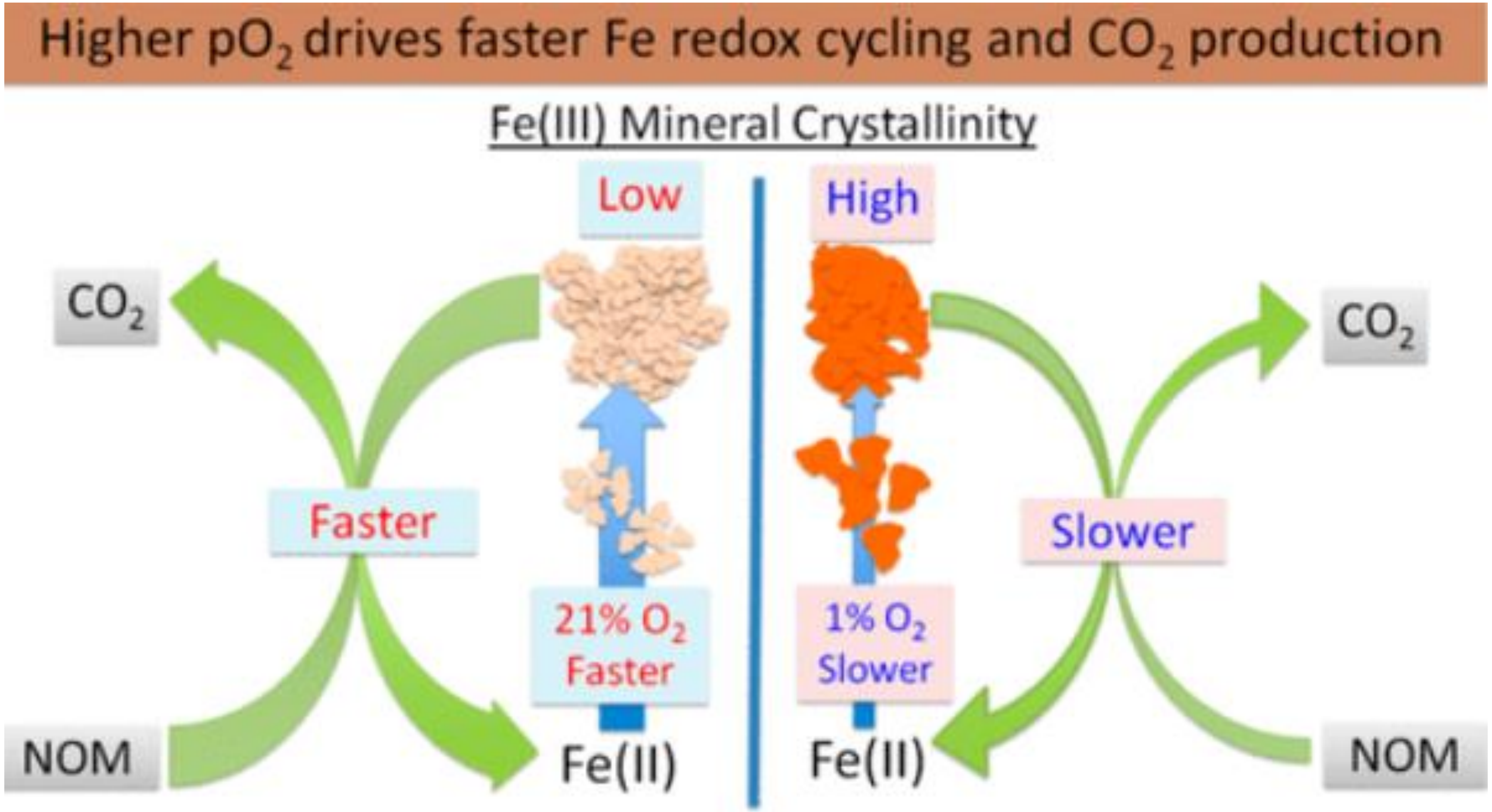
- Association of Fe and organic carbon
- Fenton reaction
- Iron reduction coupled with organic carbon oxidation



Under anoxic condition, Iron reduction release organic carbon that associated with iron oxides

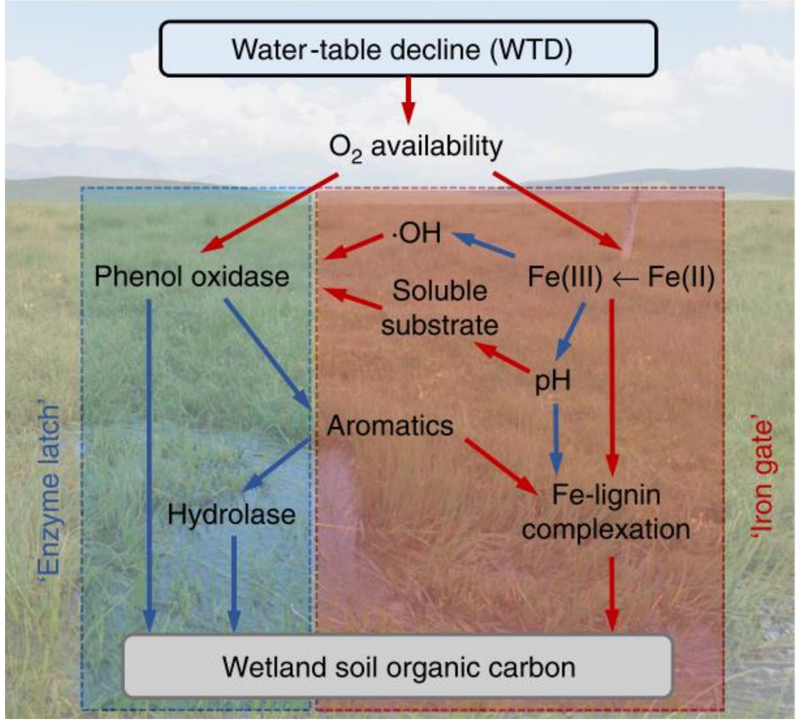




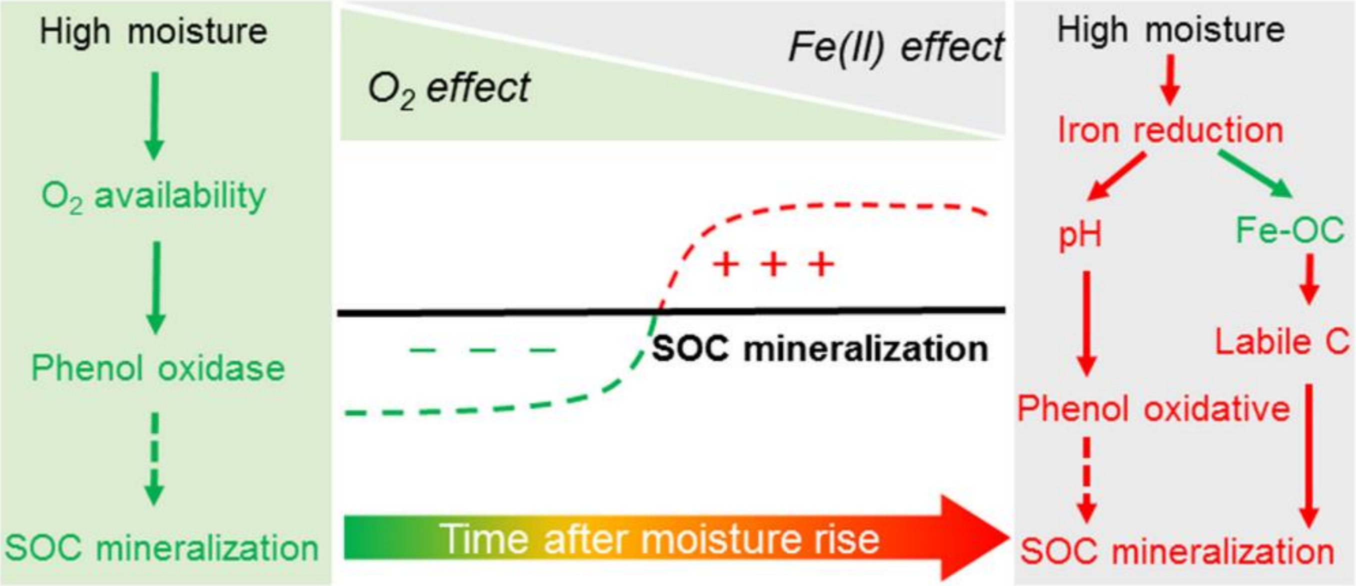


Higher pO_2 drives faster Fe redox cycling and CO_2 production

Enzyme latch vs Iron gate



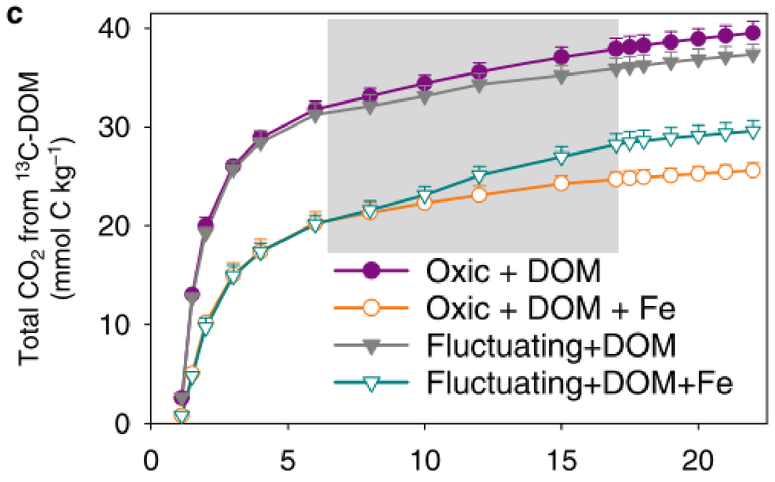
Wang et al. (2017)



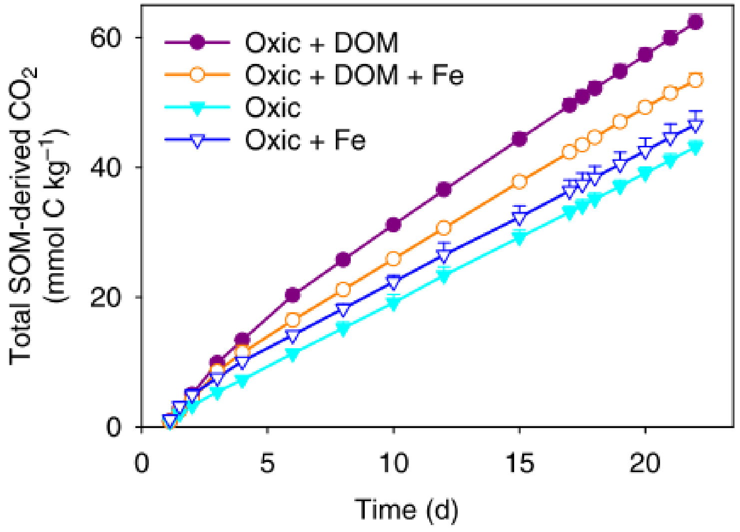
Wen et al. (2019)

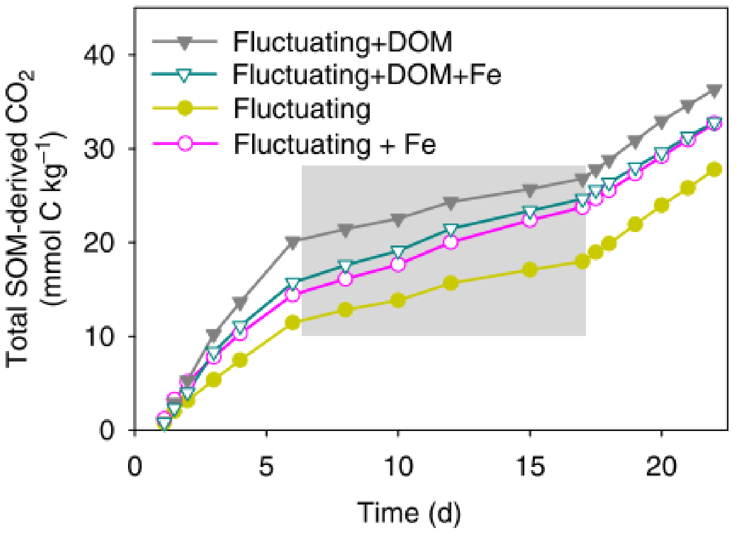
- Vegetation
- Soil mineral
- Water table and duration

Input labile C under oxic and redox-fluctuating conditions

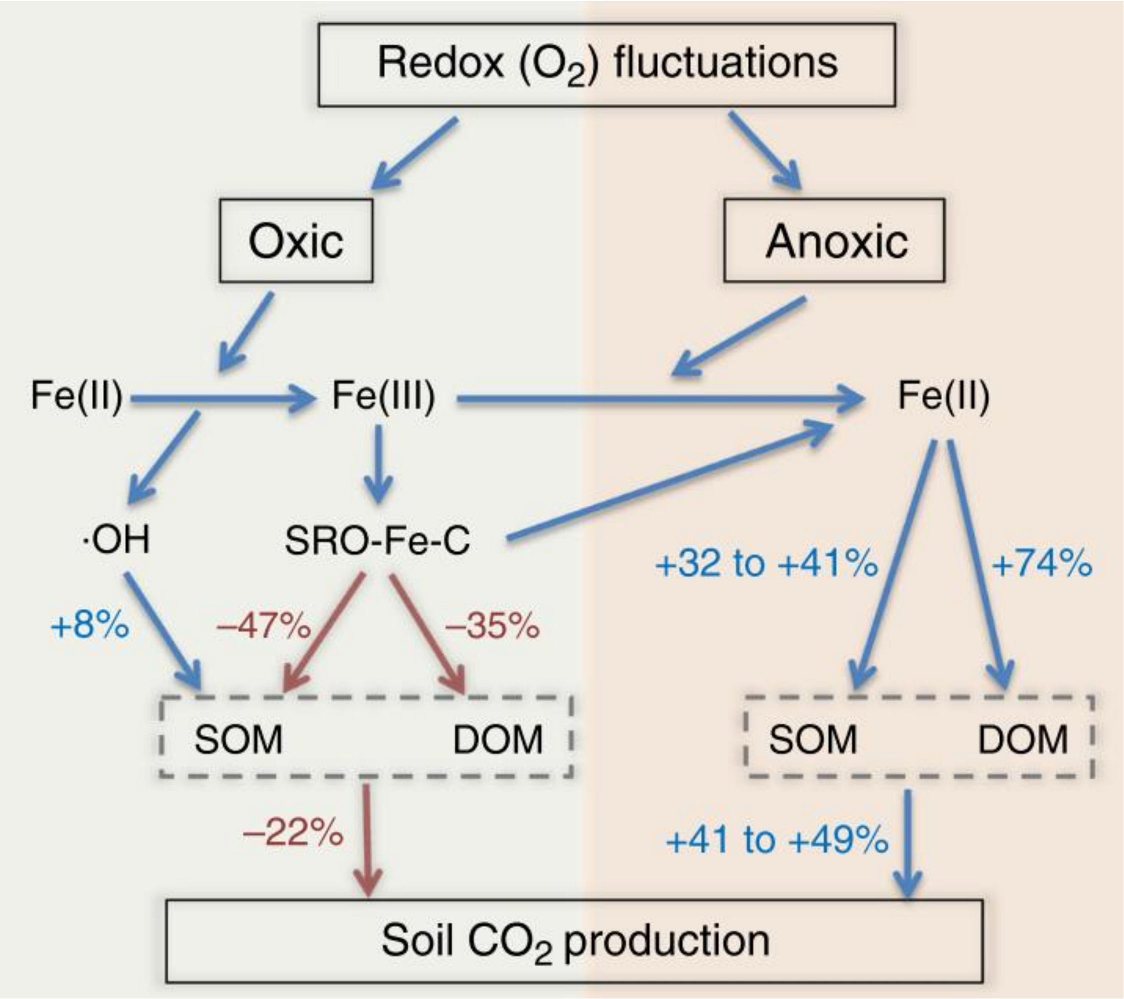


- Under oxic condition, C-Fe coprecipitates protect SOC and input C
- In soil with frequent alteration of oxic and anoxic conditions, Iron reduction increased mineralization of SOC and input C by 32–41% and 74%, respectively
- The mineralization of organic C induced by iron can counterbalance the protection of organic carbon by iron oxidation





Chen et al., Nature Communications, 2020


Redox (O_2) fluctuations

Oxic

Anoxic

Fe(II)

Fe(III)

Fe(II)

·OH

SRO-Fe-C

+8%

−47%

−35%

+32 to +41%

+74%

SOM

DOM

SOM

DOM

−22%

+41 to +49%

Soil CO_2 production

Chen et al., Nature Communications, 2020

ELSEVIER

FEMS Microbiology Ecology 31 (2000) 73–86

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Turnover of glucose and acetate coupled to reduction of nitrate, ferric iron and sulfate and to methanogenesis in anoxic rice field soil

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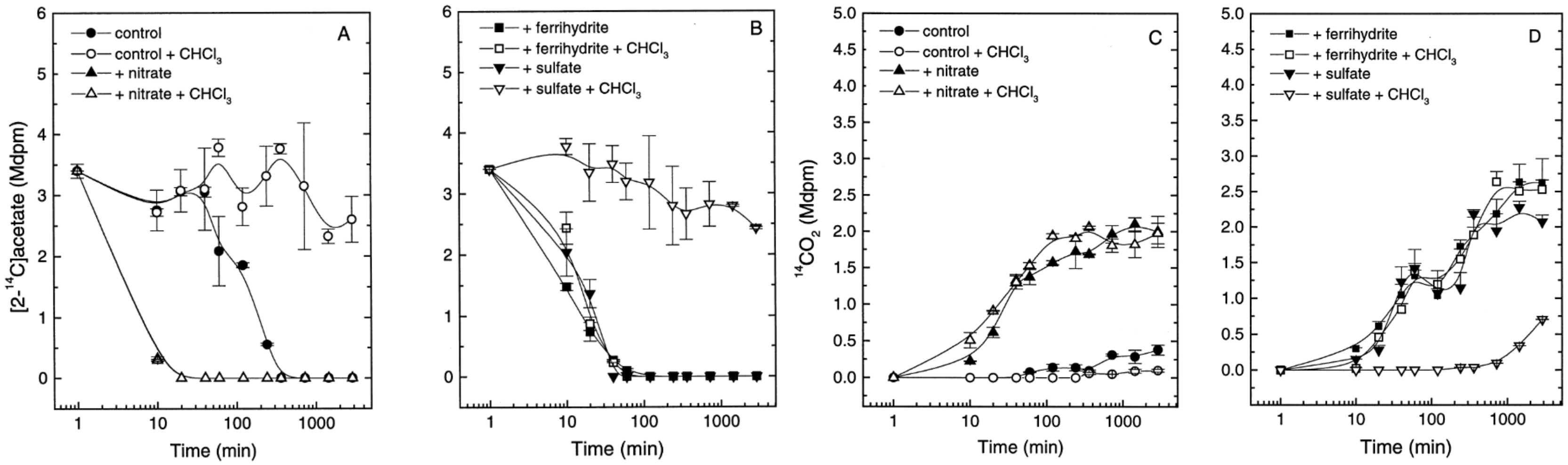


Hypotheses

- Iron oxides act as electron acceptors and increase the mineralisation of both acetate and SOC
- The reduction of microbial biomass due to fumigation may decrease the effects of iron oxides reduction and increase the effect of iron oxides adsorption on the mineralisation rates of acetate and SOC, but with effects differing by crystallinity of iron oxides

Materials and methods

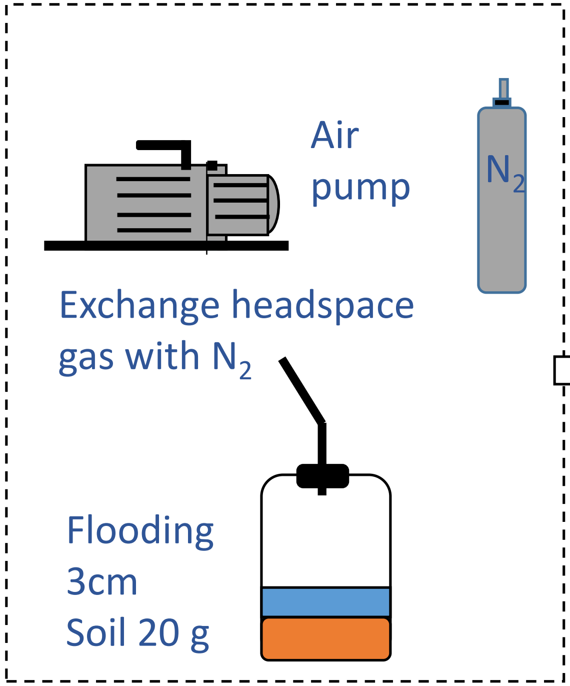
Treatments

- ^{13}C-acetate
- No acetate

- Goethite
- Ferrihydrite
- No iron oxides

- Chloroform Fumigation
- Unfumigation

Anoxic incubation


Air pump

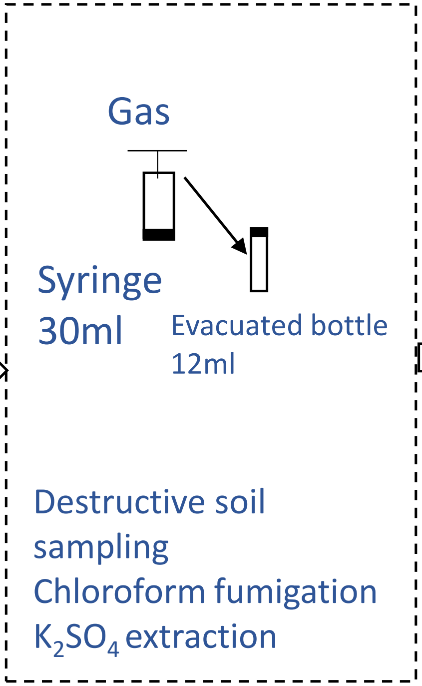
N_2

Exchange headspace gas with N_2

Flooding 3cm

Soil 20 g

Sampling


Gas

Syringe 30ml

Evacuated bottle 12ml

Destructive soil sampling

Chloroform fumigation

K_2SO_4 extraction

Analysis

CO_2

$^{13}CO_2$

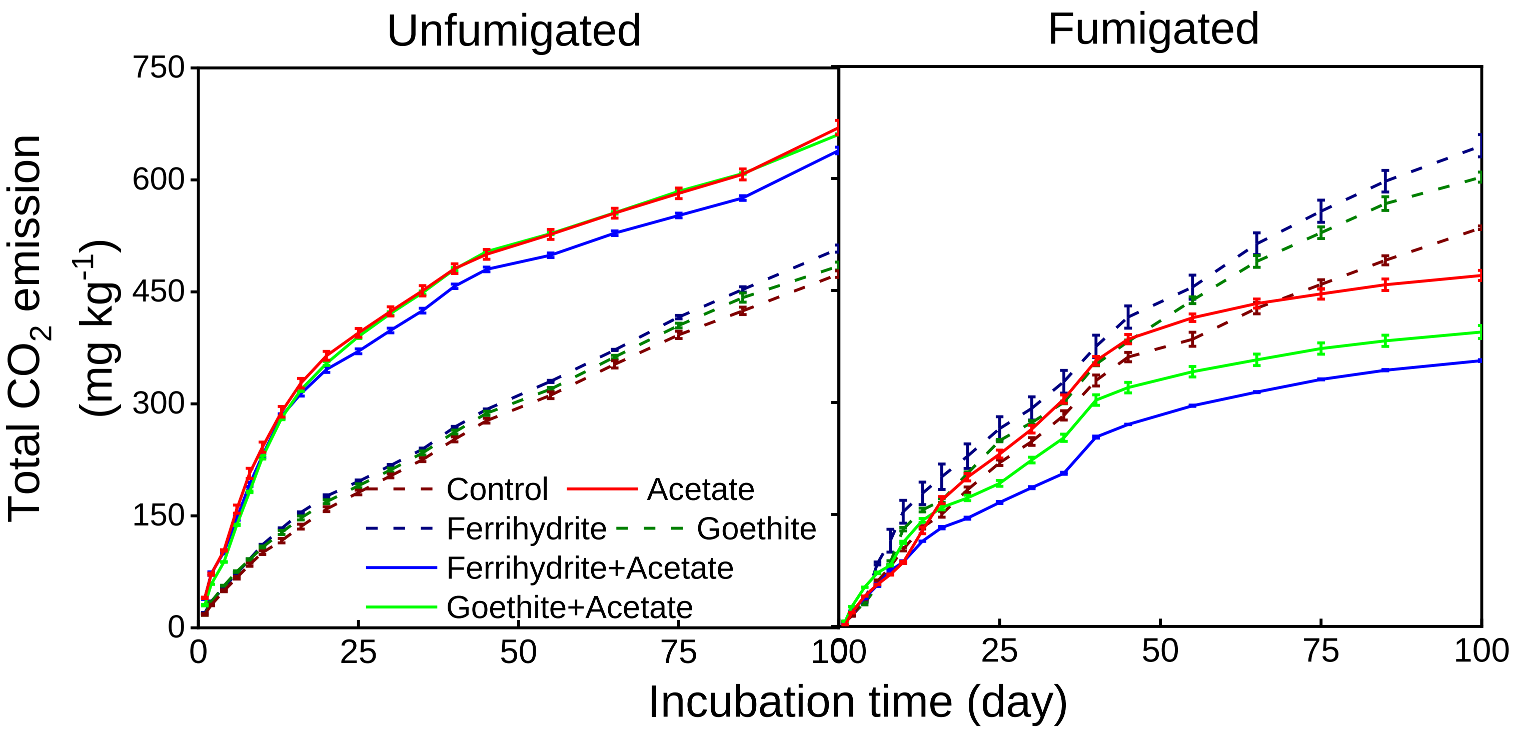
- DOC
- MBC
- $DO^{13}C$
- $MB^{13}C$


Gas Chromatograph


Isotope ratio mass spectrometer

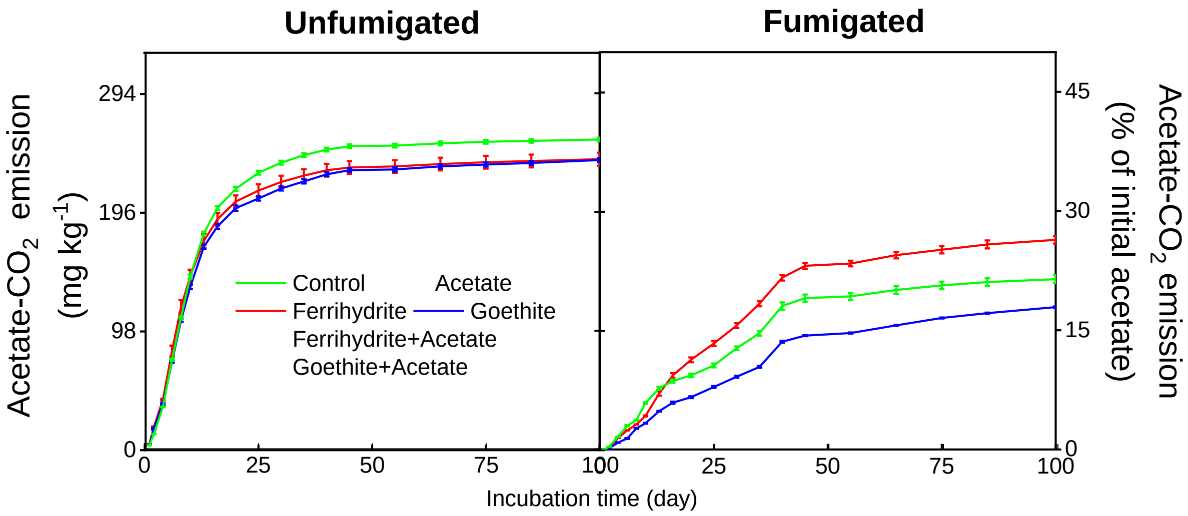
Results

Total CO_2 emission



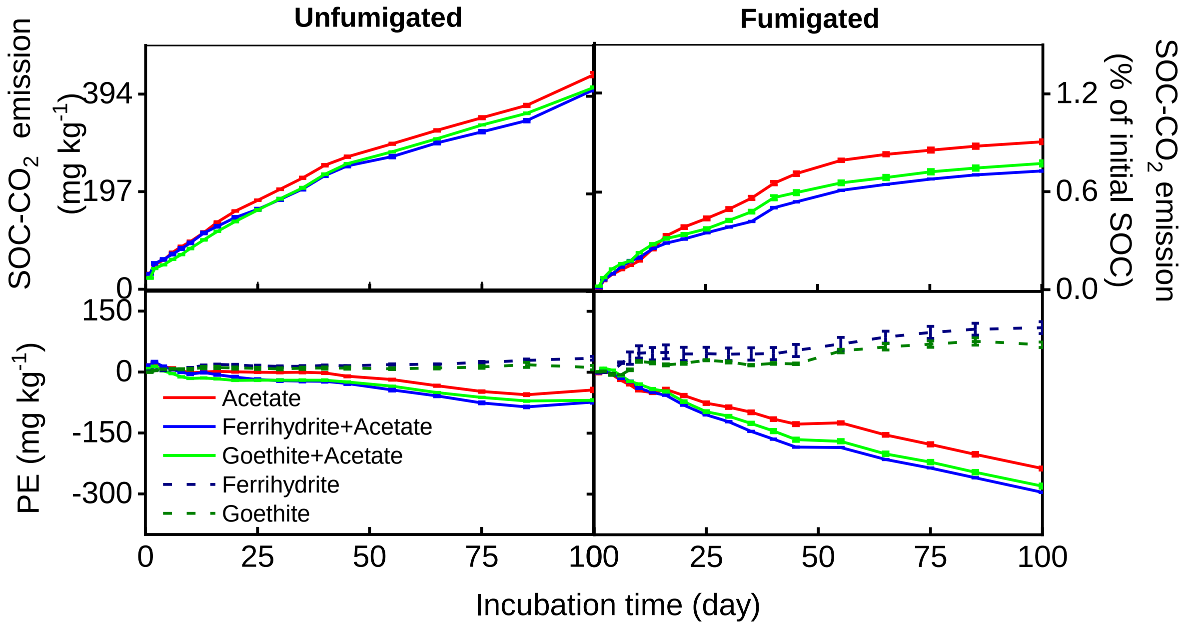
- The addition of ferrihydrite and goethite alone increased cumulative CO_2 emissions in the unfumigated soil
- In the unfumigated soil with acetate, goethite addition showed little influence on cumulative CO_2 emission. While ferrihydrite addition reduced the cumulative CO_2 emission

Acetate-CO_2 emission



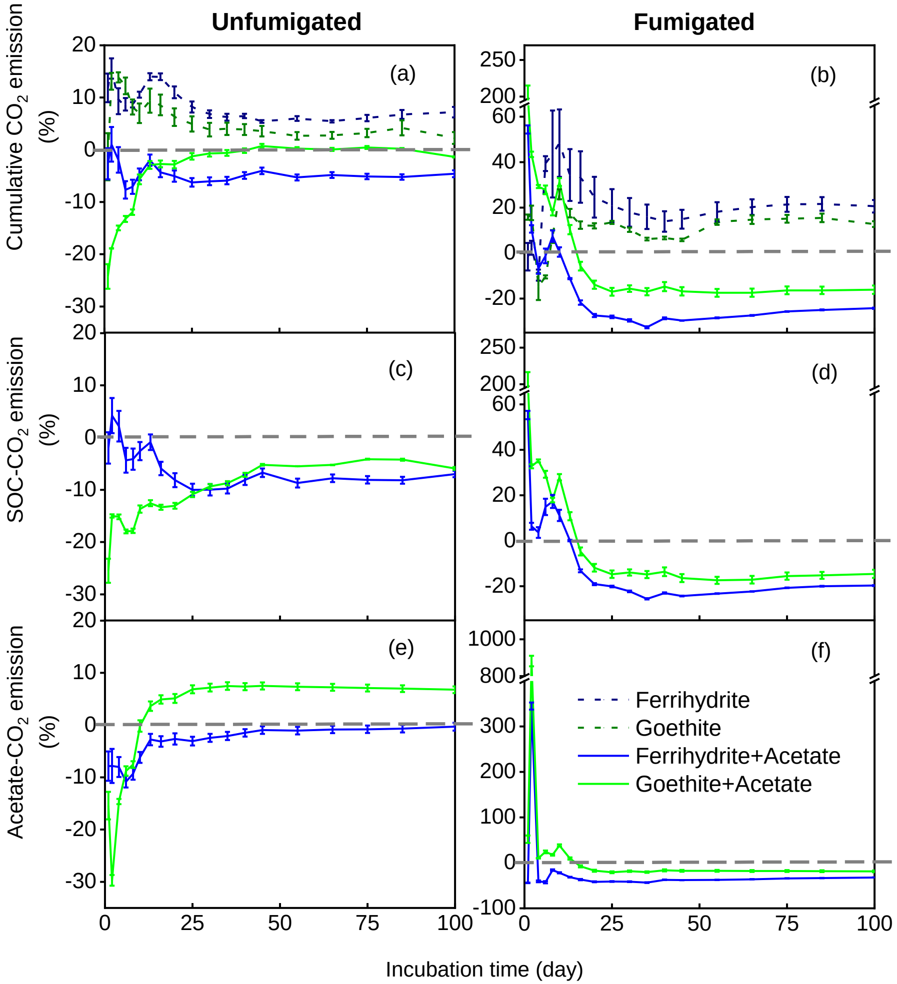
Soil	**Treatment**	**Acetate**	
		Labile C pool size (%)	MRT (day)
Unfumigated	Acetate	36.6 b	12 b
	Ferrihydrite + Acetate	36.4 b	13 a
	Goethite + Acetate	39.6 a	13 a
Fumigated	Acetate	30.5 a	41 b
	Ferrihydrite + Acetate	21.3 c	50 a
	Goethite + Acetate	23.8 b	36 c
Iron oxides		***	***
Fumigation		***	***
Iron oxides × Fumigation		***	***

SOC-CO_2 emission



Soil	Treatment	SOC	
		Labile C pool size (%)	MRT (day)
Unfumigated	Acetate	1.4 a	48 b
	Ferrihydrite + Acetate	1.3 b	47 b
	Goethite + Acetate	1.4 a	57 a
Fumigated	Acetate	1.0 a	44 a
	Ferrihydrite + Acetate	0.8 b	39 b
	Goethite + Acetate	0.8 b	36 c
Iron oxides		***	***
Fumigation		***	***
Iron oxides × Fumigation		***	***

Iron oxide effect



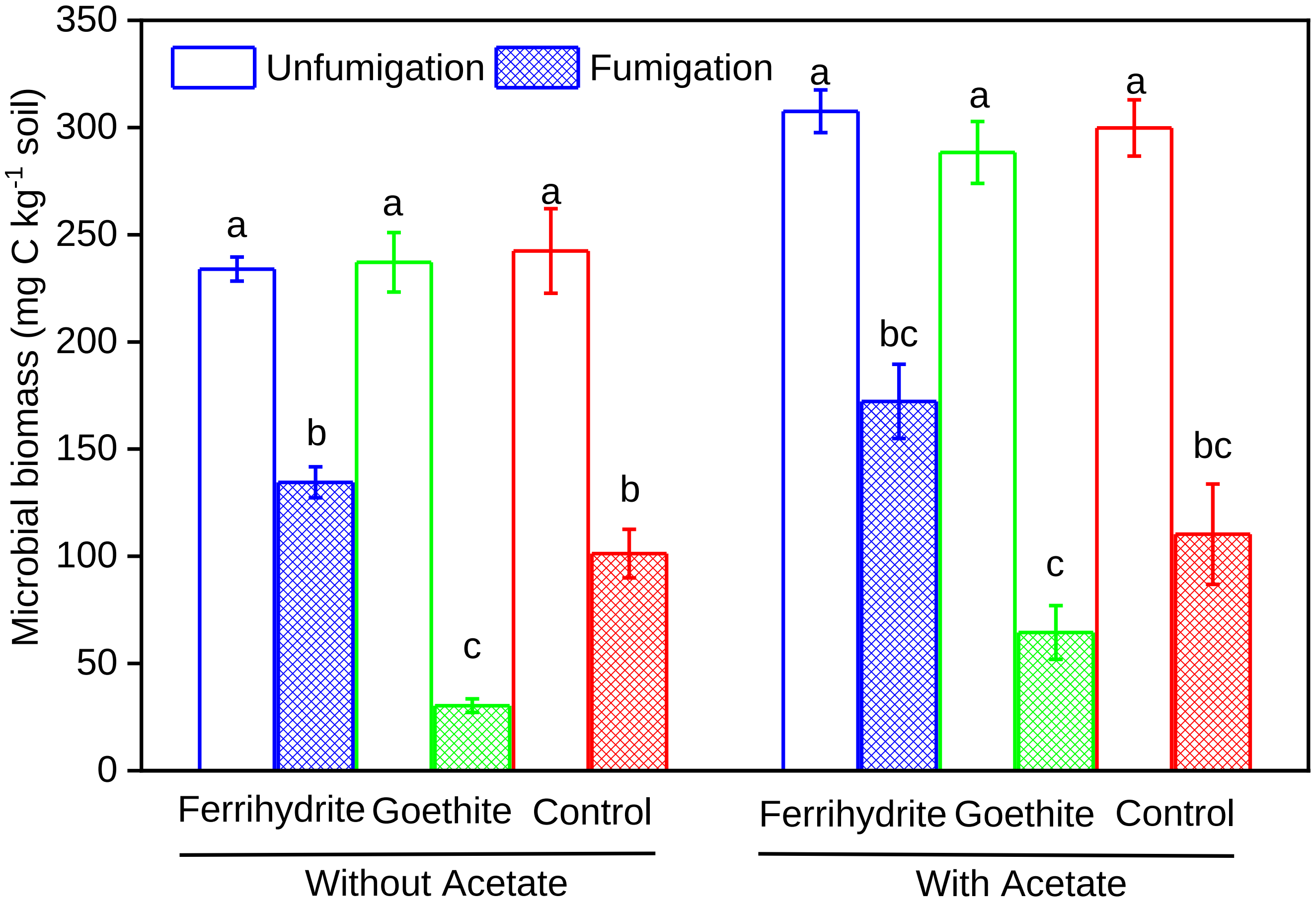
Iron oxides effect

$$= \frac{(CO_{2\,(+\text{Iron oxides})} - CO_{2\,(-\text{Iron oxides})})}{CO_{2\,(-\text{Iron oxides})}} \times 100\%$$

In unfumigated soil

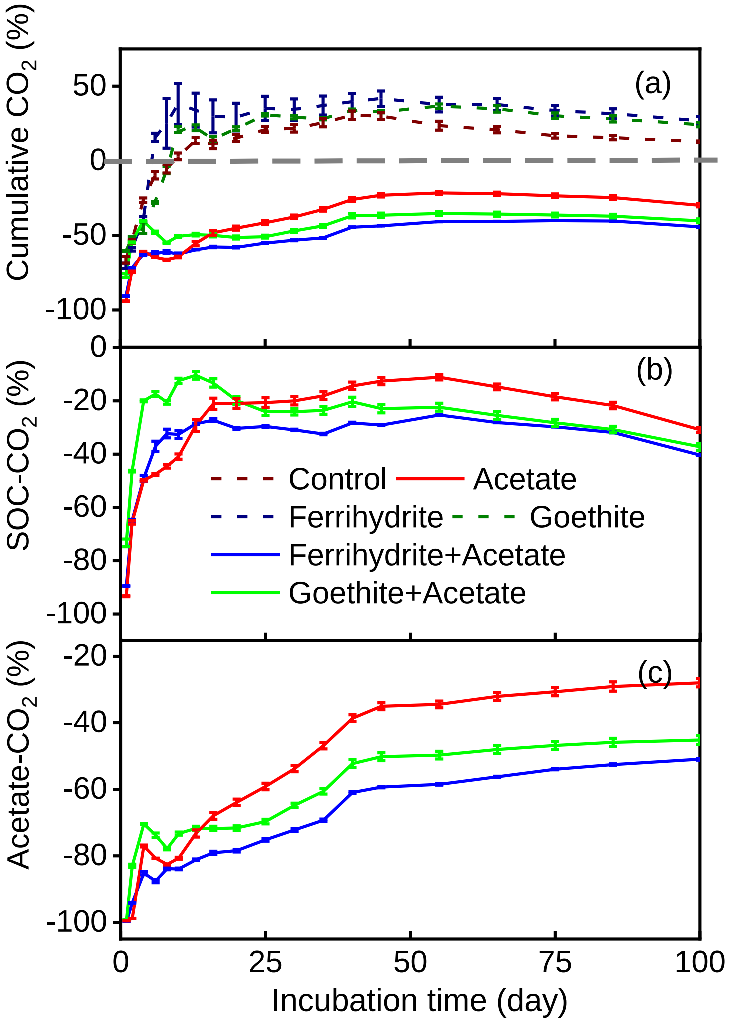
- Goethite addition increased acetate-CO_2 emissions and decrease SOC-CO_2 emissions
- Ferrihydrite addition reduced SOC-CO_2 emissions and labile C pool of SOC, and had little effect on acetate-CO_2 emission
- Acetate caused negative PE. Goethite and ferrihydrite strengthened this PE

MBC at the end



At the end of the incubation period, the MBC content of the fumigated soil was 13–57% that of the corresponding unfumigated soil

Fumigation effect



Fumigation effect

$$= \frac{(CO_{2\ (Fumigated)} - CO_{2\ (Unfumigated)})}{CO_{2\ (Unfumigated)}} \times 100\%$$

Allocation of added acetate into the different C pools on day 100 of the incubation (as % of initial acetate)

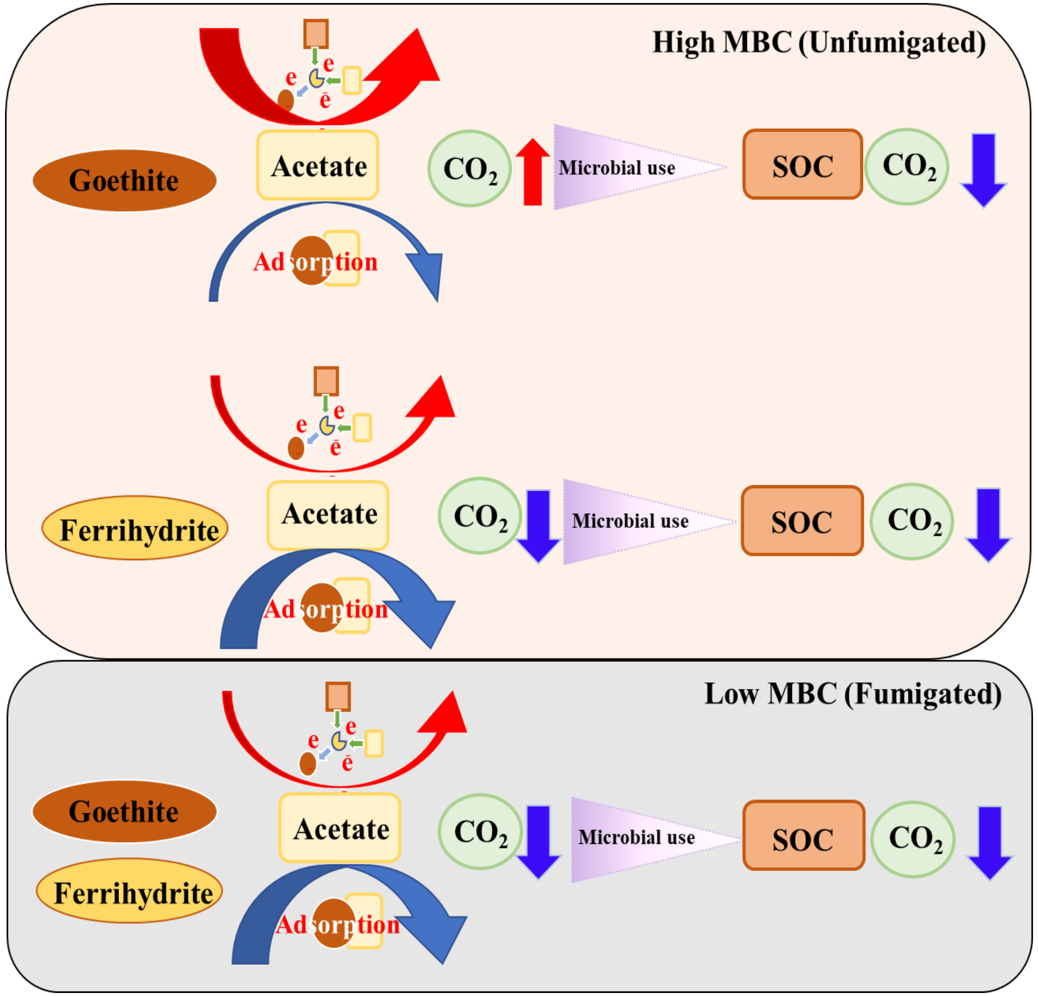
Soil	Treatment	DOC	MBC	CO_2	SOC
Unfumigated	Acetate	0.12 ab	1.99 c	36.6 b	27.6 c
	Ferrihydrite + Acetate	0.15 a	2.46 a	36.5 b	31.4 a
	Goethite + Acetate	0.11 b	2.29 b	39.1 a	27.8 b
Fumigated	Acetate	0.31 ab	1.77 a	26.4 a	71.5 c
	Ferrihydrite + Acetate	0.20 b	1.47 a	17.9 c	80.4 a
	Goethite + Acetate	0.44 a	0.72 b	21.4 b	77.4 b
Iron oxides		*	***	***	***
Fumigation		***	***	***	***
Iron oxides × Fumigation		***	***	***	***

In fumigated soil

- Fumigation substantially reduced MBC
- Fumigation reduced CO_2 emissions and the labile C pool of SOC and acetate
- More acetate was retained as SOC and DOC than the unfumigated soil

In fumigated soil

- Without acetate, iron oxides addition increased cumulative CO_2 emissions, and the effect was stronger after soil fumigation
- With acetate, ferrihydrite and goethite decreased CO_2 emission from acetate
- More acetate-C was present as SOC with ferrihydrite and goethite addition than without
- Ferrihydrite and goethite caused greater reduction in SOC mineralisation and PE than in the unfumigated soil
- The reduction effects of ferrihydrite on acetate-CO_2 and SOC-CO_2 emissions were stronger than those of goethite



Our results highlight the importance of microbial biomass in shifting the role of iron oxides in the organic C mineralisation in soils under anaerobic conditions.

Conclusions

✓**In high MBC soil (unfumigated)**

- Both ferrihydrite and goethite decreased SOC-CO_2 in the acetate-treated unfumigated soil
- Goethite mainly acts as electron acceptors and increases acetate-CO_2
- Ferrihydrite causes both iron reduction and acetate adsorption, resulting little negative effect on acetate-CO_2

✓**In low MBC soil (fumigation)**

- Iron oxides addition decreased SOC-CO_2 and acetate-CO_2, because the dominant role of iron oxides was to adsorb and limit acetate accessibility to microorganisms

Acknowledgements

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Thank you!