Toward a framework for representing phosphorus in earth system models

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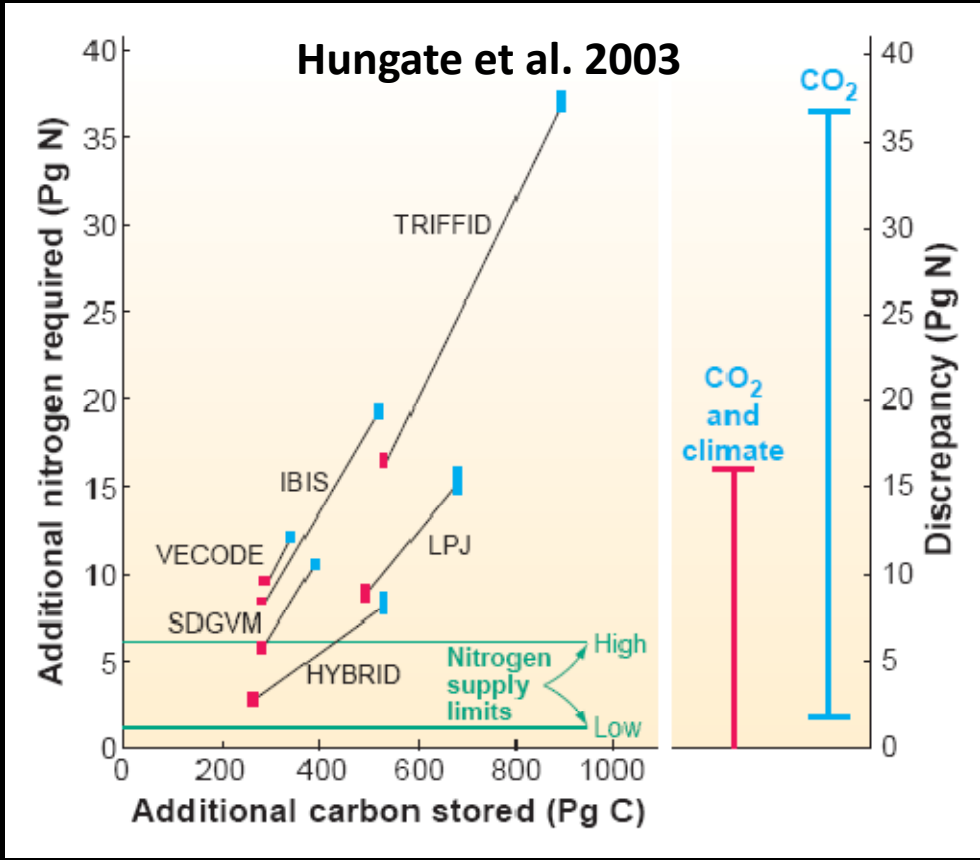
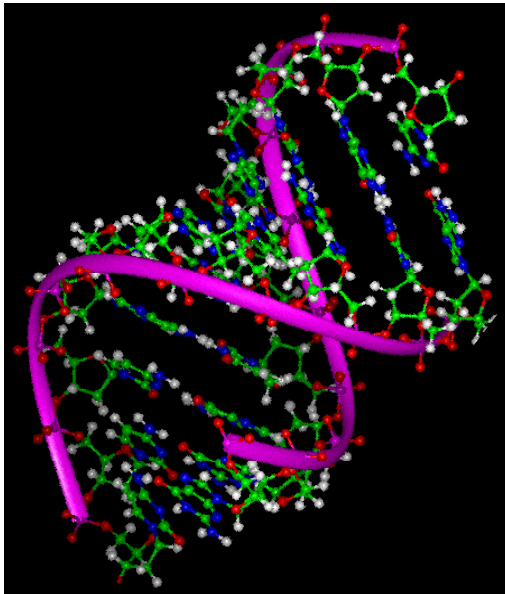
We're beginning to deal with N singly – though we still have much to learn…

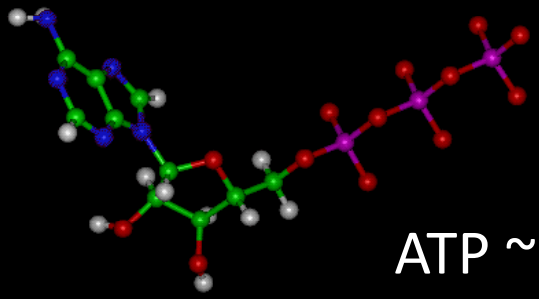


(See also: Sokolov et al., 2008; Xu-Ri and Prentice, 2008; Churkina et al., 2009; Thornton et al., 2009; Zaehle et al. 2010; Wang and Houlton, 2009; Gerber et al., 2010)

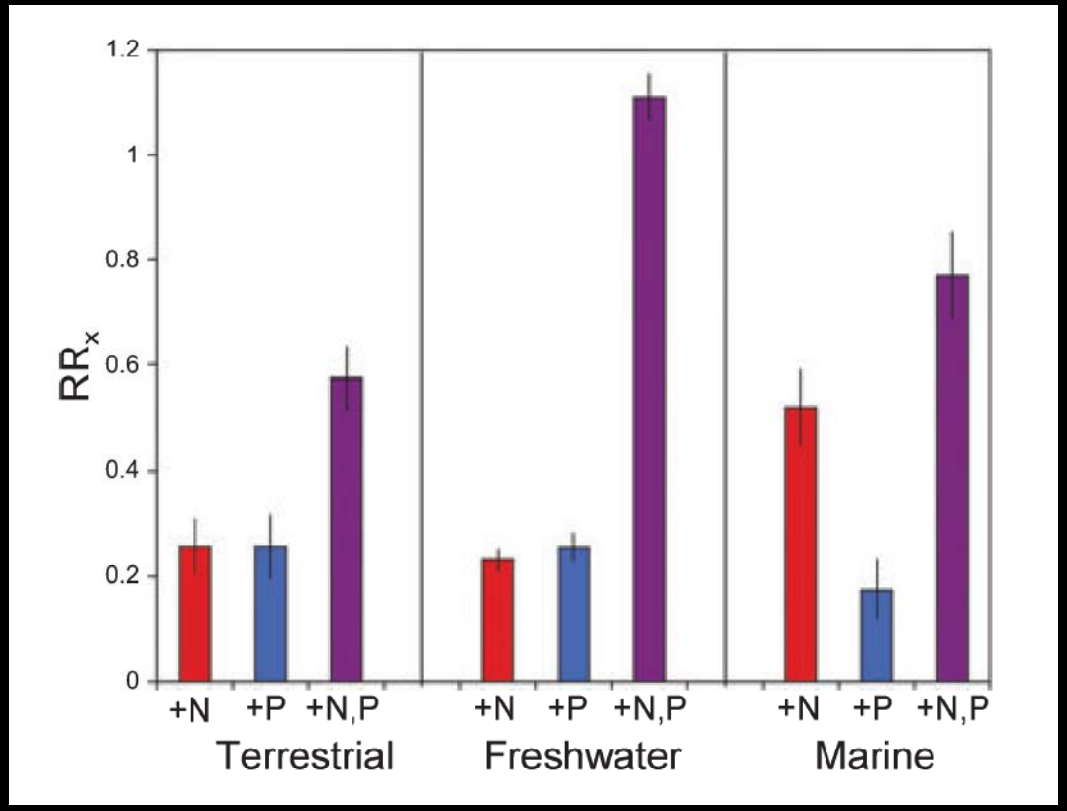
Nutrient limitation: not a case of either or



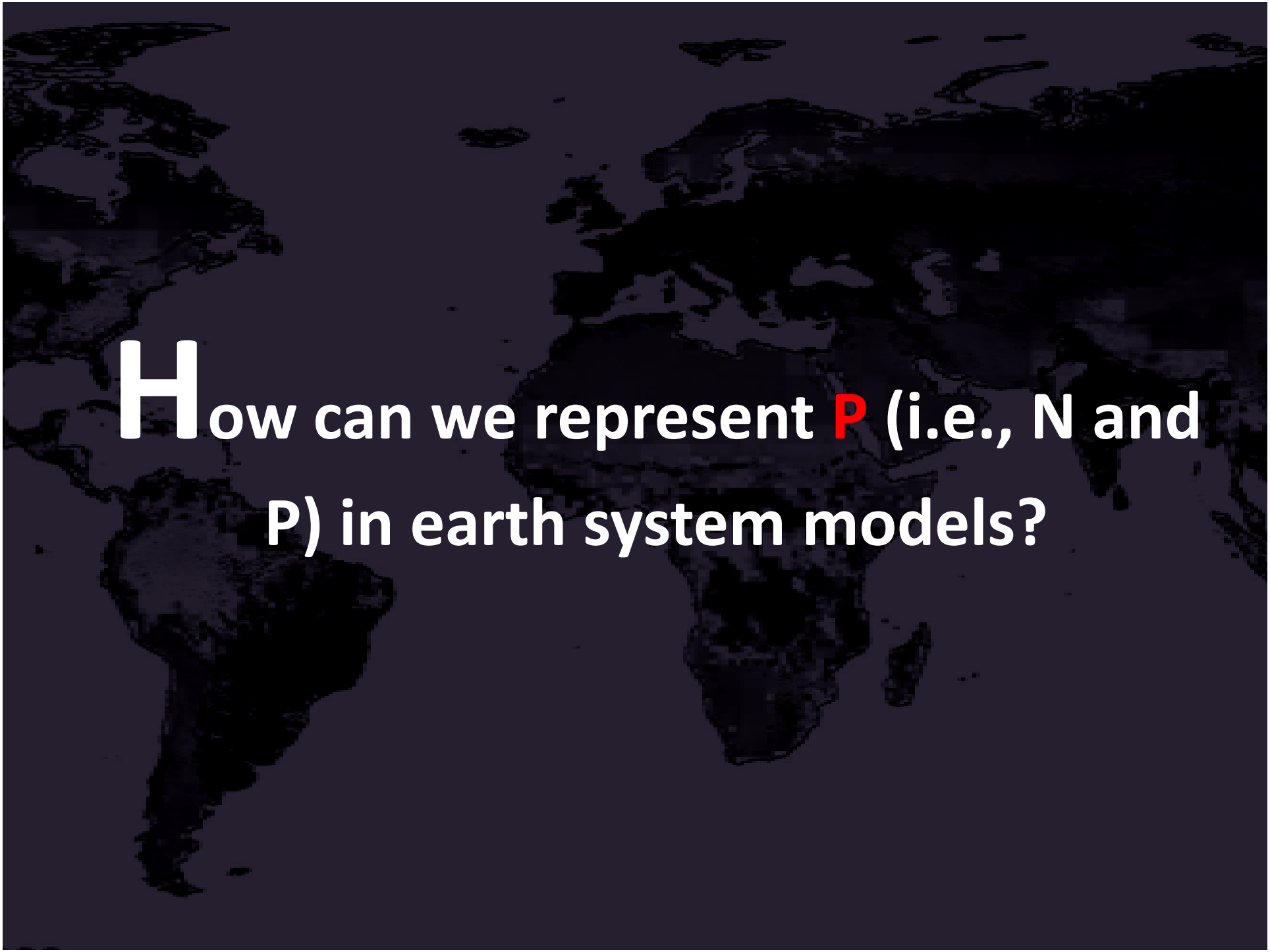
DNA ~ 15 % N, 9 % P



ATP ~ 14 % N, 17 % P



Elser et al., Ecology Letters, 2008


How can we represent P (i.e., N and P) in earth system models?

Three interactions relevant to global CO_2 rise by 2100

1. N x P interactions: P mineralizing enzymes

(Years to Decades)

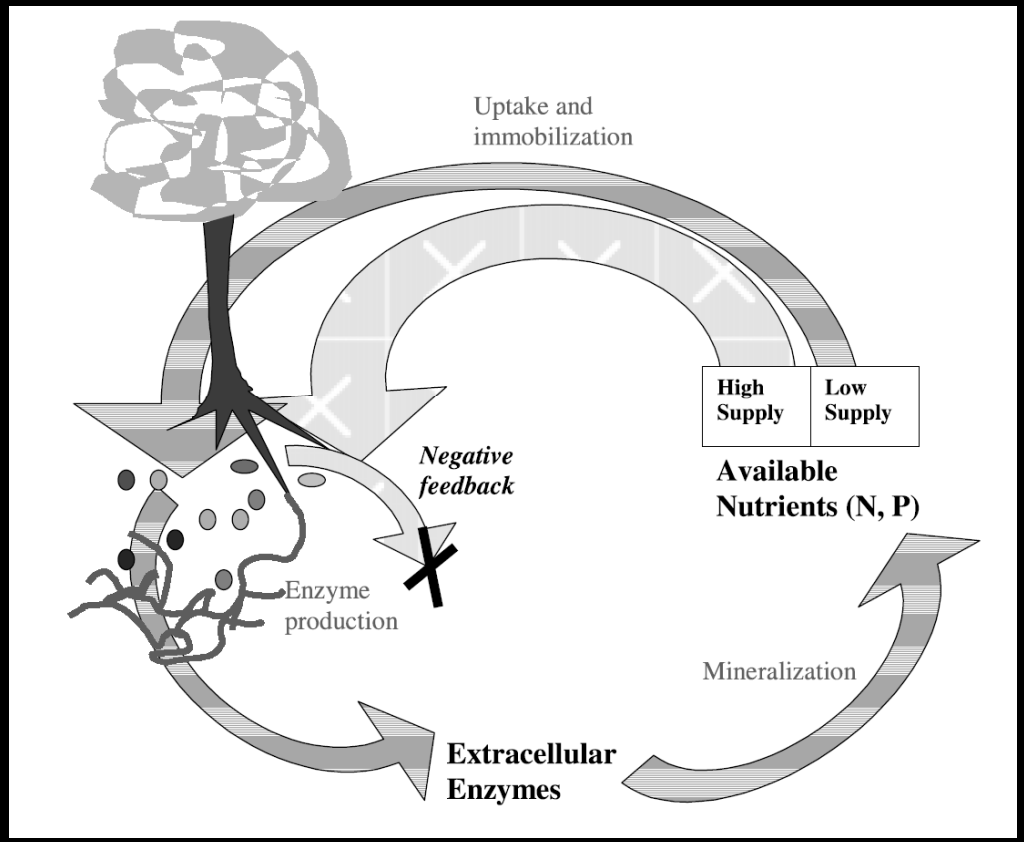
2. N x P interactions: N fixation

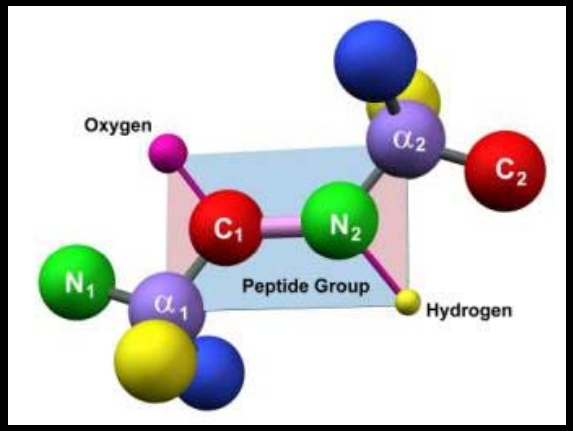
(Decades to Centuries)

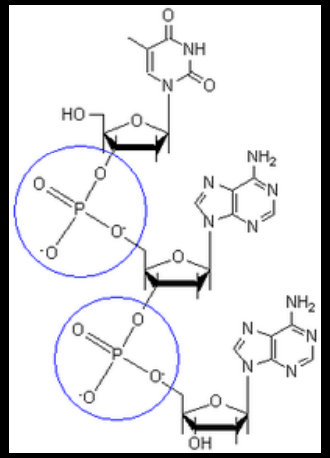
3. These mechanisms appear reciprocal

(Years to Centuries)

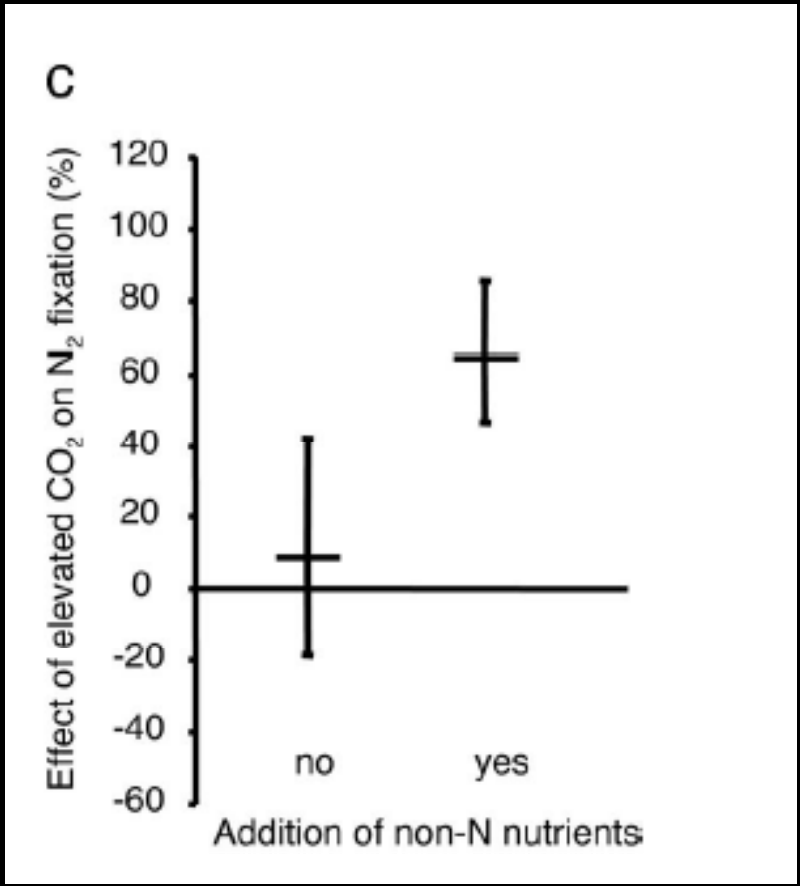
1. N vs. P mineralization – decoupling from C (McGill and Cole model)





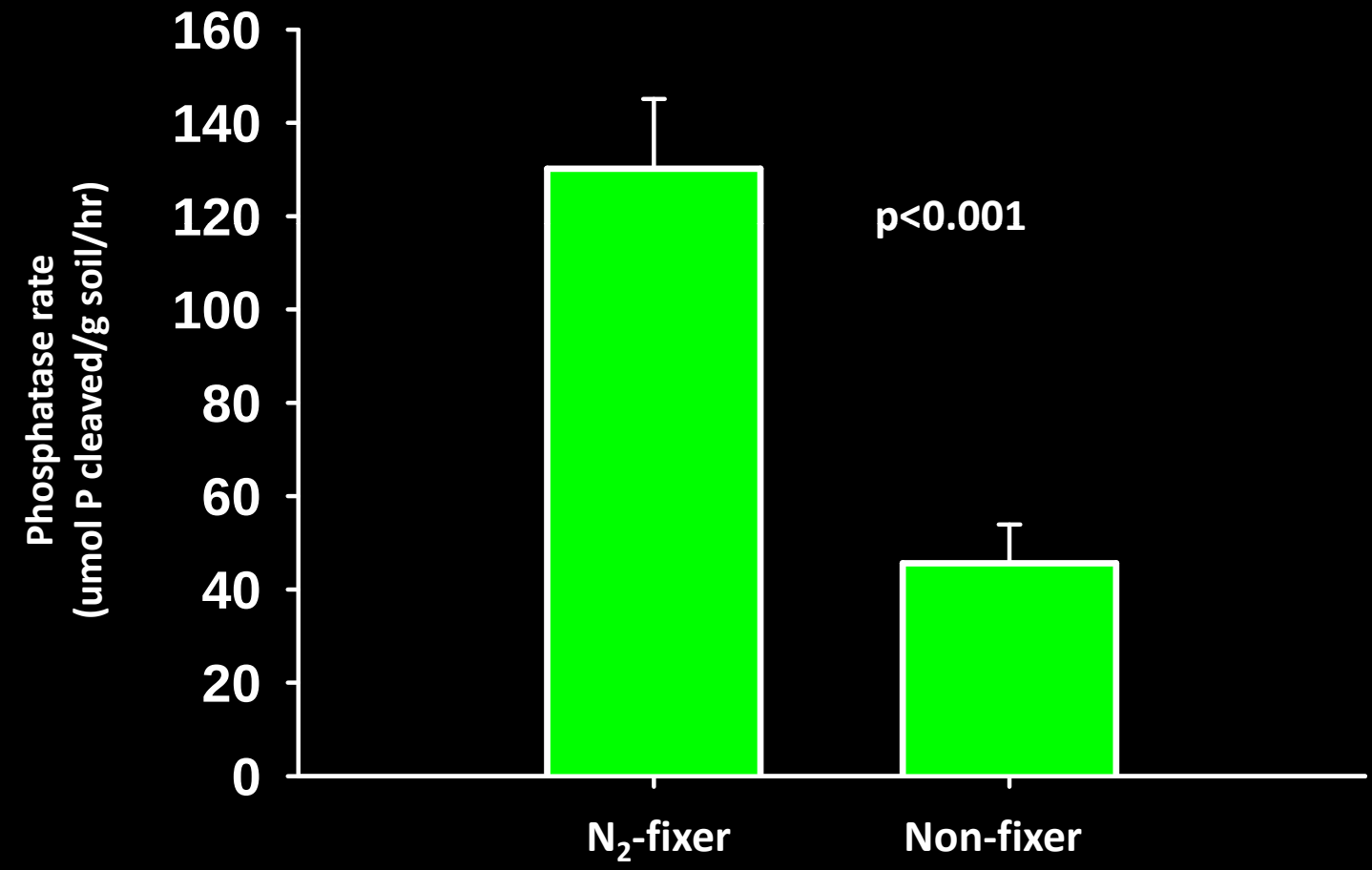


2. N fixation responds to non-N nutrients (especially P)



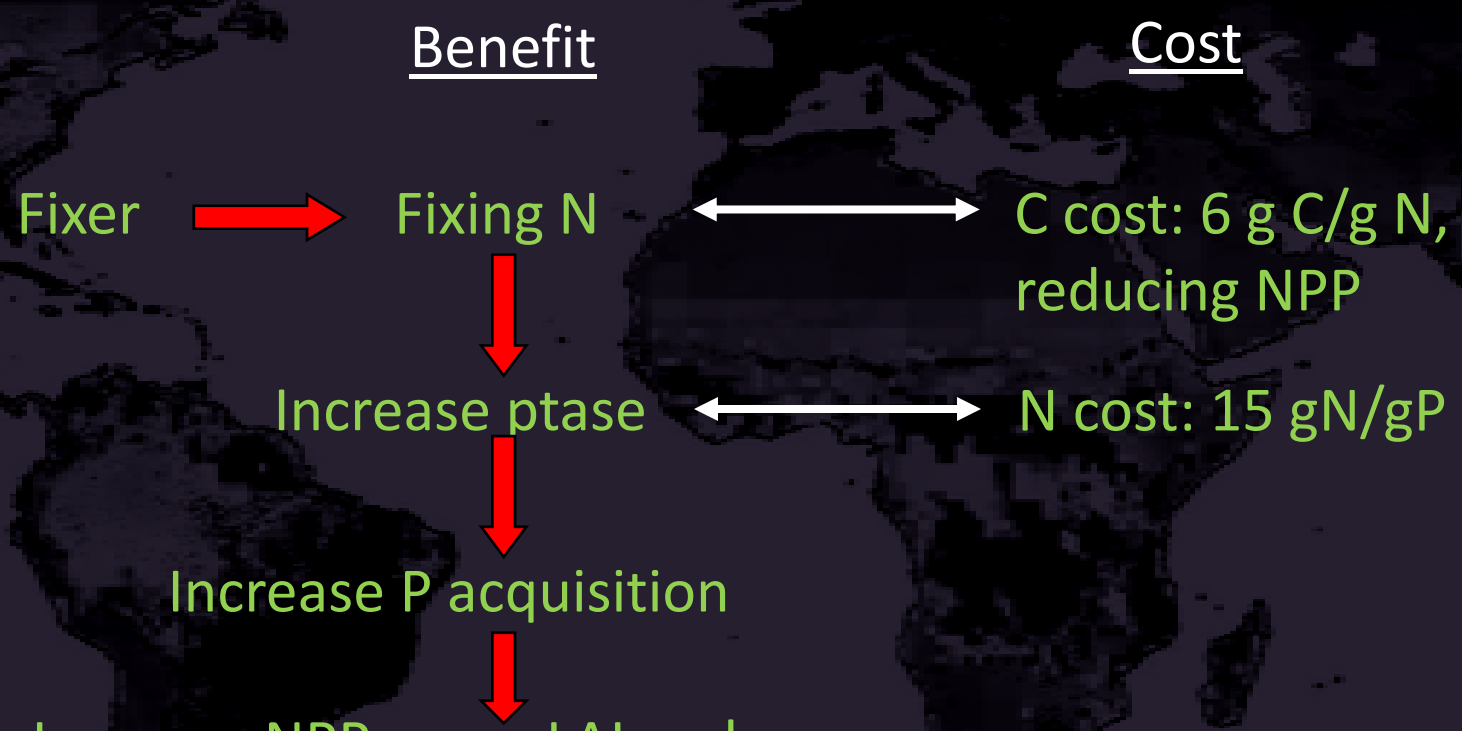
van Groenigen et al., PNAS, 2006

3. interactions 1 and 2 are reciprocal



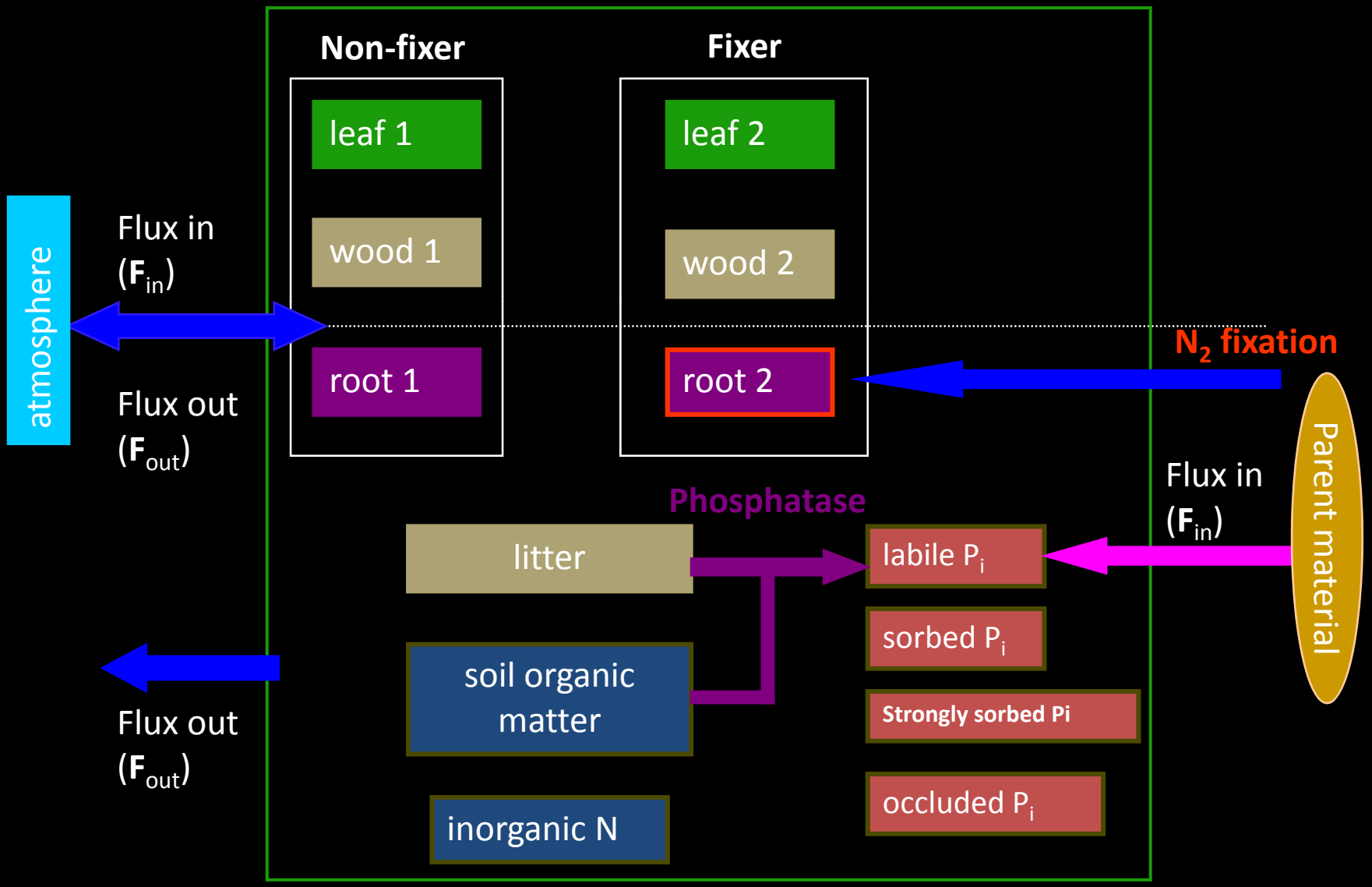
Houlton et al., Nature, 2008

C, N, P interactions – our working hypothesis



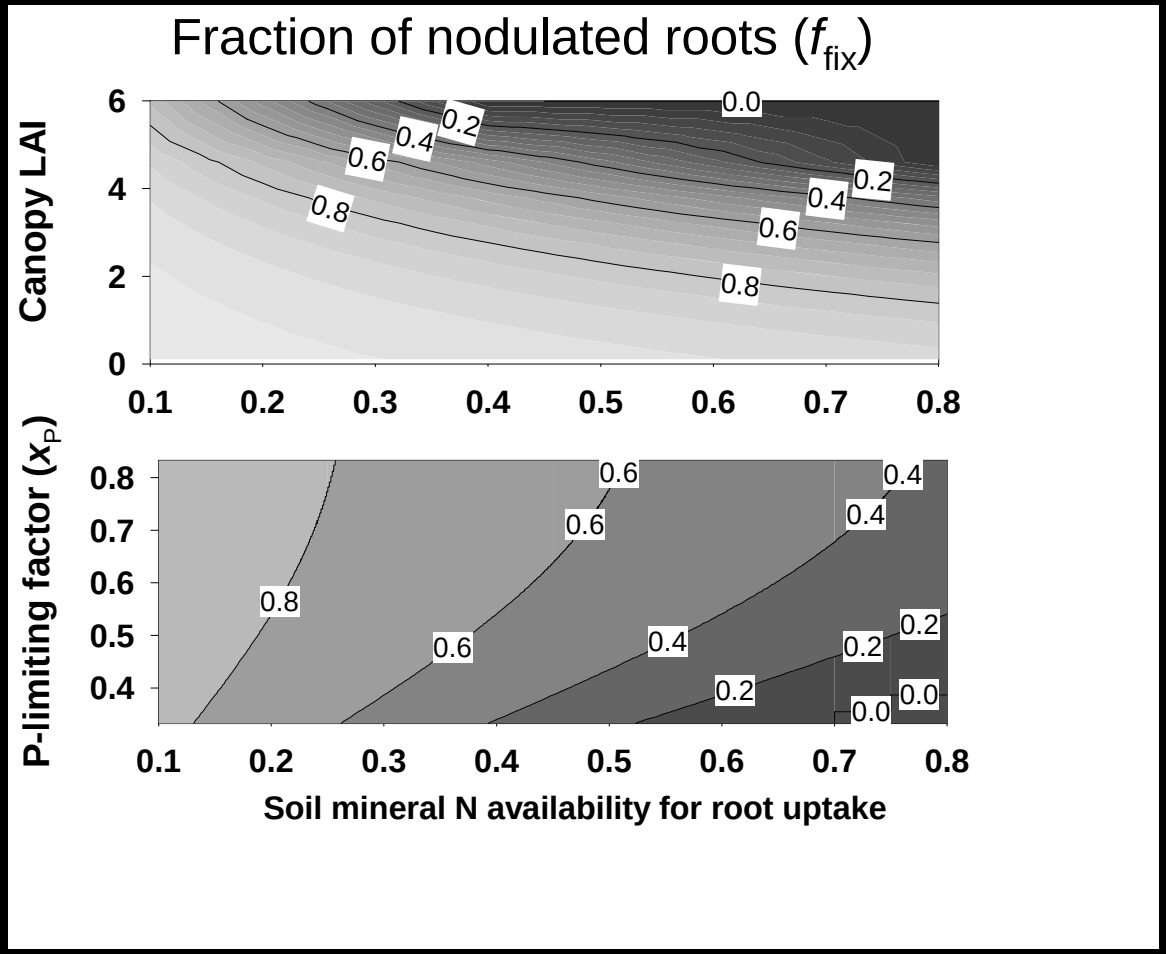
Fixer will be successful only if benefit ≥ cost in NPP

CASA-C,N,P



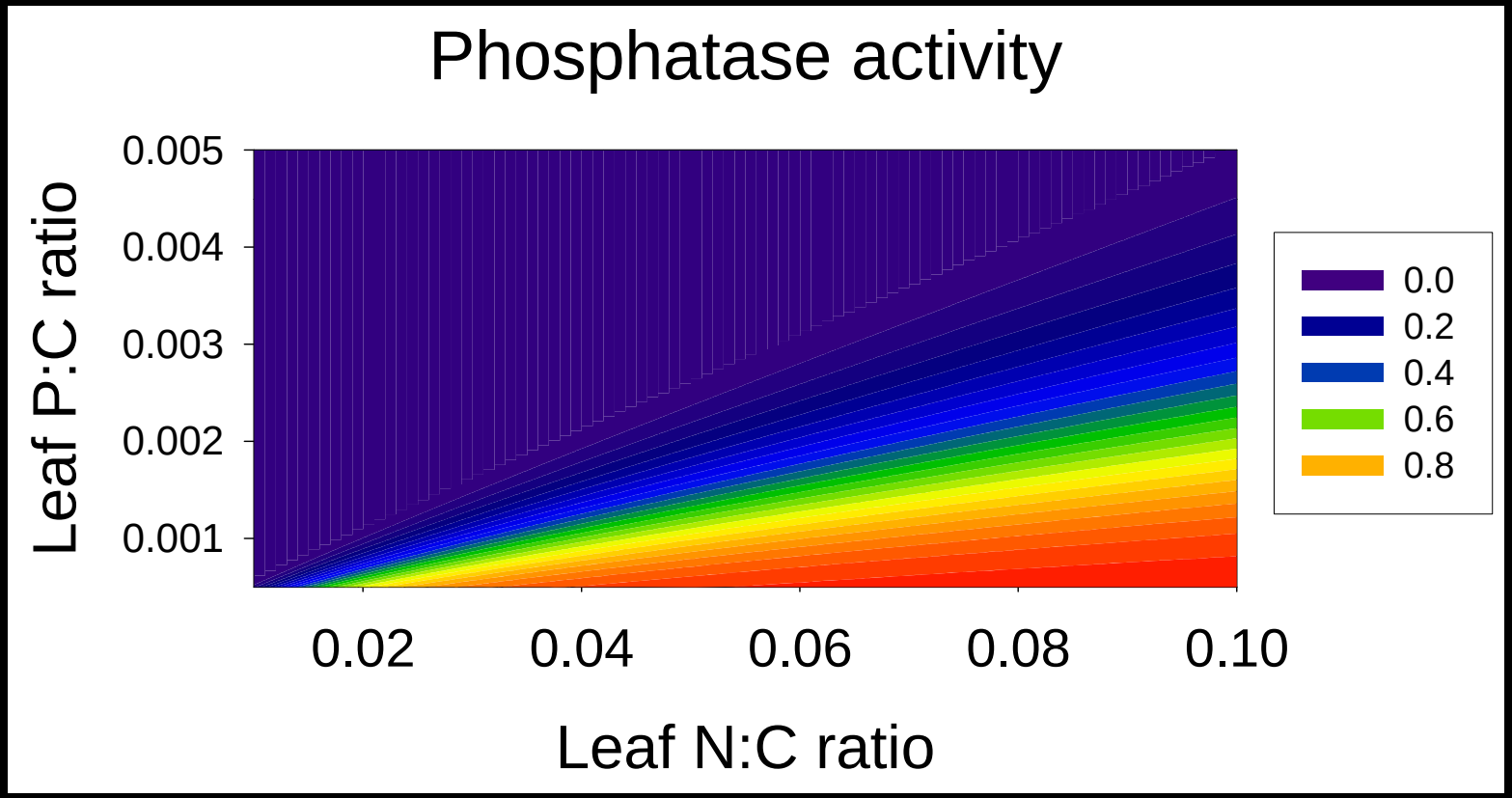
Wang, Houlton, and Field, GBC, 2007

Resource Optimization: N_2 Fixation



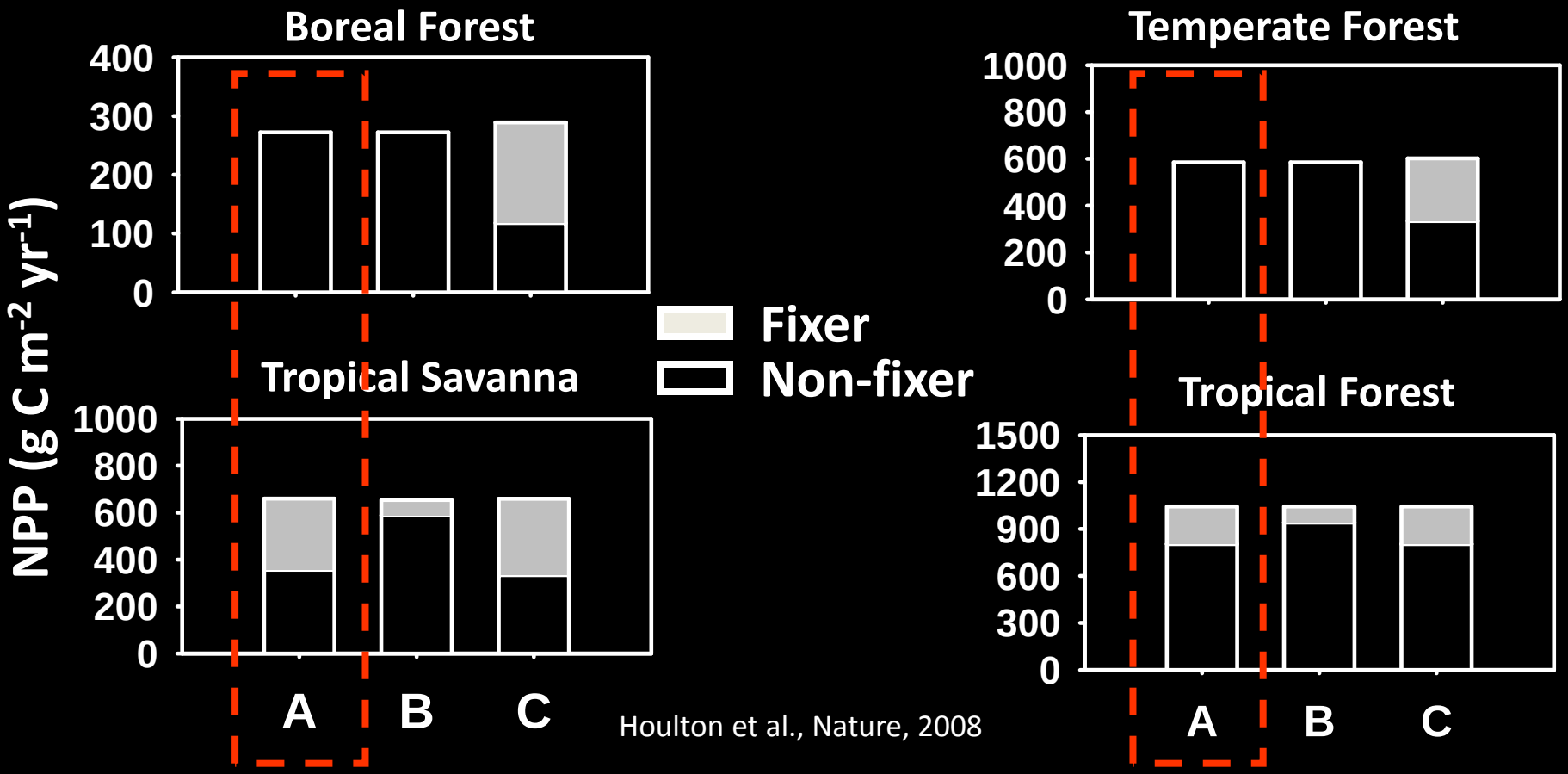
(Wang, Houlton, and Field, GBC, 2006)

Resource Optimization: Root Phosphatase Activity



(Wang, Houlton, and Field, GBC, 2006)

simulation results



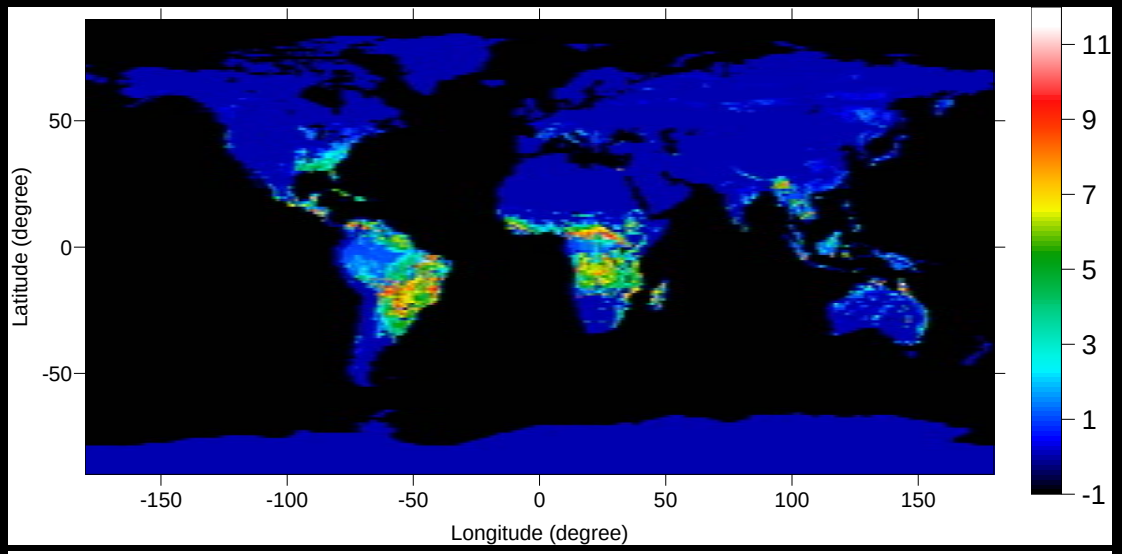
Houlton et al., Nature, 2008

Simulation	N fixation varies with soil temp	N x P interactions
A	Yes	Yes
B	Yes	No
C	No	Yes

N fixation based on C, N, P framework

CASA-CNP simulation (Based on Houlton et al., Nature, 2008; Wang and Houlton GRL, 2009)

Global estimate: 126 Tg N



PET – extrapolated estimates (Cleveland et al., GBC, 1999)

Global estimate: 100 – 290 Tg N

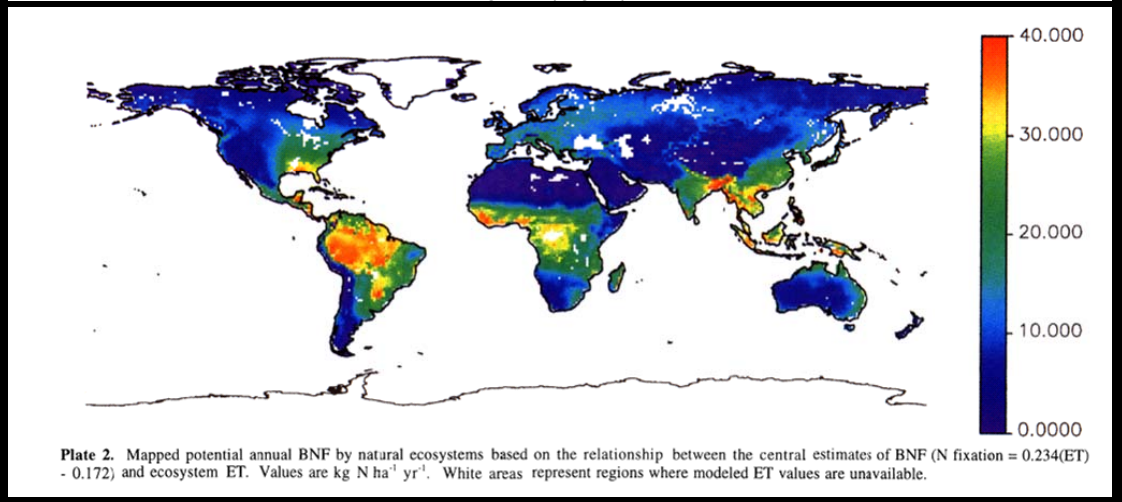
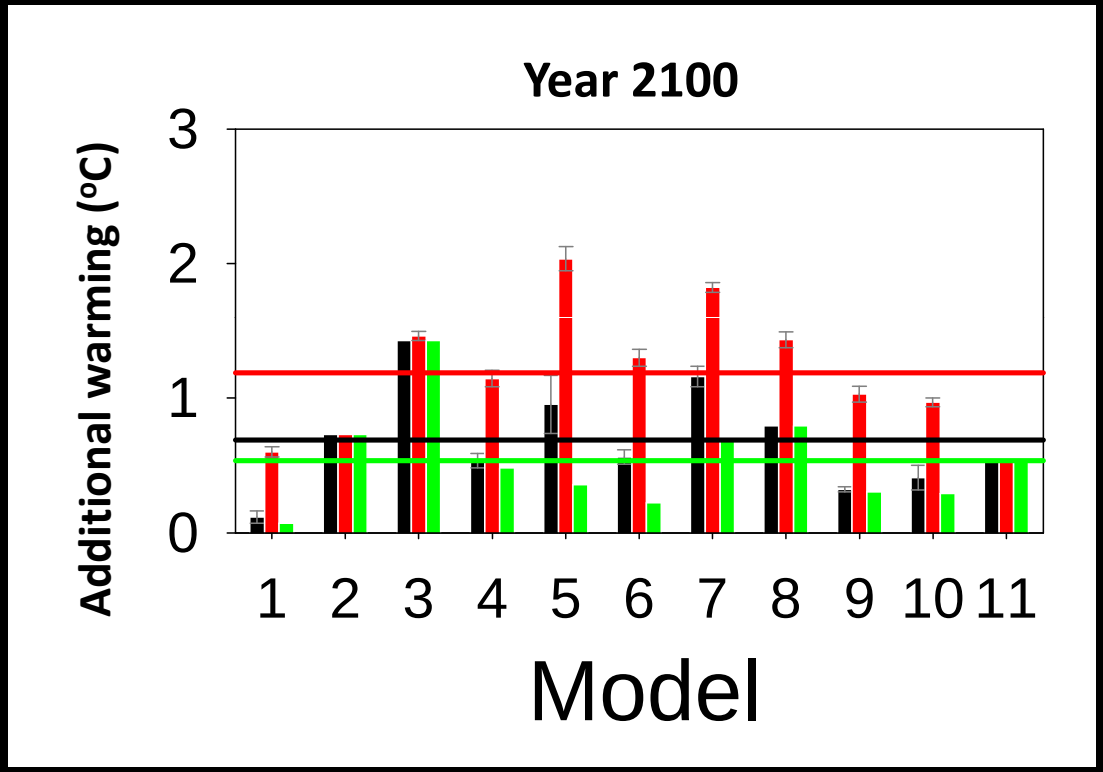


Plate 2. Mapped potential annual BNF by natural ecosystems based on the relationship between the central estimates of BNF (N fixation = 0.234(ET) - 0.172) and ecosystem ET. Values are kg N ha^{-1} yr^{-1}. White areas represent regions where modeled ET values are unavailable.

N fixation and climate warming



Green: C⁴MIP results (CO_2-climate; no nutrient limitation)

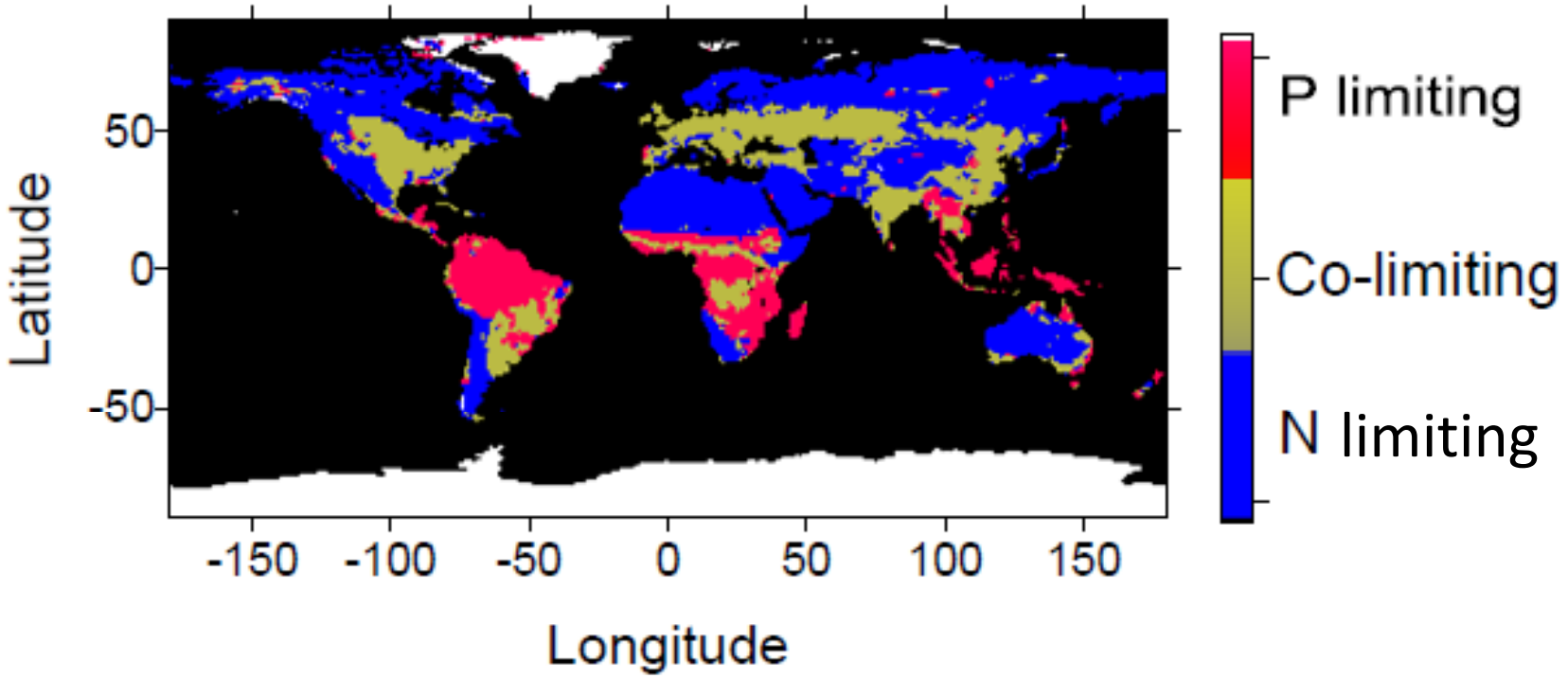
Black: High N fixation, with P interactions

Red: Low N fixation, with P interactions

2100-1900: 0.54°C (C⁴MIP); 0.69 to 1.19°C (N limiting)

Wang and Houlton, GRL, 2009

Global nutrient limitation predictions



Wang et al., Biogeosciences, 2010

Main points

- Like N, P constrains rates of primary productivity on land; N x P co-limitation appears most substantial
- Several N x P interactions are relevant to year 2100 predictions – i.e., phosphatase vs. N fixation (and feedbacks therein)
- A framework that includes these interactions may be more robust than one without C, N, P

Other thoughts for discussion

- When to stop? Trace elements (Mo, Fe)? Base cations (Ca, K)…
- Fate of the occluded P pool?
- P mineralization rates?
- C based pathways of P acquisition – i.e., root exudations, mycorrhizae?
- How to parameterize without global data???