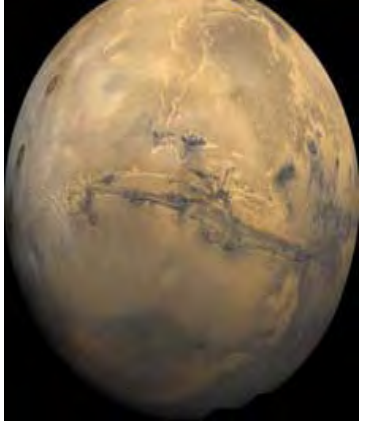
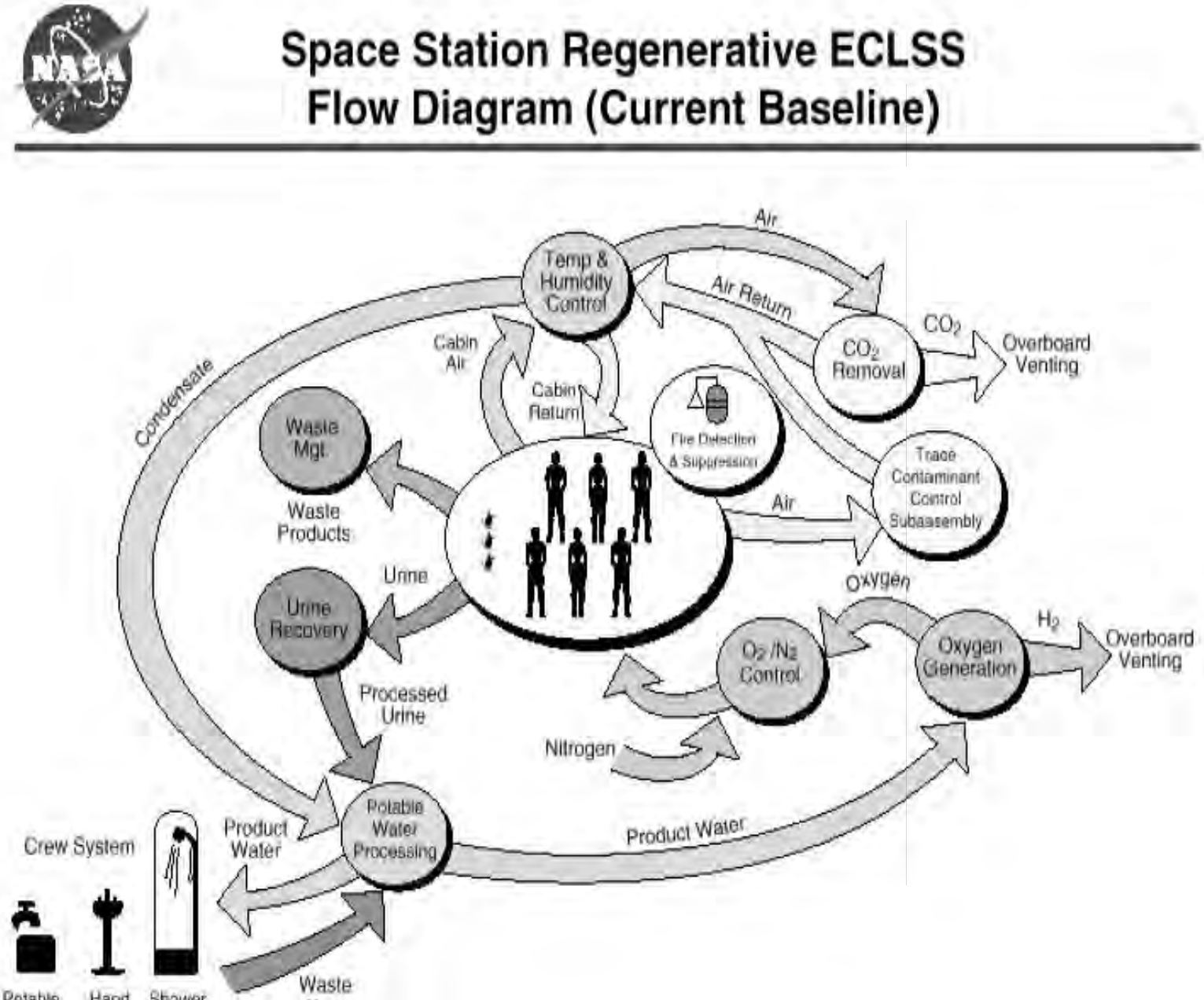


Hypobaria, Hypoxia and Ethylene Influence Growth and Gas Exchange of Lettuce Plants

Fred T. Davies Jr., Chuanjiu He and Ronald E. Lacey

Depts. of Horticultural Sciences &
Biological and Agricultural Engineering,
Texas A&M University, College Station, Texas

Chemical & Physical Systems



lant Growth at Sub-Ambient Atmospheric Pressures

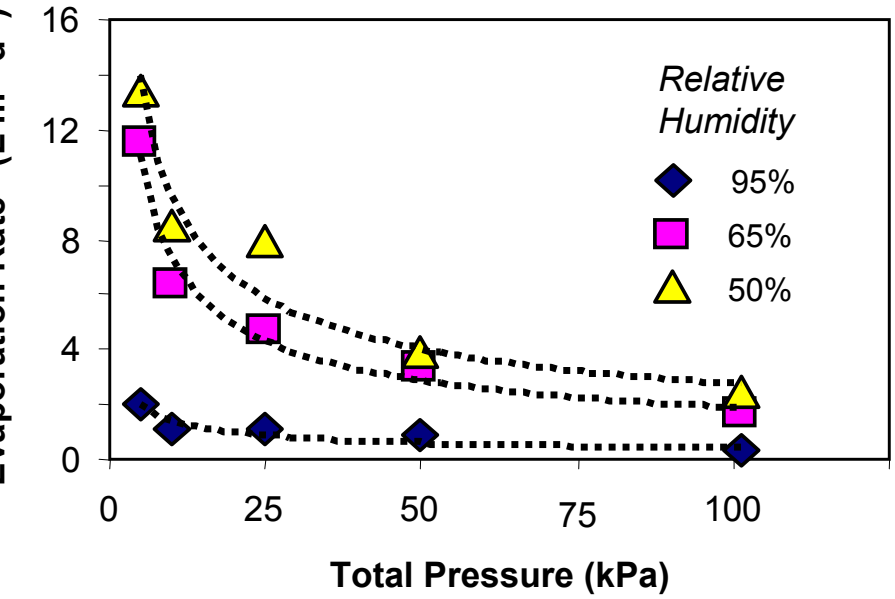
Advantages of Low Pressure System

- ⇨ Less structure needs to be shipped into space.
- ⇨ Less gas leakage from low pressure crop production to vacuum of Moon or nea vacuum of Mars.
- ⇨ Crew could tend crops without suiting up.
- ⇨ Won't have to ship or produce as much Nitrogen gas

Subambient Atmospheric Pressure

⇨ **Increased gaseous diffusion.**

⇨ **Loss of boundry-layer resistance.**



Low Pressure Plant Growth (LPPG) System

- 6-chambered, clear acrylic, modular LPPG system which uses weak-acid electrolyte oxygen sensors, non-dispersive infrared CO_2 sensors and a pressure transducer.

- Controls the partial gas pressures of oxygen, nitrogen and carbon dioxide from 20 kPa to 200 kPa (101 kPa = ambient).

- Has cross flow heat exchanger to control humidity and condensation.

- Changes in CO_2 tracked during the light and dark periods on a whole canopy basis.

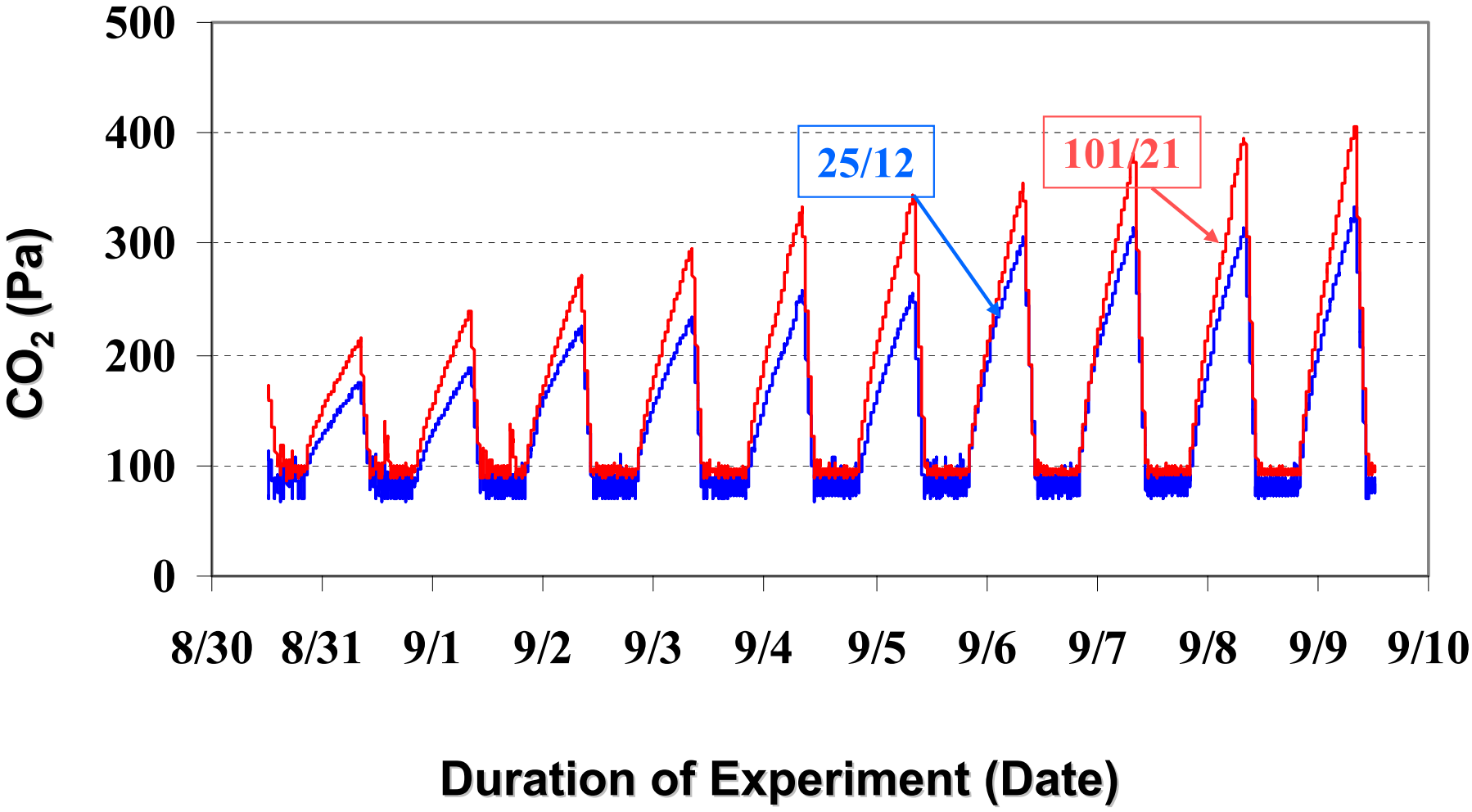
Research Objectives

- **Characterize the influence of hypobaric conditions on plant growth of lettuce (*Lactuca sativa*).**

- **Characterize influence of hypobaric conditions on plant gas exchange**

- **Separate the effects of hypobaria and hypoxia.**

CO_2 Assimilation & Dark-Period Respiration



- 10-day study; 25kPa/ 12kPa pO_2; 101kPa (ambient)/ 21kPa pO_2
- Setpoint of 100 Pa pCO_2 during light period


25/12 pO_2
101/12
101/21
25/12
101/21
101/12

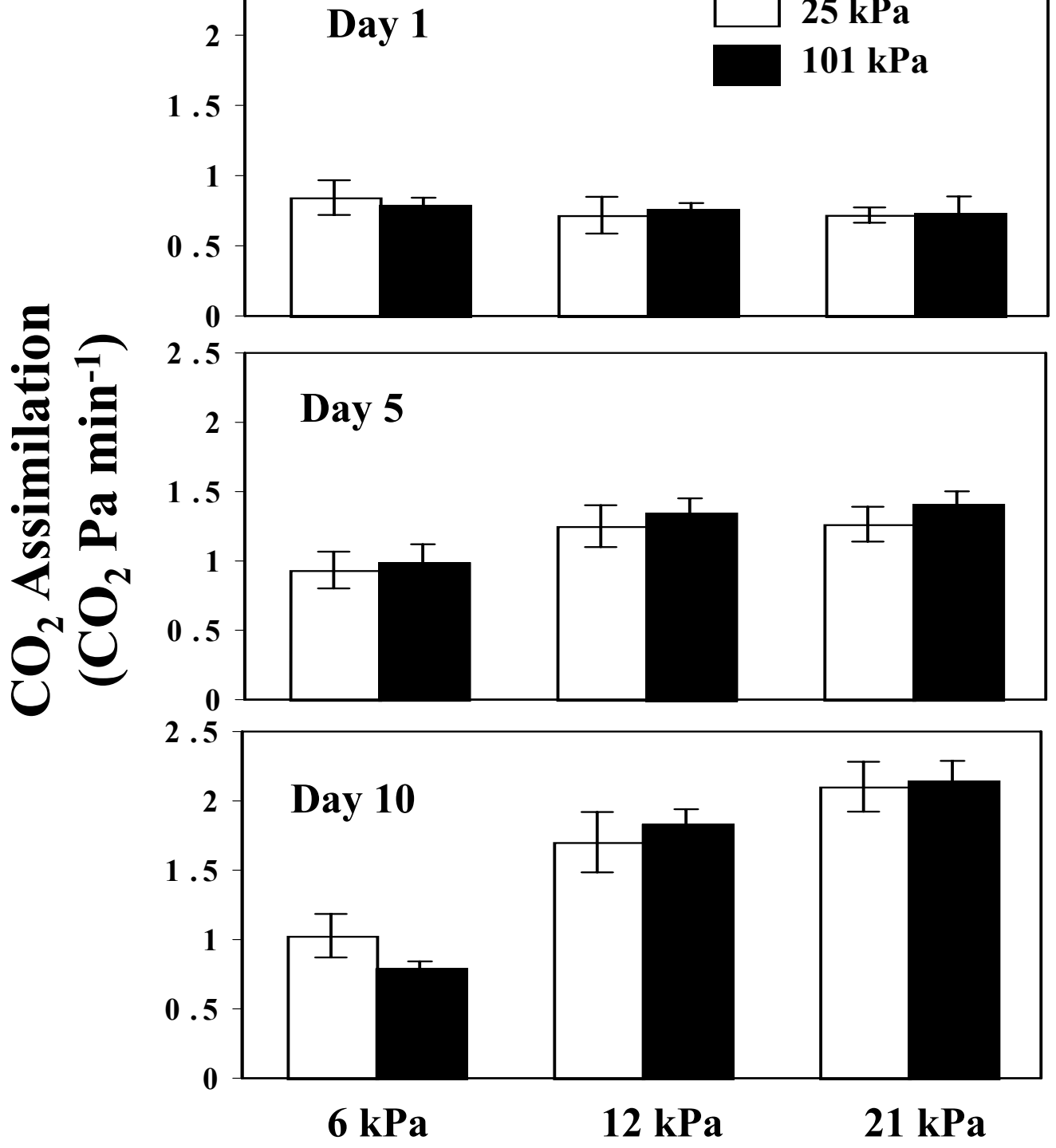

Day 1
25 kPa
101 kPa
Day 5
Day 10
CO_2 Assimilation
(CO_2 Pa min^{-1})
0
0 .5
1
1 .5
2
2 .5
6 kPa
12 kPa
21 kPa

Fig. 7.

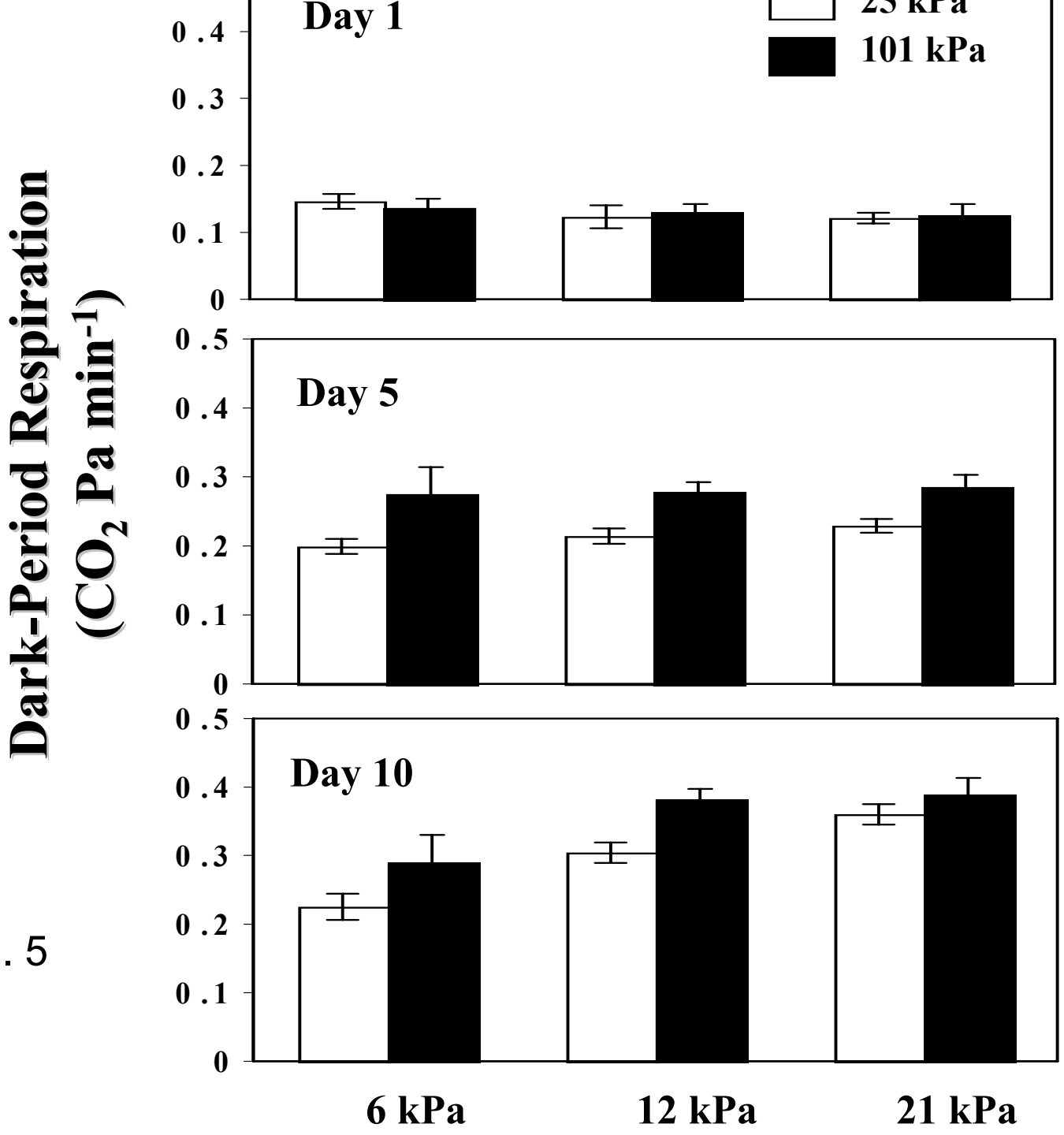

Dark-Period Respiration
(CO_2 Pa min^{-1})
Day 1
Day 5
Day 10
23 kPa
101 kPa
0
0.1
0.2
0.3
0.4
0.5
6 kPa
12 kPa
21 kPa

Fig. 5

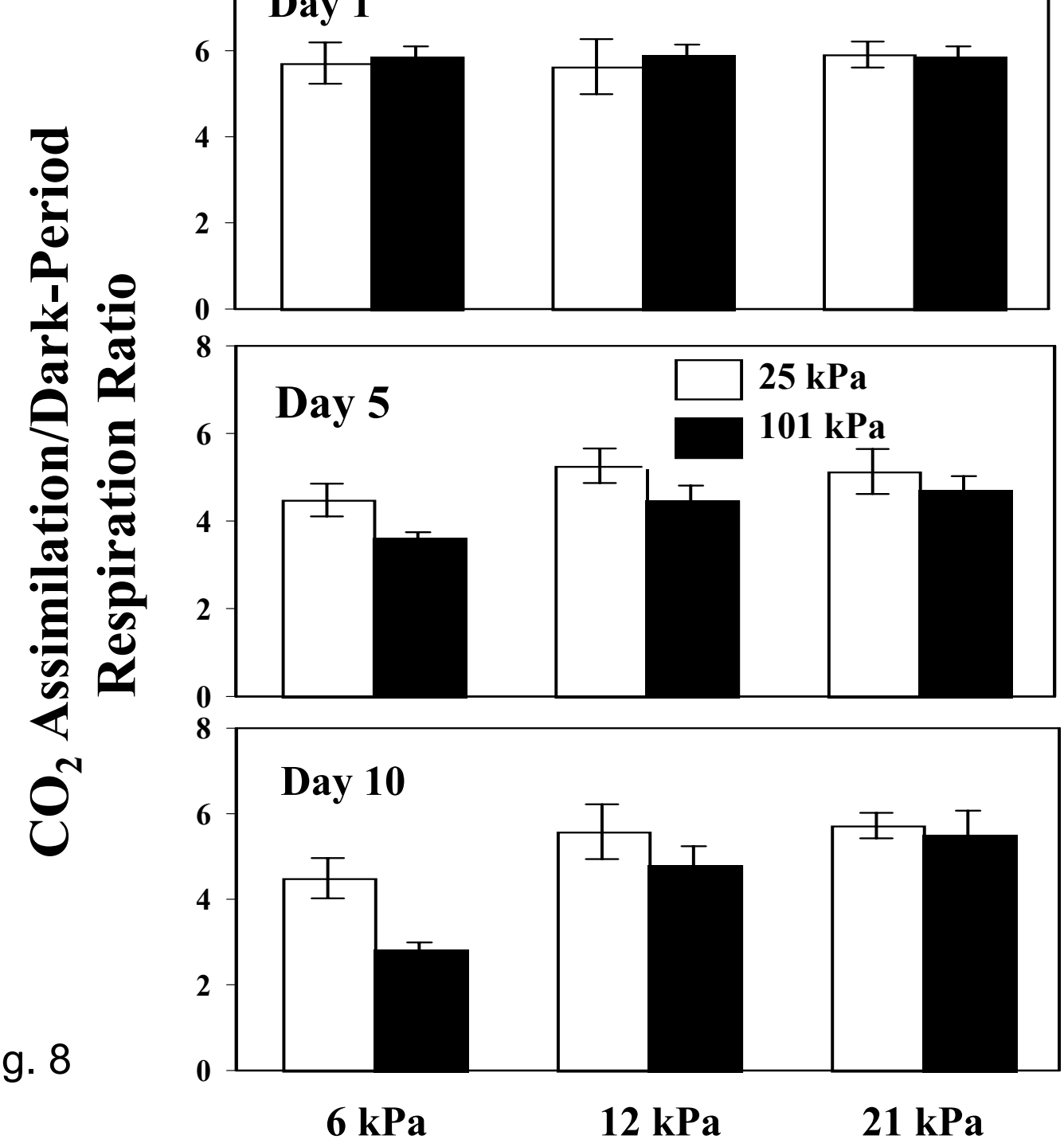

CO_2 Assimilation/Dark-Period Respiration Ratio
Day 1
Day 5
Day 10
25 kPa
101 kPa
0
2
4
6
8
6 kPa
12 kPa
21 kPa

Fig. 8

Effect of Total Pressure and Partial Pressure of Oxygen (pO_2) on Lettuce Plant Growth, Chlorophyll and Relative Water Content (RWC)

Total pressure (kPa)	**pO_2** (kPa)	**Leaf area** (cm^2)	**SLA** (cm^2g^{-1})	**Leaf DM** (g)	**Root DM** (g)	**Total plant DM** (g)	**Chl** (**µg. cm^{-2}**)	**RGR** ($mg.g^{-1}.day^{-1}$)
25	6	857	44.5	2.7	0.4	3.2	42.1 ± 1.7	0.18
	12	1190	50.1	3.6	0.8	4.4	39.9 ± 0.5	0.22
	21	1349	54.5	3.5	0.8	4.3	37.3 ± 0.5	0.21
101	6	832	37.6	2.3	0.3	2.7	37.8 ± 1.4	0.16
	12	1172	49.9	3.4	0.8	4.2	37.8 ± 0.7	0.21
	21	1250	54.2	3.5	1.0	4.4	34.2 ± 0.7	0.22
Signif.	Pres.(P) O_2 P x O_2	NS *** NS	NS *** NS	NS *** NS	NS ** NS	NS *** NS	*** *** NS	NS *** ***

- 10-day studies; seedling transplants 20-days old.
- Setpoint of 100 Pa pCO_2 during light period

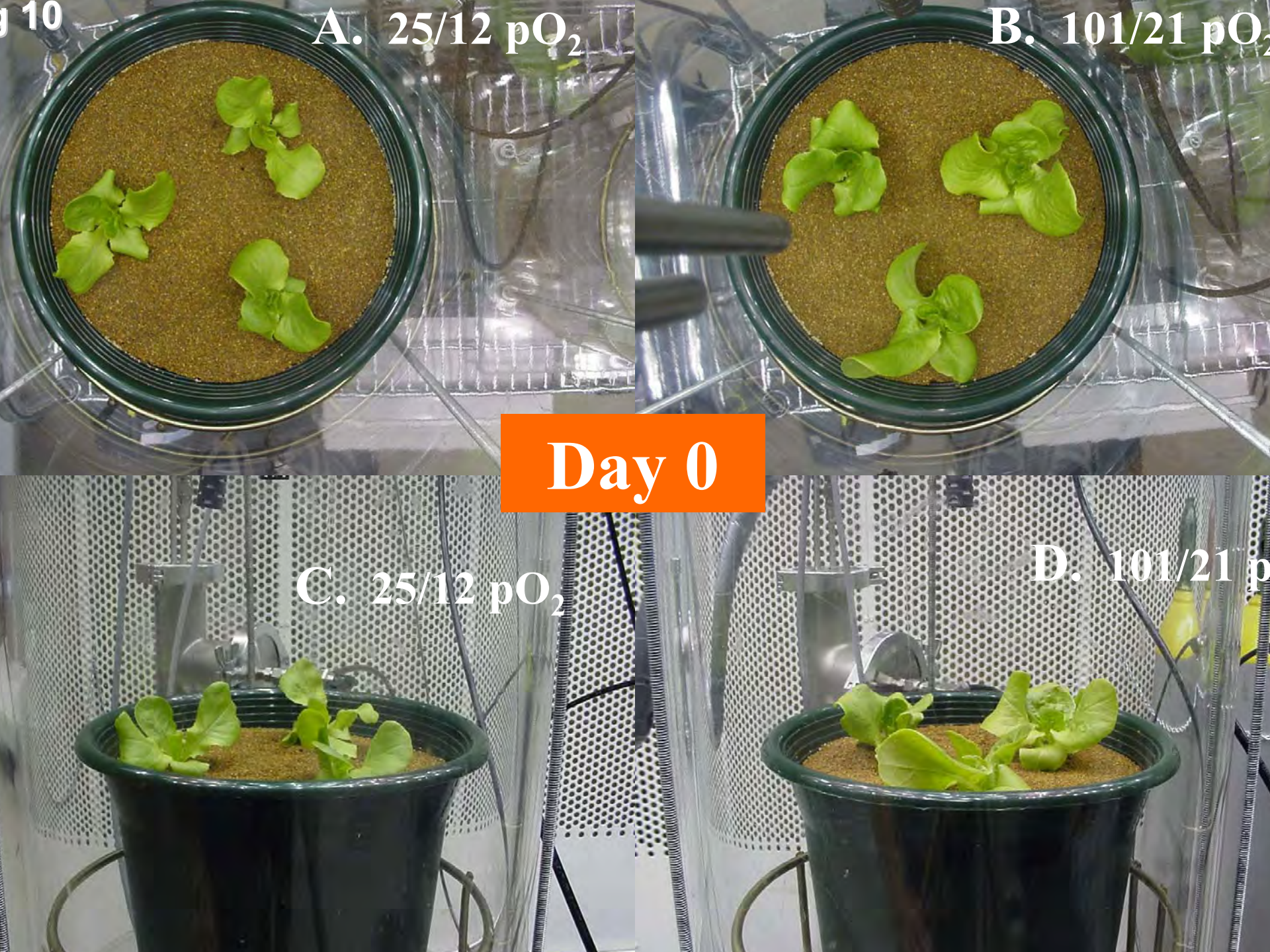

g 10
A. 25/12 pO2
B. 101/21 pO2
Day 0
C. 25/12 pO2
D. 101/21 p

Fig 11

Fig 12

Summary

- Growth was comparable between low (25kPa) and ambient (101kPa) pressure lettuce plants during 10-day studies.

- Low pO_2 (6 kPa) reduced plant growth compared to 12 and 21 kPa pO2. (oxidative phosphorylation limited)

- Low pO2 (6 kPa) caused greater growth reduction & stress with ambient (101 kPa) than low (25kPa) pressure plants — trend in lower SLA, leaf + total plant DM

- Leaf chlorophyll was higher at 25 than 101kPa; RWC was unaffected by total pressure or pO_2.

Summary (con)

- 25/12 kPa pO_2 had comparable CO_2 assimilation and 25% lower dark-period respiration than 101/21 kPa pO_2 (ambient) plants.

- Greater efficiency of CO_2 assimilation/dark-period respiration (ratio) with low pressure plants (6 kPa pO_2). [↑ diffusion rate, ↓ boundary layer res???]

- Hypobaria ≠ Hypoxia.

  (Paul et al., 2004; less half genes up-regulated or down-regulated; response to hypobaria is unique)

  (Richards et al., 2006; no effect 5 photorespiratory enzymes – Rubisco; hypobaria – no altered regulation photorespiratory pathway)

Elevated Ethylene Levels

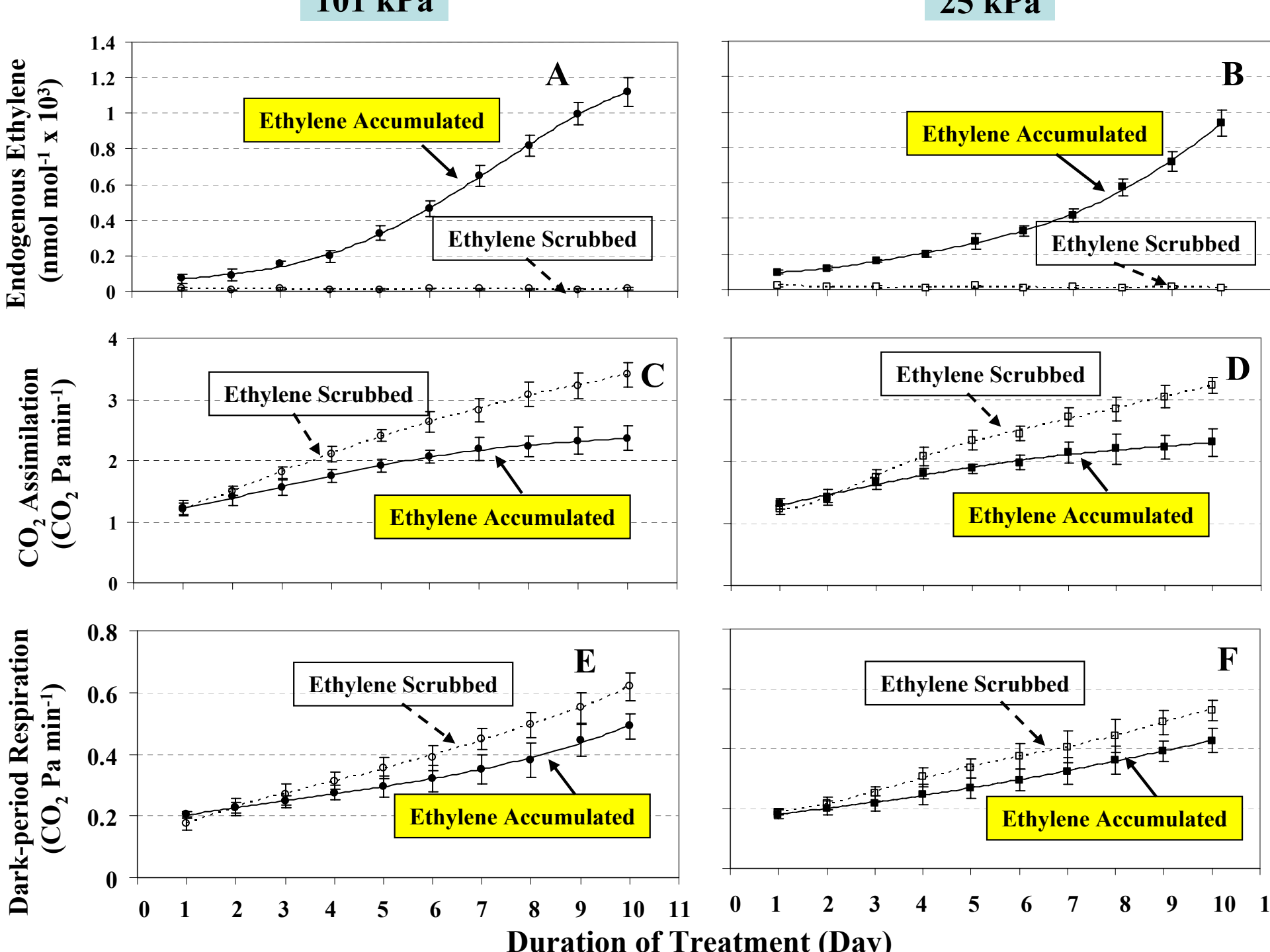
- Elevated levels of ethylene occur in CEA and microgravity- spaceflight environments, leading to adverse plant growth & sterility (Wheeler et al., 1996; Bugbee, 1999; Stutte, 1999).

- Russian Space Station Mir: ethylene ranged from 1000 to 1700 nmol mol^{-1} (ppb) (Campbell et al., 2001).

- **International Space Station (ISS): 50 nmol mol^{-1} (ppb) ethylene.**

Research Objective

- Characterize influence of ethylene on plant gas exchange (CA, DPR) and growth of lettuce (*Lactuca sativa*) under ambient (101 kPa) and hypobaric (25 kPa) conditions

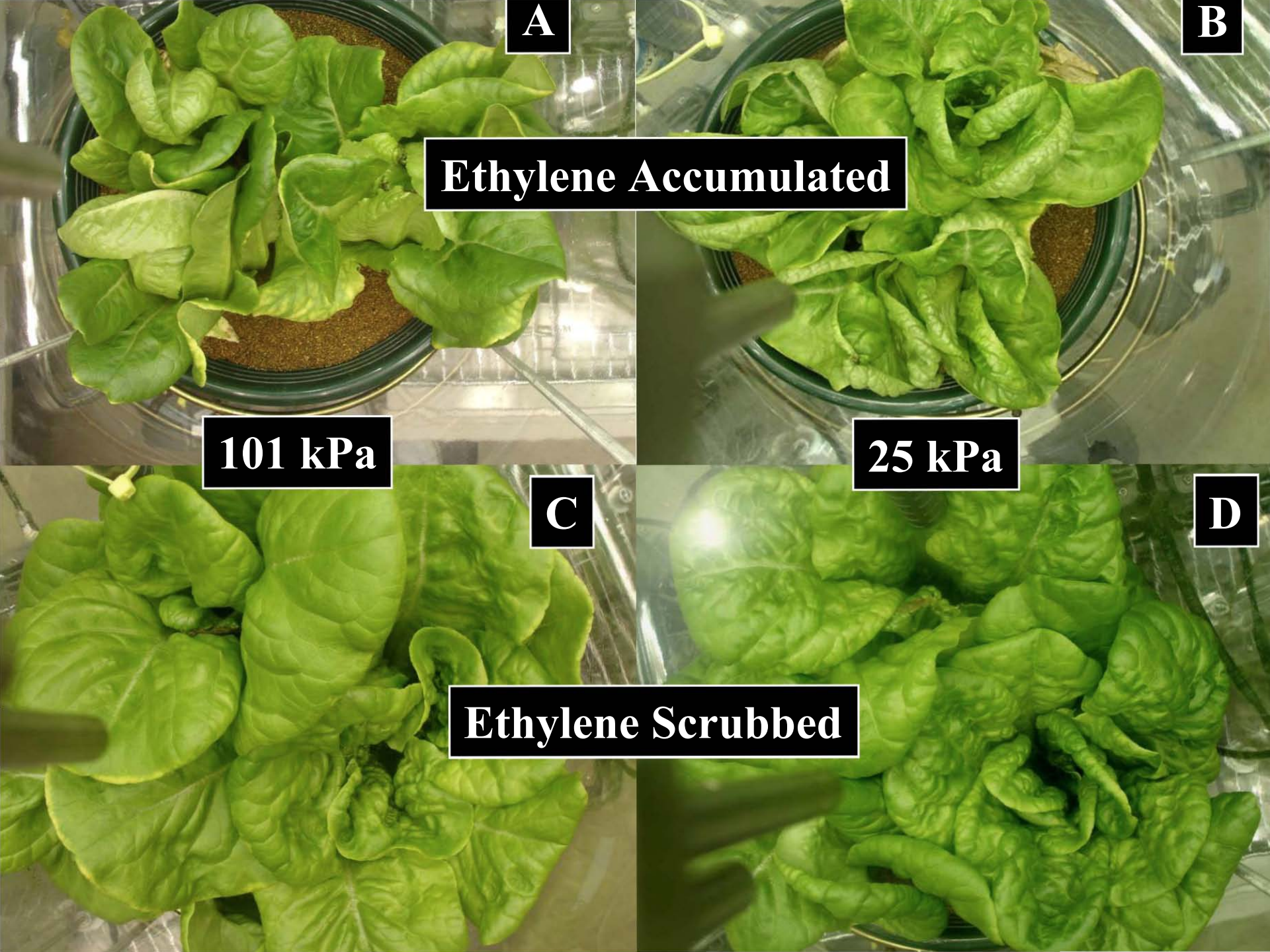

101 kPa
25 kPa
A
B
C
D
E
F
Ethylene Accumulated
Ethylene Scrubbed
Endogenous Ethylene (nmol mol-1 x 10³)
CO2 Assimilation (CO2 Pa min-1)
Dark-period Respiration (CO2 Pa min-1)
Duration of Treatment (Day)

Effect of Total Atmospheric Pressure and Ethylene [(C_2H_4), either scrubbed or endogenously accumulated] on CO_2 Assimilation (CA), Dark-Period Respiration (DPR) and the CA /DPR ratio

Total Pressure (kPa)	C_2H_4 Treatments	C_2H_4 level in Chamber (nmol mol^{-1})	C_A (CO_2 Pa min^{-1})	DPR (CO_2 Pa min^{-1})	C_A /DPR Ratio
101	Accumulated	1119^{a}	2.45^{b}	0.50^{bc}	4.85^{b}
	Scrubbed	11^{b}	3.40^{a}	0.62^{a}	5.46^{ab}
25	Accumulated	936^{a}	2.30^{b}	0.46^{c}	5.03^{ab}
	Scrubbed	8^{b}	3.12^{a}	0.53^{b}	5.83^{a}
Significance	Pressure (Pres)	NS	NS	**	NS
	C_2H_4	***	***	***	*
	Pres x C_2H_4	NS	NS	NS	NS

Effect of Total Atmospheric Pressure and Ethylene [(C_2H_4), either scrubbed or endogenously accumulated] ; Lettuce (*Lactuca sativa* L cv. Butter Crunch)

Pres (kPa)	C_2H_4 Treatment	Leaf area (cm^2)	SLA ($cm^2\ g^{-1}$)	Leaf DM (g)	Root DM (g)	Total Plant DM (g)	RGR ($mg\ g^{-1}\ d^{-1}$)	RWC (%)
101	Accumulated	211[b]	52.3[b]	6.04[b]	0.97[b]	7.02[b]	0.173[b]	94.2
	Scrubbed	297[a]	56.4[a]	7.31[a]	1.22[a]	8.53[a]	0.195[a]	94.7
25	Accumulated	230[b]	52.9[b]	6.19[b]	0.98[b]	7.17[b]	0.178[b]	94.1
	Scrubbed	321[a]	56.6[a]	7.42[a]	1.14[a]	8.56[a]	0.201[a]	94.7
Significance	Pres	NS	NS	NS	NS	NS	NS	NS
	C_2H_4	***	**	**	**	**	***	NS
	Pres x C_2H_4	NS	NS	NS	NS	NS	NS	NS


A
B
Ethylene Accumulated
101 kPa
25 kPa
C
D
Ethylene Scrubbed

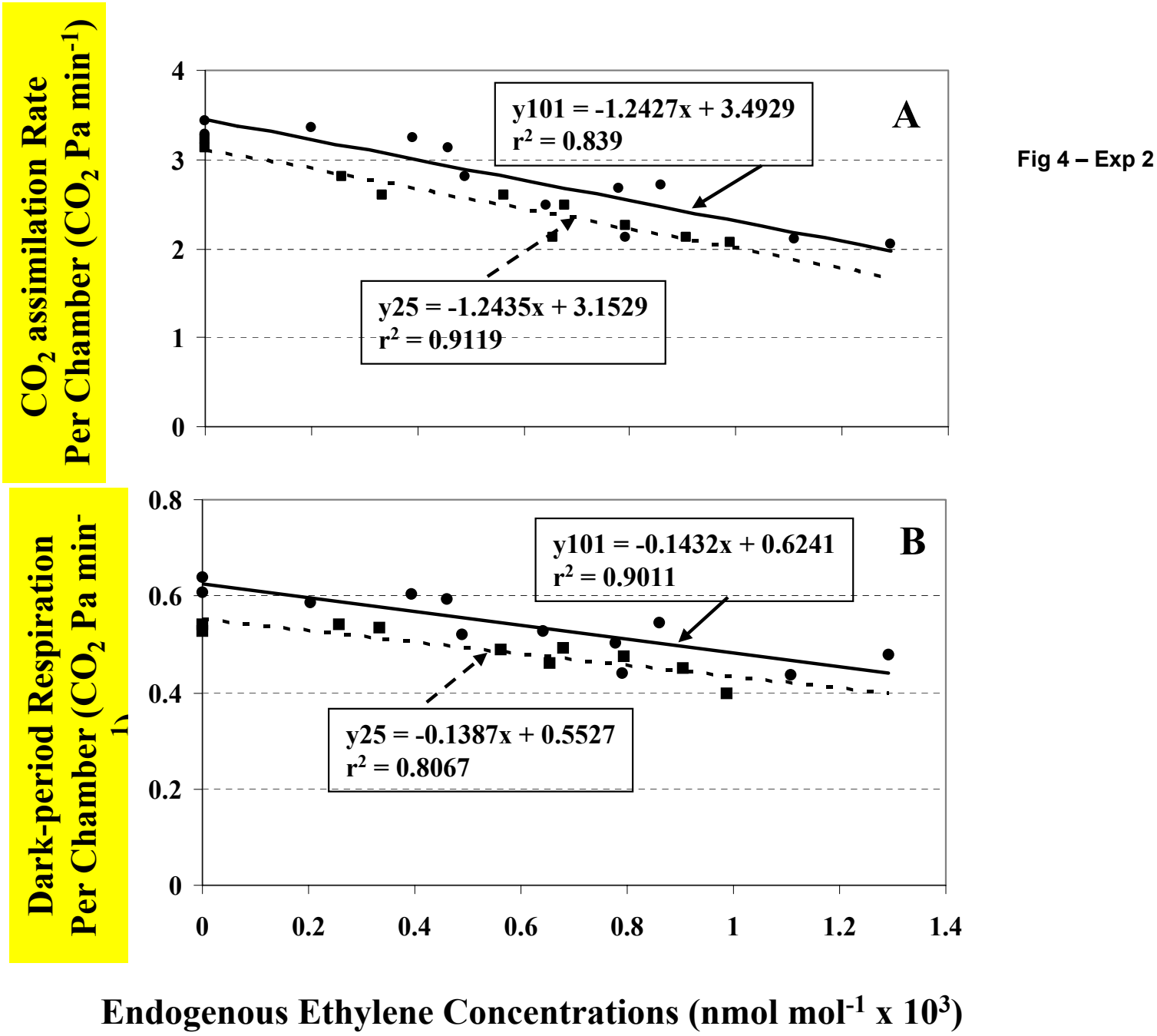

CO_2 assimilation Rate
Per Chamber (CO_2 Pa min^{-1})
y101 = -1.2427x + 3.4929
r^2 = 0.839
A
y25 = -1.2435x + 3.1529
r^2 = 0.9119
Dark-period Respiration
Per Chamber (CO_2 Pa min^{-1})
y101 = -0.1432x + 0.6241
r^2 = 0.9011
B
y25 = -0.1387x + 0.5527
r^2 = 0.8067
Endogenous Ethylene Concentrations (nmol mol^{-1} x 10^3)

Fig 4 – Exp 2

Summary

- Ethylene reduced C_A, DPR and plant growth of both ambient and hypobaric plants.

- Negative, linear correlation of increasing ethylene up to 1000 nmol mol^{-1} (ppb).

- Hypobaria had no significant effect on endogenous ethylene production

Acknowledgements

NASA- NAG-9-1067 — Plant Growth and Metabolism at Sub-Ambient Atmospheric Pressures.

NASA- NAJ04HF53G — Plant Growth at Sub-Ambient Atmospheric Pressures with Control of the Partial Pressures of Constituent Gases.

http://aggie-horticulture.tamu.edu/faculty/davies/research/nasa.html