Decline of net primary production over 10 years at a forest FACE experiment is associated with increasing nitrogen limitation

Ross McMurtrie
Univ. NSW, Sydney
Rich Norby
Oak Ridge National Lab
TN, USA

This talk

- The Oak Ridge FACE experiment – NPP decline
- Model
- Is NPP decline caused by reduced N uptake?
- Is reduced N uptake caused by high-CO_2?
- What next?

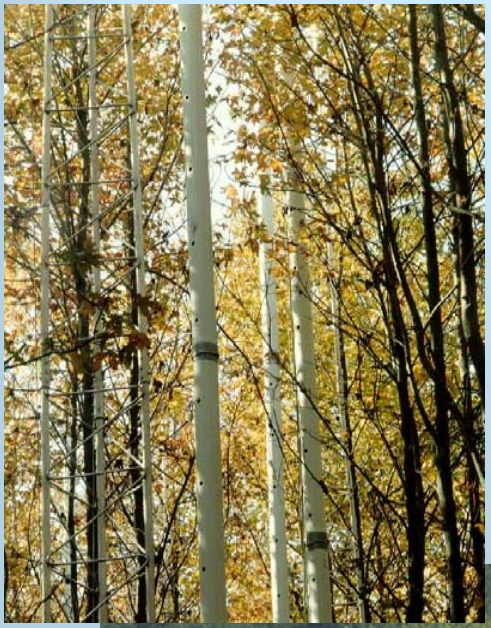
Oak Ridge Free-Air CO_2 Enrichment Experiment

Goals

- How will eastern-USA deciduous forests be affected by CO_2 enrichment of the atmosphere
- What are the feedbacks from the forest to the atmosphere

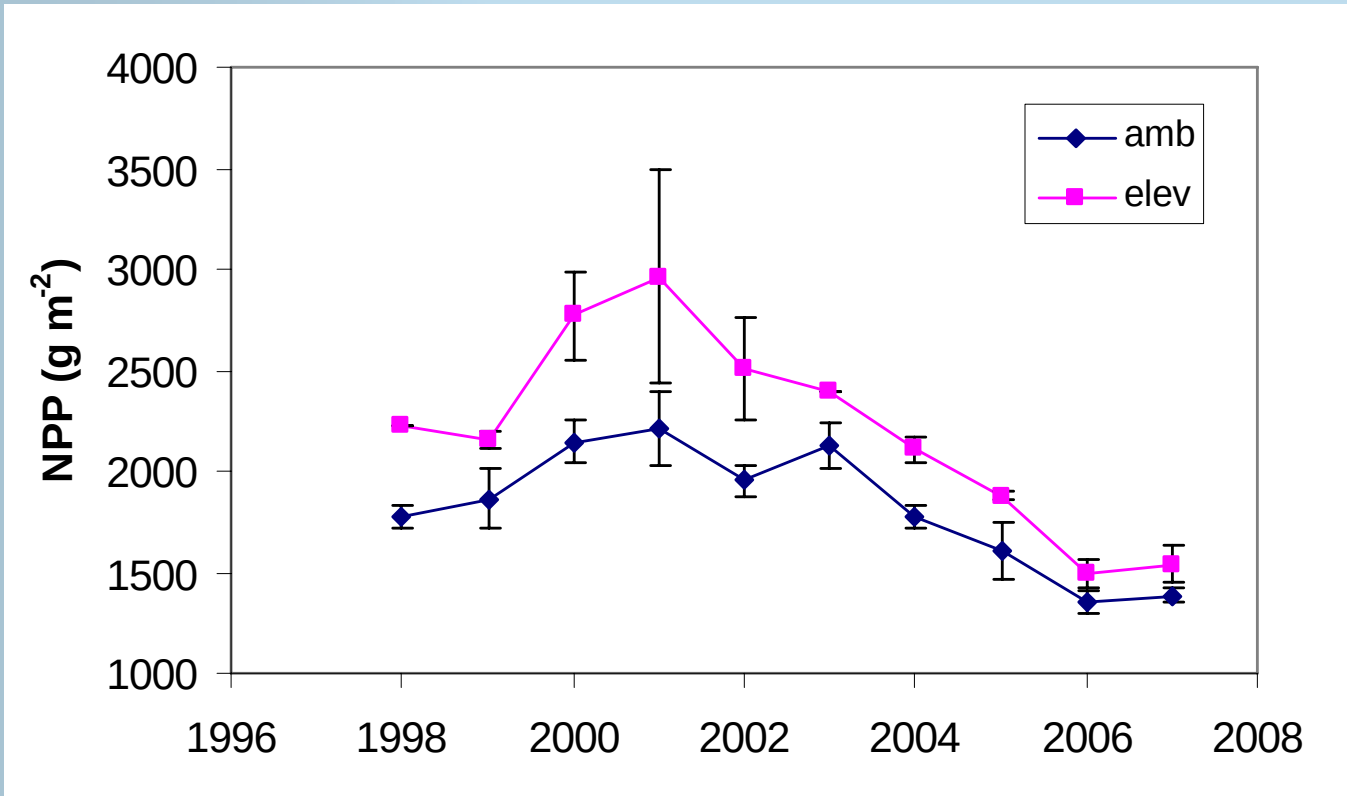
http://face.ornl.gov

Oak Ridge Free-Air CO_2 Enrichment Experiment



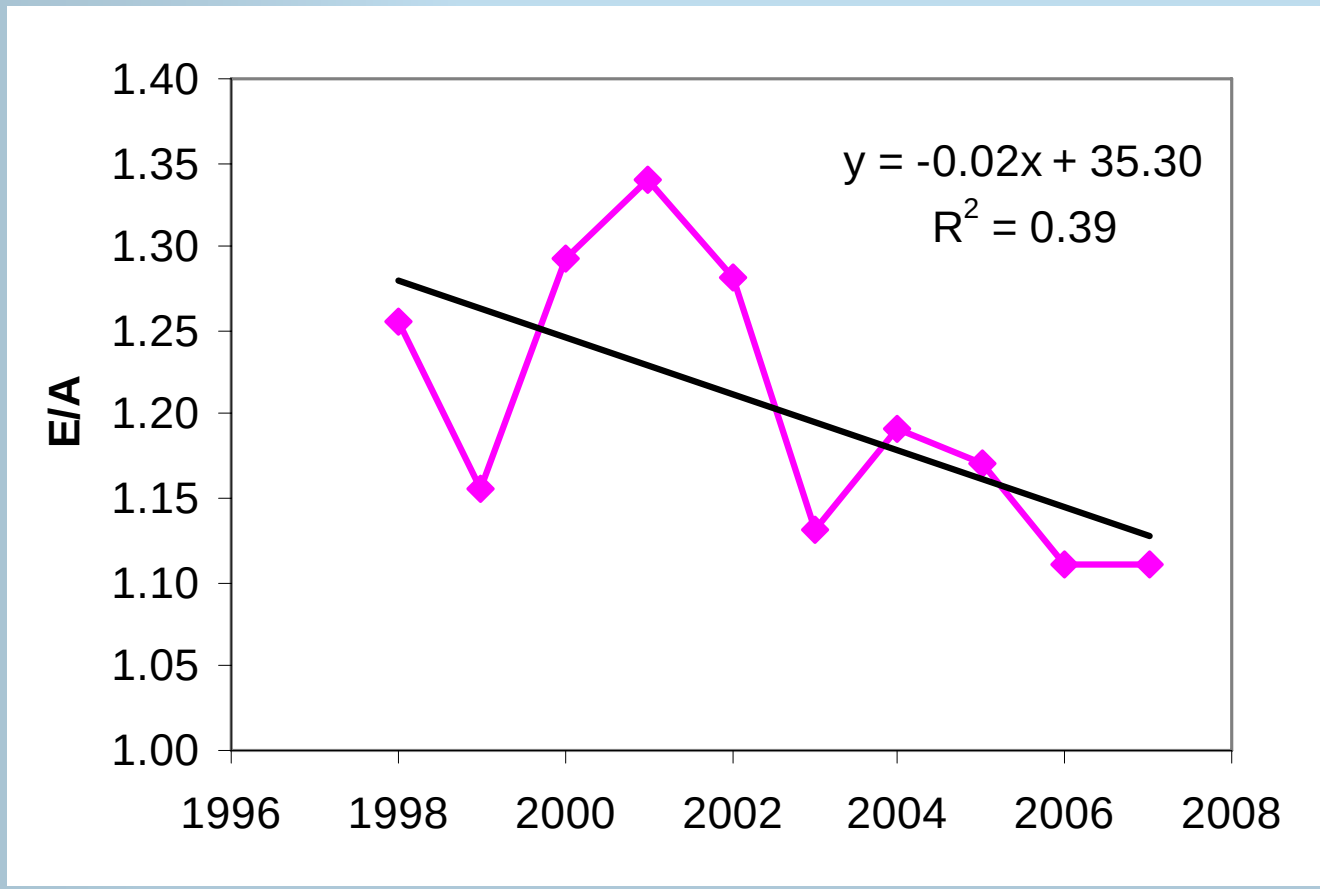
- ***Liquidambar styraciflua*** **(sweetgum) monoculture planted in 1988**
  - **<u>deciduous</u>, closed canopy**
  - **CO_2 exposure (550 ppm) started spring, 1998**

Annual net primary productivity



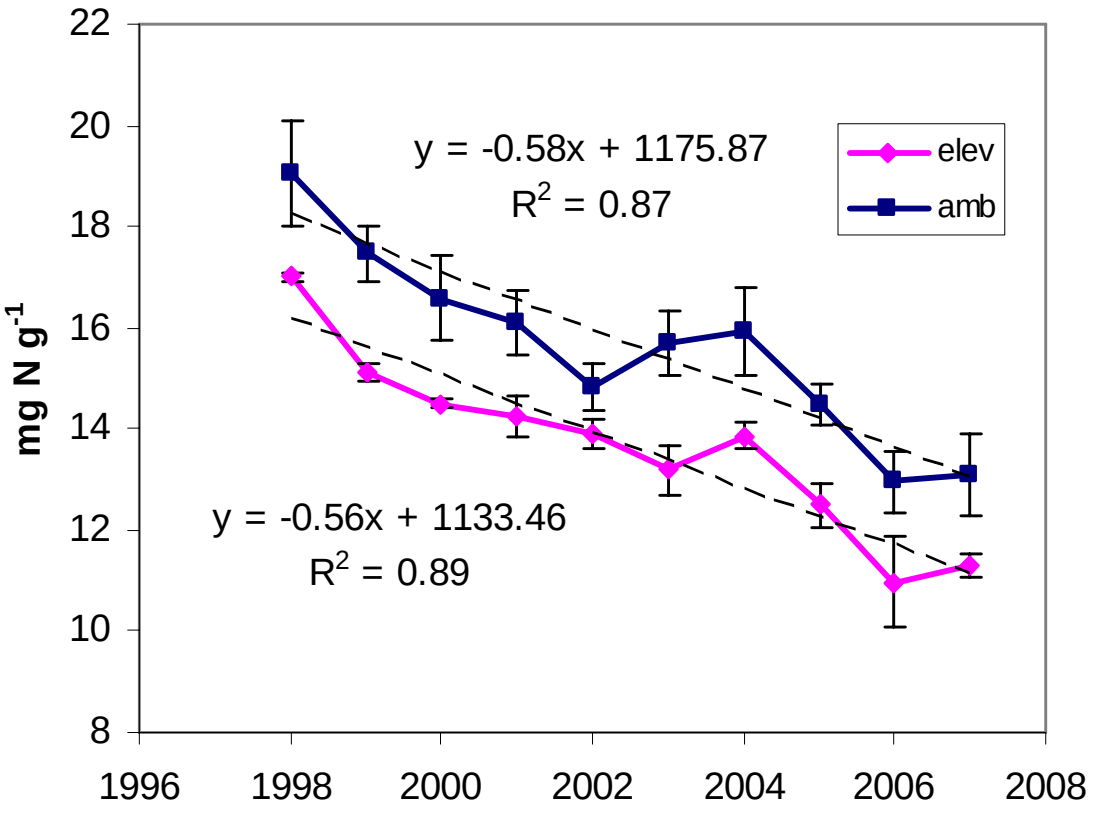
- CO_2 has consistently stimulated NPP
- Average NPP response over 10 years is 21%
- NPP response declined from 2004 to 2007

NPP at Elevated CO_2 / NPP at Ambient CO_2



- NPP response declined from 20% in 2004 to 11% in 2007

Leaf nitrogen concentration



- Leaf [N] is lower at eCO_2
- Leaf [N] has declined by 0.6 mg g^{-1} per year at both aCO_2 and eCO_2
- LAI does not change at eCO_2

This talk

- The Oak Ridge FACE experiment – NPP decline
- Model
- Is NPP decline caused by reduced N uptake?
- Is reduced N uptake caused by high-CO_2?
- What next?

Research question:

Can all these results be obtained from a simple model of carbon (C), water and nitrogen (N) economy?

Ockham's Razor

Do not unnecessarily multiply your hypotheses beyond what you need for a satisfactory explanation

or K.I.S.S

Direct CO_2 effect

$$NPP = LUE \times APAR$$

Light-use efficiency

Absorbed photosynthetically active radiation

LUE is function of light-saturated photosynthetic rate (A_{max})

(Sands 1996, *Aust. J. Plant Physiol*)

A_{max} depends on [CO_2], leaf N_{area} & stomatal conductance

APAR is function of leaf-area index

What if water or nitrogen is limiting?

NPP = net primary production
g_s = stomatal conductance
[N] = leaf N concentration
APAR = absorbed phot. active radn
LAI = leaf-area index

C – N – water model:

1. NPP = LUE(g_s, $[N]_{leaf}$) * APAR (LAI)
2. Annual water balance
3. Annual N balance

Depends on N uptake

3 equations in 4 unknowns (g_s, $[N]_{leaf}$, LAI, NPP)

What does N balance equation look like?

Annual N uptake to above-ground pools (U_{net}):

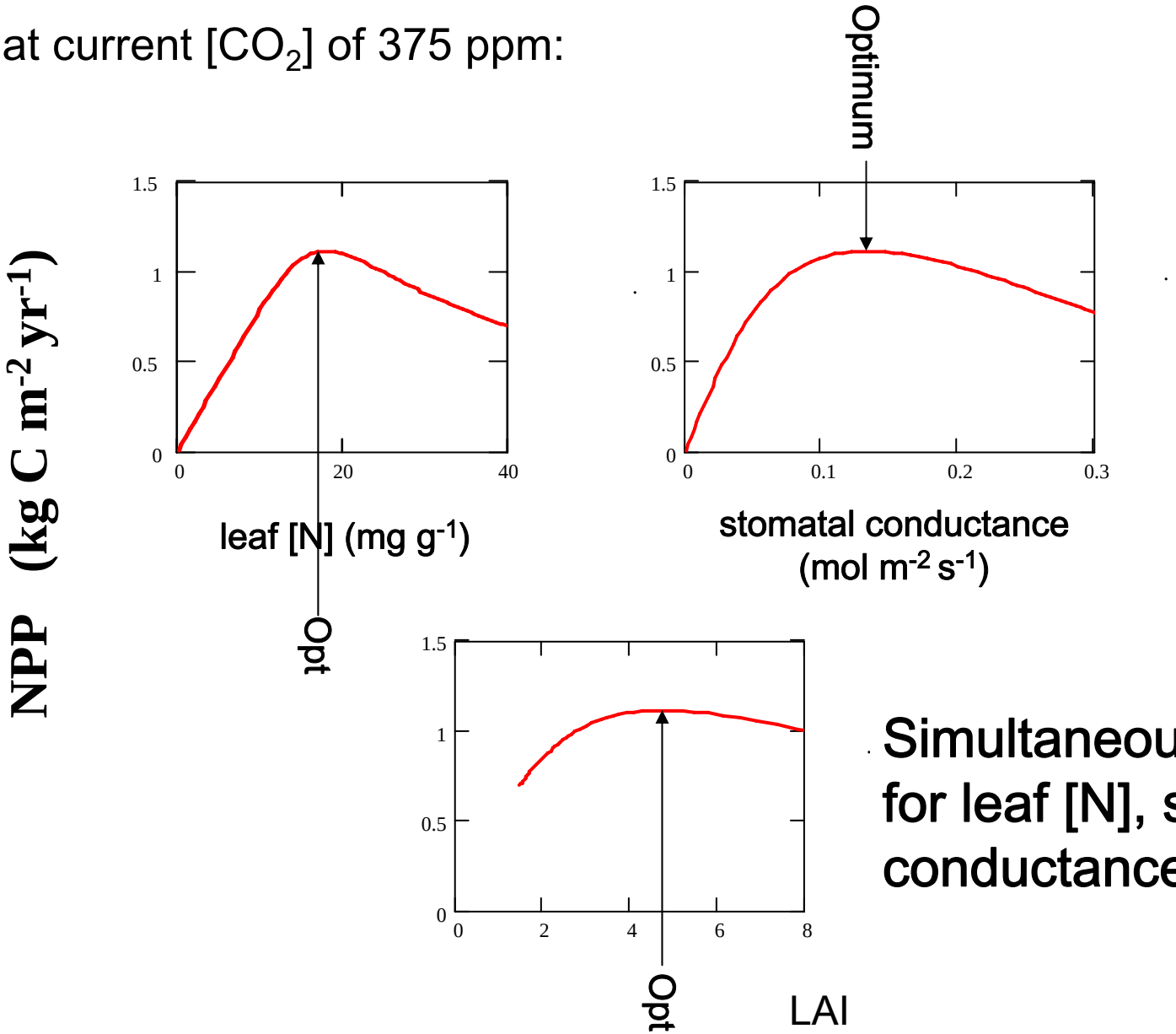
C_f, C_w = Annual C production of leaves, wood
$[N]_f$,$[N]_{fL}$, $[N]_w$ = N concentration of live leaves, leaf litter, wood
LAI = Leaf-area index

$$U_{net} = (C_f * [N]_{fL} + C_w * [N]_w) / 0.5$$

$$U_{net} \sim \text{constant} * LAI * [N]_f + \text{constant} * NPP * [N]_w$$

If both water & nitrogen are limiting:

NPP at current [CO_2] of 375 ppm:



Simultaneous optimum for leaf [N], stomatal conductance & LAI

McMurtrie et al. (2008) *Functional Plant Biology* (in press)

Conclusions so far:

1. Model has an optimum for leaf [N], stomatal conductance & LAI

2. At high CO_2
   - NPP increases
   - Leaf [N] and stomatal conductance decline
   - LAI changes little

McMurtrie et al. (2008) *Functional Plant Biology* (in press)

This talk

- The Oak Ridge FACE experiment – NPP decline
- Model
- Is NPP decline caused by reduced N uptake?
- Is reduced N uptake caused by high-CO_2?
- What next?

Is NPP decline caused by reduced N uptake?

Maximise NPP = LUE X APAR

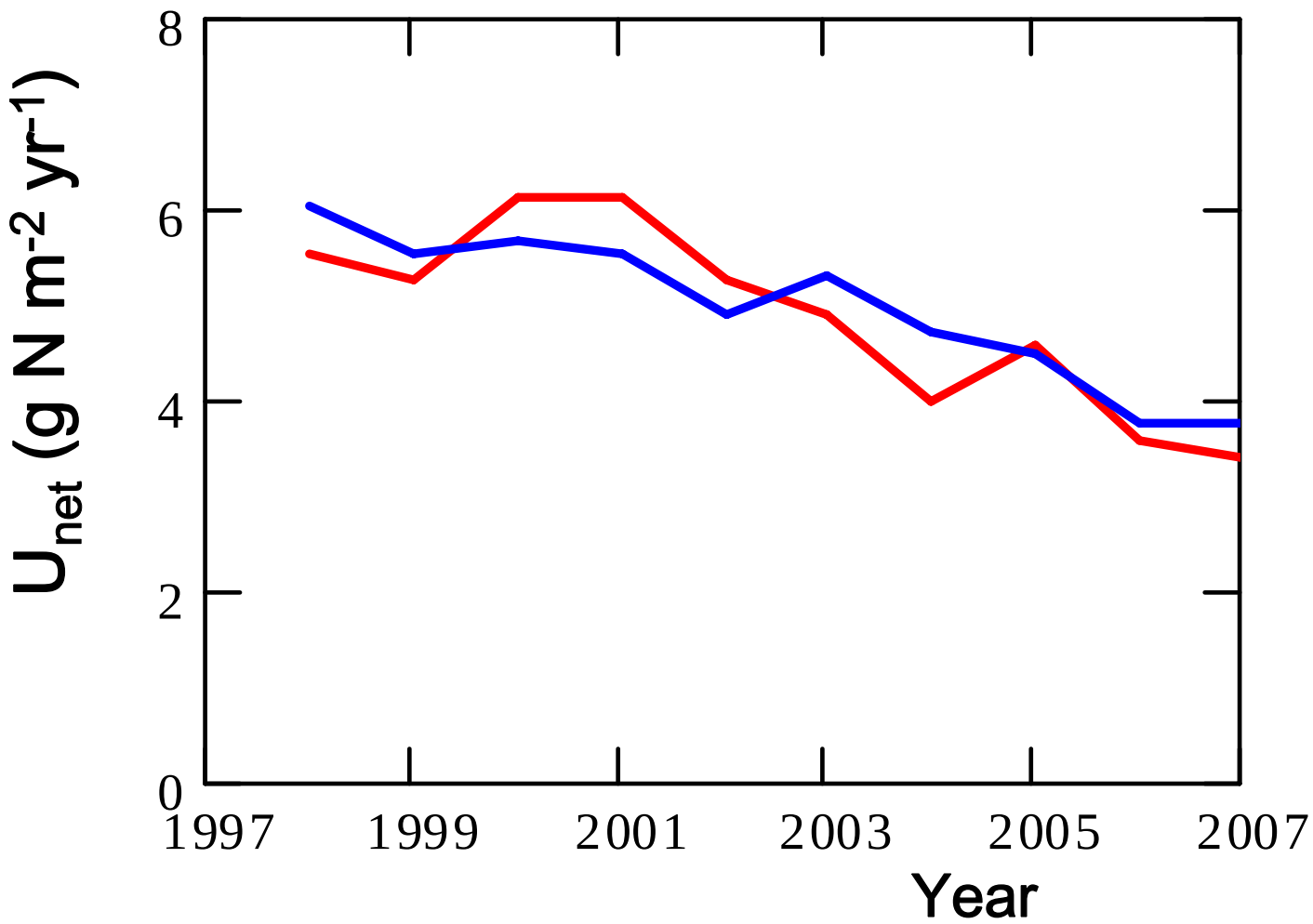
NPP = net primary production
LUE = light-use efficiency
APAR = absorbed phot. active radn

LAI = Leaf-area index
U_{net} = annual N uptake to above-ground pools
$[N]_f$, $[N]_w$ = N concentration of live leaves, wood

$$\mathbf{U_{net} \sim constant * LAI * [N]_f + constant * NPP * [N]_w}$$

Estimated N uptake (g N m^{-2} $year^{-1}$)

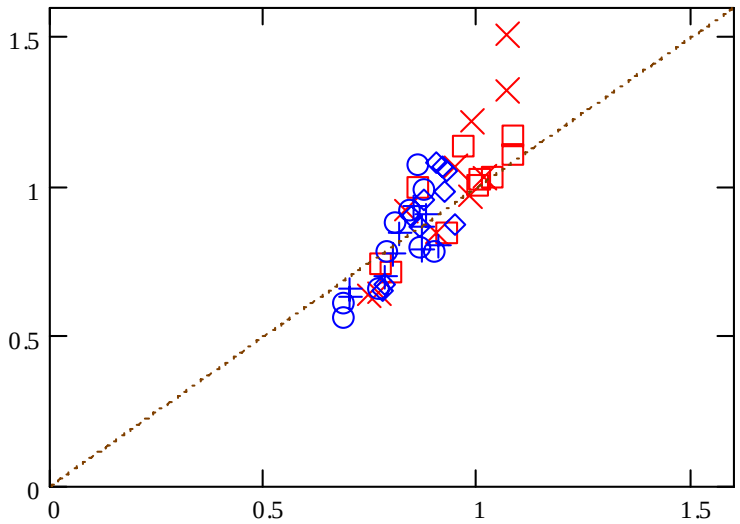
$[CO_2]$ = 375, 550 ppm



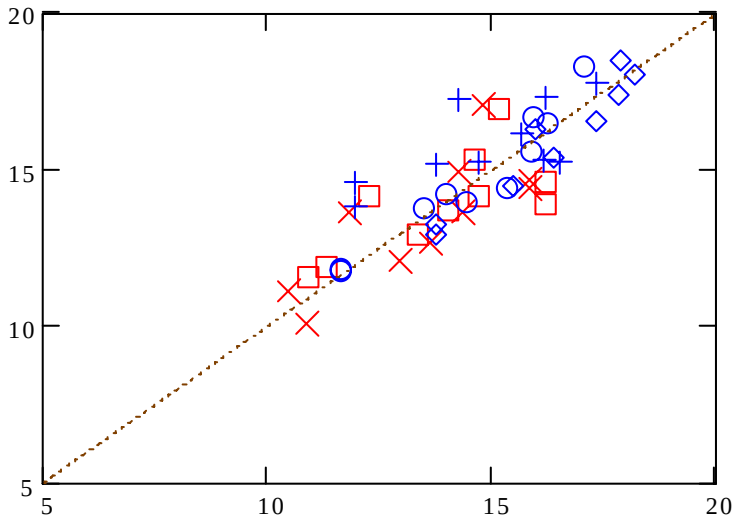
Measured (y) versus Simulated (x)

[CO_2] = 375, 550 ppm

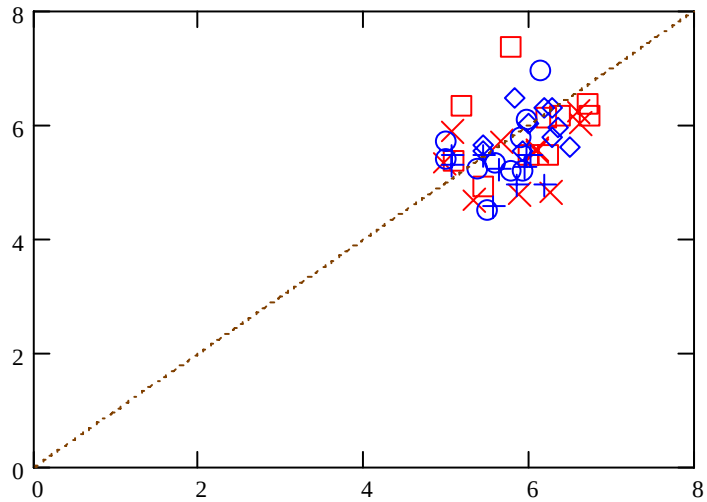
NPP
(kg C m^{-2} $year^{-1}$)



Leaf [N] (mg N g^{-1})



Peak LAI



Conclusions

1. Model has an optimum for leaf [N], stomatal conductance & LAI

2. Leaf [N] and stomatal conductance decline at high CO_2

3. N uptake to above-ground pools (U_{net}) has declined since 2001 at both aCO_2 and eCO_2

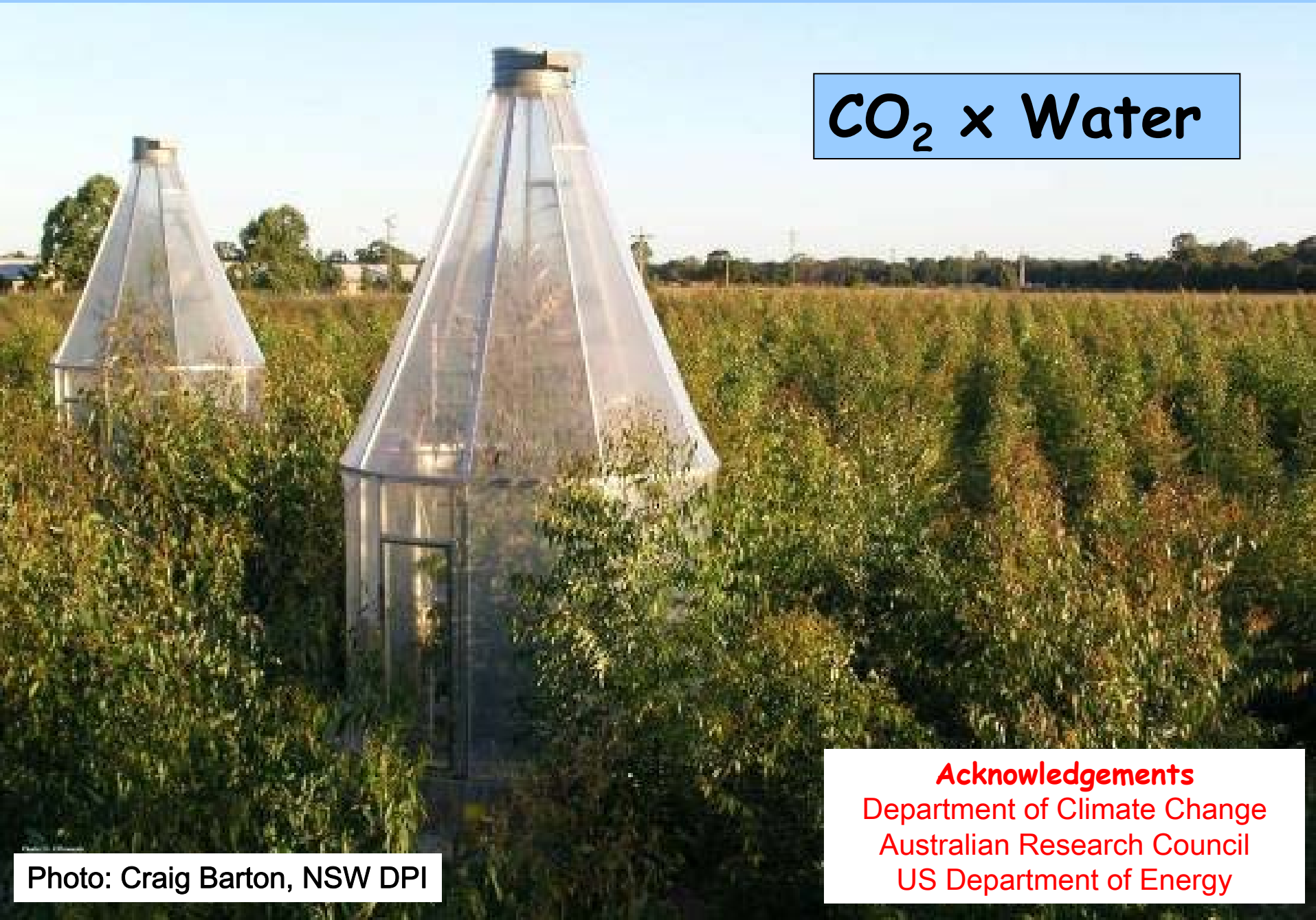
4. As U_{net} declines
   - leaf [N] and NPP decline
   - LAI changes little
   - NPP response to eCO_2 declines

5. Rate of decline of U_{net} is same at aCO_2 and eCO_2.
   i.e. No evidence of CO_2-induced N limitation

What next?

1. **Oak Ridge FACE**: Continue experiment:
   - Why does N uptake decline?
   - What are consequences for growth response to eCO_2?
   - Is there evidence of "progressive N limitation" at eCO_2?
2. **Root N uptake**:
   - Incorporate root N uptake
   - Does model predict increased root production & increased N uptake at eCO_2?
   - Does the model correctly predict inter-year variation in NPP response & C allocation?
3. **Biogeochemical cycling (G'DAY model)**
   - Incorporate soil feedbacks in N balance equation
   - Does model predict "progressive N limitation" due to soil feedbacks at eCO_2?
4. **What do plants maximise?** - NPP, or GPP or ?

The Hawkesbury Forest Experiment, Richmond, NSW



CO_2 x Water

Photo: Craig Barton, NSW DPI

Acknowledgements
Department of Climate Change
Australian Research Council
US Department of Energy