



# Understanding the Phosphorus Cycling Strategies of Beech Forest Ecosystems along a Natural Soil Phosphorus Gradient: Observational Evidence and Modeling Challenges



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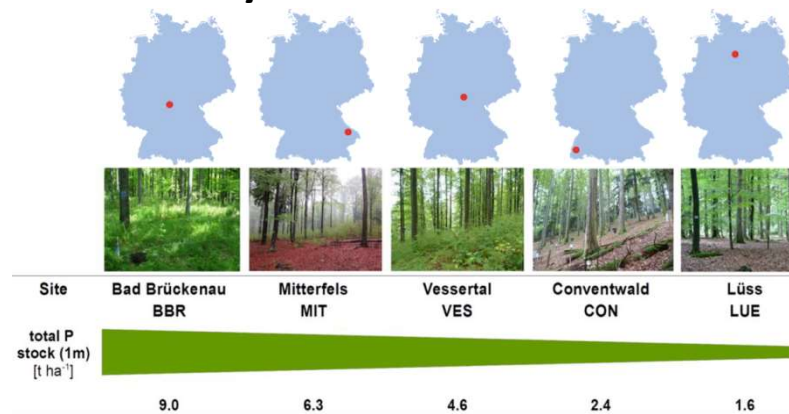
*SP<sup>P</sup>* 1685

# 1 Study sites: SPP1685-Ecosystem nutrition

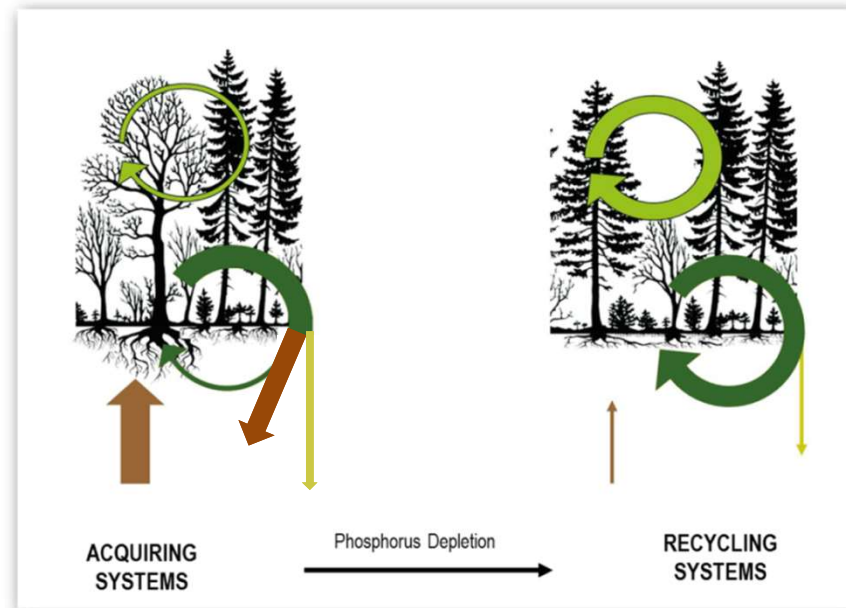
- Plants and microorganisms of P-rich forests carry over mineral-bound P into the biogeochemical P cycle (**acquiring strategy**). In contrast, P-poor ecosystems establish tight P cycles to sustain their P demand (**recycling strategy**).

<https://www.ecosystem-nutrition.uni-freiburg.de/>

## Study sites along a natural soil P gradient in Germany



Lang et al. 2016, 2017



## 2 Observed signals along the soil P gradient

1. **Vegetation:** NO systematical trends observed in foliar N and P contents, tree height, basal area, and tree volume [1]
2. **Vegetation:** Higher leaf P resorption in low-P forest [2]
3. **Soil:** decreasing litter turnover, increasing soil CP ratio, increasing fine root C, decreasing fine root P content [1,3]
4. **Soil:** decreasing SOC, **soil organic N**, increasing **soil CN ratio**, and **CP ratio** [3]
5. **Soil:** higher phosphatase activity in low-P soil [2,4]
6. **Soil:** biological processes (mineralization/microbial uptake) dominant in low-P soil, while geophysical processes (diffusion & adsorption) dominant in high-P soil [5,6]

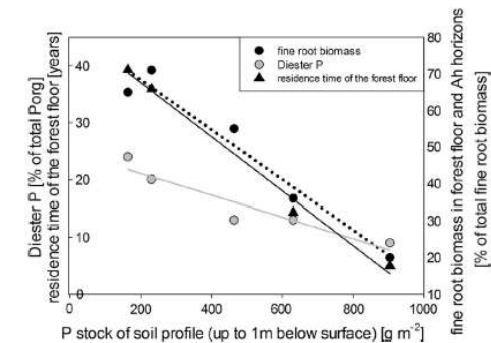
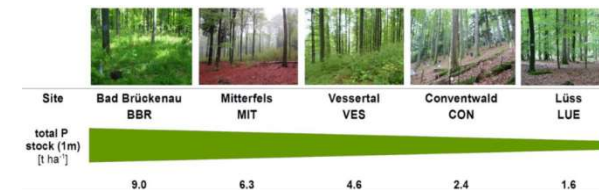


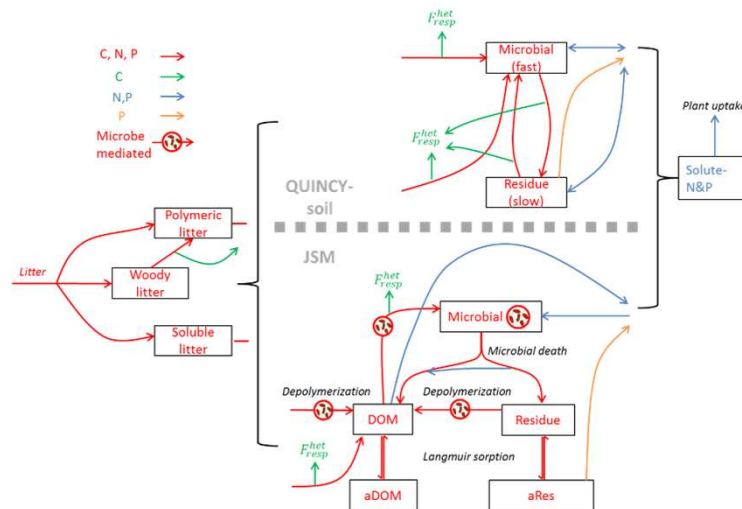
Fig. 3 Three of the soil properties applied as indicators for the recycling strategy against the total P stock of the soil at the five study sites



- [1] Lang et al. 2017, *Biogeochemistry*  
 [2] Hofmann et al. 2016, *Oecologia*  
 [3] Yu et al. 2020a, *Front. For. Glob. Change*  
 [4] Spohn et al. 2018, *SBB*  
 [5] Bünemann et al. 2016, *SBB*  
 [6] Pistocchi et al. 2018, *SBB*

### 3 Challenges in ecosystem modeling

- 1) fixed first-order kinetics of decomposition
- 2) lack of mechanisms for soil C storage/stabilization
- 3) lack of explicit microbial dynamics and processes
- 4) fixed stoichiometry in plant and soil
- 5) lack of dynamic plant C allocation to roots and root exudation
- 6) Lack of competition between plant-soil-microbe and C cost for P mobilization

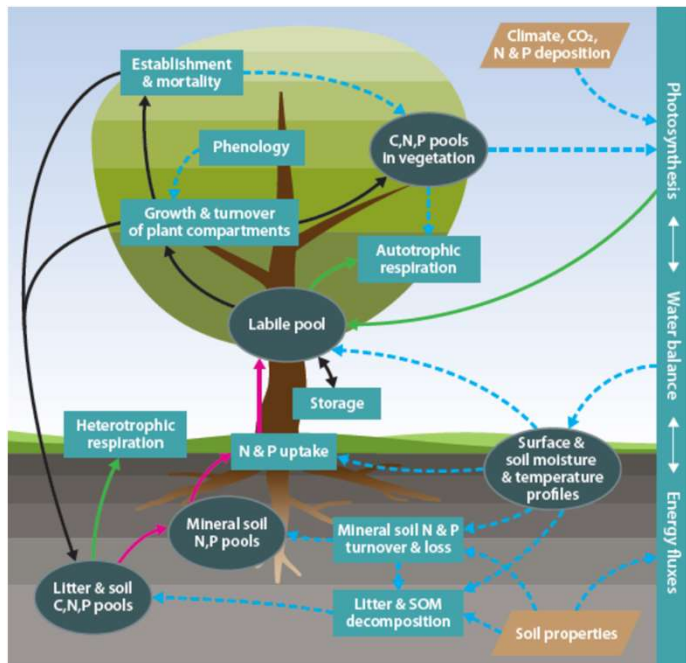


Schematic comparison between a first-order decomposition model (QUINCY-soil) and microbial SOC model (JSM)

Yu et al. 2020a, Front. For. Glob. Change

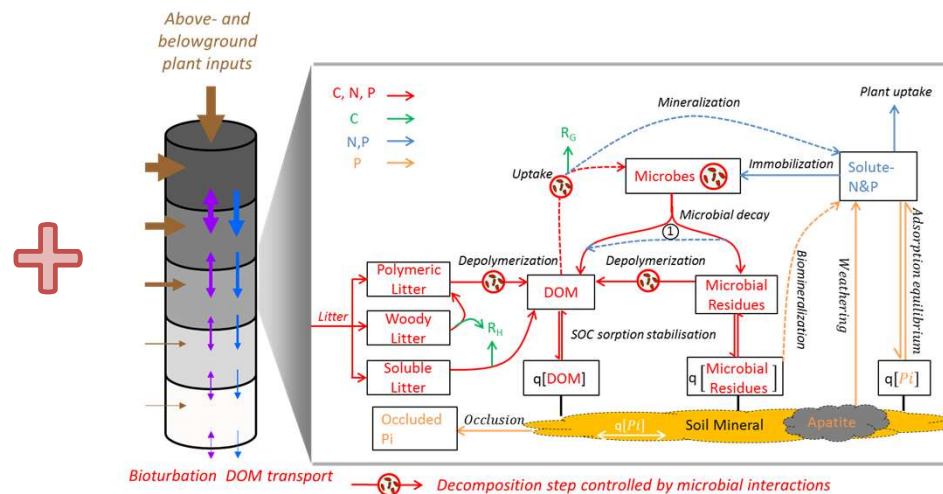
# 4 Proposed model framework: QUINCY-JSM

## Land surface model: QUINCY



Thum et al. 2019, GMD

## Jena Soil Model (JSM)



Yu et al. 2020b, GMD

# 5 Results: soil profiles and their trends along soil P gradient

- JSM is capable of reproducing observed soil CNP profiles and microbial CNP contents
- QUINCY-JSM is better reproducing the observed trends in SOC, N, P and CN ratio than QUINCY with conventional soil module

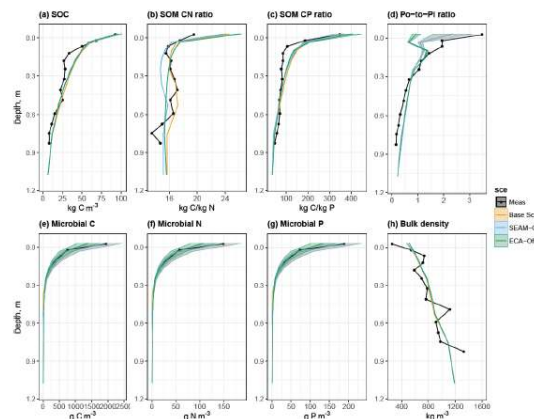


**Figure 3.** Simulated and observed (a) SOC content, (b) C : N ratio in SOM, (c) C : P ratio in SOM, (d) organic-P-to-inorganic-P ratio in soil, (e) microbial C content, (f) microbial N content, (g) microbial P content and (h) soil bulk density at the study site up to 1 m soil depth. Black lines and dots: observations; coloured lines and shades: simulated mean values and ranges of standard deviation by different model experiments in Sect. 2.3. Microbial C, N and P values were only measured in the top 30 cm of soil. Simulated means and standard deviations were calculated using data from the last 10 years of model experiments.

| Sce/Var     | SOC  | SON  | SOP  | SIP  | CNr | CPr  |
|-------------|------|------|------|------|-----|------|
| Measurement | -0.6 | -1   | -0.1 | -0.8 | 0.6 | 0.8  |
| JSM         | -0.6 | -0.4 | -0.6 | -0.8 | 0.6 | 0.2  |
| QUINCY-JSM  | -0.8 | -0.8 | -0.8 | -0.8 | 0.8 | -0.2 |
| QUINCY      | 0.2  | 0.2  | 0.2  | -0.6 | 0.2 | 0    |

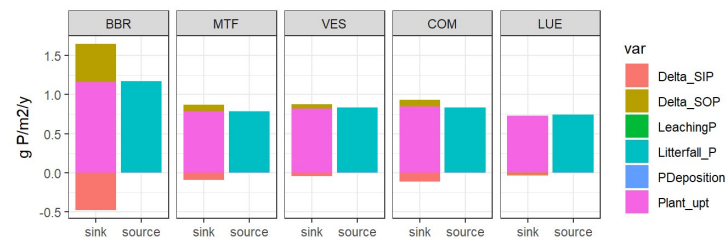
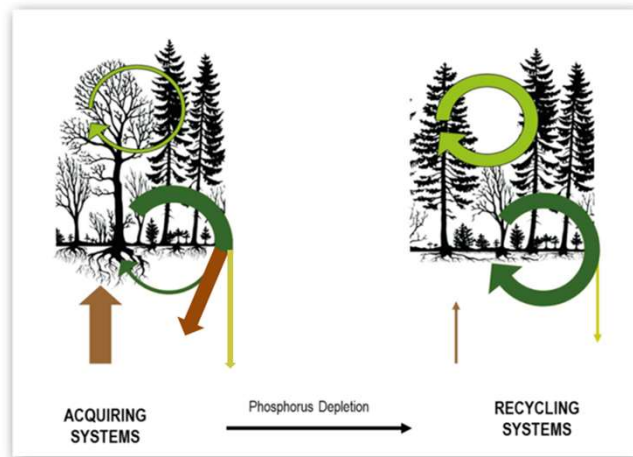
The tau ( $\tau$ ) values of Mann-Kendall trend test for main soil variables along the decreasing soil P stock gradient (**BBR>MTF>VES>COM>LUE**) of field measurements, stand-alone **JSM**, coupled **QUINCY-JSM**, and **QUINCY**.

$\tau = -1$  indicates a significant **decreasing** trend while  $\tau = 1$  indicates a significant **increasing** trend

Yu et al. 2020a, b

## 6 Results: QUINCY-JSM soil phosphorus budget

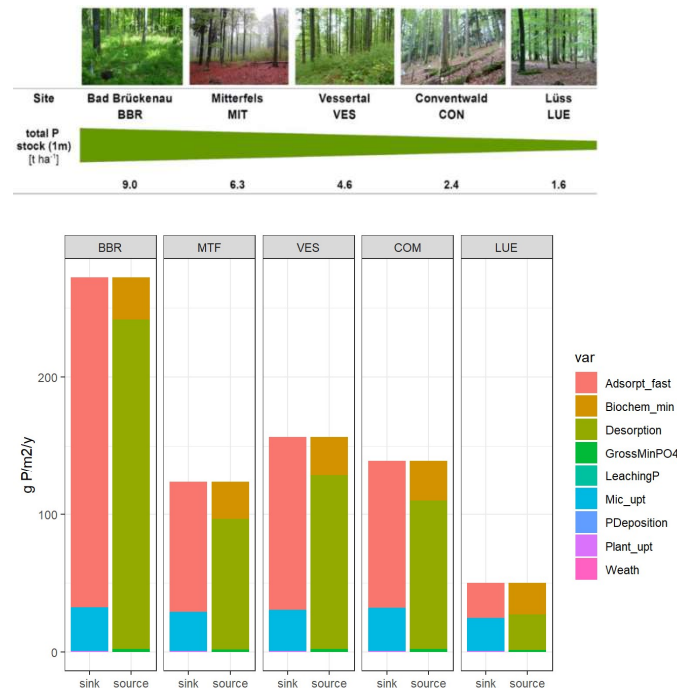
- QUINCY-JSM results are supporting the hypothesis of Lang et al. (2017) that an “acquiring system” brings the mineral-bound P into biogeochemical cycle while a “recycling system” establish tight organic P cycle.



Simulated annual soil phosphorus budget (g P/m²/y) of the study sites along soil P gradient. The soil P sinks include: Changes of soil inorganic P (Delta\_SIP), changes of soil organic P (Delta\_SOP), plant uptake and leaching; The soil P sources include: P in litterfall and P deposition. Plot is produced using simulation results from 2006 to 2015.

## 7 Results: QUINCY-JSM soil solution P budget

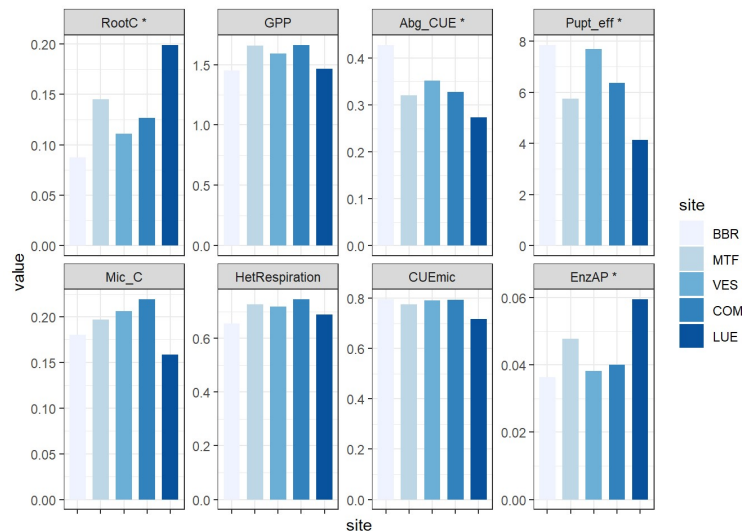
- The shift from an “acquiring system” to a “recycling system” seems to be largely regulated by adsorption and diffusion, while the size of biological processes remain comparable among sites



Simulated annual phosphorus budget (g P/m<sup>2</sup>/y) in topsoil (0-30 cm) solution of the study sites along soil P gradient. The soluble P sinks include: adsorption, microbial P uptake, plant P uptake, and leaching; The soluble P sources include: biochemical P mineralization, gross P mineralization, desorption, P deposition and weathering. Plot is produced using simulation results from 2006 to 2015.

## 8 Results: Effects of soil P availability on plant-soil-microbe C cycle

- Soil P availability does not affect GPP but affects root C allocation and aboveground C growth
- P-poor system has higher root C allocation but lower P uptake efficiency
- Microbial biomass seem not correlate with soil P availability until high P stress
- Phosphatase (EnzAP) production is affected by soil P availability



Simulated fine root C ( $\text{kg C/m}^2$ ), GPP ( $\text{kg C/ m}^2/\text{y}$ ), aboveground carbon-use-efficiency, plant P uptake efficiency ( $\text{g P/g C root/y}$ ), microbial C ( $\text{kg C/ m}^2$ ), heterotrophic respiration ( $\text{kg C/ m}^2/\text{y}$ ), microbial carbon-use-efficiency, and phosphatase abundance (normalized to microbial C,  $\text{kg C/m}^2$ ) of the study sites along soil P gradient. Plot is produced using simulation results from 2006 to 2015. The asterisk indicates a slight trend, i.e.  $\tau$  value of Mann-Kendall trend test larger than 0.6 or smaller than -0.6

## 8 Summary

- Beech forest can adapt to varying soil P availabilities by establishing different P cycling strategies. It leads to more profound observational differences in soils than in plants.
- State-of-art models don't have all the necessary mechanisms to simulate such adaptability, especially due to the inadequate representations of soil BGC processes and plant-soil interactions
- We have developed a mechanistic soil model which is microbially and vertically explicit and coupled it to a novel land surface model, forming the new model framework QUINCY-JSM. The new model allows us to tackle some of the challenges in modeling the different P cycling strategies of beech forests, and reproduce some of the observed patterns under different soil P availabilities.