

Electrochemical Control of pH in a Hydroponic
Nutrient Solution

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ABSTRACT

The pH of hydroponic nutrient solution is usually controlled by addition of dilute acid or base solutions. In a CELSS, this sort of control would eventually produce an accumulation of the elements composing the acid and base. This paper describes the utilization of an electrochemical cell for pH control, and discusses its effects on hydroponically grown lettuce.

INTRODUCTION

In a functional CELSS system, a large number of environmental variables will require careful monitoring and control. One environmental variable of major importance for the higher plants will be the pH of the hydroponic nutrient solution. During the growth cycle of higher plants, individual nutrient elements are taken up in different amounts, and at varying rates. As a result, the pH of the nutrient solution changes. Additionally, plants release a variety of organic compounds into the nutrient solution, and these compounds also change the pH of the solution. Consequently, the pH of the nutrient solution shifts with the changes produced by the uptake/release of substances in the nutrient solution.

Nutrient solution pH is usually controlled by adding either dilute acid or base to maintain the desired value. There are two problems with this technique in a CELSS, however. First, the use of acid and base for pH control adds the chemical elements of those compounds to the nutrient solution, and eventually may produce an accumulation of those elements. The effects of this accumulation have not been determined experimentally for higher plants, but in bacterial chemostats, such accumulations can retard the growth of the cultured cells (1). Secondly, the use of dilute acidic or basic solutions requires that suitable concentrates be carried along with the CELSS unit in order to mix the required solutions. These concentrates could add significantly to the amount of mass required to assemble a functional CELSS.

An alternative method of pH control, the use of an electrochemical cell, circumvents both of these problems. The use of an electrochemical method of pH control presents a possible problem, however, in that the compounds in the nutrient solution could potentially be affected by the flow of electrons. The focus of this paper is to describe an experiment in which conventional chemical pH control was compared with electrochemical pH control, with regard to both the efficiency of the electrochemical system and to any effects it might have on the growth of higher plants.

MATERIALS AND METHODS

Seedlings were prepared for the experiment by germinating Lettuce (Lactuca sativa, cv. Grand Rapids) seeds between sheets of filter paper suspended over standard ASHS nutrient solution (2). Opaque plastic covers were placed over the seeds to maintain humidity and enhance hypocotyl elongation. The covers were removed 4 days after sowing, and 3 days later the seedlings were transferred to an NFT nutriculture system located inside a controlled environment room. Each seedling was held in the nutriculture system in a polyurethane foam plug, treated to prevent toxicity to the seedlings (3). Two identical nutriculture systems were used, each consisting of a 120 l nutrient reservoir, a magnetically coupled pump to circulate the solution, a supply manifold of PVC pipe, 4 troughs (1.5 m long by 12.7 cm wide) made of PVC vinyl gutter, and a drain manifold of PVC which returned the nutrient solution to the reservoir. The troughs for the control and experimental groups were arranged in alternating order across the width of the environment room to minimize the effects of any environmental gradients on the experiment. Trough covers were made from 3mm thick PVC vinyl sheet, cut to cover each trough completely. Each cover was drilled with 31 holes (1.6 cm diameter) on 3.8 cm centers through which the polyurethane plugs holding the seedlings were inserted. For each experiment, 100 l of modified Hoaglands solution (2) was used in each reservoir. Nutrient solution was maintained at a constant volume in both reservoirs during the experiment by a level-controlling float

relay connected to a pump and a make-up reservoir filled with deionized water. Water use was monitored by recording the amounts of make-up water added.

Environment room air temperature was controlled at 25/20°C D/N. Relative humidity was maintained at 70%. CO₂ concentration was monitored and controlled at 1200 ppm. PAR was supplied by four 400 W metal halide HID and two 400 W high pressure sodium lamps, producing an average total irradiance of 550 $\mu\text{mol}/\text{m}^2/\text{s}$. Photoperiod was 16h/8h D/N.

The pH control system was identical for both nutrient solutions, and consisted of a pH electrode, a pH controller with high and low limit switches (Chemtrix 45e), and the pH controlling hardware. In the control reservoir, the hardware consisted of two peristaltic pumps, one connected to a reservoir of 0.1N HCl, and the other connected to a reservoir of 0.1N KOH. In the experimental reservoir, the pH control system consisted of two platinum wires, one placed directly in the nutrient solution, and the other placed in an agar bridge partially submerged in the solution. The two wires were connected to a DC power supply (1).

In the conventional pH control system, the pH controller applied power to the acid or base pumps to add the required chemical. In the electrochemical reservoir, the pH controller added "acid" or "base" by turning on one of a pair of relays which determined the polarity of the electrodes and applied a voltage across them. The relays applied a voltage of either +45 V DC or -45 V DC across the platinum electrode wires,

depending on whether the pH was too high or too low.

Plants were harvested at 14, 21 and 28 days of age. For the first two harvests every other plant from each trough was removed, thus thinning the plants as well as providing data on growth. For the third and final harvest, all the remaining plants in each trough were removed. Fresh weights were determined, the plants dried to constant weight at 60°C, and the dry weights measured.

RESULTS

Figure 1 illustrates the record of nutrient solution pH for the two nutrient reservoirs. As can be seen from this figure, the electrochemical cell lost some control capability near the end of the experiment.

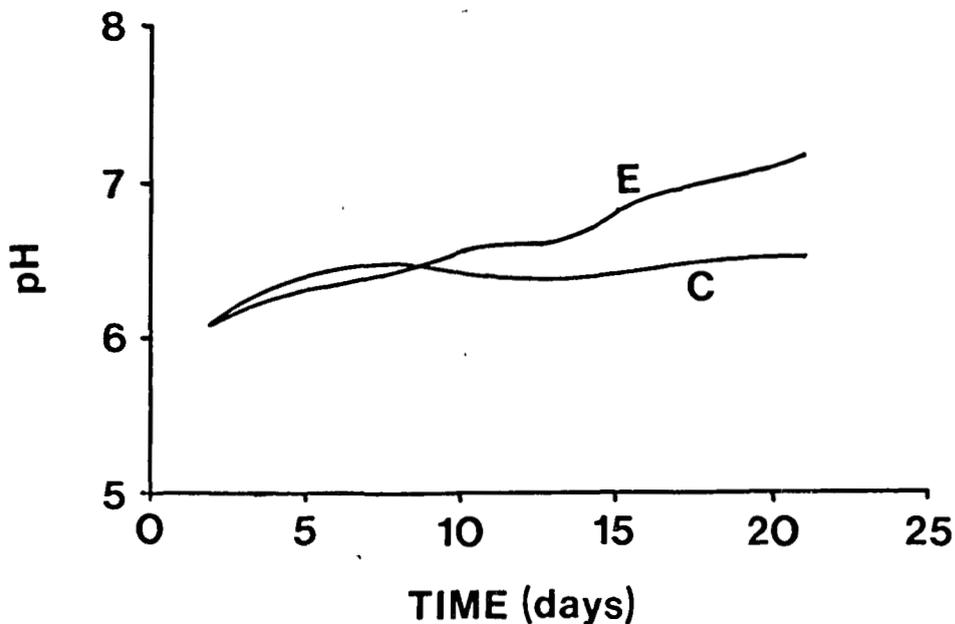


Figure 1. Nutrient solution pH versus time for control (C) and electrochemically-controlled (E) reservoirs.

Table 1 presents biomass data collected from the lettuce plants harvested from the control and experimental treatments. These data indicate that both the control and experimental treatments produced the same results with regard to plant growth.

Table 1. Average sizes of harvested plants for control and electrochemically-controlled (experimental) groups.

Harvest Age (Days)	Fresh Weight(gm)		Dry Weight(gm)	
	Control	Experimental	Control	Experimental
14	0.43	0.40	0.03	0.03
21	9.21	9.44	0.57	0.60
28	74.29	71.85	3.49	3.37

DISCUSSION

The most serious problems encountered with the electrochemical pH control method seem to be related to the design of the agar bridge. This bridge design worked well at low current densities, but near the end of the experiment did not operate at sufficiently high current flow to correct the pH, and consequently the nutrient solution pH tended to drift out of bounds. Additionally, the limited volume of electrolyte in the cell (approximately 200 ml) required replacement every 24 hours in order to maintain a sufficient pool of electrolytes for pH control.

Despite these difficulties, the electrochemical control method worked well, and there were no detectable differences between the lettuce plants grown in the electrochemical system and the conventional control system. Apparently, there was no accumulation of toxic or inhibitory compounds in the electrochemically controlled nutrient solution. This finding provides support for the idea of using electrochemical pH control for CELSS applications.

From the pH record in Figure 1, however, it seems advisable to develop a new electrode design for long term use. This development is currently in progress.

CONCLUSION

The electrochemical pH control system described here was found to provide a feasible alternative method of controlling nutrient solution pH for CELSS applications. The plants grown in nutrient solution in which the pH was controlled electrochemically showed no adverse effects. Further research into the design of a larger capacity electrode bridge for better control is indicated by the results of this experiment, and is currently under way.

LITERATURE CITED

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