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Biogeochemical processes influencing phosphorus dynamics in freshwater mud deposits

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Research in perspective

Currently, lake Markermeer (680 km^2) provides poor environmental conditions for the development of flora and fauna due to a thick fluffy layer that prevails at the lake's bed. In the Netherlands, the MarkerWadden project is proposed to create a dynamic wetland system with gradients in topography, sediments, and rich benthic and wetland biodiversity. In this ecosystem design fine sediments will be accumulated in atolls to form new soil which can eventually develop into valuable ecosystems.

The acquired scientific knowledge will be used to assess which ecosystem services will evolve and how such systems should be managed. The results of this project may both guide the design of the MarkerWadden and serve as an international, scientific example of building with mud to create new land.

Aim: Distinguish biogeochemical processes influencing nutrient dynamics in porewater during oxidation and desiccation of mud deposits from lake Markermeer. We focus on three important aspects that potentially influence these processes: granulometry, sediment type and modification by plants.

Method: A greenhouse experiment was conducted with three types of sediment that potentially will function as building material for the islands: fluffy mud (**FM**), sandy mud (**SM**) and Southern Sea deposit (**SSD**). Reed (*Phragmites australis*) was planted in half of the pots to distinguish influence by plants. For 24 weeks, porewater-, soil- and plant quality was monitored to determine important biogeochemical processes.

Pots with a diameter of 10 cm and 18 cm in length were prepared by horizontally installing two soil moisture samplers at two different depths: 1 cm and 11 cm below soil surface.

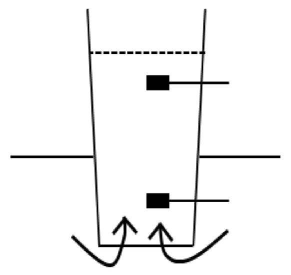


Table 1. Main biogeochemical processes expressed in total mole transfer (mMol) modelled by PHREEQC[1] based on porewater data. The initial oxidation phase of the soils were excluded to better distinguish influence by plants. Reactants that showed very little mole transfers are not included in the table for clarity (these include Chalcedony, Hydroxyapatite, Jarosite-K and Rhodocrosite). Positive values indicate dissolution, negative values indicate precipitation.

Mole transfer (mMol) after three weeks of initial oxidation								
	Reactant	Composition	No plant FM	Plant	No plant SSD	Plant	No plant SM	Plant
1 cm depth	**Pyrite**	**FeS_2**	**0.00**	**3.47**	**4.12**	**7.11**	**0.83**	**1.23**
	O_2	**O_2**	**0.00**	**11.75**	**11.40**	**21.29**	**3.08**	**3.32**
	Water	H_2O	$2.0 \cdot 10^4$	$2.2 \cdot 10^4$	$4.1 \cdot 10^4$	$-8.8 \cdot 10^4$	$2.8 \cdot 10^4$	$-4.2 \cdot 10^4$
	Calcite	$CaCO_3$	3.71	3.26	-2.30	-2.10	4.46	-2.14
	$Fe(OH)_3$	$Fe(OH)_3$	-2.23	2.02	4.48	7.44	-1.99	3.05
	Gypsum	$CaSO_4{:}2H_2O$	-7.87	-7.76	-0.51	0.00	-2.18	0.00
	CEC (release)	ΣCaX_2, FeX_2, KX, MgX_2, NaX, N4X	2.98	7.80	12.63	21.36	2.92	4.62
	CEC (uptake)	ΣCaX_2, FeX_2, KX, MgX_2, NaX, N4X	-3.06	-6.70	-9.83	-15.72	-2.48	-7.53
11 cm depth	**Pyrite**	**FeS_2**	**0.00**	**0.46**	**0.00**	**1.29**	**0.00**	**1.32**
	O_2	**O_2**	**0.00**	**1.52**	**0.00**	**3.81**	**0.00**	**3.28**
	Water	H_2O	0.00	0.00	0.00	$-2.1 \cdot 10^4$	0.00	$-7.4 \cdot 10^4$
	Calcite	$CaCO_3$	0.56	0.83	2.43	0.68	3.01	-4.03
	$Fe(OH)_3$	$Fe(OH)_3$	-0.09	-0.26	-2.59	0.61	-1.88	4.01
	Gypsum	$CaSO_4{:}2H_2O$	0.00	-0.16	0.00	0.00	0.00	0.00
	CEC (release)	ΣCaX_2, FeX_2, KX, MgX_2, NaX, N4X	0.67	0.31	0.57	0.70	2.19	2.87
	CEC (uptake)	ΣCaX_2, FeX_2, KX, MgX_2, NaX, N4X	-0.43	-0.25	-0.58	-0.50	-2.13	-2.74

Fe-P + SO_4^{2-} → P mobilization

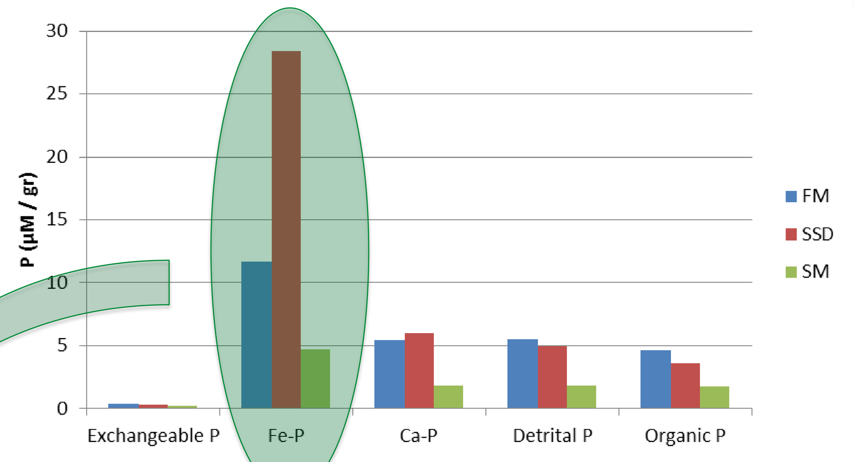


Figure 1
Average values for all five P-fractions, separated per soil type. Values are reported in µM / gr, dry weight.

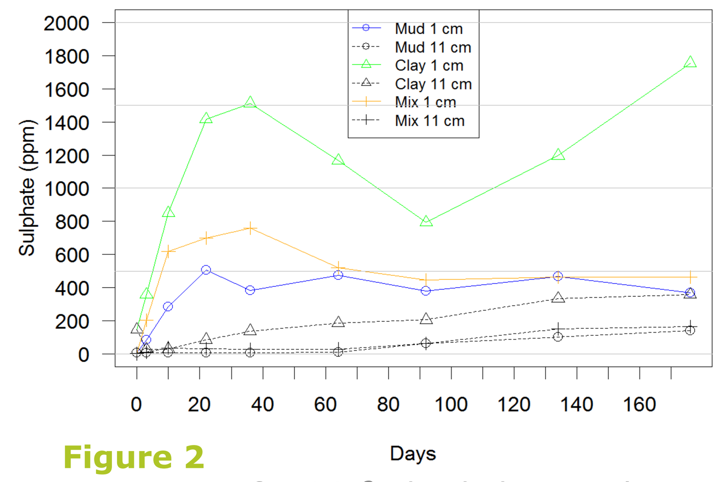
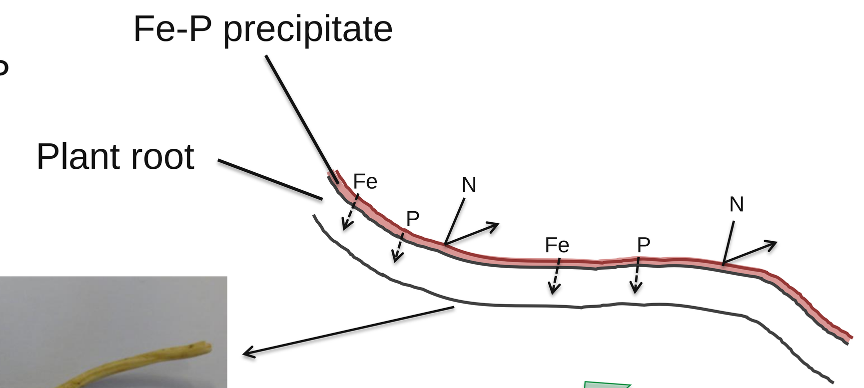


Figure 2
Time series for SO_4^{2-} divided per soil type. Values reported in ppm.

A high pool of Fe-P in soils, combined with high concentrations of SO_4^{2-}, will result in P mobilization when soils become inundated as reduction SO_4^{2-} will lead to reduction of Iron(III)(hydr)oxides and Fe-P.



High Fe-P content in soils promotes **Fe toxicity** for plants by producing iron precipitates on roots.[2]

This will disrupt nutrient metabolism by enhancing uptake of Fe and P while blocking other (micro)nutrients. **Fe toxicity** will lead to reduced growth and plant death.

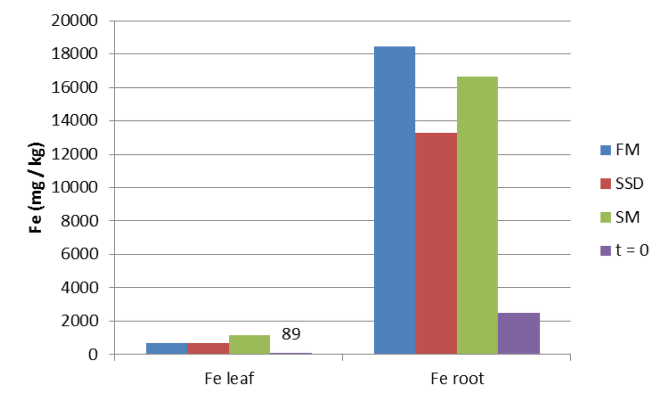


Figure 3
Average values of Fe concentration in plant tissue in leafs and in roots (mg / kg).

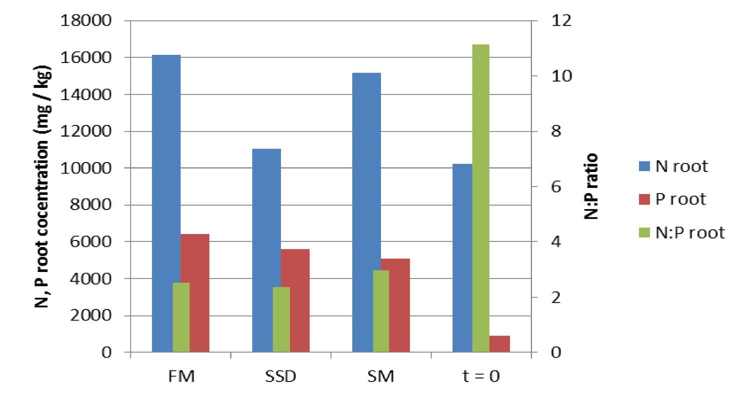


Figure 4
Average values of N and P concentration of root plant tissue (mg / kg) and root N:P ratio.

Conclusions

- Concentrations of SO_4^{2-} rose rapidly as a result of pyrite oxidation at the top-soil.
- Oxygenation at the bottom part of the pot occurred in planted conditions after several weeks due to radial oxygen loss by plant roots, causing an increase in SO_4^{2-} concentrations in porewater.
- Increasing grain size by adding coarse sand to FM soils lead to increased oxygenation by plants.
- Fe-P appeared to be the dominant P pool in all three soils but was twice as high in SSD soils than in FM soils.

- Five weeks after transplantation, plants stopped growing.
- Ten weeks after transplantation, leafs shrivelled green or turned yellow.

Hypothesis

Radial oxygen loss caused Fe-P to precipitate on roots, promoting Fe and P uptake but blocking uptake of N and other micronutrients.

We hypothesize that this mechanism caused reduced plant growth and death and might be an important factor determining ecosystem development on MarkerWadden.

[1]Parkhurst DL (1995). User's guide to PHREEQC - A computer program for speciation, reaction-path, advective-transport, and inverse geochemical calculations: U.S. *Geological Survey Water-Resources Investigations* 95-4227, 143 p.
[2]Snowden RED, BD Wheeler (1995). Chemical Changes in Selected Wetland Plant Species with Increasing Fe Supply, with SpecificReference to Root Precipitates and Fe Tolerance. *New Phytologist* 131: 503-520.