

**Germany may have to pay €850,000 per day
for exceeding EU nitrate levels** (Schulz, 2019)



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**EU mahnt Deutschland wegen
Nitratbelastung** (Nitrat im Grundwasser, 2019)

Ambiente&Clima

**Nitrati agricoli, la Germania
rischia una maxi multa da
850mila euro al giorno**
(Nitrati agricoli, 2019)



**Tribunal de Justicia de la UE condena a
Alemania por exceso de nitrato en agua
subterránea** (Tribunal..., 2018)

(Elsamargriet, 2022)

**L'Allemagne devant la Cour de
justice en raison de la pollution de l'eau par les
nitrates** (L'Allemagne, 2016)

Groundwater nitrate contamination



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Good condition
(up to 50 mg NO₃/l)

Bad condition
(above 50 mg NO₃/l)

(DVGW, 2017)

EU nitrate monitoring network

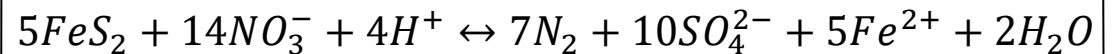
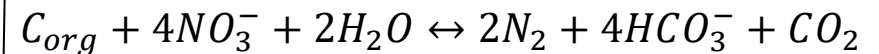
- 700 observation wells (~ 18 % > 50 mg/l)

Problems

Not directly at
the entry point

Time delay

Mixture of
processes

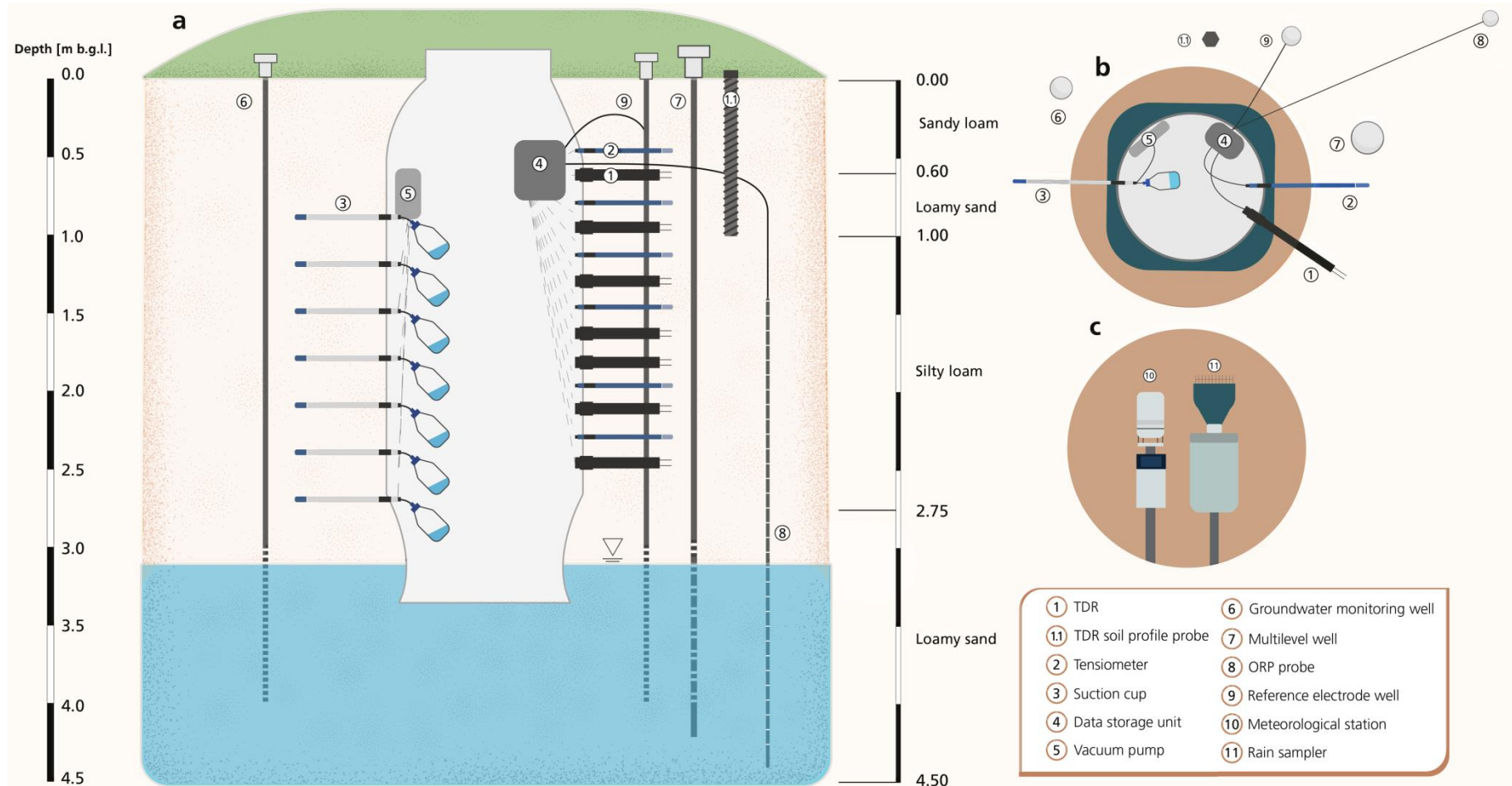


Timely evaluation of measures not possible

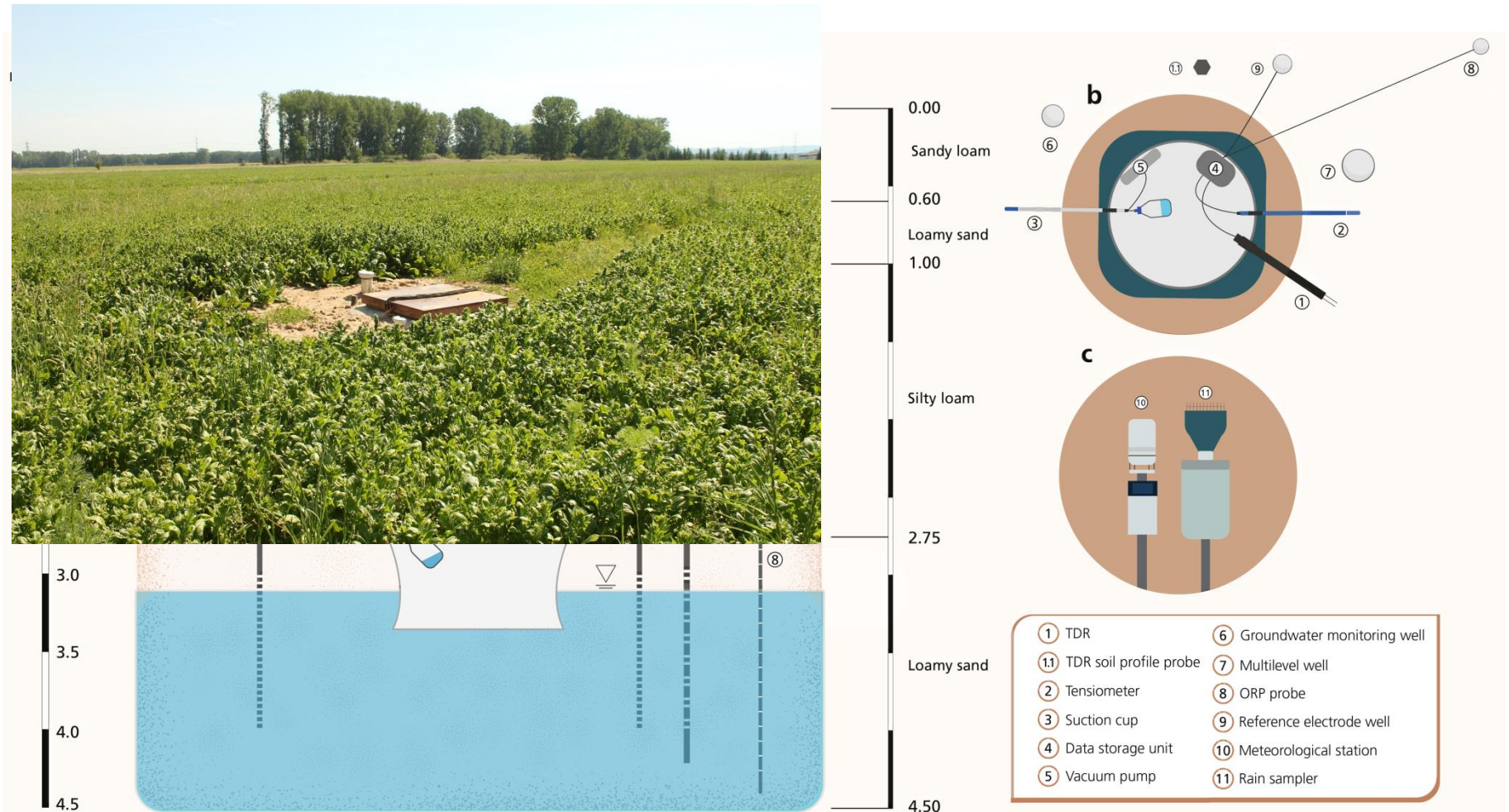
Solution approach

- Monitoring directly at the entry point

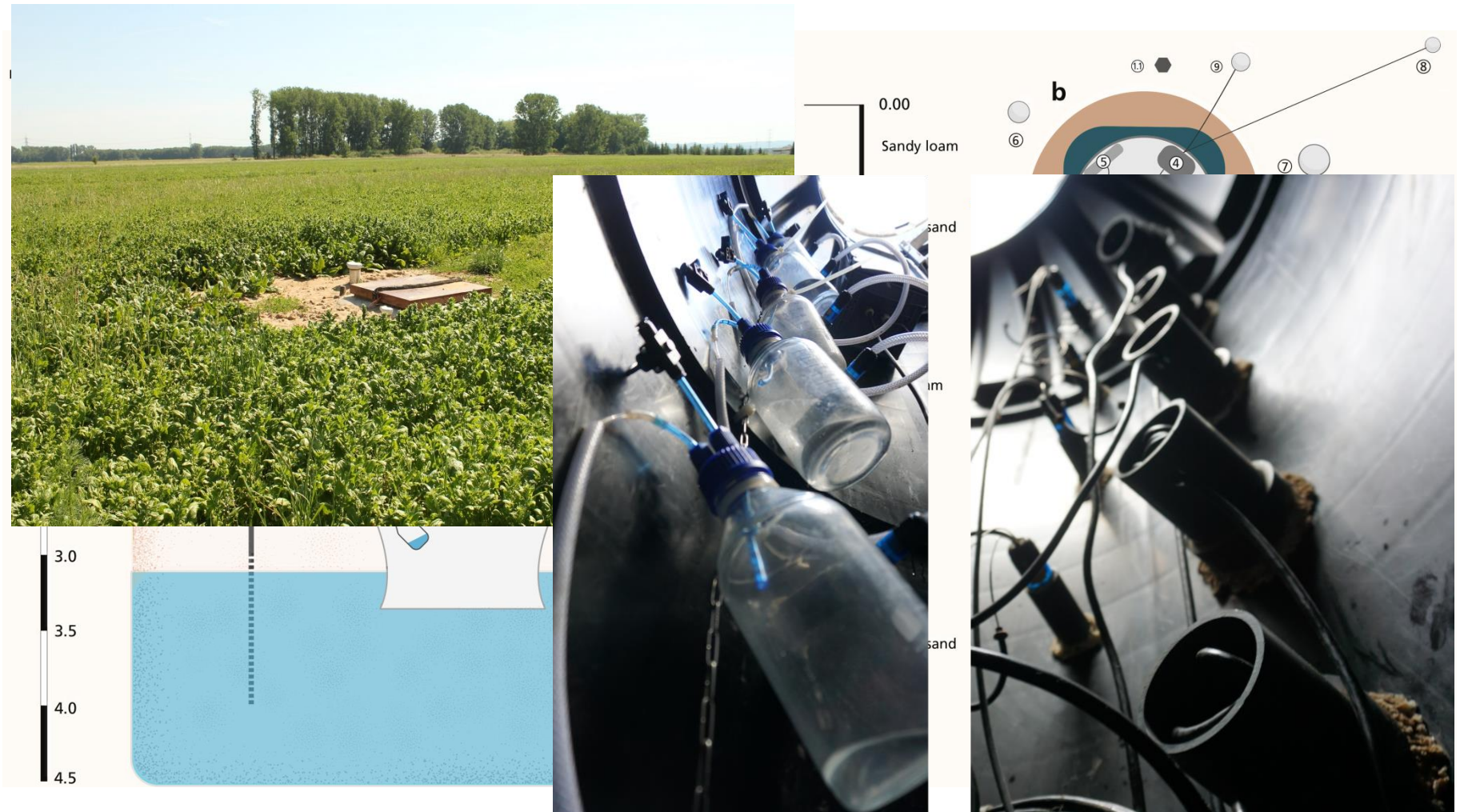
Combined modeling and high-resolution monitoring approach for the assessment of nitrate-related redox processes at an agricultural site



Combined modeling and high-resolution monitoring approach for the assessment of nitrate-related redox processes at an agricultural site

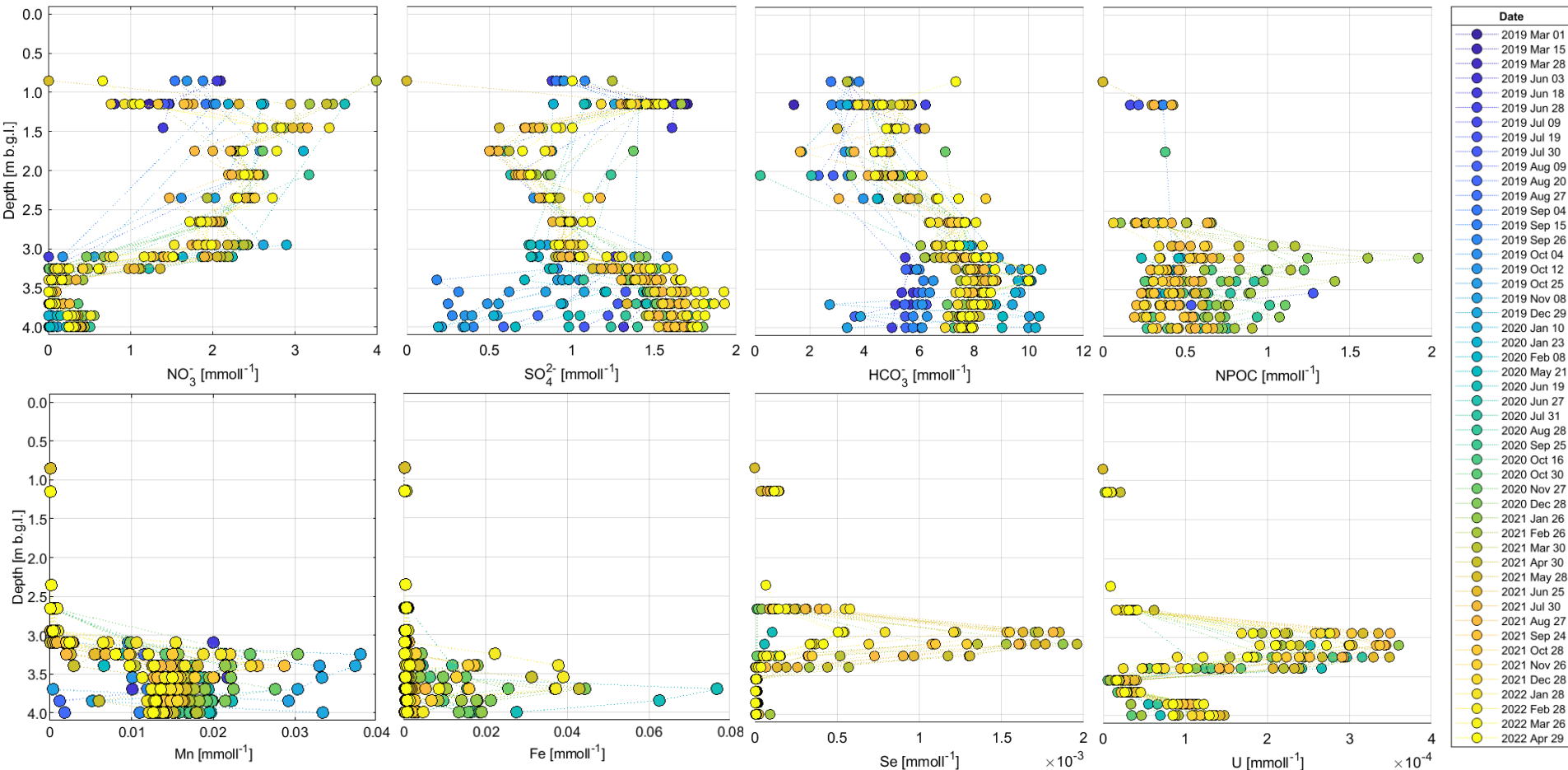


Combined modeling and high-resolution monitoring approach for the assessment of nitrate-related redox processes at an agricultural site



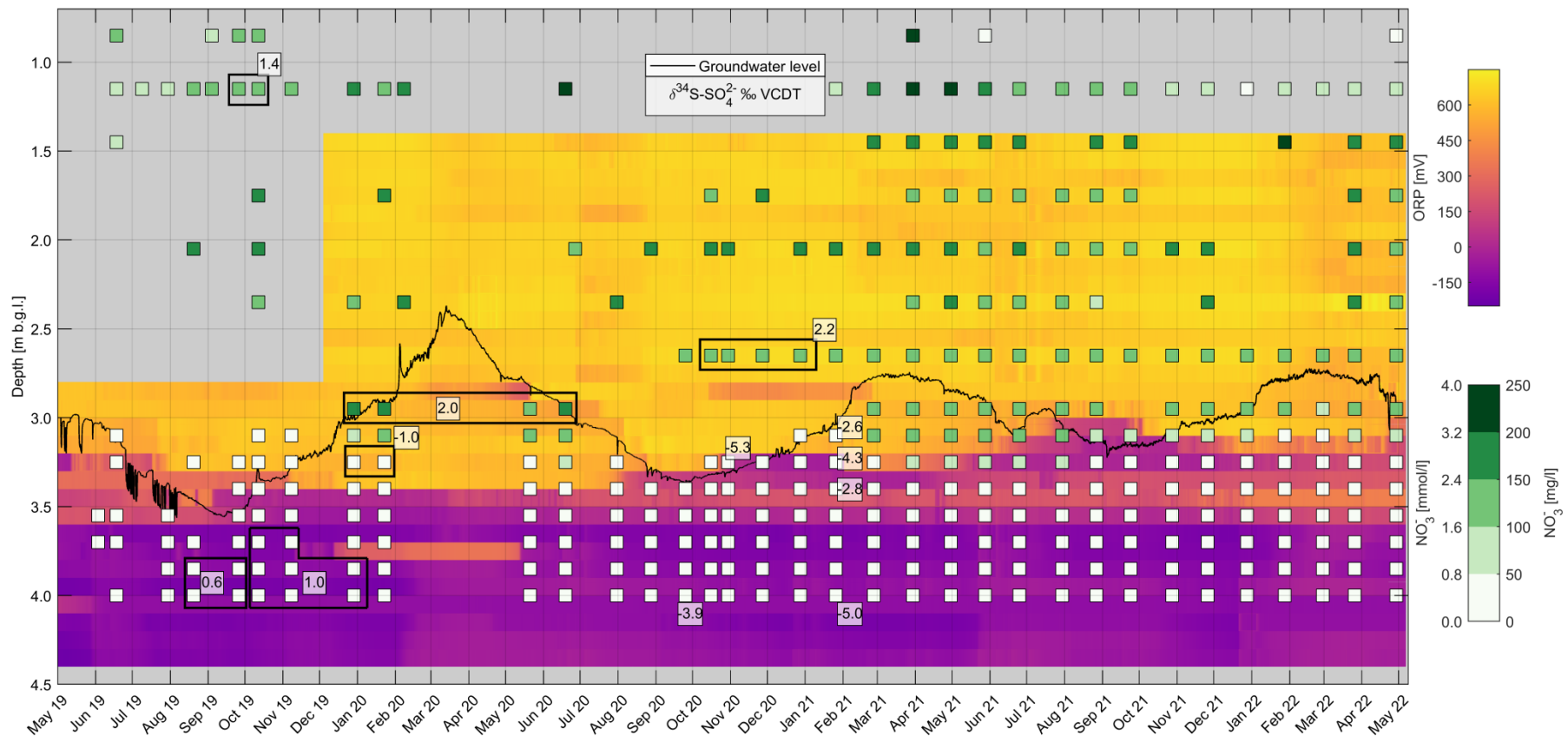
Monitoring – Redox sensitive species

- Redoxcline at $\sim 300 \pm 10$ cm b.g.l.
- Trace elements mobilization



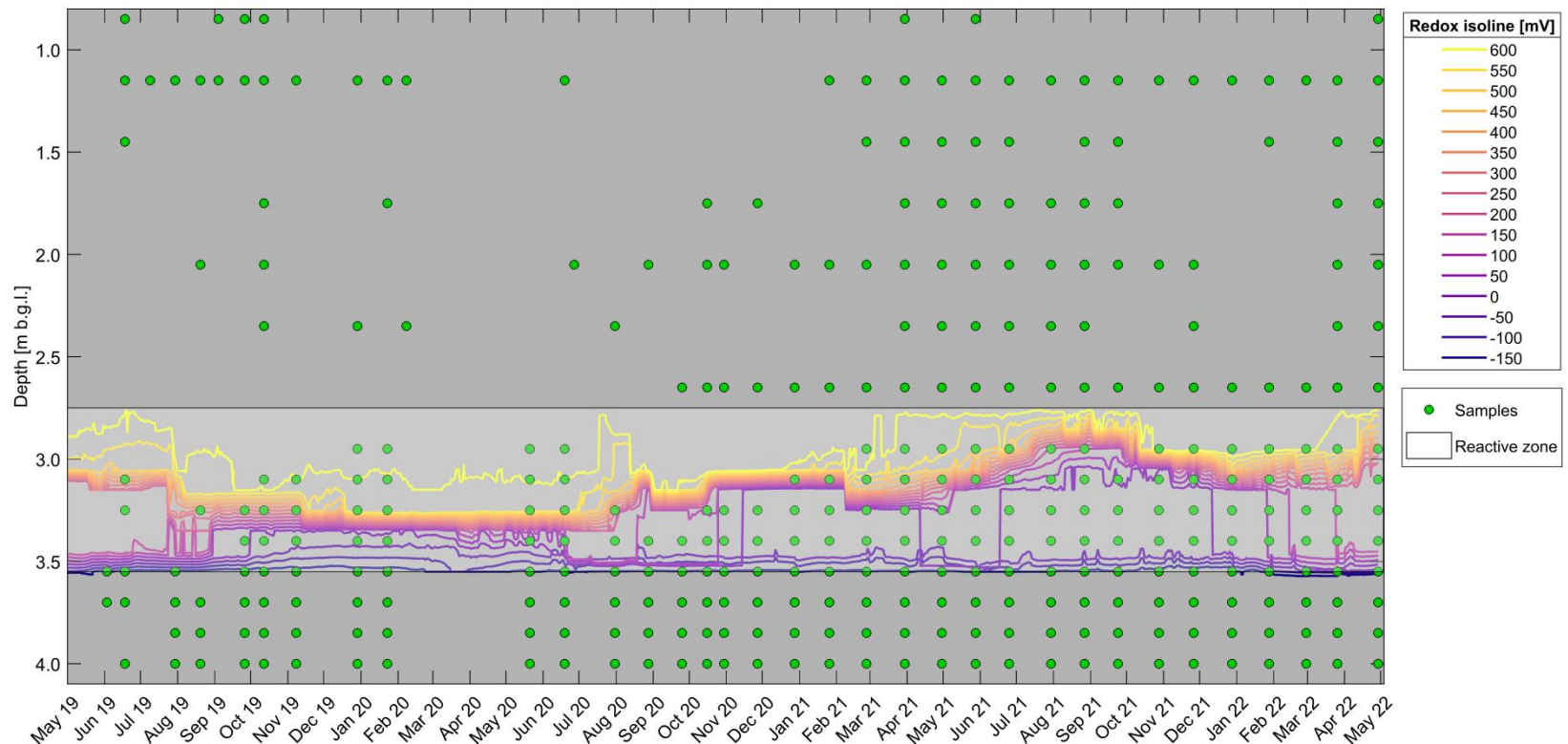
Monitoring – ORP, NO_3^- , $\delta^{34}\text{S}\text{-SO}_4^{2-}$, GWL

- Transient behavior of ORP
- Evidence of lithotrophic denitrification



Mass balance

$$\int_{z_1}^{z_2} \theta_t(z) \cdot C_t(z) dz = \int_{z_1}^{z_2} \theta_{t-1}(z) \cdot C_{t-1}(z) dz + Q_{in} \cdot C_{in} - Q_{out} \cdot C_{out} + \Delta m_{rx}$$

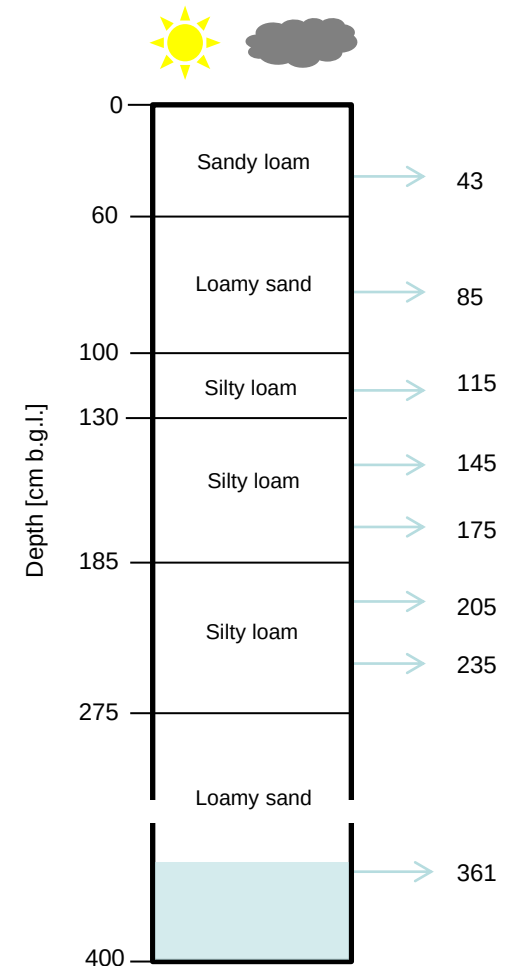


Water & heat transport model - Hydrus

- 3 years (hourly scale)
- 4 different crops – spinach, dill, wheat, sunflower

Variable	Number of observations	RMSE	NRMSE
Matric potential	133,885	102 cm	0.11
Volumetric water content	159,236	0.02 cm ³ ·cm ⁻³	0.06
Temperature	185,117	1.3 °C	0.05

- Sensitivity analysis (LH-OAT)
 - GWR: n(L1), n(L4), n(L5)
 - θ in reactive zone: θ_s (L6)



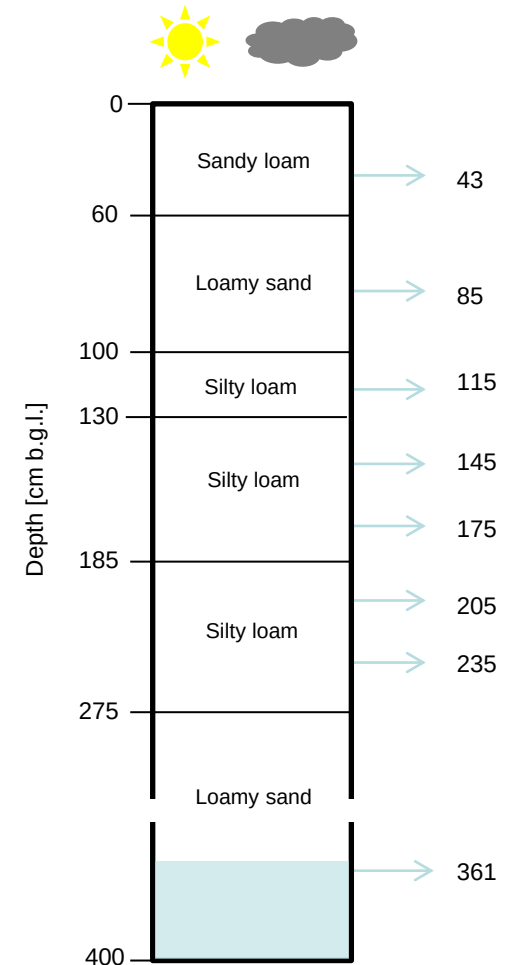
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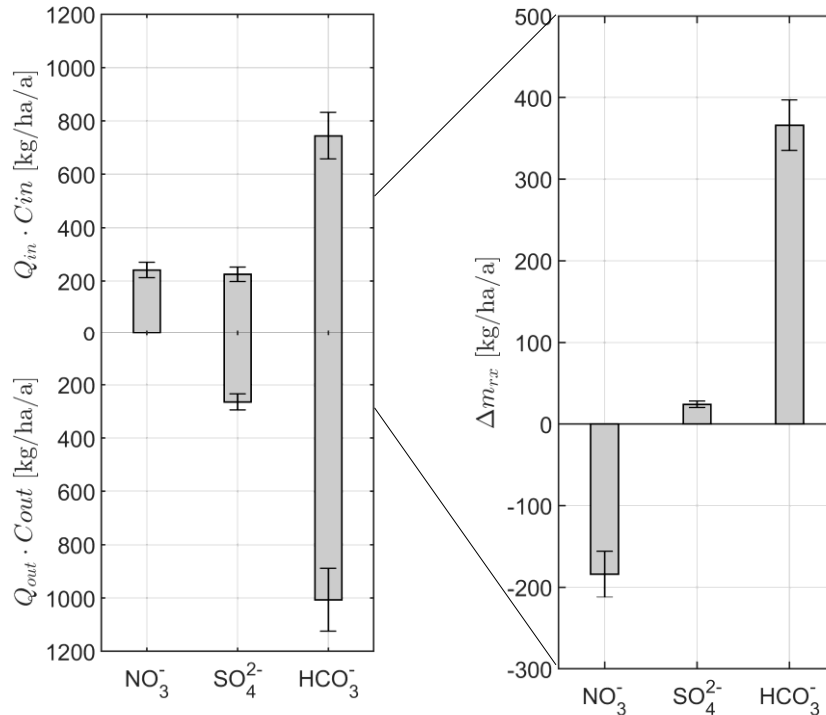
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GW Recharge = 234 ± 28 mm/a
 $36 \pm 4\%$ of precipitation



Results

$$\int_{z_1}^{z_2} \theta_{tf}(z) \cdot C_{tf}(z) dz = \int_{z_1}^{z_2} \theta_{t0}(z) \cdot C_{t0}(z) dz + Q_{in} \cdot C_{in} - Q_{out} \cdot C_{out} + \Delta m_{rx}$$



- NO_3^- into GW 241 ± 29 kg/ha/a
- SO_4^{2-} production 24 ± 4 kg/ha/a
- $\sim 8.4 \pm 0.7\%$ of the denitrification is lithotrophic
- HCO_3^- production 366 ± 31 kg/ha/a
- HCO_3^- also produced and consumed in other processes

Combined modeling and high-resolution monitoring approach for the assessment of nitrate-related redox processes at an agricultural site



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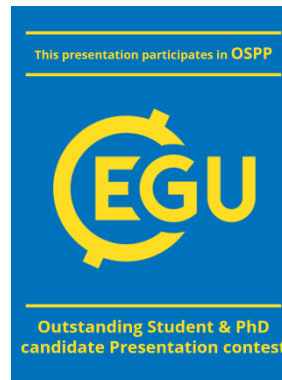
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