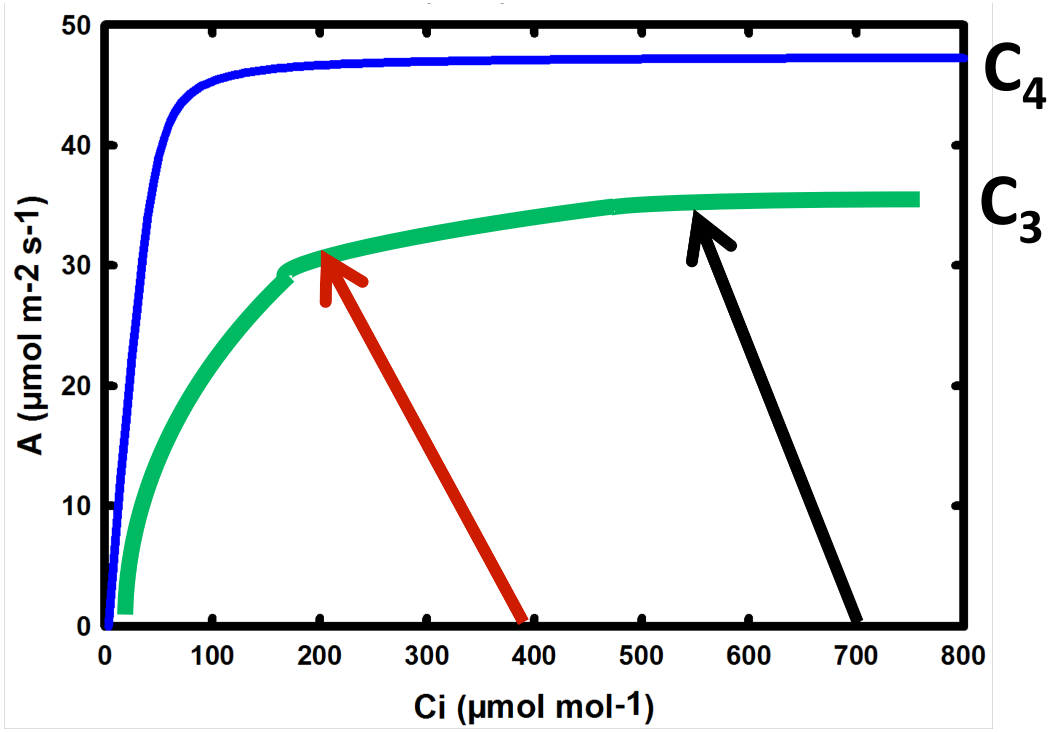
Plant primary productivity: Environmental Impacts on C-Fixation (EICF)



RJ Cody Markelz

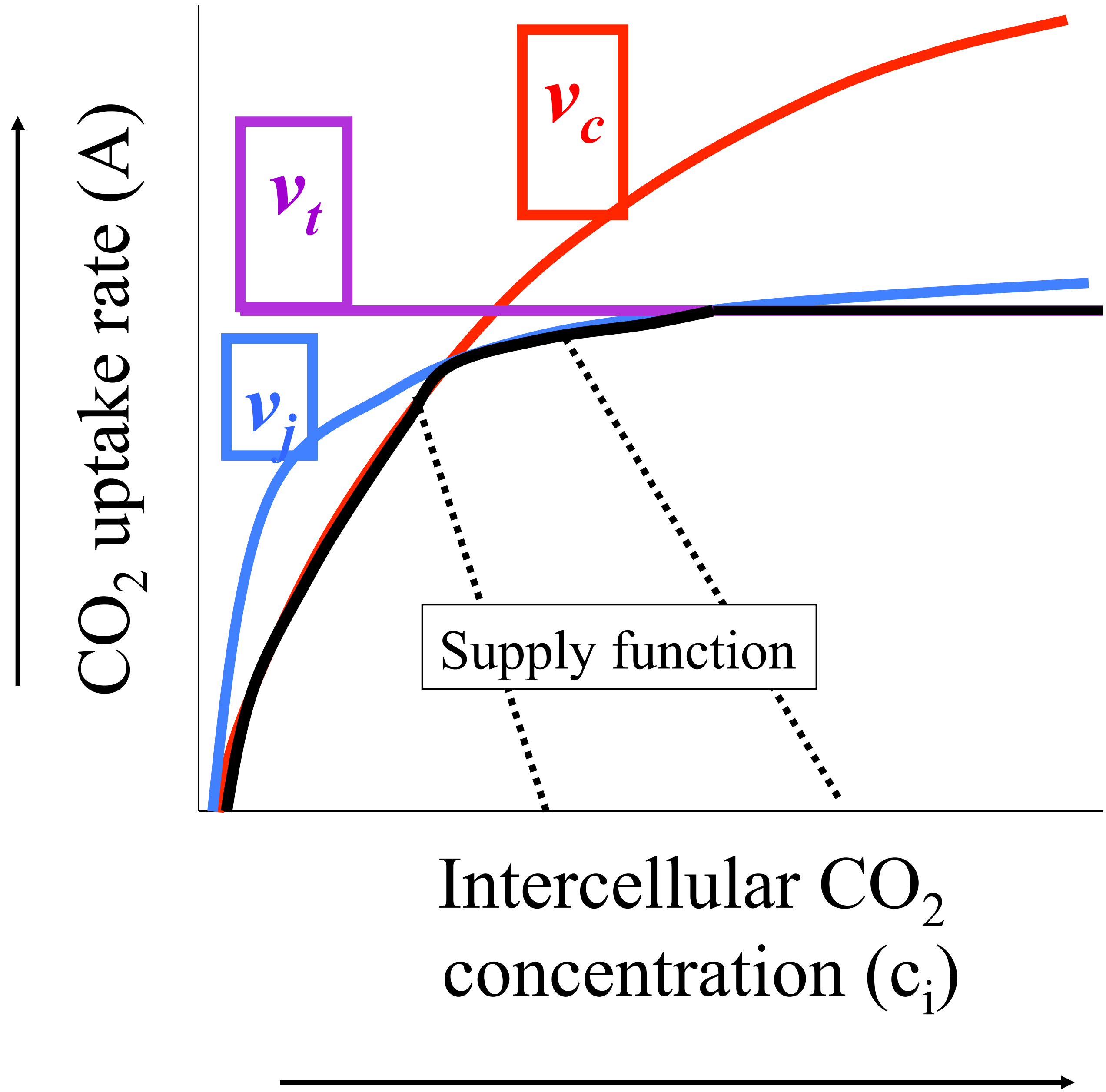
NSF Postdoctoral Fellow

PBI200C- Spring 2016

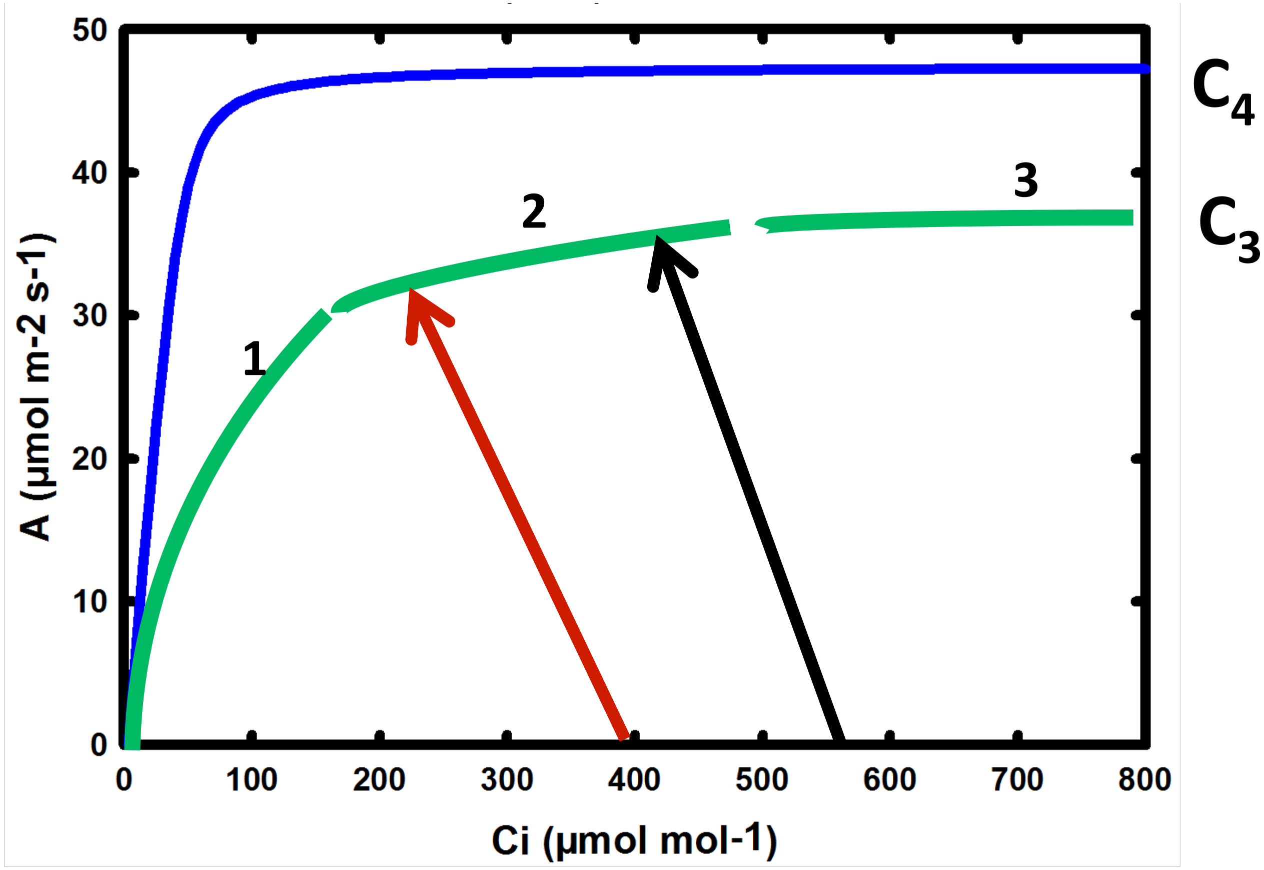
Today

- Quick Review
- C_4 photosynthetic response to climate change variables in the field
- Physiological genomics of C_3 respiration
- Gas exchange measurement theory

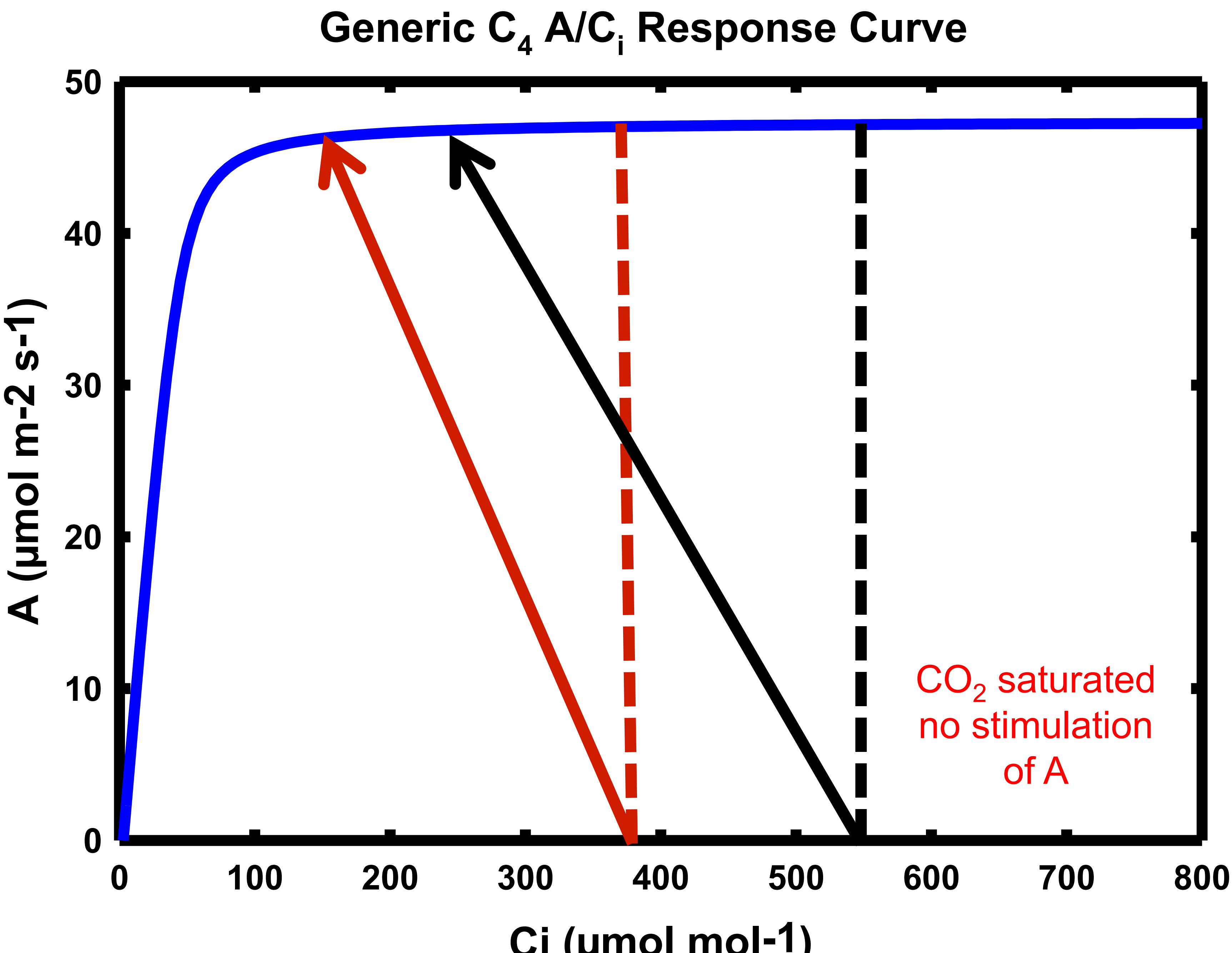
- Gas exchange equipment demo (LiCOR 6400)
- Paper discussion
- C_3 photosynthesis model



v_c
v_t
v_j
Supply function
CO_2 uptake rate (A)
Intercellular CO_2 concentration (c_i)

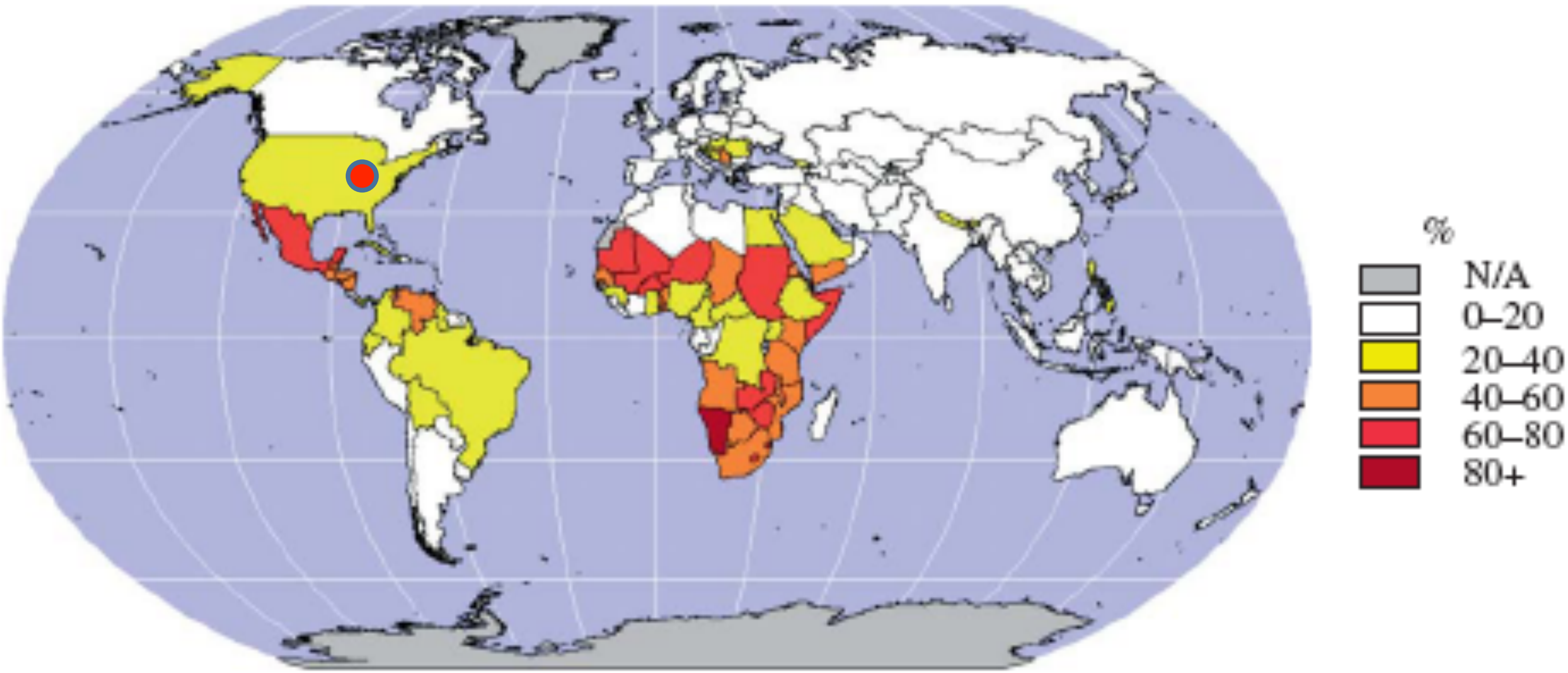


- C_4 A/Ci curves have a different shape that reflects their biochemistry
- C_3 photosynthesis is stimulated directly by elevated CO_2
- Can you extend the supply functions on this curve?



Leakey (2009) Proceedings of the Royal Society B

% Arable land in C_4 Crops



From Leakey (2009) Proceedings of the Royal Society B

- C_4 crops are very important for global food production
- US Midwest produces 40% of the world's annual maize crop

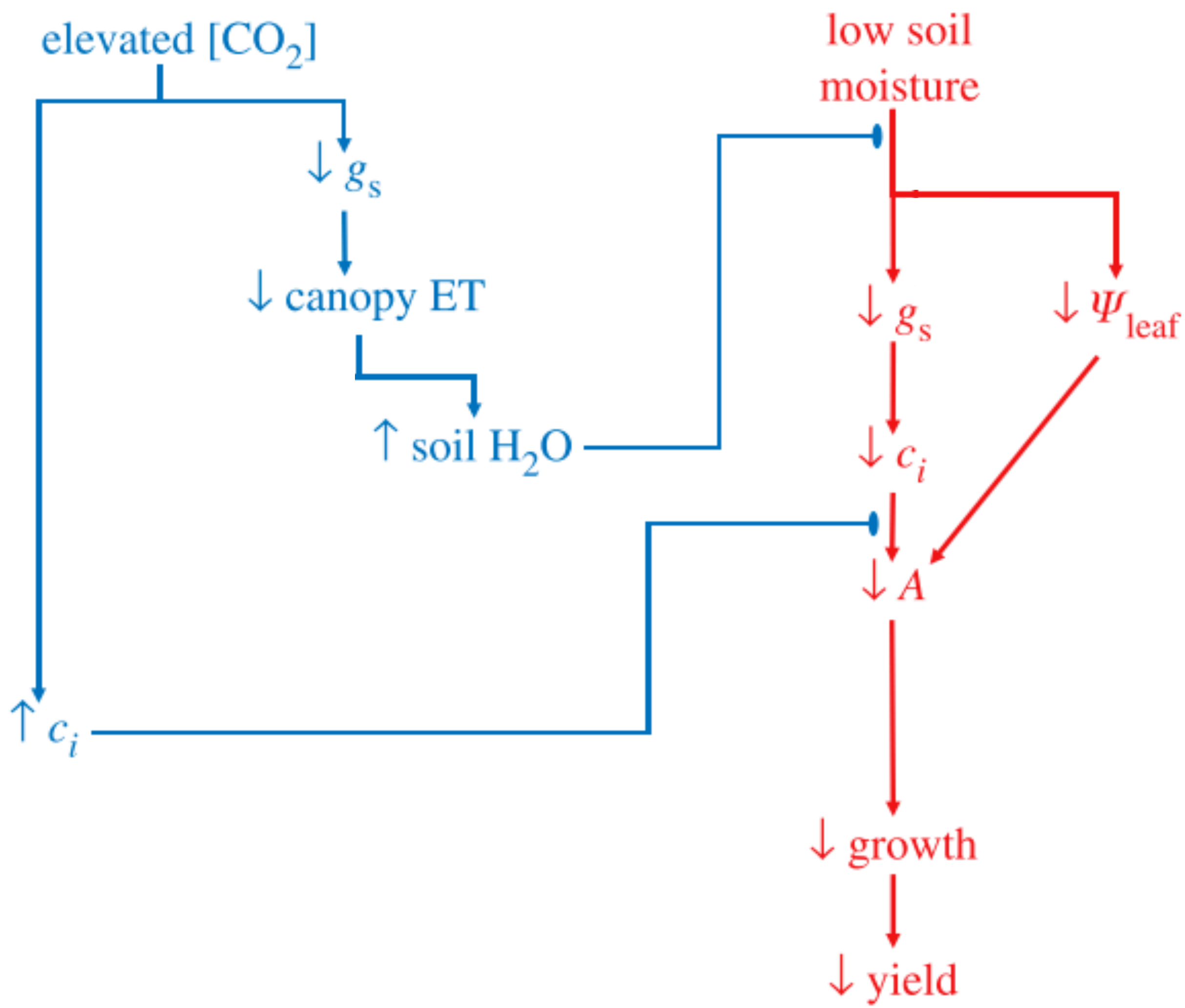
1

Photosynthesis

$H_2O + CO_2 \rightarrow$ sugars $\rightarrow$ respiration $\rightarrow$ growth $\rightarrow$ yield

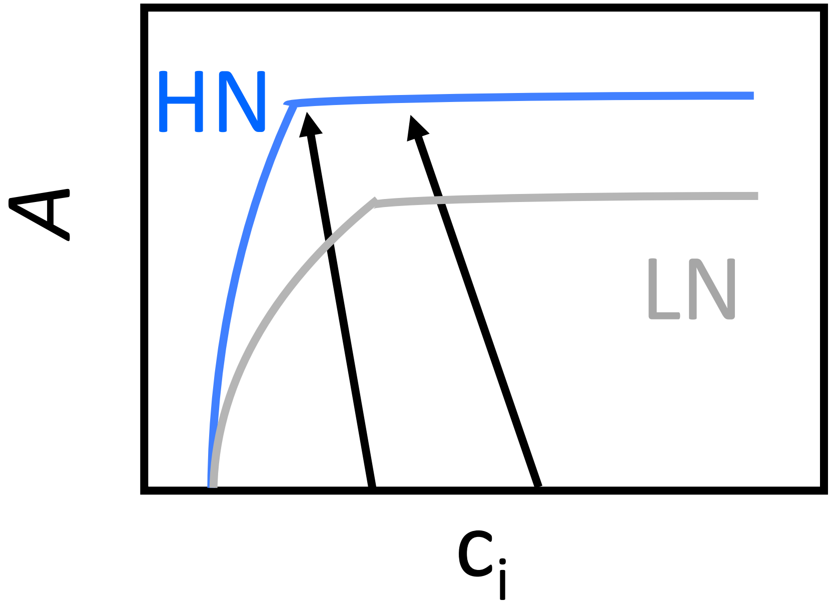
C_4 Maize

Proposed interaction mechanism between water availability and elevated CO_2 on C_4 photosynthesis

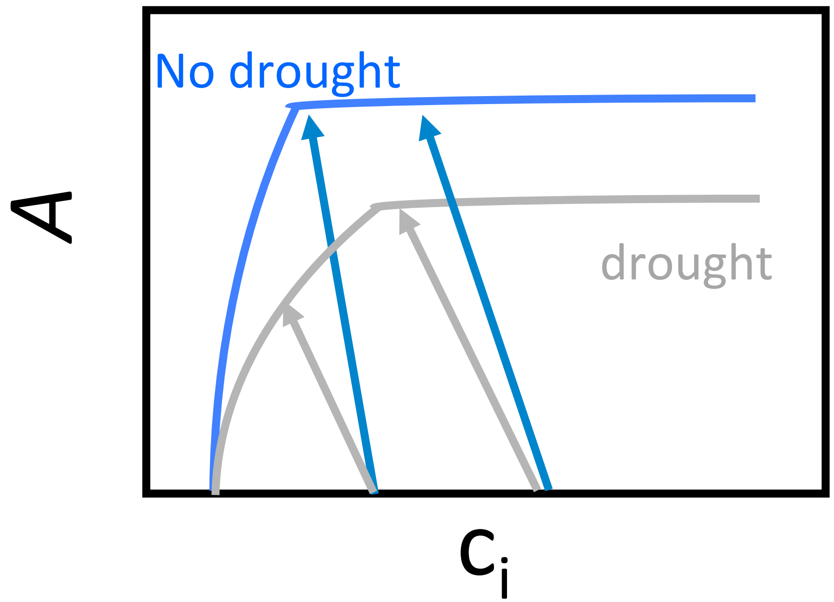


***Simplified from Leakey (2009) Phil. Trans. Royal. Soc. B.**

Hypotheses



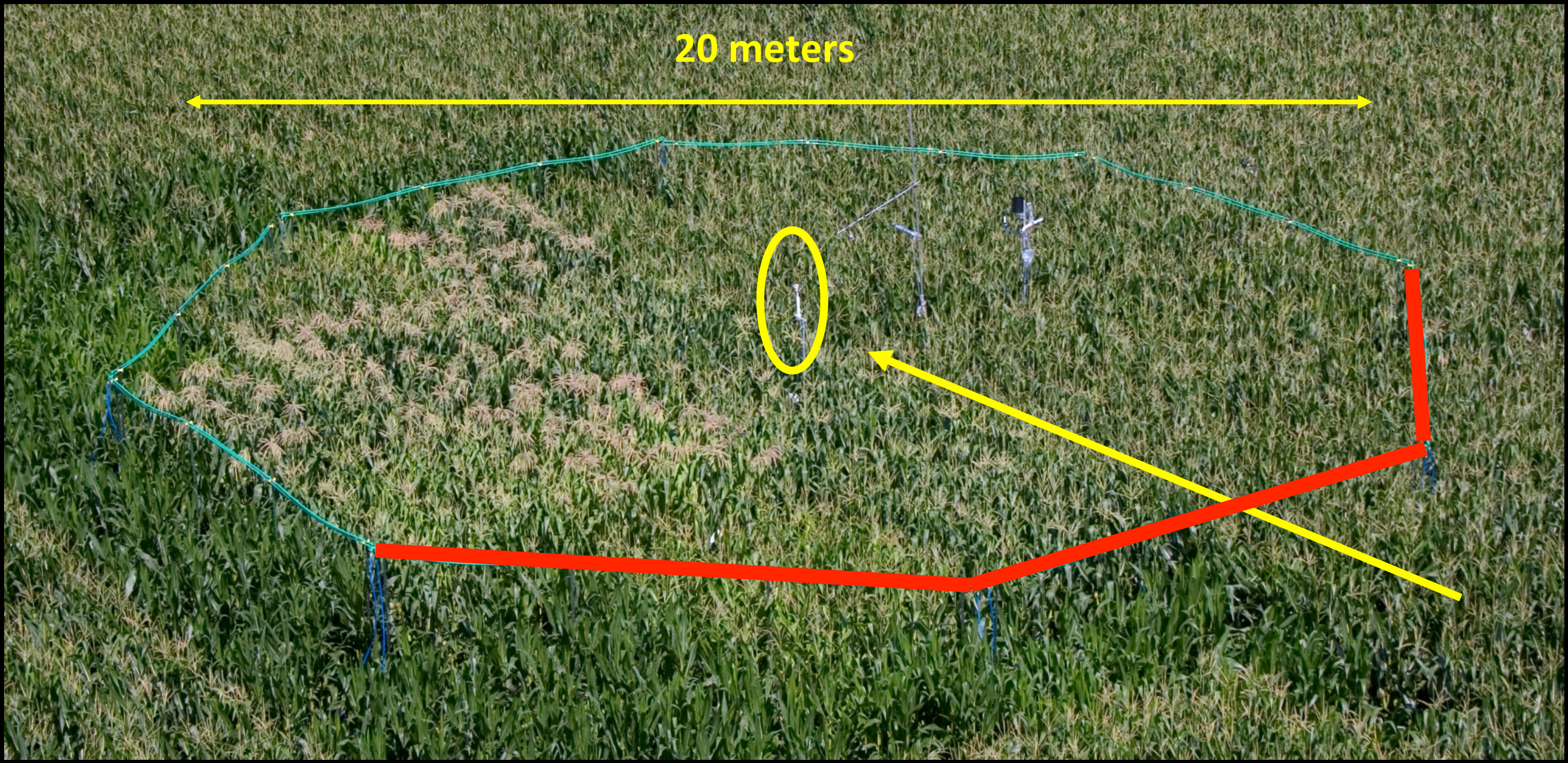
Limiting N supply will reduce photosynthetic capacity, resulting in CO_2-limited *A* under current [CO_2]

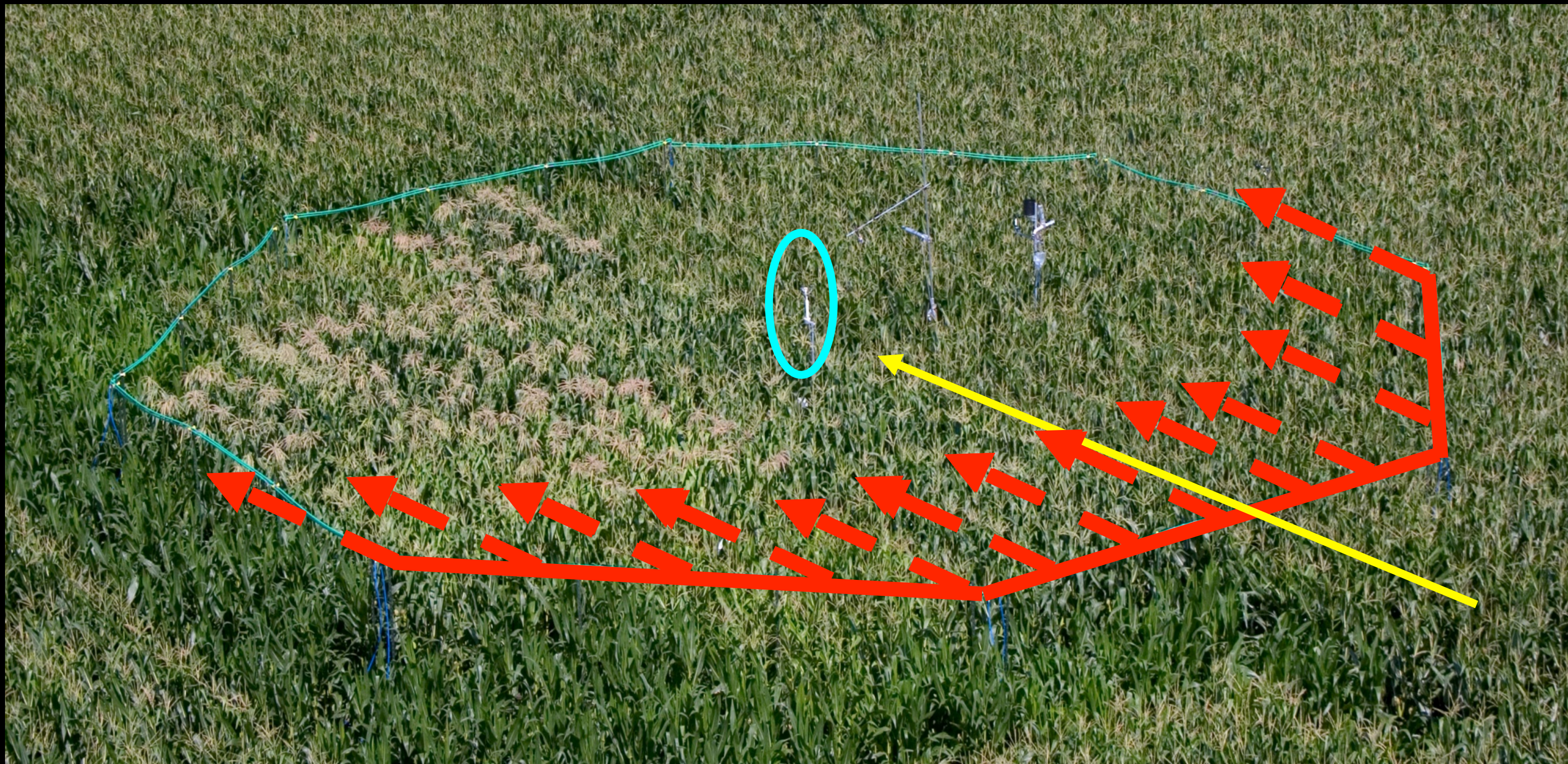


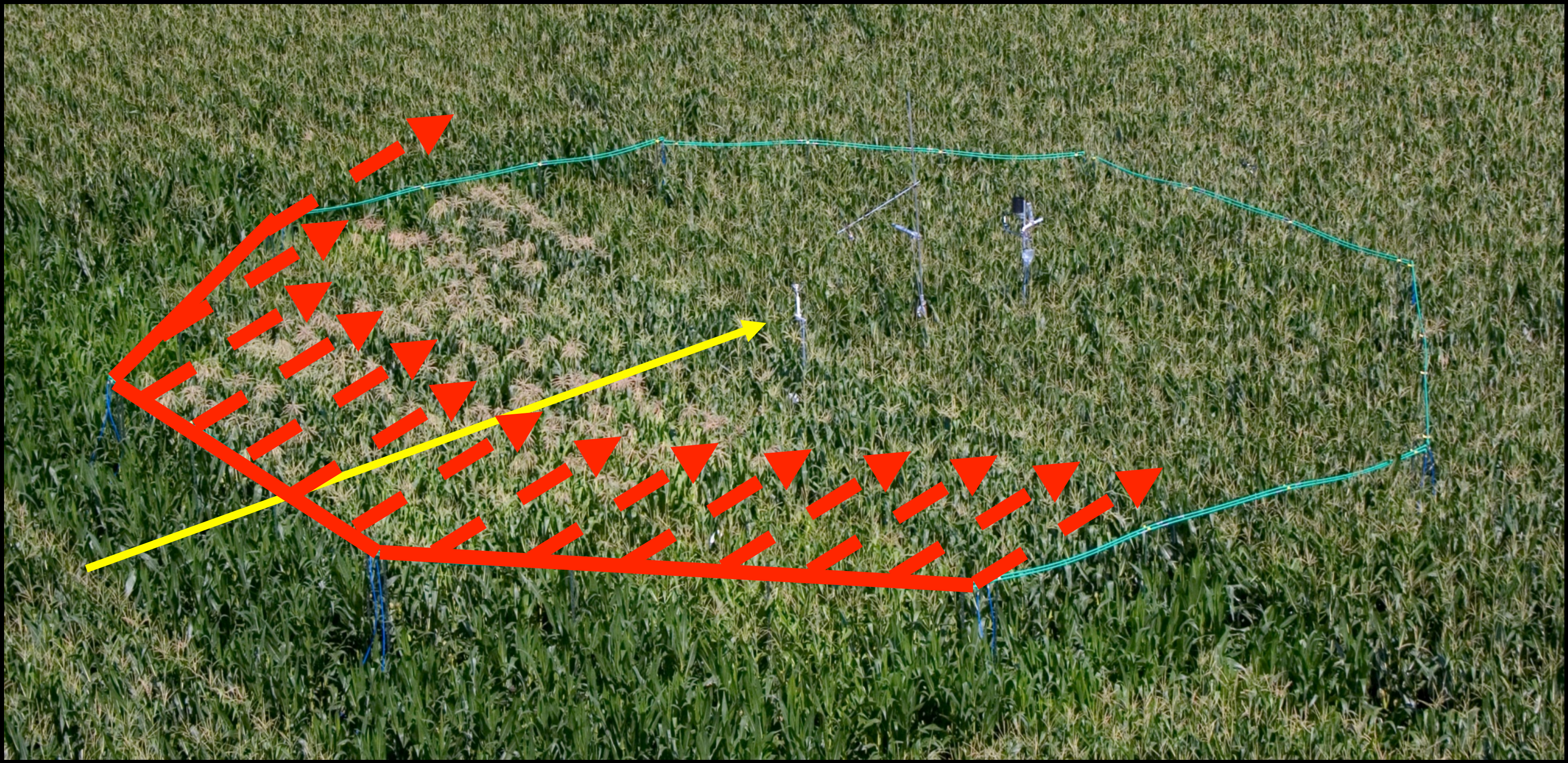
Drought will increase stomatal and non-stomatal limitations to *A*, which are ameliorated by elevated [CO_2]

Testing physiological mechanisms of maize response to elevated [CO_2]

SoyFACE - A unique facility to study soybean and maize at future CO_2 and ozone concentrations, temperatures and drought conditions

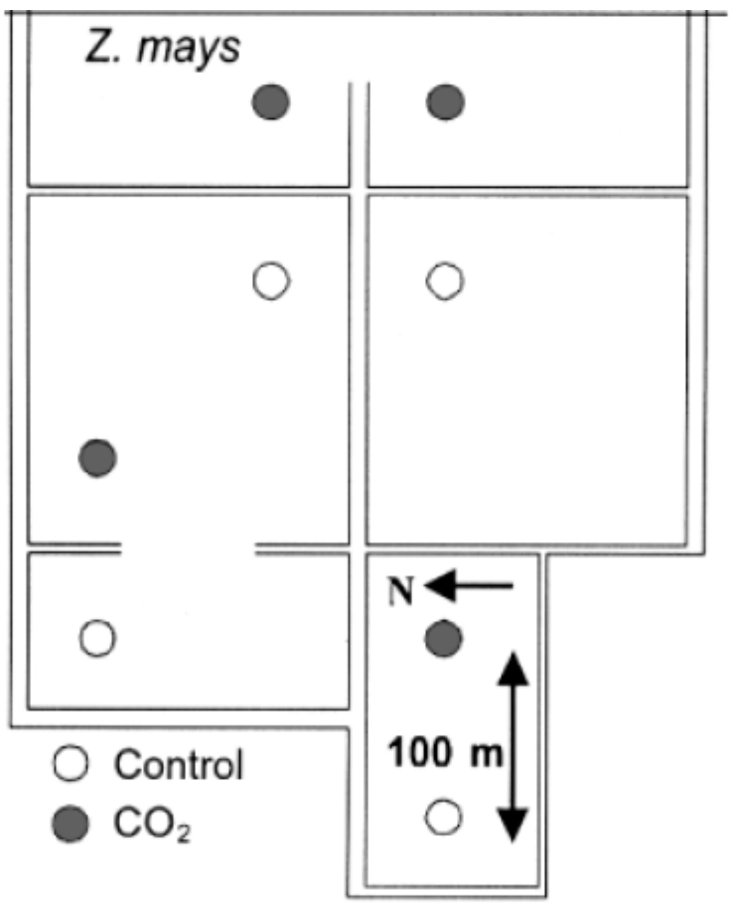

20 meters

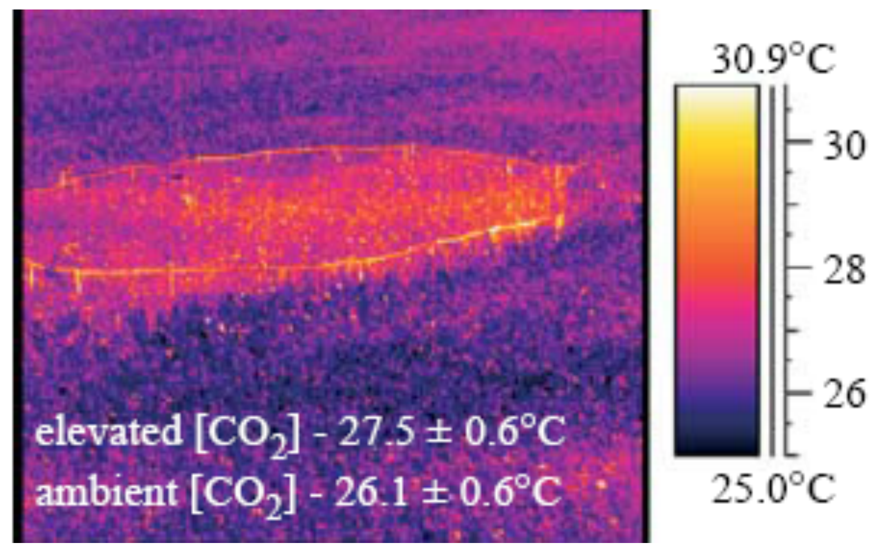




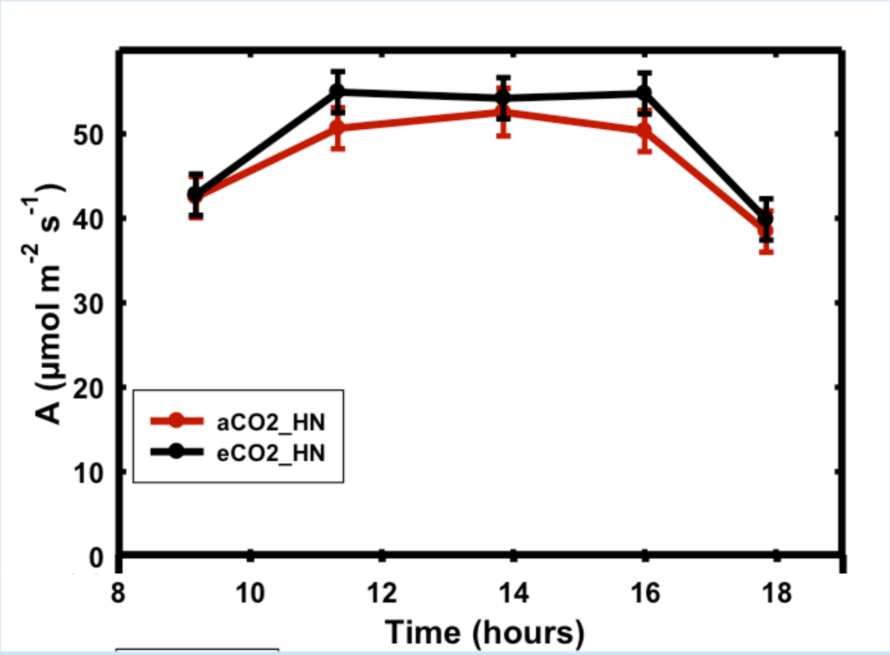
EXPERIMENTAL DESIGN

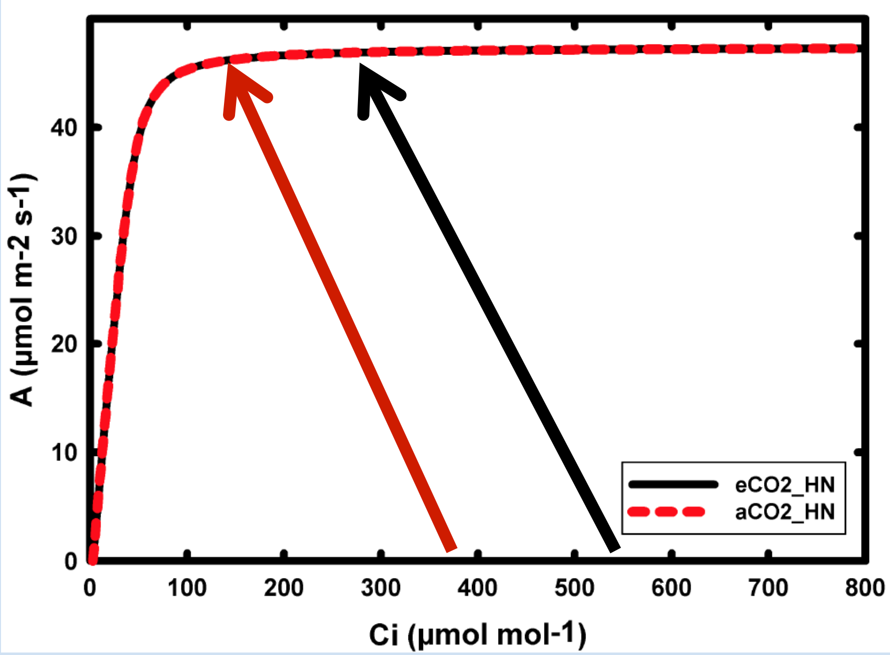
FACE technology: 4 ambient [CO_2] plots (380 µmol mol^{-1})
4 elevated [CO_2] plots (550 µmol mol^{-1})
Fumigation from planting to harvest
34N43 Pioneer Hi-Bred





Elevated $[CO_2]$ has no effect on photosynthetic capacity in the absence of drought

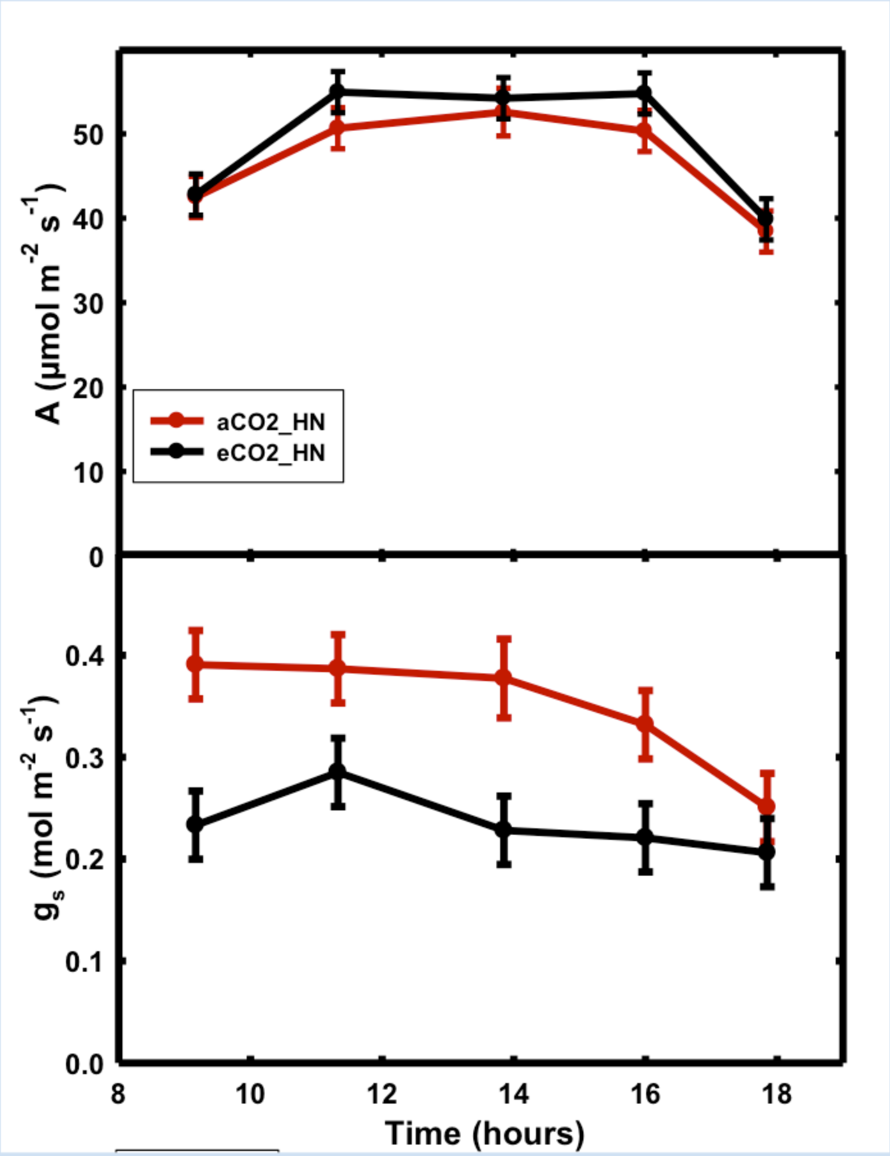


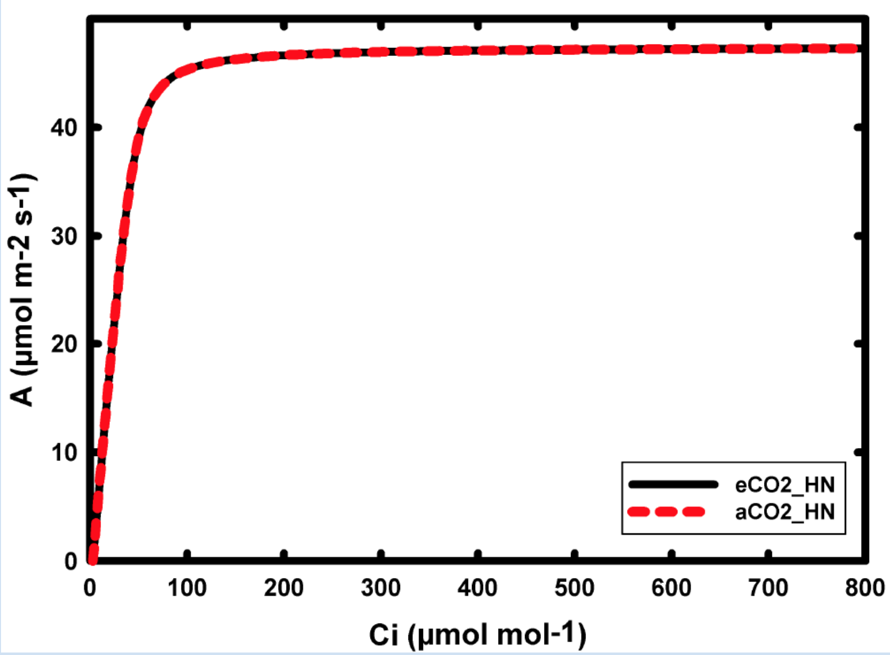


Combine midday field C_i data with lab A/C_i curves to examine operating points

Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*

Elevated $[CO_2]$ reduces stomatal conductance, but has no effect on photosynthetic capacity in the absence of drought

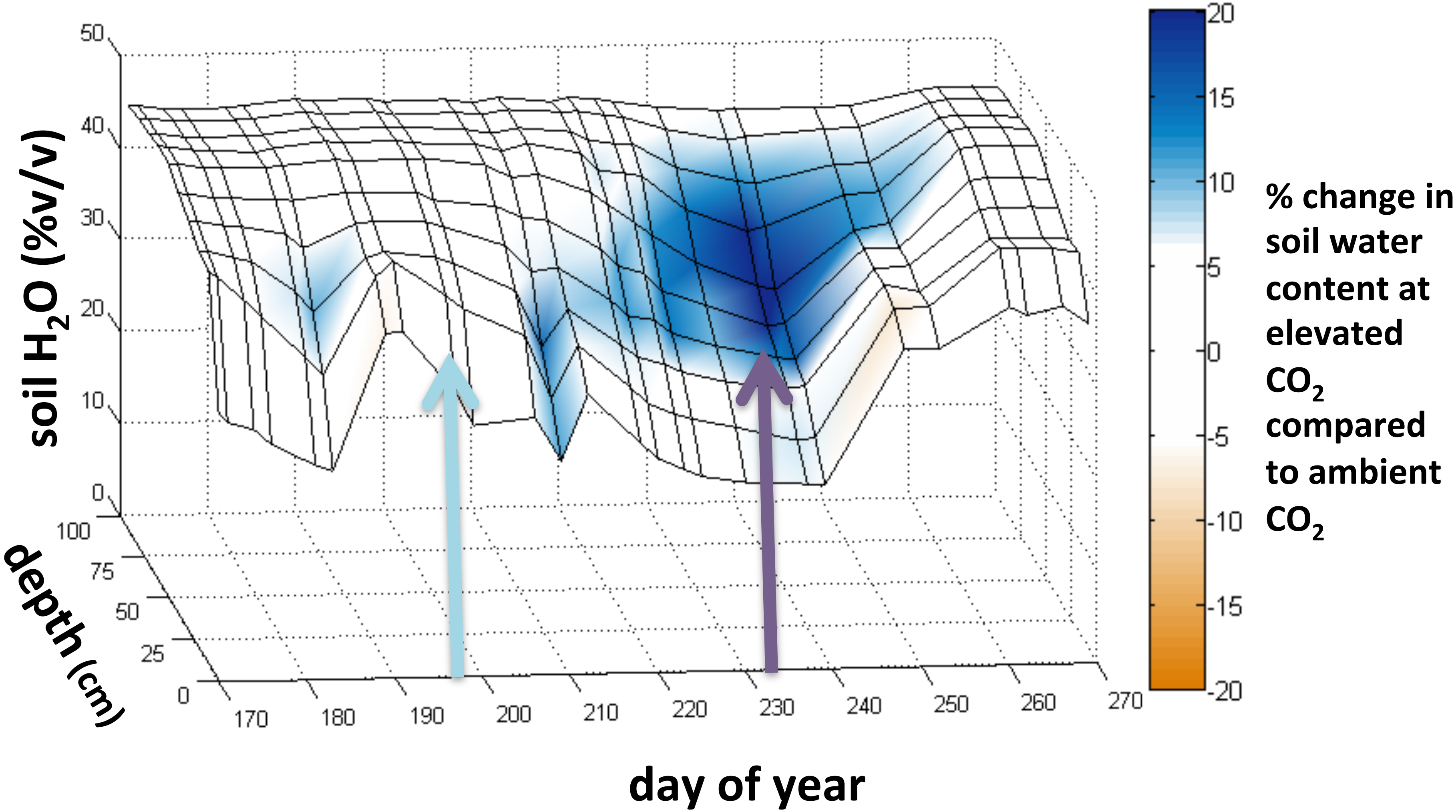




- Reduced stomatal conductance in elevated $[CO_2]$ reduces plant water use

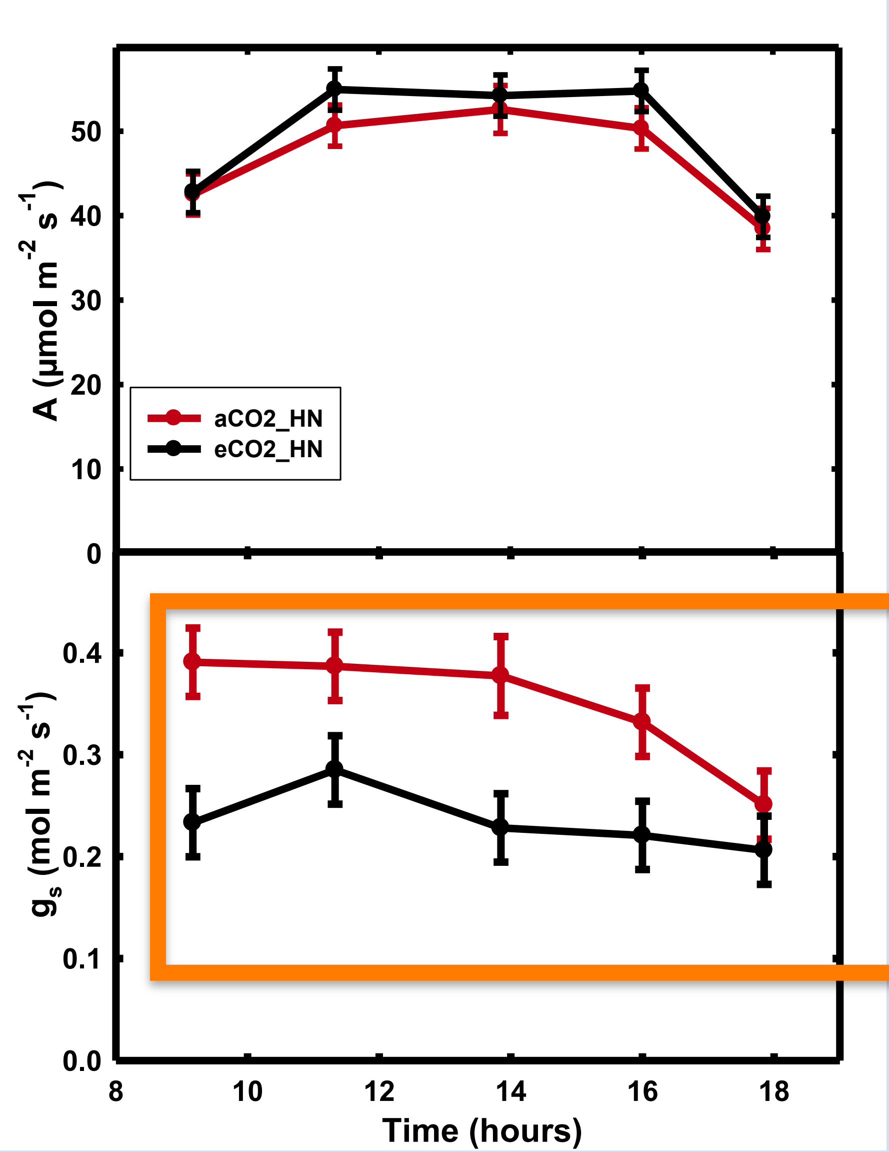
Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*

26,000 observations provides a high temporal and spatial resolution of water availability

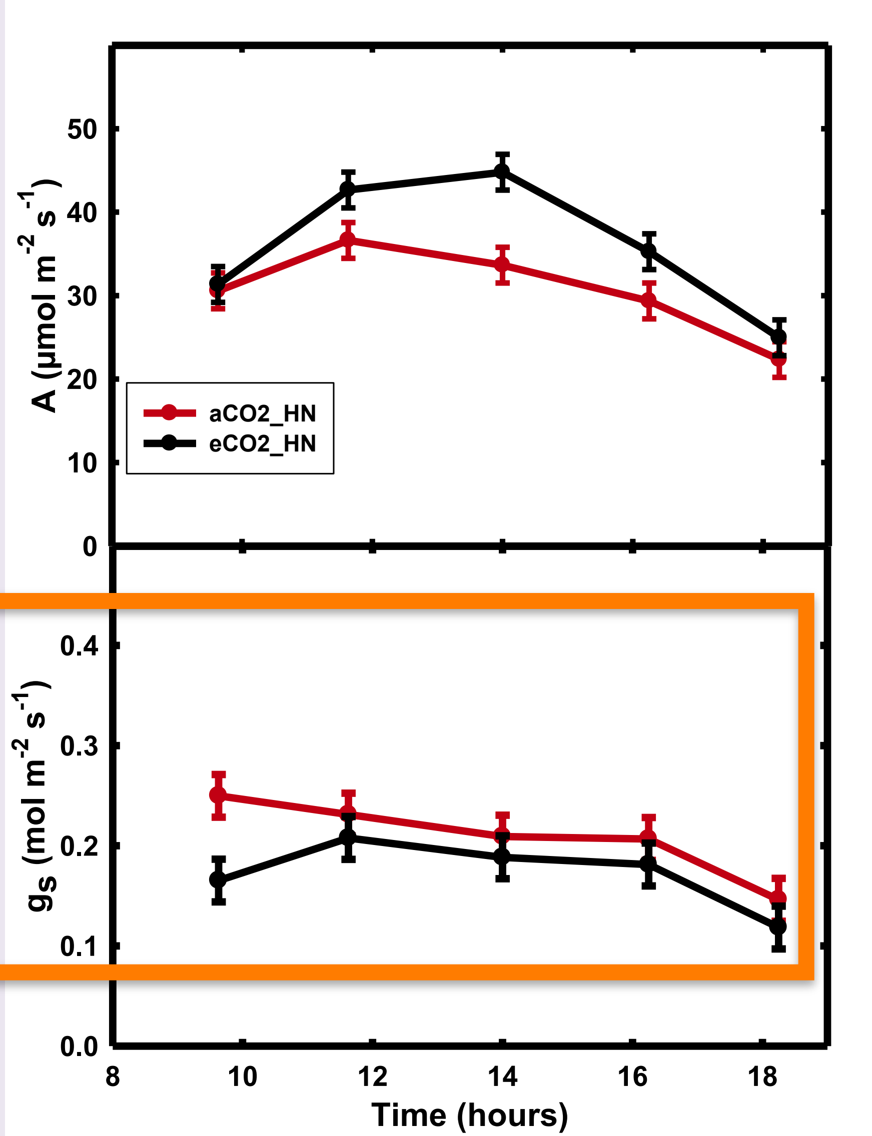


Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*

No drought stress

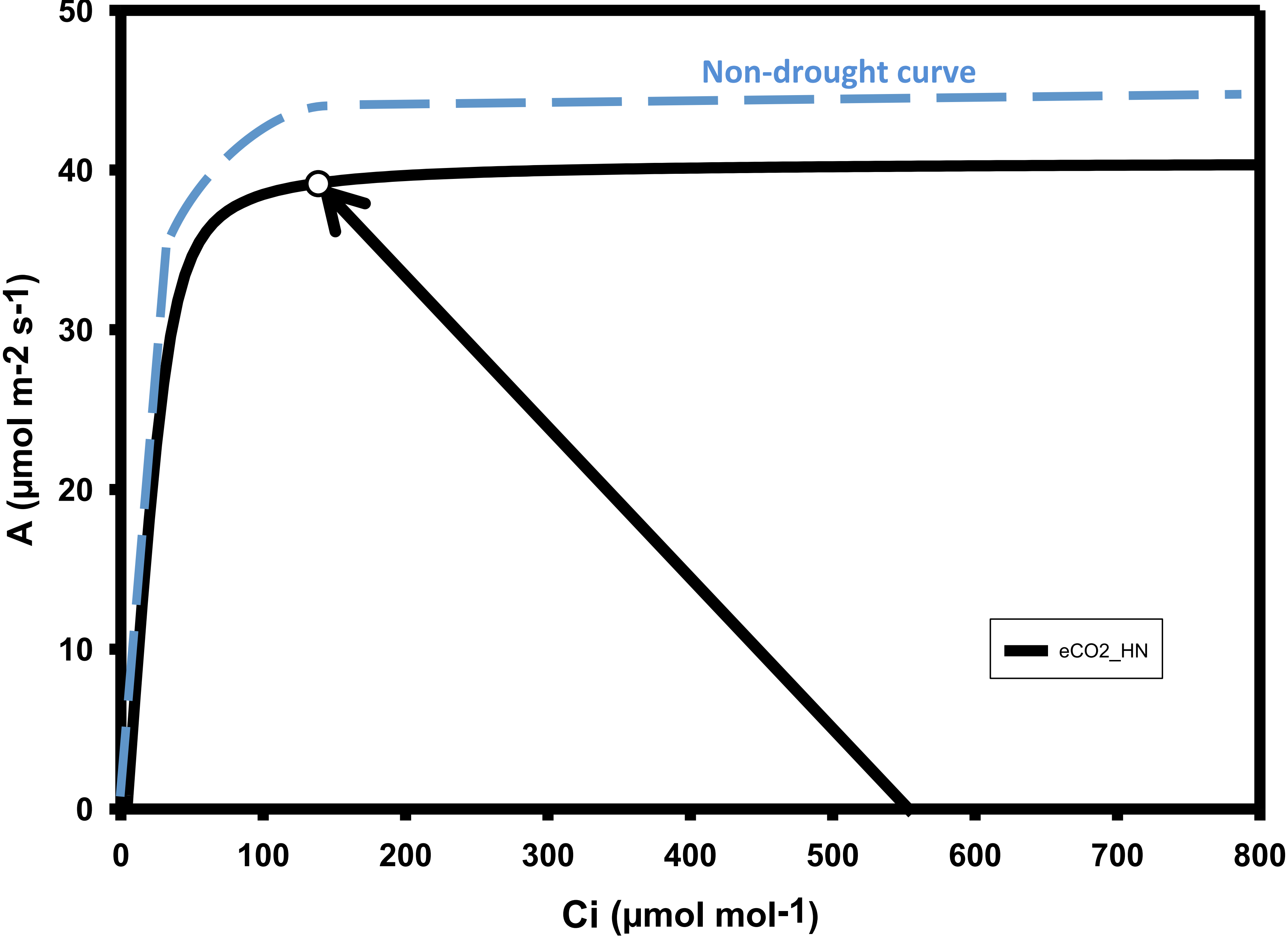


Drought stress



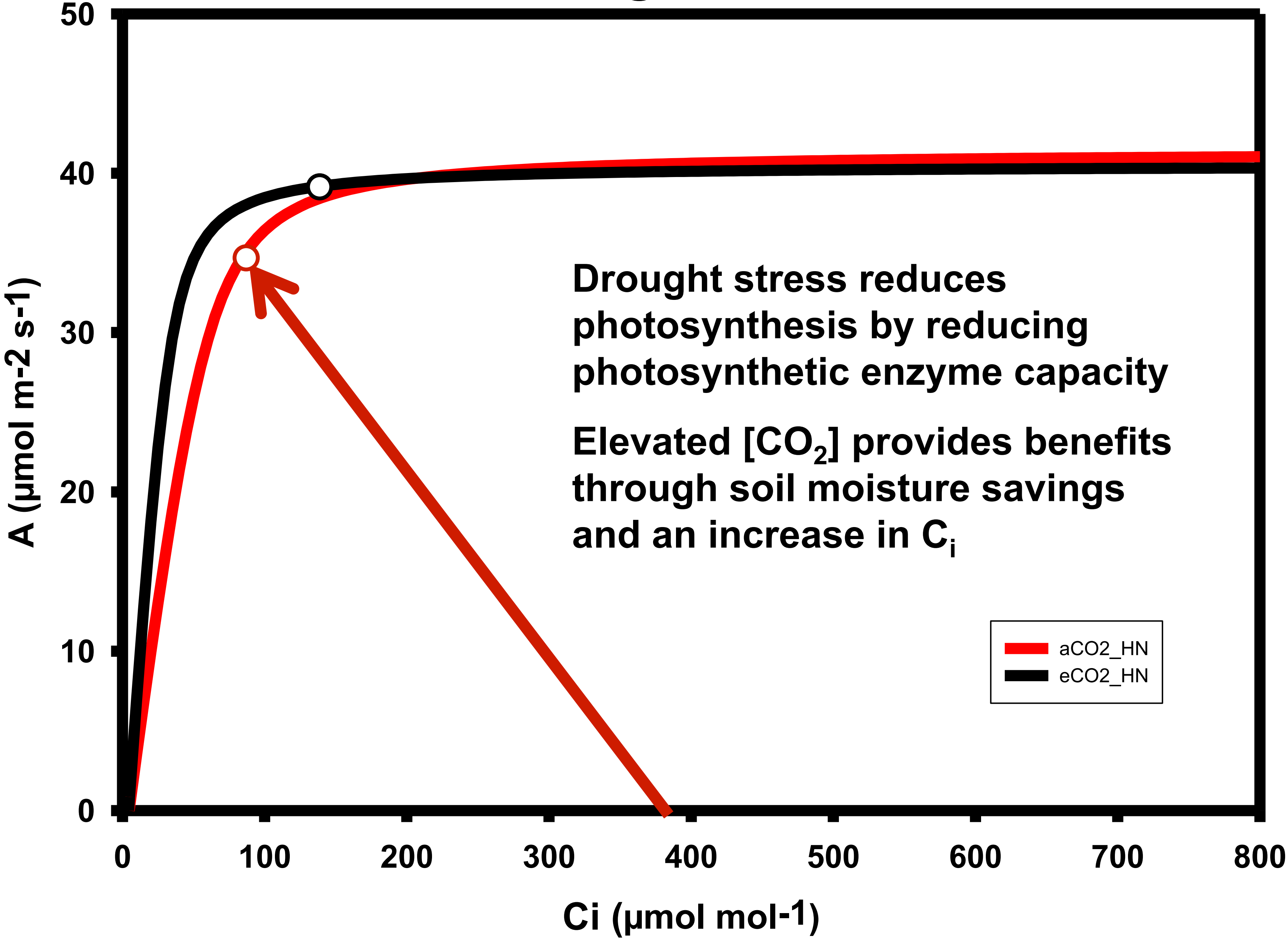
Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*

Drought Stress



Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*

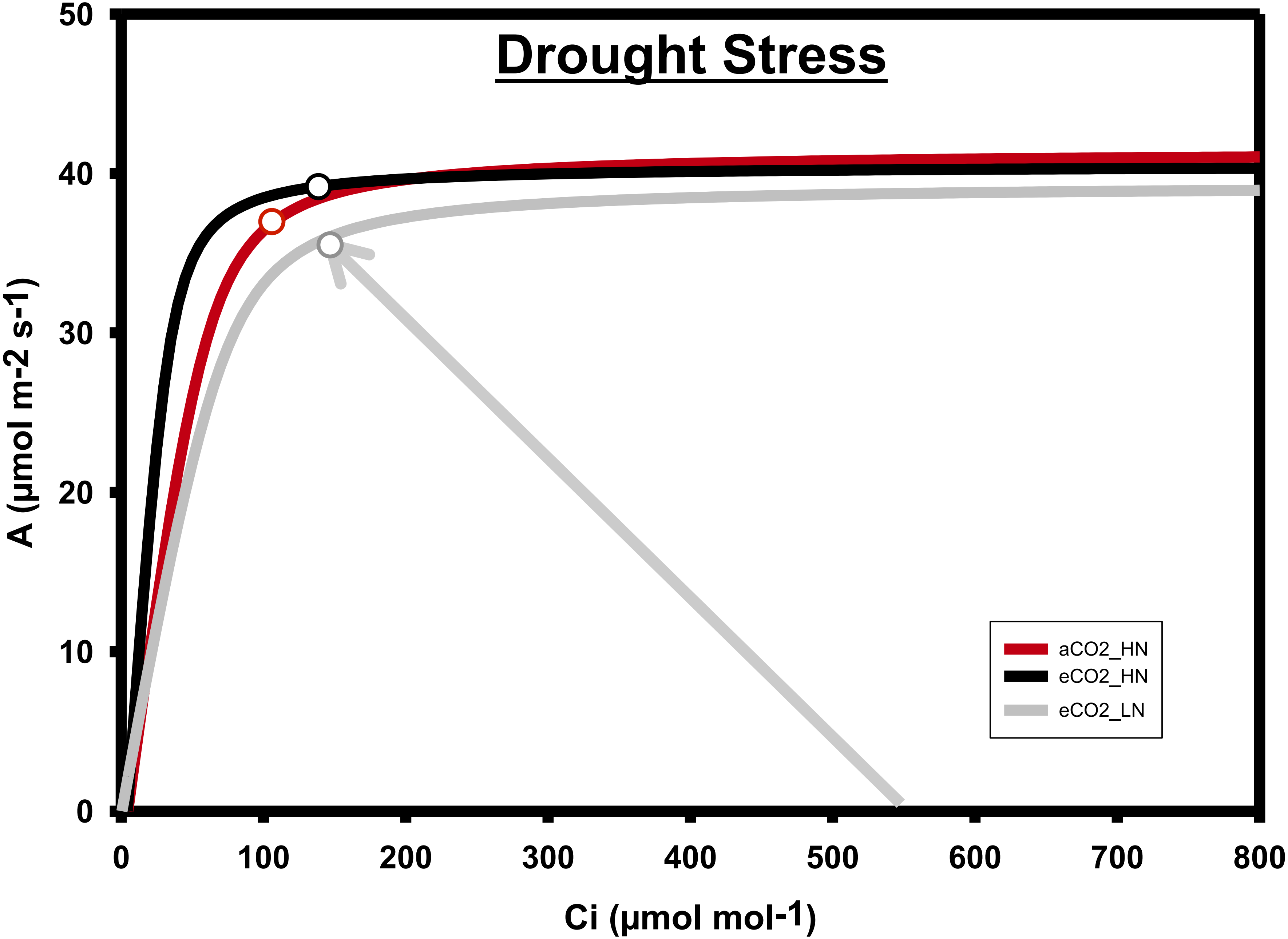
Drought Stress



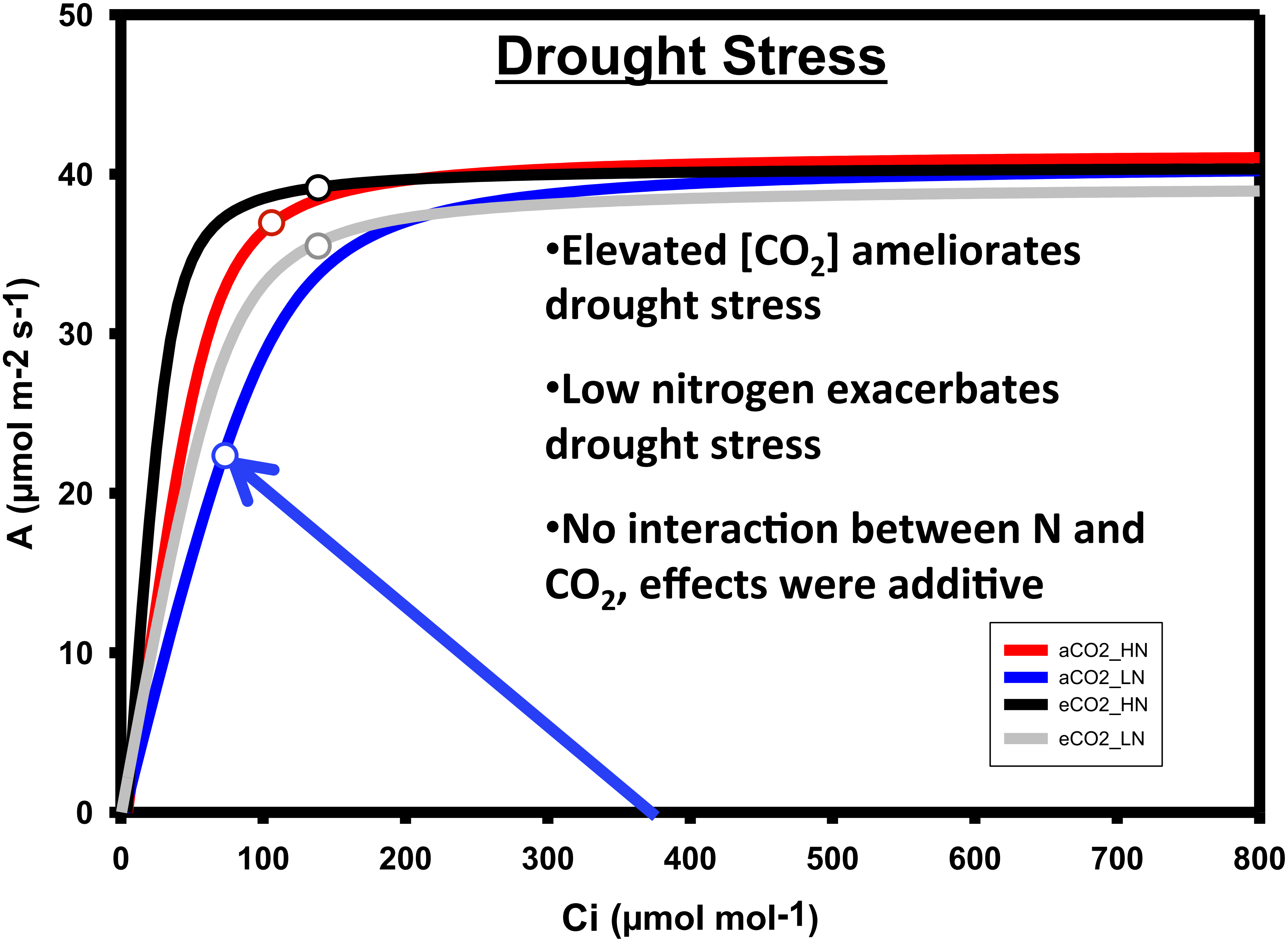
Drought stress reduces photosynthesis by reducing photosynthetic enzyme capacity

Elevated [CO_2] provides benefits through soil moisture savings and an increase in C_i

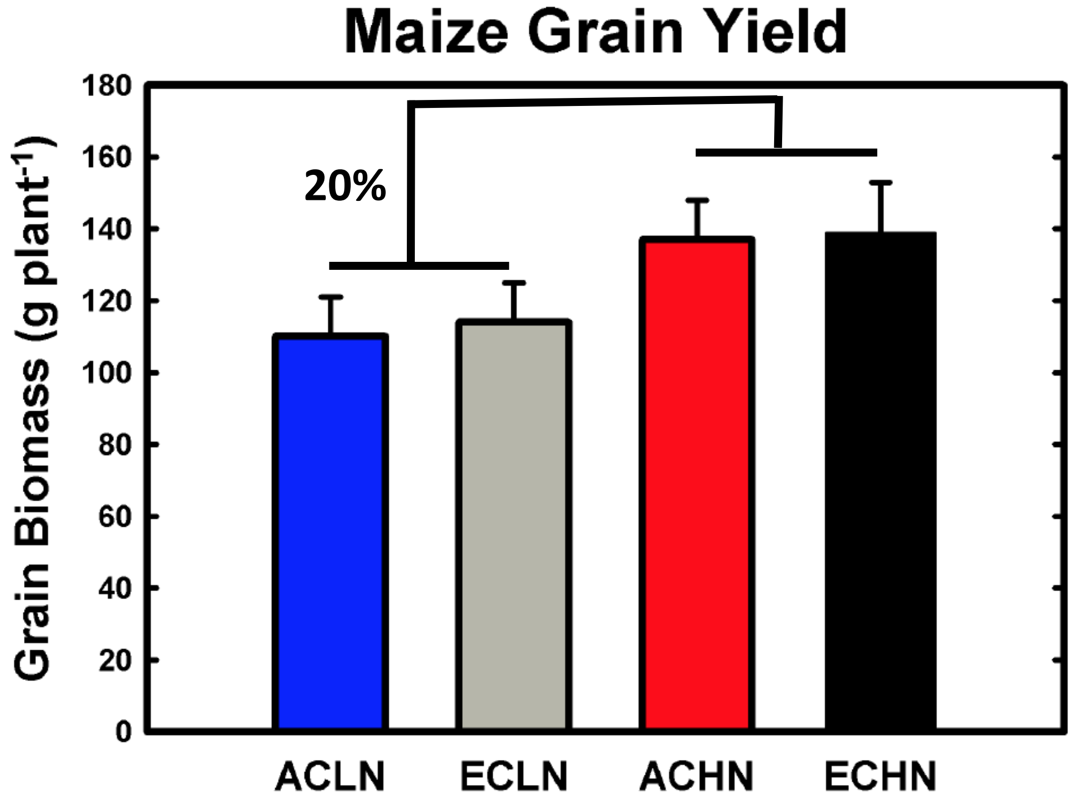
Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*



Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*



Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*



- Low N reduced yield by 20%
- Benefits of elevated [CO_2] for leaf level photosynthesis were not enough to contribute to an increase in yield
- Timing of the drought with plant development may be important (i.e. silking date)

Markelz, Strellner and Leakey (2011) *Journal of Experimental Botany*

Photosynthesis

Physiological mechanism?

2

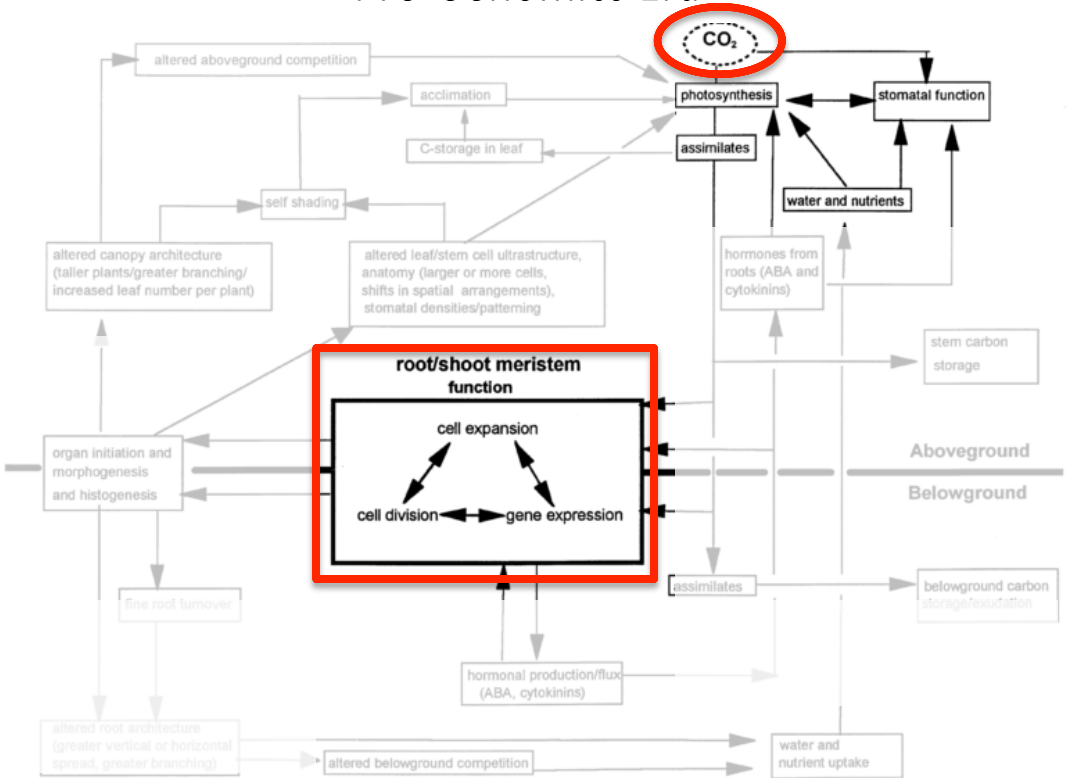
H_2O + CO_2 → sugars → respiration → C balance → yield

C_3 Arabidopsis

- Respiration provides the energy and carbon skeletons needed for plant growth and maintenance

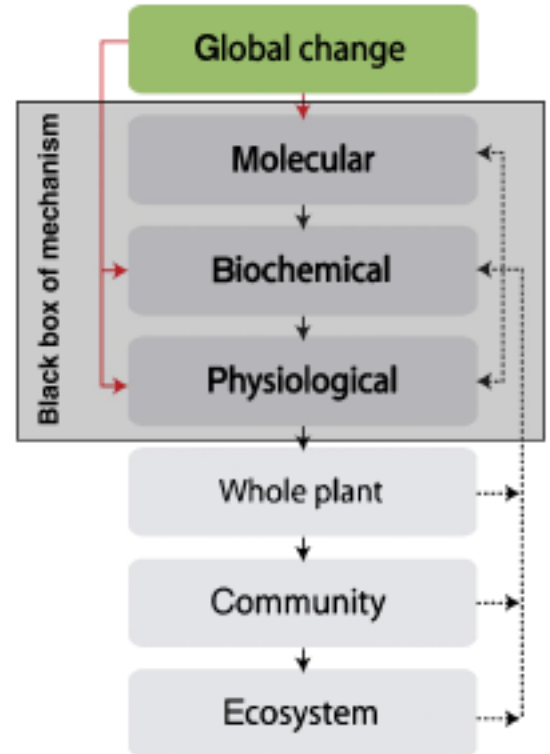
- There is poor mechanistic understanding of the link between carbon supply, respiration rates, and plant productivity

Pre-Genomics Era



Pritchard et al. (1999) Global Change Biology 5: 807-837

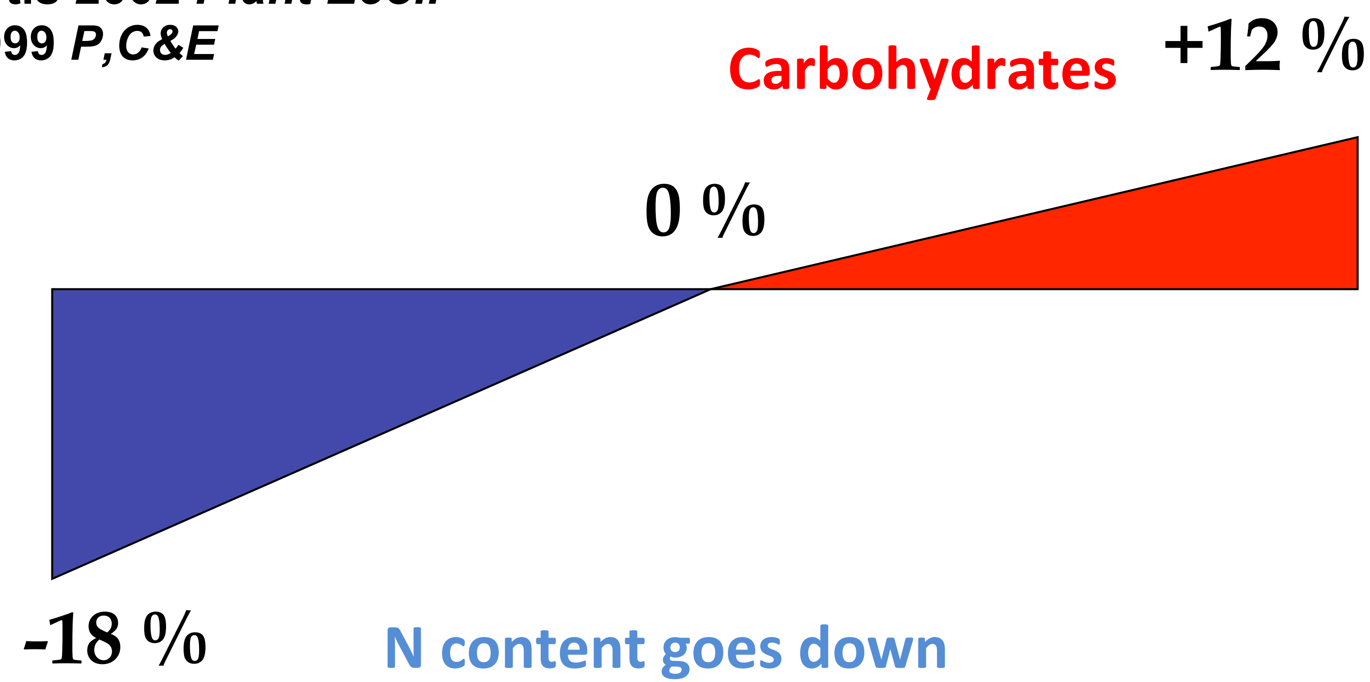
Post-Genomics Era



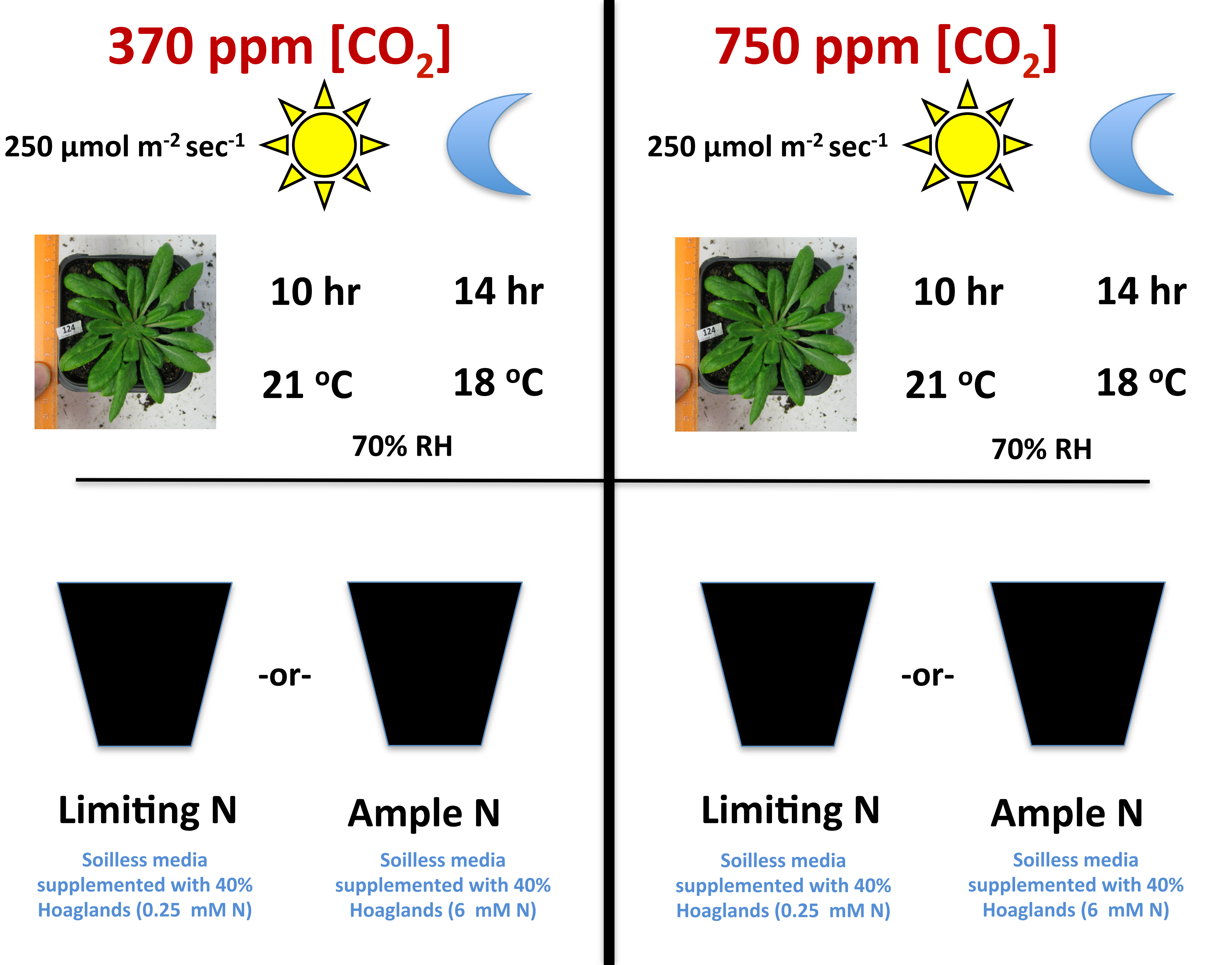
Leakey ADB, Ainsworth EA, Bernard SM, Markelz RJC, Ort DR et al. (2009) Global Change Biology 15: 1201-1213

- **Post-genomics era allows for a detailed systems level understanding of climate change biology**
- **Study of plant responses through this integrative framework can advance both mechanisms and provide targets for genetic manipulation**

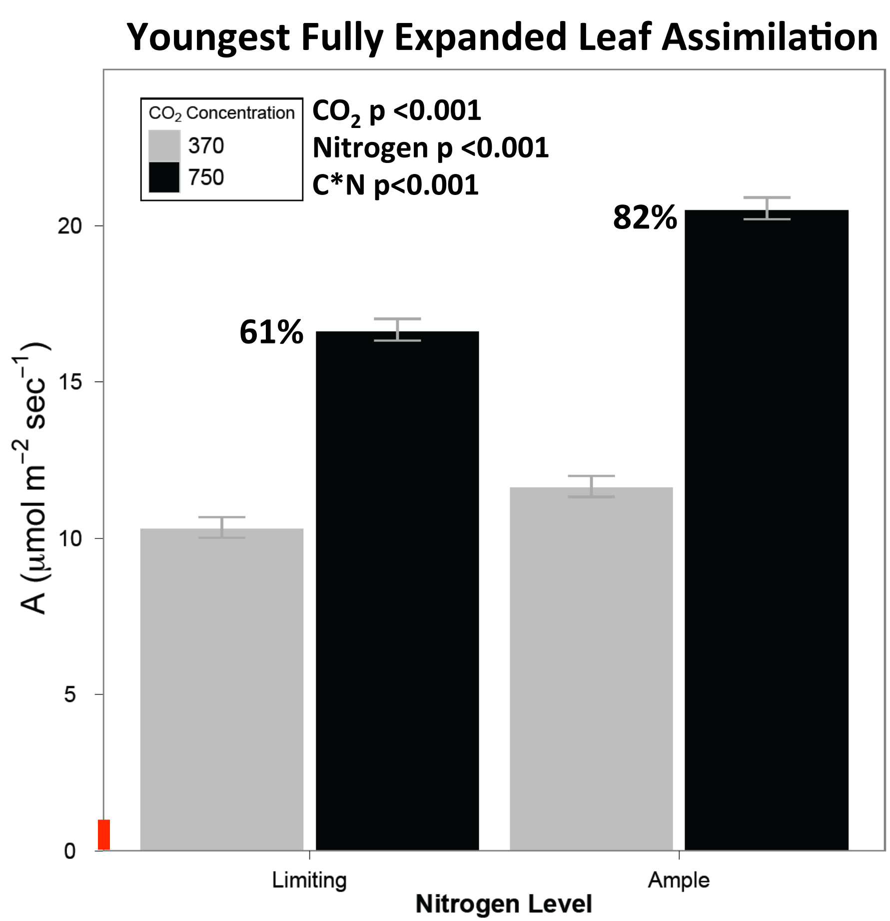
Davey et al. 2004 *Plant Phys.*
Gifford 2003 *Func. Plant Biol.*
Wang and Curtis 2002 *Plant Ecol.*
Drake et al. 1999 *P,C&E*

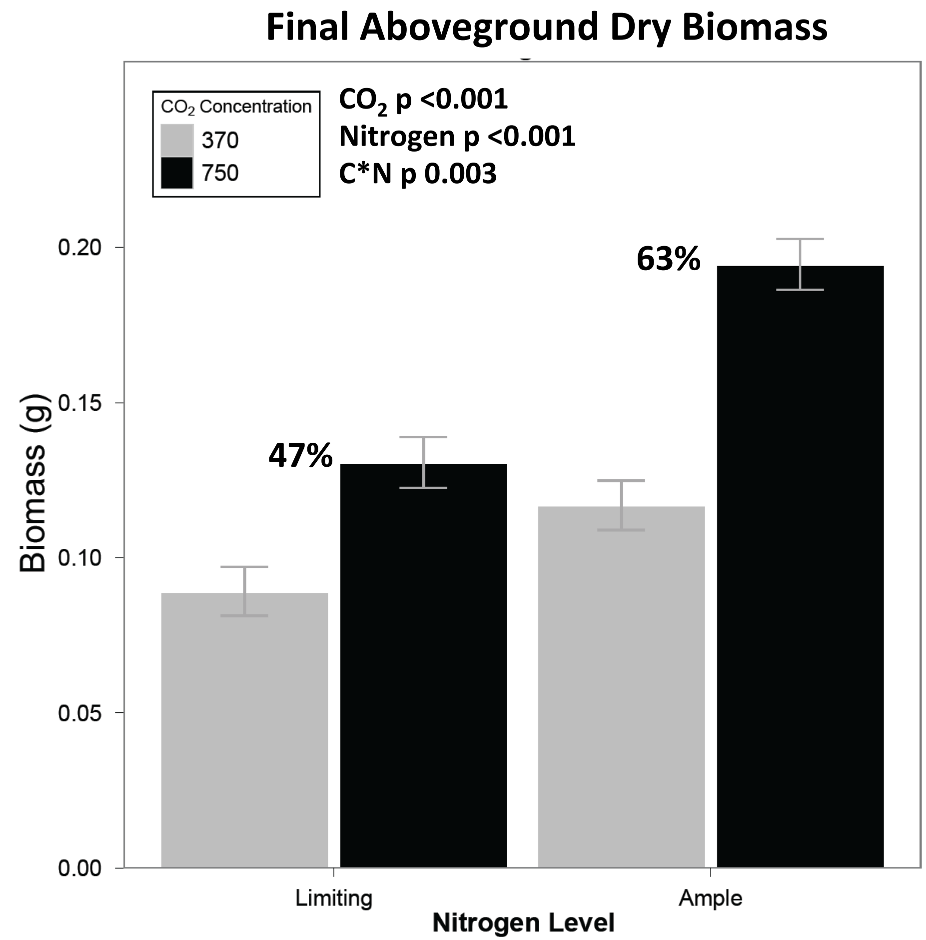


- Increase in respiration due to carbohydrate increase (**more supply**)
- Decrease in respiration because protein turnover is the major sink for respiratory energy (**more demand**)
- No change justified by cancellation of the other two



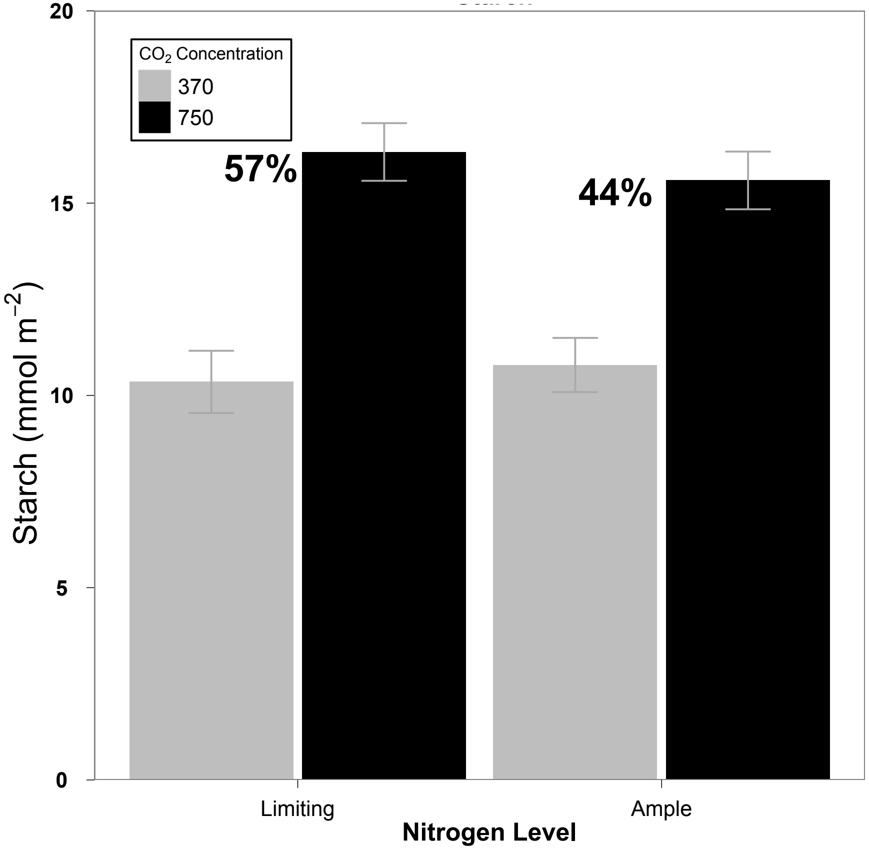
370 ppm [CO_2]
250 µmol m^{-2} sec^{-1}
10 hr
14 hr
21 °C
18 °C
70% RH
-or-
Limiting N
Soilless media supplemented with 40% Hoaglands (0.25 mM N)
Ample N
Soilless media supplemented with 40% Hoaglands (6 mM N)
750 ppm [CO_2]
250 µmol m^{-2} sec^{-1}
10 hr
14 hr
21 °C
18 °C
70% RH
-or-
Limiting N
Soilless media supplemented with 40% Hoaglands (0.25 mM N)
Ample N
Soilless media supplemented with 40% Hoaglands (6 mM N)



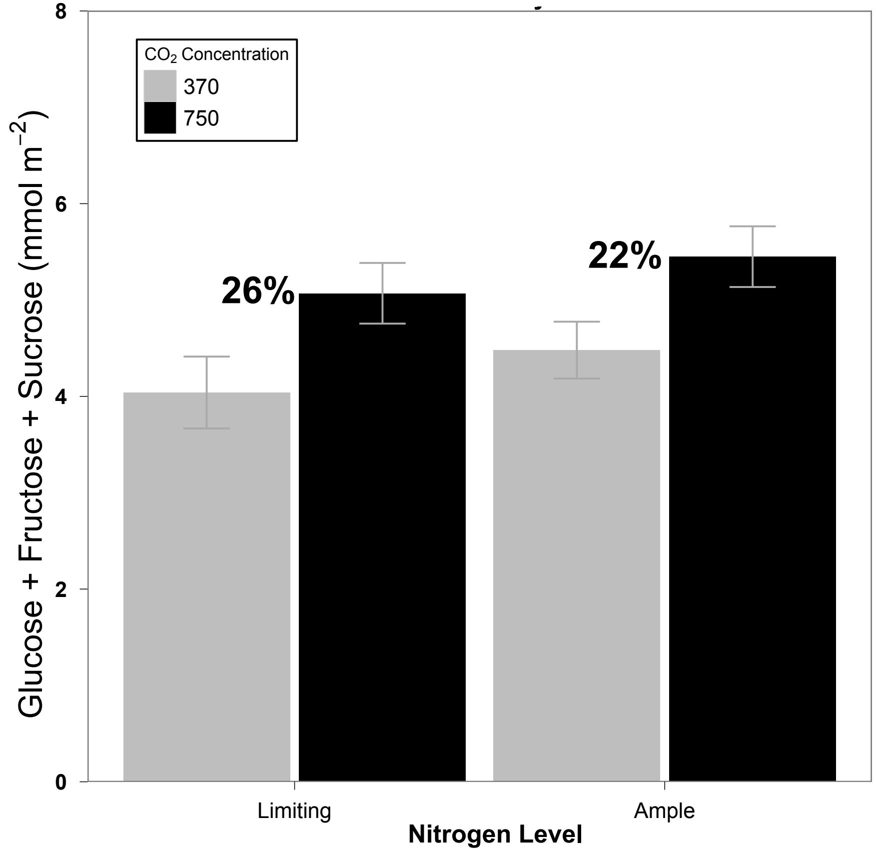


- These responses are consistent with the literature.
- The stimulation of photosynthesis to elevated [CO_2] was greater under ample N availability and matches the biomass response.
- Greater substrate supply for respiration?

Midnight Leaf Starch Content

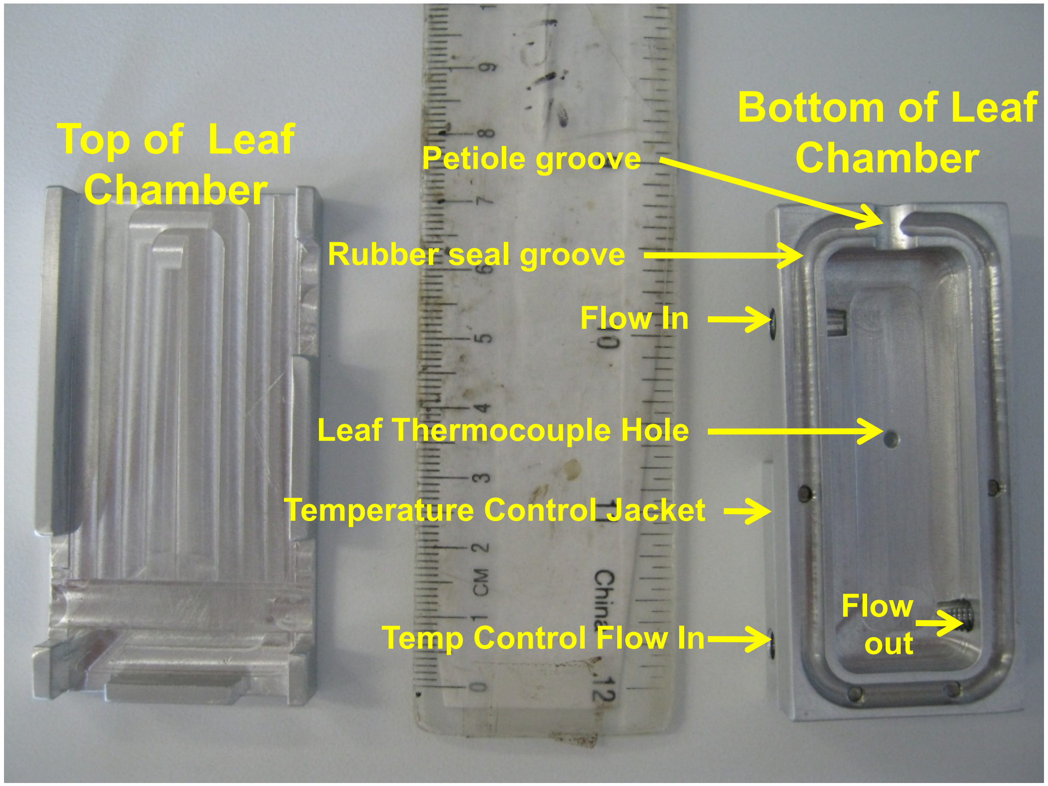


Midnight Leaf Mobile Carbohydrate Content

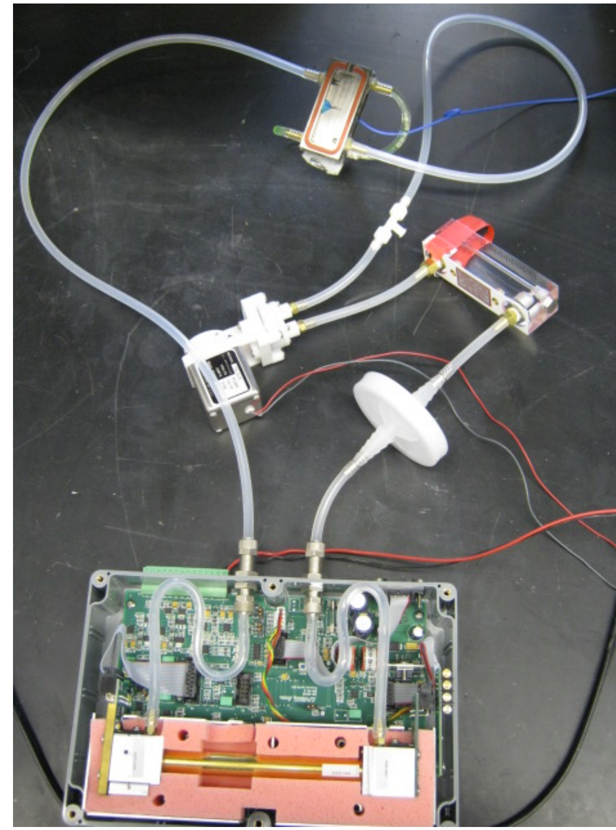


- **The stimulation of photosynthesis in elevated [CO_2] lead to greater leaf starch mobile carbohydrate content at midnight.**
- **These responses are also consistent with literature.**

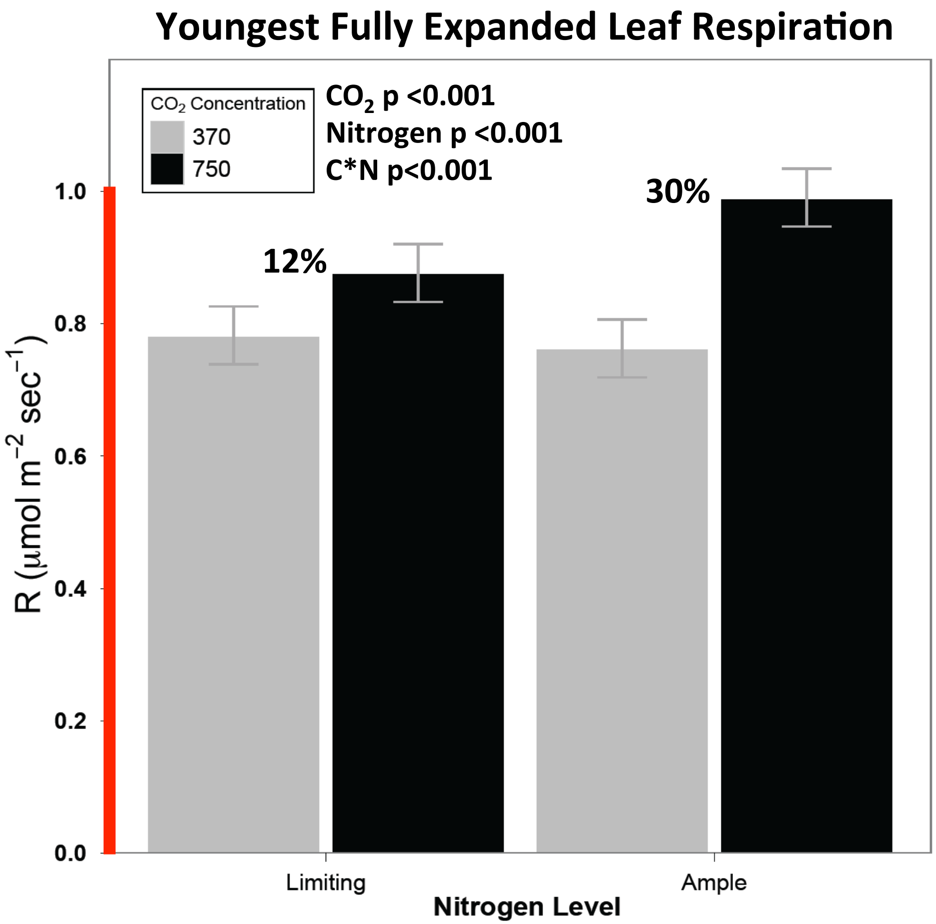
Accurately measuring individual Arabidopsis leaf respiration is non-trivial

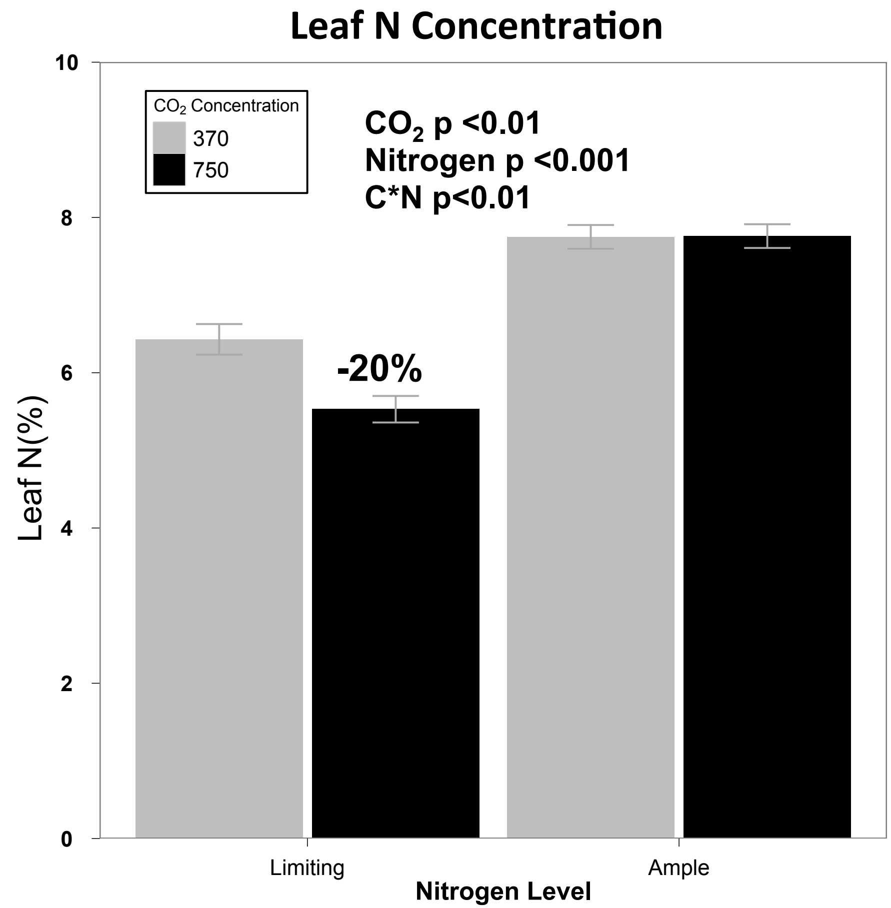


Basic System Layout

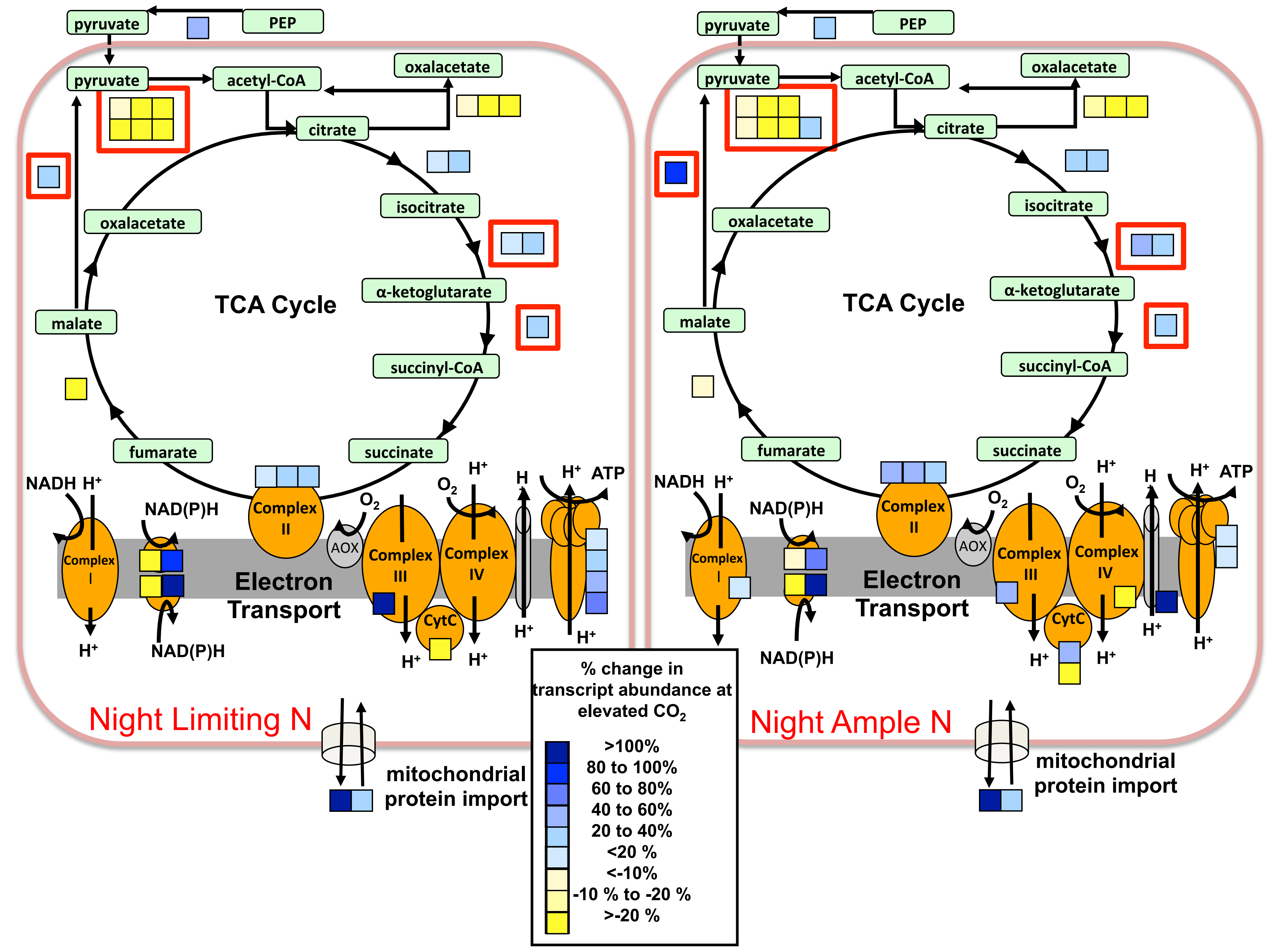


Five gas exchange systems running simultaneously allows one person to accurately measure respiration rates of > 50 plants in less than two hours





- **The stimulation of leaf respiration to elevated [CO_2] was greater in the ample N treatment**
- **There was a stimulation of leaf respiration despite a reduction in leaf N in the limiting N treatment**
- **This system allows us to detect relatively small treatment differences (12%) that other non-specialized systems failed to detect.**



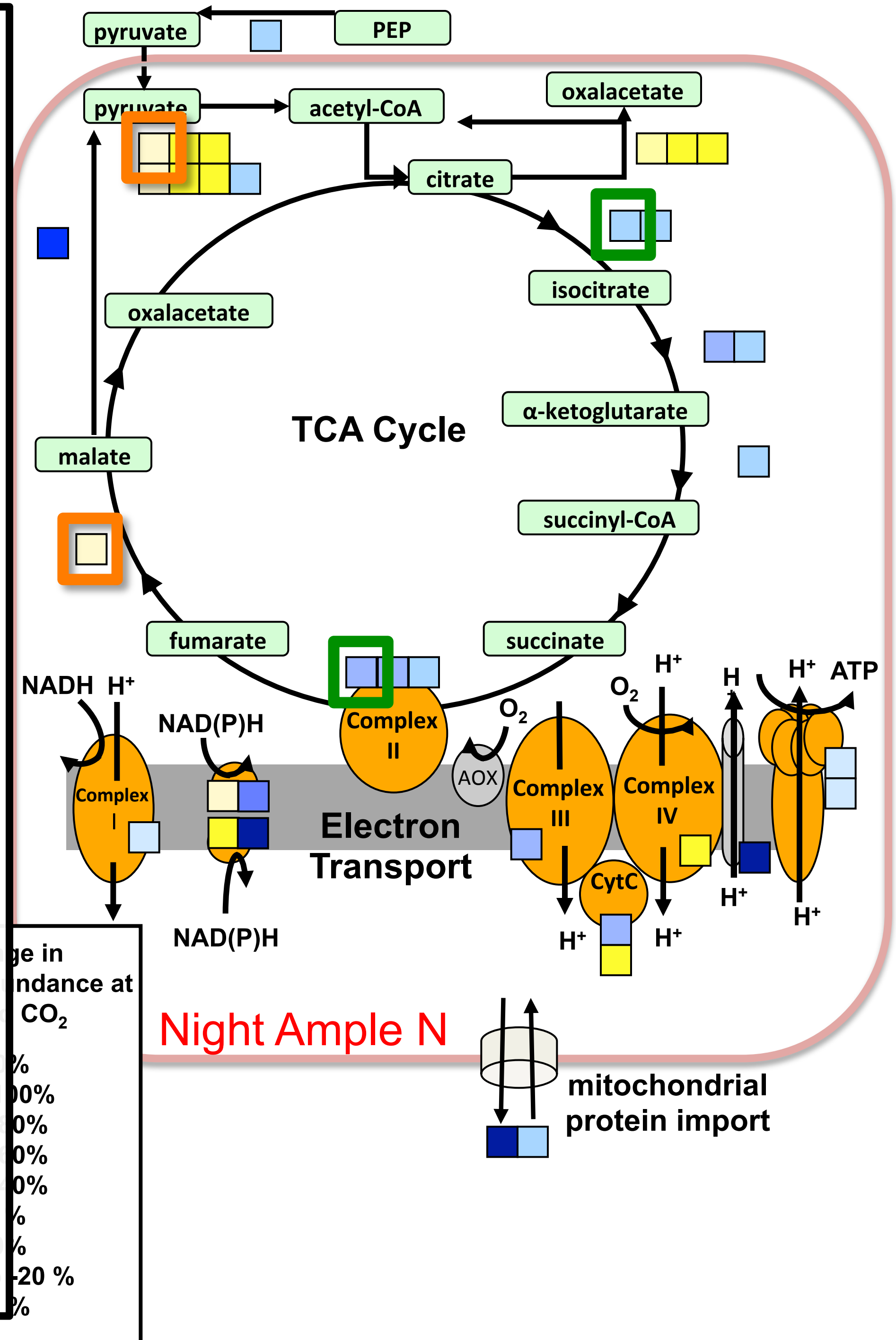
pyruvate
PEP
pyruvate
acetyl-CoA
oxalacetate
citrate
isocitrate
oxalacetate
α-ketoglutarate
TCA Cycle
malate
succinyl-CoA
fumarate
succinate
NADH H+
NAD(P)H
Complex II
O2
AOX
Complex III
Complex IV
H+
H
ATP
Complex I
Electron Transport
CytC
NAD(P)H
H+
Night Limiting N
mitochondrial protein import
% change in transcript abundance at elevated CO2
>100%
80 to 100%
60 to 80%
40 to 60%
20 to 40%
<20 %
<-10%
-10 % to -20 %
>-20 %
Night Ample N
mitochondrial protein import

Acotinase (*AtACO2*)
Succinate Dehydrogenase (*AtSDH-1*)

High correlations between transcript and protein abundance (**green boxes**).

Fumerase (*AtFUM1*)
Electron-transfer flavoprotein:ubquinone oxidoruductase
Poor correlations between transcript and protein abundance (**orange boxes**).

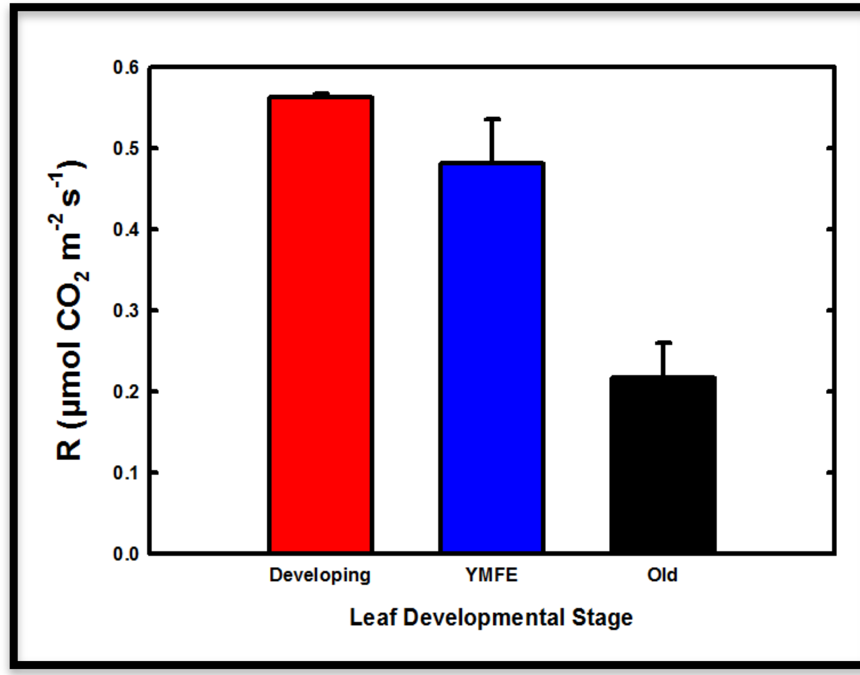
This lends support to greater transcript abundance in elevated [CO_2] for the TCA cycle is leading to greater protein abundance.



Lee et al. (2012) Journ. Prot. Res. 11 3326-3343

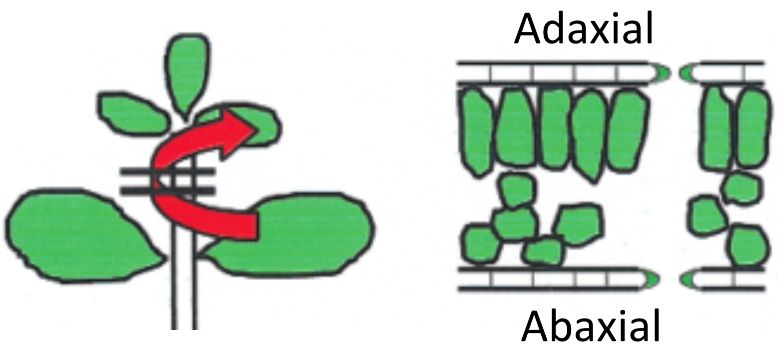
Days After Germination

17 20 23 30



- Past research focused on mature leaf tissue
- Respiratory demand is greater for developing leaves due to growth ***and*** maintenance processes
- How is the stimulation of respiration in elevated [CO_2] coordinated through leaf development?

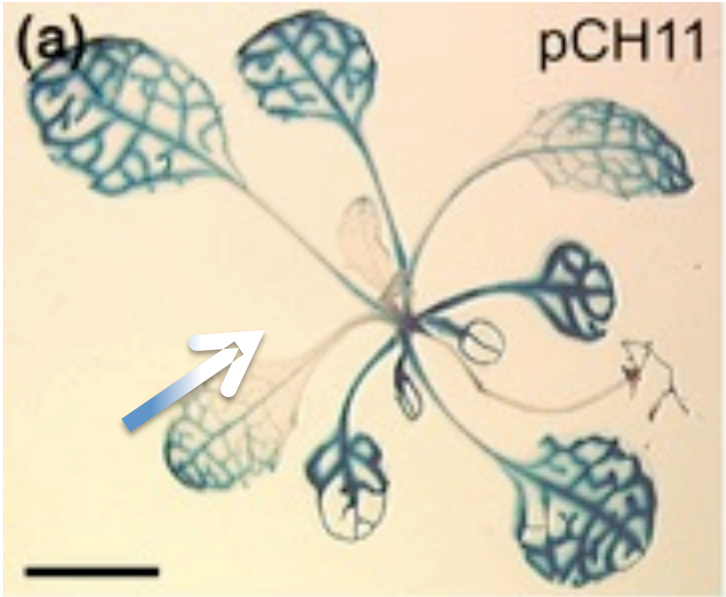
Systemic Signaling



Lake et al. (2002) J. Exp. Bot. 228: 651-662;
Coupe et al. (2006) J. Exp. Bot. 57: 329-341

- Systemic signaling from mature leaves in elevated [CO_2] to developing leaves not in elevated [CO_2] alters epidermal patterning
- Mature leaves relaying information to developing leaves about environmental conditions

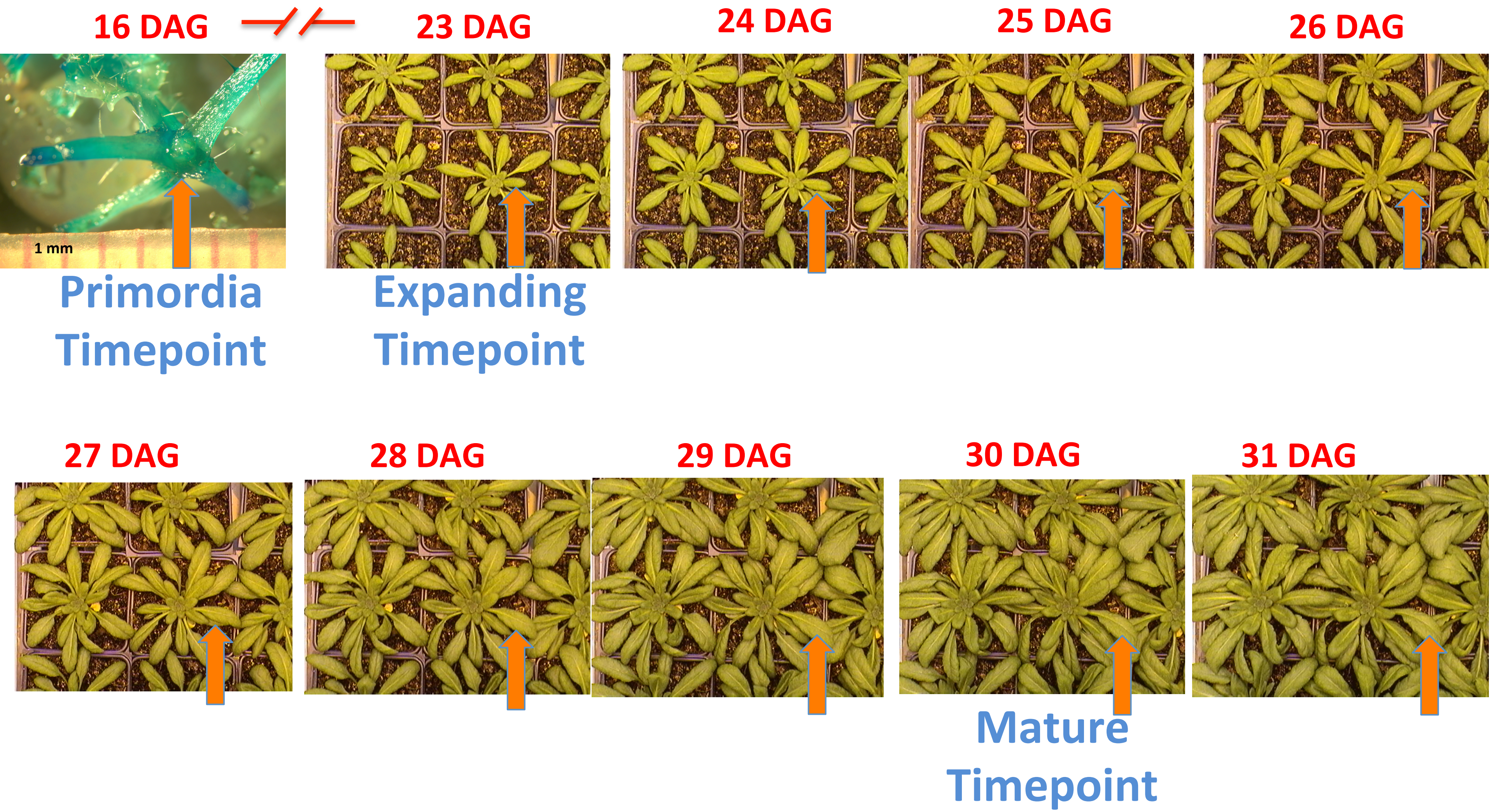
Source-Sink Relationships



Schneidereit et al. (2008) Planta 228: 651-662

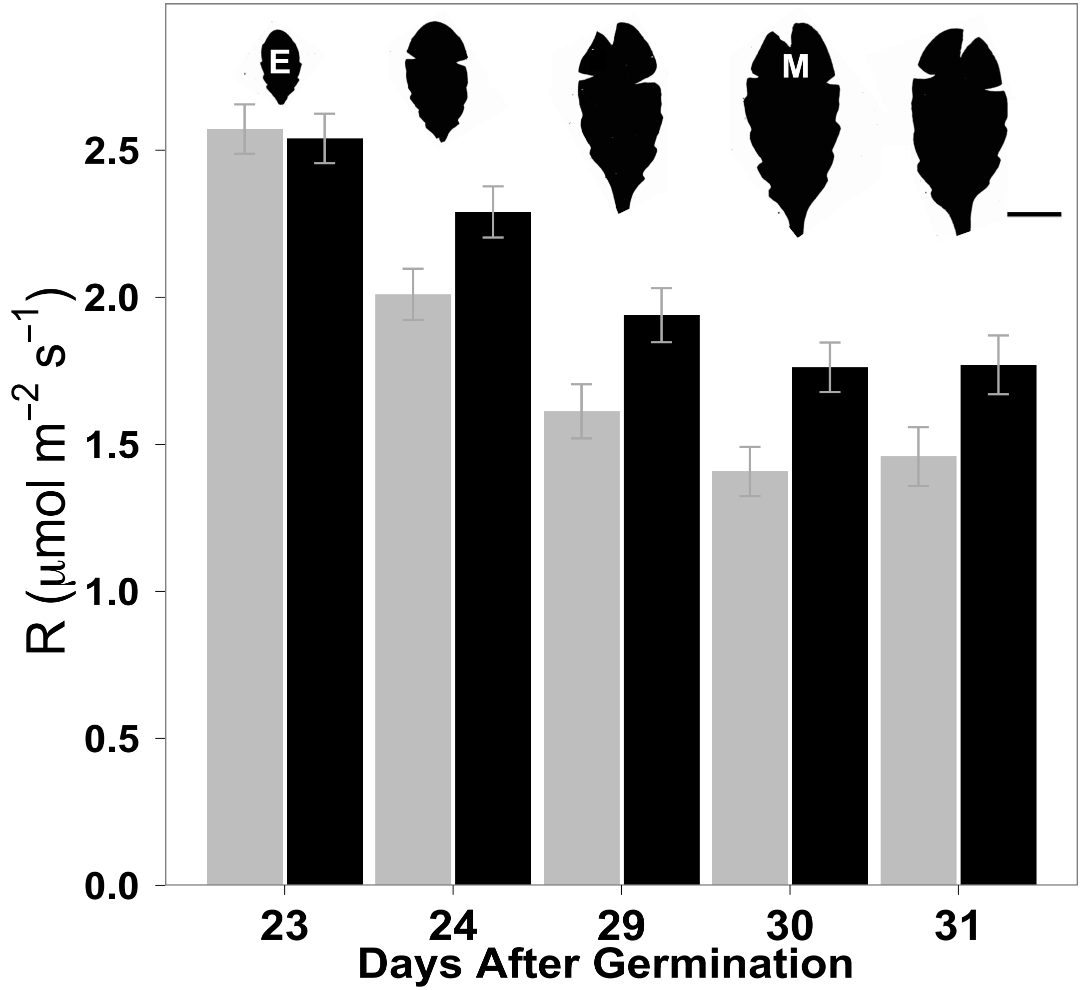
- ***AtSUC2*** **promotor:GUS Fusion---Blue is where sucrose can be transported into the phloem for distribution around the plant**
- **Clear sink-to-source developmental transition starting at the leaf tip**

Combine physiology, high-throughput phenotyping, and genomics

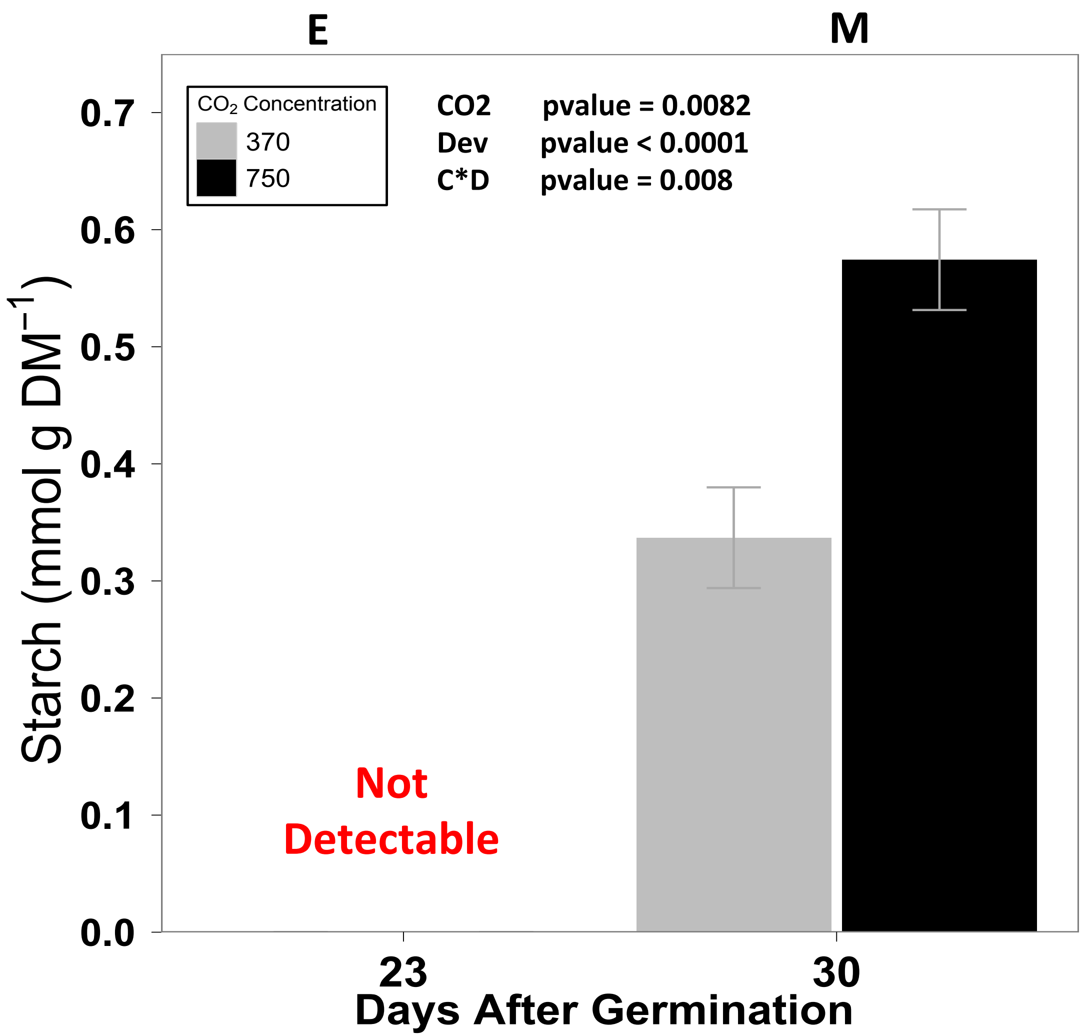


Ambient CO_2

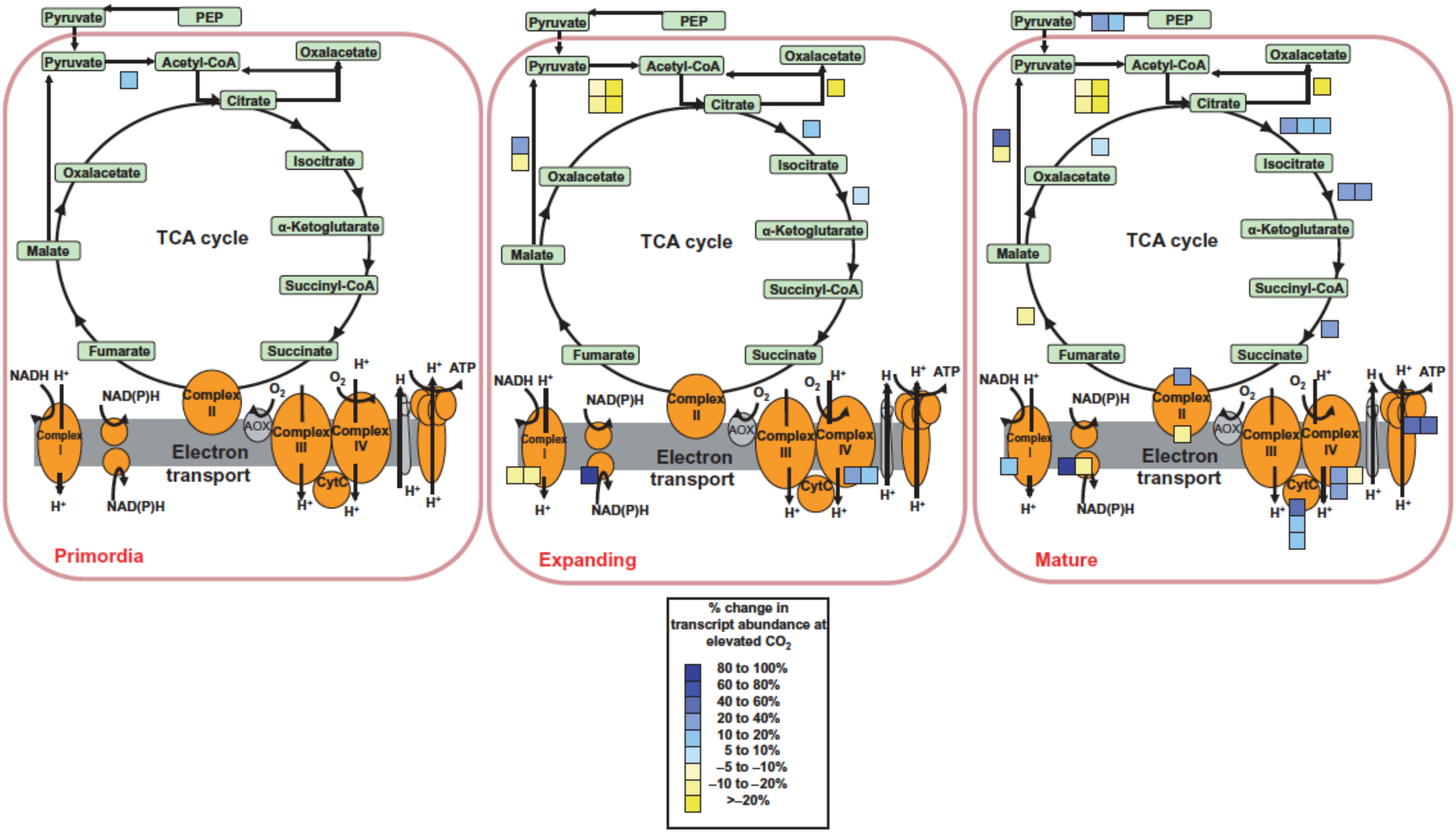
Elevated CO_2



- Leaf respiration decreases across leaf development
- No difference in respiration rates between ambient and elevated [CO_2] in rapidly expanding sink tissue
- Greater leaf respiration rates in elevated [CO_2] as leaves transition into source tissues later in leaf development



- No detectable leaf starch content during expanding time-point (23 DAG)



- **The difference in transcript abundance ambient and elevated [CO_2] increases as leaves develop**

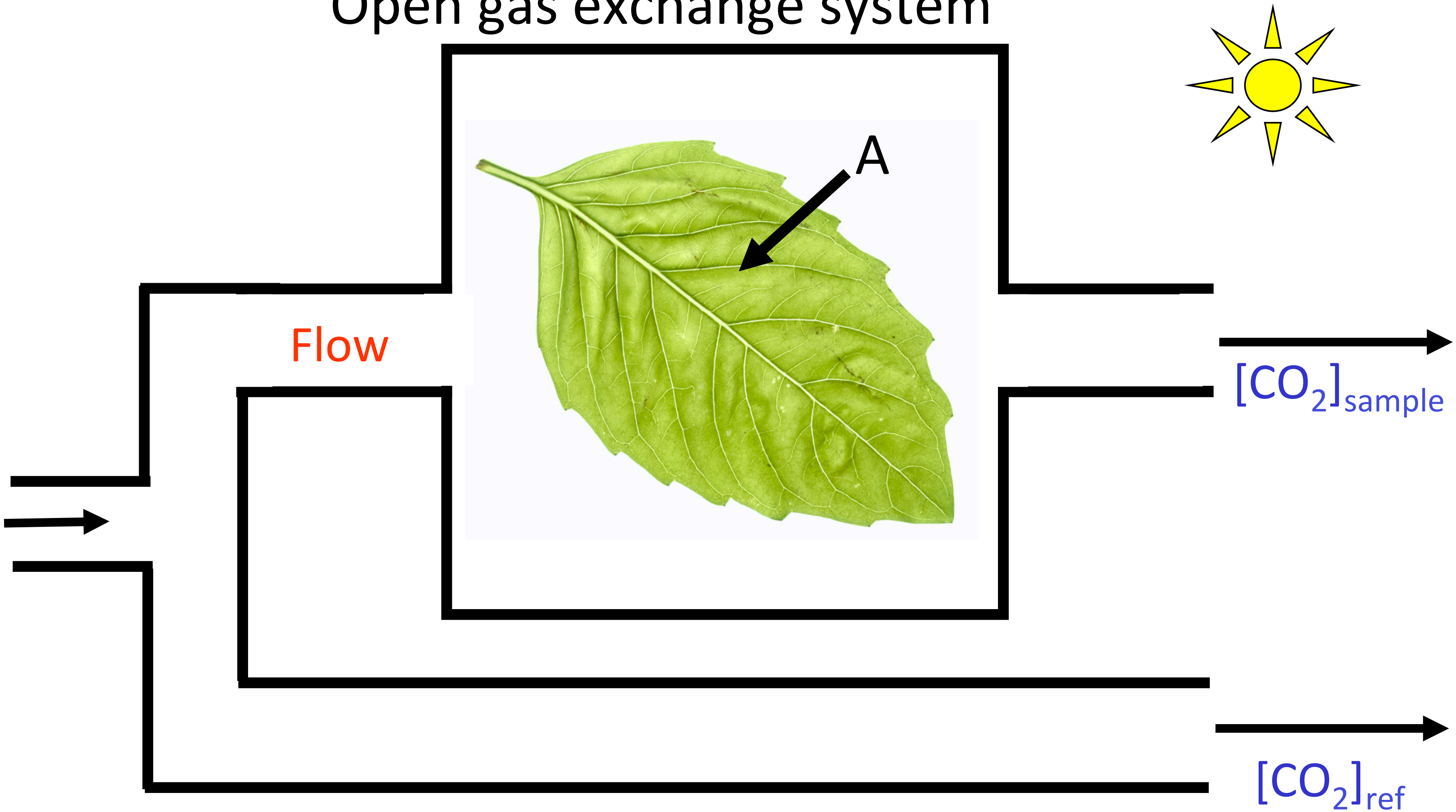
Today

- Quick Review
- C_4 photosynthetic response to climate change variables in the field
- Physiological genomics of C_3 respiration

- Gas exchange measurement theory
- Gas exchange equipment demo (LiCOR 6400)

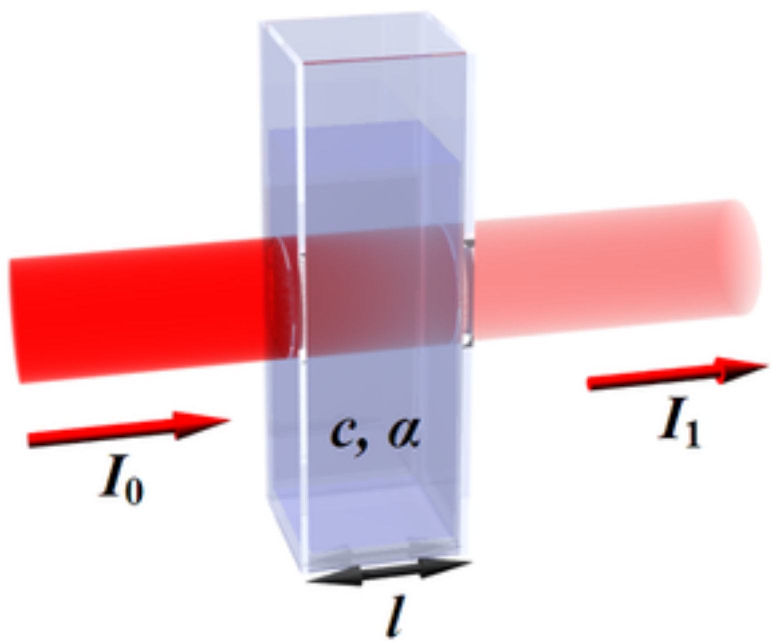
- Paper discussion
- C_3 photosynthesis model

Open gas exchange system



$$A \approx ([CO_2]_{ref} - [CO_2]_{sample}) * \text{flow rate} / \text{leaf area}$$

Beer's Law



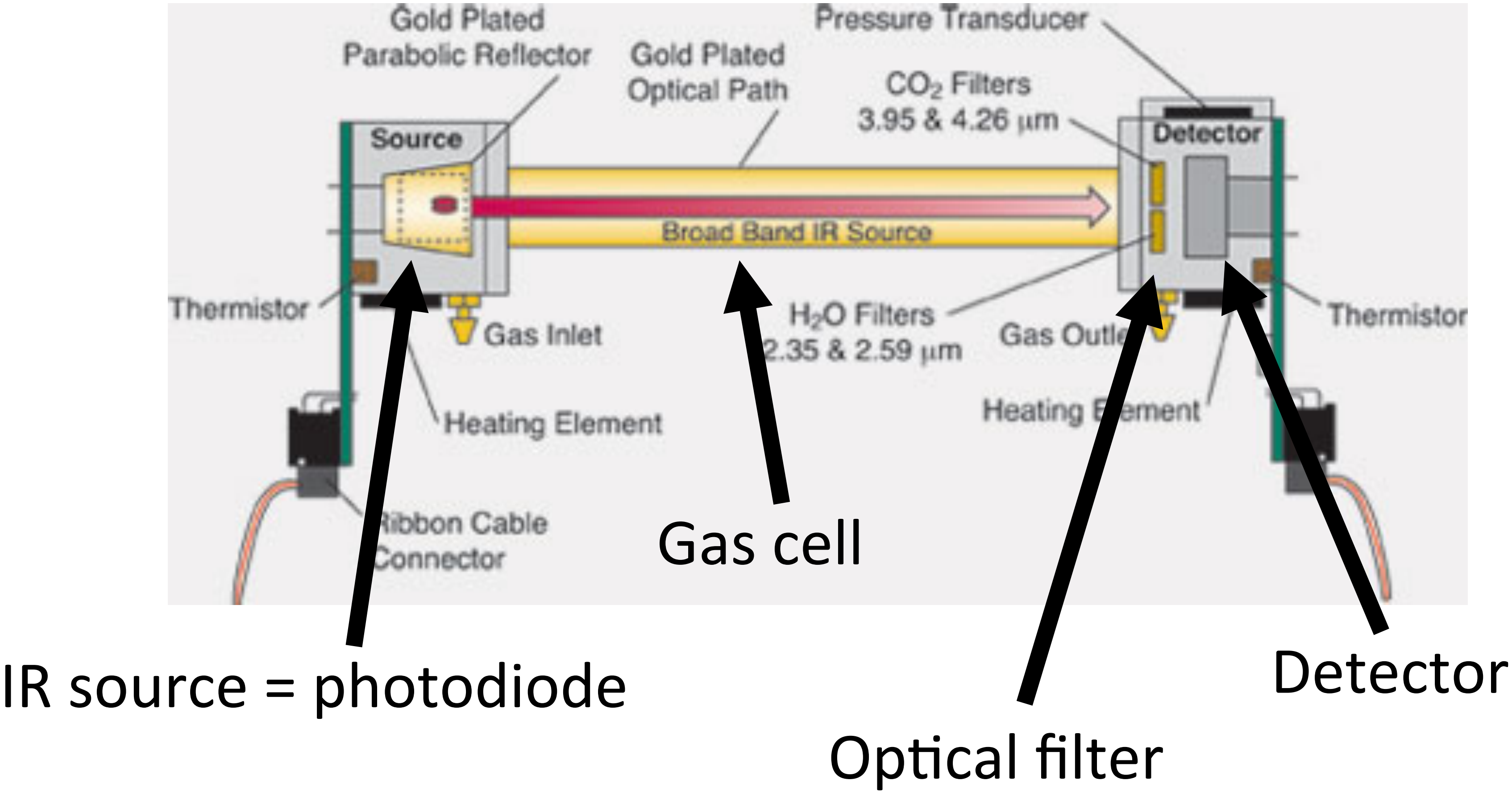
$$A = I_0 - I_1$$

I is intensity

$$A = \alpha l c$$

A is absorption
α is absorption coefficient
l is pathlength
c is concentration

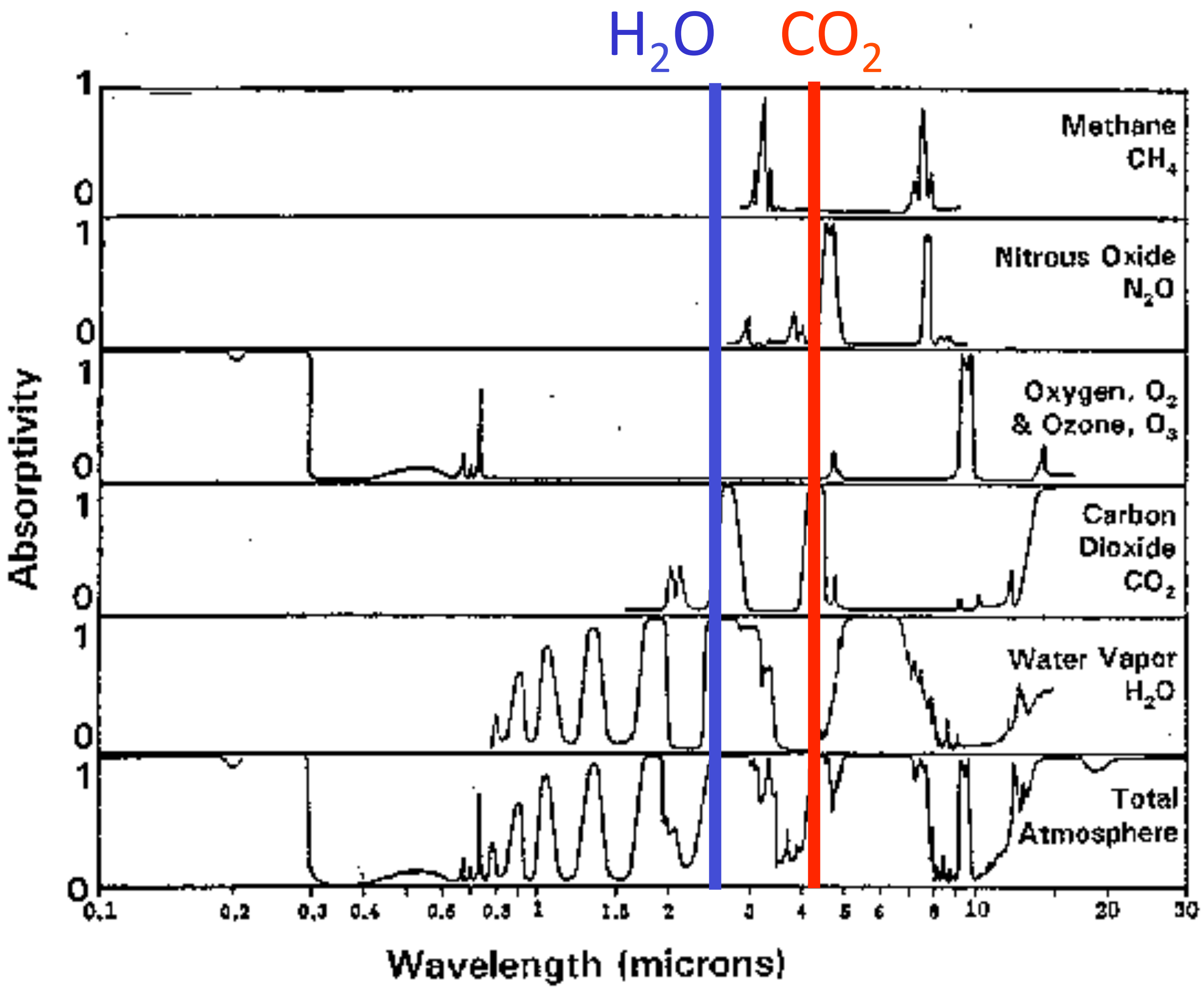
4 key components of IRGA-based gas exchange system



Detector V α source IR – IR absorbed by CO_2 or H_2O

So, ↑ concentration ↑ absorbance and signal ↓ at detector

ABSORPTION SPECTRA FOR MAJOR NATURAL GREENHOUSE GASES IN THE EARTH'S ATMOSPHERE



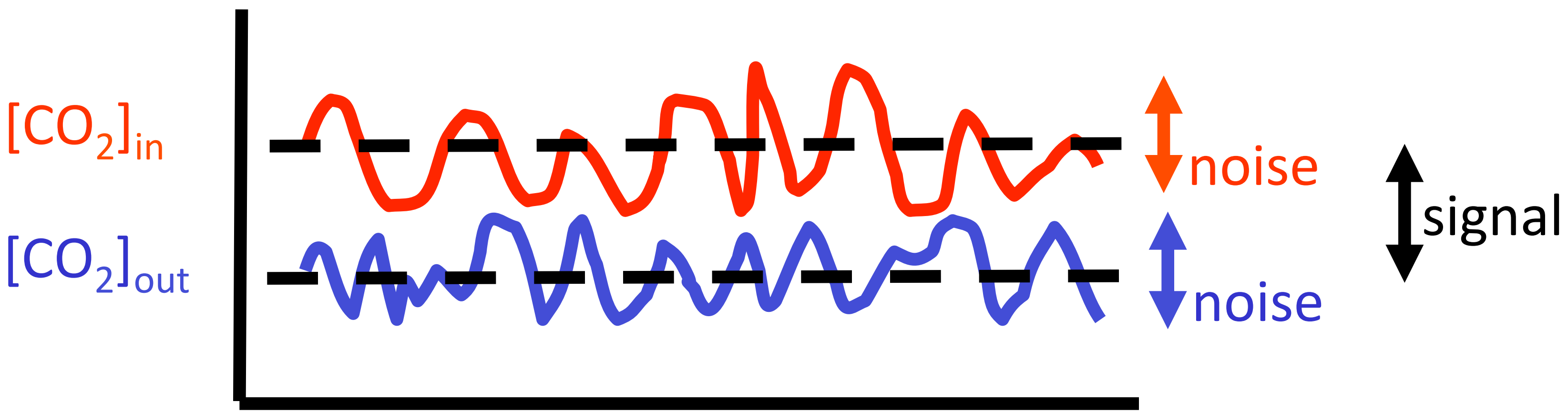
[After J. N. Howard, 1959: *Proc. I.R.E. 47*, 1459; and R. M. Goody and G. D. Robinson, 1951: *Quart. J. Roy. Meteorol. Soc. 77*, 153]

Advantages of open gas exchange system

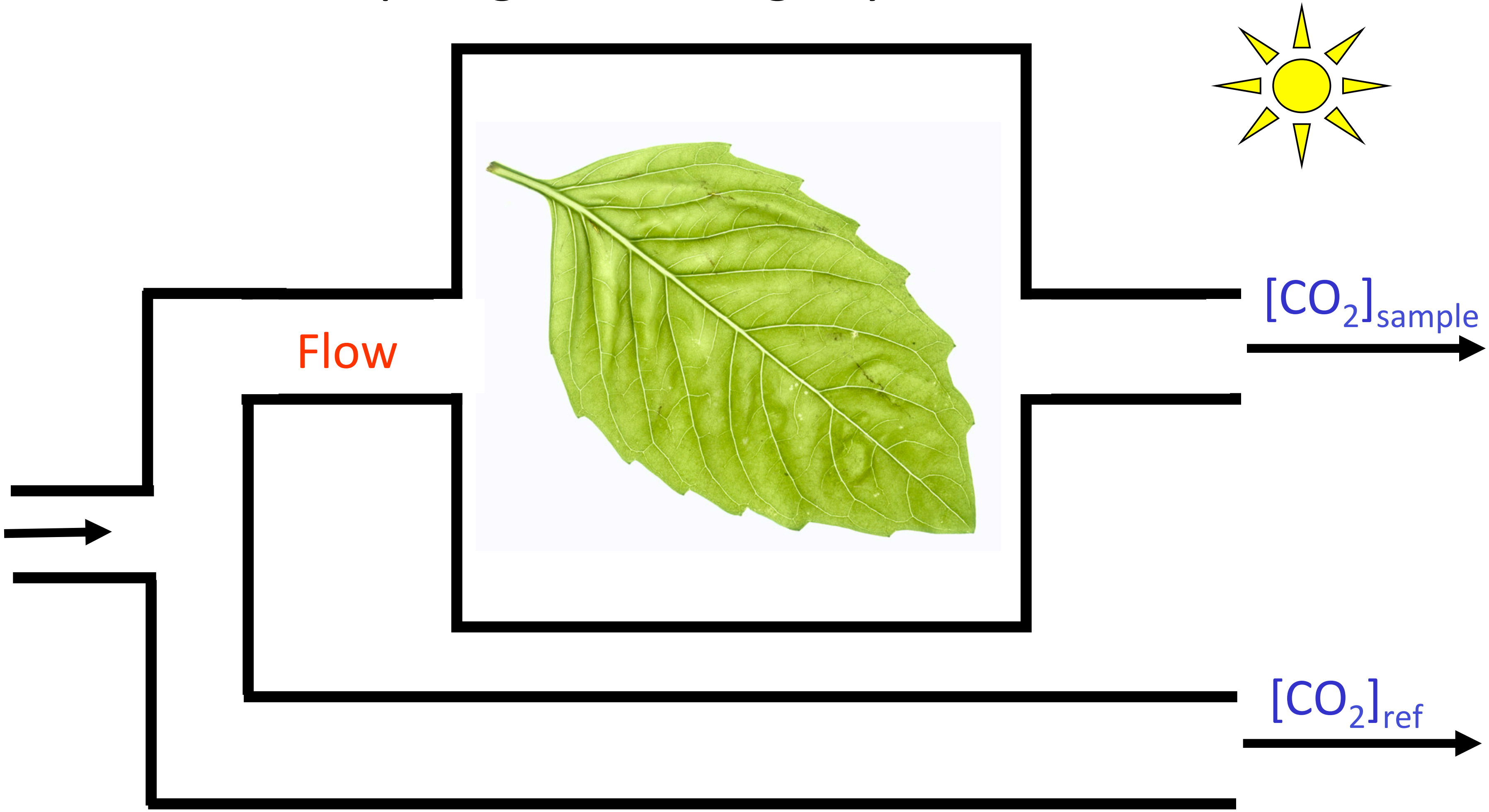
- Steady state conditions – no change in $[CO_2]$ or $[H_2O]$
- Easy to control and vary RH, temperature, c_i

Disadvantages of open gas exchange system

- Requires appropriate leaf area/rate to be sampled to get sufficient signal to noise ratio

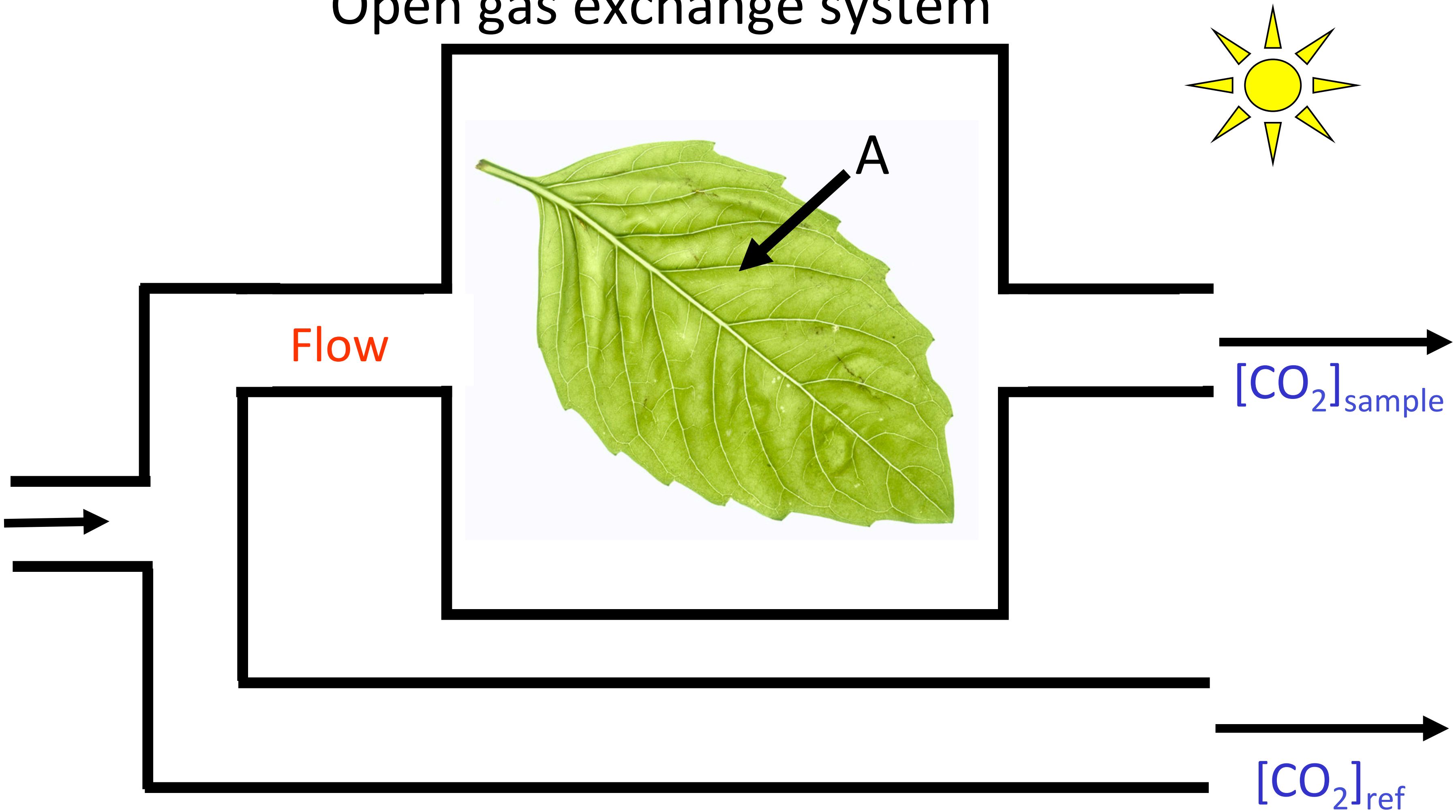


Open gas exchange system



Steady state conditions allow easy measurement of response curves (A/c_i, light, vpd) and dynamic photosynthesis in response to sunflecks, O_2 pulses…

Open gas exchange system



$$A \approx ([CO_2]_{ref} - [CO_2]_{sample}) * \text{flow rate} / \text{leaf area}$$

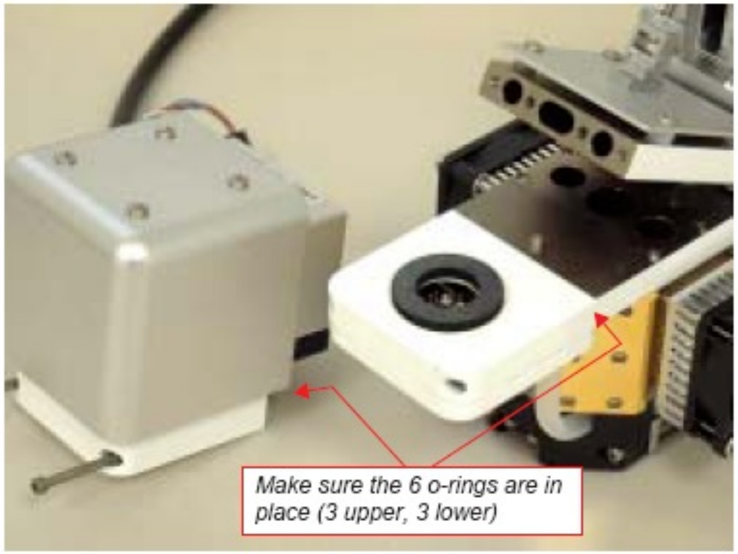


Figure 27-7. The LCF lower chamber attached, and the upper chamber ready.

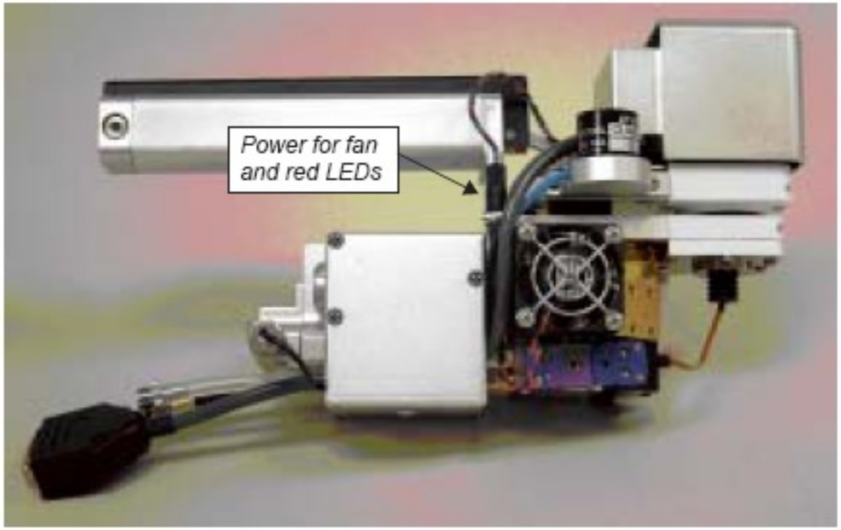


Figure 27-8. The LCF attached to the sensor head. The main cable can be routed behind the quantum sensor, and through the tripod mount (remove to do this).