A mechanistic nitrogen limitation model for CLM(ED)

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15 year-old forest  50 year-old forest  150 year-old forest

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The Community Land Model (CLM) uses an estimate of $V_{c,max25}$ (maximum carboxylation rate at 25°C limited by nitrogen) to drive projection of photosynthesis (Gross Primary Productivity).

Uncertainty in the photosynthetic parameter $V_{c,max25}$ results in a 110% variation in GPP.

Roger 2014.
"Optimal" nitrogen allocation at the leaf level

To predict $J_{\text{max25}}$ [maximum electron transport rate] and $V_{c,\text{max25}}$ [maximum carboxylation rate], which are two important parameters for Farquhar Photosynthesis Model, given a certain level of area-based leaf nitrogen content ($\text{LNC}_a$).
For test case 1, nitrogen allocation change for $CO_2$ enrichment for loblolly pine ($Pinus taeda$) [Crous et al 2008]; for test case 2, $V_{c,max}$ and $J_{max}$ were measured for poplar ($Populus tremula$) leaves located at a light radiation levels in the canopy [Niinemets et al 1998]; for test case 3, Japanese plantain ($Plantago asiatica$) was grown in pots from seeds within greenhouses for about 1–2 months at two contrasting temperatures: 30°C and 15°C [Hikosaka 2005].
Global survey of $V_{c, max25}$

Number of field studies: 57

Number observations: 831  
Number of species: 121  
Time range: 1989-2013

Ali, Xu et al. In Review.
Use linear mixed model fitting to account temporal and spatial autocorrelations, based on monthly climate data.
Environmental control vs leaf nitrogen

E: Environmental variables; D+T+R+RH
D: daylength
T: temperature
R: radiation
RH: relative humidity
\( \tilde{E} \): E excluding day length
\( LNC_\alpha \): Leaf Nitrogen Content
Nitrogen allocation model fitting (MCMC)

Baseline proportion of nitrogen for electron transport rate

Electron transport rate response to light

Baseline proportion of “storage” nitrogen

Response of “storage” nitrogen to photosynthetic rate

Ratio of Rubisco-limited rate to light limited rate

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Jmaxb0</th>
<th>Jmaxb1</th>
<th>Nstoreb0</th>
<th>Nstoreb1</th>
<th>Wc/Wj</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>0.0298</td>
<td>0.1270</td>
<td>0.0103</td>
<td>1.99E-5</td>
<td>0.7833</td>
</tr>
<tr>
<td>std</td>
<td>0.0002</td>
<td>0.0007</td>
<td>0.0004</td>
<td>1.65E-5</td>
<td>0.0025</td>
</tr>
</tbody>
</table>
$V_{c,\text{max}25}$ across the growing season

\[ V_{c,\text{max}25} (\text{umol/m}^2/\text{s}) \]

Observation
Prediction

$R^2=0.46$
Model sensitivity analysis and implications for climatic change

- **T**: Temperature (increased from 14 to 19°C)
- **CO₂**: carbon dioxide (increased from 393 to 780 ppm)
- **R**: Radiation (decreased from 182 to 91 Wm⁻²)
Temperature acclimation

![Graph showing net photosynthetic rate (umol/m²/s) against transient temperature (°C) for plants grown under 10°C and 20°C. The graph has two curves, one blue for plants grown under 10°C and one red for plants grown under 20°C. Both curves peak at an optimum temperature, with the blue curve peaking at a lower temperature than the red curve. The x-axis represents transient temperature (°C) ranging from 0 to 50. The y-axis represents net photosynthetic rate (umol/m²/s) ranging from 0 to 25.]
Leaf nitrogen optimization fails

Net photosynthesis rate (g biom)

Leaf nitrogen (g/m²)

Optimal

Nitrogen use efficiency

Observed leaf nitrogen (g/m²)

Predicted nitrogen (g/m²)
## Area-based leaf nitrogen content

<table>
<thead>
<tr>
<th>PFT grouping 1: growth form</th>
<th>LNC$_a$ (top of the canopy &amp; peak growing season)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbaceous</td>
<td>1.32</td>
</tr>
<tr>
<td>Shrubs</td>
<td>1.88</td>
</tr>
<tr>
<td>Trees</td>
<td>2.42</td>
</tr>
</tbody>
</table>

$r_{LNCa} = 0.1524 \ln(r_R) + 0.8453$

$R^2 = 0.6933$

$r_{LNCa} = 0.4918(r_D) + 0.3543$

$R^2 = 0.8829$
Goodness of fit of LNCa

![Graph showing the relationship between observed and predicted leaf nitrogen (g/m²). The graph includes a scatter plot with data points and a line of best fit. The $r^2$ value of 0.11 is indicated.]
Implementation of nitrogen limitation in CLM(ED)

- Prescribed area-based leaf nitrogen content
- Dynamic mass-based leaf nitrogen content
- Dynamic leaf thickness
- Dynamic $V_{c,max25}$ and $J_{max25}$
- Cohort-based photosynthesis
Test ED-N model against nitrogen fertilization observations

Xu et al. In prep.
Acknowledgments

- **Funding Sources:** DOE Office of Science (NGEE arctic), UC-Laboratory FEE Research Program

- **Key collaborators:** Stan Wullschleger (ORNL), Alistair Roger (BNL), Rosie Fisher (NCAR), Peter Thornton (ORNL), Bryan Travis (LANL), Bill Riley (LBL), Jasper Vrugt (UCI), Sanna Sevanto (LANL)
Model sensitivity analysis

- R: Radiation
- $LNC_a$: Leaf Nitrogen Content
- T: Temperature
- Complete: All environmental variables + $LNC_a$