# The Exchange of Inorganic Phosphorus between Soil Solution and Matrix might Largely Affect the Model Predictions of Terrestrial Carbon Cycle

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QUINCY

Max Planck Institute for Biogeochemistry

SPP 1685

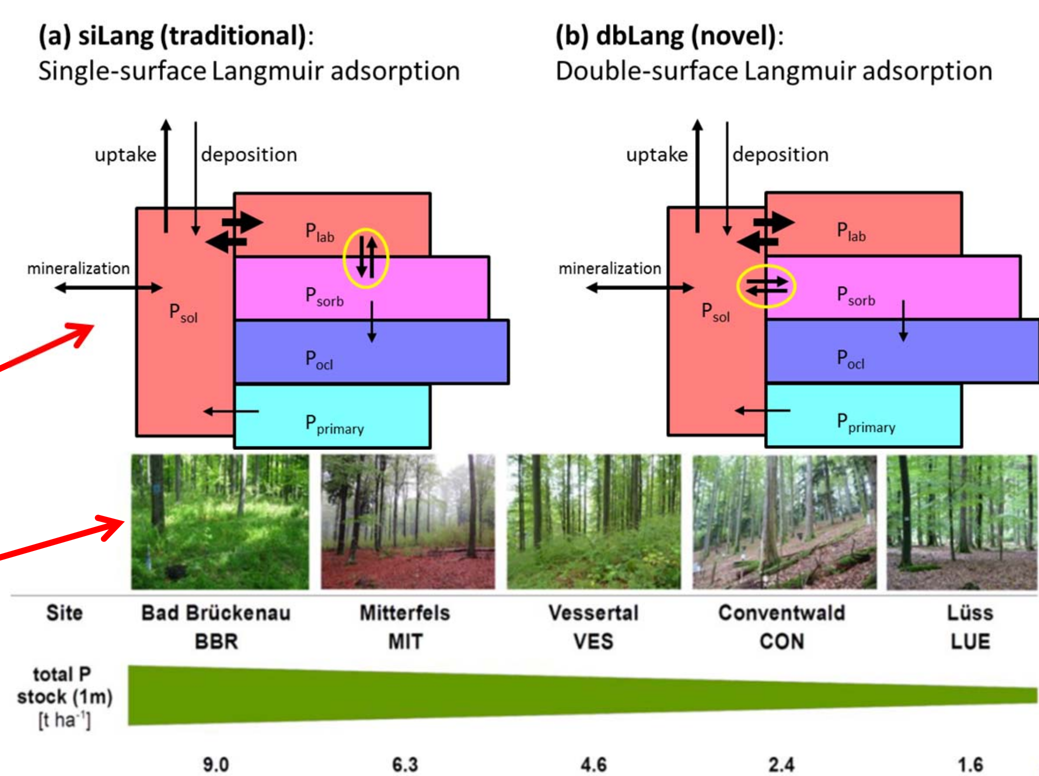
DFG

# Display Summary

❶ Background (slide 3):
- Phosphorus (P) availability affects the terrestrial carbon (C) cycle
- Current Terrestrial Biosphere Models (TBMs) failed to reproduce the ecosystem responses to elevated $CO_2$ in P-limited ecosystems

❷ Methods (slide 4):
- QUINCY TBM
- Two inorganic P (Pi) accessibility schemes: Single-surface Langmuir (**siLang**) and double-surface Langmuir (**dbLang**) isotherms
- ***Study sites along a soil P gradient***
- Sensitivity tests

❸ Results and discussion (slides 5-7):
- **dbLang** was much better capturing the observed soil Pi pool sizes (slide 5)
- **dbLang** was better in reproducing the observed leaf P and aboveground C (slide 6)
- **siLang** lead to stronger P limitation of GPP than **dbLang** (slide 7)



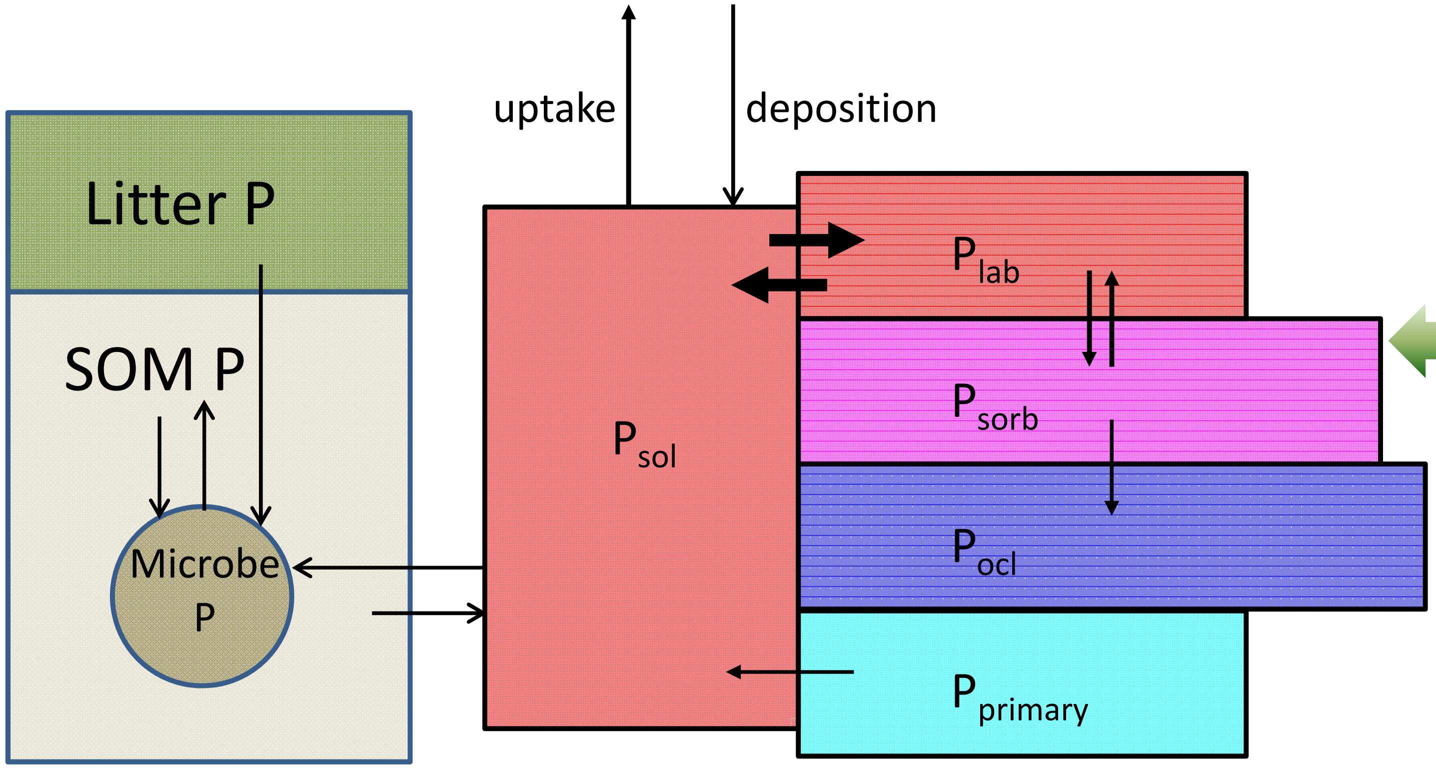

❹ Conclusion and outlook (slide 8):
- The Pi exchange between solution and soil matrix was better described with the novel model (**dbLang**)
- GPP may be overly constrained by P in TBMs using traditional scheme (**siLang**), particularly in P-poor sites.
- At extreme low-P ecosystems, organic P cycling and its interactions with Pi cycling (Yu et al. 2020) might be the key to solve the puzzles.

# ❶ Background

- Phosphorus availability is one key factor regulating the ecosystem productivity and carbon (C) balance (Fernández-Martínez et al., 2014; Wieder et al., 2015; Terrer et al. 2019).
- The responses to elevated $CO_2$ of ecosystems like the Amazon rainforests and *Eucalyptus* forests have shown clear symptoms of P limitation, which are not reproduced by current TBMs (Fleischer et al., 2019; Jiang et al., 2020)
- ***The plant productivity is constrained by P uptake, which is STRONGLY affected by the exchange of phosphate between solution and soil matrix, i.e. phosphate sorption and desorption***

**Organic P cycling** in most TBMs is featured with several litter pools, two or three SOM pools including one implicit microbial pool; transfer fluxes between pools are commonly described with first-order kinetics

**TBMs** that use this scheme include: Wang et al. 2010, Goll et al. 2012, Yang et al. 2014, Zhu et al. 2016, Goll et al. 2017, Thum et al. 2019




Schematic figure of soil P cycling in TBMs, reproduced from Thum et al. (2019)

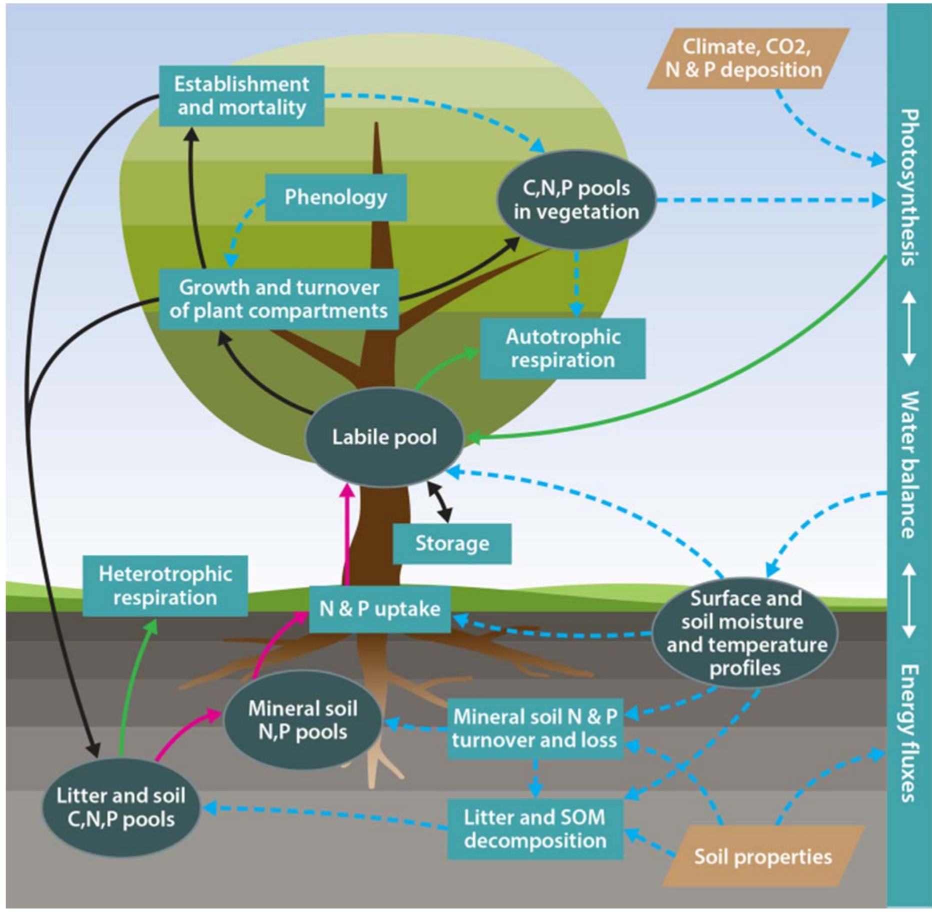
**Inorganic P (Pi) cycling** in most TBMs is featured with a five-pool structure: soluble Pi ($P_{sol}$), labile Pi ($P_{lab}$), sorbed Pi ($P_{sorb}$), occluded Pi ($P_{ocl}$), and primary P. Langmuir isotherm is used to described the exchange between $P_{sol}$ and $P_{lab}$, and all the other fluxes are described using first-order kinetics.

# ❷ Methods

- QUINCY Model:
  - ➢ QUINCY (Quantifying Interactions between terrestrial Nutrient CYcles and the climate system) is a novel land surface model with fully coupled C, N, P and water cycles.

  [Model description] [Code availability]

- Sites and data:
  - ➢ Five beech forest sites in Germany along a soil P stock gradient, within the DFG funded priority programme [SPP1685 Ecosystem Nutrition]
  - ➢ Measured SOC, N, and P and [Hedley Pi] pools at different soil depths; Leaf N and P contents measured in August.
- Model scenarios
  - ➢ **dbLang**: Both labile Pi and sorbed Pi exchanges with soluble Pi, which are constrained by two different sorption capacities of Langmuir isotherm
  - ➢ **siLang**: Only labile Pi exchange with soluble Pi using Langmuir isotherm, sorbed Pi exchanges with labile Pi
  - ➢ **Control**: Soluble Pi is constant to avoid P limitation
- Sensitivity analysis
  - ➢ 16 parameters of P cycling processes, varied ±20% of default values, 1000 Latin hypercube samplings for both **siLang** and **dbLang**

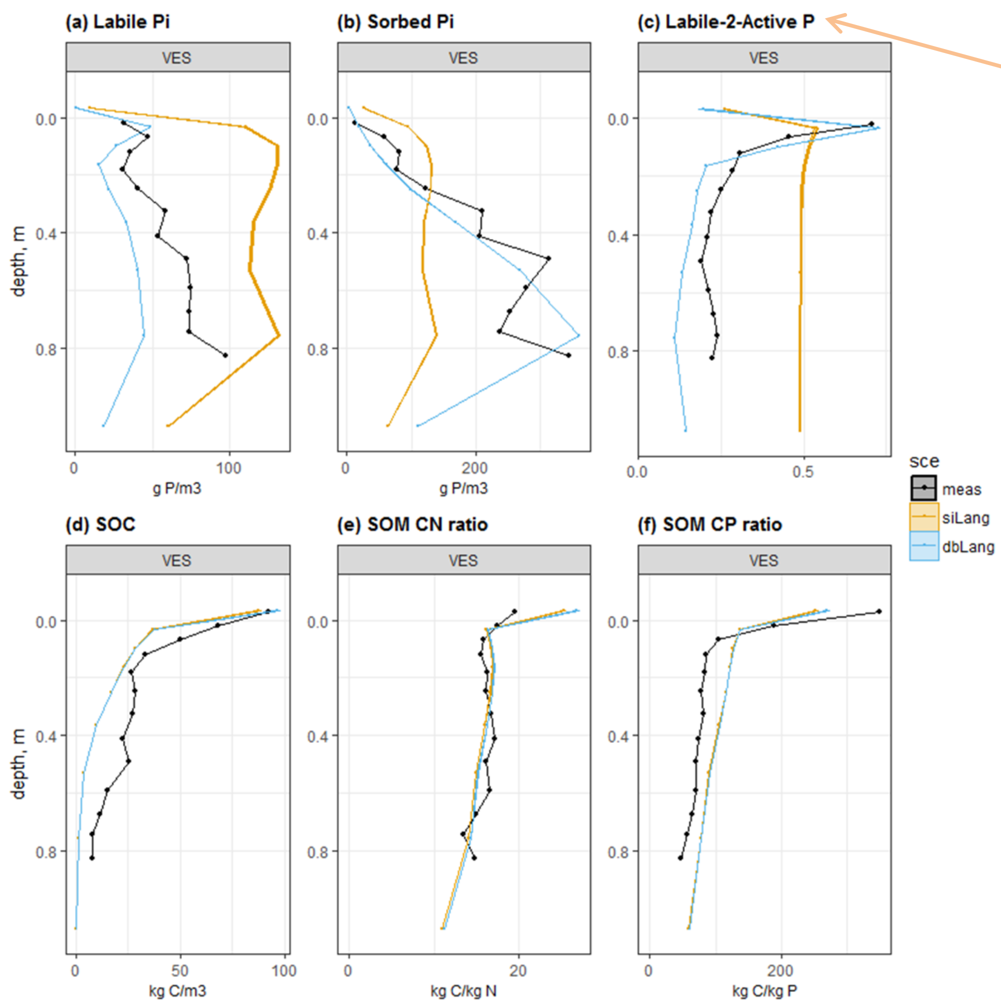



QUINCY model, Thum et al. 2019

# ❸ Results and discussion

- **Simulated vs observed**: Soil labile and sorbed Pi, SOM profile at VES site

The conventional model (**siLang**) largely overestimates the labile Pi pool, overestimates sorbed Pi in topsoil and underestimates it in subsoil. The conventional model also misses the vertical pattern of Pi exchange between labile and sorbed Pi.

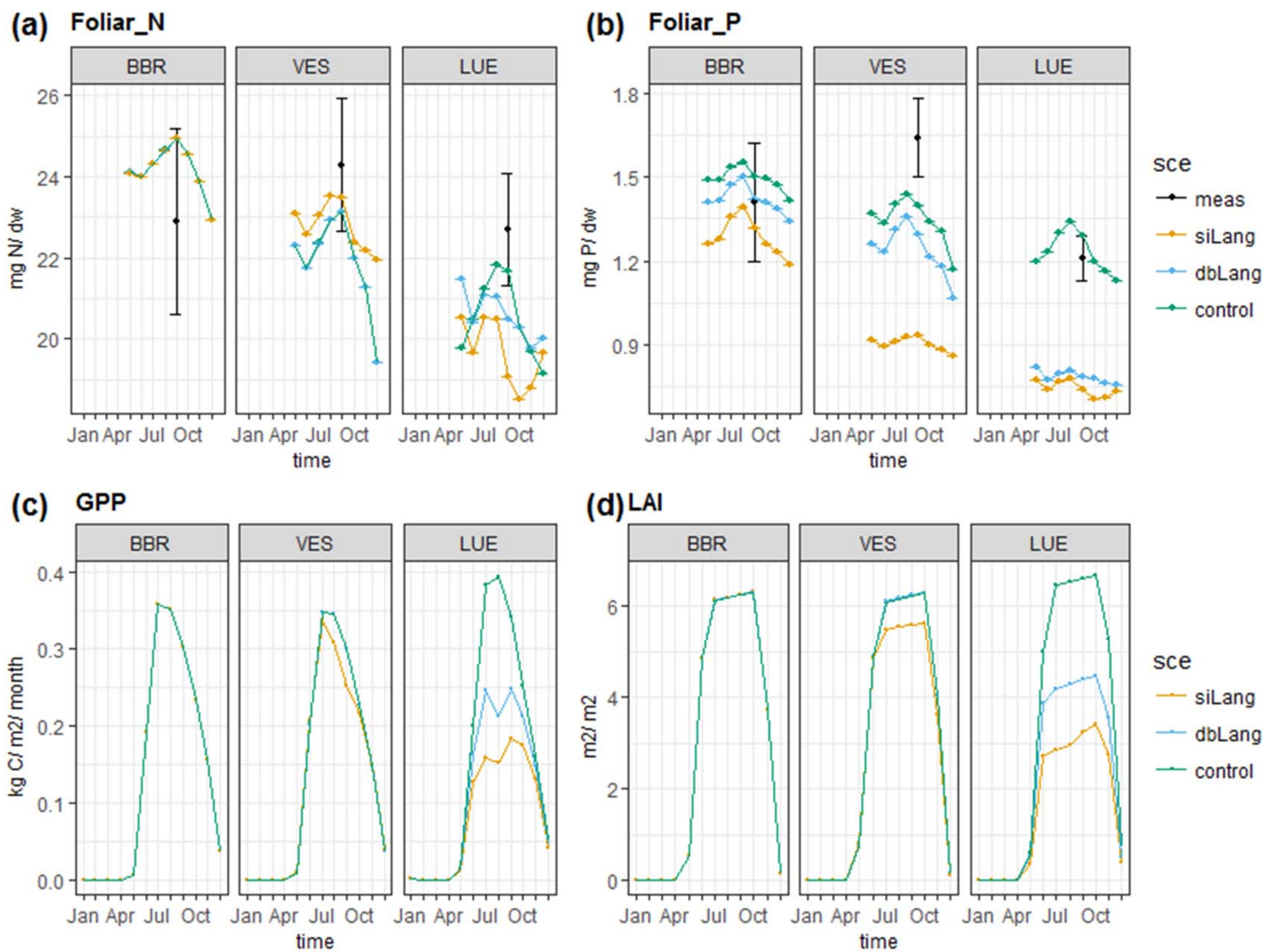



Defined as: $\frac{Labile\ Pi}{Labile\ Pi + Sorbed\ Pi}$

Both models are able to adequately reproduce the observed SOM profile after tuning. It also ensures that both models have similar SOM pools and fluxes, thus all the differences we see are due to differences in Pi cycling.

# ❸ Results and discussion

- **Simulated vs observed**: Leaf N and P at BBR, VES, and LUE sites
- **Simulated**: LAI, and GPP at BBR, VES, and LUE sites




**FACT**
The observed data showed that there were no clear trends in leaf N, and P content as well as in tree biomass along the soil P gradient (BBR>VES>LUE), because ecosystems are able to establish different P cycling strategies on different P availabilities (Lang et al. 2017).

- All models (**siLang**, **dbLang** and **Control**) were able to capture the observed leaf N content range, but not the leaf P content range.
- A significant decreasing trend in leaf P content were found in all three models, but **siLang** clearly had a much stronger P stress than **dbLang**.
- Such a strong P stress at VES site is not supported by observations, which was much improved by **dbLang** compared with **siLang**
- LUE showed symptoms of P limitation only in belowground observations (roots and microbes) but not aboveground (Lang et al. 2017). The gap between **dbLang** and observations (also **contral** as an optimal P uptake scenario) indicates organic P cycling play an important role mediating P supply at extreme low P site.

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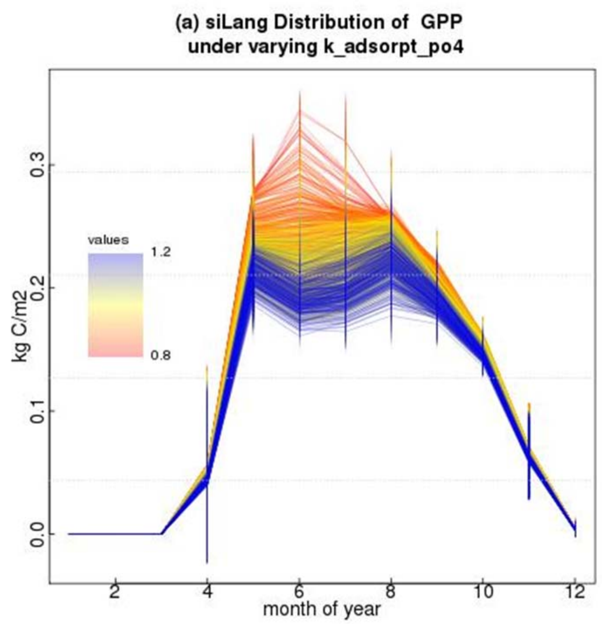
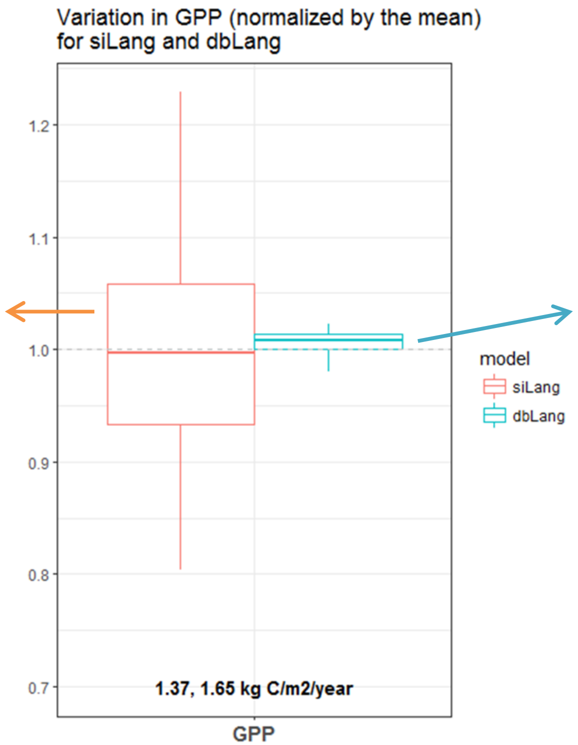
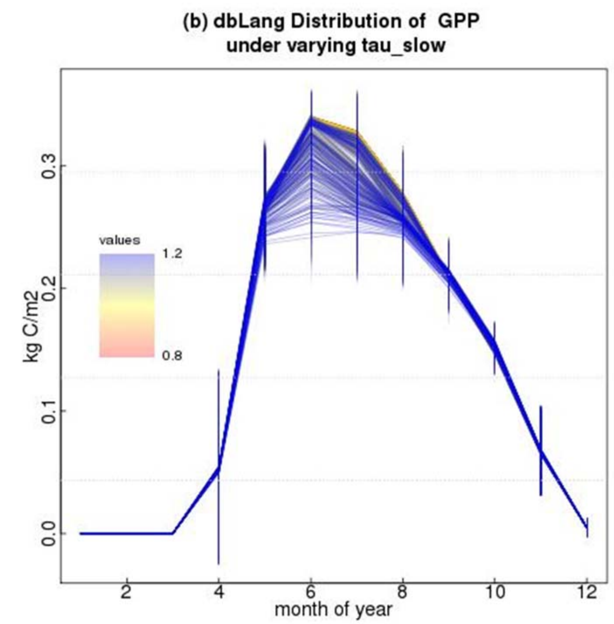
# ❸ Results and discussion

- **Sensitivity analysis**: GPP bar plot (middle), Spaghetti plot of most affecting parameter for **siLang** (left) and **dbLang** (right)



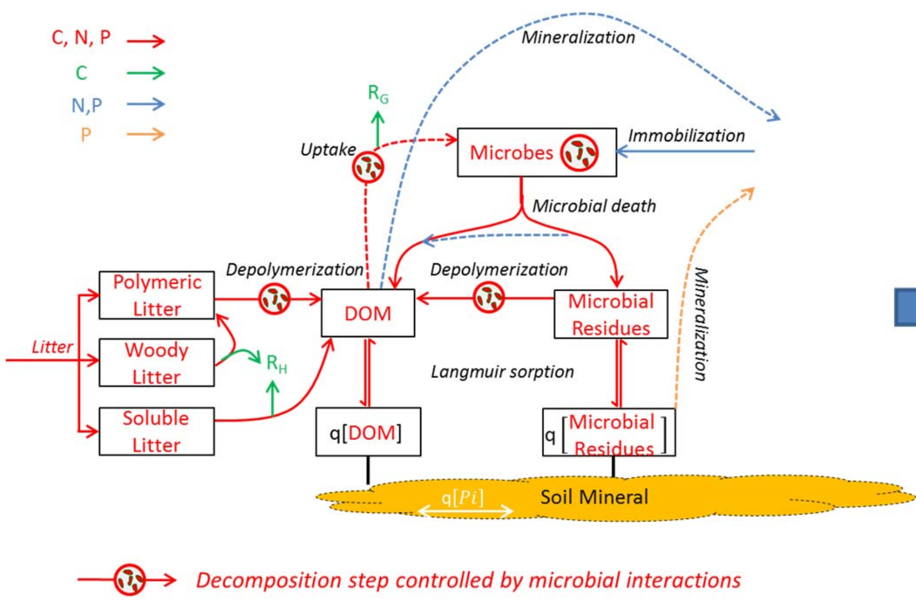

For **siLang** model, GPP is most influenced by $\boldsymbol{k_{abs}}$, i.e. the sorption rate from labile Pi to sorbed Pi. Changes in P cycling parameterization has a much stronger impact on GPP than **dbLang**.

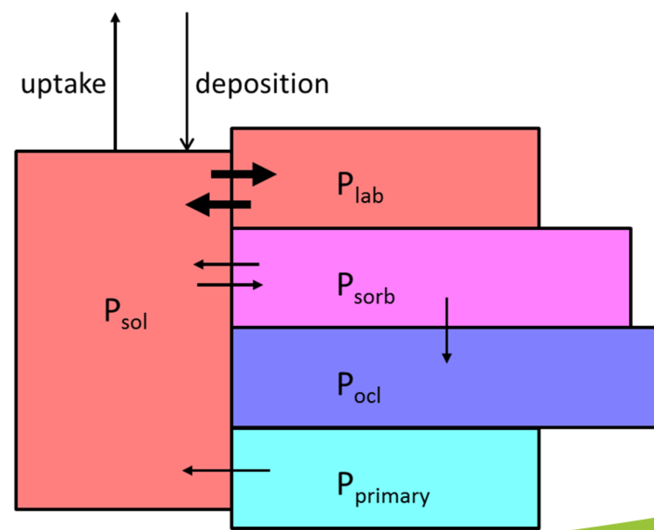
| | Rank 1 | | | |
|---|---|---|---|---|
| **Variable** | **siLang** | **RPCC** | **dbLang** | **RPCC** |
| **GPP** | $k_{abs}$ | -0.97 | $\tau_{slow}$ | -0.88 |

For **dbLang** model, GPP is most influenced by $\boldsymbol{\tau_{slow}}$, i.e. the turnover rate of stable SOM pool. The simulated GPP is generally higher than **siLang**, and the model is more robust to the changes of P cycling.

# ❹ Conclusion and outlook

- Although conventional Pi cycling algorithm (**siLang**) overestimated labile and sorbed Pi pools, the QUINCY model underestimated leaf P concentration at moderate to low P availabilties, indicating a misrepresentation of Pi exchange between solution and soil matrix.
- Such a model misrepresentation of Pi exchange in soil influences plant P uptake, thus imposes a very strong P stress on photosynthesis, resulting in very strong responses of simulated GPP to changes in P cycling. Our novel algorithm (**dbLang**) greatly improves the simulation of soil Pi pools and releases the unrealistic P stress in the model.
- However, at the extreme low P site, our improvement in Pi cycling seems not sufficient to reproduce the soil and vegetative observations, indicating that organic P cycling play a more essential role under such condition, suggesting the need to combine more mechanistic organic P cycling and interactions between organic and inorganic P cycling (e.g. Yu et al. 2020).

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