Microbial phosphorus processing in a gradient of agricultural soil development following mining activity

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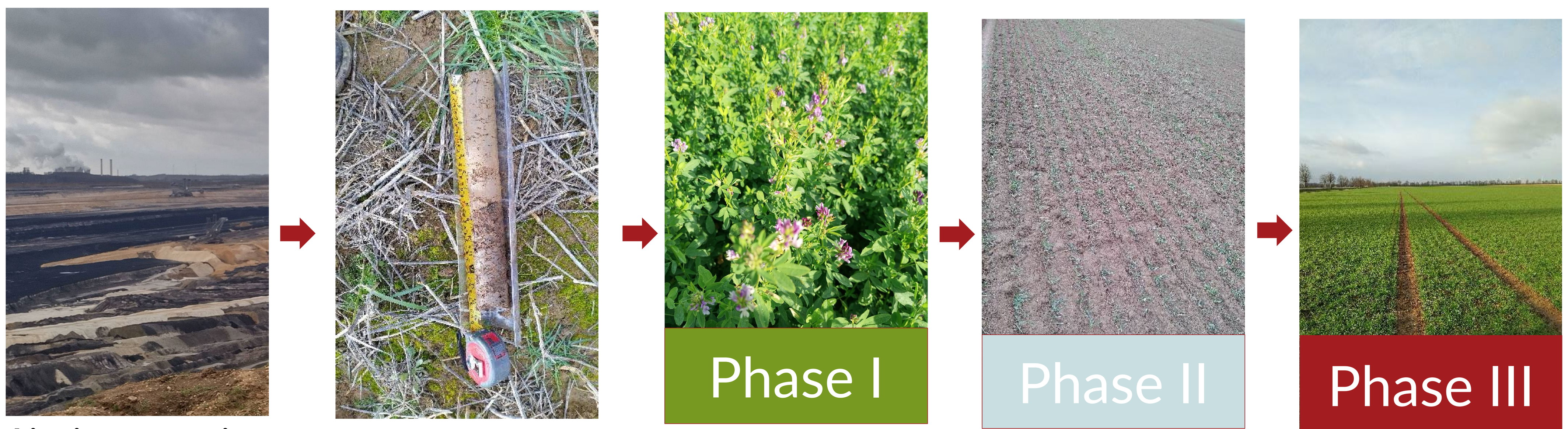
INTRODUCTION

- Microorganisms are the key driver of soil phosphorus (P) cycling.
- Promoting their role in agricultural systems to support crop production to shift reliance away from non-renewable mineral P inputs.
- But, poor understanding of how soil P status, soil microorganisms, and soil properties interactively determine P supply to plants.
- **Main objective: characterizing the soil P × soil microorganisms × soil properties interaction promoting microbial P cycling along a unique managed gradient of soil development.**

METHODS

1. Experimental site: Inden mine (RWE), Germany (Fig. 1).
2. Collected soils: soils restored from 2022 – year 0 (Phase I), 2018 – year 5 – (Phase II), 1964 – year 59 (Phase III) and an original soil undisturbed.
3. Soil properties: range of physico-chemical soil properties, Hedley P fractionation, ion-exchange kinetics (IEK).
4. Biological P cycling: soil incubations with ^{18}O-enriched water and ^{33}P labelling.



Lignite extraction | **Year 0:** Mix of soil and loess + basal mineral fertiliser | **Year 2-3:** permanent *Alfalfa* + biomass mulching | **Year 4 to 7:** cereal crops + initial green waste compost (30 t ha^{-1}) + mineral fertiliser y^{-1} | **Year 5-…:** Farmer managed (sugar beet-winter wheat crop rotation) + organic and mineral fertilisation

***FIGURE 1:** Inden mine soil recultivation process*

RESULTS

- Decrease in pH and $CaCO_3$ over time ($P < 0.0001$) (Table 1).
- Increase in SOC, oxalate-Fe & Al, microbial biomass C & P, Ptot and P exchangeability (E_{1min}) over time ($P < 0.05$) (Table 1).
- Decrease in the relative size of the most labile-P pools (Resin-, $NaHCO_3$-, and NaOH-) between year 0 and 5. Then, proportion of the most labile-P pools increased again in Phase III. The original soil had the greatest proportion of more labile-P pools (±50%) (Fig. 2).
- Decrease in P reactivity and turnover time of P in soil solution ($P < 0.0001$).

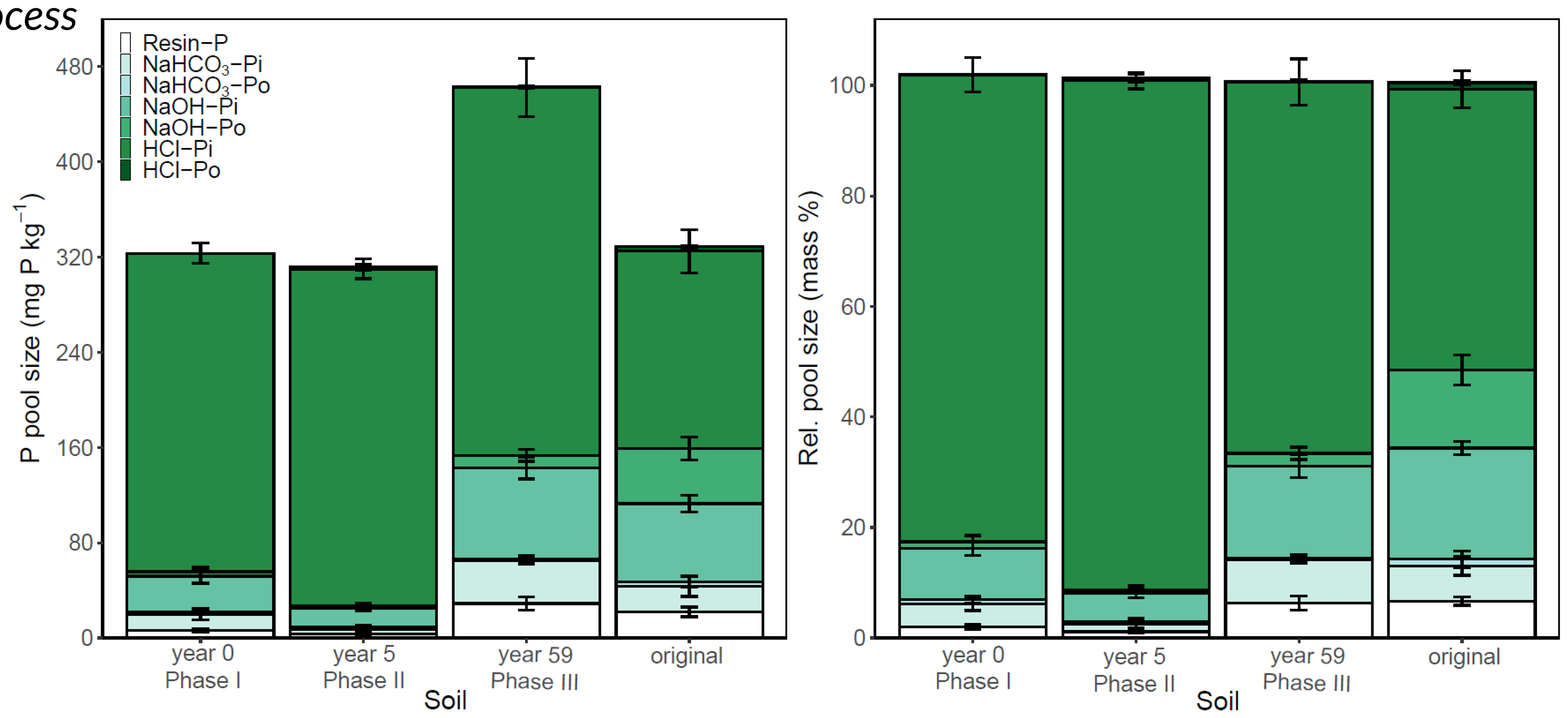


***FIGURE 2:** Sequential fractions of Resin-, $NaHCO_3$-, NaOH- and HCl- extractable inorganic (Pi) and organic P (Po) (n=5; error bar = standard deviation)*

***TABLE 1:** Selected soil properties along the Inden mine recultivation gradient*

Soil properties	year Phase I	year 5 Phase II	year 59 Phase III	Original soil
pH_{H2O}	8.0±0.1	7.9±0.1	7.6±0.1	7.3±0.1
SOC (g kg^{-1})	0.54±0.04	0.51±0.17	1.24±0.07	1.62±0.05
$CaCO_3$ (%)	35.9±3.2	49.0±3.1	7.8±4.5	6.7±2.7
Oxalate-Fe (g kg^{-1})	1.46±0.11	1.21±0.06	2.08±0.28	2.75±0.19
Oxalate-Al (g kg^{-1})	0.74±0.04	0.69±0.02	0.81±0.05	0.75±0.03
Mic-C (mg kg^{-1})	140±42	59±22	263±56	368±65
Mic-P (mg kg^{-1})	6±3	3±1.5	17±6	23±9
$Ptot_{Aqua\ Regia}$	442±24	412±10	698±23	537±38
P reactivity ((r(1)/R) - IEK)	0.25±0.06	0.21±0.03	0.47±0.04	0.61±0.03
E_{1min} (mg kg^{-1}) (IEK)	3.2±1.2	1.0±0.1	12.4±1.9	9.9±2.5
Solution P turnover (Km (min^{-1}) - IEK)	46.1±29.5	36.4±15.0	8.0±3.5	2.4±0.7
Cumulative gross P mob (15 days)	ND	ND	22.0±8.6	31.4±6.0

- Cumulative gross P mobilization over 15 days could not be determined in years 0 & 5 and remained greater in the original soil.
- The $\delta^{18}O$-P_{resin} and $\delta^{18}O$-P_{hex} of the OR soil increased by several permil during the incubation ($P < 0.0001$). In the 1964 only a significant increase was observed in the $\delta^{18}O$-P_{resin} ($P < 0.0001$). No significant changes were detected for the 2022 soil ($P > 0.05$).

DISCUSSION & CONCLUSION

- Soil P content and exchangeability regained the original soil levels.
- Microbial P processing is highly correlated with total soil organic C and did not reach the original soil rates.
- Difficulties to measure gross P mobilization in soils of year 0 & 5 because of the high $CaCO_3$ and very soil solution P concentrations.
- **Despite measured P levels similar or surpassing those of the original soil in the oldest soils, biologically-driven P cycling has not fully recovered more than 50 years after soil re-cultivation.**

Acknowledgments: Nelly S. Raymond acknowledges the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement No MSCA-HE-2021 No. 101064654 for supporting the research and the participation to EGU25

Marie Skłodowska-Curie Actions

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