Gross primary production is stimulated for *Populus* species grown under free-air CO_2 enrichment

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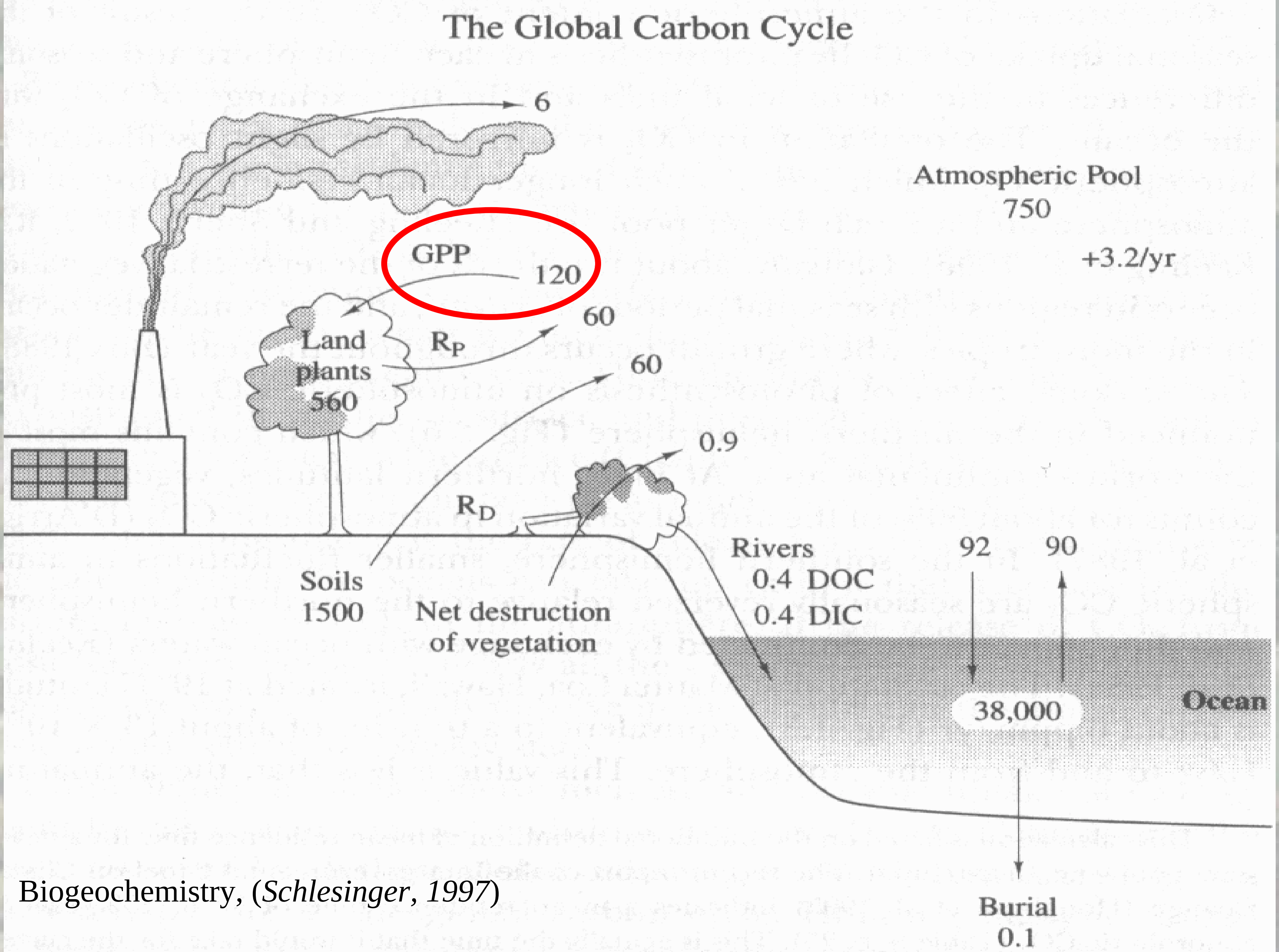
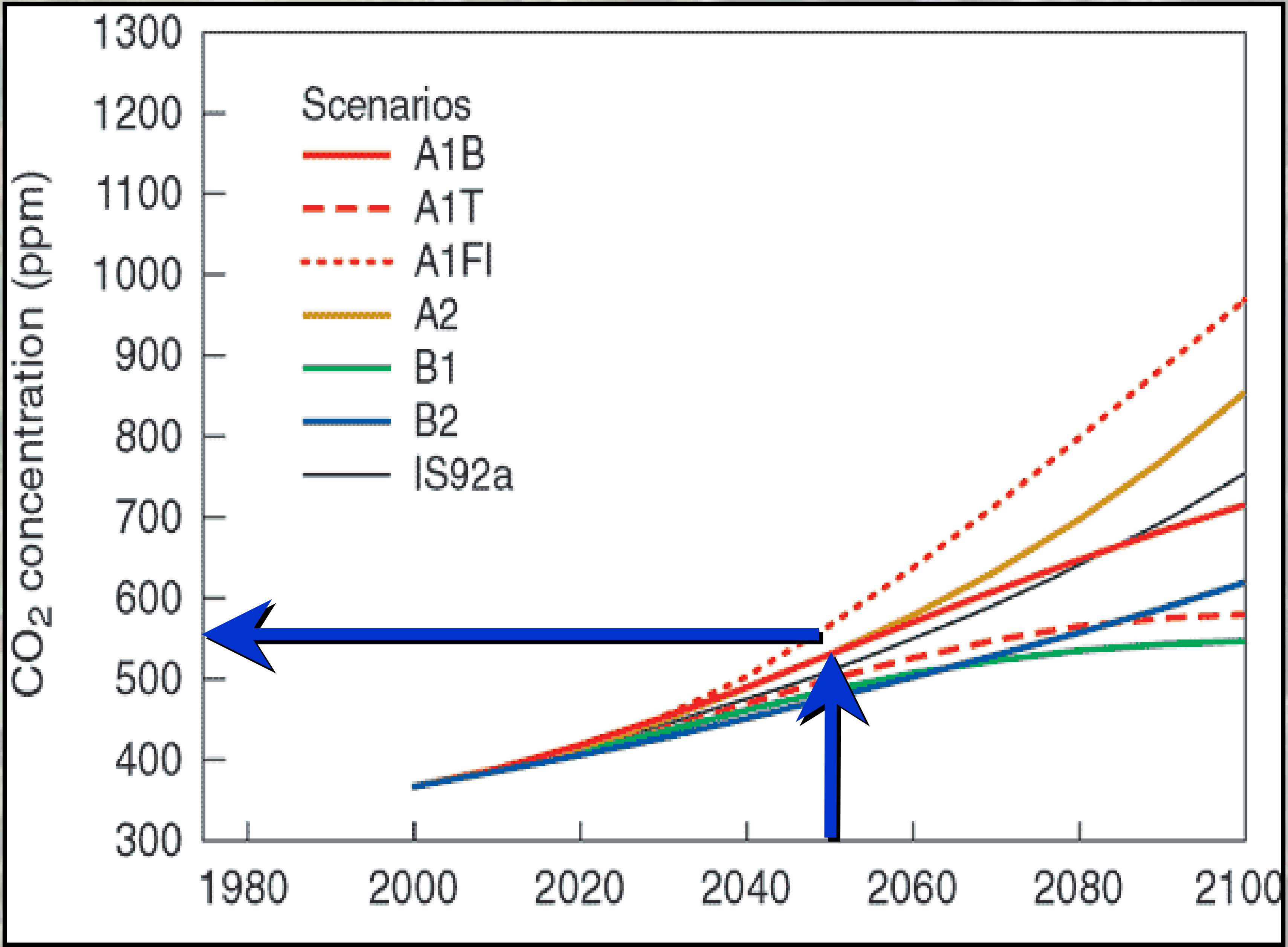


Biogeochemistry, (*Schlesinger, 1997*)

Gross Primary Production

- GPP = gross photosynthetic carbon assimilation
- Driving step of the global carbon cycle
- Forest trees account for large proportion of terrestrial GPP



Intergovernmental Panel on Climate Change *(Houghton, 2001)*

How will GPP of trees be changed in an elevated CO_2 world?

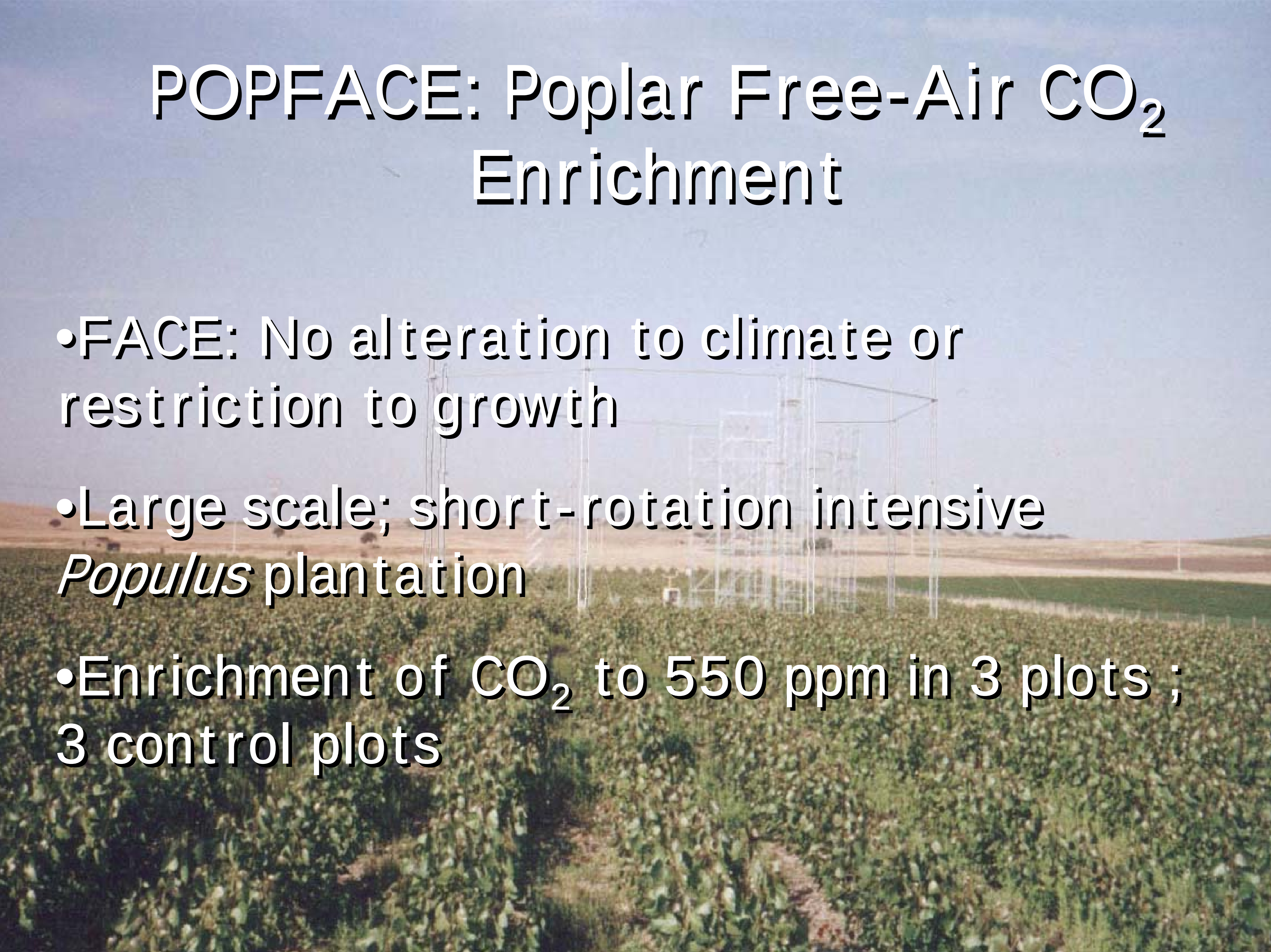
Two Problems

1. Growing trees in an elevated CO_2 atmosphere: OTC's

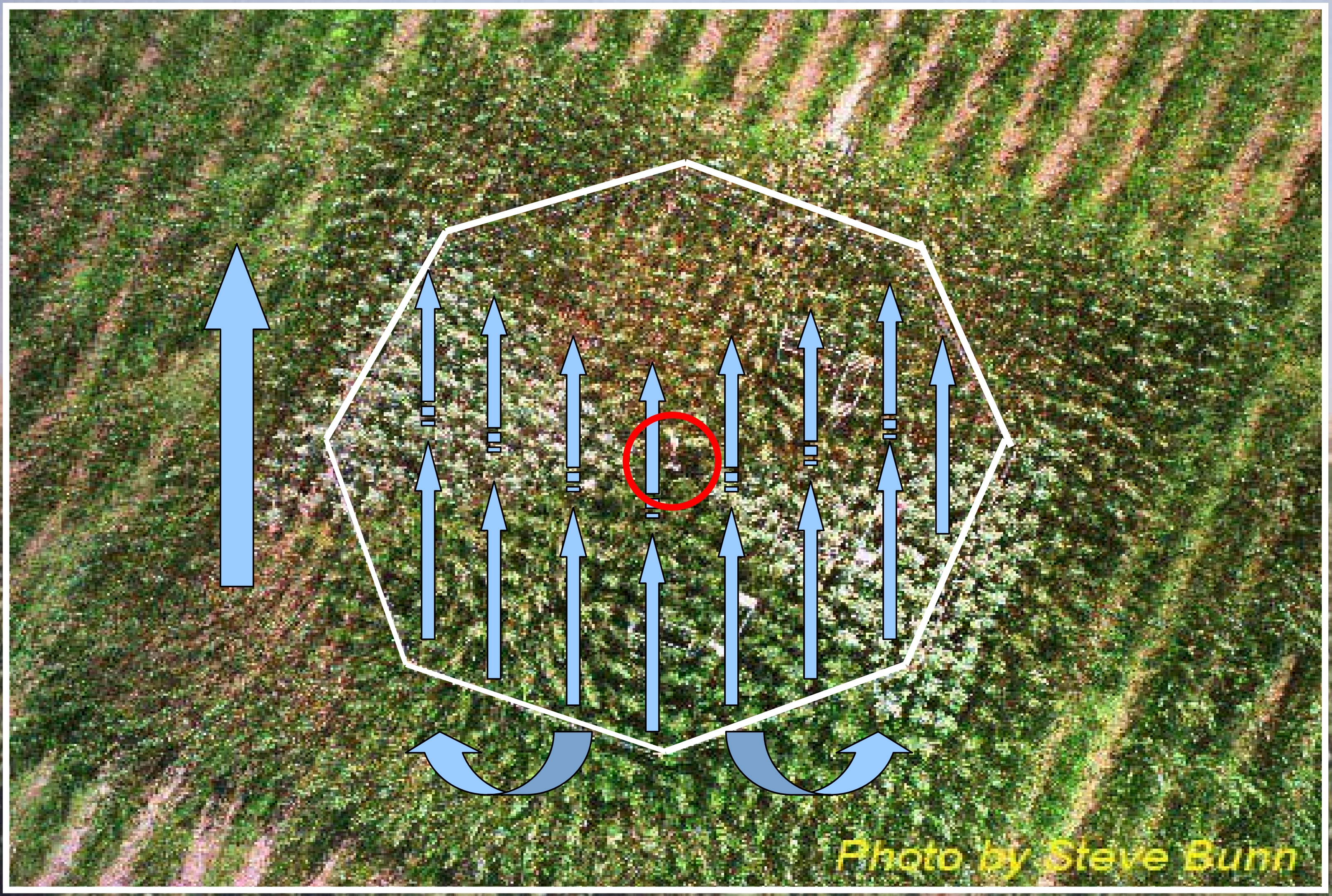
2. Measuring GPP of CO_2 enriched trees: Closed Chambers

POPFACE: Poplar Free-Air CO_2 Enrichment

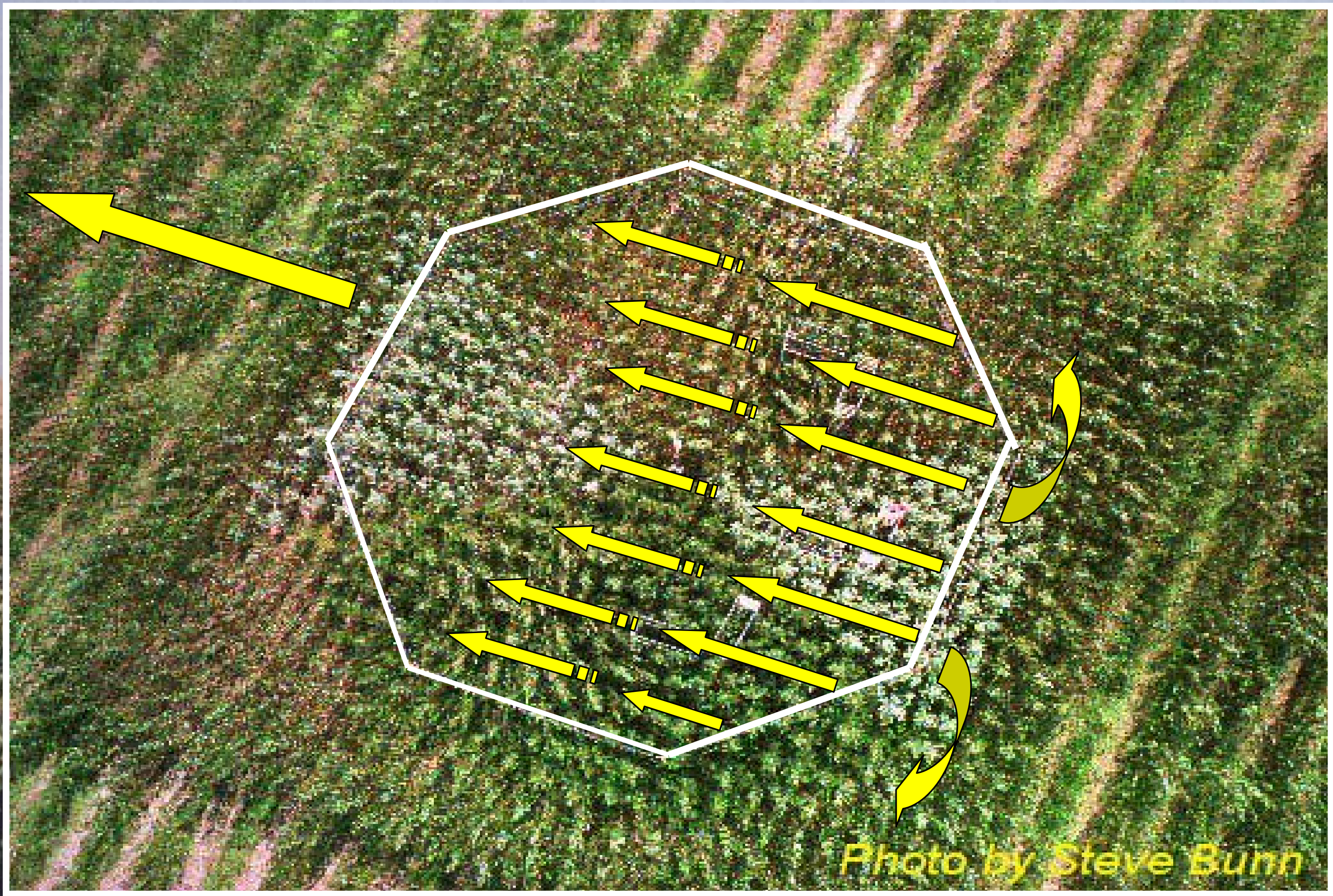
- FACE: No alteration to climate or restriction to growth
- Large scale; short-rotation intensive *Populus* plantation
- Enrichment of CO_2 to 550 ppm in 3 plots ; 3 control plots



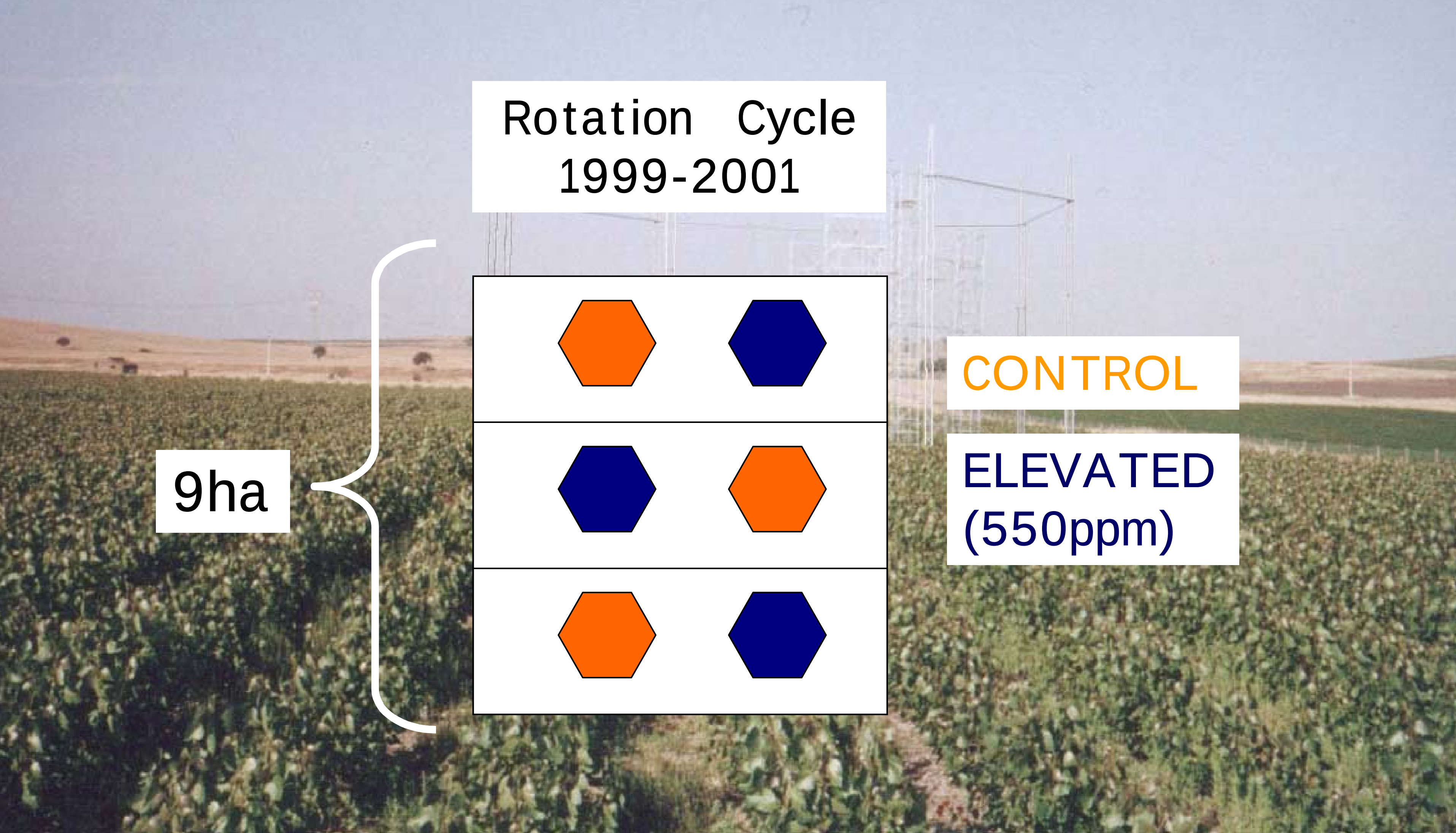
FACE Technology

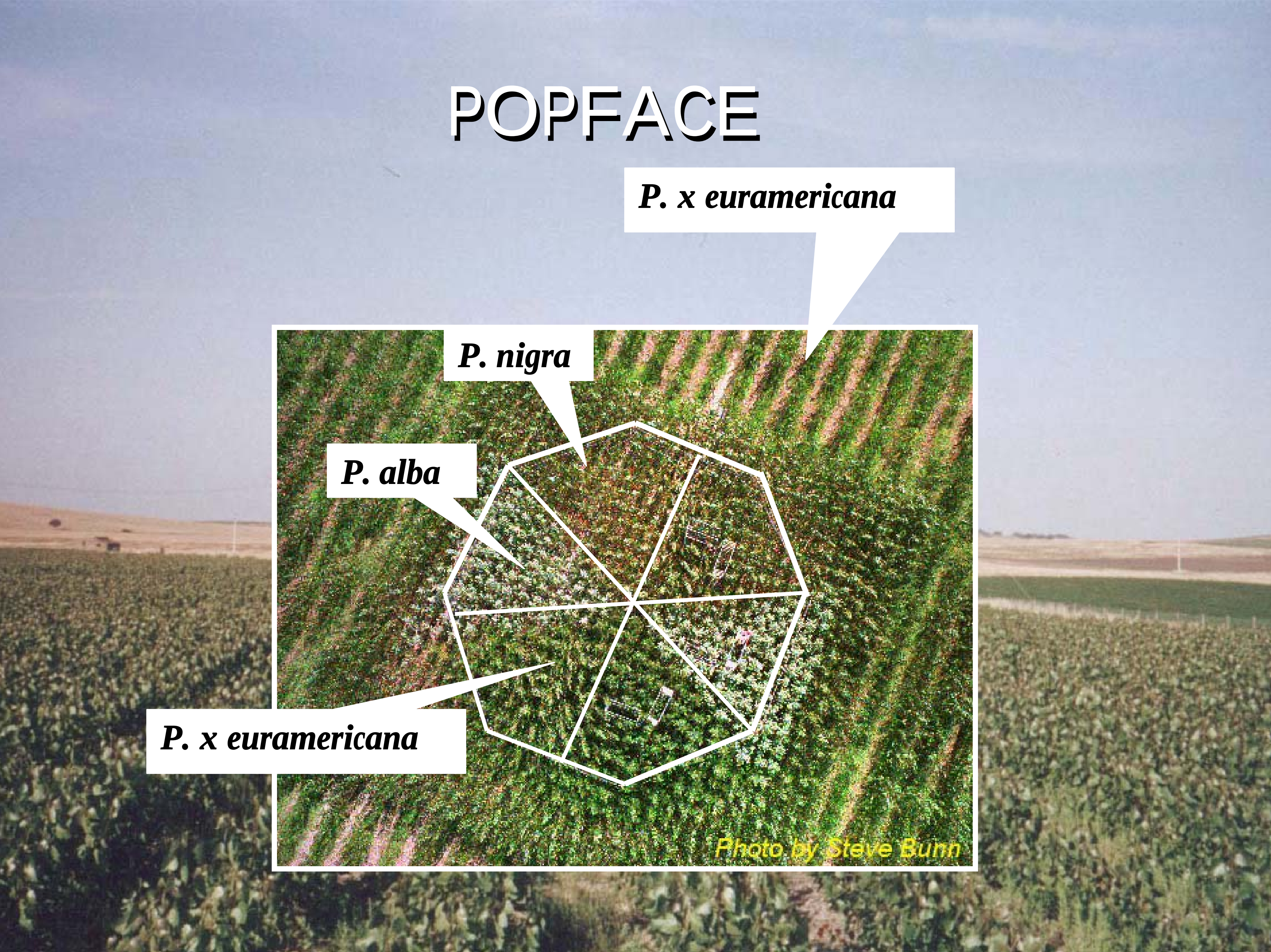


FACE Technology



POPFACE: Poplar Free-Air CO_2 Enrichment




POPFACE
P. x euramericana
P. nigra
P. alba
P. x euramericana
Photo by Steve Bunn

Measurements

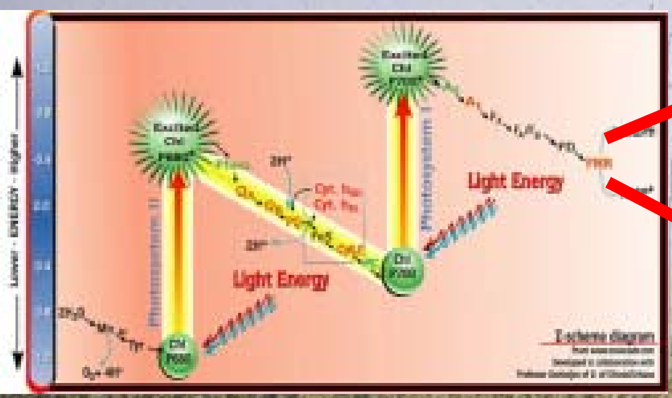
- Photosynthetic Photon Flux Density (PPFD)-30 min
- Temperature –30 min
- Leaf Area Index (LAI)-

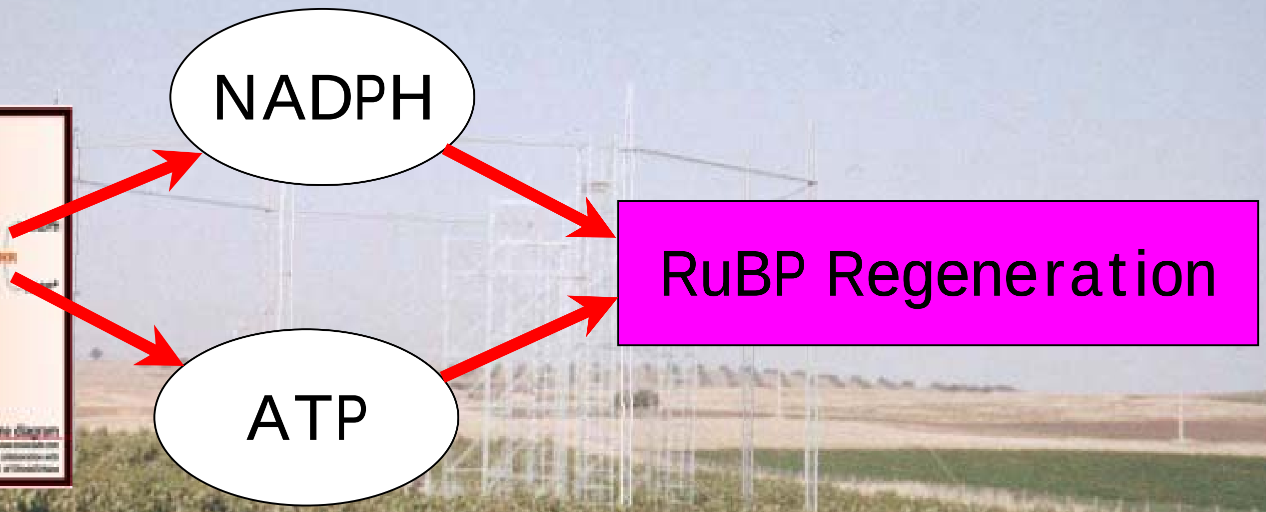
biweekly

Measurements

- Gas exchange measurements
- Maximum rate of electron transport: J_{max}
- Maximum rate of carboxylation: $V_{c,max}$

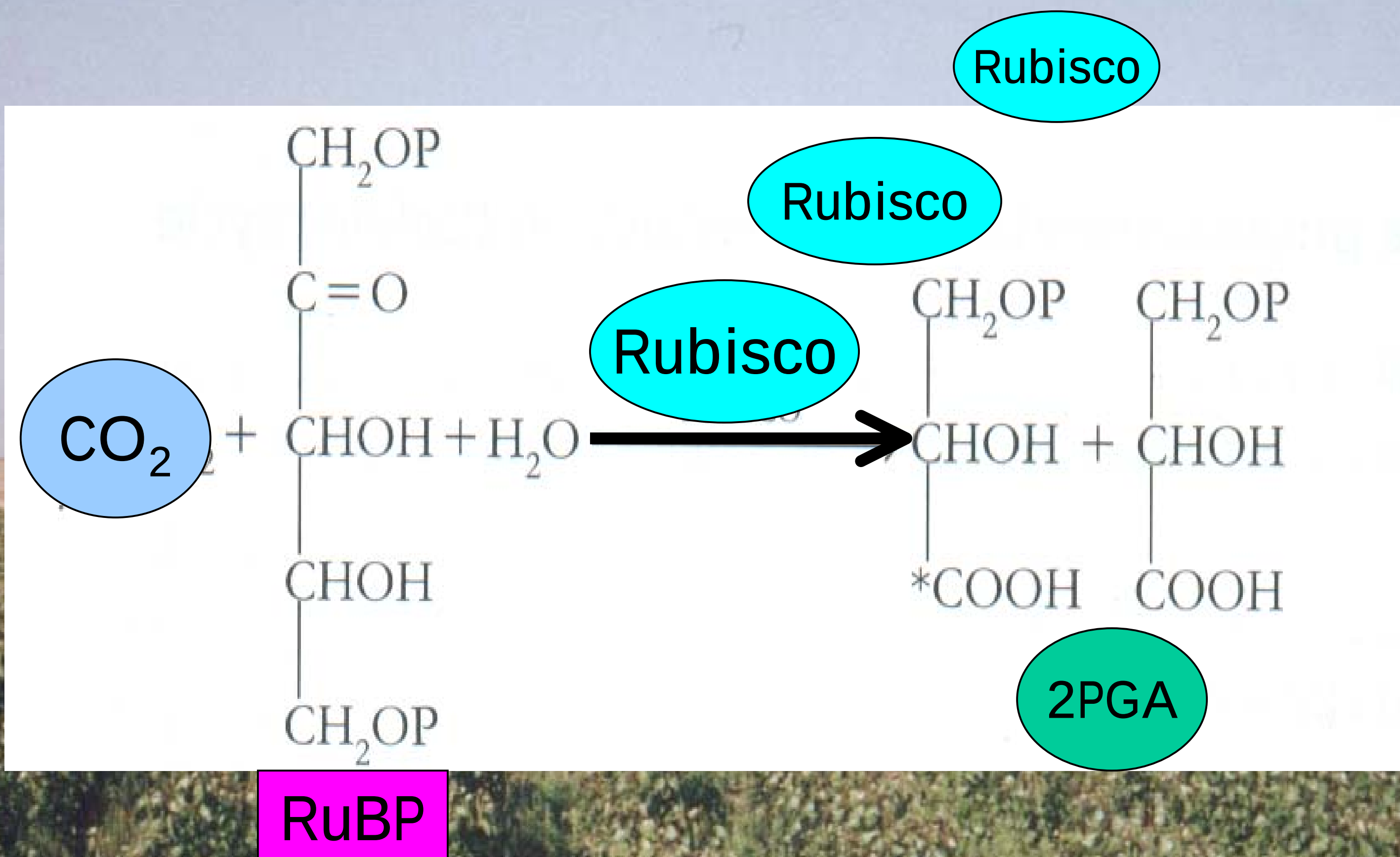
Maximum rate of electron transport: J_{max}





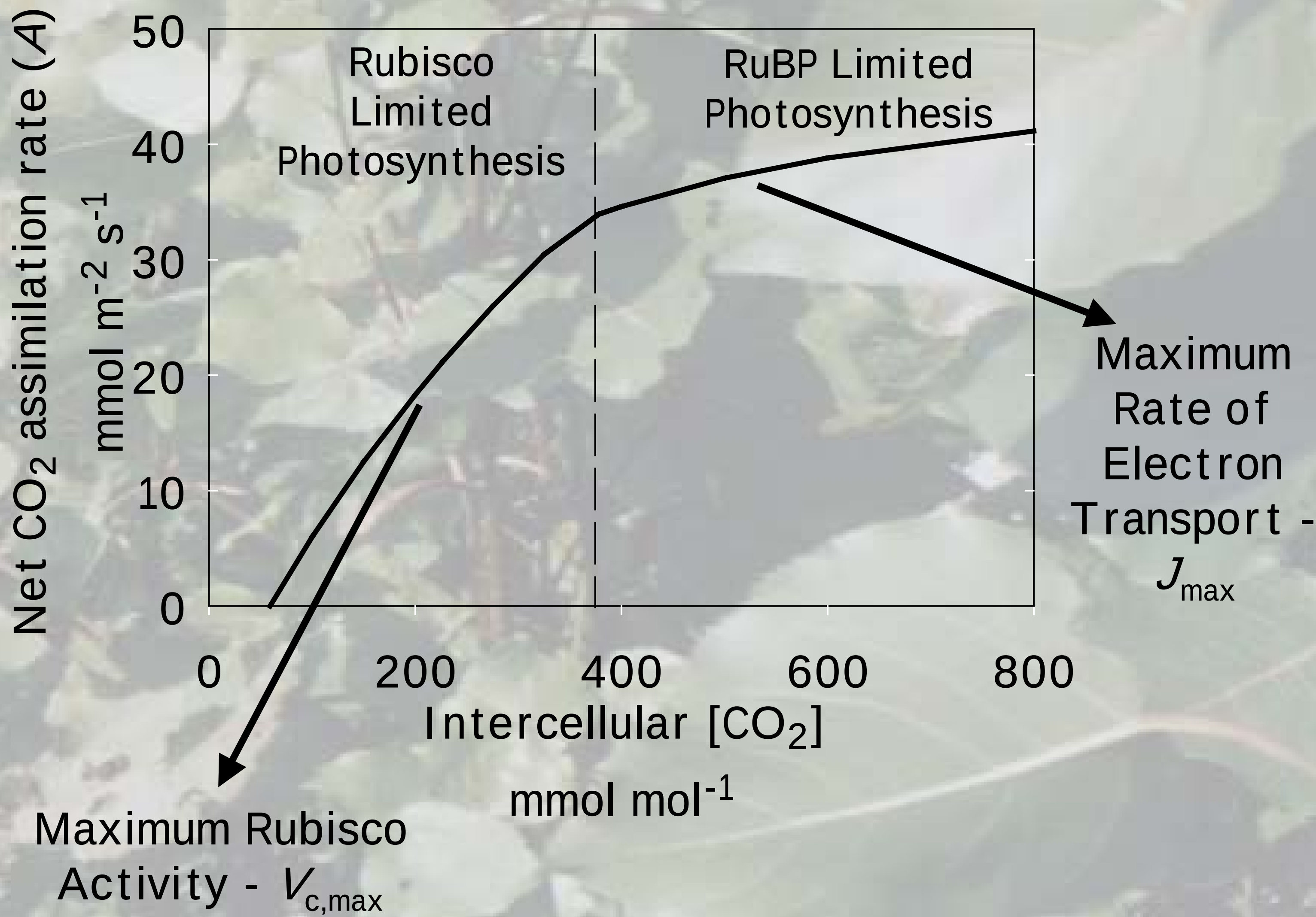
RuBP-Limited Photosynthesis

Maximum rate of carboxylation: $V_{c,max}$

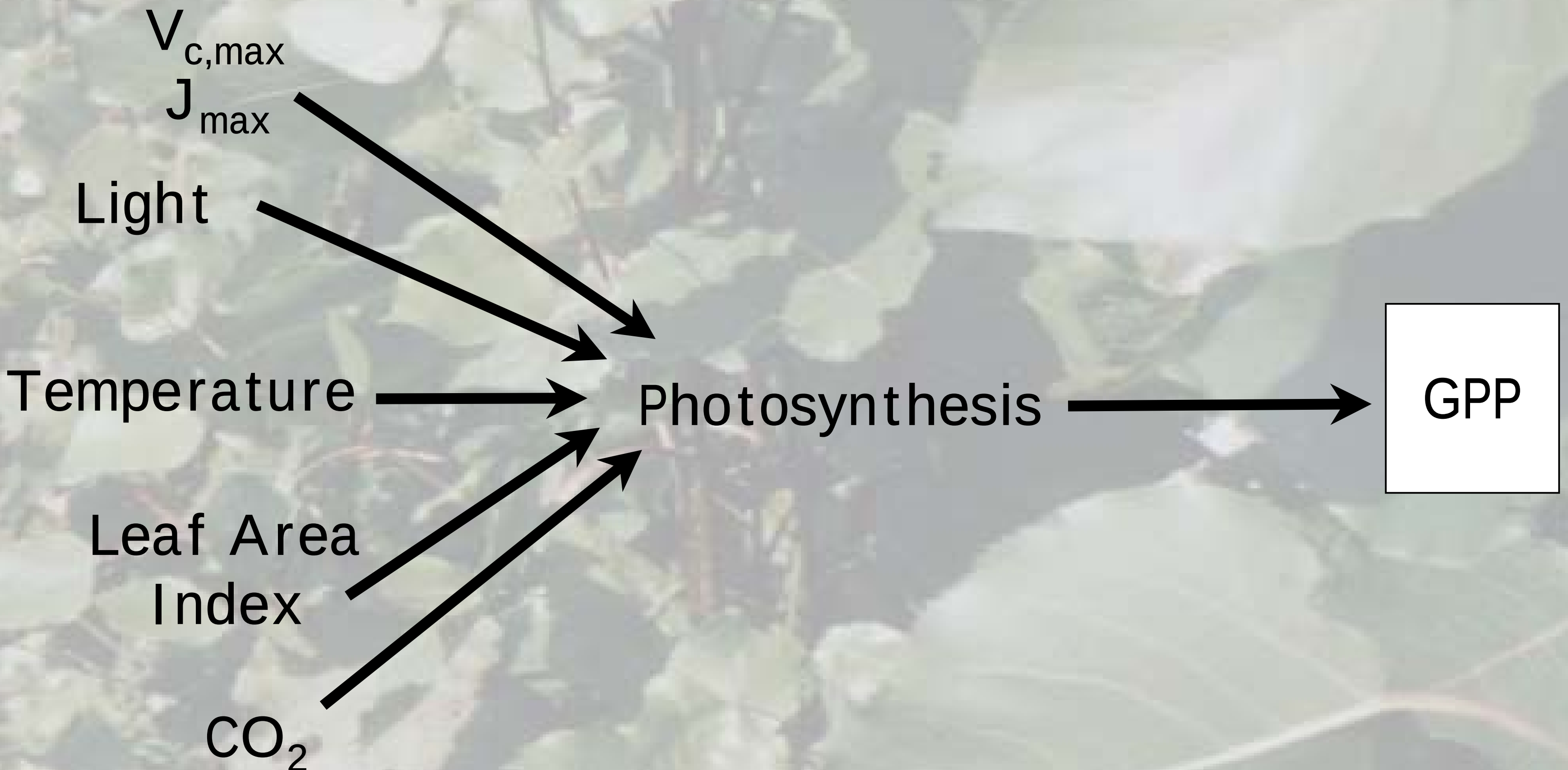


Rubisco-Limited Photosynthesis

A/c_i Response Curve



From Measurements to a Model of GPP



Utilize Independent Data to Model GPP

1. Data
2. Leaf Photosynthesis
3. GPP

Utilize Independent Data to Model GPP

1. Data
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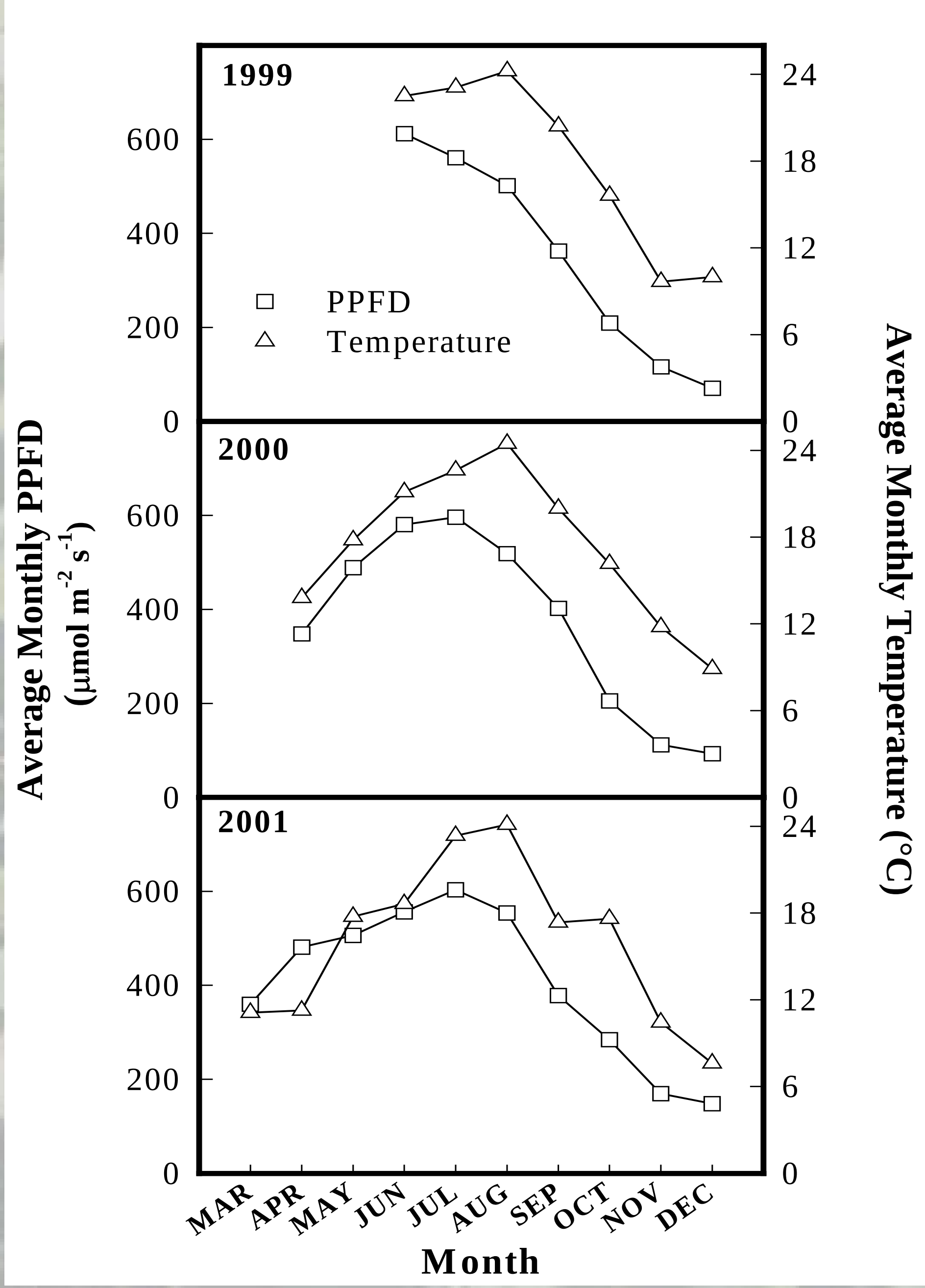
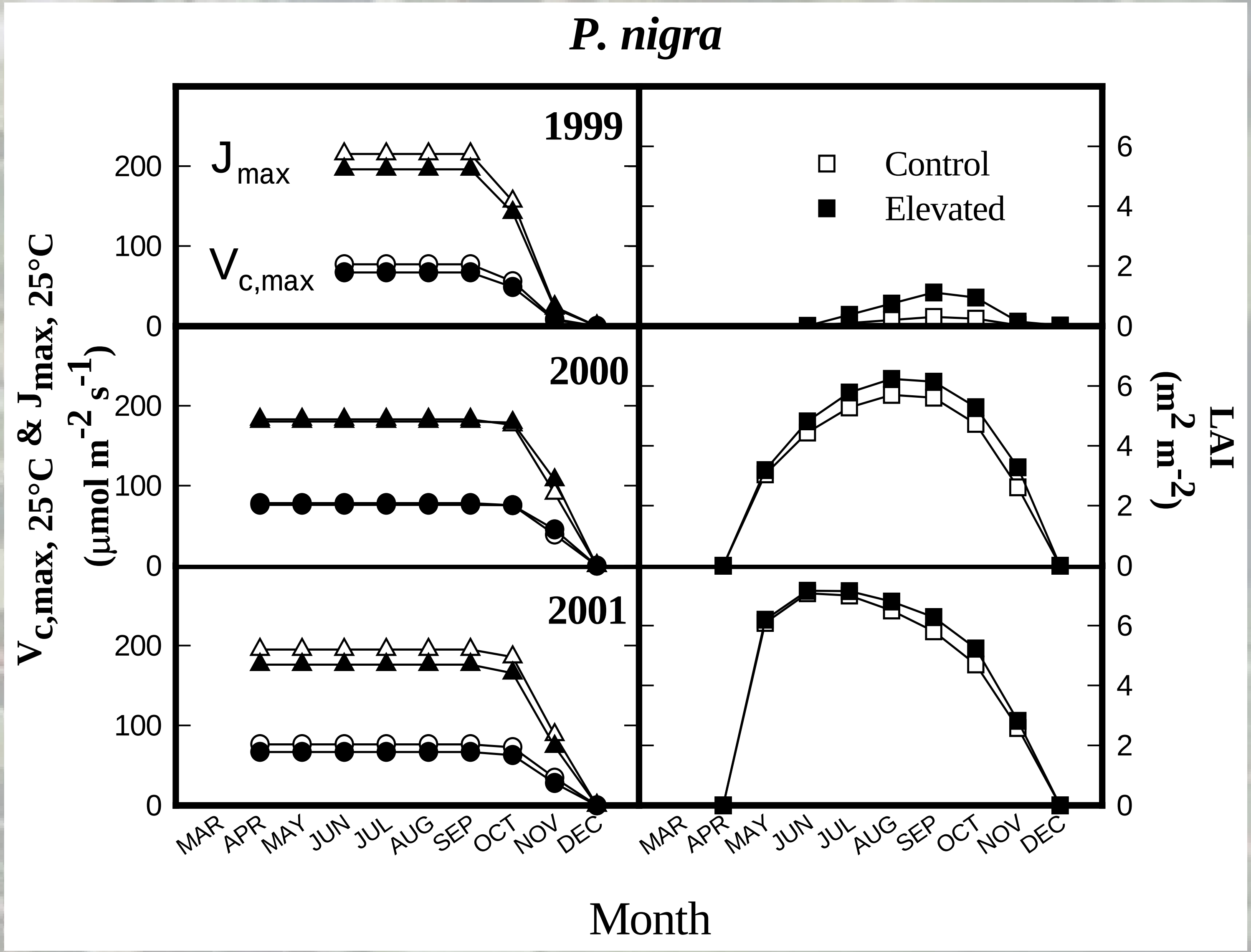

1999
2000
2001
PPFD
Temperature
Average Monthly PPFD
(μmol m-2 s-1)
Average Monthly Temperature (°C)
0
200
400
600
0
6
12
18
24
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month



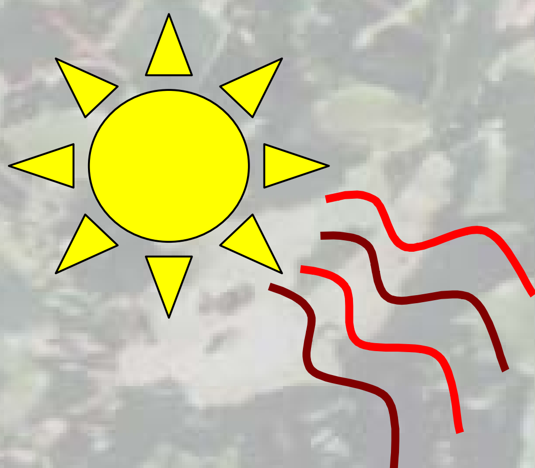
P. nigra
1999
2000
2001
Jmax
Vc,max
Control
Elevated
Vc,max, 25°C & Jmax, 25°C (μmol m-2 s-1)
LAI (m2 m-2)
0
100
200
2
4
6
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month

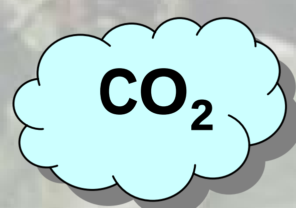
Utilize Independent Data to Model GPP

1. Data
2. Leaf Photosynthesis
3. GPP

Farquhar Model of Leaf Photosynthesis (A_{leaf})

$$A_{leaf} = f\,(PPFD,\ T,\ CO_2,\ J_{MAX},\ V_{C,\,MAX})$$





Leaf Photosynthesis (A_{leaf})

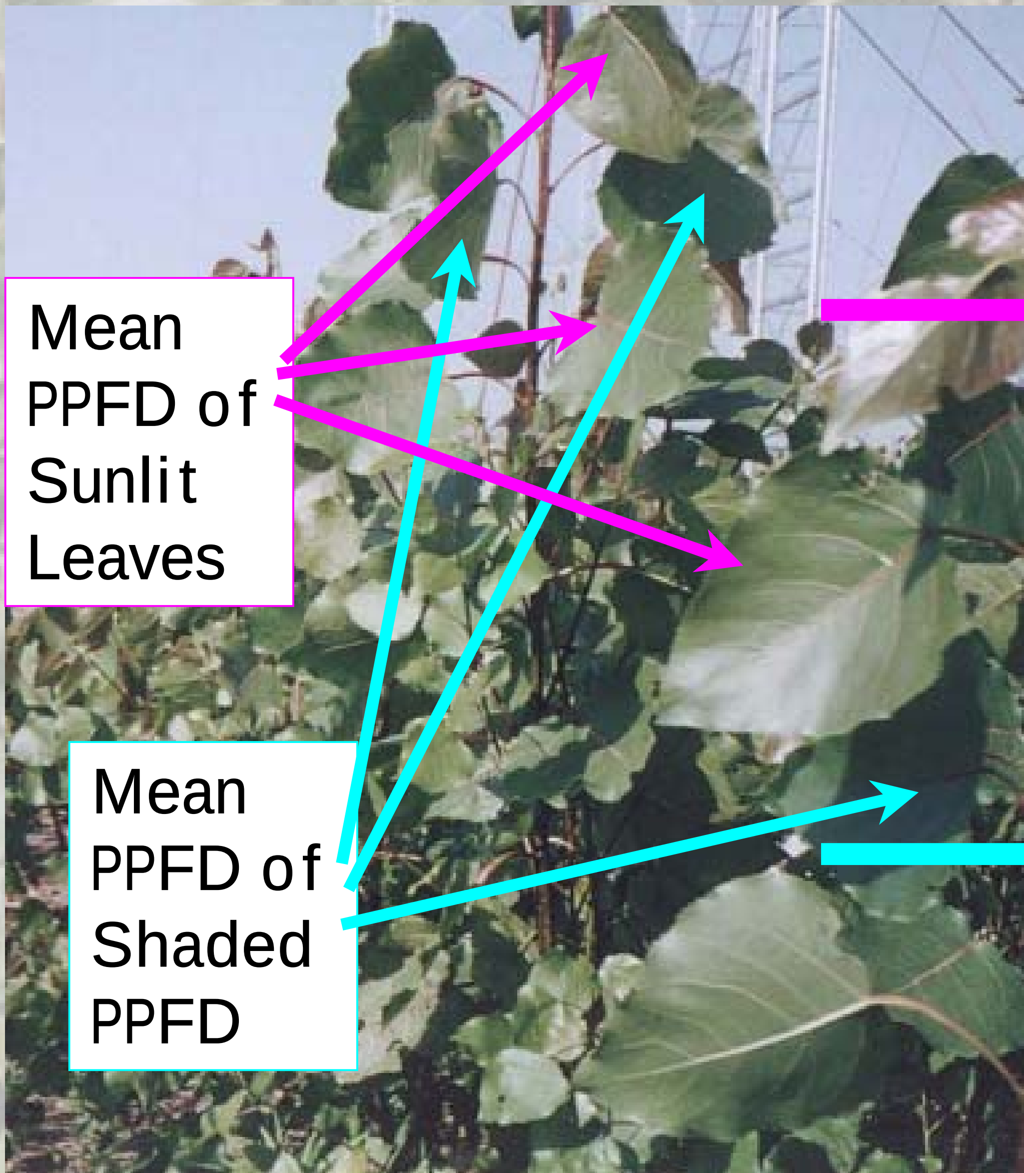
$$A_{leaf} = [1 - \frac{\Gamma *}{C_i}] \cdot \min\{W_c, W_j\}$$

W_c= Rubisco-Limited photosynthesis

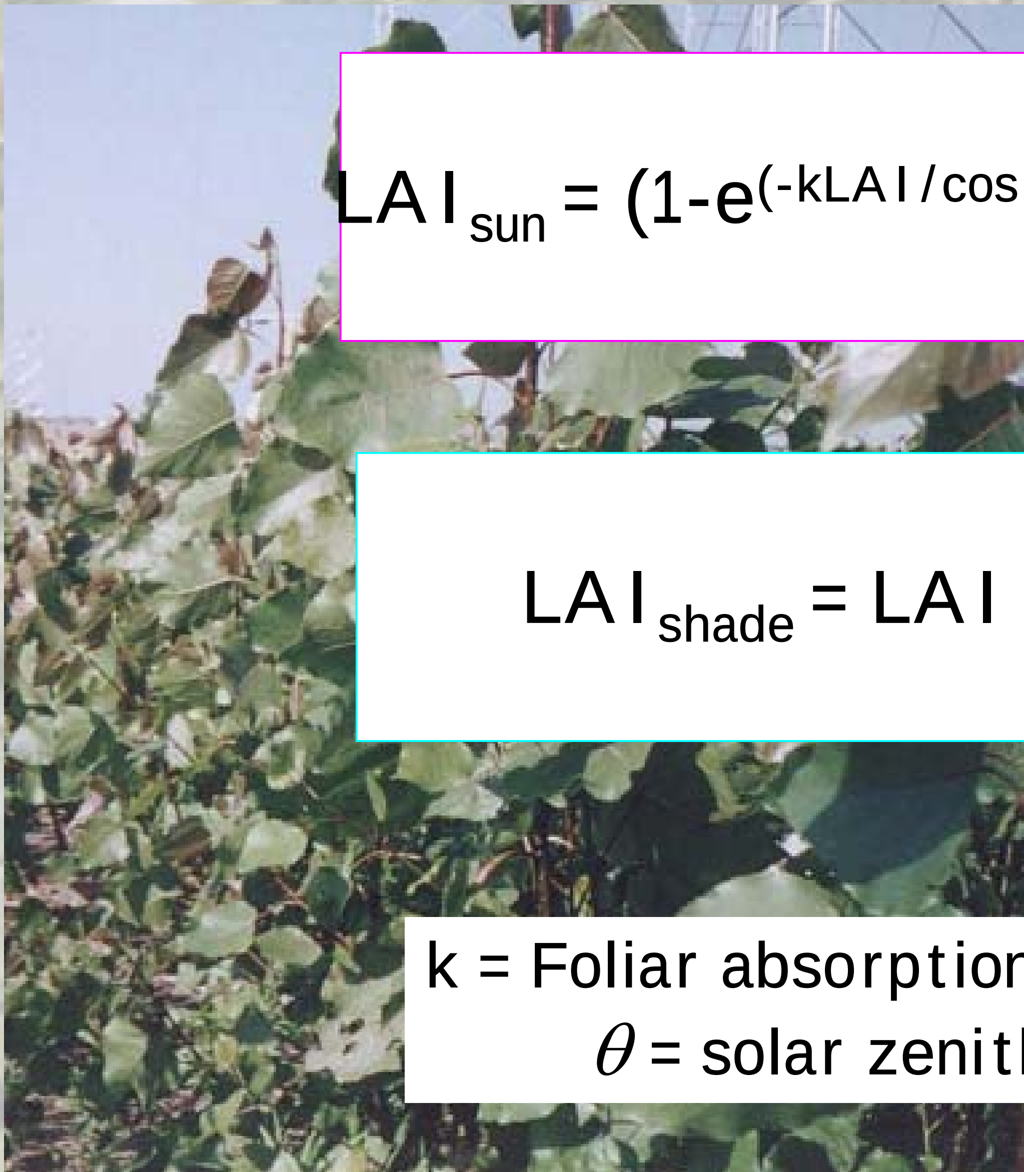
W_j= RuBP-Limited photosynthesis

Utilize Independent Data to Model GPP

1. Data
2. Leaf Photosynthesis
3. GPP



Forseth & Norman, 1993; Long 1991



$$LAI_{sun} = (1-e^{(-kLAI/\cos\theta)}) * \cos\theta / k$$

$$LAI_{shade} = LAI - LAI_{sun}$$

k = Foliar absorption coefficient

θ = solar zenith angle

Forseth & Norman, 1993; Long 1991

GPP

$$GPP = A_{sun} * LAI_{sun} + A_{shade} * LAI_{shade}$$

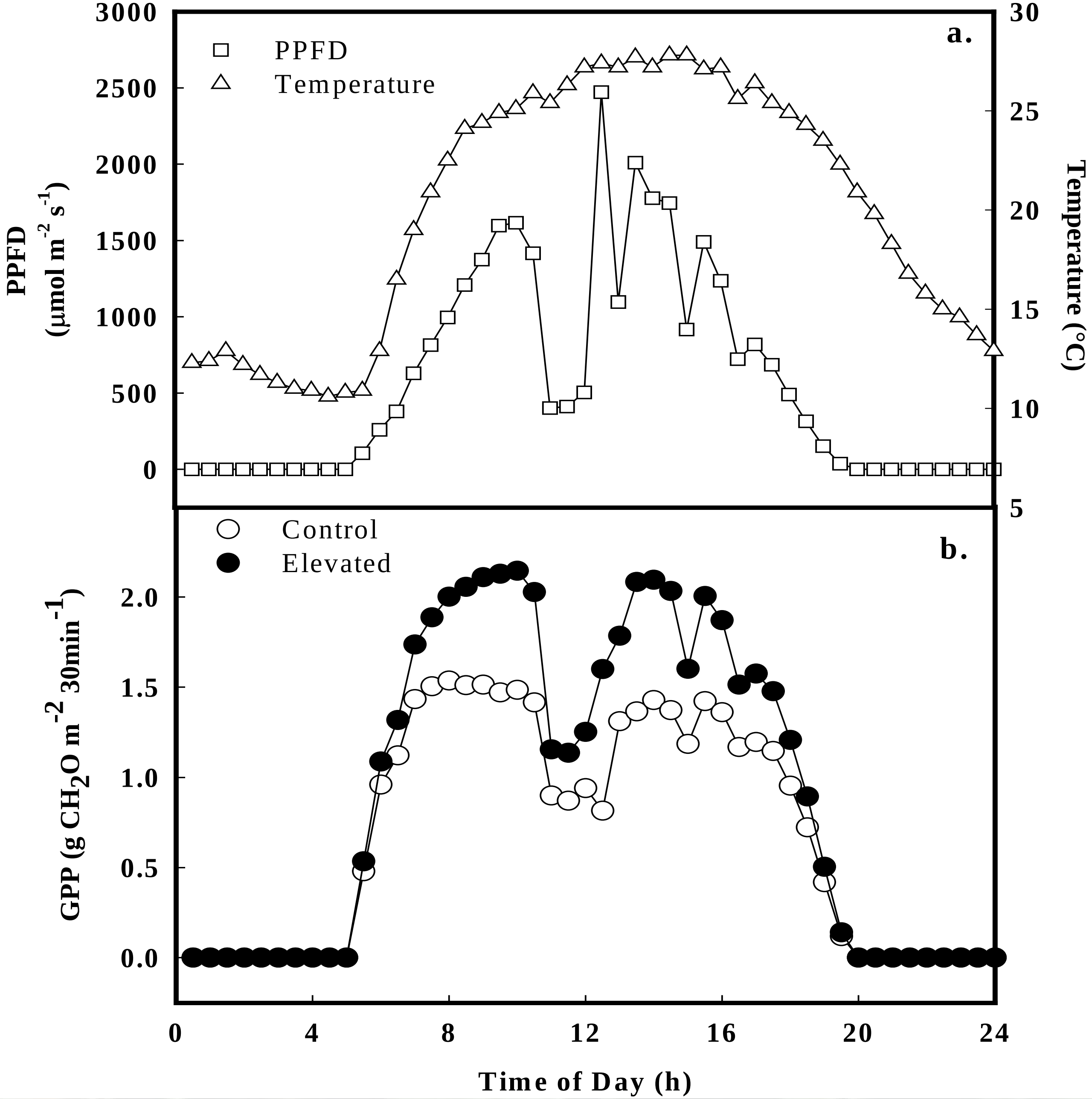
Hypotheses

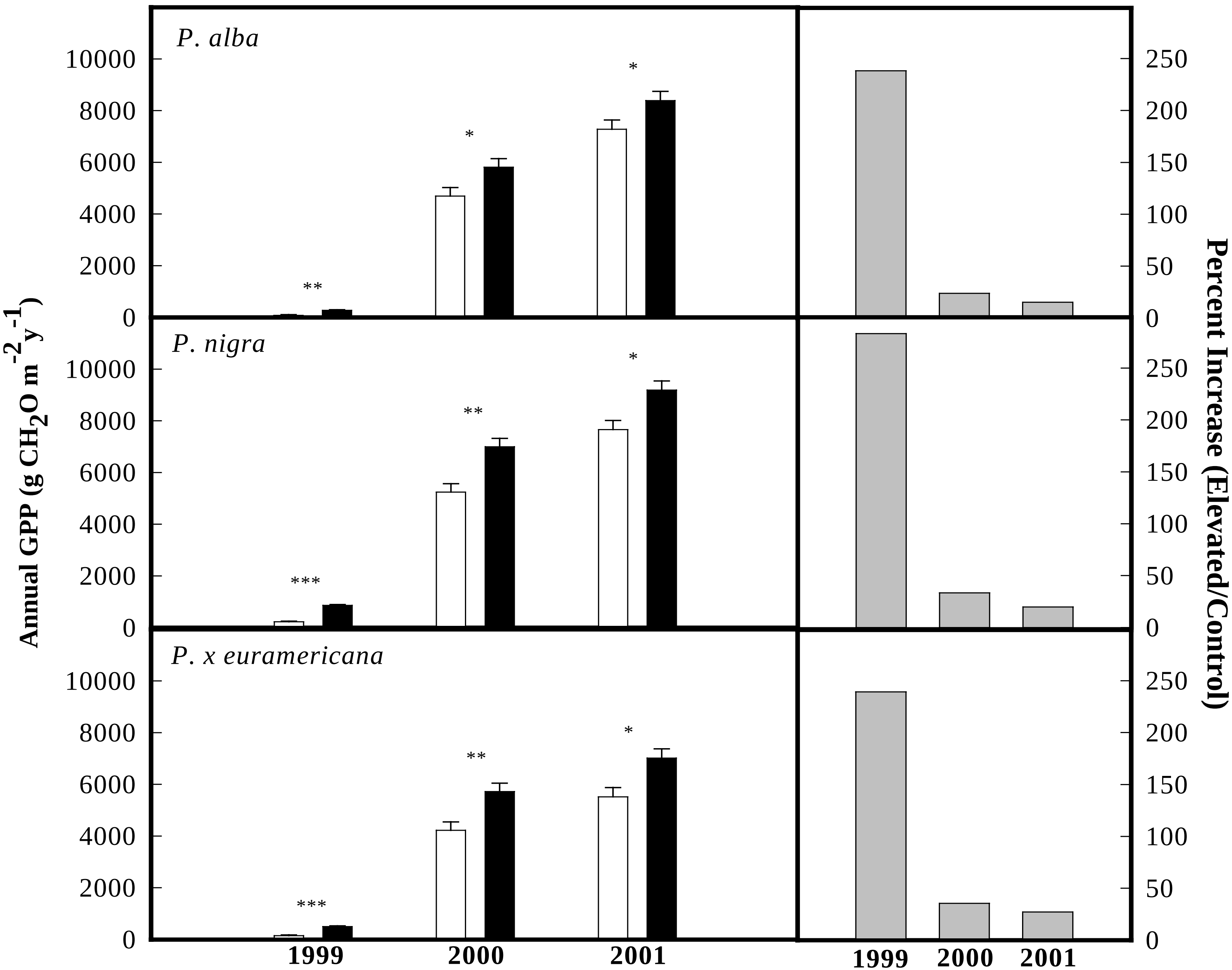
1. Elevated CO_2 will stimulate Gross Primary Production (GPP)

2. Sustained stimulation of GPP throughout rotation cycle (1999-2001)


Results?

P. nigra
July, 2000




P. alba
P. nigra
P. x euramericana
Annual GPP (g CH_2O m^{-2} y^{-1})
Percent Increase (Elevated/Control)
10000
8000
6000
4000
2000
0
250
200
150
100
50
*
**
***
1999
2000
2001

Percent Stimulation Decreased

- Absolute GPP higher in elevated plots all years
- Relative stimulation decreased with canopy closure.


03 09 2002

GPP Validation: Net Primary Production (NPP)

- NPP = GPP - Autotrophic Respiration (Ra)
- Assuming 40% GPP lost to Ra, can calculate NPP
- Adding up biomass increments from POPFACE and making minor assumptions about litter turnover, can calculate NPP

NPP (t CH_2O ha^{-1})

Species	GPP(1-0.4)		Biomass increments + root and leaf turnover	
	Control	Elevated	Control	Elevated
P. alba	73	87	63	80
P. nigra	79	103	81	97
P. x euramericana	59	79	66	83
Average Stimulation		27%		24%

*Biomass increments + root and leaf turnover reproduced from Calfapietra *et al.* 2003 and Lukac *et al.* 2003

Discussion

- The decline in relative stimulation in GPP is a function of canopy closure not acclimation
- An increasing proportion of GPP occurs in the shade: RuBP-Limited Photosynthesis
- RuBP-Limited Photosynthesis not as responsive to elevated CO_2 as Rubisco-Limited Photosynthesis

Conclusion

- Hypothesis 1 supported: Stimulation of GPP in elevated CO_2 treatments
- Hypothesis 2 not supported: Although absolute GPP was stimulated in all years, the relative magnitude of the stimulation decreased with canopy closure

Implications

- Important to understand the dynamics in tree canopies
- Sun-shade model effective at capturing these dynamics
- GPP can be effectively estimated

Future Directions

- Interacting Global Changes:

  Rising CO_2 + Rising O_3

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UIUC Environmental Council

Q dir = I_s * ♋$^{((P/Po)/ \cos ❑)}$

Qdiff = 0.5 * I_s (1-♋ $^{((P/Po)/ \cos ❑)}$) * cos❑

Qscat = 0.07 * Qdir * (1.1-0.1 * LAI) * e$^{(- \cos ❑)}$

Qshade = Qdiff * e$^{(-0.5\ LAI0.7)}$ + Q scat

Qsun = Qdir $^{(\cos d / \cos ❑)}$ + Qshade

Where: I_s = solar constant; ♋ = atmospheric transmittance;
d = angle between the leaf surface and the direct beam solar radiation;
P/Po = ratio of standard and sea level atmospheric pressure