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Feasibility of lettuce growth at hypoxic and sub-ambient total gas pressures

Summary

Lettuce (*Lactuca sativa* L. cv. 'Waldmann's Green') plants were grown (I) either from seed to 5 days old to study the effect of low atmospheric pressure (70 kPa) on their germination and early growth, or (ii) until maturity at 30 days old to determine any long-term growth effects. The data were compared to plants grown in a second matching chamber which was maintained at ambient pressure (101 kPa) that served as a control. In other experiments, plants were grown at ambient pressure until maturity and then subjected to low atmospheric pressure for periods of 24 hours to determine possible effects of intermittent low pressure. The O_2 and CO_2 partial pressures in the low pressure chamber were adjusted to levels equal to those in the ambient pressure chamber to prevent differences in plant response which would have resulted from differences in the partial pressure of those gasses. The O_2 partial pressure in the ambient chamber was maintained at 21 kPa and provision was made for additional CO_2 during the light phase. The germination rate and early seedling growth were insensitive to a low pressure environment. The rate of root elongation of plants grown at 70 kPa and at 101 kPa was also approximately the same. The rate of net carbon assimilation (per unit leaf area) of plants grown at low atmospheric pressure was unaffected at all growth stages even though plants grown at 70 kPa had slightly greater fresh and dry weights. There were consistent differences in assimilate partitioning, as shown by higher root/shoot ratios of plants grown at low pressure. Transpiration rates of plants grown until maturity under either constant or intermittent low pressure were reduced. Dark respiration rates of plants grown until maturity under either constant or intermittent low pressure were approximately 20% higher than the control plants

Background

Plants are an indispensable part of the Earth's ecology. They provide food for other organisms, evolve oxygen as they remove carbon dioxide from the air through photosynthesis, and purify water. These four key roles make plants an essential component in the development of Advanced Life Support Systems for space exploration. Controlled environment plant growth under optimal conditions can enhance three of those characteristics through an increase in the photosynthetic capacity of plants (Bugbee and Salisbury, 1988).

The National Aeronautics and Space Administration is pioneering the development of life support systems for a permanent lunar base. There are a number of reasons why it is preferable to maintain the atmospheric pressure within such systems at a lower than ambient total pressure: 1) A reduced pressure differential between the plant growth facility and its external environment would permit the use of less massive materials in its construction. 2) Reducing the mass of the plant growth facility would reduce the total lift-of payload to deploy the facility. 3) A lower pressure differential between the plant growth facility and its external environment would reduce atmospheric leakage from the plant growth facility. 4) The lower total pressure of the plant growth facility would require less N_2 gas to be transported to the facility to supplement the physiologically active gases (O_2 and CO_2).

The response of plants growing in a low atmospheric pressure environment has not been characterized in detail. There have been some predictions about possible effects on photosynthesis (Gale, 1972; Gale, 1973; Musgrave and Strain, 1988), but no long-term plant growth studies have been published to date.

System Description:

Two 66 L chambers are used to provide separate atmospheric pressure environments. The initial low pressure plant growth studies are being carried out with the total atmospheric pressure maintained at 100 kPa in one of the chambers (ambient control), and 70 kPa in the other chamber (low pressure). Oxygen is measured by an O_2 sensor in each of the chambers. CO_2 is measured by removing a small volume of gas from each chamber and sending it through an infrared gas analyzer (IRGA). The CO_2 level is controlled to a setpoint concentration only during the light phase. A pressure transducer mounted on each cylinder monitors the total pressure of gasses within each cylinder. Air temperature is measured by a thermocouple mounted inside each chamber. The air temperature is controlled by turning on or off the flow of coolant circulating through coolant loops mounted within each chamber. Plants are watered with a modified 1/2 strength Hoagland's solution using a peristaltic pump located outside the chambers. The water that is transpired by the plants is condensed on a coolant loop located inside each cylinder and collected in reservoirs outside of the cylinders. The condensate reservoirs are plumbed directly to the growth chambers as part of the closed sealed system. Atmospheric samples are collected by pumping full a syringe using a peristaltic pump connected to a sample port on each of the chambers. These samples are then run through a gas chromatograph to measure volatiles produced by the plants, such as ethylene.

RESULTS

Germination and Early Growth

Germination of lettuce seeds was unaffected by the pressure environment they were subjected to, as there were only very small differences in the percent germination.

The percent germination of lettuce seeds in the low-pressure chamber was 4.4% higher in the first study, while in the second and third experiments the percent germination in the low pressure chamber was 1.23% lower. In the second and third germination experiments the total length of the seedlings was not significantly different between the treatment and control plants ($p< 0.01$). Root elongation of plants grown at 70 kPa was similar to the control plants. There were no consistent differences between the fresh weights of seedlings grown at low pressure and the control plants. The average length of the roots was statistically different in the second low-pressure germination study ($p< 0.01$), but this was not a consistent effect when these results are compared with the root length data of lettuce plants in the first and third experiments. In the second experiment, roots of seedlings in the low-pressure chamber were elongating faster than those of control plants throughout the experiment. However, in the third study, root elongation was slightly higher initially for seedlings grown under low pressure, but not for the remaining two days of the experiment. Stem lengths of seedlings grown at low pressure in the second study were significantly shorter than those in the control chamber, but there were no significant differences in stem lengths between treatment and control plants in the third experiment ($p< 0.01$).

Long-term (30 and 31 day) Studies

The fresh weights of the tops of the plants grown at low pressure ranged from 1.19% to 14.59% greater than those of plants grown at ambient pressure. The dry weight of the tops of the plants grown at a lowered atmospheric pressure were from 3.81% to 6.73% greater than that of the control plants. The water content of the tops of the plants grown in either the low or ambient pressure chambers showed only slight differences in any of the three long-term studies.

The dry weight of the roots of plants grown at 70 kPa total pressure was from 15.9% to 29.7% greater than that of the ambient (101 kPa) pressure grown plants. The leaf areas of plants grown at low total atmospheric pressure in the first and second long-term experiments was slightly greater than the controls, but not in the third long-term experiment. There were very small and inconsistent differences in the photosynthetic rate (Psn) of plants grown in either pressure environment.

The amount of water transpired by plants grown at low pressure ranged from 1.73% to 24.9% lower than the controls. The root/shoot ratios for plants grown at low pressure was from 11.8% to 24.9% higher in all three experiments when compared with the control plants. There were no consistent differences in the specific leaf areas of plants in all three studies.

The rate of dark respiration was higher for the plants in the low-pressure chamber. The amount of CO_2 that had to be injected to maintain the setpoint CO_2 concentration was slightly lower in the low pressure chamber initially, but beginning on day 25 in the first experiment more CO_2 was used compared to the ambient chamber until the study was concluded on day 30. Ethylene concentrations were not different in either the low or ambient pressure chambers.

Low-Pressure Transient Studies

To determine if there are any differences in long and short term plant response to a low-pressure environment plants were grown from seeding to maturity at ambient pressure and then subjected to 70 kPa for alternating 24 h periods. The amount of dark respiration, as indicated by the increase in CO_2 when the lights in the growth chamber are turned off, was consistently higher for plants during the 24h 70 kPa periods in both short-term response studies. This is consistent with the data on nighttime CO_2 accumulation from the long-term low pressure experiments. During the second study, there was always less water being transpired during the low-pressure treatments, with a total of 51% more water transpired by plants under ambient pressure conditions. This effect is similar to the decrease in transpiration which was observed in the long term experiments as well.

References

Bugbee, B.G. and F.B. Salisbury. 1988. Exploring the limits of crop productivity. I. Photosynthetic efficiency of wheat in high irradiance environments. Plant Physiol. 88:879-878.

Gale, D.E. 1973. Experimental Evidence for the effect of barometric pressure on photosynthesis. In: "Plant response to climatic factors." Proceedings Uppsala Symposium (UNESCO) 1973 (Ecology and Conservation) p 289-294.

Gale, D.E. 1972. Availability of carbon dioxide for photosynthesis at high altitudes: Theoretical considerations. Ecology 53:494-497.

Musgrave, M.E. and D.R. Strain. 1988. Response of two wheat cultivars to CO_2 enrichment under sub ambient oxygen conditions. Plant Physiol. 87:346-350

Reports Issued

Spanarkel R, Drew MC 1996 The growth and gas exchange of lettuce at low atmospheric pressure. Plant Physiology **111** 72 (Abstract).
Spanarkel R, Drew MC 1995 The growth of lettuce at low atmospheric pressure. Plant Physiology **108** 58 (Abstract).