HORTSCIENCE 25(6):707. 1990.

A Porous Stainless Steel Membrane System for Extraterrestrial Crop Production

Harold V. Koontz
Department of Ecology and Evolutionary Biology, University of Connecticut, Storrs, CT 06268

Ralph P. Prince
NASA, Mail Code MD-RES, Kennedy Space Center, FL 32899

Wade L. Berry
Laboratory of Nuclear Medicine and Radiation Biology, University of California, Los Angeles, CA 90024

Additional index words. hydroponics, *Lactuca sativa*

A system was developed in which nutrient flow to plant roots is controlled by a thin (0.98 or 1.18 mm) porous (0.2 or 0.5 μm) stainless steel sheet membrane: The flow of nutrient solution through the membrane is controlled by adjusting the relative negative pressure on the nutrient solution side of the membrane. Thus, the nutrient solution is contained by the membrane and cannot escape from the compartment even under microgravity conditions if the appropriate pressure gradient across the membrane is maintained. Plant roots grow directly on the top surface of the membrane and pull the nutrient solution through this membrane interface. The volume of nutrient solution required by this system for plant growth is relatively small, since the plenum, which contains the nutrient solution in contact with the membrane, needs only to be of sufficient size to provide for uniform flow to all parts of the membrane. Solution not passing through the membrane to the root zone is recirculated through a reservoir where pH and nutrient levels are controlled. The size of the solution reservoir depends on the sophistication of the replenishment system. The roots on the surface of the membrane are covered with a polyethylene film (white on top, black on bottom) to maintain a high relative humidity and also limit light to prevent algal growth. Seeds are sown directly on the stainless steel membrane under the holes in the polyethylene film that allow a pathway for the shoots (Fig. 1).

The use of a porous membrane for control of water and nutrients for plant growth is based on the work of Wright (1984), Wright et al. (1988), Dreschel et al. (1987), and Koontz and Koontz (1987). They used a plastic membrane, however, which is difficult to reuse and is not dimensionally stable. The plastic (Versapor, Gelman Sciences, Ann Arbor, Mich.) membrane (filter) expands ≈2% when wetted. However, Dreschel et al. (1987) and Koontz and Koontz (1987) showed that plants could be grown on a membrane to an edible size. The design by Wright et al. (1988) was for the use in short-duration growth periods.

Our prototype plant growth tray was constructed of 49,400 mm^2 (200 × 247 mm) porous stainless steel (type 316) sheet mounted on a polyvinyl chloride plastic framework: Nutrient solution flowed under the stainless steel sheet in a 6-mm deep plenum. The 0.25-strength Hoagland nutrient solution was circulated through the system with a peristaltic pump providing a flow rate of 100 $ml \cdot min^{-1}$ and ≈25 mm of water negative pressure under the porous sheet. The pH and temperature of the recirculated nutrient solution were maintained at 5.9 ± 0.2 and 23 ± 0.3C, respectively.

The relative humidity and temperature of the canopy were 68 ± 5% and 23 ± 0.5C, respectively. Cool-white fluorescent lights provided 250 $\mu mol \cdot s^{-1} \cdot m^{-2}$ photosynthetic photon flux at the canopy top of 2-week-old plants. The CO_2 was ambient at ≈350 $\mu mol \cdot mol^{-1}$.

Four 'RubyConn' loose-leaf lettuce plants (*Lactuca sativa* L.) grown for 33 days obtained top fresh and dry weights of 64, 51, 65, and 59 g each. The average fresh and dry weights were 60 and 4.2 g, respectively. The root average dry weight was 1.0 g.

Since the first experiment noted, we have obtained a 58% increase (12 plants in three trays averaged 95 g in only 28 days) in the top fresh weight of leaf-lettuce plants, mainly by reducing the negative pressure of the nutrient solution under the membrane to just below zero (just enough negative pressure to keep the solution from oozing through the pores) and by doubling the atmospheric CO_2 concentration.

Root hairs that were ≈10 μm in diameter did not penetrate the stainless steel membrane; however, the membrane, being of sintered construction, contained a few pores of sufficient size to allow a few root hairs to partially penetrate and thus anchor the root mat securely to the membrane. This feature, coupled with the ability of the system to deliver water and nutrients to the roots at a controllable rate, makes a membrane system highly desirable for use in microgravity and other experimental conditions. The plants grown on this stainless steel membrane have not shown toxic symptoms from metallic components, and elemental tissue analysis (arc emission spectrography) showed very low levels of Cr, Ni, and Mo. Stainless steel or titanium membranes, which have been used in plant growth trials, exhibit strength and durability not shown by similar plastic membrane systems, characteristics that are highly desirable in space environments where repair and maintenance may be difficult.

Literature Cited

Dreschel, T. W., R.P. Prince, C.R. Hinkle, and W.M. Knott. 1987. Porous membrane utilization in plant nutrient delivery. Presented to the Amer. Soc. Agr. Eng. June 28-July 1. Baltimore, Md. Paper no. 87-4025.

Koontz, Harold V. and R.F. Koontz. 1987. Hydroponic membrane system for extraterrestrial crop production. HortScience 22:1060. (Abstr.)

Wright, B.D. 1984. A hydroponic method for plant growth in microgravity. 35th Cong. Intl. Astronautical Fed., Lausanne, Switzerland. Amer. Inst. of Aeronautics and Astronautics, Paper no. IAF-ST-84-05.

Wright, Bruce D., W.C. Bausch, and W.M. Knott. 1988. A hydroponic system for microgravity plant experiments. Trans. Amer. Soc. Agr. Eng. 34(2):440-446.

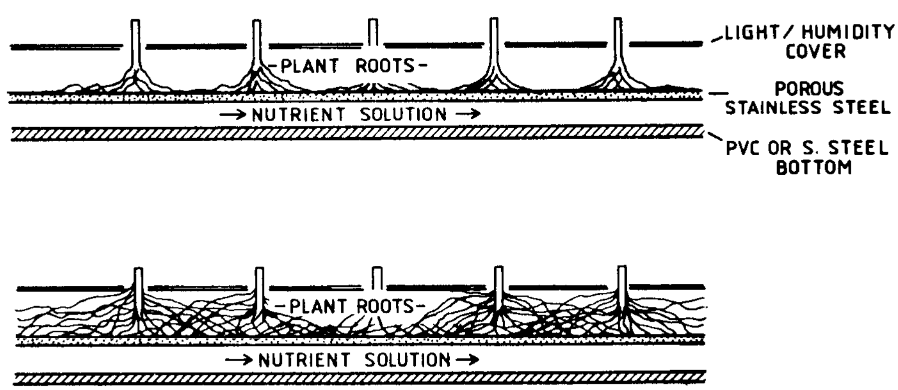

Fig. 1. Diagrammatic cross section of a microgravity plant growth tray showing a high-density crop (such as wheat). The nutrient solution is under a slight negative pressure. As the plants mature, the roots stack up **(bottom)** with younger roots next to the porous stainless steel sheet (membrane).

Received for publication 27 Feb. 1989. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.