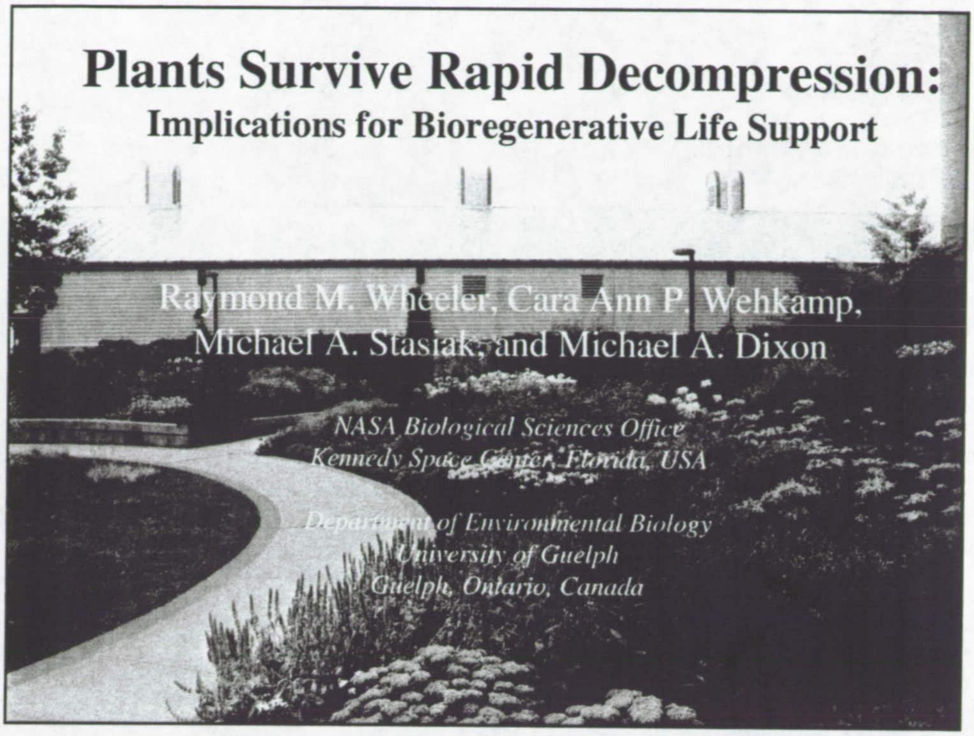

Why Reduced Pressures for Space Missions?

- Reduced gas leakage and hence reduced resupply costs
- Reduced structural mass
- Increased potential for finding transparent materials for space "greenhouses"
- Rapid egress for EVAs (spacewalks) without prolonged prebreathing and acclimation

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Plant Responses to Reduced Pressures

- Increased transpiration **although there can stomatal acclimation** *(Gale, 1972; Daunicht and Brinkjans, 1992; Andre and Massimino, 1992; Iwabuchi and Kurata, 2003).*
- Increased photosynthesis with sufficient pCO_2 but results vary with conditions *(Iwabuchi et al., 1995; Corey et al., 1997).*
- No effect on growth down to 25 kPa but only with sufficient pO_2 *(Goto et al., 2002; He et al., 2007).*
- Plant survival down to 7 kPa and 10 kPa--barley and wheat *(Andre and Richaud, 1985; Massimino and Andre, 1999).*
- Wheat seeds did not geminate at 1 kPa of simulated Mars atmosphere (SMA) but did germinate and survive at 1 kPa SMA plus 5 kPa O_2 = 6 kPa total pressure *(Schwartzkopf and Mancinelli, 1991).*

- Based on the literature, it appears the survival threshold for plants is 6-7 kPa.
- But what would happen if there is a catastrophic pressure loss in the plant greenhouse / chamber in a life support system?
- To study this, we exposed lettuce, radish, and wheat plants to a rapid depressurization to ~1.5 kPa and held them there for 30 min and then restored the original pressure.

Plant Growing Procedures

- Radish (*Raphanus sativa* L. cv. Cherry Bomb II), lettuce (*Lactuca sativa* L. cv. Grand Rapids) and wheat (*Triticum aestivum* L. cv. Sable) used for study
- All plants grown in 140 x 40 cm stainless steel troughs in rockwool with recirculating NFT (two troughs of radish, two of lettuce, and one of wheat).
- Wheat sown at 574 plants m^{-2}; lettuce at 13 plants m^{-2}, and radish at 38 plants m^{-2}.
- Seeds germinated under ambient pressure (~98 kPa) then thinned at 3 days before closing the chambers.

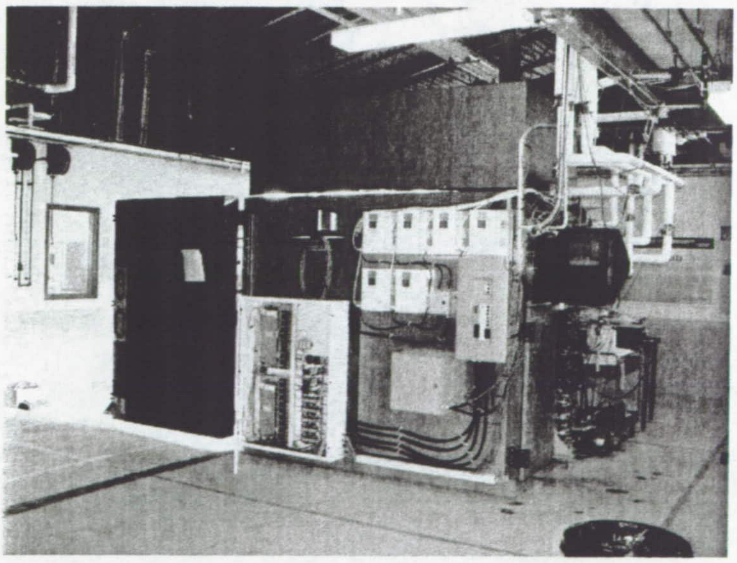
Environmental Conditions

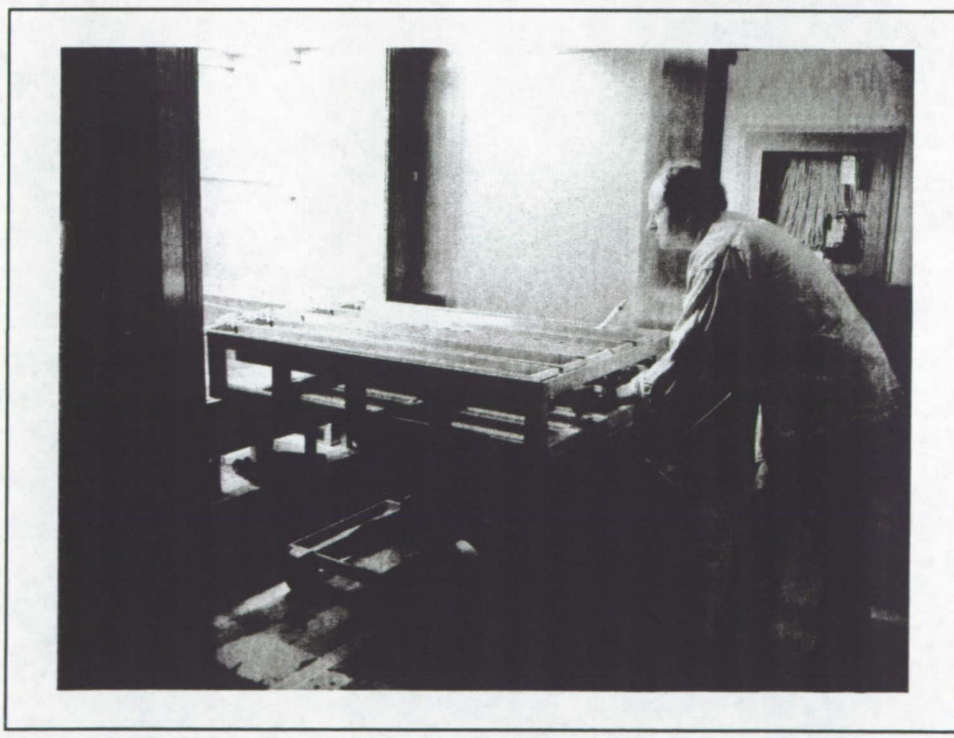
- Plants grown at ~98 kPa or 33 kPa pressure with 20 kPa O_2, and 0.12 kPa CO_2.
- Light at 300 μmol m^{-2} s^{-1} PAR with HPS lamps, 16-h photoperiod (17.3 mol m^{-2} d^{-1})
- Temperature at 22°C.
- Relative Humidity at 65% or 1.7 kPa, giving a VPD = 0.9 kPa.

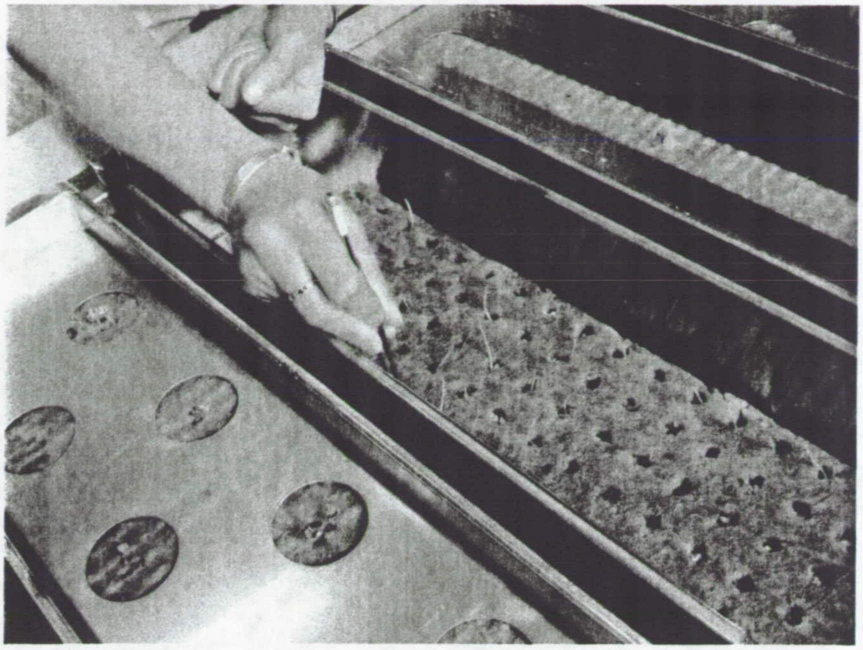
Experimental Treatments

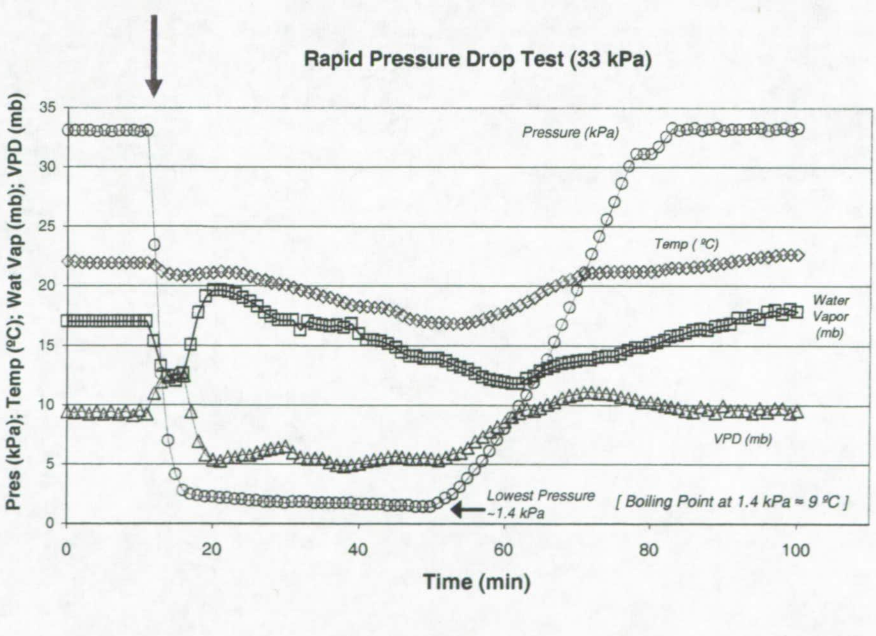
- At 20 after planting, chambers pumped down as rapidly as possible, reaching ~5 kPa after 5 min and ~1.5 kPa after 10 min.
- Chambers held at ~1.5 kPa for 30 min.
- Pressure then restored to 33 kPa (over 30 min) or 98 kPa (over 60 min).
- Temperature and humidity control engaged throughout the pressure drop although some adiabatic cooling was apparent.

Hypobaric Test Chamber
University of Guelph, CESF

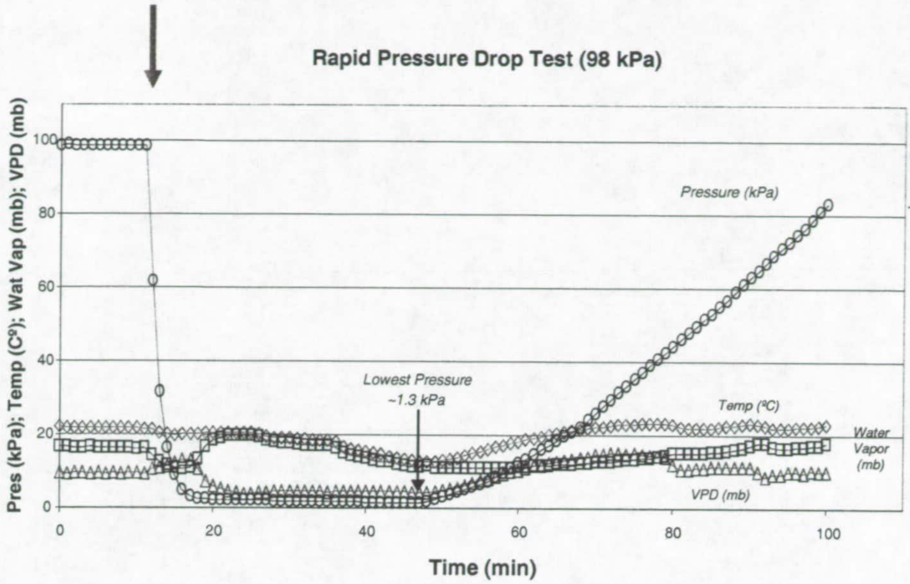








Day 20 After Planting

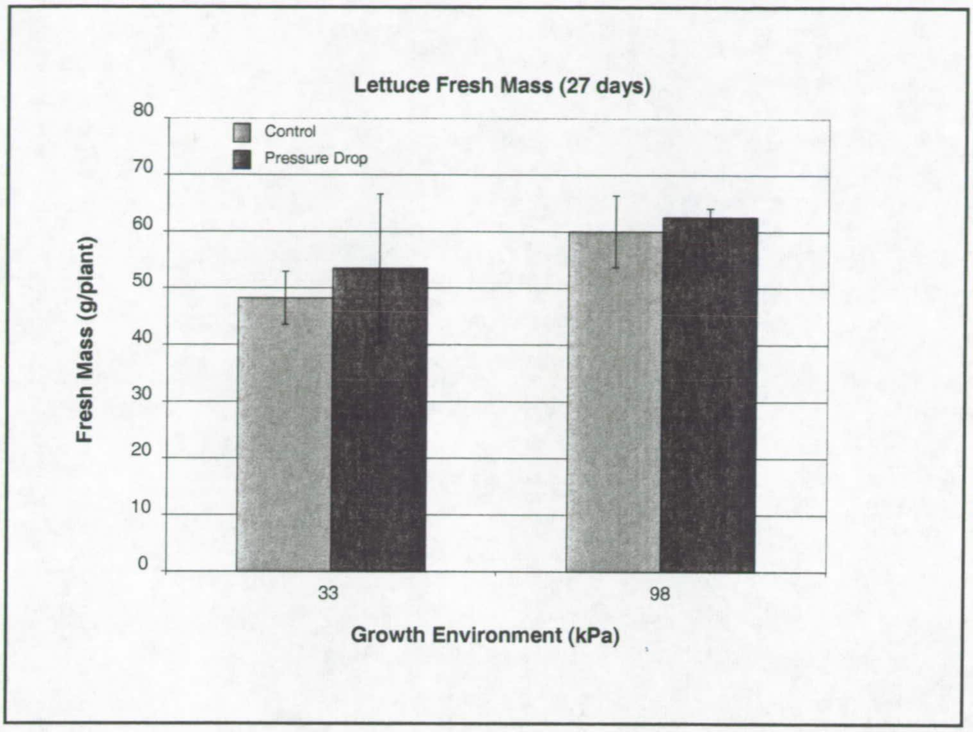


Day 20 After Planting

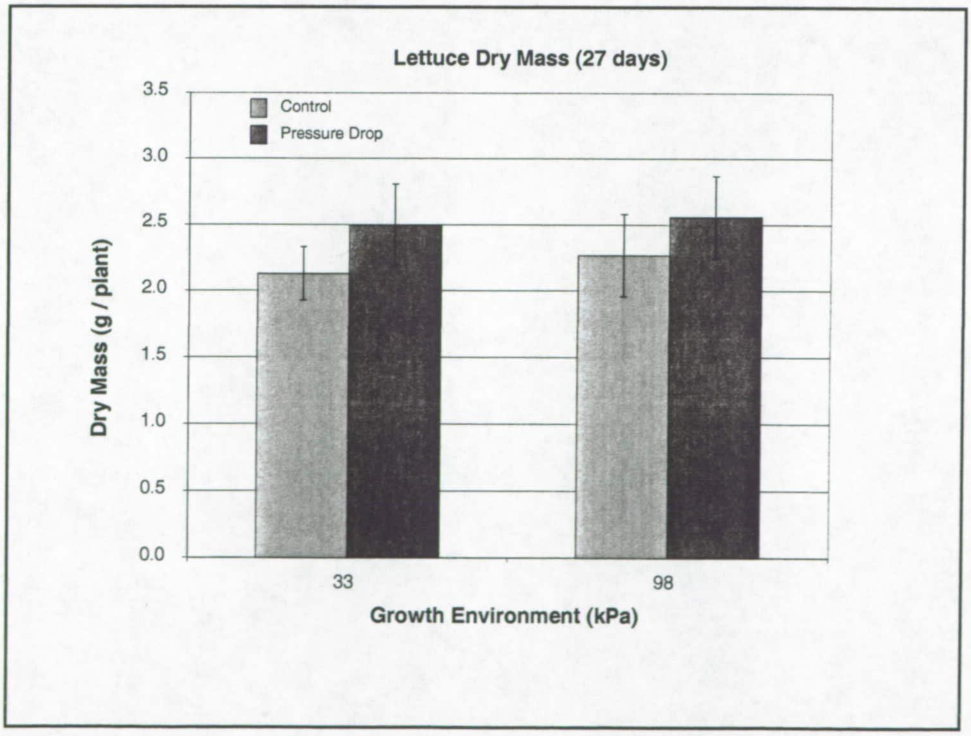
Removing Plants at 27 days after planting

Lettuce, radish, and wheat plants ready for harvest (27 days old)

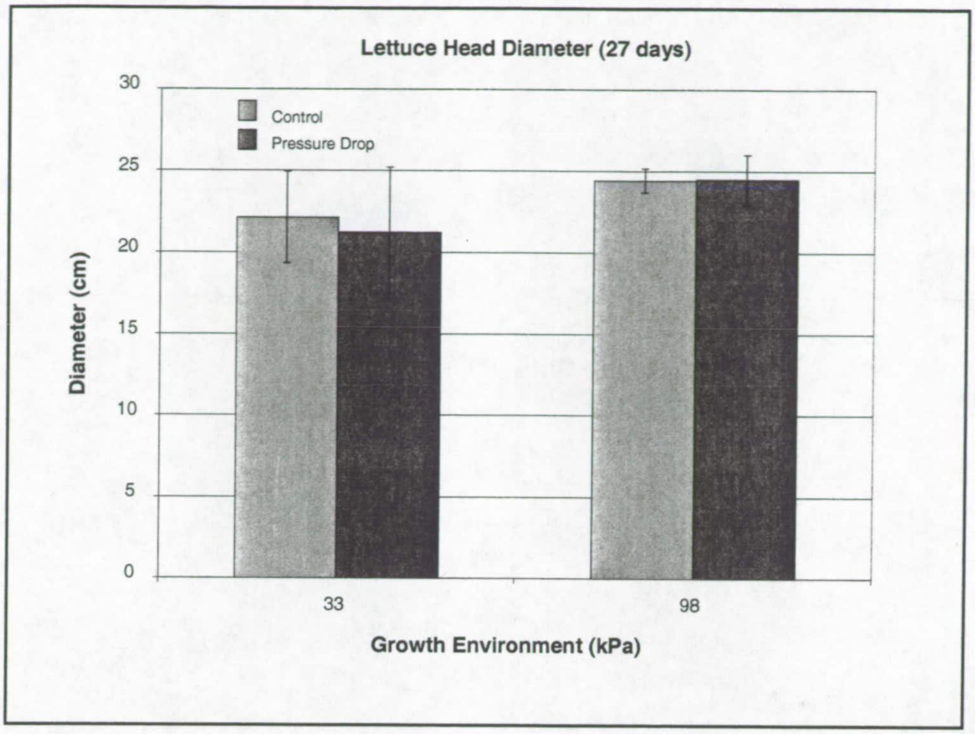
Measuring weights, dimensions, and health status of plants after rapid depressurization



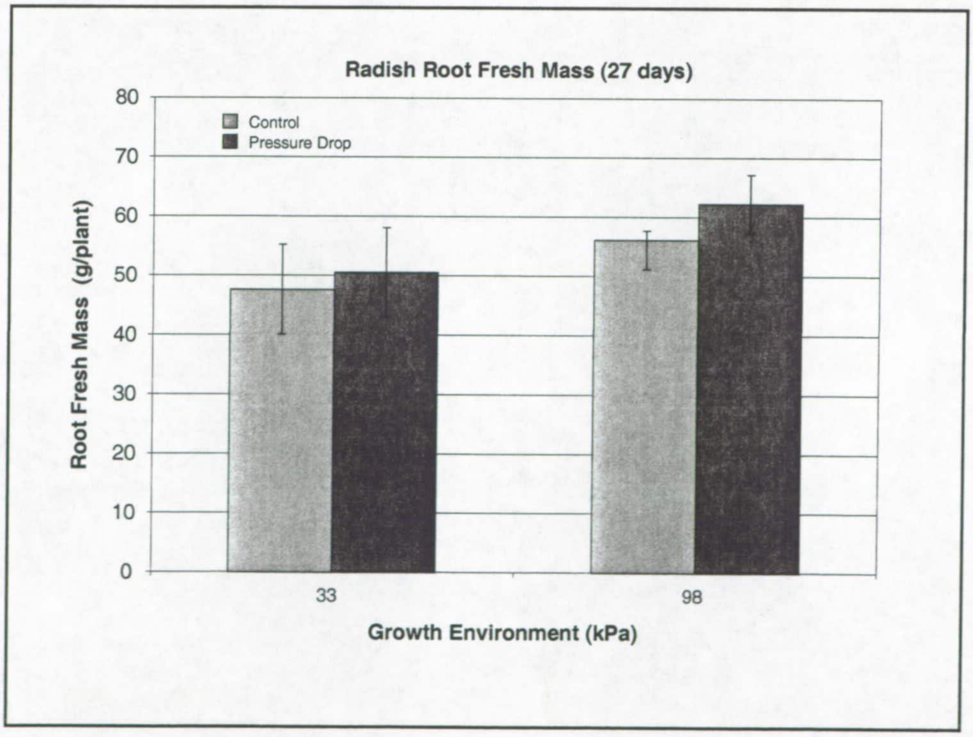
Lettuce Fresh Mass (27 days)
Control
Pressure Drop
Fresh Mass (g/plant)
0
10
20
30
40
50
60
70
80
33
98
Growth Environment (kPa)



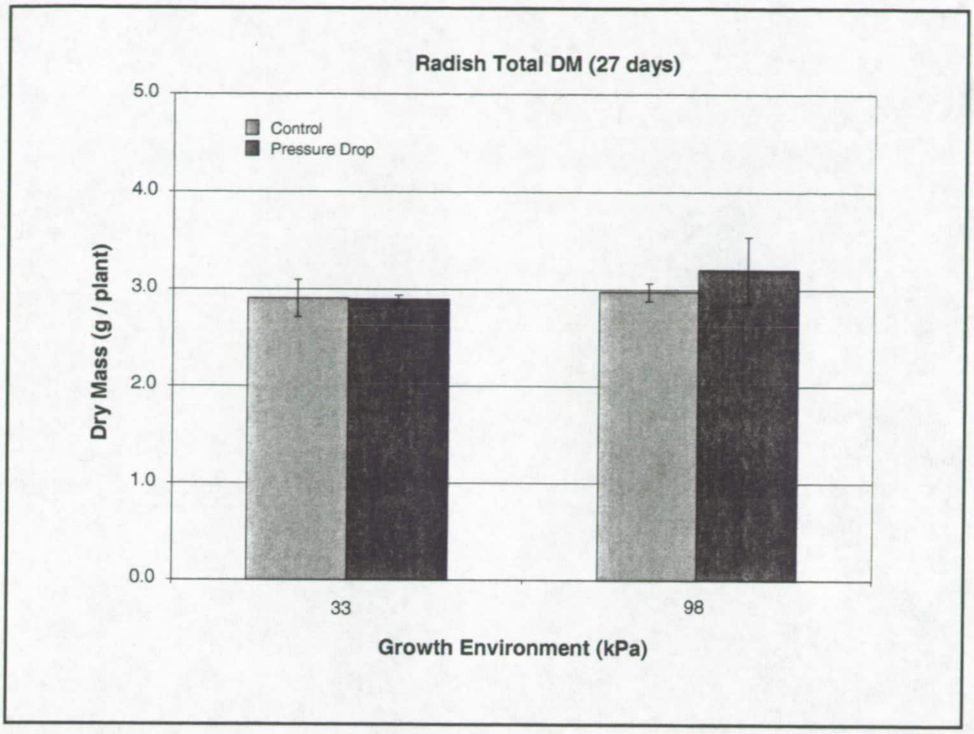
Lettuce Dry Mass (27 days)
Control
Pressure Drop
Dry Mass (g / plant)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
33
98
Growth Environment (kPa)

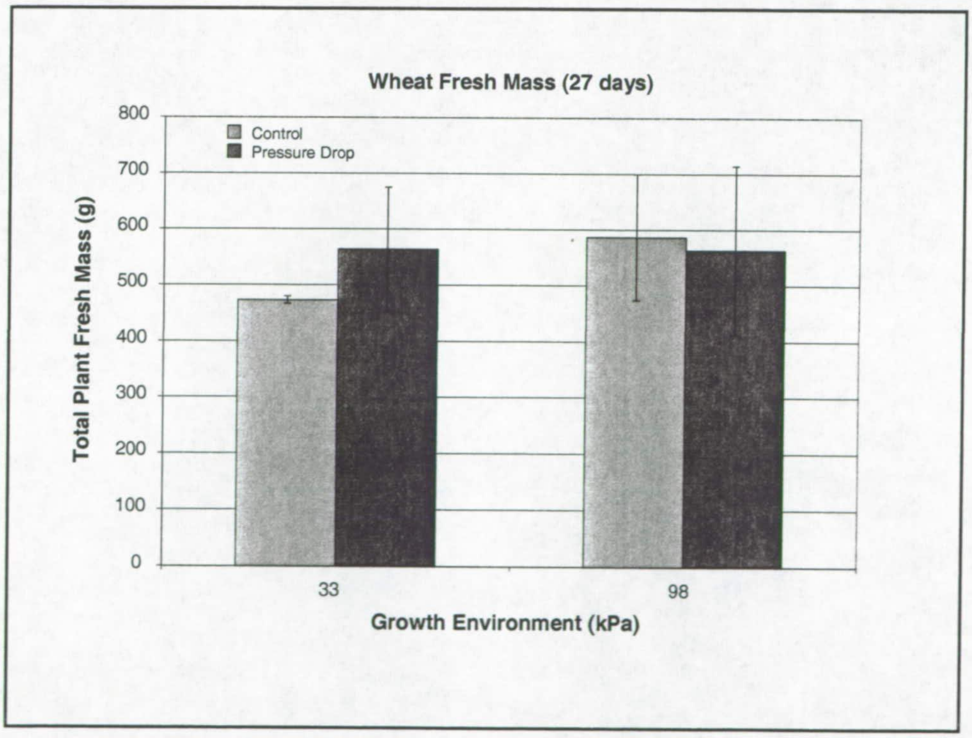


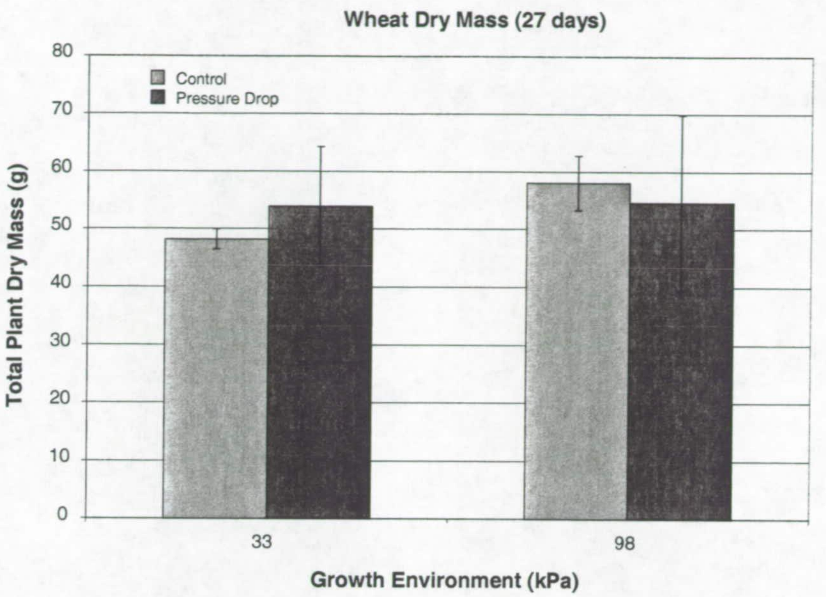
Lettuce Head Diameter (27 days)
Control
Pressure Drop
Diameter (cm)
30
25
20
15
10
5
0
33
98
Growth Environment (kPa)

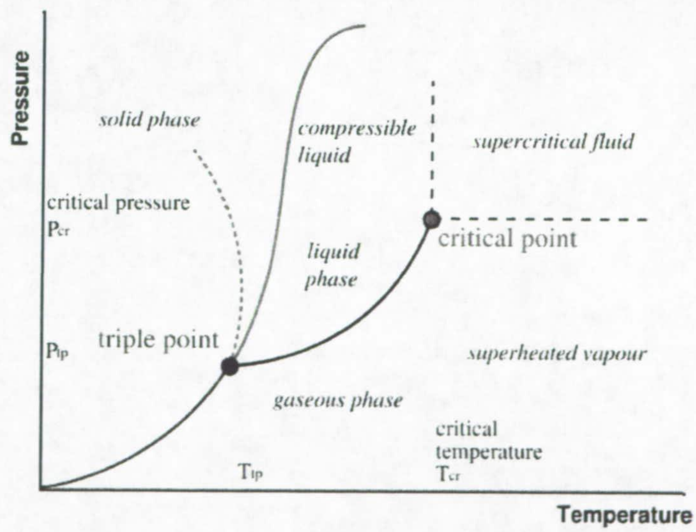


Radish Root Fresh Mass (27 days)
Control
Pressure Drop
Root Fresh Mass (g/plant)
80
70
60
50
40
30
20
10
0
33
98
Growth Environment (kPa)

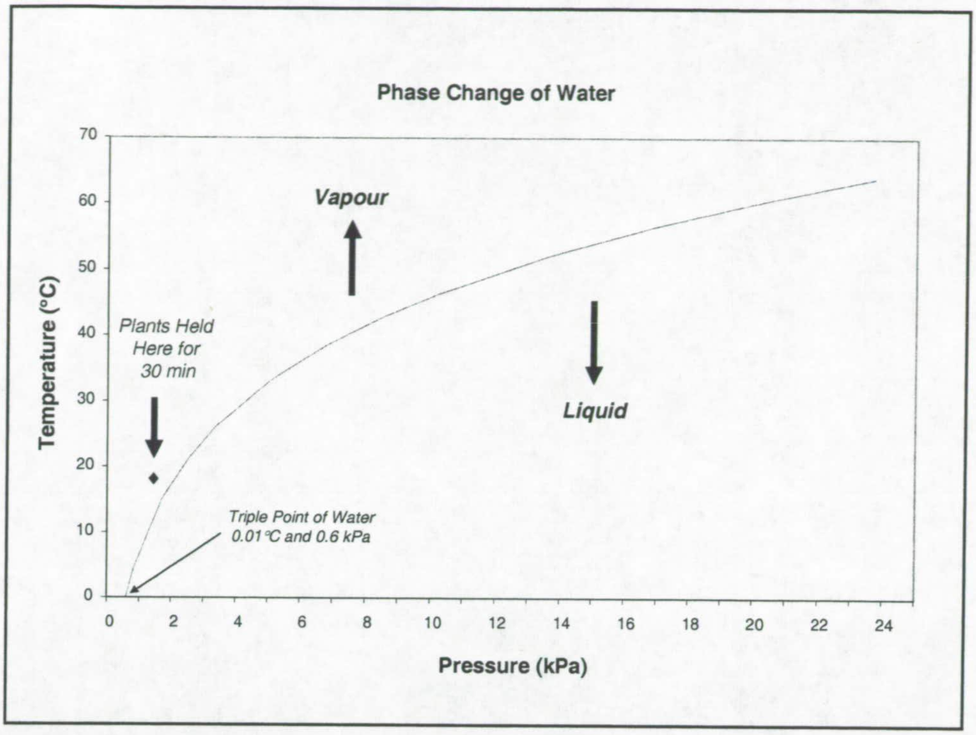

Radish Total DM (27 days)
Control
Pressure Drop
Dry Mass (g / plant)
5.0
4.0
3.0
2.0
1.0
0.0
33
98
Growth Environment (kPa)

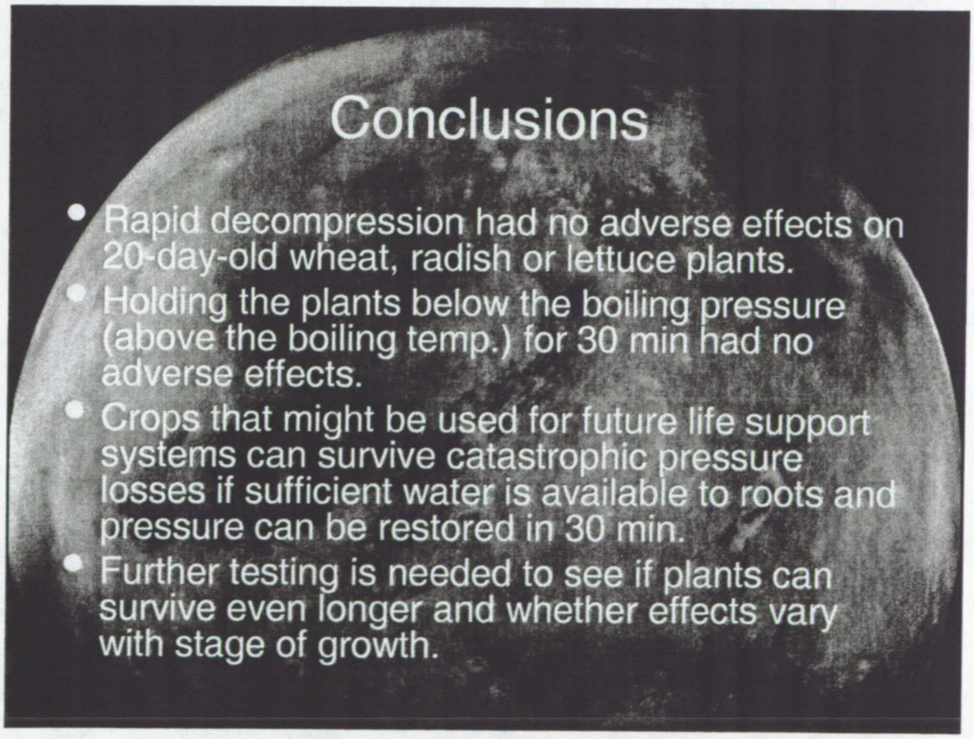

Wheat Fresh Mass (27 days)
Control
Pressure Drop
Total Plant Fresh Mass (g)
800
700
600
500
400
300
200
100
0
33
98
Growth Environment (kPa)

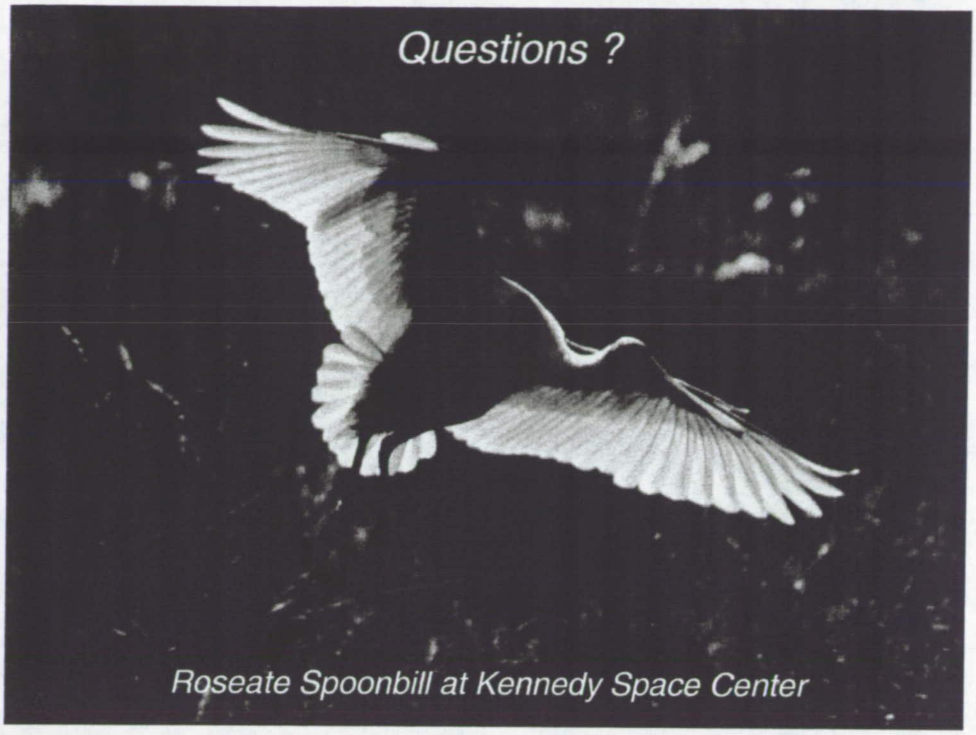




The triple point is the single combination of pressure and temperature at which pure water, pure ice, and pure water vapor can coexist in a stable equilibrium. This occurs at exactly 273.16 K (0.01 °C) and a pressure of 611.73 Pa (0.61173 kPa, or 0.0060373057 atm).


Phase Change of Water
Vapour
Liquid
Plants Held Here for 30 min
Triple Point of Water 0.01°C and 0.6 kPa
Temperature (°C)
Pressure (kPa)
0
10
20
30
40
50
60
70
0
2
4
6
8
10
12
14
16
18
20
22
24


Conclusions
Rapid decompression had no adverse effects on 20-day-old wheat, radish or lettuce plants.
Holding the plants below the boiling pressure (above the boiling temp.) for 30 min had no adverse effects.
Crops that might be used for future life support systems can survive catastrophic pressure losses if sufficient water is available to roots and pressure can be restored in 30 min.
Further testing is needed to see if plants can survive even longer and whether effects vary with stage of growth.


Questions ?
Roseate Spoonbill at Kennedy Space Center