BERKELEY LAB Lawrence Berkeley National Laboratory

EARTH & ENVIRONMENTAL SCIENCES

Towards a robust representation of nutrient control of the land carbon cycle: Formulation and numerics

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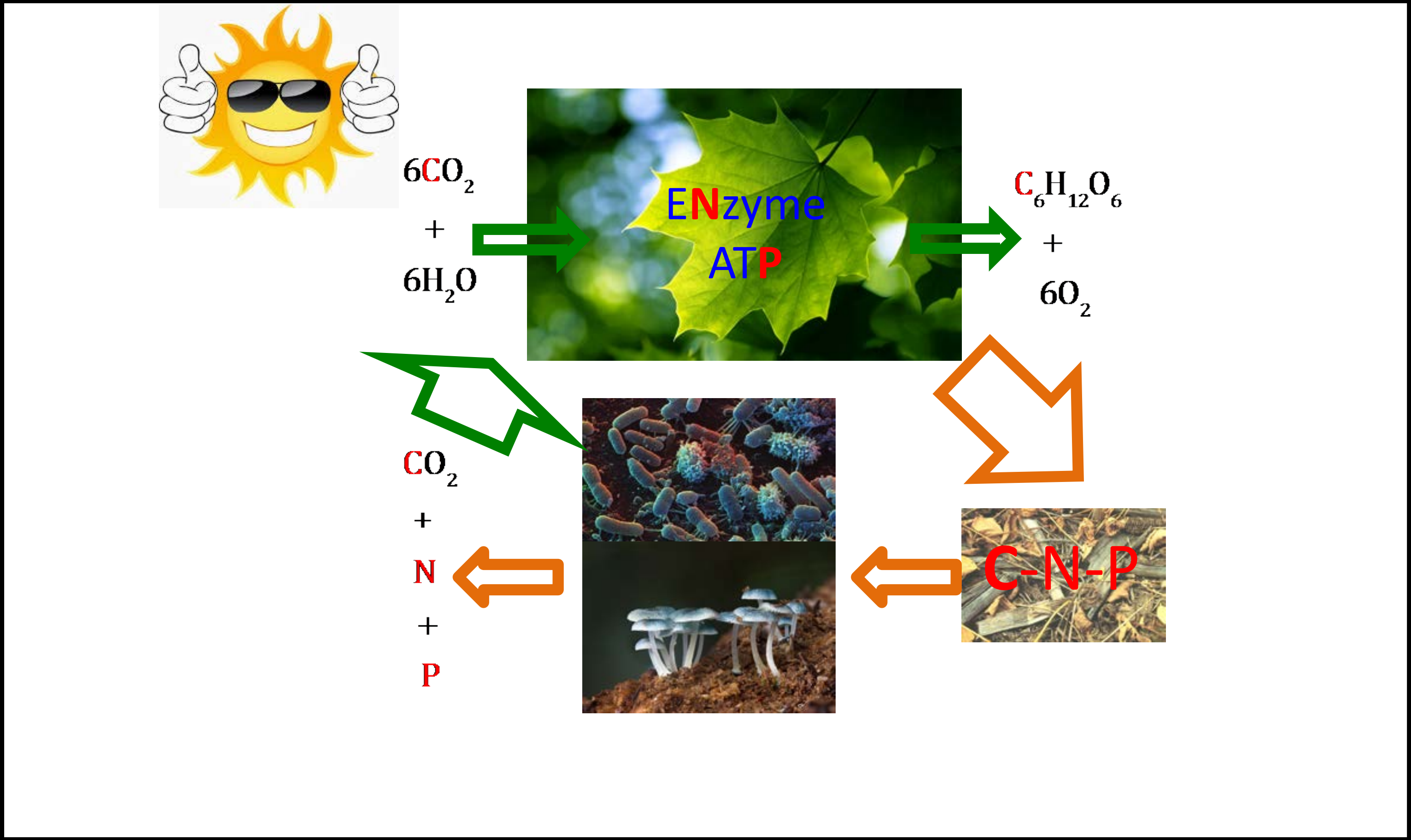
U.S. DEPARTMENT OF ENERGY | Office of Science

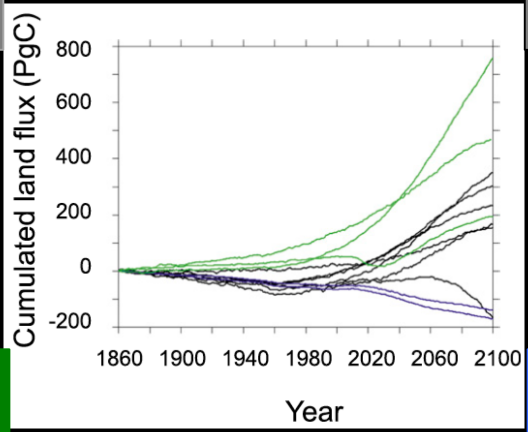
Theme of biogeochemistry



Not easy to do it well

Parameterization

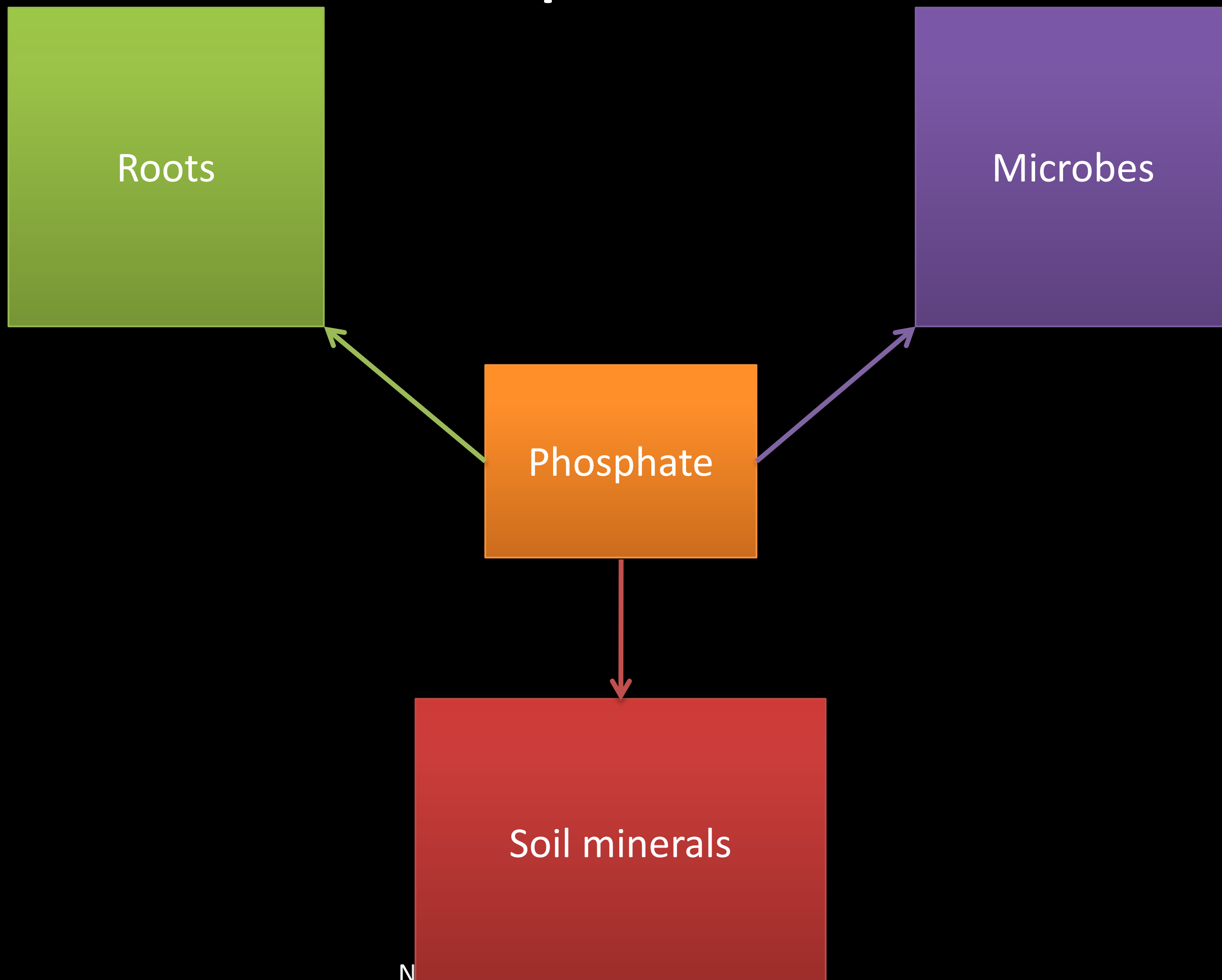
Initial and boundary forcing



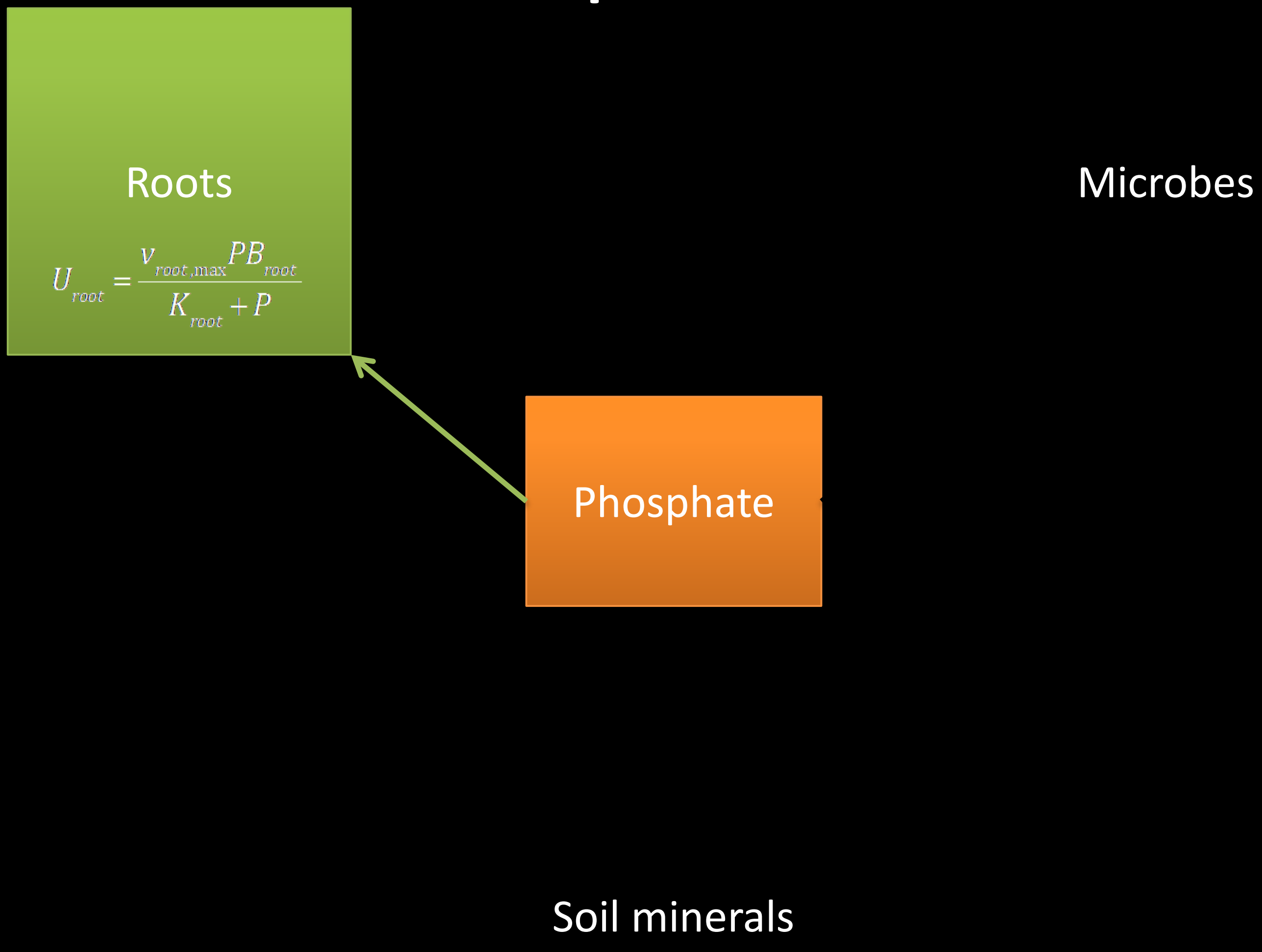
Mechanistic formulation

Numerical encoding

The plant-soil-microbe nutrient competition



The plant-soil-microbe nutrient competition



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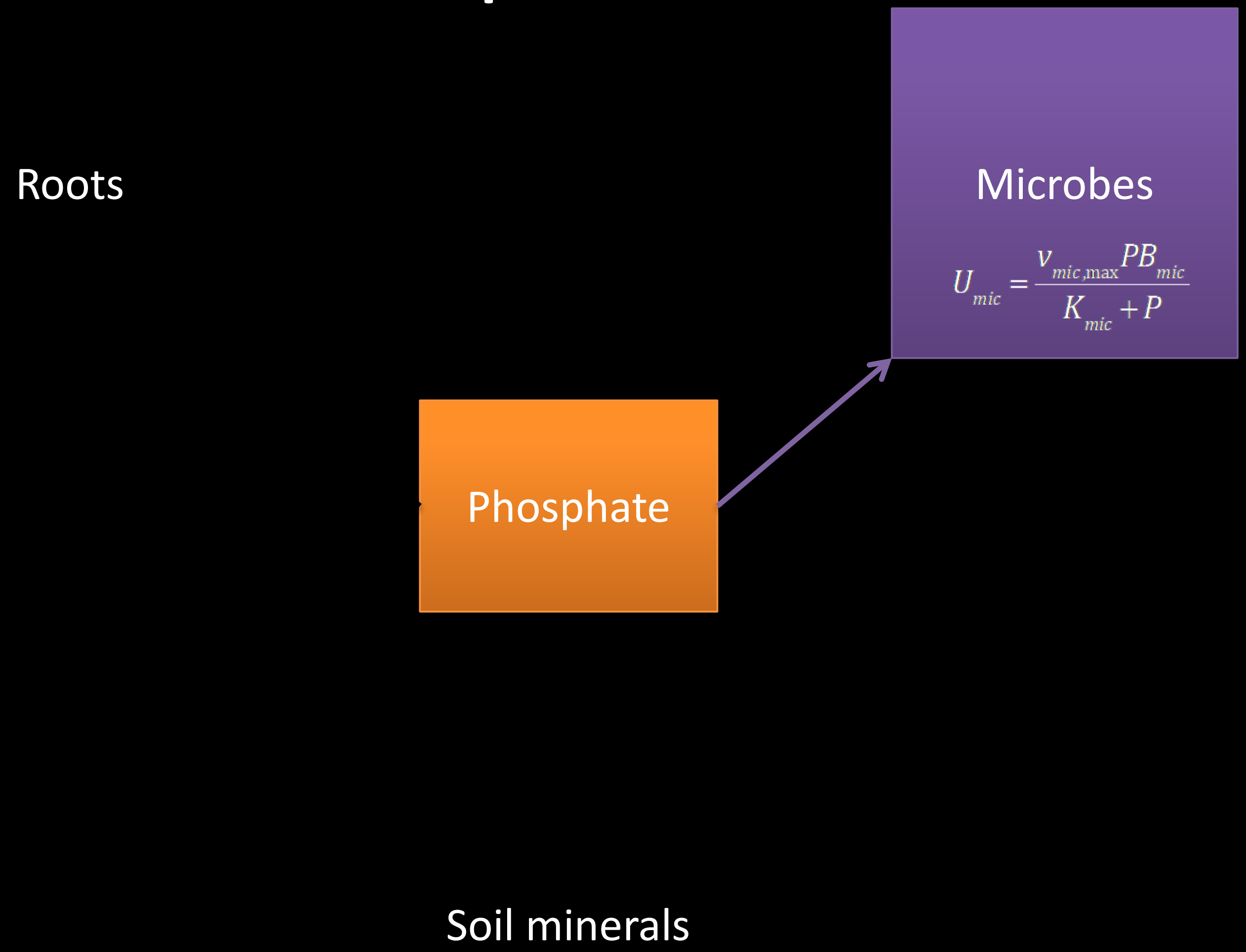

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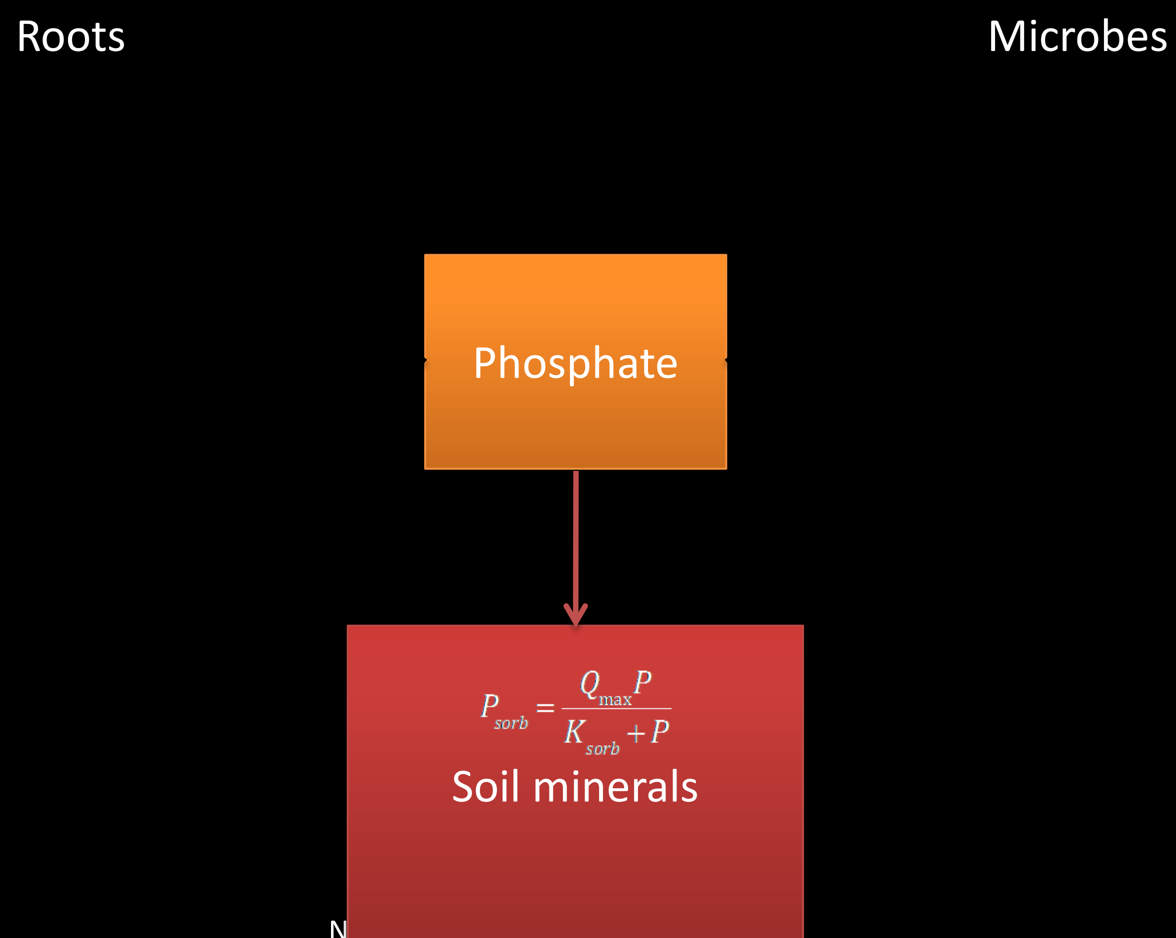
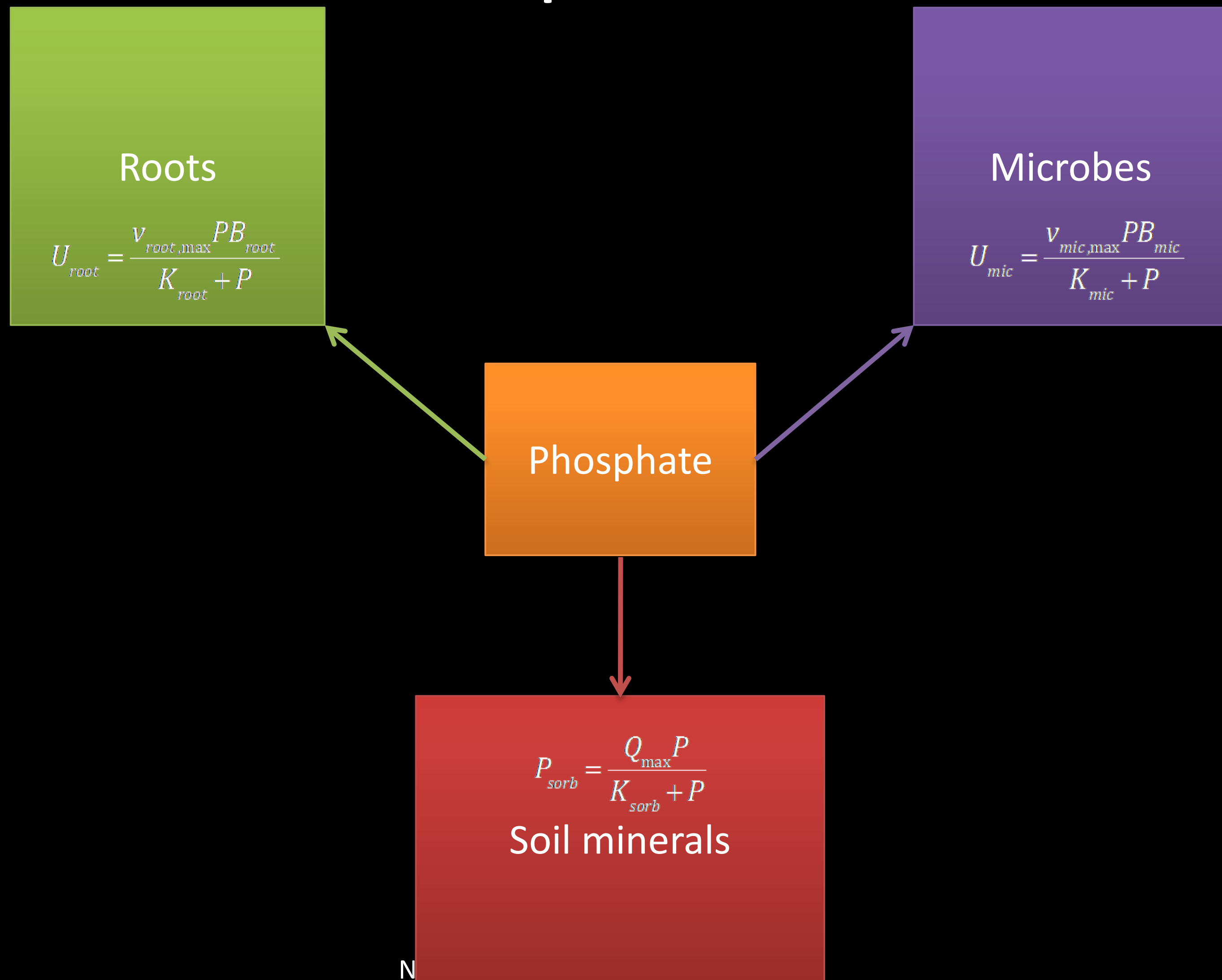


The plant-soil-microbe nutrient competition



The competition conundrum

$$\frac{dP}{dt} = -Uroot - Umic$$

$$= -\frac{v_{root,\max} PB_{root}}{K_{root} + P} - \frac{v_{mic,\max} PB_{mic}}{K_{root} + P}$$

The competition conundrum

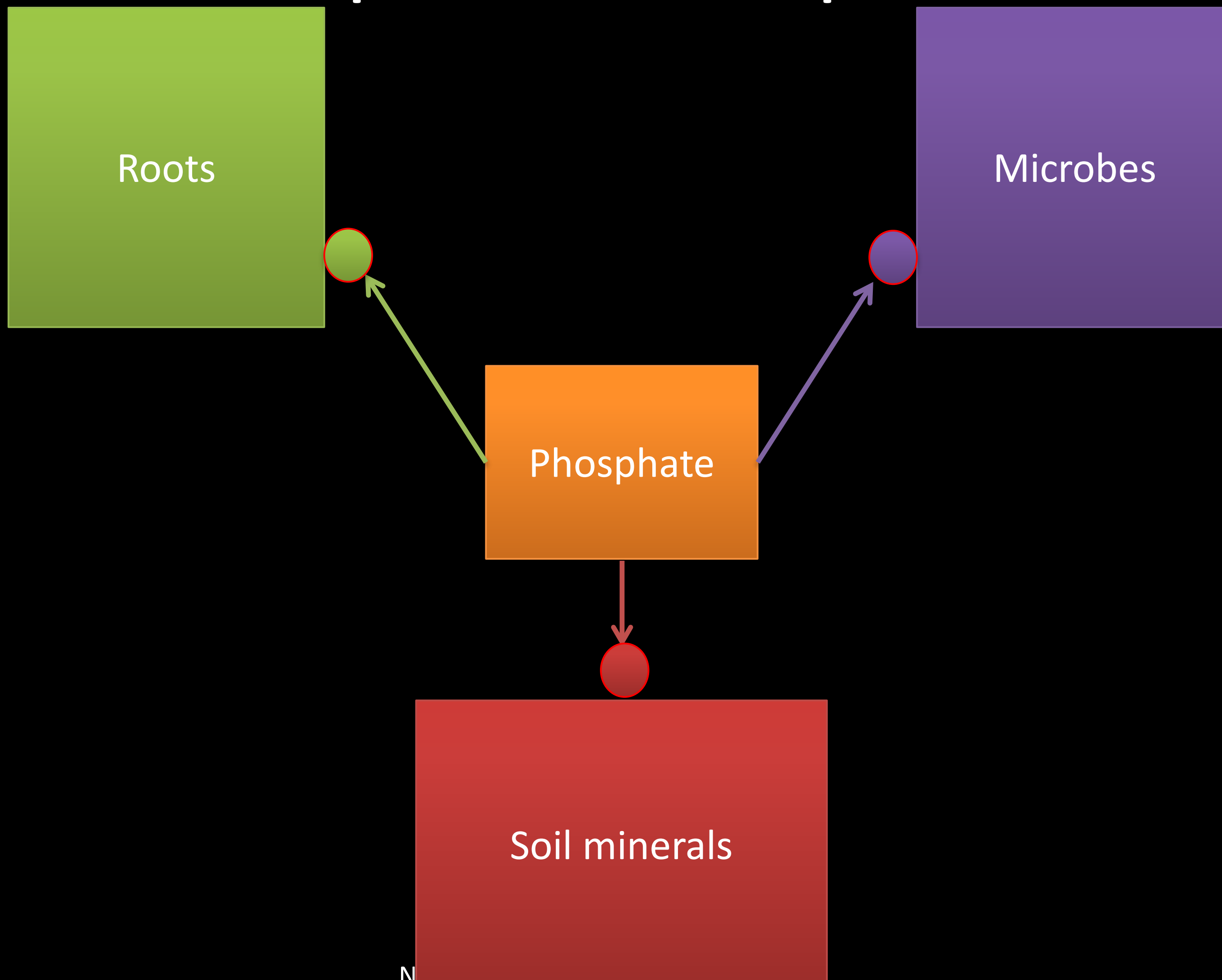
$$\frac{dP}{dt} = -Uroot - Umic$$

$$= -\frac{v_{root,\max} PB_{root}}{K_{root} + P} - \frac{v_{mic,\max} PB_{mic}}{K_{root} + P}$$

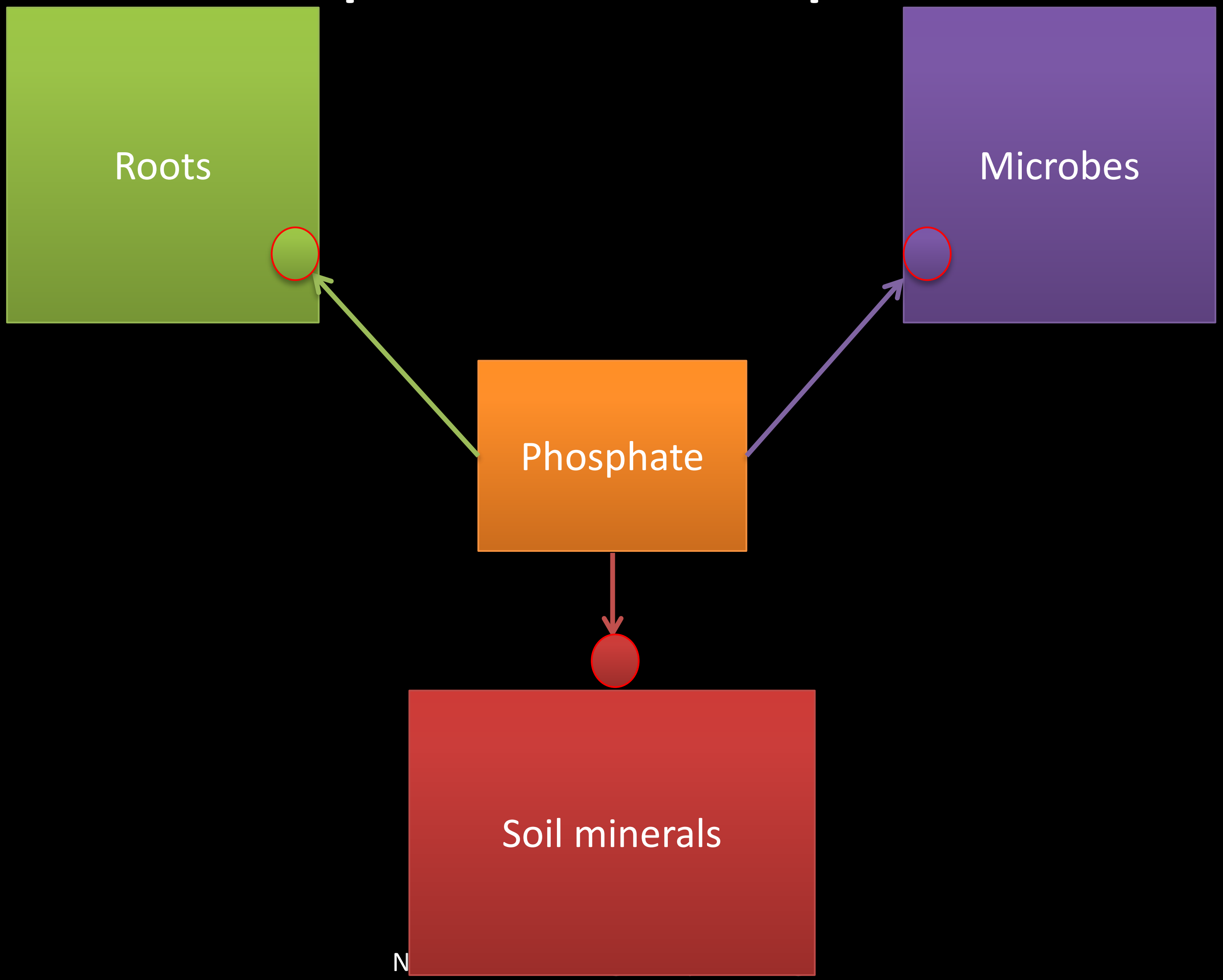
$$P_{sorb} = \frac{Q_{\max} P}{K_{sorb} + P}$$

?

Two-step plant-soil-microbe nutrient competition: step one



Two-step plant-soil-microbe nutrient competition: step two



The Equilibrium Chemistry Approximation Theory for nutrient competition

Step one

$$P_T = P + P_{sorb} + \left(PB_{root}\right) + \left(PB_{mic}\right)$$

$$B_{root} + \left(PB_{root}\right) = B_{root,T}$$

$$B_{mic} + \left(PB_{mic}\right) = B_{mic,T}$$

$$Q + P_{sorb} = Q_{\max}$$

$$\left(PB_{root}\right) K_{root} = B_{root} \cdot P$$

$$\left(PB_{mic}\right) K_{mic} = B_{mic} \cdot P$$

$$P_{sorb} K_{sorb} = P \cdot Q$$

Step two

$$U_{root} = v_{root,\max} \left(PB_{root}\right)$$

$$U_{mic} = v_{mic,\max} \left(PB_{mic}\right)$$

The Equilibrium Chemistry Approximation Theory for nutrient competition

$$U_{root} = \frac{v_{\max,root} P_T B_{root,T} / K_{root}}{1 + P_T / K_{root} + B_{root} / K_{root} + B_{mic} / K_{mic} + Q_{\max} / K_{sorb}}$$

$$U_{mic} = \frac{v_{\max,mic} P_T B_{mic,T} / K_{mic}}{1 + P_T / K_{mic} + B_{mic} / K_{mic} + B_{root} / K_{root} + Q_{\max} / K_{sorb}}$$

Tang and Riley, 2013

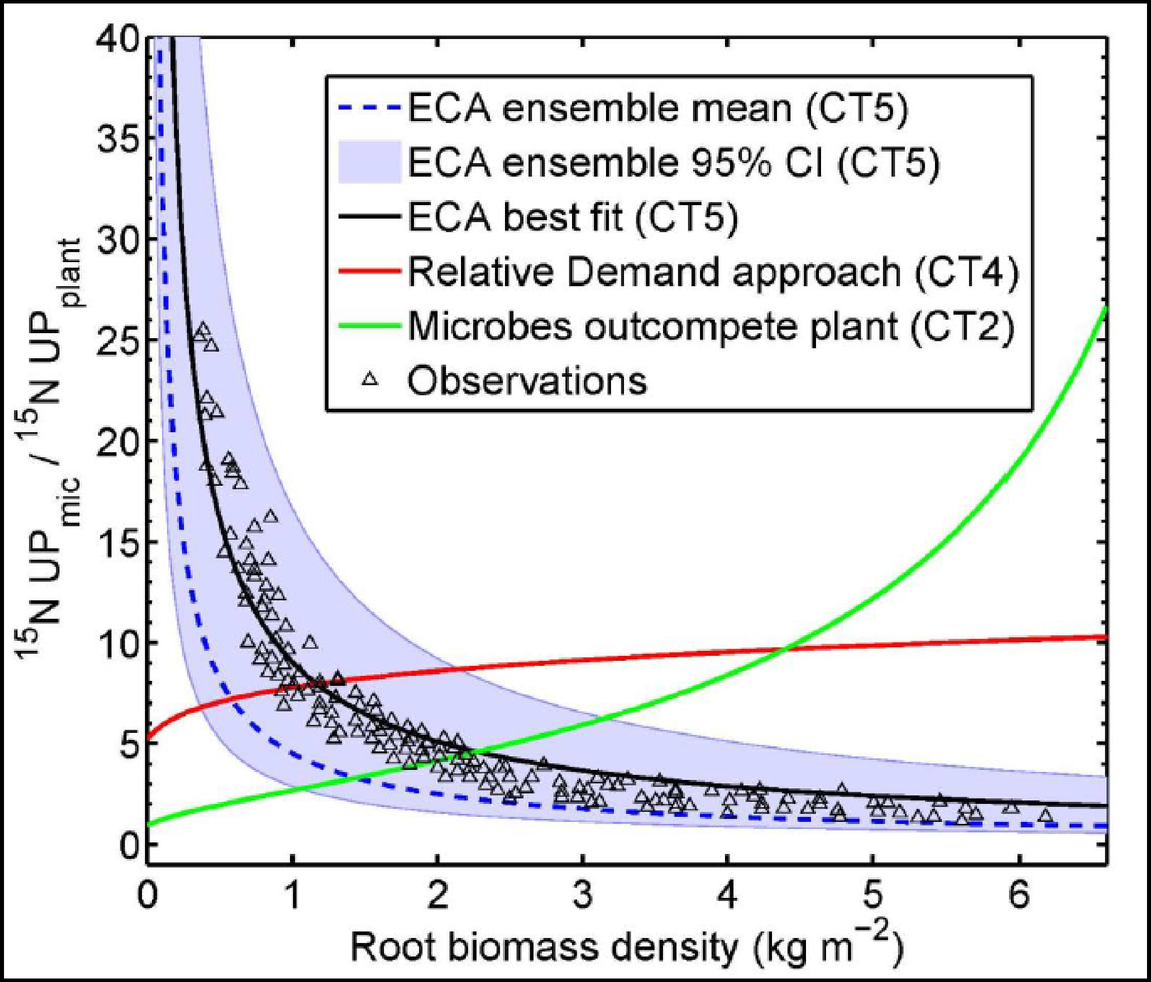
The Equilibrium Chemistry Approximation Theory for nutrient competition

$$U_{root} = \frac{v_{\max,root} P_T B_{root,T} / K_{root}}{1 + P_T / K_{root} + B_{root} / K_{root} + B_{mic} / K_{mic} + Q_{\max} / K_{sorb}}$$

$$U_{mic} = \frac{v_{\max,mic} P_T B_{mic,T} / K_{mic}}{1 + P_T / K_{mic} + B_{mic} / K_{mic} + B_{root} / K_{root} + Q_{\max} / K_{sorb}}$$

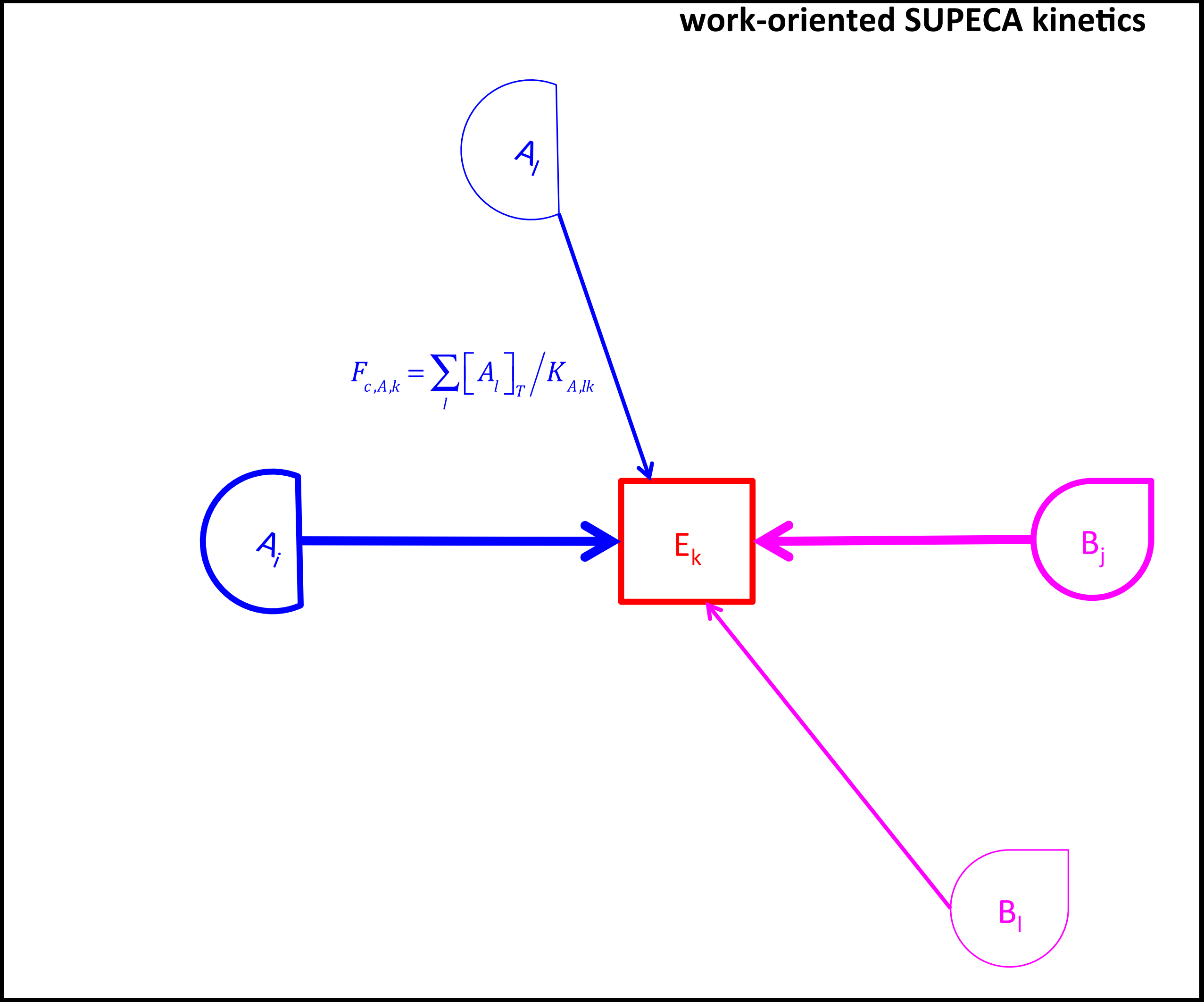
Tang and Riley, 2013

ECA is quite good: nitrogen competition



Zhu et al., 2016

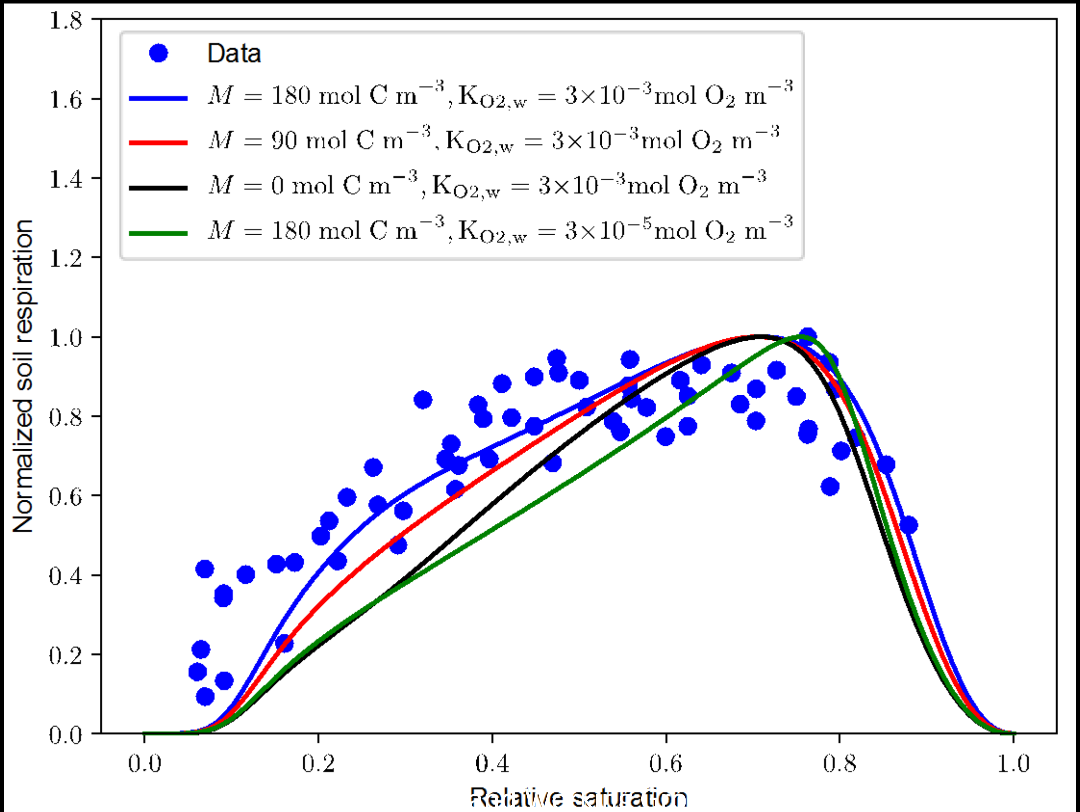
SUPECA: extended ECA for more realistic substrate-competitor networks



Tang and Riley, 2017

Application for aerobic decomposition

$$CH_2O + O_2 \xrightarrow[M]{B} CO_2 + dB$$



Tang and Riley, 2017

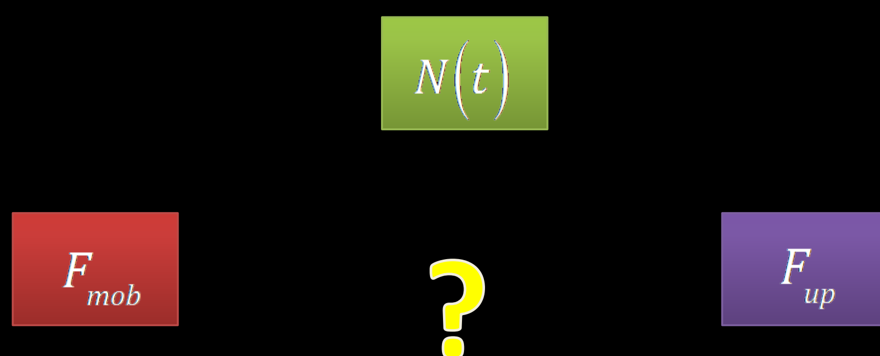

Mechanistic formulation
Numerical encoding

The substrate limitation problem

$$N\left(t+\Delta t\right)=N\left(t\right)+\Delta t\left(F_{mob}-F_{up}\right)\geq 0$$

The substrate limitation problem

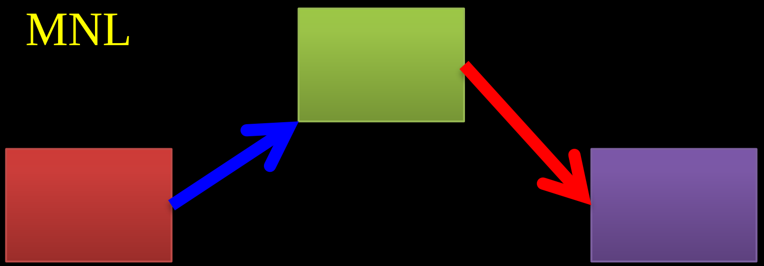
$$N(t+\Delta t) = N(t) + \Delta t\left(F_{mob} - F_{up}\right) \geq 0$$



Three different ways

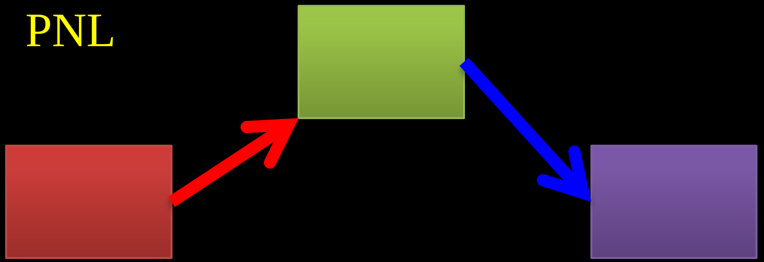
MNL

$$\bar{F}_{up} = \min\left\{\frac{N(t)/\Delta t}{F_{up}}, 1\right\} F_{up}$$



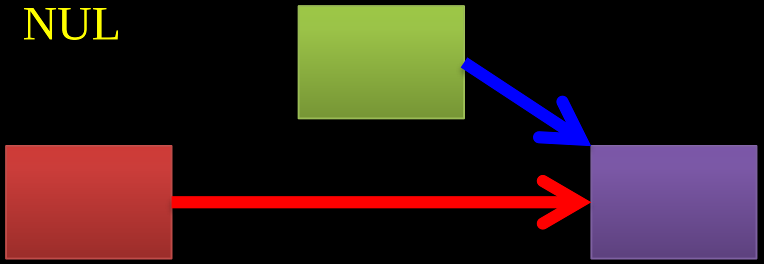
PNL

$$\bar{F}_{up} = \min\left\{\frac{N(t)/\Delta t + F_{mob}}{F_{up}}, 1\right\} F_{up}$$

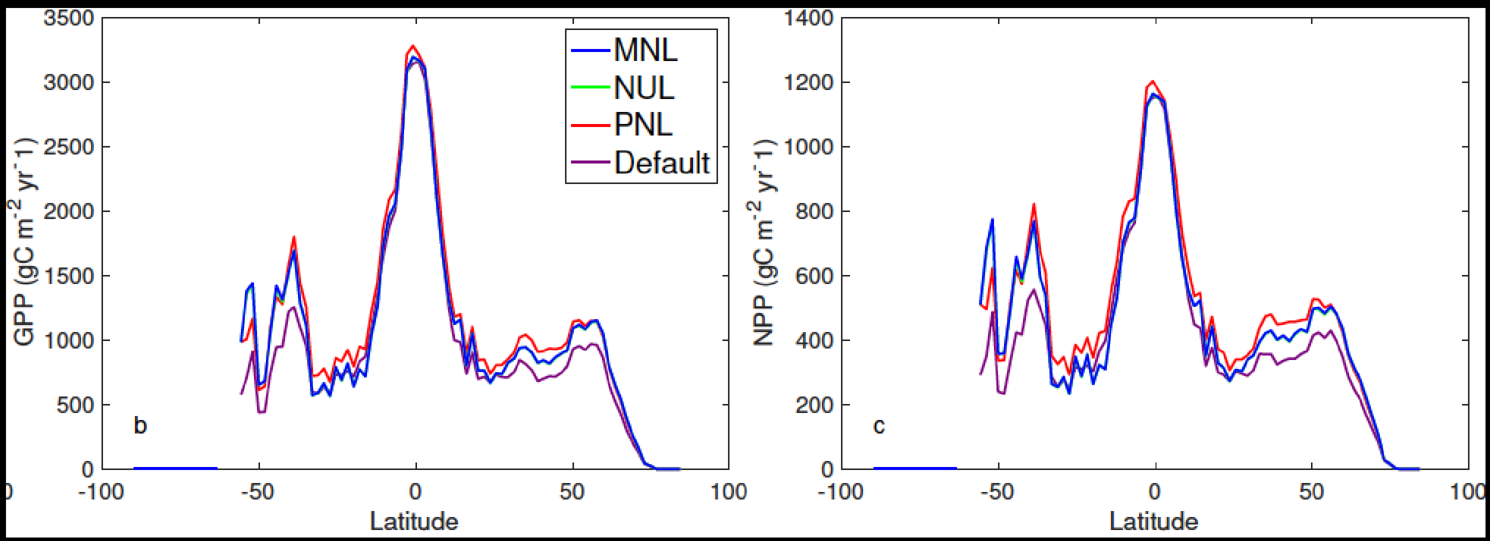


NUL

$$\bar{F}_{up} = \min\left\{\frac{N(t)/\Delta t}{F_{up} - F_{mob}}, 1\right\} F_{up}$$

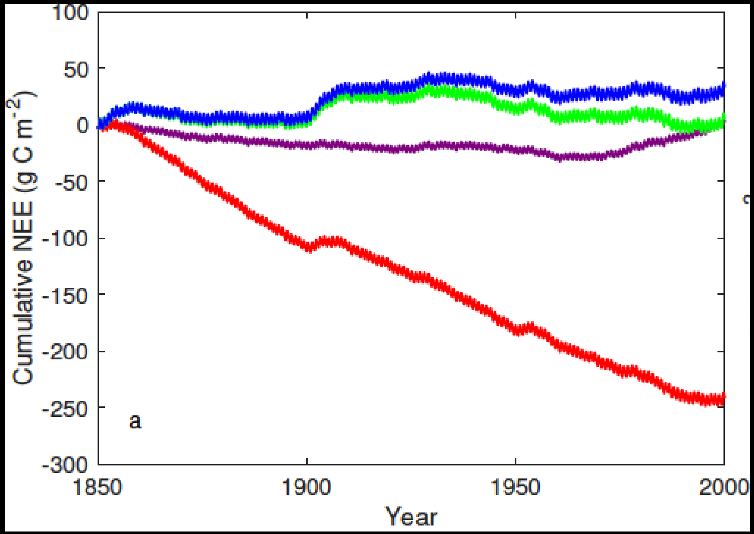


Small difference in fast response variables

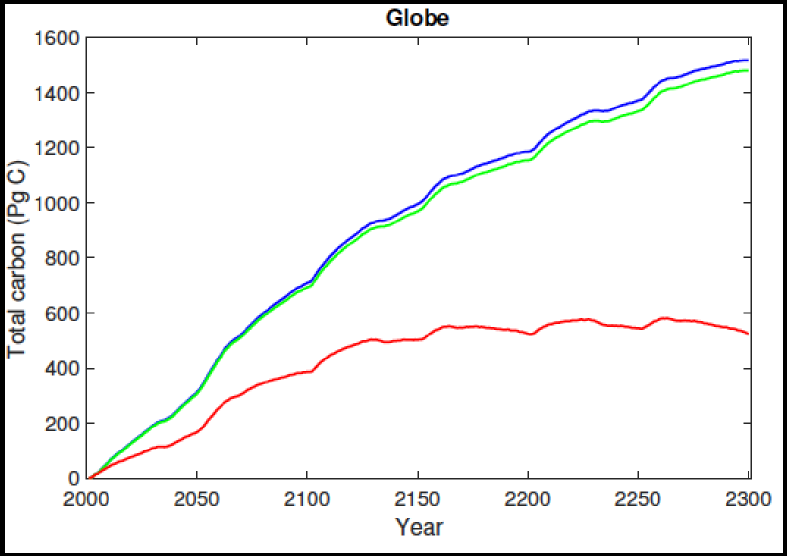


10-year mean for 1991-2000 historical run

Large differences for slow response variables

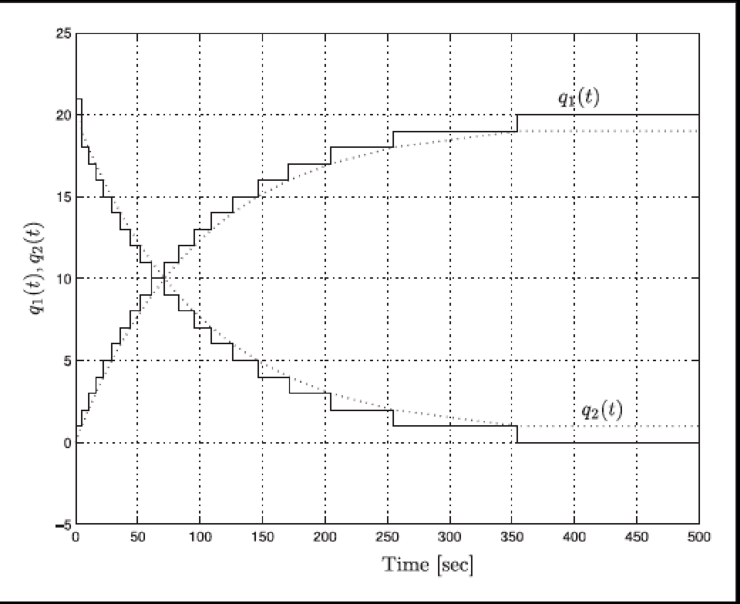


Historical run

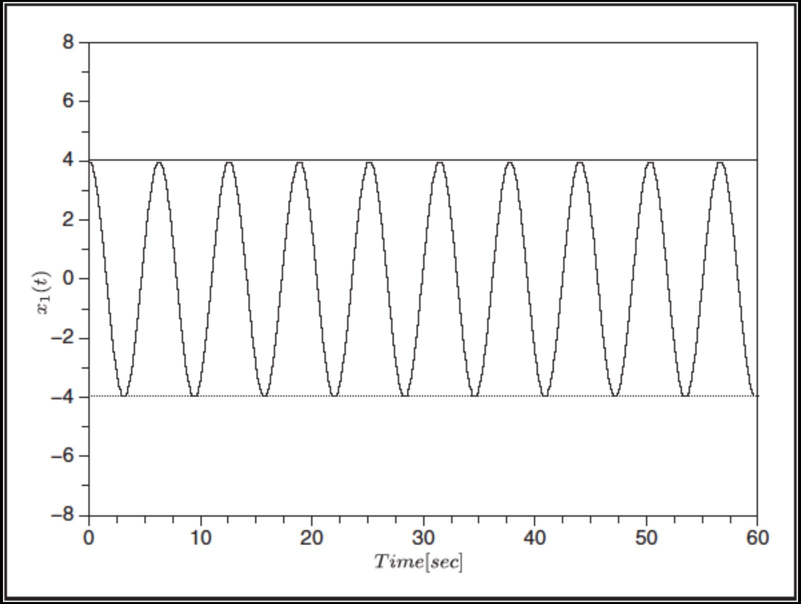


RCP4.5 atmospheric CO_2 forcing

Poor numerical implementation could be fatal: one more example



Wrong



Right

Migoni et al., 2012

Summary

- It's critical to
  - get mechanistic formulations consistent with the processes
  - get the numeric encoding consistent with the mechanistic formulations
- Existing uncertainty analysis of parameterization and initial boundary conditions could be severely biased.


Questions?