PRO AGRO LECTORIUM

‘Regulatory Gate’ of soil organic matter mineralization in paddy soil

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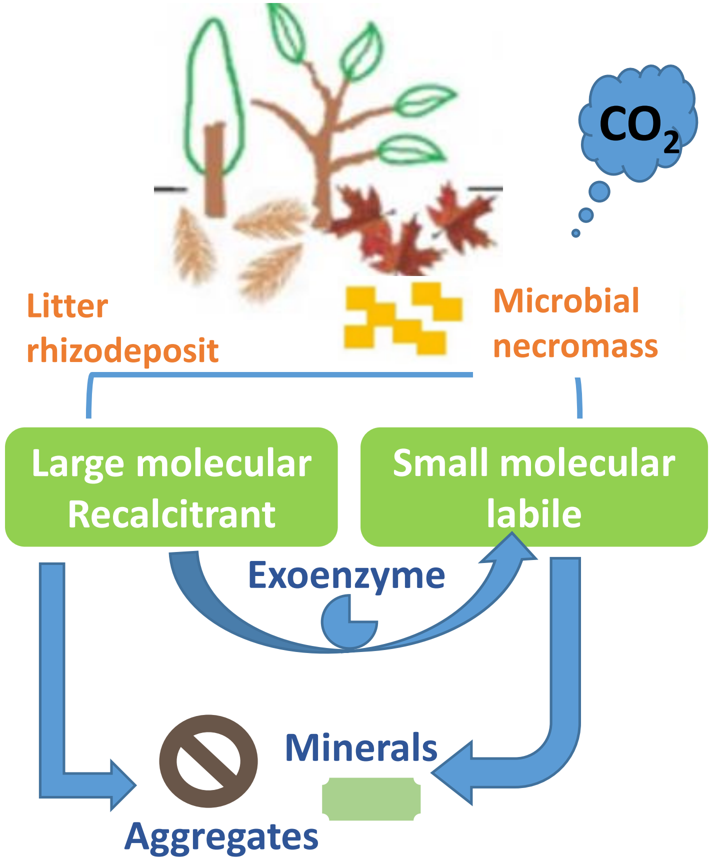
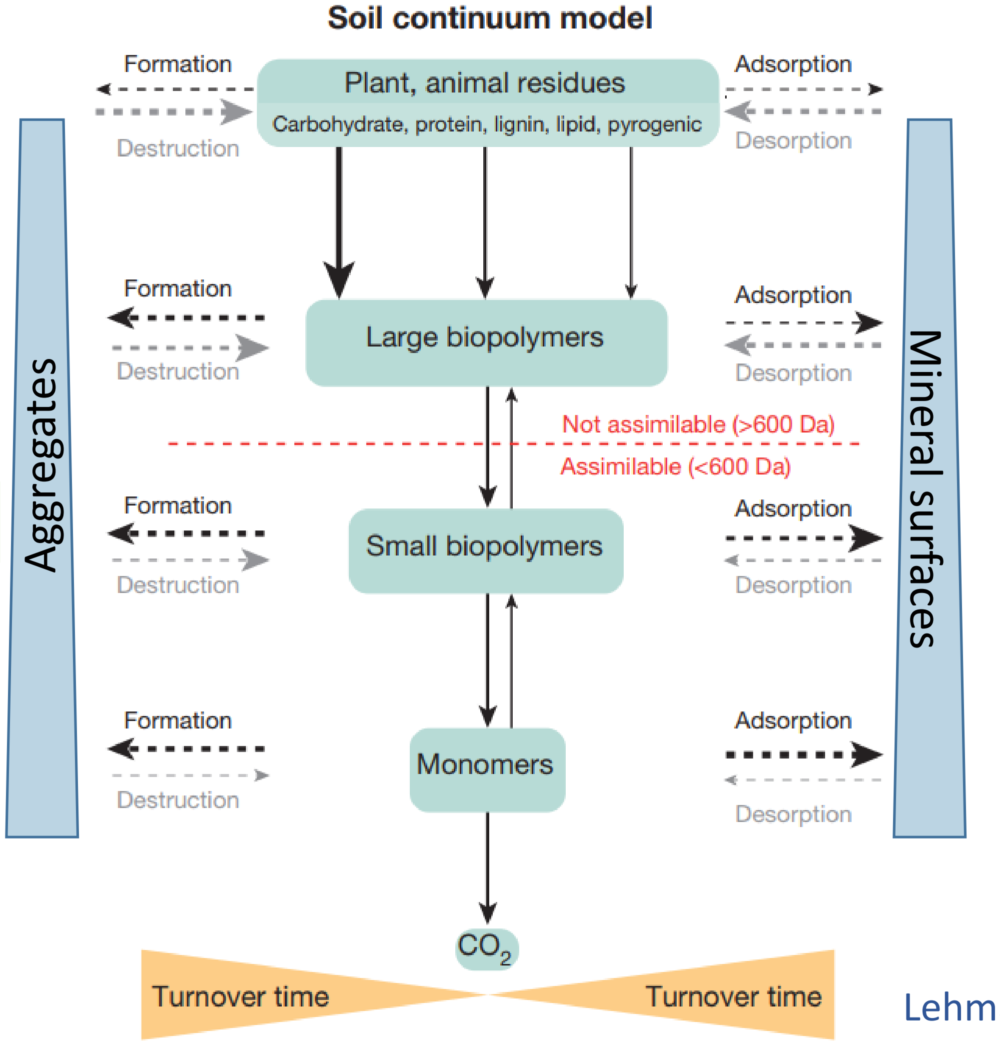
Contents

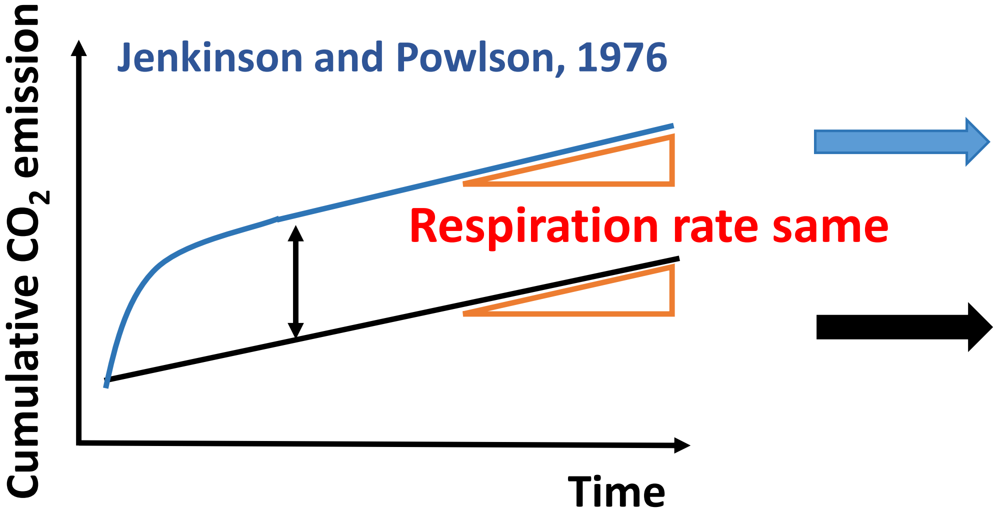
Soil organic carbon turnover





Lehmann & Kleber (2015)

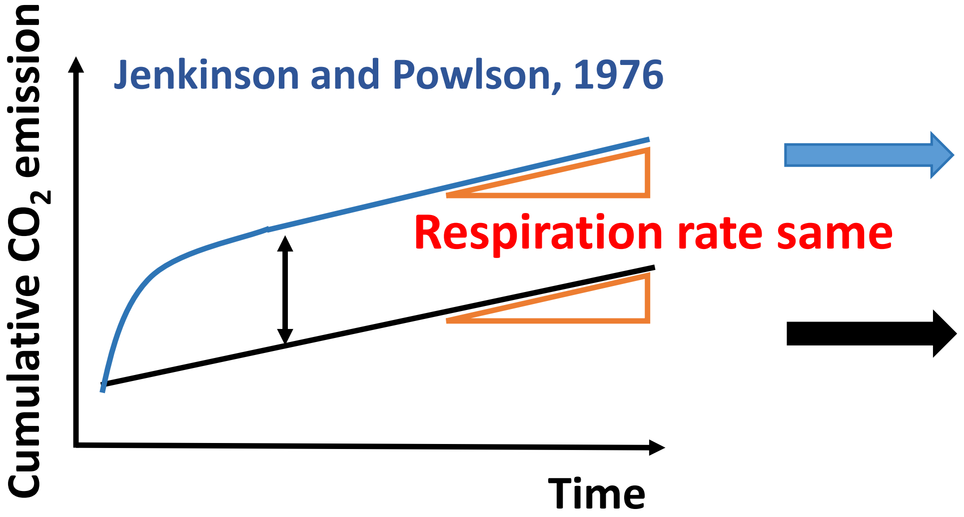
Soil organic carbon mineralization



Chloroform fumigated soil
- Only 10% microbial biomass survives
- Microbial community is simple

Unfumigated soil
- Microbial biomass is large
- Microbial community is complex

Soil organic carbon mineralization



Chloroform fumigated soil

- Only 10% microbial biomass survives
- Microbial community is simple

Unfumigated soil

- Microbial biomass is large
- Microbial community is complex

Paradox!

Why the mineralization rates of soil organic carbon are same when soils have such big differences in microbial biomass and community?

‘Regulatory gate’ hypothesis

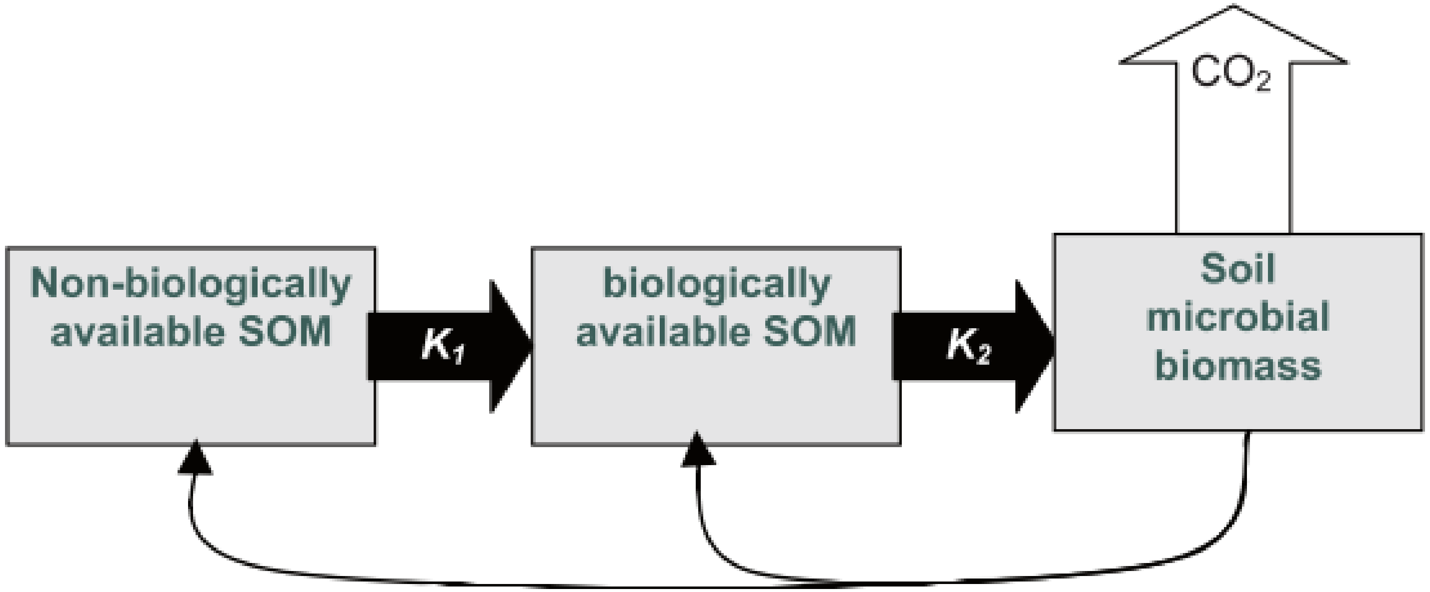
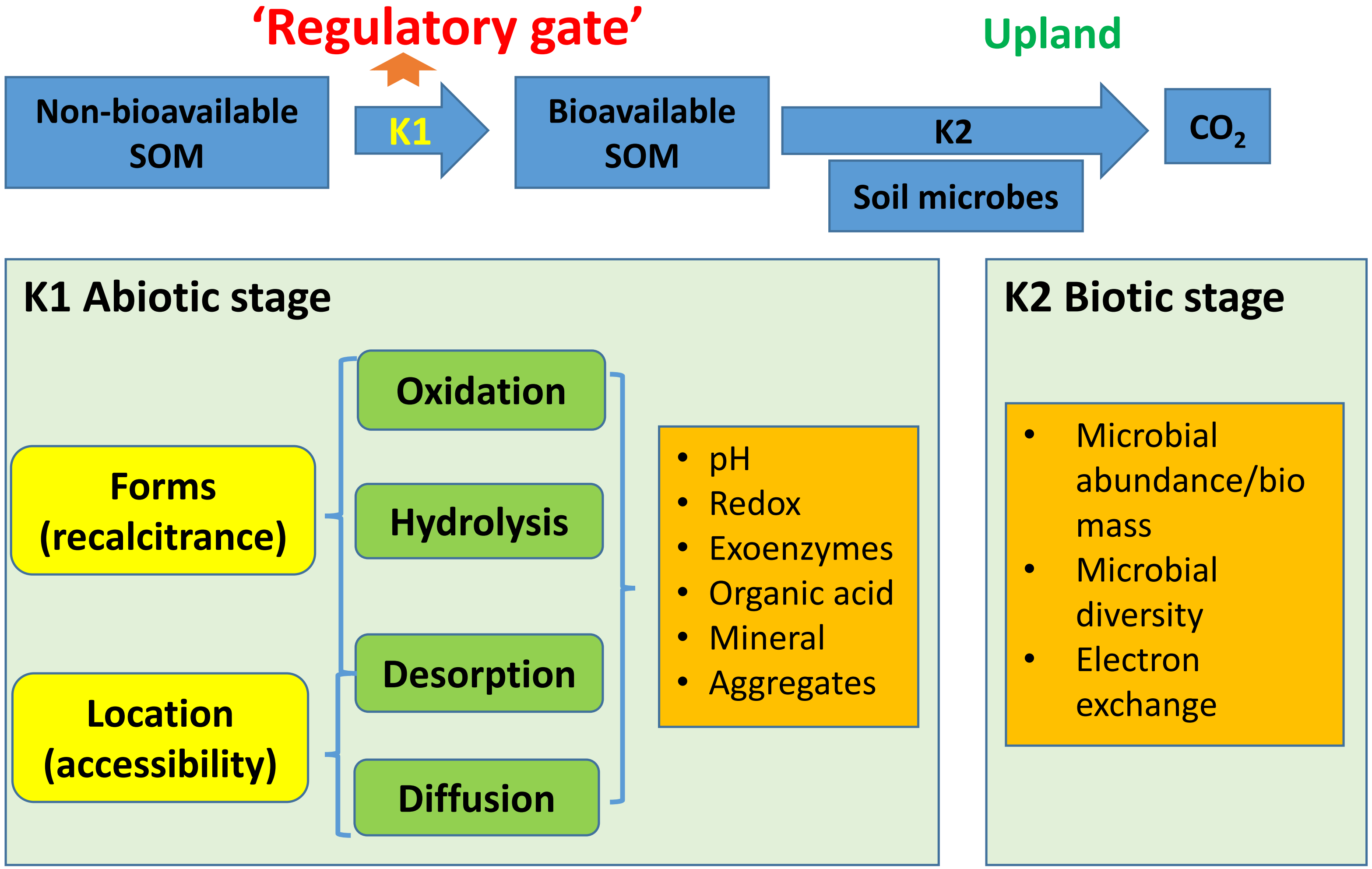


Fig. 7. Diagrammatic representation of the Regulatory Gate. *K1* is the abiological transformation of non-bioavailable soil organic matter. *K2* is the biological mineralization of bioavailable soil organic matter. Arrows indicate that microbial biomass may create both non-bioavailable and bioavailable organic matter, but is not able to influence directly the rate of *K1*.

S.J. Kemmitt et al. / Soil Biology & Biochemistry 40 (2008) 61–73

Organic matter mineralization



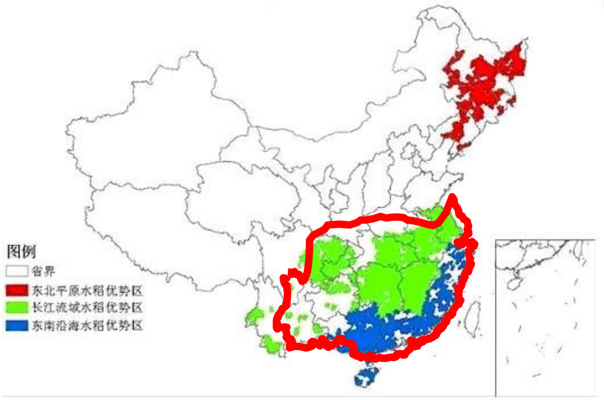
Kemmitte et al., 2008

Paddy soil

- Total area of paddy soil globally is 170 million ha
- There is 33 million ha of paddy soil, 60% of which is in the South

Artificial wetland

Ecological function of C sequestration



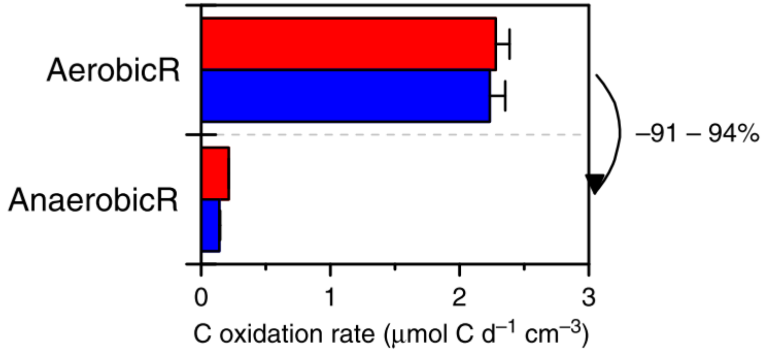
Paddy soil in China

Piao et al. (2009); Guo and Lin (2001); Tian et al. (2015); FAO (2017)

Upland

Paddy

- 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



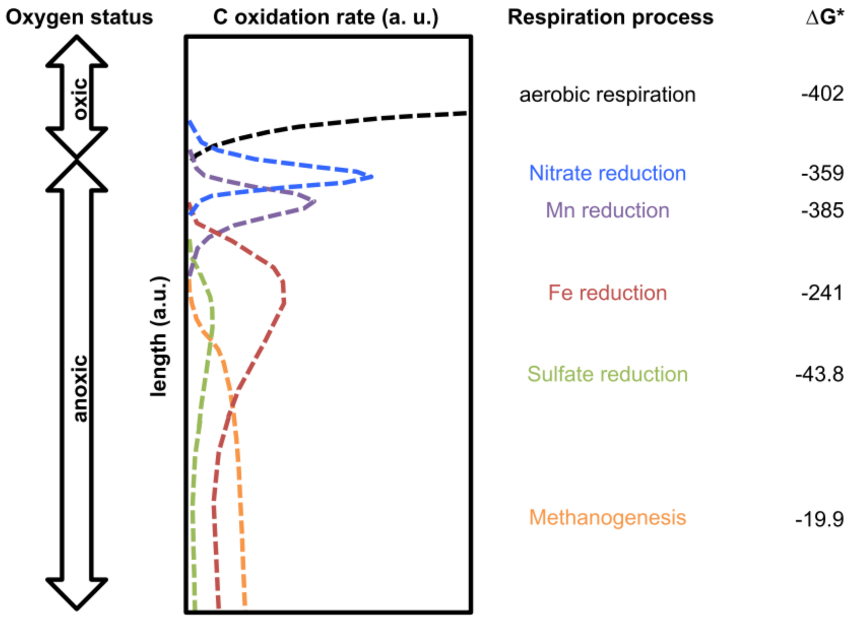
Soil organic matter content（g kg^{-1}） in China

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)

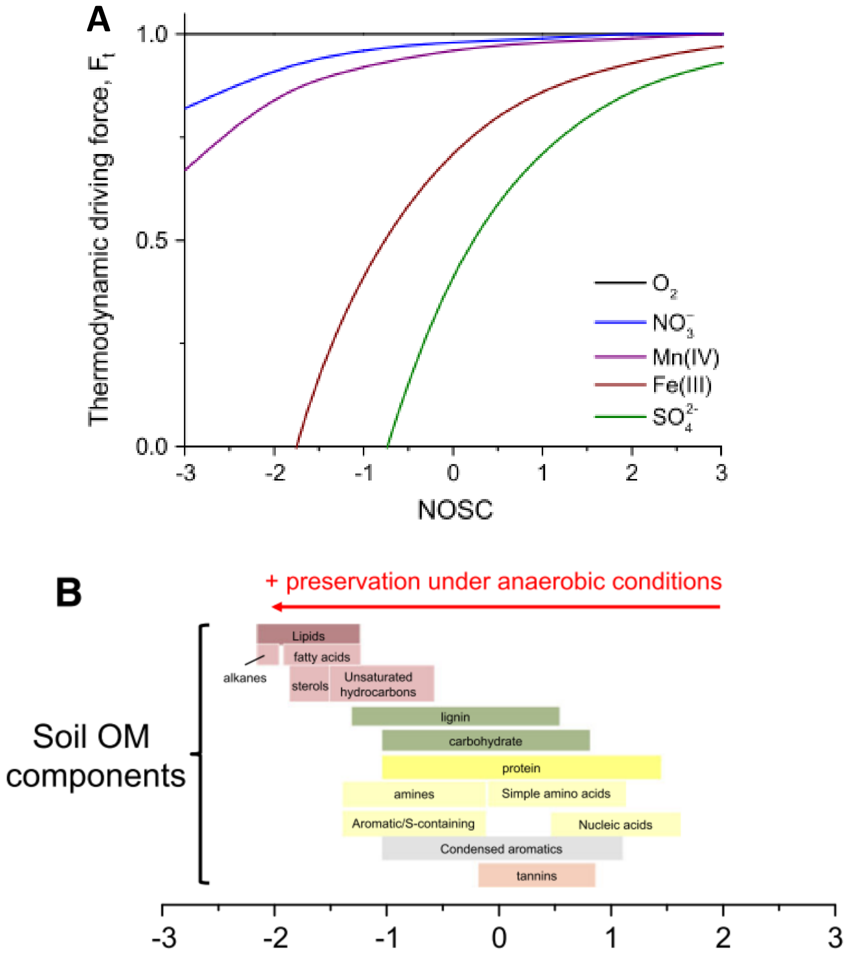
Keiluweit et al., 2017

Oxygen status and C oxidation



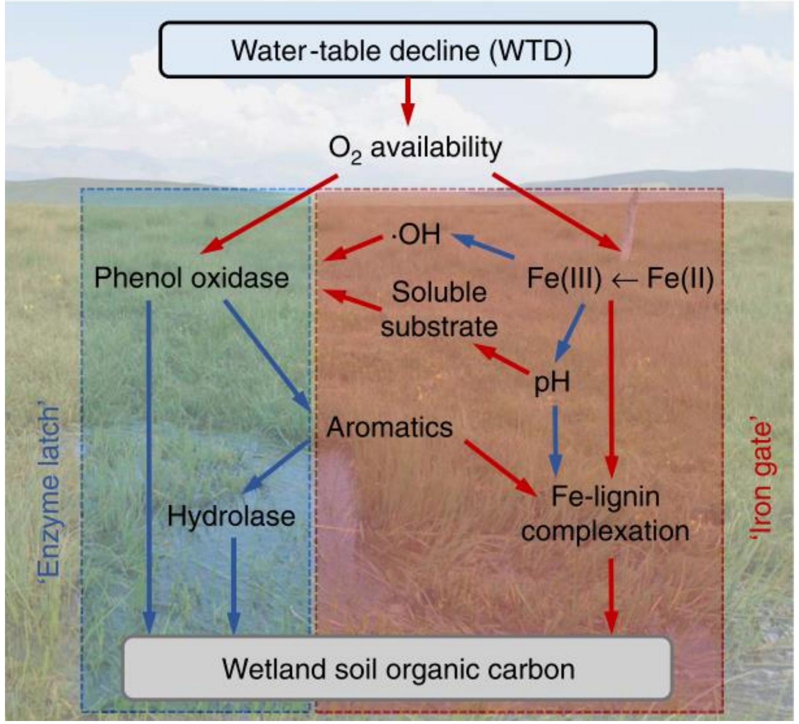
*Standard Gibbs free energy with acetate as an electron donor (kJ per reaction, ΔG)

Keiluweit et al., 2016

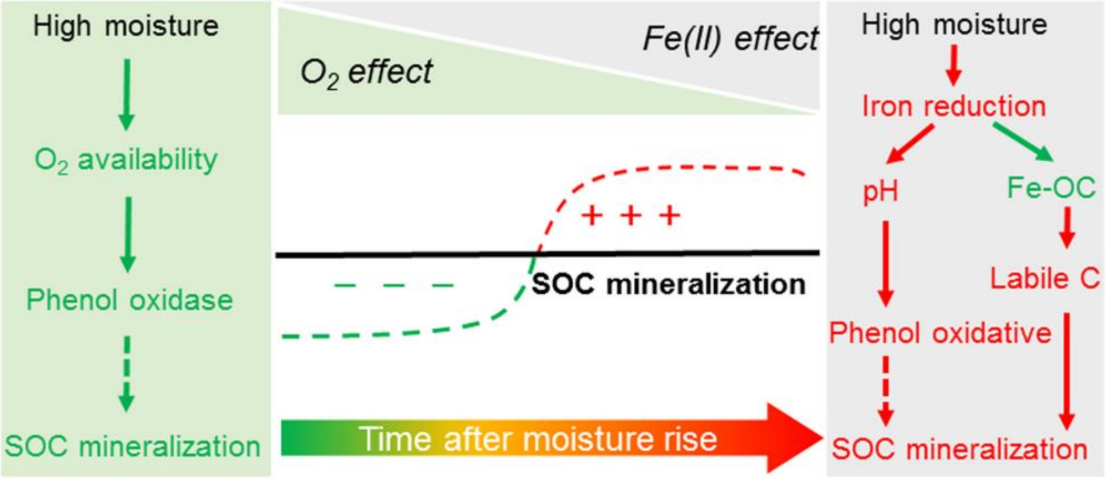


Nominal oxidation state of carbon (NOSC)

Enzyme latch vs Iron gate



Wang et al. (2017)



Wen et al. (2019)

- **Vegetation**
- **Soil mineral**
- **Water table and duration**

Paddy soil

K1 Abiotic stage

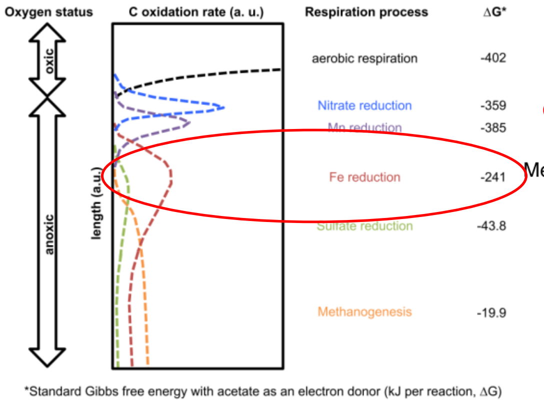
Non-bioavailable SOM → **Bioavailable SOM**

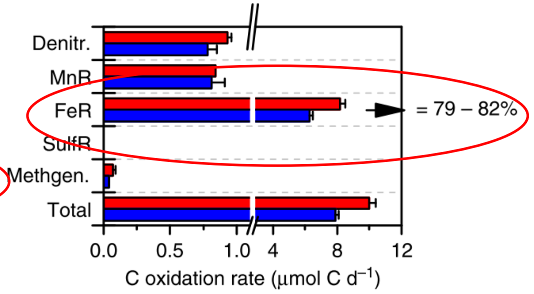
- Not accessible → (Desorption, Diffusion) → Accessible
- Recalcitrant → (Oxidation, Chemical hydrolysis, Exoenzyme hydrolysis) → Labile

K2 Biotic stage

Microbial use → CO_2, CH_4

Sorption/ Desorption ↑ Phenol Oxidation





Keiluweit et al., 2016

Hypotheses

- Soil oxygen availability determines the rate-limiting factors involved in SOC mineralisation
- SOC bioavailability is the rate-limiting factor under oxygen-abundant conditions, while microbial biomass size is the rate limiting factor under oxygen-limited conditions
- Fe influences SOC mineralisation by acting as an adsorbent and electron acceptor as well as a regulator of hydrolase and oxidative activities

Materials and methods

Treatments

- Nonflooding-flooding alteration (NF)
- Continuous flooding (CF)
- Anoxic flooding (AF)

Oxygen

- High Fe (FeH)
- Medium Fe (FeM)
- Low Fe (FeL)

Total Fe

- Chloroform Fumigation
- Unfumigation

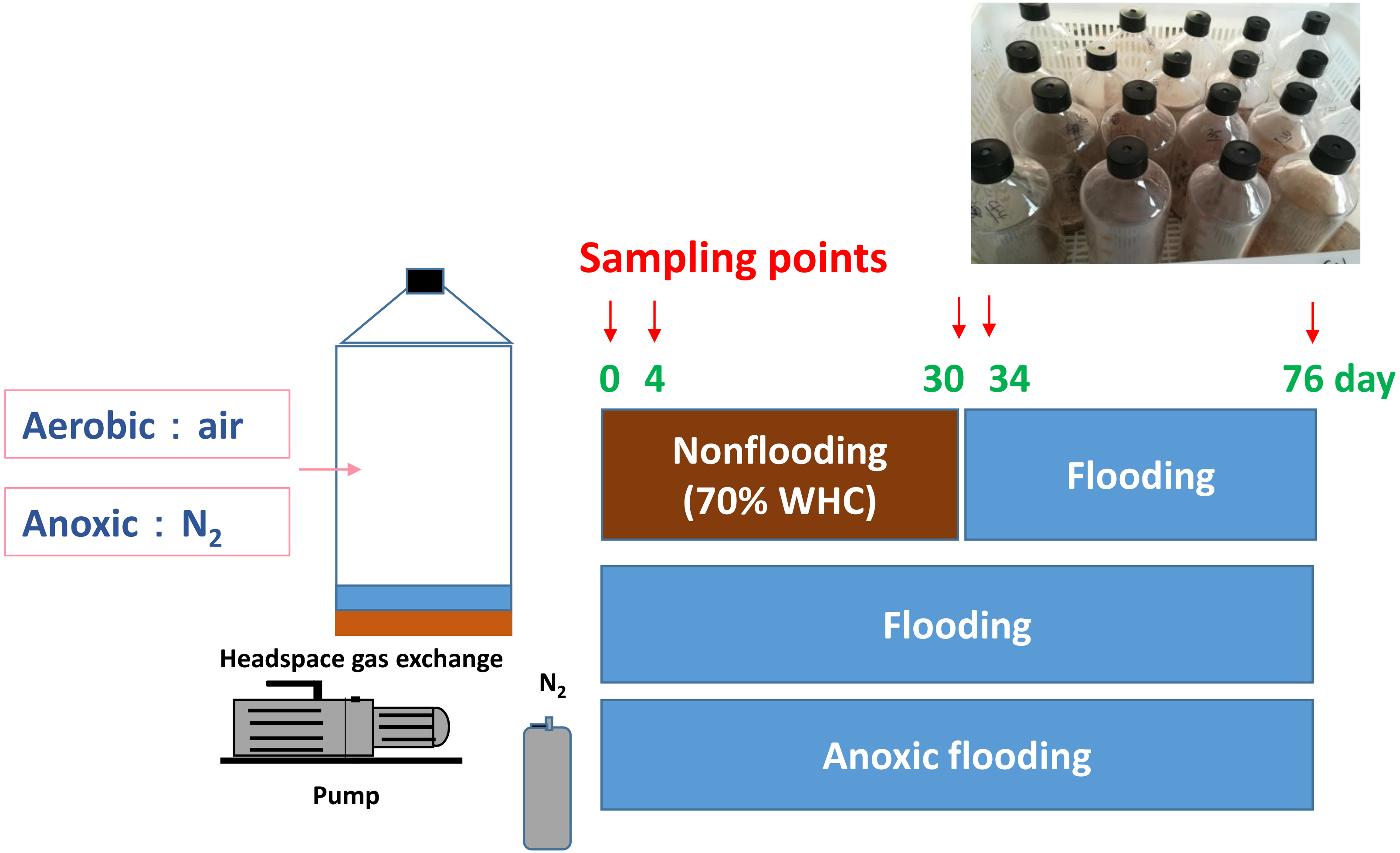
MBC

Materials and methods

Soil properties

Soil	Clay %	Silt %	Sand %	pH	Total Fe (Fe_2O_3) g kg^{-1}	SOC g kg^{-1}	Total N g kg^{-1}	Total P g kg^{-1}	Available N mg kg^{-1}	Olsen P mg kg^{-1}
High Fe	4.8 (0.02)	76.3 (0.08)	18.9 (0.06)	5.1 (0.01)	55.8 (0.68)	27.8 (0.23)	2.2 (0.00)	0.8 (0.00)	216.4 (3.76)	21.1 (0.31)
Medium Fe	6.2 (0.01)	65.7 (0.10)	28.1 (0.10)	4.7 (0.02)	25.8 (2.10)	32.8 (0.18)	2.4 (0.00)	0.6 (0.00)	173.7 (0.00)	20.9 (0.94)
Low Fe	9.8 (0.06)	71.1 (0.25)	19.1 (0.31)	5.3 (0.02)	13.7 (0.21)	21.3 (0.04)	1.6 (0.01)	0.4 (0.00)	137.5 (0.84)	8.2 (0.23)

Incubation


Sampling points
0
4
30
34
76 day
Aerobic : air
Anoxic : N_2
Headspace gas exchange
Pump
N_2
Nonflooding
(70% WHC)
Flooding
Flooding
Anoxic flooding

Sample analysis

Gas

CO_2
CH_4

Iron

- Fe^{2+}, Fe^{3+}
- DCB-Fe
- Oxalate-Fe
- Pyrophosphate-Fe

Soil properties

- pH
- Eh
- NO_3^- NH_4^+
- DOC

Biotic parameters

- MBC
- Enzyme (NAG, BG, PER)

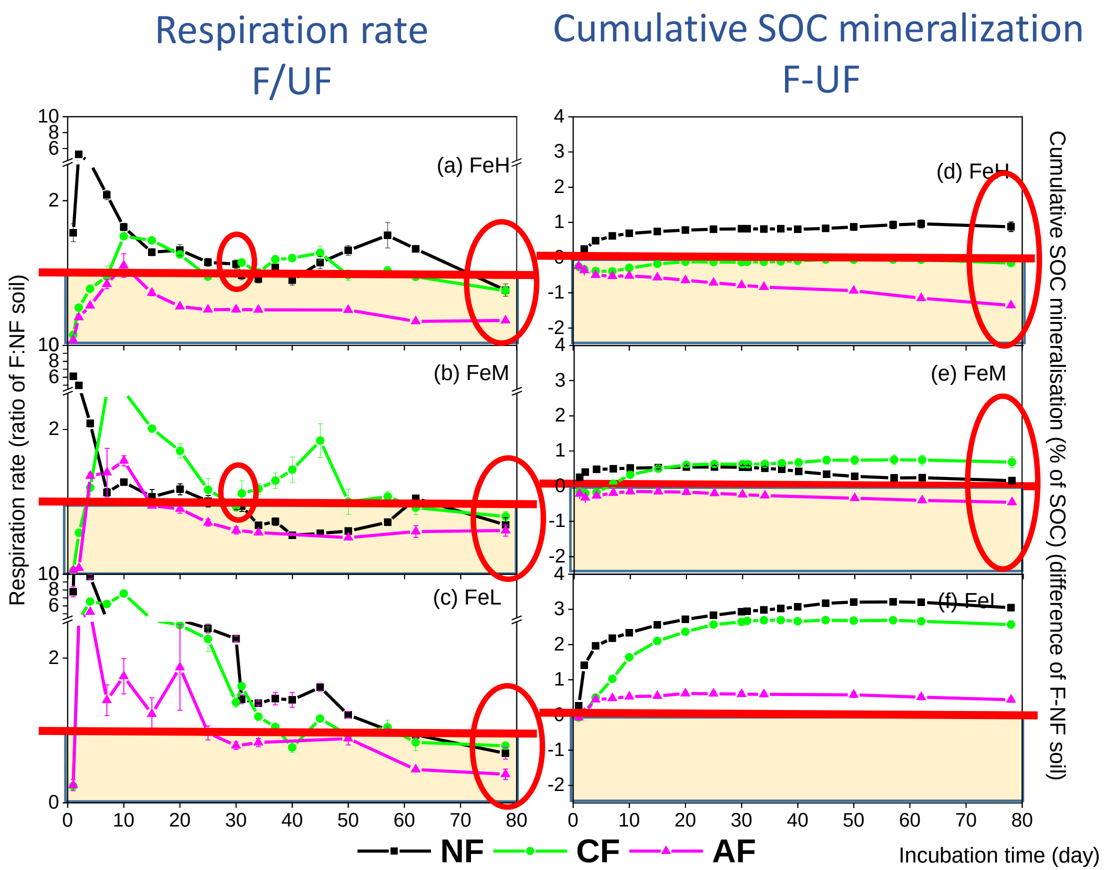
Results

SOC mineralisation under different oxygen conditions

Fumigated>Unfumigated

Fumigated=Unfumigated

Fumigated<Unfumigated



Results

Ratio of F/UF on 76d

Soil	DOC			MBC		
	NF	CF	AF	NF	CF	AF
High Fe	2.09 (0.01)	1.36 (0.06)	1.09 (0.04)	0.26 (0.29)	0.19 (0.35)	0.05 (4.86)
Medium Fe	2.33 (0.04)	1.42 (0.04)	1.37 (0.08)	0.18 (0.98)	0.24 (0.85)	0.10 (1.11)
Low Fe	3.06 (0.02)	3.72 (0.03)	1.83 (0.04)	0.12 (0.55)	0.10 (0.43)	0.04 (8.25)

Nonflooding period of NF

- Final respiration rate (30d)
- F/UF≈ 1

Aerobic (NF, CF)

- Final respiration rate (76d)

F/UF=68–80%

- MBC

F/UF=3–33%

- DOC

F>UF

Anaerobic

- Final respiration rate (76d)

F/UF=34–60%

- MBC

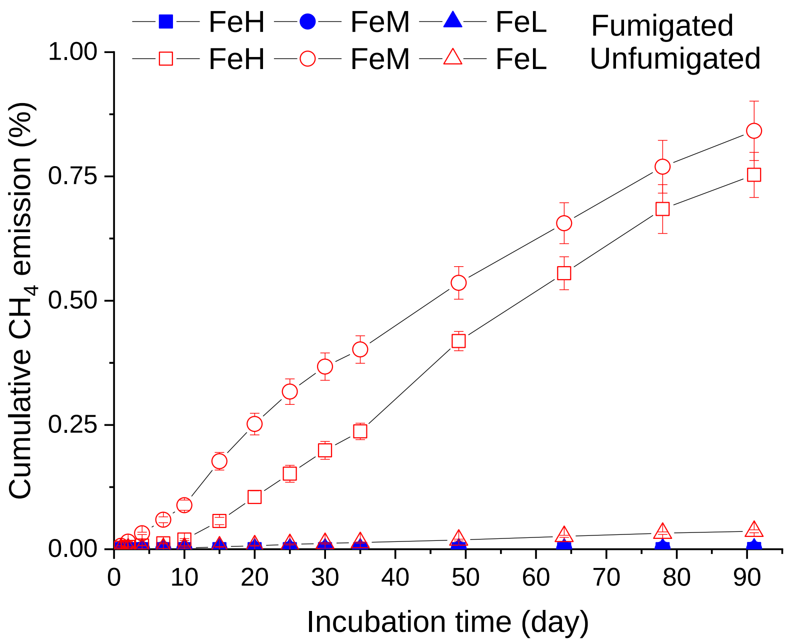
F/UF=3–10%

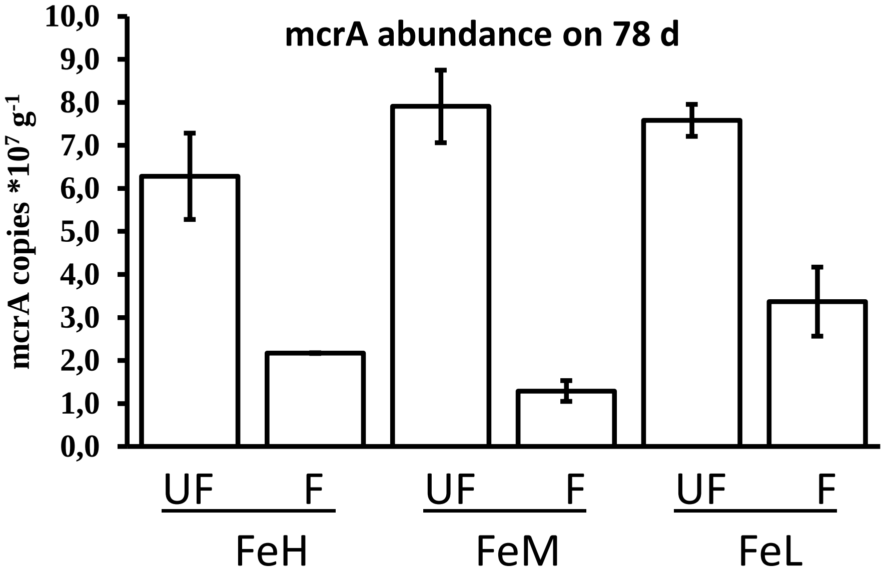
- DOC

F>UF

- Results suggest that microbial biomass acts as a rate-limiting factor in SOC mineralisation when oxygen is limited

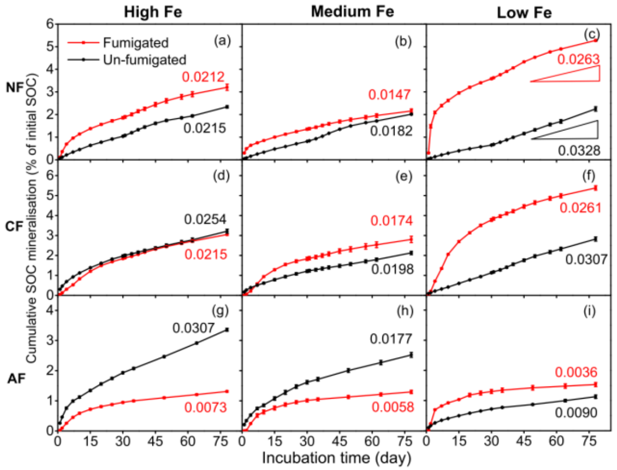
CH_4 production in anoxic paddy soil





- CH_4 was almost 1/3 of CO_2 production in anaerobic incubation
- Methanogenesis was largely killed and hardly recoverable

Labile C pool size and mean residence time (MRT)



SOC mineralization=b (1 - e^{-kt})

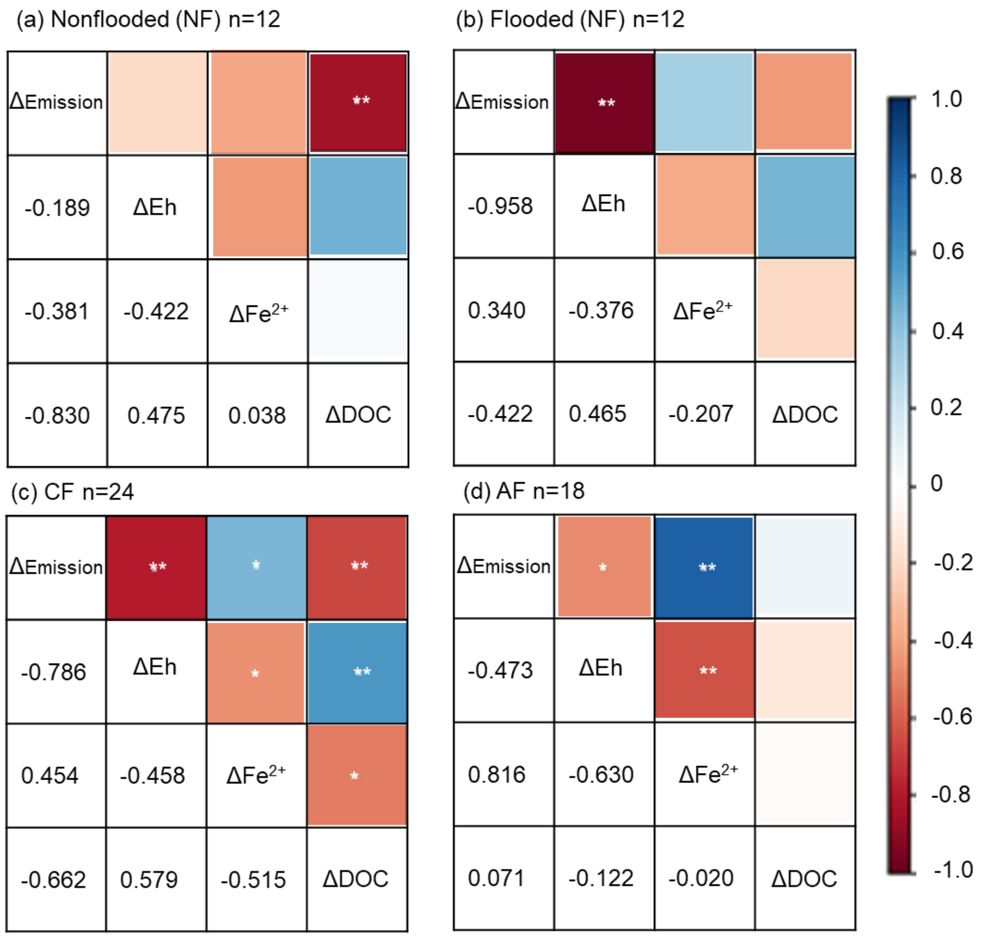
b is labile C pool size

MRT=1/k

The labile C pool size was smaller in the anaerobically flooded treatment than in the other treatments. This implies that organic C may be more recalcitrant under oxygen-depleted conditions.

Treatment		NF	CF	AF	NF	CF	AF
	Soil	Pool size (% of SOC)			MRT (day)		
Un-fumigated	High Fe	3.0b	4.3a	3.4b	26.9b	102.0a	31.7b
	Medium Fe	2.2b	8.1a	2.5b	37.4b	261.5a	26.3b
	Low Fe	18.3	-	1.1	457.8	-	25
Fumigated	High Fe	3.4a	3.3a#	1.2b#	37.6a#	32.1b#	18.8c#
	Medium Fe	2.9a#	2.0b#	1.2c#	29.1a#	23.0b#	16.5c#
	Low Fe	5.4a#	4.5b	1.4c#	24.1a#	13.2b	9.4b#

Pearson correlation



ΔEh, ΔFe^{2+}, and ΔDOC (Δ: change between sampling dates)
ΔEmission, C emission between sampling dates

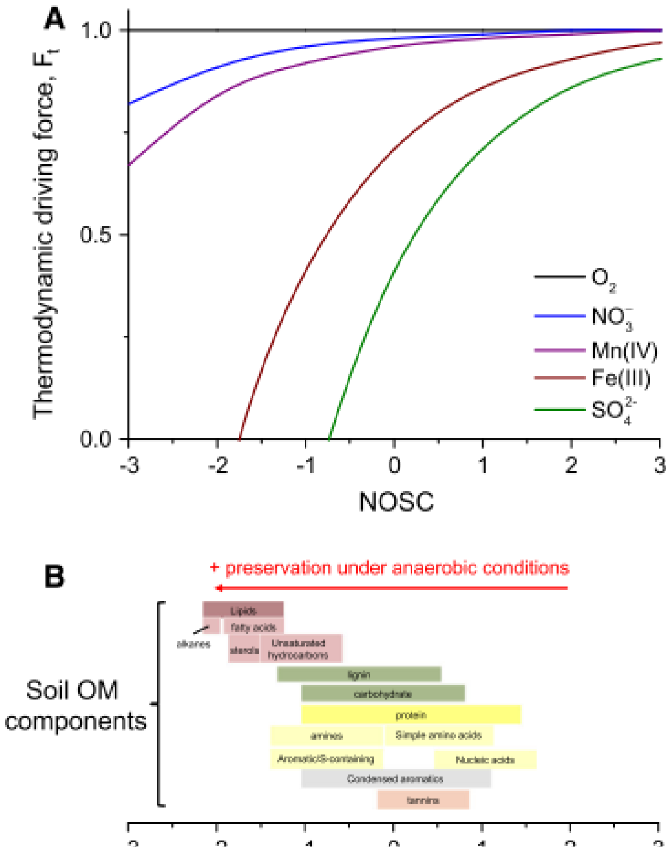
- *$p<0.05$, **$p<0.01$

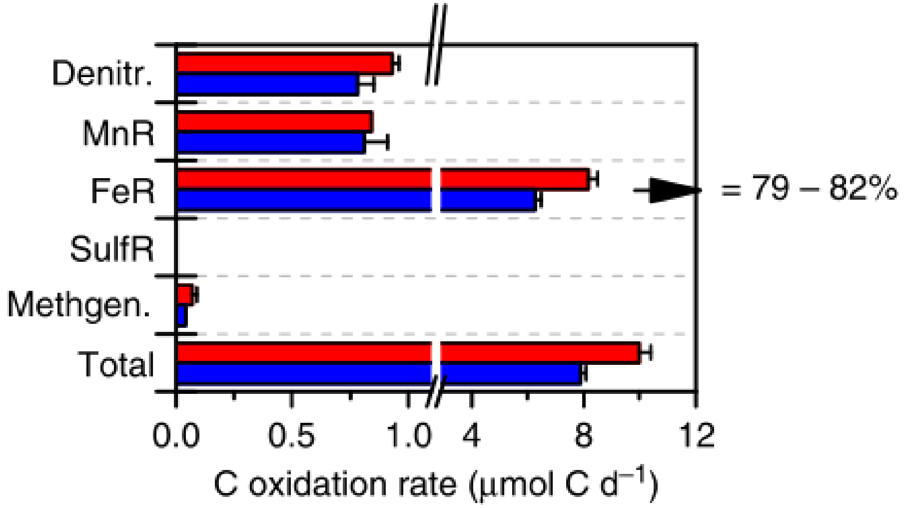
- Nonflooded period of NF, ΔDOC is correlated with C emission
- Flooded period of NF, CF and AF, ΔEh, ΔFe^{2+} are correlated with C emission

Multiple regression for ΔEmission with variables of ΔEh, ΔFe^{2}+, and ΔDOC

Treatment	Variable	Standardised Coefficient	P of coefficients	R^2 of the regression	P of the regression
Nonflooded (NF) n = 12	ΔEh mV	0.087	0.674	0.816	0.003
	ΔFe^{2+}g kg^{-1}	-0.312	0.113		
	ΔDOC mg kg^{-1}	-0.859	**0.001**		
Flooded (NF) n = 12	ΔEh mV	-0.980	**<0.001**	0.919	<0.001
	ΔFe^{2+}g kg^{-1}	-0.023	0.838		
	ΔDOC mg kg^{-1}	0.029	0.807		
CF n = 24	ΔEh mV	-3.788	**0.001**	0.683	<0.001
	ΔFe^{2+}g kg^{-1}	0.154	0.879		
	ΔDOC mg kg^{-1}	-1.836	0.081		
AF n = 18	ΔEh mV	-0.055	0.793	0.649	0.002
	ΔFe^{2+}g kg^{-1}	0.764	**0.002**		
	ΔDOC mg kg^{-1}	-0.087	0.599		

Nominal oxidation state of carbon (NOSC) and Iron reduction are important under anoxic condition





Nominal oxidation state of carbon (NOSC)

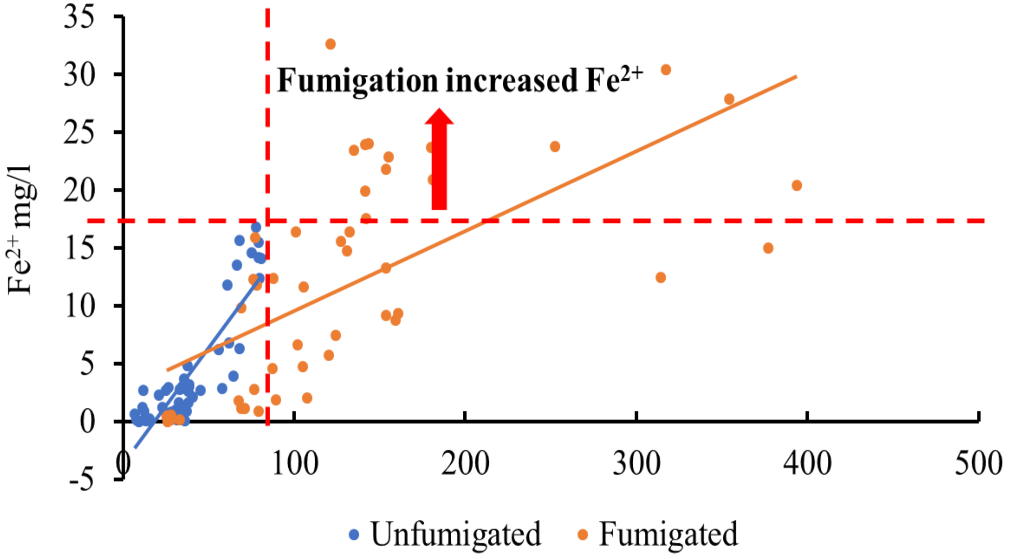
Keiluweit et al., 2017; Li et al., 2011; Yi et al., 2012

- The multiple regression and correlation suggest that the bioavailability of organic C regulates SOC mineralisation under oxygen abundant conditions but not under oxygen-limited conditions
- The redox potential, the electron acceptor of Fe and organic carbon composition form play significant roles during anaerobic SOC mineralisation

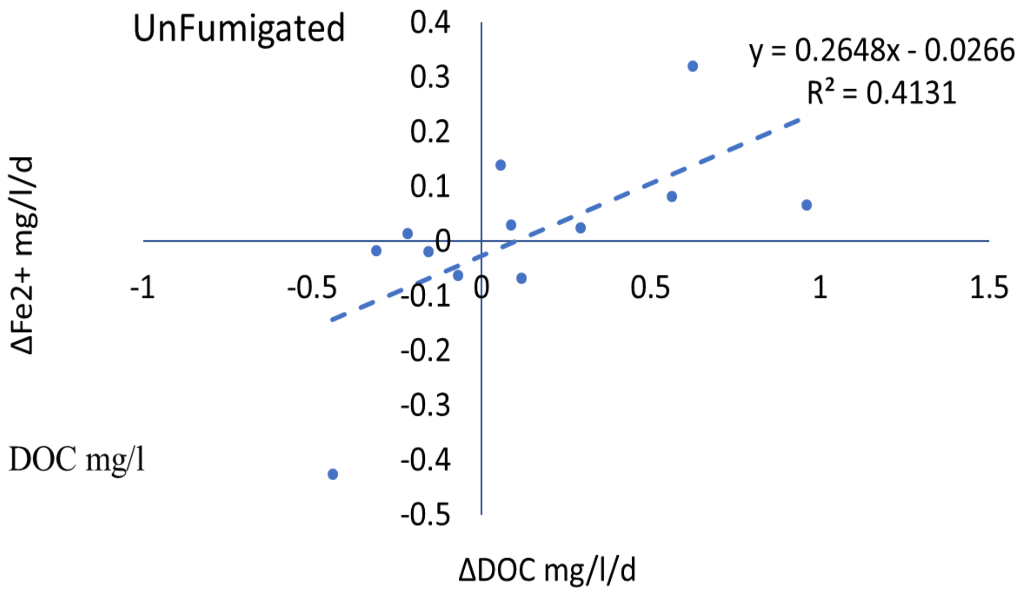
The role of Fe

Relationship between Fe^{2+} and DOC concentration and change in soil suspension

Concentration



Changes over time Δ



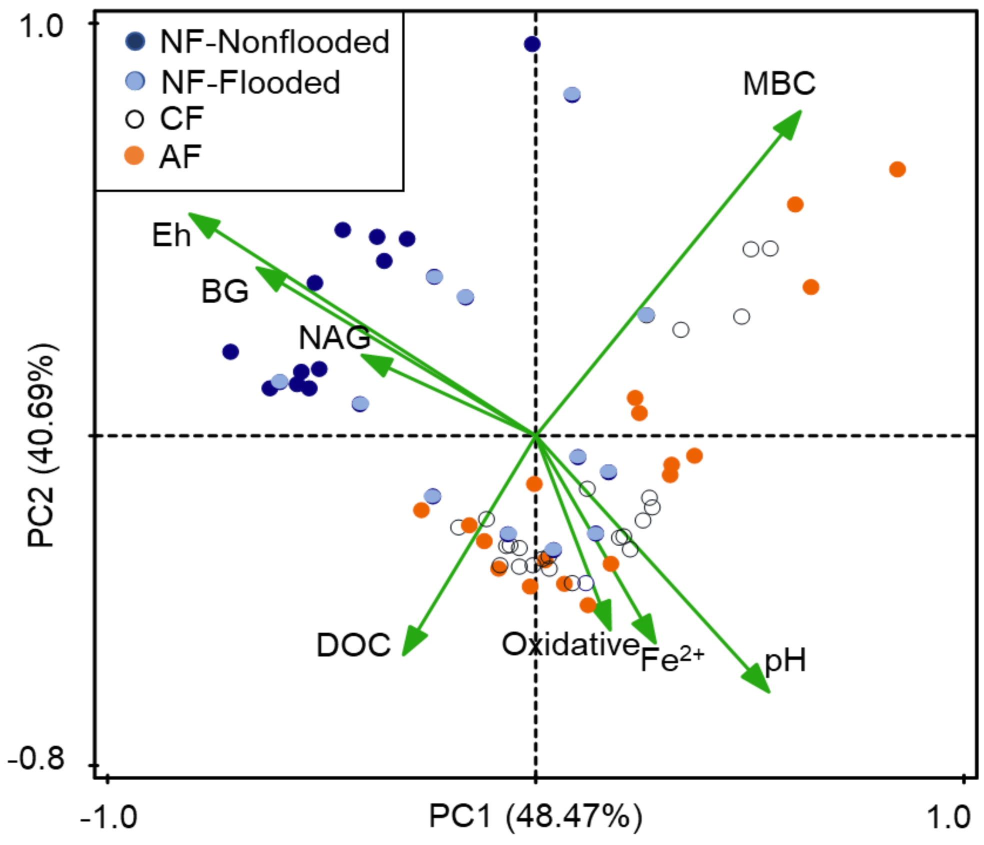
The role of Fe

Pearson's correlation between soil DOC content and other parameters in soil

	Total Fe	HCl Fe^{2+}	DCB			Oxalate			Pyrophosphate			NH_4^+
			Al	Fe	Mn	Al	Fe	Mn	Al	Fe	Mn	
DOC	.761**	.802**	.707*	.723**	.737**	.739**	.769**	.750**	.671*	.799**	.757**	.855**

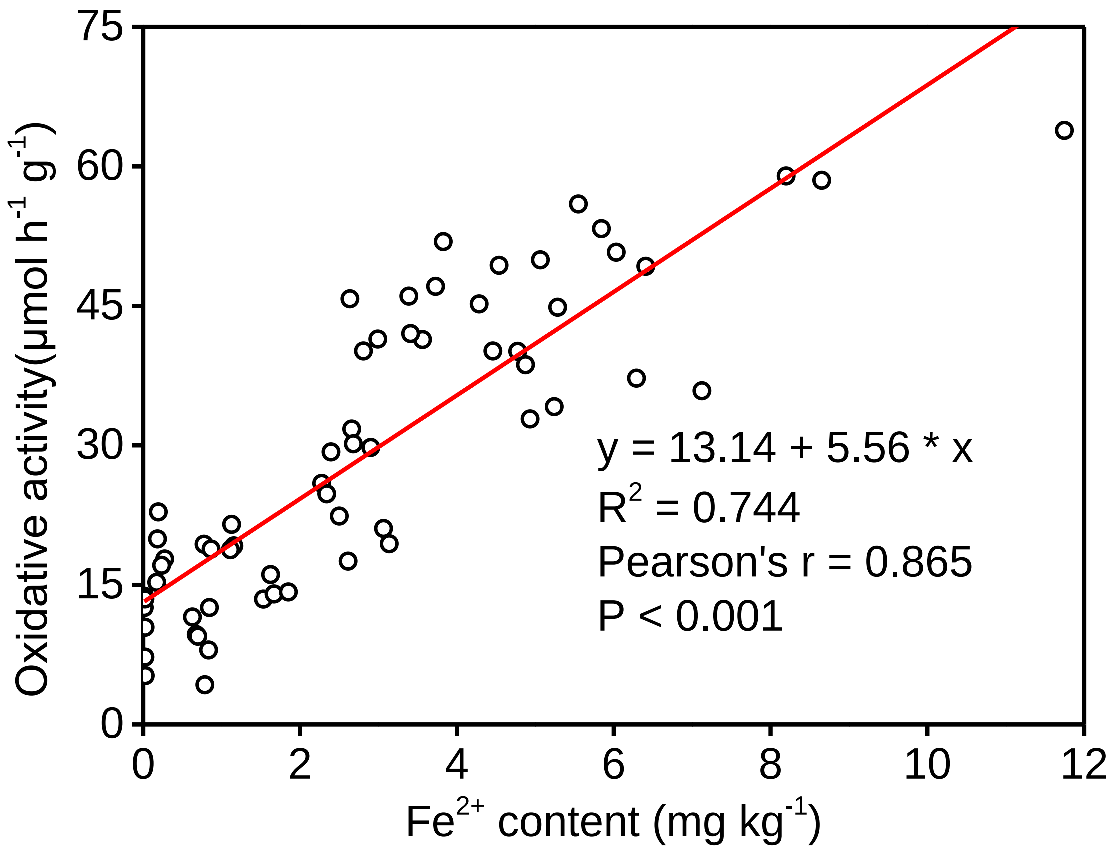
The role of Fe

Principal component analysis (PCA) of the Eh, pH, MBC, Fe^{2+} and DOC contents, β-1,4-glucosidase (BG), β-1,4-N-acetylglucosaminidase (NAG) and potential oxidative activities

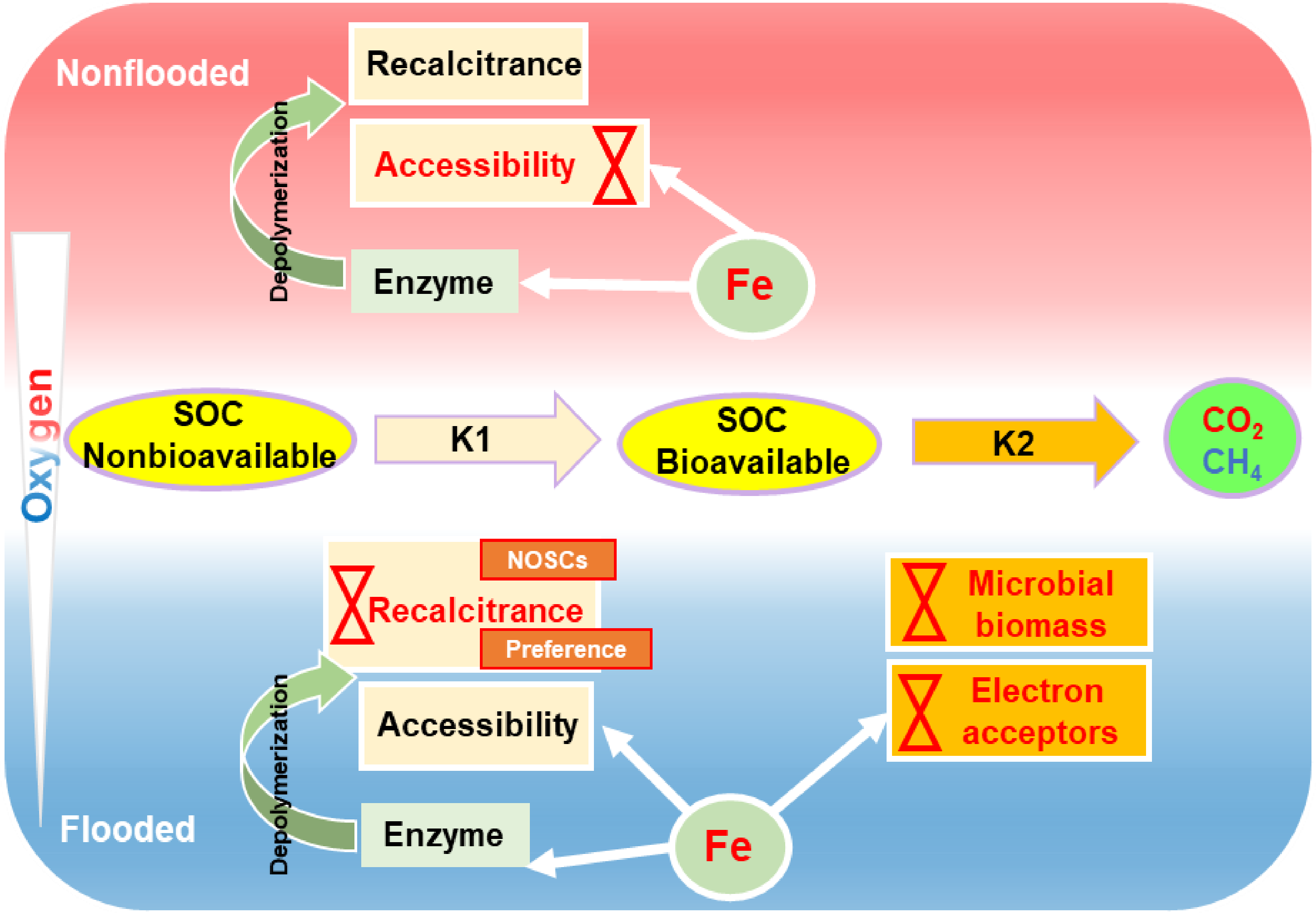


The role of Fe

Linear regression of potential oxidative activity and soil Fe^{2+} content



- Total, crystalline, amorphous, and complexed Fe contents were correlated with DOC contents, which implies that Fe plays a role in preserving the labile organic C pool
- A significant linear relationship between Fe^{2+} contents and oxidative activity indicates that Fe also plays a role in regulating enzyme activity


Nonflooded
Recalcitrance
Accessibility
Depolymerization
Enzyme
Fe
Oxygen
SOC
Nonbioavailable
K1
SOC
Bioavailable
K2
CO_2
CH_4
NOSCs
Recalcitrance
Preference
Microbial
biomass
Electron
acceptors
Accessibility
Depolymerization
Enzyme
Fe
Flooded

Conclusions

- The mechanisms of SOC mineralisation in paddy soil vary depending on aerobic and anaerobic dynamics
- The so called ‘Regulatory Gate’ hypothesis (i.e. SOC mineralisation is solely regulated by abiotic factors) could only be applied to nonflooded conditions
- In oxygen-limited flooded paddy soil, the recalcitrance of organic C substrates, microbial biomass size, and electron acceptors are regulatory factors

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Thank you!