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FACTORS AFFECTING PLANT GROWTH IN MEMBRANE NUTRIENT DELIVERY

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ABSTRACT
The development of the tubular membrane plant growth unit for the delivery of water and nutrients to roots in microgravity has recently focused on measuring the effects of changes in physical variables controlling solution availability to the plants. Significant effects of the membrane pore size and the negative pressure used to contain the solution have been demonstrated. Generally, wheat (Triticum aestivum cv. Yecora Rojo) grew better in units with a larger pore size but equal negative pressure and in units with the same pore size but less negative pressure. Lettuce (Lactuca sativa cv. Waldmann's Green) also exhibited better plant growth at less negative pressure.

INTRODUCTION

A plant nutrient delivery system for microgravity is under development for the Controlled Ecological Life Support System (CELSS) Breadboard Project at the John F. Kennedy Space Center (KSC). This system utilizes a hydrophilic, porous tube to transfer solution (under a slight negative pressure) to plant roots which use capillary action to obtain water and nutrients through the pores (1, 2). Several different materials and configurations of the porous tube have been used to support plant growth and these trials indicated that the amount of negative pressure and the pore size of the material may have a significant effect on plant growth (3, 4). Two trials were conducted to test the effects of pressure and pore size on the growth of wheat

(*Triticum aestivum* cv. Yecora Rojo) and the effects of pressure on the growth of lettuce (*Lactuca sativa* cv. Waldmann's Green).

MATERIALS AND METHODS

The tubular membrane plant growth units used in the wheat trial and the porous tube plant growth units used in the lettuce trial were constructed as shown in Figures 1 and 2, respectively. The membrane used was a hydrophilic, acrylic (membrane) filter material and the porous tube a hydrophilic, polyethylene tube. A standpipe manifold system was located in a 1.8 by 2.4 m plant growth chamber. The manifold system utilized a centrifugal pump to maintain a constant solution level. A series of peristaltic pumps, one for each tube, was used to deliver nutrient solution from the plant growth units. The peristaltic pumps also exerted a slight negative pressure, preventing the solution from freely leaking from the porous tube. Negative pressure differential was monitored with a vacuum gauge and adjusted daily, if needed, using a valve located upstream to the plant growth units. Solution level in the reservoir was maintained by daily additions of fresh nutrient solution (modified one-quarter strength Hoagland's), and pH was controlled by the automatic addition of 1 M HNO_3. The chamber was programmed to provide a 18-h light, 6-h dark photoperiod with corresponding 20 C and 18 C for the wheat and 23 C and 20 C for the lettuce. Relatve humidity was set at 65 % with ambient CO_2 concentration and PPF at 300 umole s^{-1} m^{-2}.

Triplicates of each treatment were operated and maintained among a set of 20 units which were randomly arranged. The pressure treatments for the wheat trial included -0.4 kPa, -1.5 kPa, and -3.0 kPa with a pore size of 0.2 uM. The pore size treatments for the wheat trial were 0.2 uM and 5.0 uM with a pressure of -0.4 kPa. The pressure treatments for the lettuce trial were -0.2 kPa, -0.3 kPa, and -1.2 kPa.

RESULTS AND DISCUSSION

The results of the negative pressure and pore size treatments in the wheat trial are presented as Tables 1 and 2, respectively. Significant differences were found among the negative pressures and pore size treatments in all but three of the harvest variables using Analysis of Variance (ANOVA). The results of the negative pressure treatments in the lettuce trial are presented as Table 3. Significant differences were found in all the variables measured among the treatments. In general, better plant growth occurred at less negative pressures and in the units with the larger pore size material. Recent measurements suggest that leaf photosynthetic gas exchange, transpiration and water potential in wheat are reduced at greater negative pressures, indicating a real-time effect on plant growth. These same measurements on lettuce have been unsuccessful due to the fragile nature and high latex content of lettuce leaves.

CONCLUSIONS

Significant effects of negative pressure on the growth of wheat and lettuce have been observed when these plants were grown in the tubular membrane/porous tube plant growth units. The measurements of leaf transpiration, water potential, and photosynthetic gas exchange rates should provide more insight into causal factors. Pore size was also found to affect wheat growth in the tubular membrane units. We suspect that both factors should exert direct effects on hydraulic conductivity, and consequently water and nutrient availability to the plants, and further tests of physical properties of these materials are underway. If water and nutrient avaliability are affected, negative pressure and pore size should affect plant growth independent of what configuration is used and may have greater or lesser effects dependent upon the species of plant grown. It is also believed that negative pressure and pore size interact and that adjustments in the suction may be used to overcome the effects of pore size and vice versa. The understanding of these and similar interactions between controlling variables is critical to the development of membrane nutrient delivery systems for crop production in a CELSS.

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Table 1. Data from the pressure treatments of the wheat trial. Significant differences (alpha≤0.05) denoted by "S".

Harvest variable	Treatment 1 -0.4 kPa Mean/Std. Er.	Treatment 2 -1.6 kPa Mean/Std. Er.	Treatment 3 -2.4 kPa Mean/Std. Er.
Spikelet No.- Primary heads	16.67/0.13	15.78/0.23	14.08/0.61 S
Spikelet No.- Other heads	15.44/0.05	12.83/0.88	12.22/1.40
Seed No.- Primary heads	18.83/0.62	16.50/1.29	12.93/0.47 S
Seed No.- Other heads	7.67/0.58	3.87/0.64	4.40/1.80
Primary seed- gdw/plant	0.78/0.02	0.67/0.06	0.48/0.03 S
Other seed- gdw/plant	0.29/0.02	0.15/0.03	0.17/0.07
Seed-gdw/plant	1.07/0.04	0.82/0.04	0.66/0.09 S
Root-gdw/plant	0.34/0.03	0.21/0.02	0.19/0.02 S
Chaff-gdw/plant	0.34/0.01	0.29/0.03	0.25/0.02 S
Straw-gdw/plant	0.87/0.02	0.56/0.03	0.45/0.04 S
Total-gdw/plant	2.48/0.12	1.88/0.10	1.55/0.15 S
Primary heads- gfw/plant	1.93/0.07	1.50/0.12	1.01/0.09 S
Other heads- gfw/plant	0.79/0.05	0.38/0.05	0.09/0.03 S
Root-gfw/plant	5.63/0.18	3.53/0.28	2.50/0.06 S
Straw-gfw/plant	2.47/0.07	1.47/0.07	0.99/0.16 S
Total-gfw/plant	10.83/0.22	6.89/0.04	4.59/0.27 S

Table 2. Data from the pore size treatments of the wheat trial. Significant differences (alpha≤0.05) are denoted by "S".

Harvest variable	Treatment 1 -0.4 kPa 0.2 micron Mean/Std. Er.	Treatment 4 -0.4 kPa 5.0 micron Mean/Std. Er.
Spikelet No.- Primary heads	16.67/0.13	17.40/0.07 S
Spikelet No.- Other heads	15.44/0.05	16.29/0.39
Seed No.- Primary heads	18.83/0.62	33.03/2.51 S
Seed No.- Other heads	7.67/0.58	41.37/2.81 S
Primary seed- gdw/plant	0.78/0.02	1.28/0.03 S
Other seed- gdw/plant	0.29/0.02	1.57/0.13 S
Seed-gdw/plant	1.07/0.04	2.85/0.10 S
Root-gdw/plant	0.34/0.03	0.33/0.02
Chaff-gdw/plant	0.34/0.01	0.74/0.05 S
Straw-gdw/plant	0.87/0.02	1.48/0.04 S
Total-gdw/plant	2.48/0.12	5.40/0.14 S
Primary heads- gfw/plant	1.93/0.07	2.97/0.15 S
Other heads- gfw/plant	0.79/0.05	3.89/0.38 S
Root-gfw/plant	5.63/0.18	5.53/0.29
Straw-gfw/plant	2.47/0.07	4.80/0.15 S
Total-gfw/plant	10.83/0.22	17.18/0.69 S

Table 3. Data from the pressure treatments of the lettuce trial. Significant differences (alpha≤0.05) denoted by "S".

Harvest variable N=3 (mean/unit)	Treatment 1 -0.2 kPa Mean/Std. Er.	Treatment 2 -0.3 kPa Mean/Std. Er.	Treatment 3 -1.2 kPa Mean/Std. Er.
Head fresh weight (g)	5.09/0.79	1.74/0.52	0.72/0.25 S
Head dry weight (g)	0.62/0.05	0.28/0.04	0.09/0.03 S
Root dry weight (g)	0.17/0.03	0.10/0.01	0.04/0.01 S
Total dry weight (g)	0.79/0.07	0.37/0.05	0.13/0.04 S

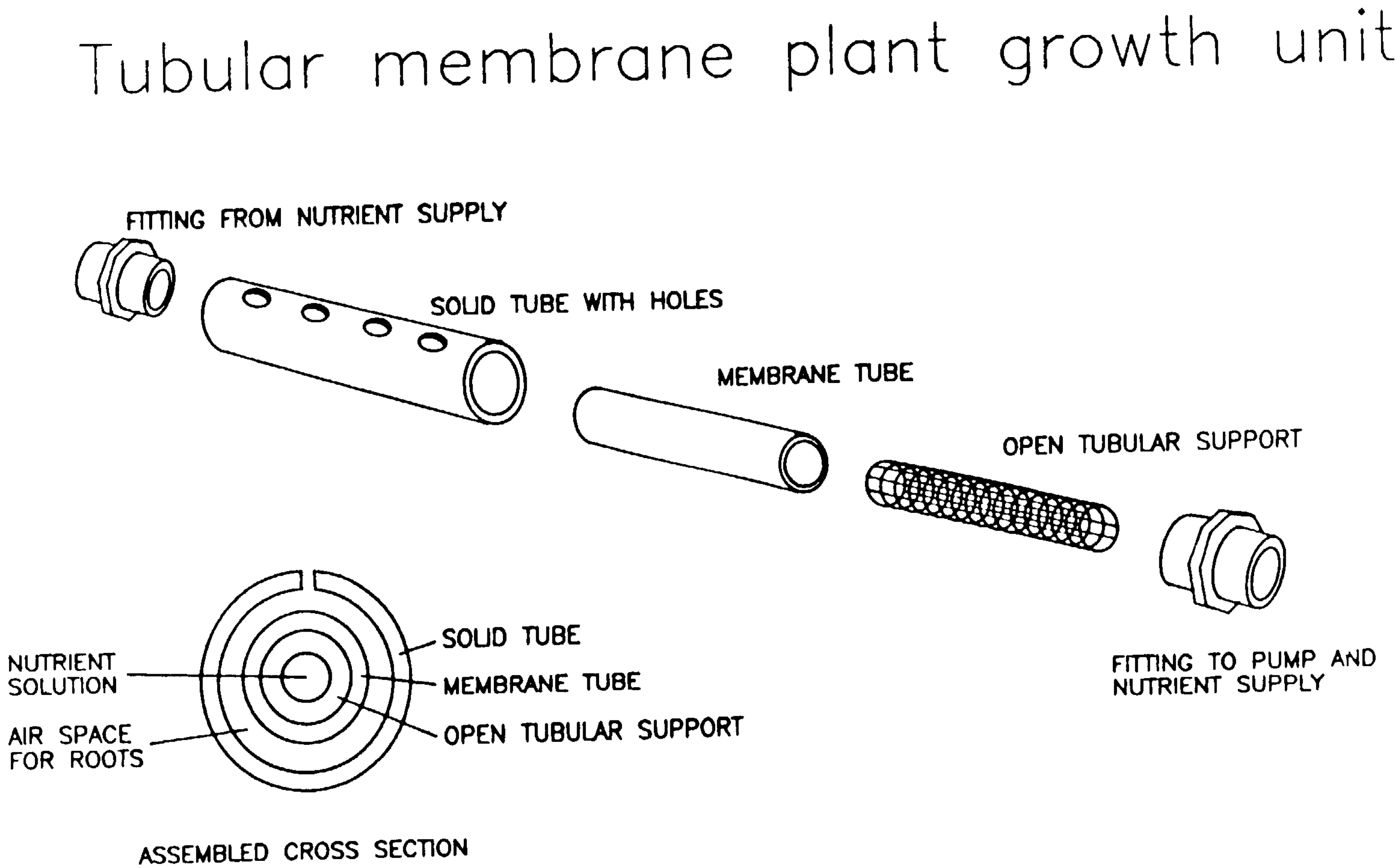

Figure 1. Schematic diagram of the Tubular Membrane Plant Growth Unit used in the wheat trial.

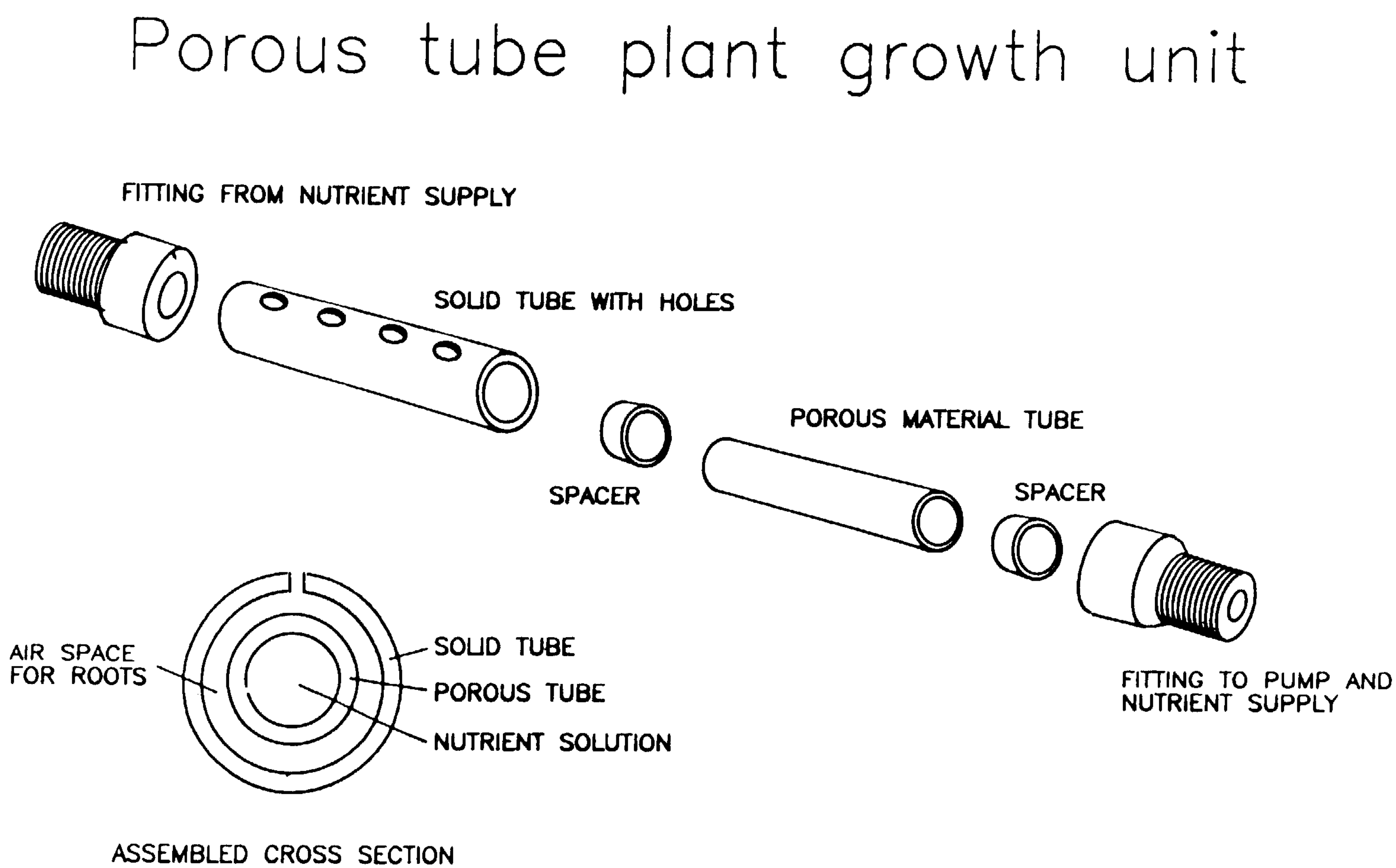

Figure 2. Schematic diagram of the Porous Tube Plant Growth Unit used in the lettuce trial.