Plant Growth at Sub-Ambient Atmospheric Pressures with Control of the Partial Pressures of Constituent Gases

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Plant 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 near vacuum of Mars.
- Crew could tend crops without suiting up.
- Won’t have to ship or produce as much Nitrogen gas.
Gas Composition

- Provided by pressurized N₂, CO₂ and O₂ cylinders.

**Perfect Gas Law:** \( PV = nRT \)

\( P = \) pressure; \( V = \) volume; \( n = \) moles; \( T = \) temperature

<table>
<thead>
<tr>
<th>Total Pressure (kPa)</th>
<th>( p_{N_2} ) (kPa)</th>
<th>( p_{O_2} ) (kPa)</th>
<th>( p_{CO_2} ) (kPa x 10⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>80</td>
<td>20.9</td>
<td>100</td>
</tr>
<tr>
<td>50</td>
<td>39.7</td>
<td>10.3</td>
<td>100</td>
</tr>
<tr>
<td>25</td>
<td>19.9</td>
<td>5.1</td>
<td>100</td>
</tr>
</tbody>
</table>
**Project Research Objectives**

1. To characterize plant growth, gas exchange (respiration and photosynthesis), constituent gases (oxygen, carbon dioxide, ethylene and other trace gases, and water reclamation (transpirate) under environmental conditions that may apply to an Advanced Life Support System.

2. To model the dynamics of carbon dioxide exchange in a closed microecosystem such as an Advanced Life Support System.
History of Low Pressure Plant Growth Systems at Texas A&M University

- **Generation I – 1987 – 1997**
  - One low pressure & one ambient pressure chamber
  - Not a closed system (CO\(_2\) measurement)
  - Control program not flexible
  - Safety and reliability issues

- **Generation II – 1999 – 2002**
  - One low pressure & one ambient pressure chamber
  - Based on upgrades from Gen I
  - System not fully closed (CO\(_2\) measurement)
  - Flexible control program with graphic readouts
History of Low Pressure Plant Growth Systems at Texas A&M University (con.)

  - 6 semi-independent chambers
    - Shared mass flow controllers
    - GC sampling manifold
  - Gas composition by industrial GC (Rosemont GCX)
  - Control of total pressure, CO2, and O2 partial pressures
  - Enhanced humidity control
  - Sampling frequency twice per hour
Figure 4. (A) Six-chambered low pressure growth (LPPG) system; (B) R. Lacey & C-J He starting an experiment; lettuce at (C) early and (D) later stage of development under low pressure.
LPPG Gen IV Chamber Schematic
Sensors

Maxtec MAX-250
Weak acid electrolyte oxygen sensor

Ohmic Instruments HT-761
Analog Relative Humidity and Temperature Transmitter

Vaisala CARBOCAP®
Carbon Dioxide Module GMM220
Sensor Calibrations

Chamber 1 Calibration data showing linear response with partial pressure for CO2 (left) and O2 (right) transducers.
Partial pressure of CO2 (left axis) and O2 (right axis) during a seven day test of lettuce in the Gen IV LPPG. During the light period (8:00 am to 8:00 pm) the level of CO2 was controlled to 100 Pa, while during the dark period (8:00 pm to 8:00 am) the level was allowed to rise with plant respiration. O2 was controlled to a minimum of 6 kPa and 21 kPa for Chambers 1 and 2, respectively. O2 was allowed to rise with photosynthesis during the light period. Data were taken at one minute intervals. Chamber 1 was at a total pressure of 25 kPa and chamber 2 was at a total pressure of 101 kPa.
Current Plant Biology Research Objectives

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

• Characterize influence of hypobaric conditions on plant gas exchange and ethylene evolution.
• Low pressure had no significant effects on net photosynthesis, stomatal conductance, and germination rate of lettuce and wheat.

• In Lettuce, low O₂ (6.2%) significantly reduced ethylene production under low or ambient pressure. In Wheat, ethylene was reduced by low pressure but not significantly by low O₂ (6.2%) at ambient pressure.

• Accumulation of ethylene in chambers had significant effect on lettuce and wheat growth.

• Lettuce was more sensitive to ethylene than wheat.
**No Tip Burn**
Low pressure: 50 kPa;
Low light: 300 µmol
100 Pa CO₂
Day 6

**Tip Burn**
Ambient: 101 kPa;
Low light: 300 µmol
100 Pa CO₂
Day 6
Figure E5. CO2 draw-down at 8:10 (10 minutes after lights on) of ambient (101 kPa) and low (50 kPa) lettuce plants.
**Figure E6.** Dark respiration over a 12-h dark cycle at ambient (101 kPa) and low (50 kPa) total pressure of lettuce plants.

**May 12**

![Graph showing dark respiration over a 12-h dark cycle at ambient (101 kPa) and low (50 kPa) total pressure of lettuce plants.](image-url)

- **101 Kpa**
  \[ y = 0.5212x + 123.66 \]
  \[ R^2 = 0.9945 \]

- **50 Kpa**
  \[ y = 0.285x + 123 \]
  \[ R^2 = 0.9923 \]
Ratio of Net CO₂ assimilation / Respiration

Date

5-16
- 6 Kpa O₂
- 21 Kpa O₂

5-23
- 12 Kpa O₂
- 21 Kpa O₂

6-2
- 12 Kpa O₂
- 21 Kpa O₂
Figure E7. Lettuce plants at day 0 @ 25 and 101 Kpa.
Figure E8. Lettuce plants at day 7 @ 25 and 101 Kpa.
Ethylene Concentration in Chambers (nmol mol\(^{-1}\))

- **101 kPa**
- **50 kPa**

**High Light: 600 µmol; CO\(_2\): 600 Pa**

**Low Light: 300 µmol CO\(_2\): 100 Pa**

Duration of Treatment (days):

1 3 6
Summary of Low Pressure (LPPG) Systems

- Lettuce can be grown under low pressure (LP).
- Photosynthesis and stomatal conductance not adversely affected by LP.
- Dark respiration and ethylene levels are much higher under ambient than low total pressure with lettuce production.

- DARK RESPIRATION (at night) lower under LPS = greater plant yield.
- Tendency for tip burn under ambient pressure.
Future Research

• Characterizing growth & development of lettuce under low pressure [LP] (25 kPa) with variable partial pressures of CO$_2$ and O$_2$.

• Characterizing CO$_2$ assimilation and dark respiration at low pressure with variable partial pressures of CO$_2$ and O$_2$.

• Characterizing ethylene biosynthesis at low pressure.

• ACC synthase and ACC oxidase activities at low pressure, and variable partial pressures of CO$_2$ and O$_2$.
**Acknowledgement**

- NASA-NNJ04HF53G — Plant Growth at Sub-Ambient Atmospheric Pressures with Control of the Partial Pressures of Constituent Gases

- NASA-TAMU Low Pressure Environment Homepage
  
  [http://aggie-horticulture.tamu.edu/faculty/davies/research/nasa.html](http://aggie-horticulture.tamu.edu/faculty/davies/research/nasa.html)

- Real Time View of the Low Pressure Plant Growth System at TAMU
  
  [http://baen.tamu.edu/users/rel/LPPG/](http://baen.tamu.edu/users/rel/LPPG/)