The CLM5 Nitrogen cycle

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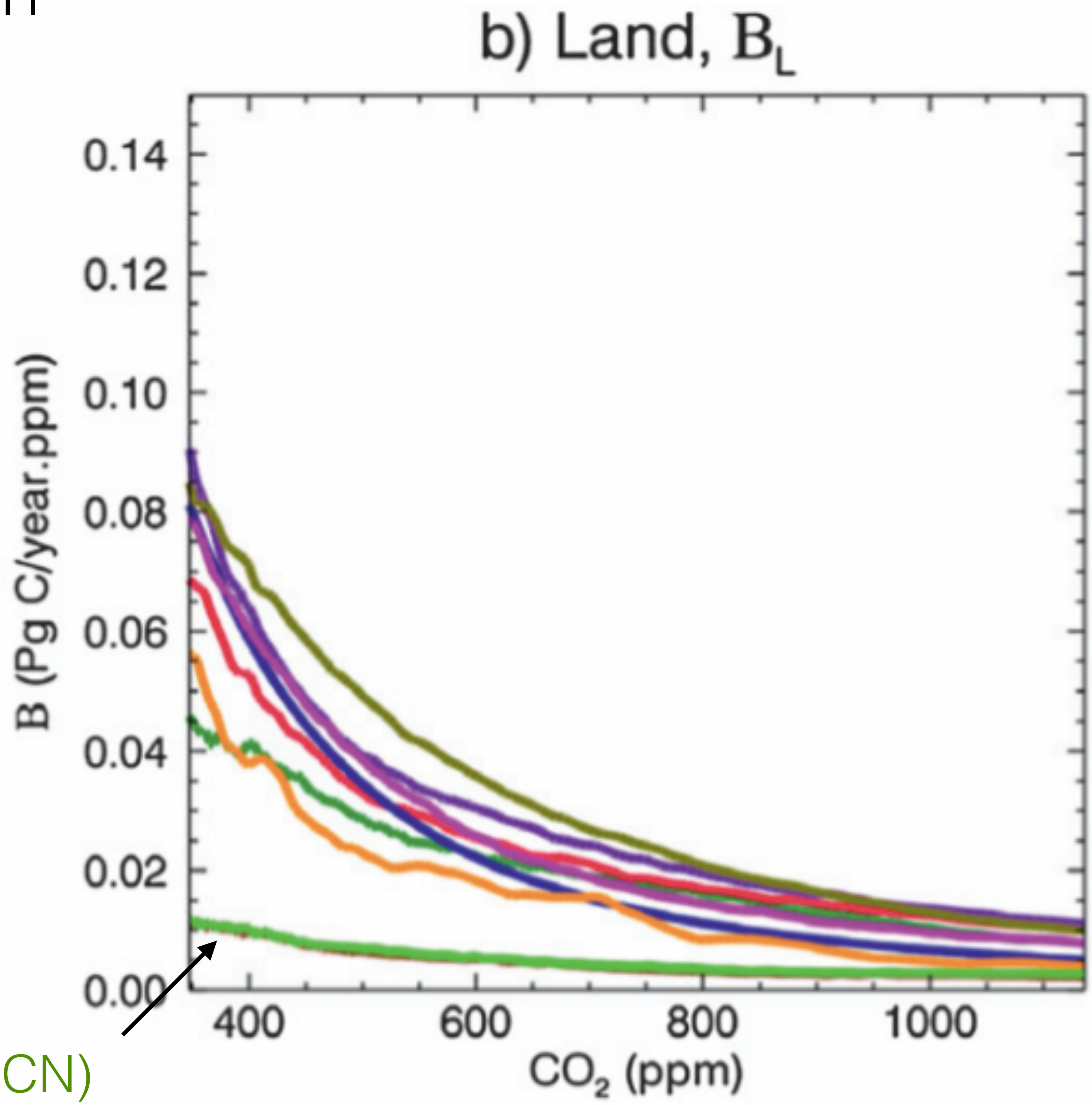
Danica Lombardozzi, Ahmed Tawfik, Justin Perket,
Erik Kluzek, Ben Andre, Bill Sacks, Mariana Vertenstein

Charlie Koven, Bill Riley, Bardan Ghmire (LBNL)
Anthony Walker (ORNL), Chonggang Xu, Ashehad Ali (LANL)
Mingjie Shi & Josh Fisher (NASA-JPL)
Eddie Brzostek (WVU), Quinn Thomas (VT),

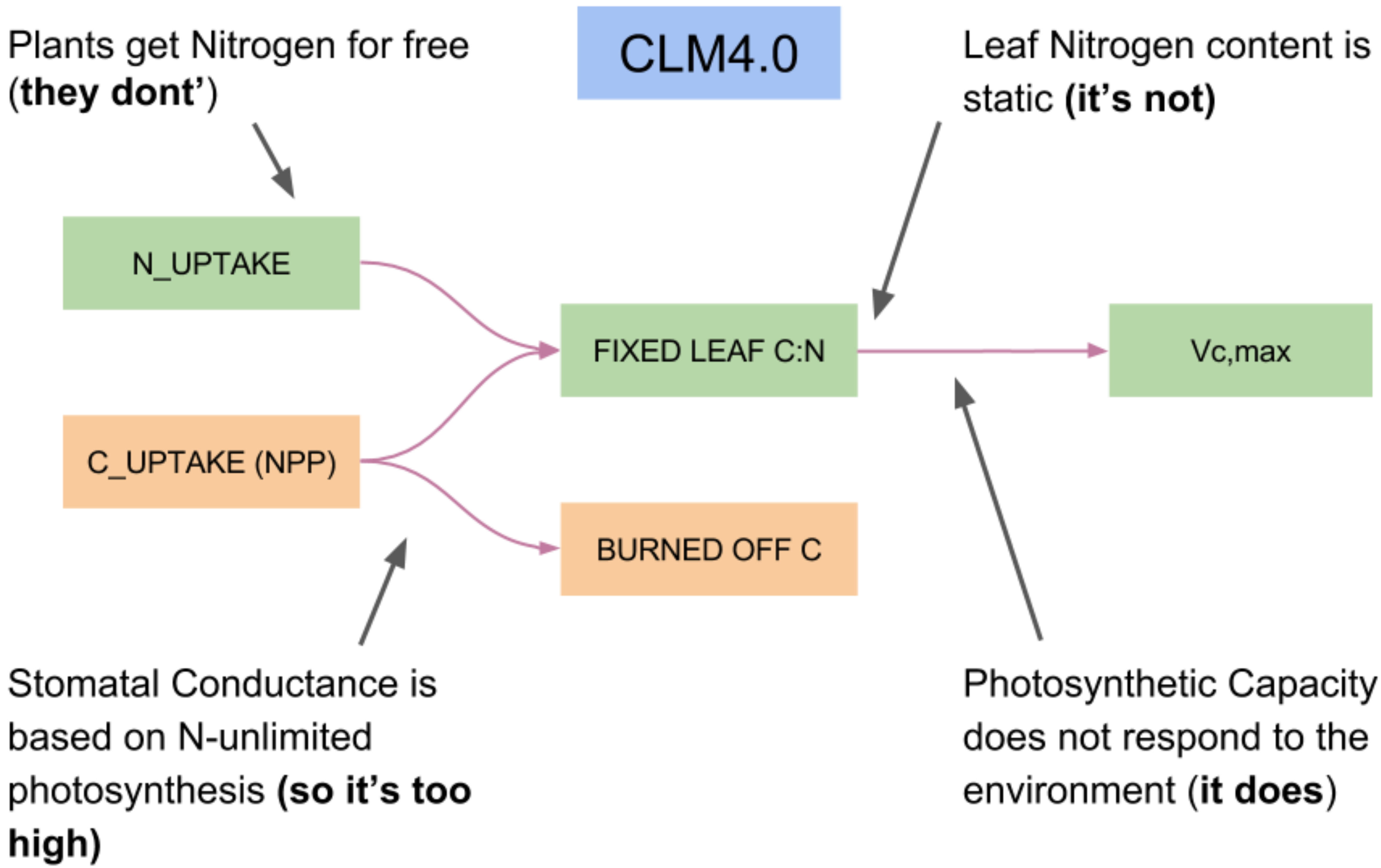
Impact of Nitrogen on simulated carbon fertilization



Carbon–Concentration and Carbon–Climate Feedbacks in CMIP5 Earth System Models

VIVEK K. ARORA,[a] GEORGE J. BOER,[a] PIERRE FRIEDLINGSTEIN,[b] MICHAEL EBY,[c] CHRIS D. JONES,[d] JAMES R. CHRISTIAN,[a] GORDON BONAN,[e] LAURENT BOPP,[f] VICTOR BROVKIN,[g] PATRICIA CADULE,[f] TOMOHIRO HAJIMA,[h] TATIANA ILYINA,[g] KEITH LINDSAY,[e] JERRY F. TJIPUTRA,[i] AND TONGWEN WU[j]

Issues raised with the CLM4.0(CN)



“Plants get Nitrogen for free”

The FUN* Model

A marketplace for Nitrogen Uptake

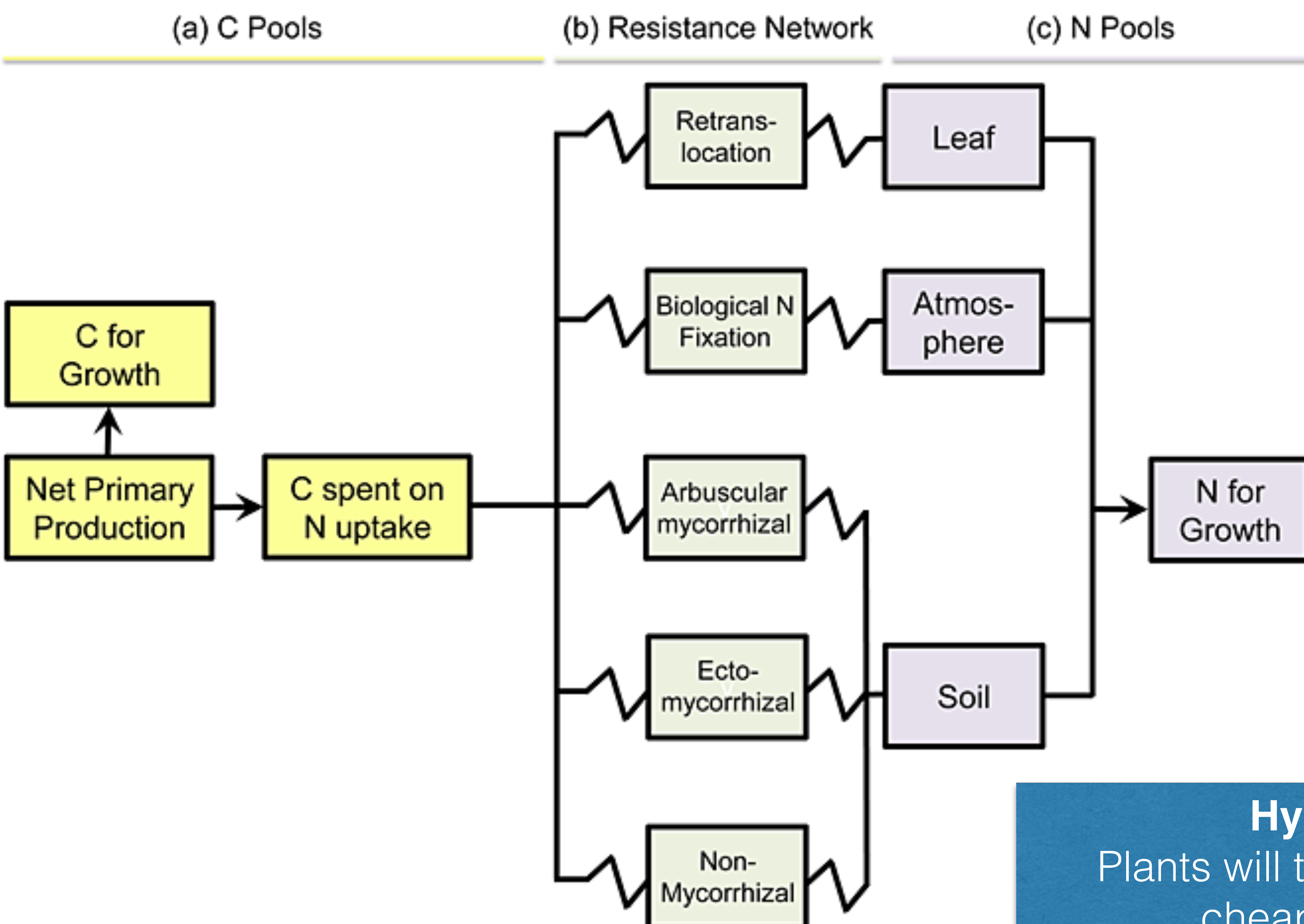
*Fixation and Uptake of Nitrogen

Carbon cost of plant nitrogen acquisition: A mechanistic, globally applicable model of plant nitrogen uptake, retranslocation, and fixation

J. B. Fisher,[1] S. Sitch,[2] Y. Malhi,[1] R. A. Fisher,[3] C. Huntingford,[4] and S.-Y. Tan[1]

Modeling the carbon cost of plant nitrogen acquisition: Mycorrhizal trade-offs and multipath resistance uptake improve predictions of retranslocation

Edward R. Brzostek[1], Joshua B. Fisher[2,3], and Richard P. Phillips[1]



Hypothesis:
Plants will take up N from the cheapest sources

Solution to FUN model

$$C_{nuptake} = \frac{GPP - Mresp}{CNtarget/CN_{uptake\_cost} + 1}$$

Solve for maximum growth

$$C_{growth} = C_{npp} - C_{nuptake}$$

$$N_{growth} = N_{uptake}$$

$$N_{uptake} = C_{nuptake} / CN_{uptake\_cost}$$

$$N_{growth} = C_{growth} / CN_{target}$$

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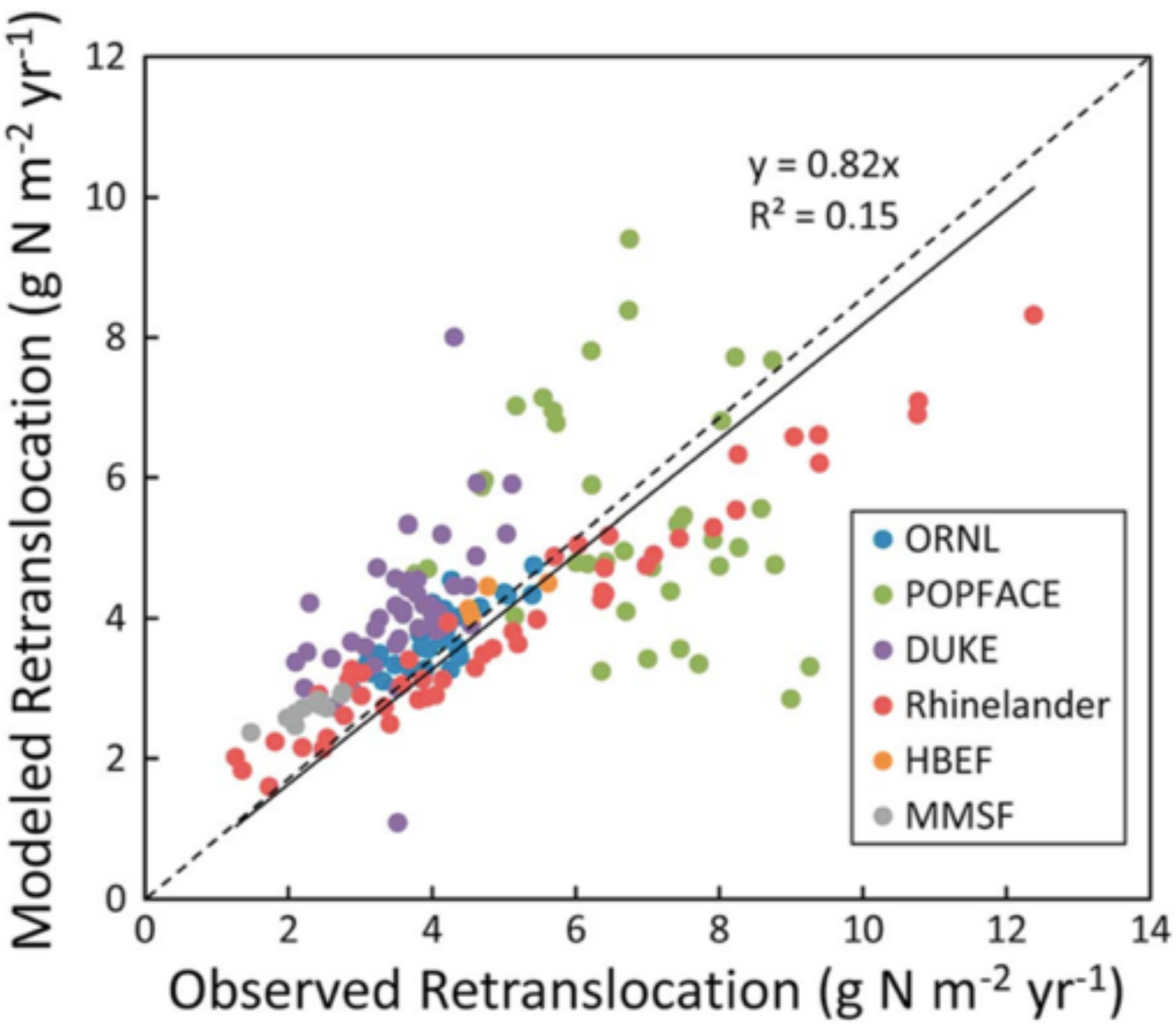
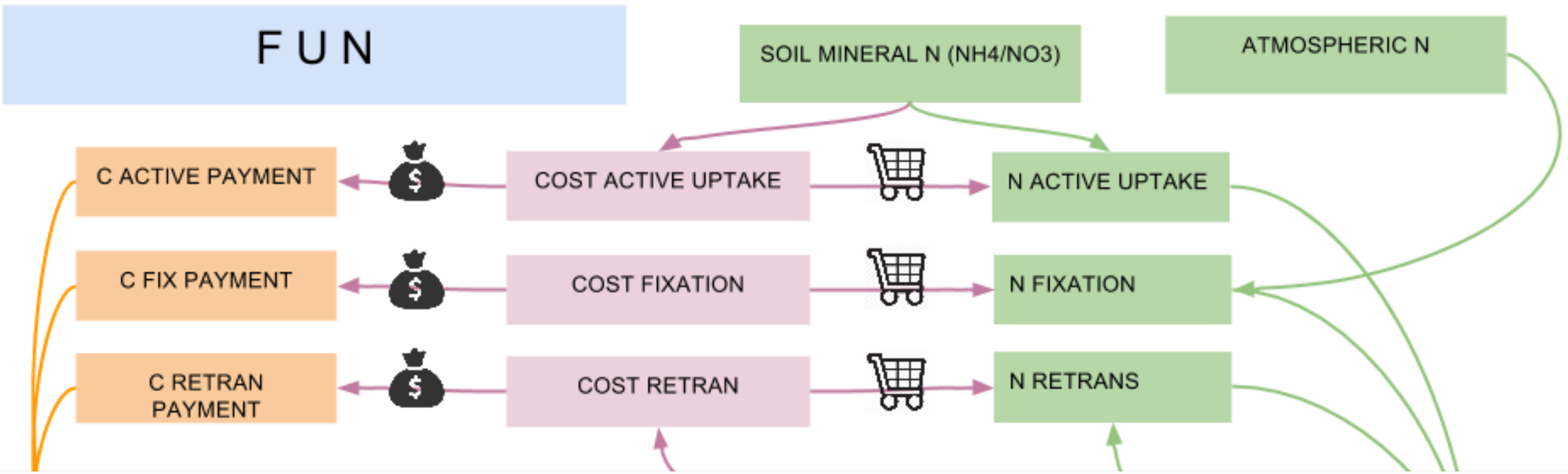



F U N
SOIL MINERAL N (NH4/NO3)
ATMOSPHERIC N
C ACTIVE PAYMENT
COST ACTIVE UPTAKE
N ACTIVE UPTAKE
C FIX PAYMENT
COST FIXATION
N FIXATION
C RETRAN PAYMENT
COST RETRAN
N RETRANS

FUNMod.F90

“Leaf Nitrogen content is static”

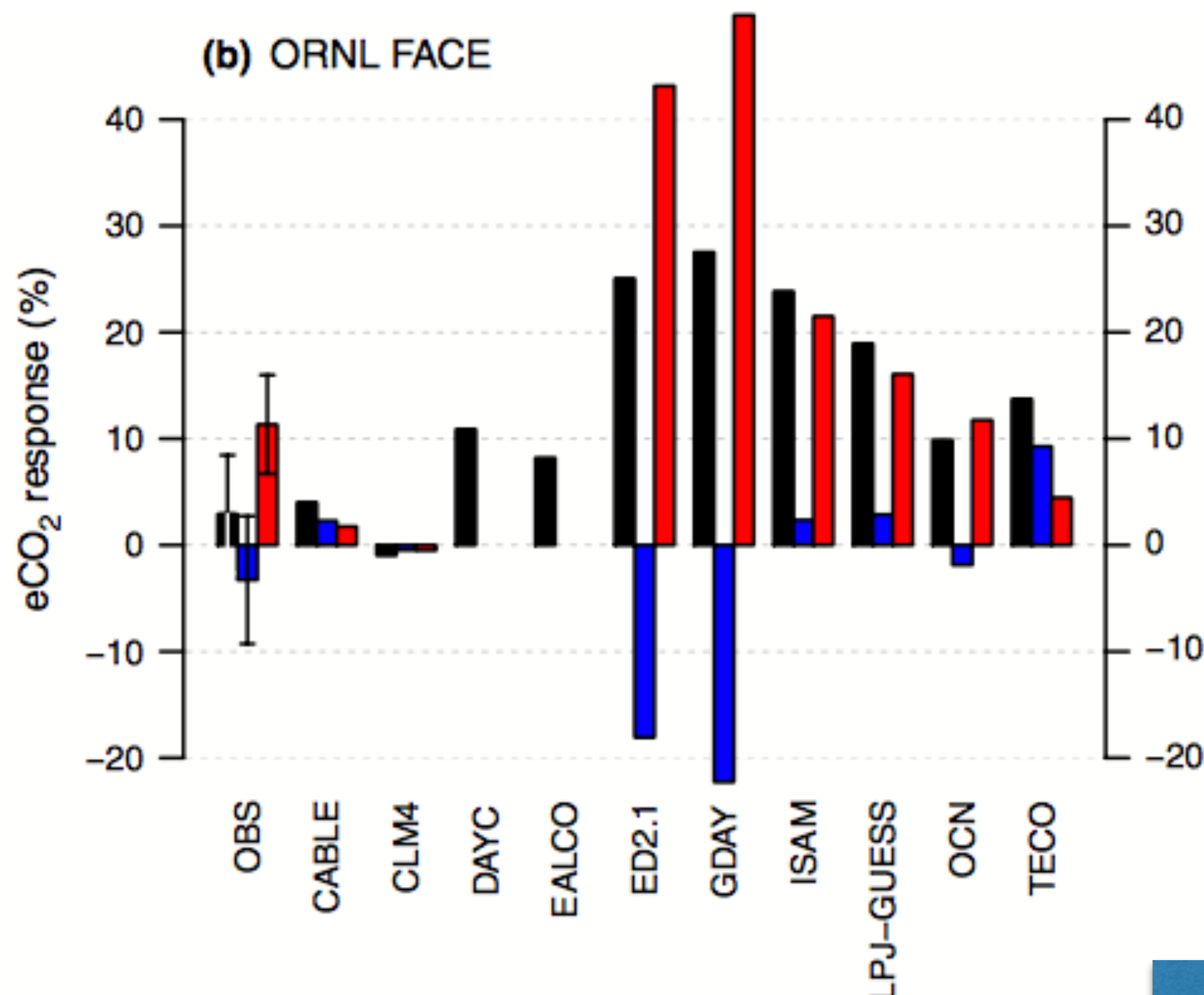
The FlexCN Model

Variable carbon:nitrogen ratios

Representing leaf and root physiological traits in CLM improves global carbon and nitrogen cycling predictions

Bardan Ghimire[1], William J. Riley[1], Charles D. Koven[1], Mingquan Mu[2], and James T. Randerson[2]

Increase in productivity due to change C:N ratio
Increase in productivity due to increased NUE (fertilization)
Increase in productivity due to increased leaf allocation



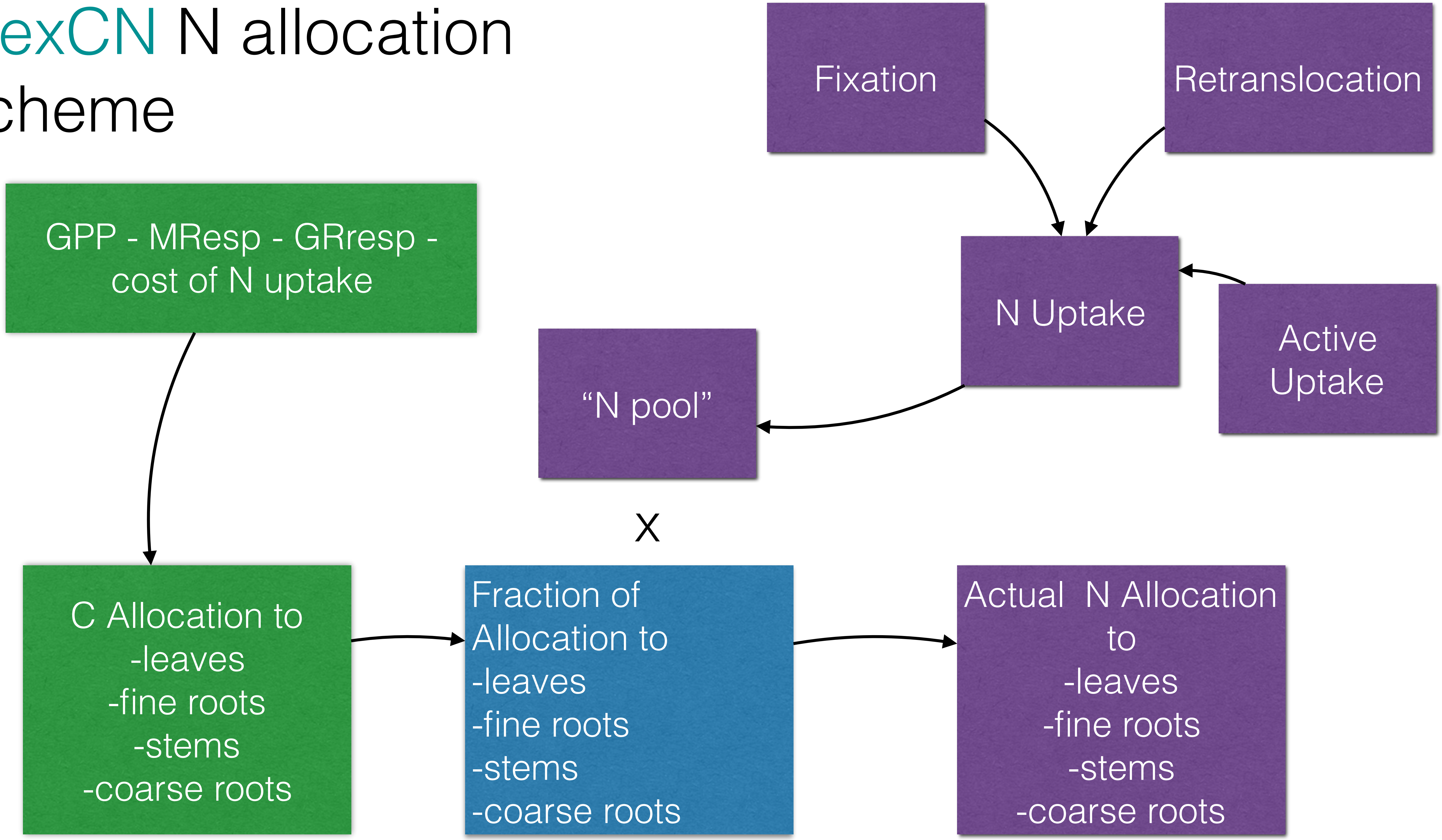
Zaehle et al. 2014

'FlexCN' allows for tissue-level variation in C:N ratio relative to target parameter.

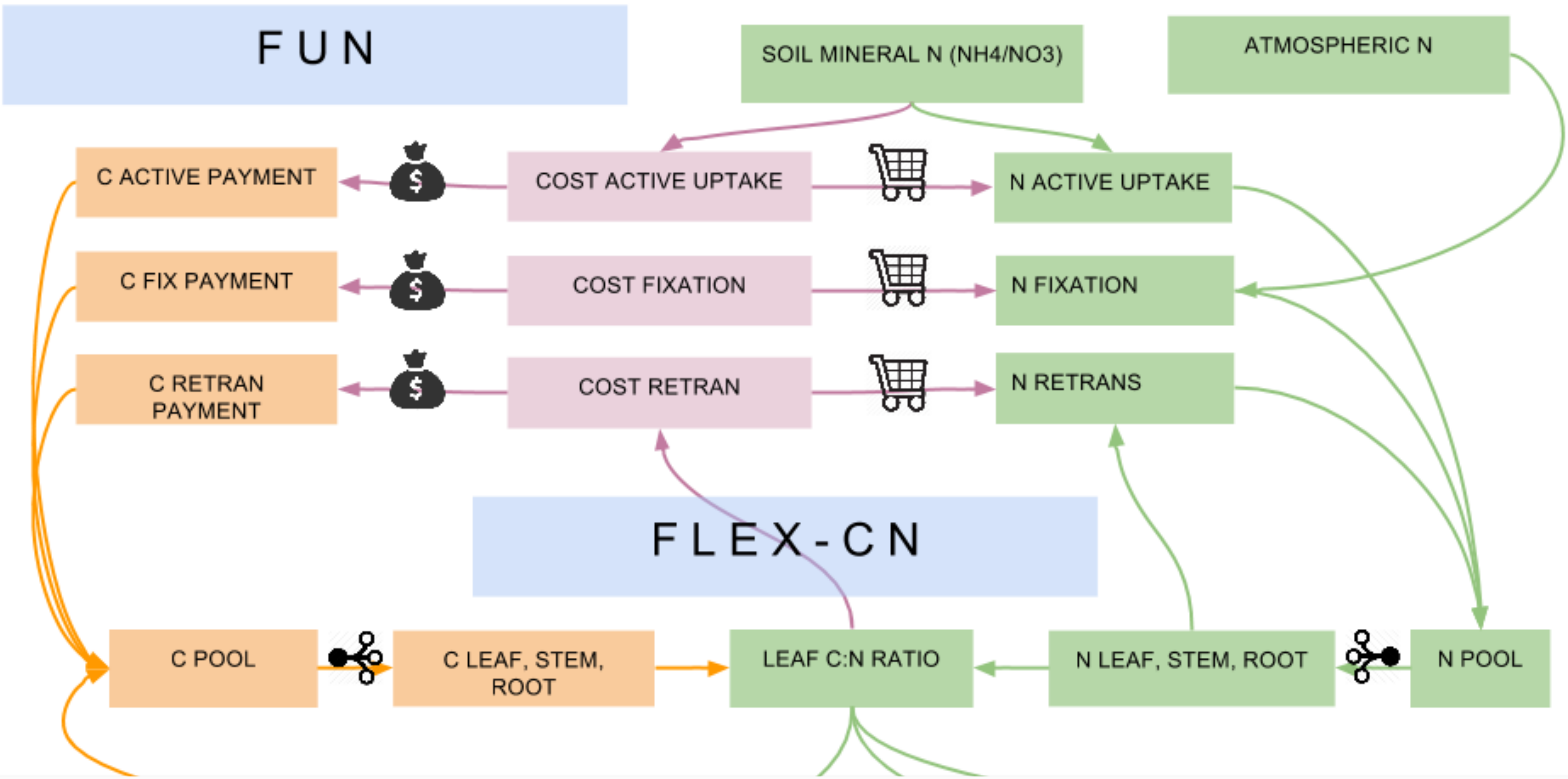
Standalone FlexCN model tested by Ghmire et al. (BGC)

Hypothesis: Plants will vary their tissue Carbon:Nitrogen ratio as N availability varies in space and time

FlexCN N allocation scheme



If N uptake is too low, C:N ratios will increase



NutrientCompetitionFlexibleCNMod.F90

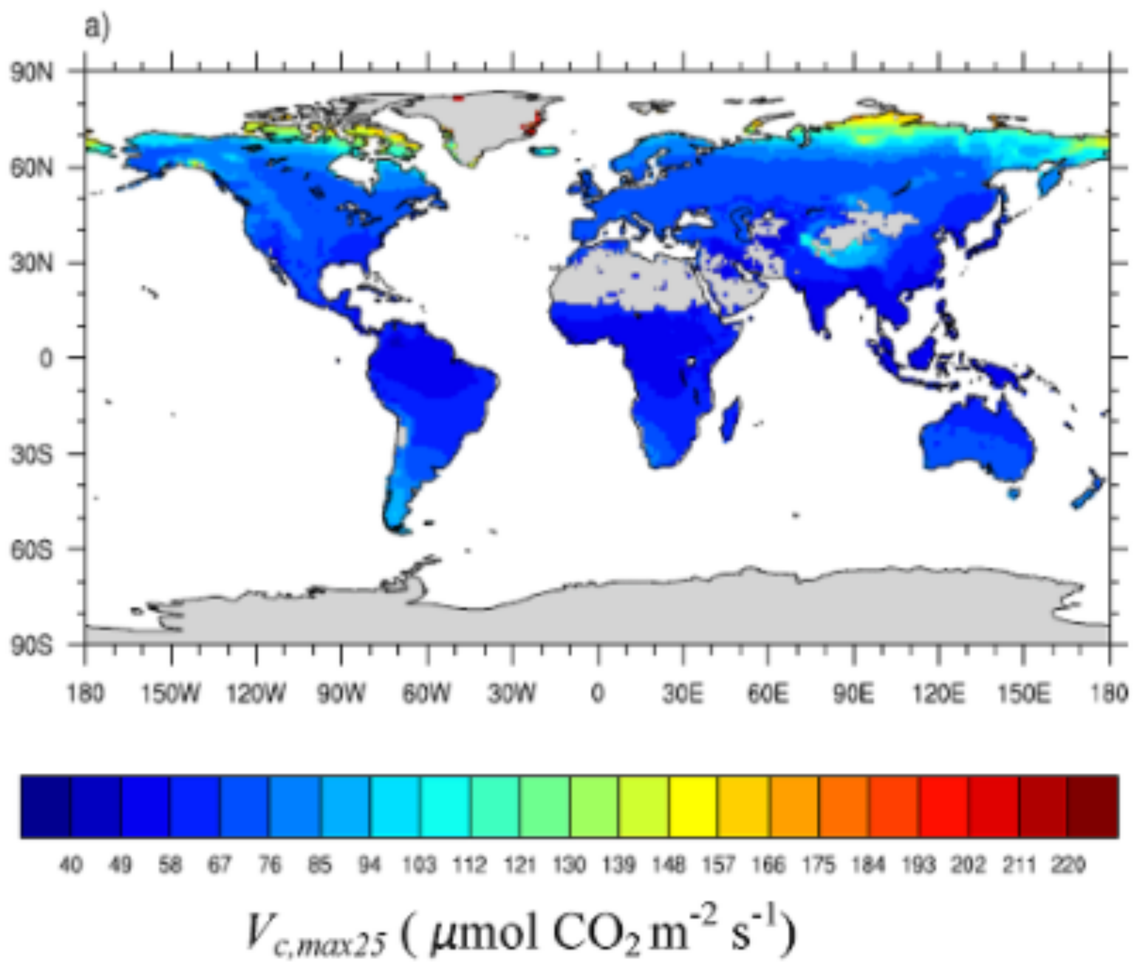
“Photosynthetic capacity does not respond to the environment”

The LUNA* Model

How best to use the Nitrogen you have?

*Leaf Use of Nitrogen for Assimilation

Predicted optimal photosynthetic capacity

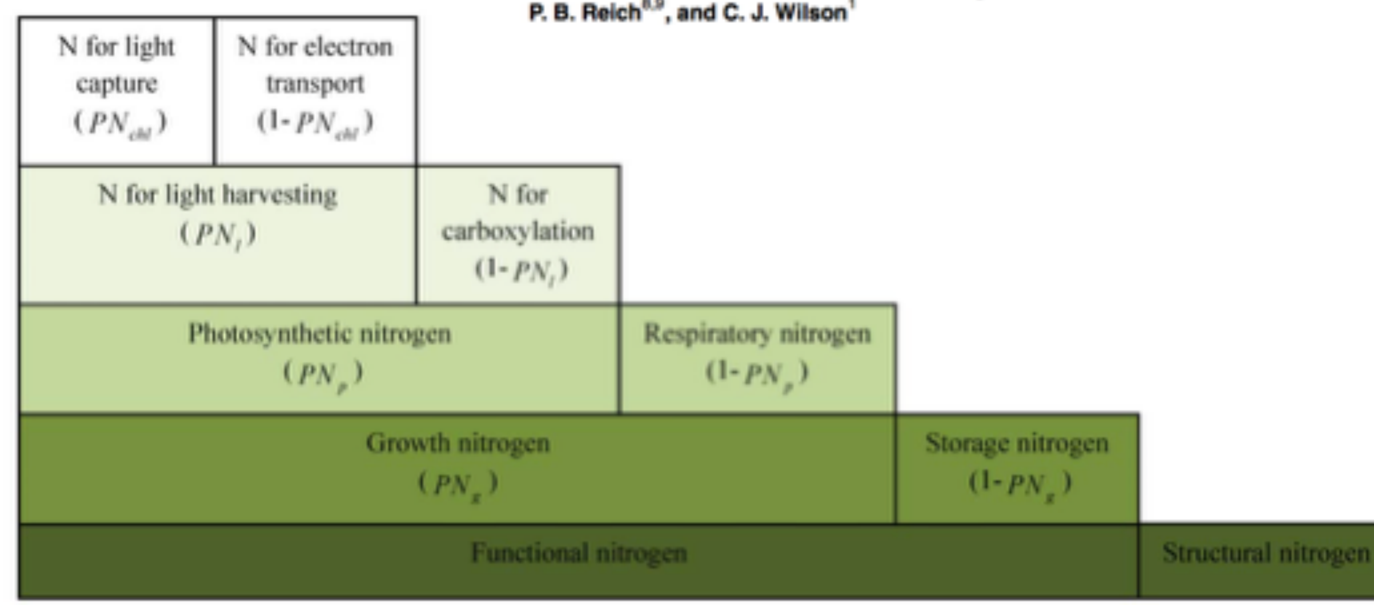


Toward a Mechanistic Modeling of Nitrogen Limitation on Vegetation Dynamics

Chonggang Xu[1*], Rosie Fisher[2], Stan D. Wullschleger[3], Cathy J. Wilson[1], Michael Cai[4], Nate G. McDowell[1]

A global scale mechanistic model of the photosynthetic capacity

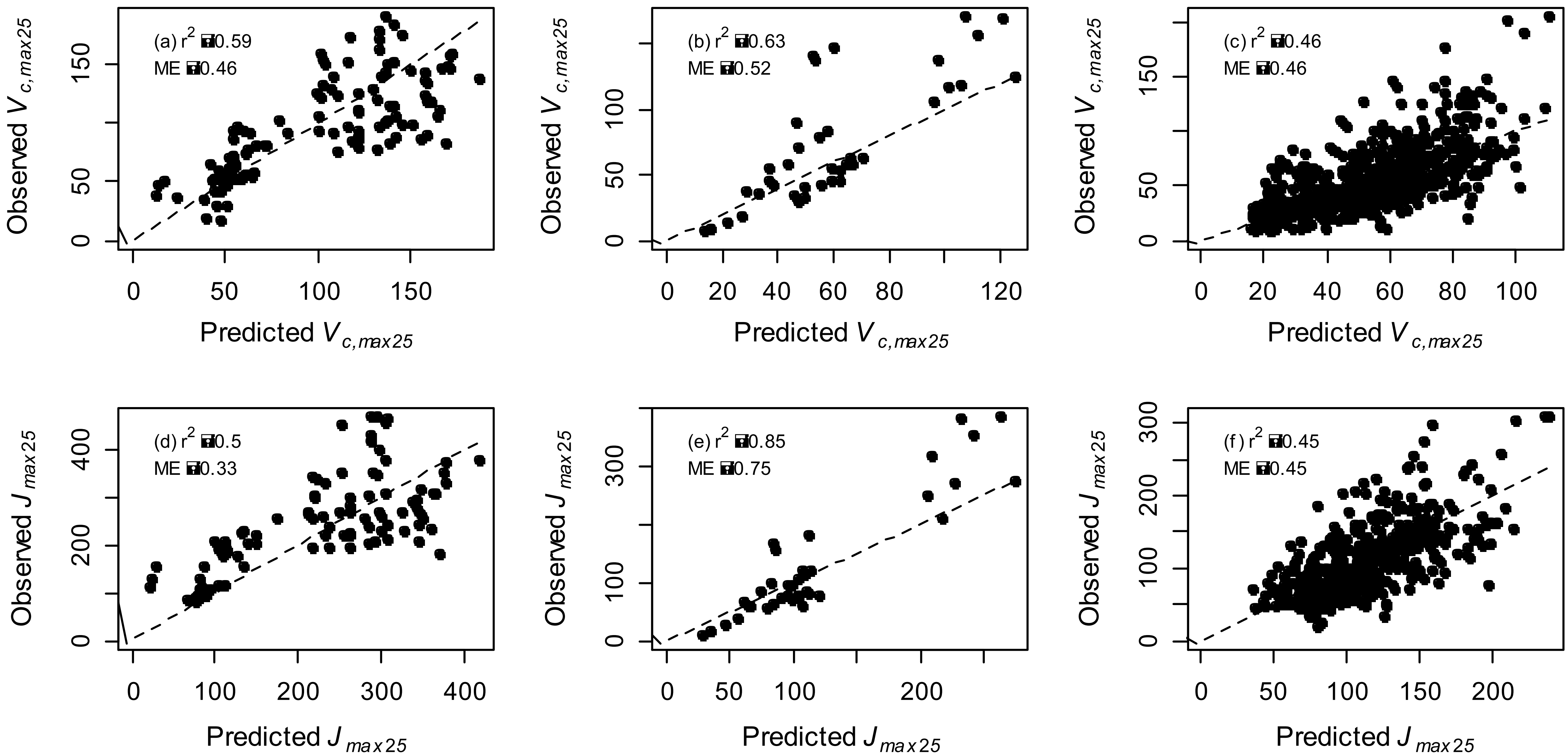
A. A. Ali[1,2], C. Xu[1], A. Rogers[3], R. A. Fisher[4], S. D. Wullschleger[5], N. G. McDowell[1], E. C. Massoud[2], J. A. Vrugt[2,6], J. D. Muss[1], J. B. Fisher[7], P. B. Reich[8,9], and C. J. Wilson[1]



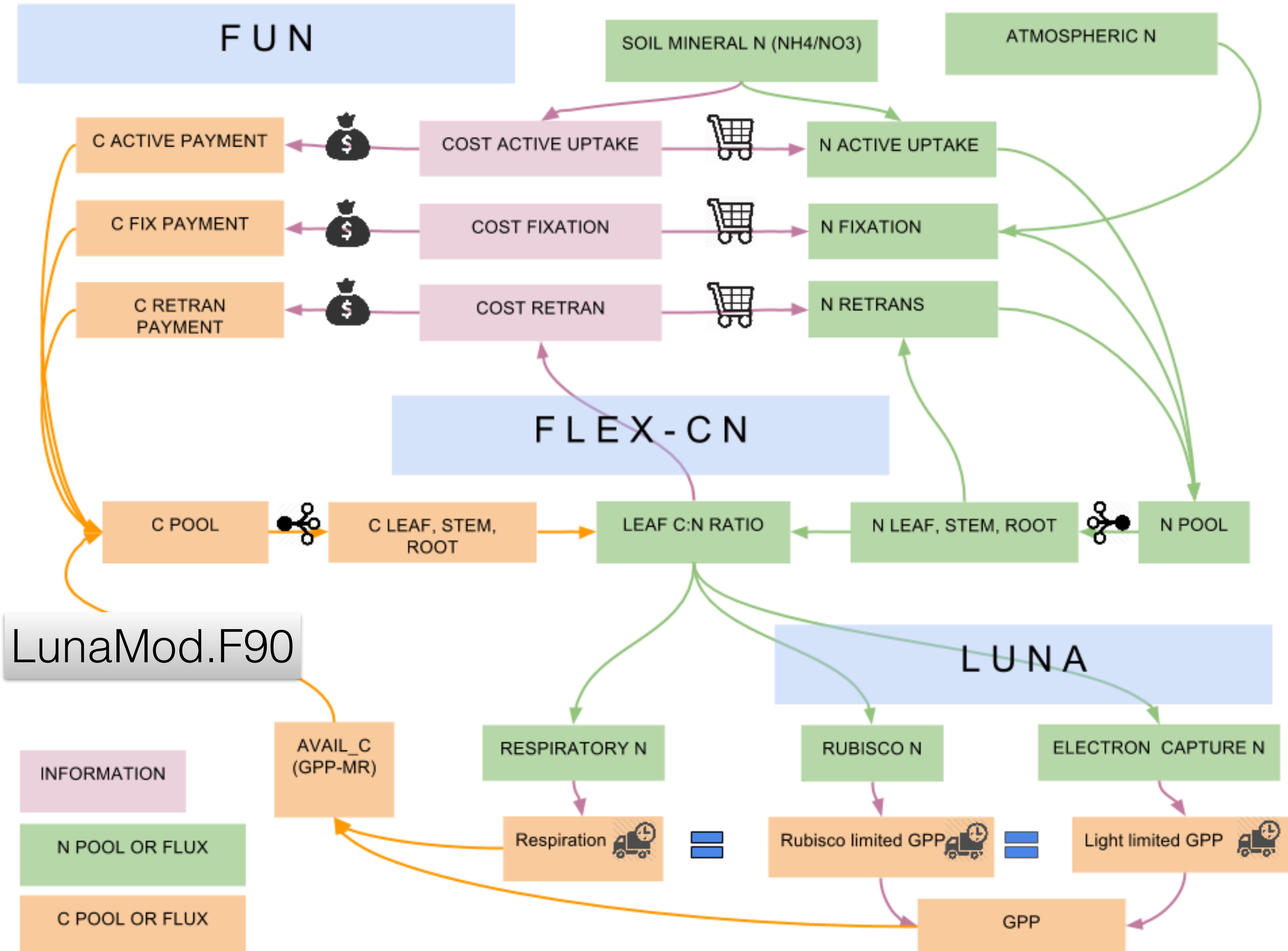
Hypothesis: Leaf Nitrogen is distributed so that light capture, carboxylation and respiration are co-limiting

LUNA performance vs. observations

Herbs Shrubs Trees



Ali et al. 2015



FUN
SOIL MINERAL N (NH4/NO3)
ATMOSPHERIC N
C ACTIVE PAYMENT
COST ACTIVE UPTAKE
N ACTIVE UPTAKE
C FIX PAYMENT
COST FIXATION
N FIXATION
C RETRAN PAYMENT
COST RETRAN
N RETRANS
FLEX-CN
C POOL
C LEAF, STEM, ROOT
LEAF C:N RATIO
N LEAF, STEM, ROOT
N POOL
LunaMod.F90
LUNA
AVAIL_C (GPP-MR)
RESPIRATORY N
RUBISCO N
ELECTRON CAPTURE N
INFORMATION
N POOL OR FLUX
C POOL OR FLUX
Respiration
Rubisco limited GPP
Light limited GPP
GPP


FUN flex-CN reconciliation

FUN-FlexCN coupling

- The FUN model **targets** a fixed C/N ratio
- This intrinsically does **not** allow flexible CN ratio.
- We thus need to change $\mathbf{C_{nuptake}}$ to allow for this

$$\mathbf{C_{nuptake}} = \frac{GPP - Mresp}{CNtarget/\mathbf{CN_{uptake\_cost}} + 1}$$

Solve for maximum growth

$$C_{growth} = C_{npp} - \mathbf{C_{nuptake}}$$

$$N_{growth} = N_{uptake}$$

$$N_{uptake} = \mathbf{C_{nuptake}} / \mathbf{CN_{uptake\_cost}}$$

$$N_{growth} = C_{growth} / CN_{target}$$

C allocation to uptake responds to $\mathbf{CN_{uptake\text{-}cost}}$ and $\mathbf{CN_{actual}}$

Adjustment factor

FUN equation

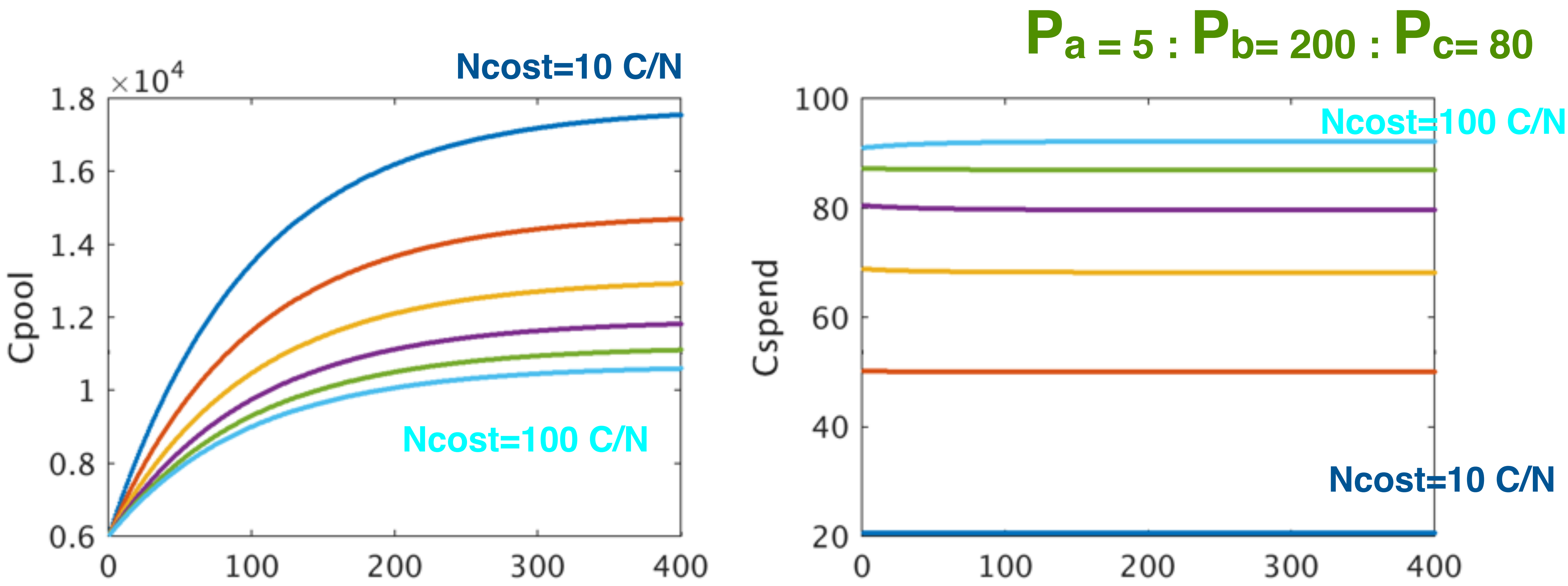
$$\textbf{Cnuptake} = \mathbf{C_{adj}} \times \frac{(GPP-MR)}{(CN_{target} / \mathbf{CN_{uptake\text{-}cost}}) + 1.0}$$

$$\mathbf{C_{adj}} = 1.0 - (\mathbf{CN_{uptake\text{-}cost}} - \mathbf{P_a}) / \mathbf{P_b}$$

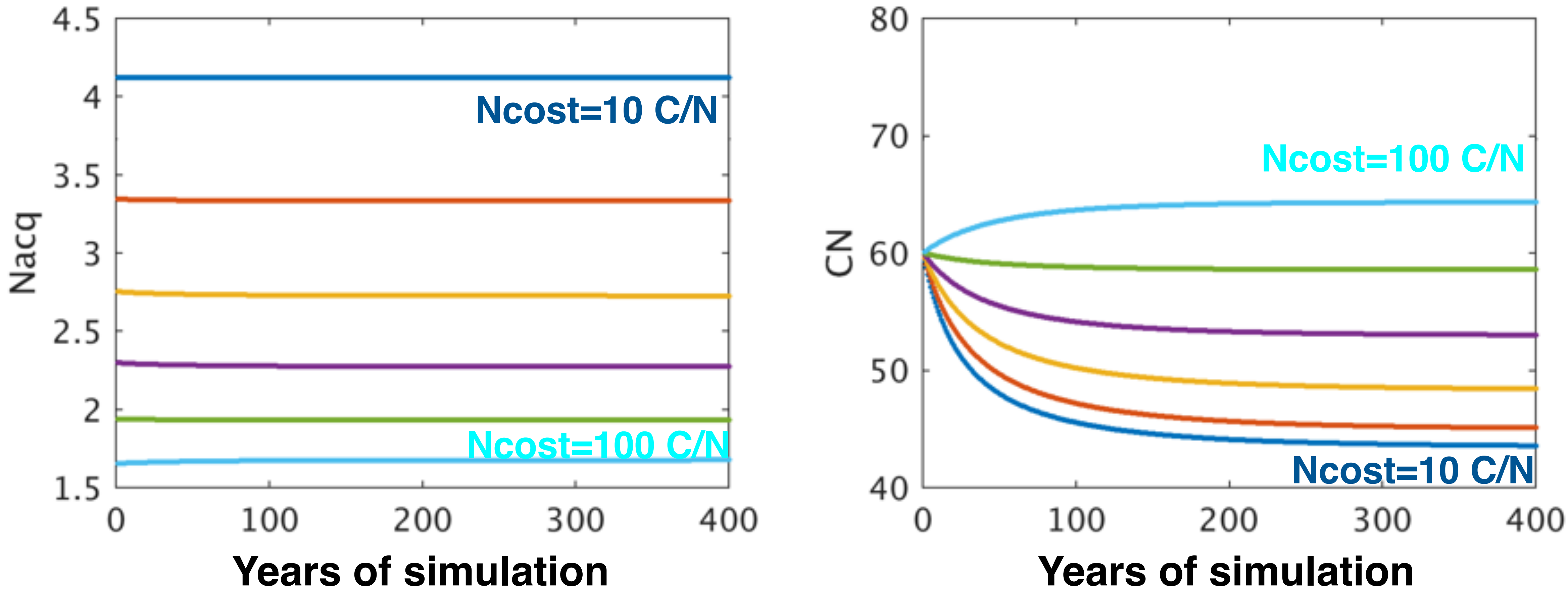
Reduce C allocation with cost

$$\mathbf{C_{adj}} = \mathbf{C_{adj}} + (1.0 - \mathbf{C_{adj}}) \times (\mathbf{CN_{actual}} - CN_{target}) / \mathbf{P_c}$$

Increase C allocation with high C:N

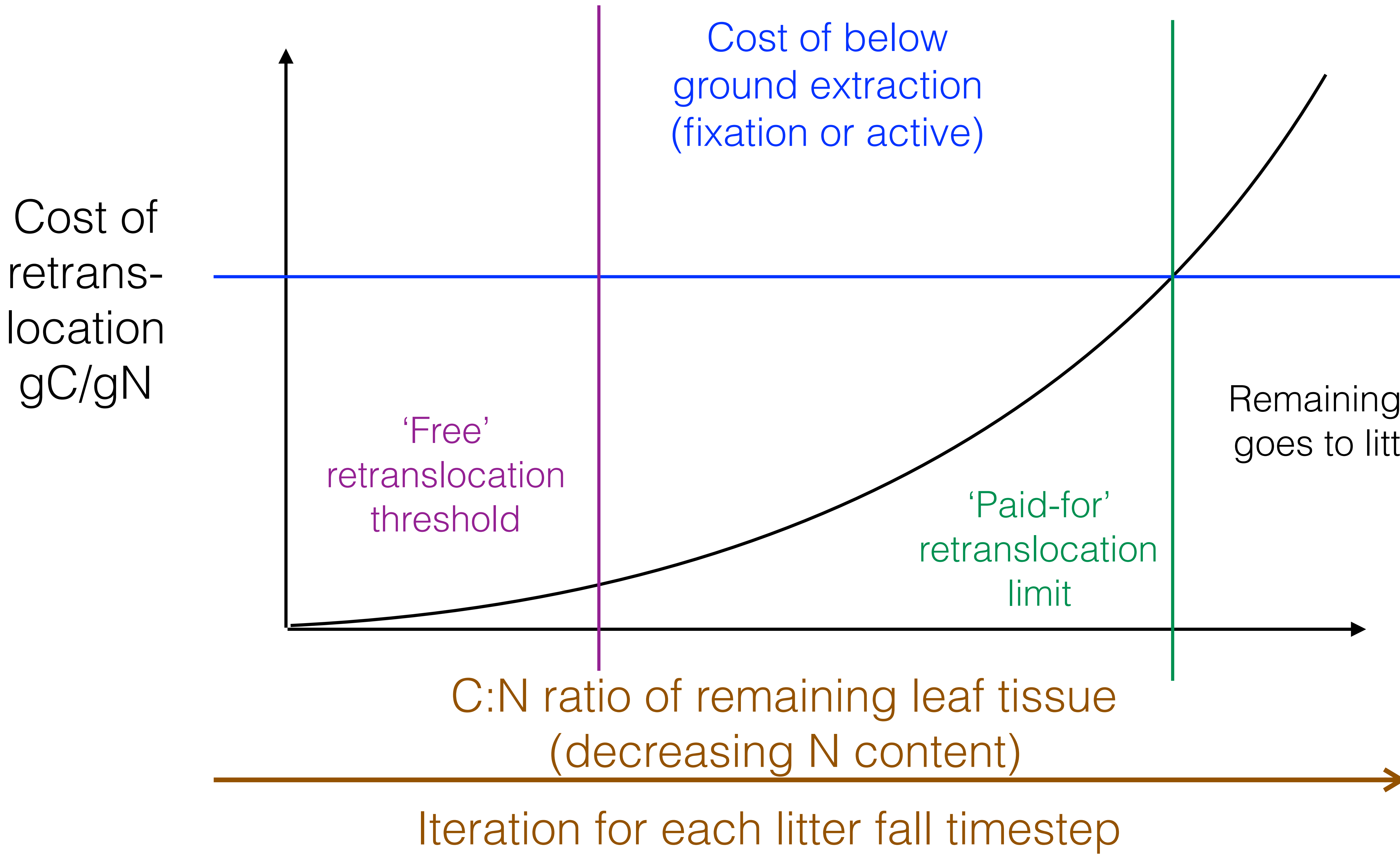


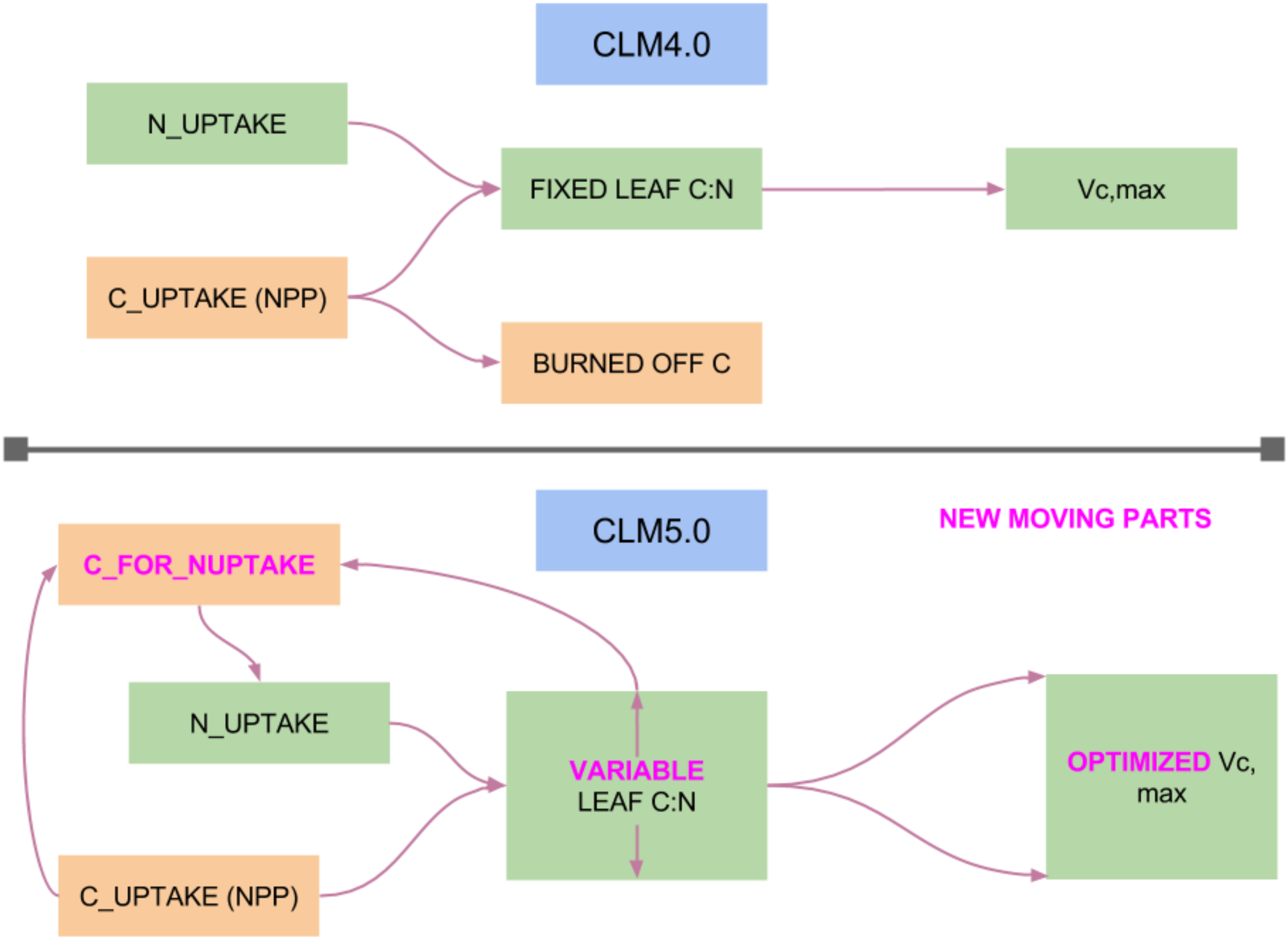
Offline FlexCN-FUN feedback behavior

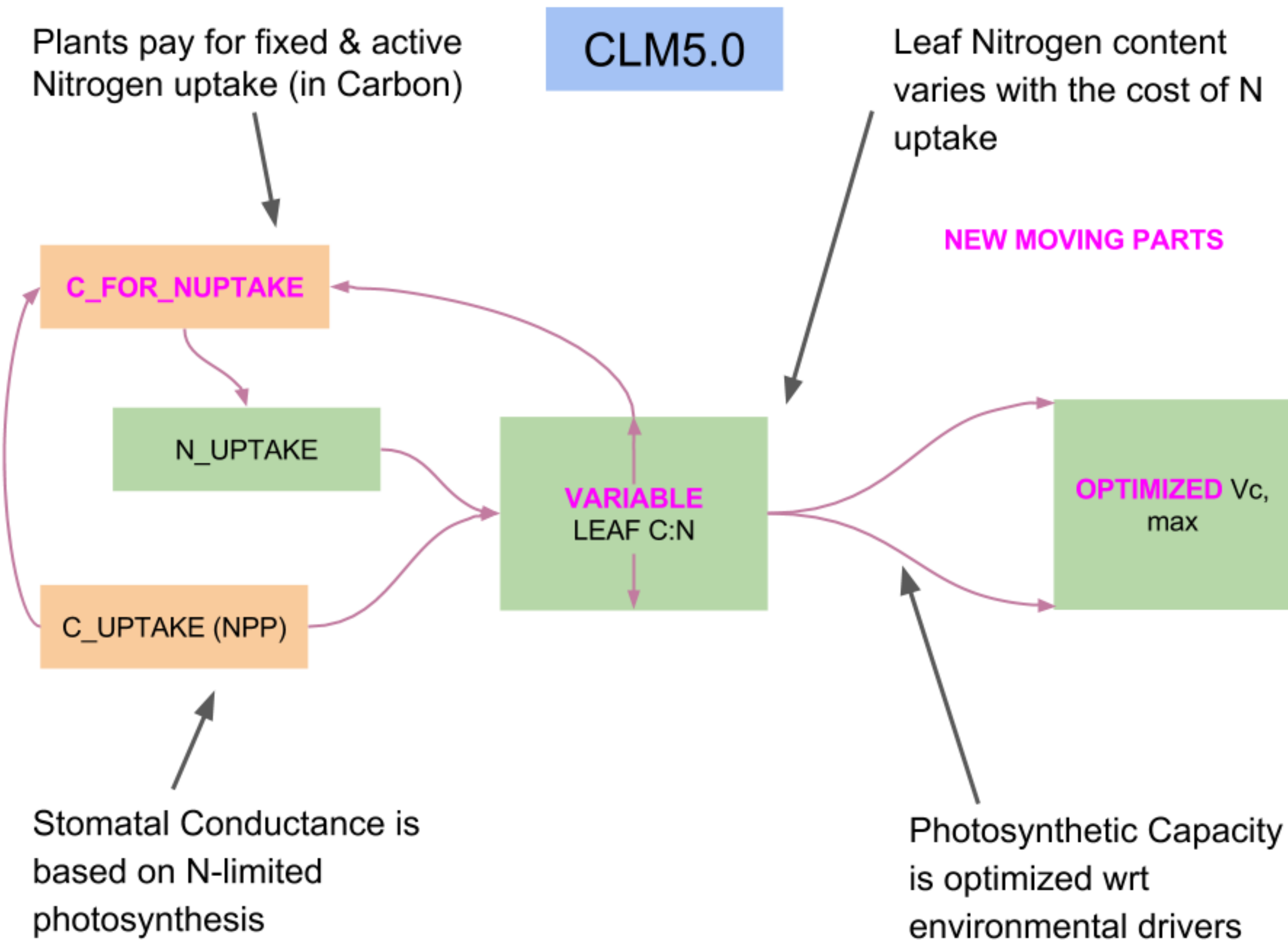



Retranslocation

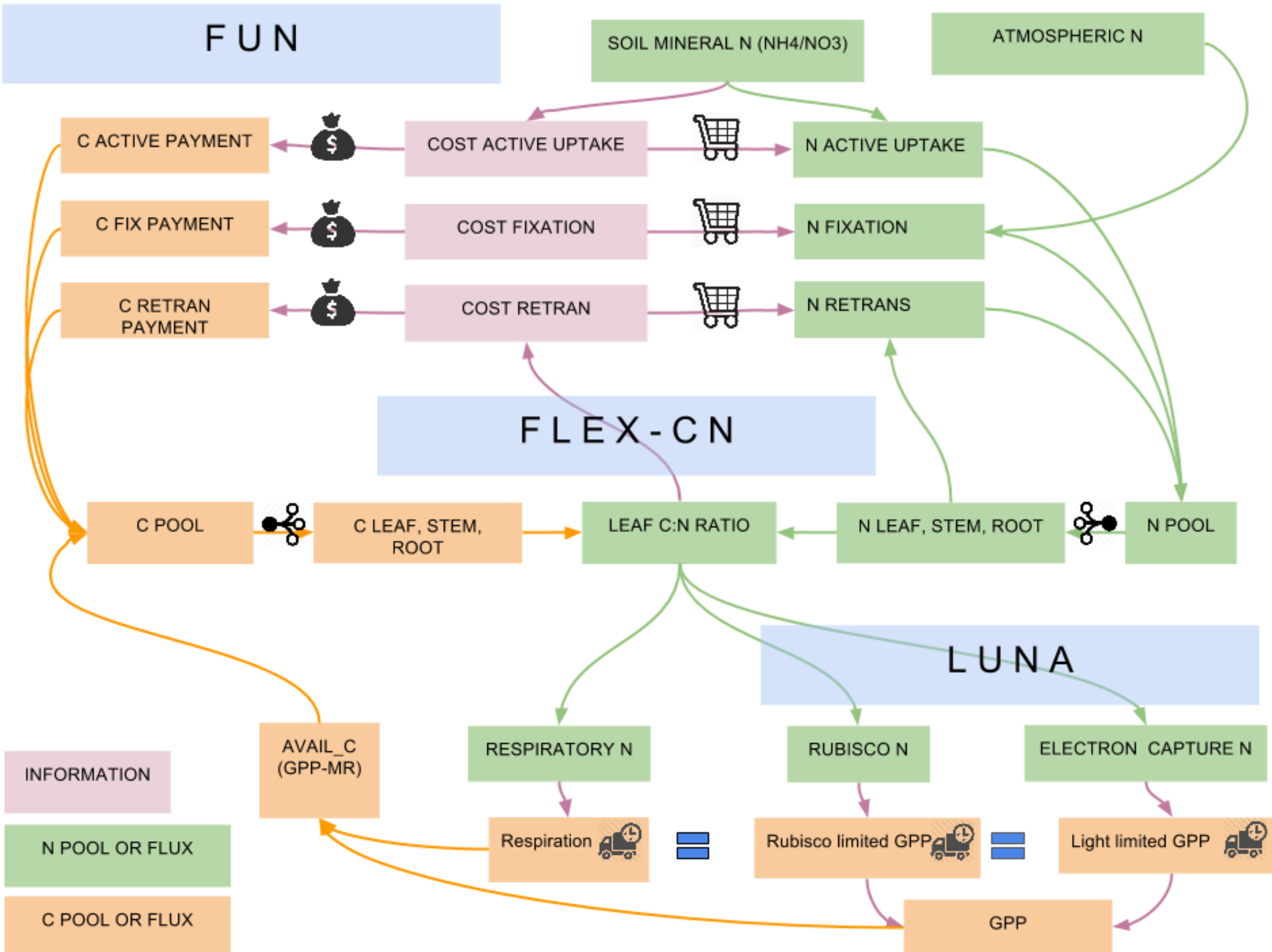
Schematic of Retranslocation Algorithm




CLM4.0
N_UPTAKE
FIXED LEAF C:N
Vc,max
C_UPTAKE (NPP)
BURNED OFF C
CLM5.0
NEW MOVING PARTS
C_FOR_NUPTAKE
N_UPTAKE
VARIABLE LEAF C:N
OPTIMIZED Vc, max
C_UPTAKE (NPP)



CLM5.0
Plants pay for fixed & active Nitrogen uptake (in Carbon)
Leaf Nitrogen content varies with the cost of N uptake
NEW MOVING PARTS
C_FOR_NUPTAKE
N_UPTAKE
VARIABLE LEAF C:N
OPTIMIZED Vc, max
C_UPTAKE (NPP)
Stomatal Conductance is based on N-limited photosynthesis
Photosynthetic Capacity is optimized wrt environmental drivers



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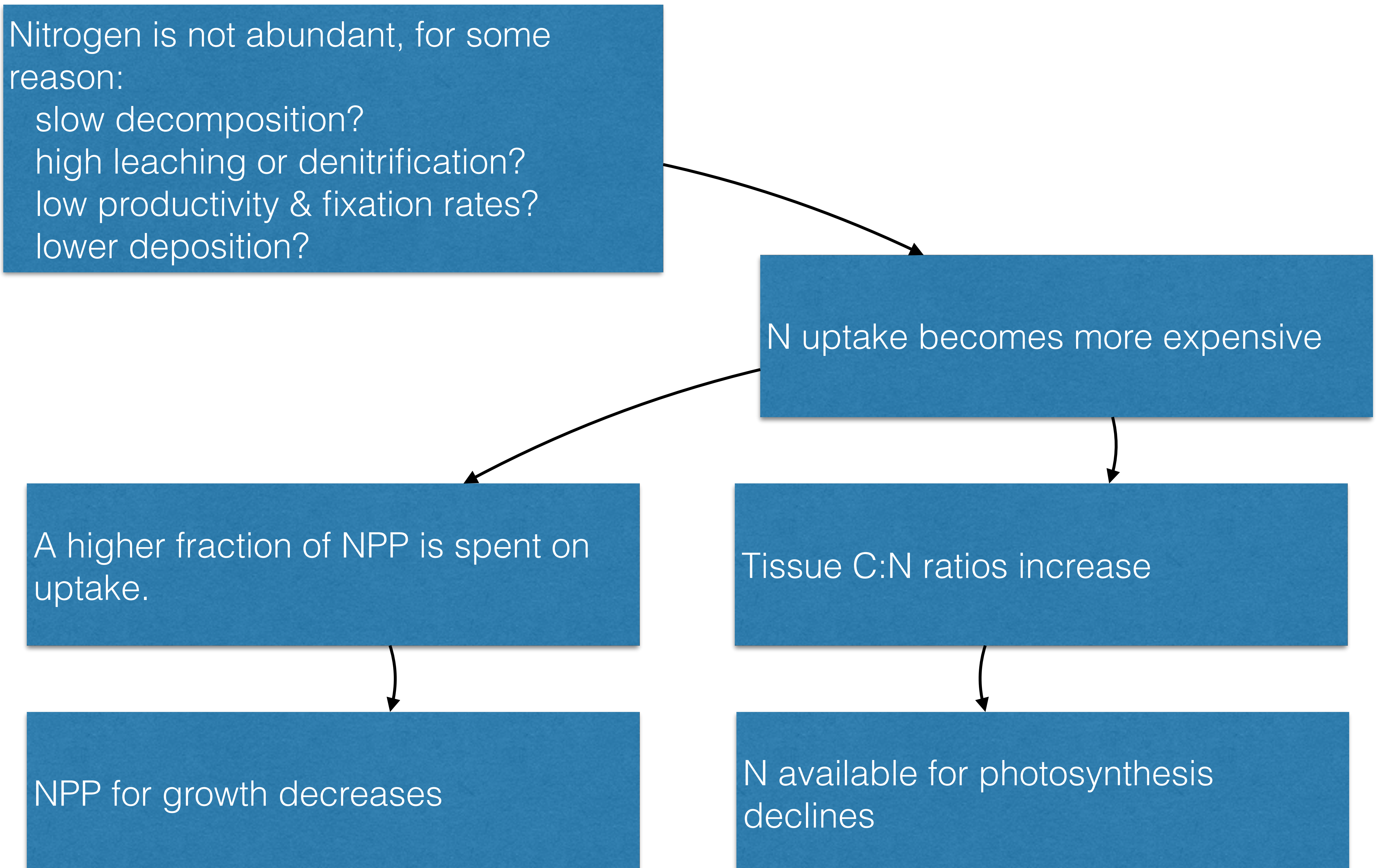
Rubisco limited GPP
Light limited GPP
GPP
INFORMATION
N POOL OR FLUX
C POOL OR FLUX

N limitation in CLM5



Metrics of N limitation

A higher fraction of NPP is spent on uptake.

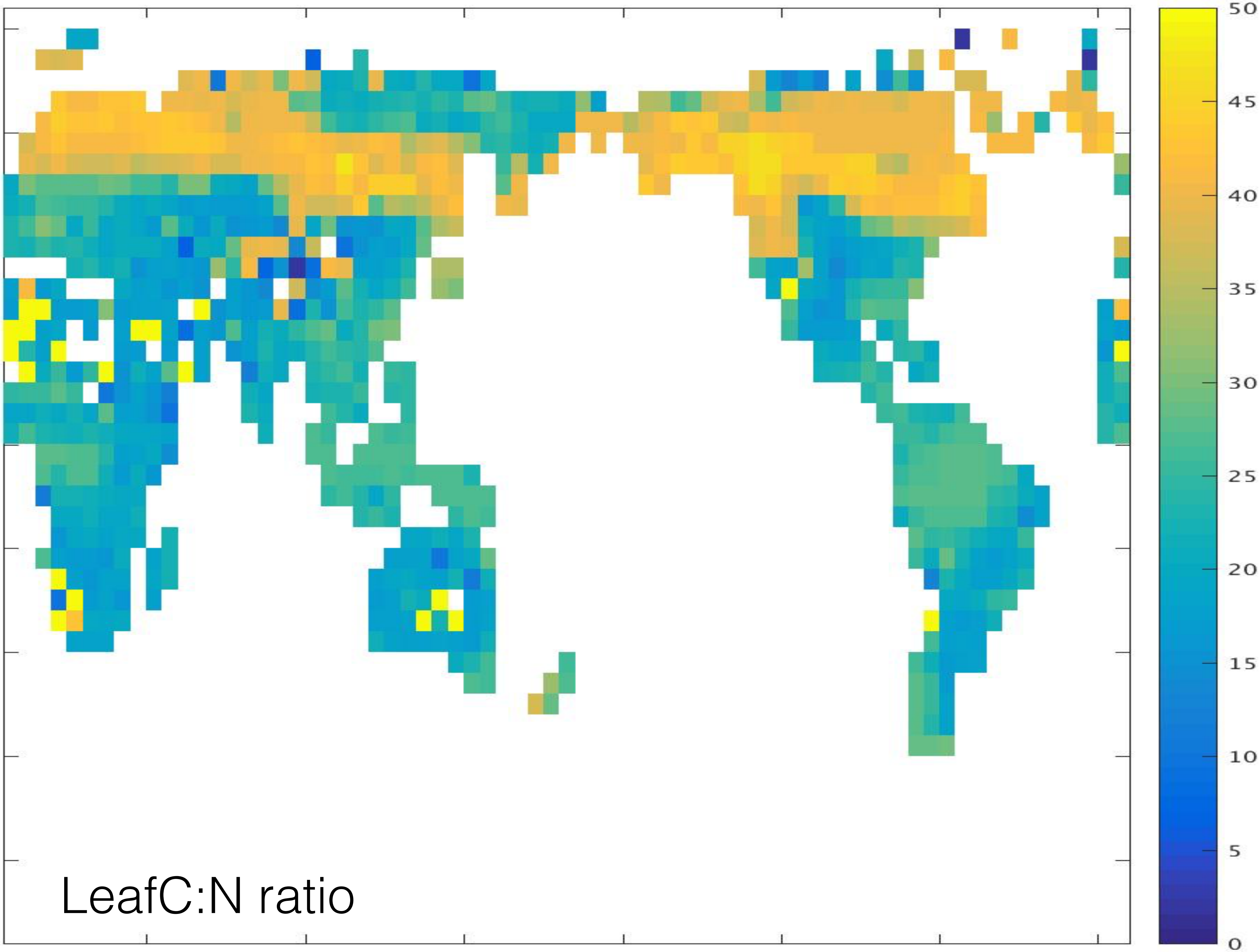
↓

NPP for growth decreases

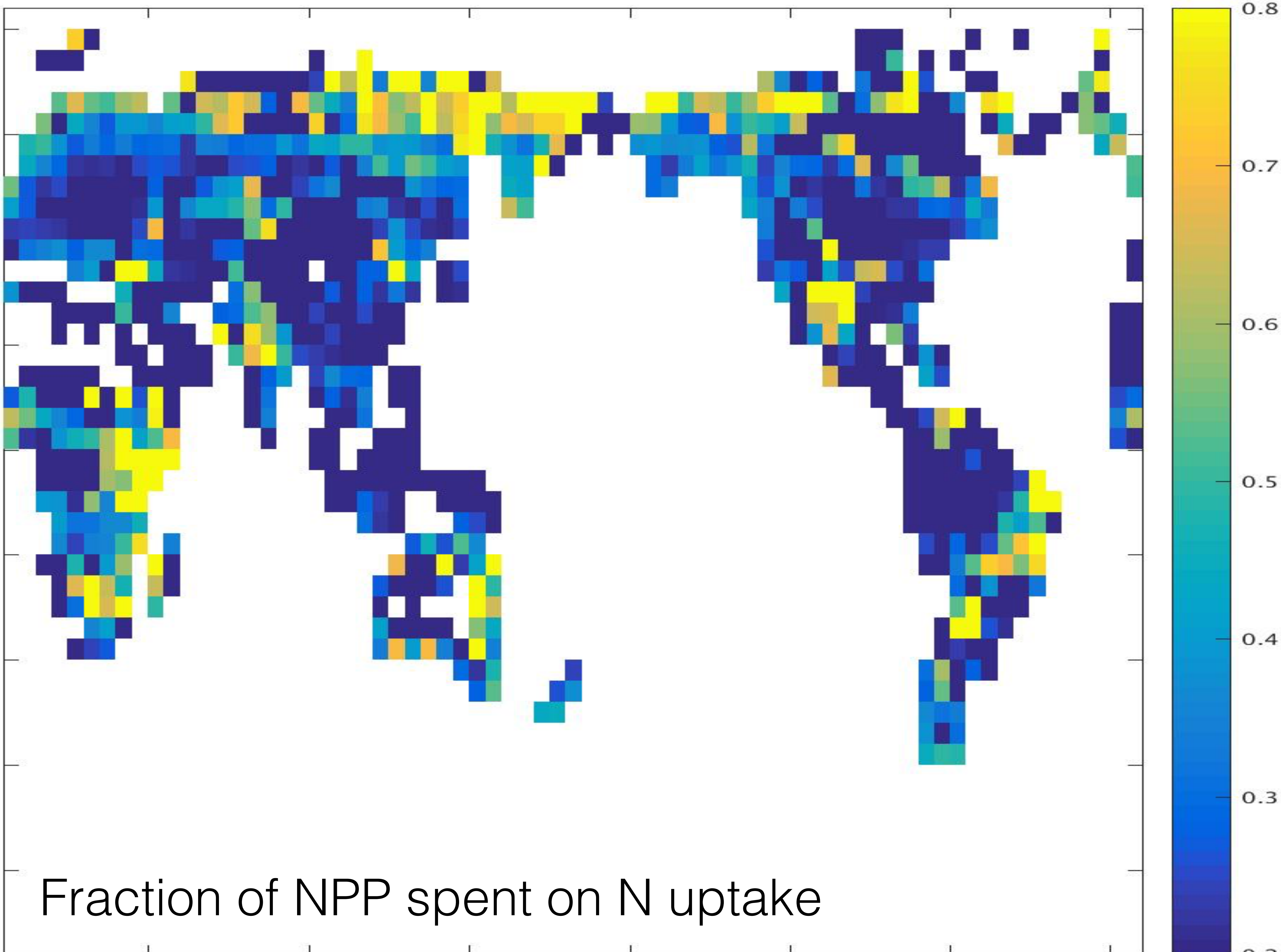
Tissue C:N ratios increase

↓

N available for photosynthesis declines



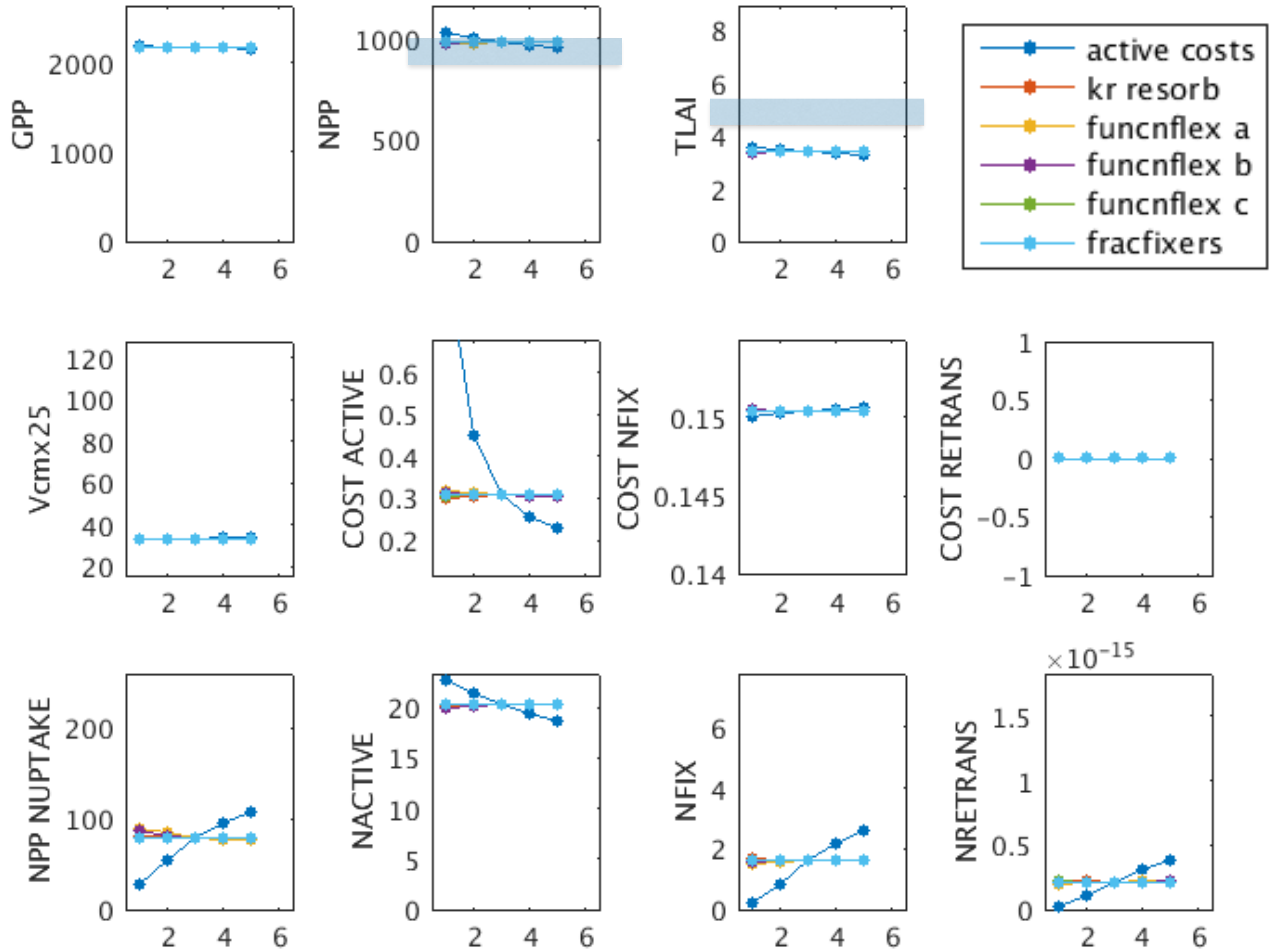
50
45
40
35
30
25
20
15
10
5
0
LeafC:N ratio


0.8
0.7
0.6
0.5
0.4
0.3
0.2
Fraction of NPP spent on N uptake

New parameters of N model

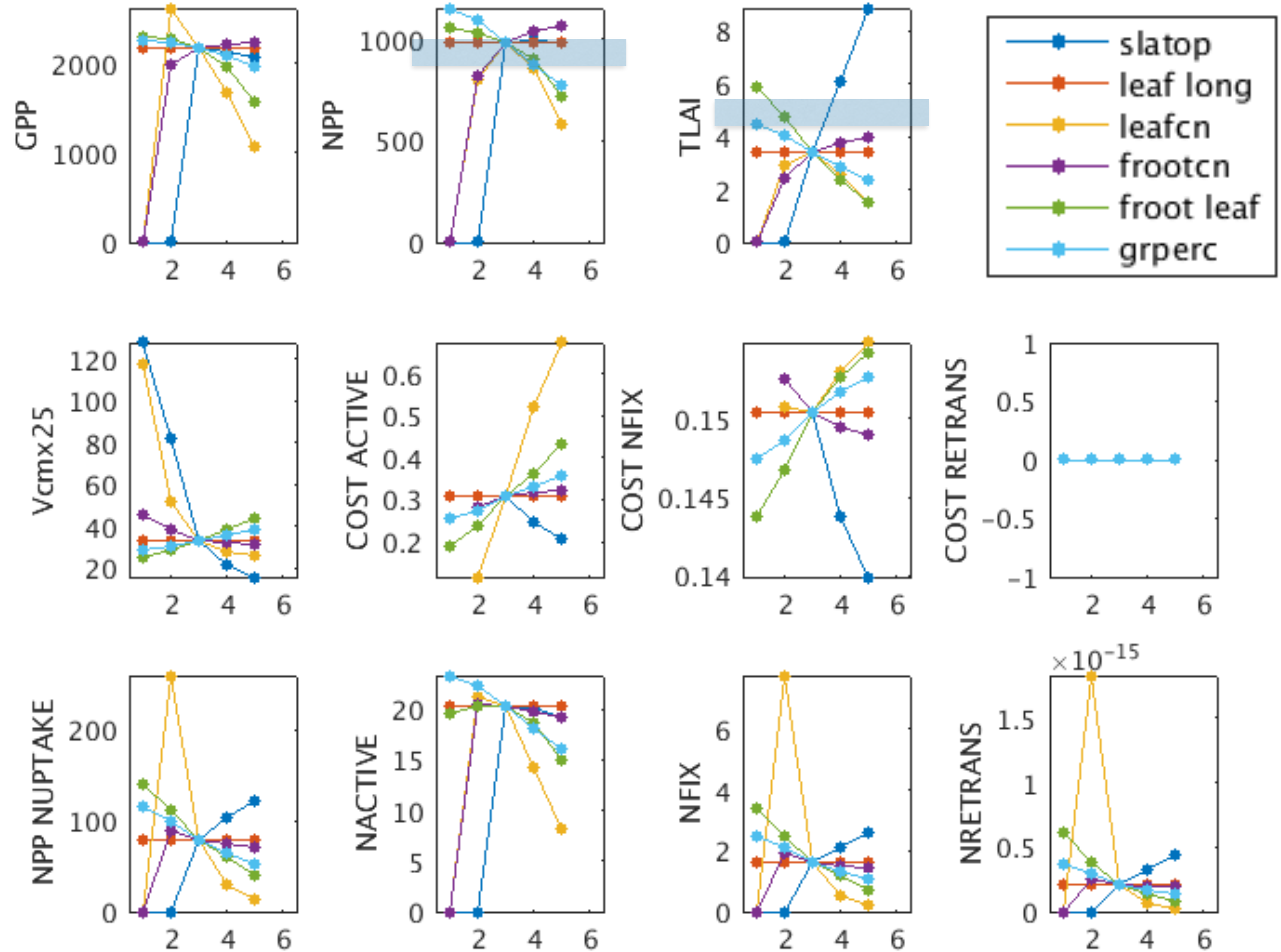
- Nitrogen cost factors
  - Fixation
  - Active uptake
  - Retranslocation
- Target leafCN ratio
- Flexible leafCN parameters
- LUNA parameters (only one is tunable)

Sensitivity Analysis of N cycle parameters



ITERATION (1-6 = 0.2 0.5 1.0 1.5 2.0)

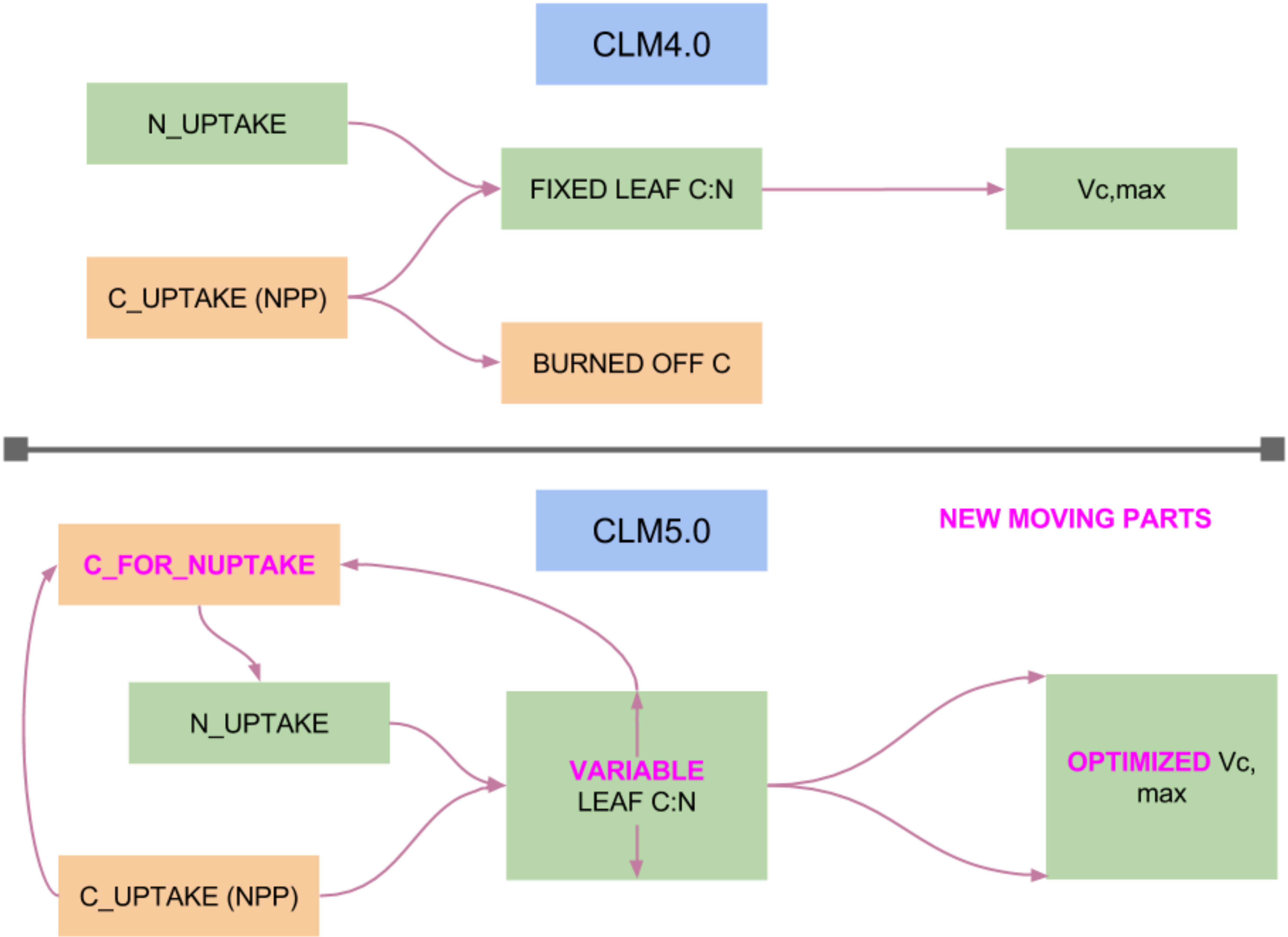
Sensitivity Analysis of non-N parameters



ITERATION (1-6 = 0.2 0.5 1.0 1.5 2.0)

Conclusions

- The new CLM5 nitrogen cycle model is substantially different to the CLM4.5 and CLM4.0.
- We are making progress on understanding the behavior and interactions in the new model
- Much remains to be tested and understood (see parameterization talk)
- The model allows comparisons with many new data streams (N fixation, CN ratio, Vcmax variation)
- …and also fixes numerous theoretical problems with the existing CLM N cycle model



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