

SYSTEM DESIGN AND ANALYSIS OF A CONTINUOUS MONITORING OF  
THE ENVIRONMENT IN NUTRIENT SOLUTION CULTURE

S. Ben-Yaakov<sup>1</sup> and J. Ben-Asher<sup>2</sup>

Ben-Gurion University of the Negev  
Beer Sheva  
Israel

Key words: Hydroponics, solution culture.

ABSTRACT

A simple system for monitoring the environment of the nutrient solution in a hydroponic system has been designed and constructed. The system is capable of continuously measuring four parameters; temperature, pH, dissolved oxygen (DO) and electrical conductivity (EC). Unique features of the system include auto-calibration of the DO sensor and application of the four electrode principle for conductivity measurement. Results from a typical measuring day have revealed a daily cycle of pH and DO. These oscillations are explained by the large differences between air and water temperature. It was found that the efficiency of aeration was reduced when warm (45°C) greenhouse air was injected into relatively cold (25°C) nutrient solution. The present study suggests that continuous monitoring of the nutrient solution can improve its management and control as compared to the classical method of periodical analysis when growing plant hydroponically.

### INTRODUCTION

The growing of plants hydroponically is now being practiced in many countries around the world. Hydroponics offer control of the rooting medium and thus have important management advantages. Since the cost of such installations has been high, it must ensure a higher and better yield. In order to achieve this, complete control of the rooting environment is required. A comprehensive review of the various techniques of solution culture indicated that the primary objectives of most experiments have been the determination of optimal nutrient concentration; i.e., pH, temperature and dissolved oxygen<sup>3,4</sup>. This was done mainly by the elaborate methods of analytical chemistry or alternatively by intuitive correlation between electrical conductivity and total nutrients in the solution<sup>5</sup>. Furthermore, because of difficulties in determining the major components of a commercial nutrient solution, the recommended testing interval is two to four weeks<sup>6</sup>, while in some cases the time for complete depletion of nutrients can occur in five to thirty minutes<sup>7</sup>. To overcome the discrepancy between optimal testing frequency and time required for it, a continuous monitoring system is required, which can benefit both the commercial producer as well as the researcher.

Depletion of various nutrient elements with time is important for calculations of their uptake rate by plants. This in itself can be a tool for studying the kinetics of ion uptake. Finally, when the variables mentioned below are detected simultaneously, the phenomena occurring within the nutrient solution can be better understood.

A novel instrumentation system was designed and constructed to permit the continuous recording of pH, air (Ta) and water (Tw) temperature, dissolved oxygen (DO) and electrical conductivity (EC) in the nutrient solution during use. Among the unique features of the system are autocalibration of the DO sensor, application of a four electrode sensor for EC measurements and

complete galvanic isolation to eliminate interferences between the sensors due to ground loops (as discussed below). Design details of the DO and EC measuring sub-units will be given elsewhere<sup>8,9</sup>. On this page, we describe the design of the complete system and present typical data that was collected.

### SYSTEM DESIGN

The measuring system (Fig. 1) consists of four sub-units for measuring pH, temperature (T), DO and EC. DO was measured by a membrane covered voltametric sensor<sup>10</sup>, conductivity by a four electrode sensor, pH by a glass combination electrode and temperature by a thermistor. The sensors are placed in a flow-through cell through which the nutrient solution is circulated by means of a submersible centrifugal pump. Autocalibration of the DO sensor is accomplished by arresting the operation of the pump, thereby allowing air to replace the solution in the DO sensor compartment (Fig. 1). Calibration then proceeds by assuming a standard atmosphere and self adjustment of the instrument to 108% saturation. The 8% increase is required to take into account the difference in the sensor's sensitivity between air (gas phase) and air saturated solution. Following the autocalibration cycle, the pump is turned on to resume normal operation.

A major effort was invested in isolating the sub-units one from the other to eliminate problems associated with ground loops. This problem could be especially severe in a multisensor system when all sensors (except those for temperature) have a galvanic connection to the solution, either by a direct contact (conductivity and reference electrode) or by leakage (DO sensor). The problem was overcome by providing a floating power supply for each sub-unit by using a galvanic isolation<sup>11</sup> at the output (Fig. 1). The electronic package and the flow-through cell are shown in Figure 2.

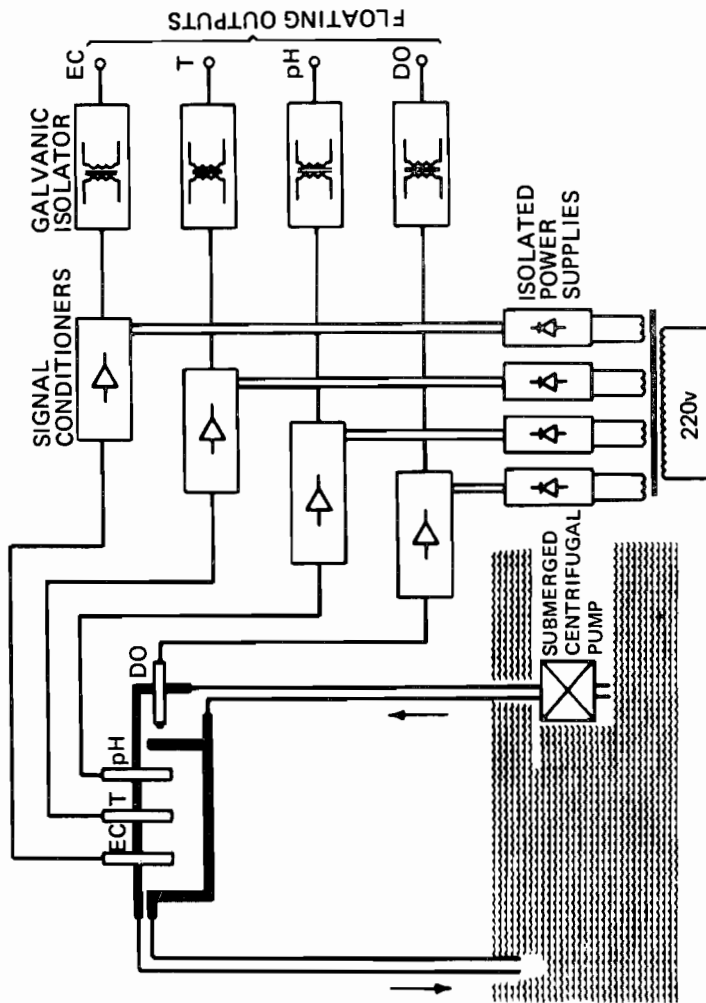


FIG. 1 A schematic presentation of the monitoring system.

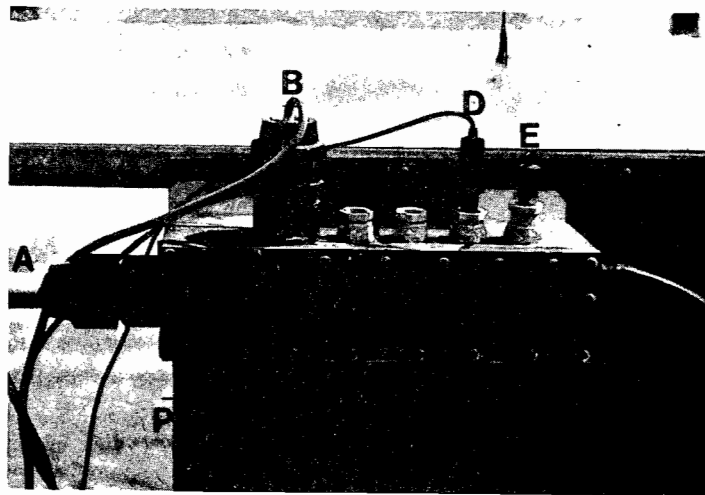
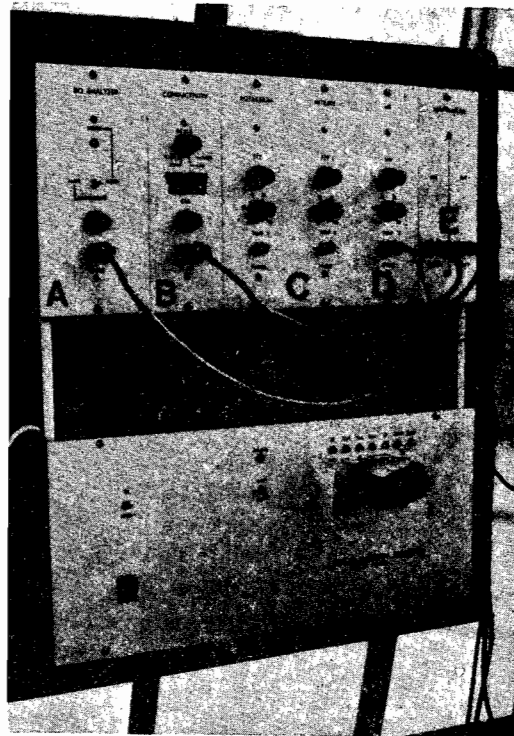


FIG. 2 The electronic package and the flow-through cell. The letters are indicating the sensors and the electronic cards as follows:  
A : DO, B : EC, C : room for specific ion electrodes, D : pH, E : temperature. P and O on the cell are the water pipes in and out of the cell respectively.

### EXPERIMENTAL

Tomatoes (*Solanum Lycopersicum* cv. Naama) was used as the indicator plant. Seedlings were transplanted into water contained in 3-m long channels with depth of 30 cm and width of 40 cm. A small 23-watt pump (Redmond Amcor, Israel) connected the extremes to form a closed circulation. A small aquarium air pump injected air into the water. The sensors were calibrated against commercial instruments commonly used for the same purposes. The DO meter was compared to MBK DO meter. The pH and conductivity sensors were calibrated against a El Hama (Israel) pH meter and conductivity bridge. The EC sensor was correlated against the solution concentration of K and  $\text{NO}_3$ . K was analysed by Corning flame photometer and  $\text{NO}_3$  analysis was carried out in duplicate using NAS reagent (diphenylaminesulfonic acid chromogen) supplied by the Research and Development Authority of the Ben-Gurion University of the Negev. A linear correlation was found between the reading of the conductivity sensor and the concentration of the two ions. It was then used as a specific ion electrode. The flow-through cell containing the sensors was connected to the system by the same type of pump and operated continuously throughout 250 days of the growing season. The signals were recorded on a multi-point recorder for a scale of 0 - 1 volt. The salts used were according to Hoagland and Arnon<sup>12</sup>. Macro-elements were introduced as  $\text{KNO}_3$ ,  $\text{KH}_2\text{PO}_4$ ,  $\text{Ca}(\text{NO}_3)_2$ ,  $\text{MgSO}_4$  and  $\text{NH}_4\text{H}_2\text{PO}_4$ . Distilled water was added to the system automatically to keep water level constant and to prevent any increase in electrical conductivity due to increased salinization caused by water loss through transpiration. When the plants were at their full activity, a set of 21 days of continuous measurements was taken. From this set a representative day is presented in this paper.

### RESULTS AND DISCUSSION

A typical example of recorded values from five sensors for 24 hours is given in Figure 3. The vertical lines which appear

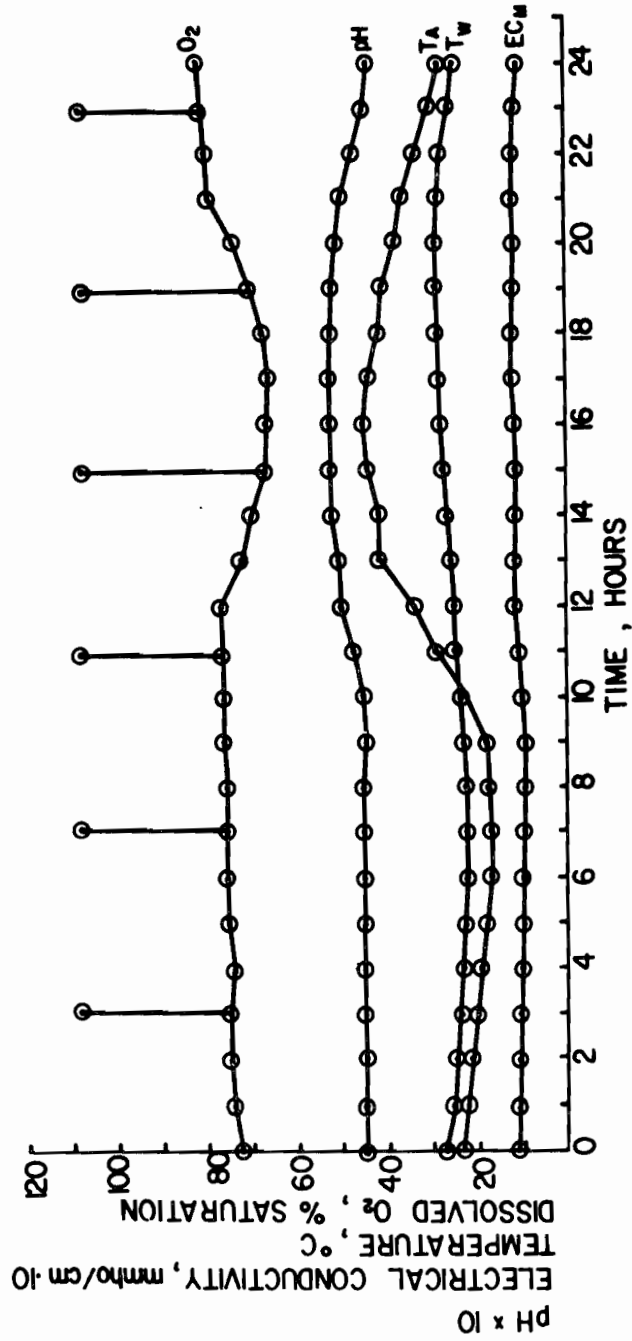


FIG. 3 An example of data recorded throughout a twenty-four hour period.

every four hours along the records of DO indicate calibration periods of the self-calibrating DO system. This period lasted only 4 minutes (which is about 2 percent of the total measuring time) and therefore did not disturb the continuous reading. The dependence of DO concentration on temperature and daylight hours is clearly shown.

An equilibrium condition can be seen during night hours at about 77 percent saturation. This equilibrium is reached when the  $O_2$  uptake rate is equal to the  $O_2$  injection rate by the air pump. When the injection rate is reduced because of environmental changes, DO in the solution is also reduced due to plant uptake. Since uptake rate is a function of concentration, its rate decreased until a new equilibrium was reached. This behaviour of the DO-curve can best be explained by relating the changes to the simultaneous records of temperature. When air and water temperature increased from 18 to 45°C and from 23 to 28°C, respectively, the DO reduced from 78 to 66 percent of saturation. This is equivalent to a reduction from 6.5 to 5.2 ppm. These relatively large changes occurred even though air injection remained constant. The phenomena can be explained by two mechanisms:

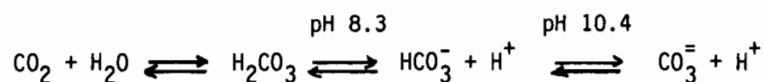
- (i)  $O_2$  consumption by active roots, an effect more pronounced during daylight hours, and
- (ii) the large deviation between air and water temperatures ( $T_a$  and  $T_w$ ).

Oxygen injection is a function of air temperature which presumably controls the temperature of the air-solution interface. Solubility of  $O_2$  at 28°C (at the 16th hour of experiment) is 7.9 mg/l, whereas the solubility at 45°C is only about 6.1 mg/l. Hence, the upper limit of DO in the solution is 6.1 mg/l, which is 77 percent of saturation at the temperature of the solution. Thus, the difference between the upper limit and the actually measured value (5.2 mg/l) is due to both  $O_2$  consumption by the roots and the partial control of  $O_2$  solubility by the temperature of solution.

For most plants, a moderately acid reaction (pH 5 - 6.5) must be maintained to ensure that phosphorus and the micro-



nutrients remain in solution. In Figure 3, the increase of pH from 4.5 to 5.2 during daylight hours is related to the decrease in solubility of  $\text{CO}_2$  in water. When water temperature increases from 23 to 28°C, solubility of  $\text{CO}_2$  in the water decreases by about 14%. This reduction in  $\text{CO}_2$  reacts with carbonate-bicarbonate system as follows:



The reaction is directed toward the left side of the equation when the pH is acid. When the  $\text{CO}_2$  concentration is reduced as a result of temperature increase, more hydrogen ions are taken from the solution to form  $\text{CO}_2 + \text{H}_2\text{O}$  as indicated by the above equation. Quantitatively, reduction of 0.0257 mMole/l of  $\text{H}^+$  ions is equivalent to loss of 1.13 mg/l  $\text{CO}_2$ . The changes in temperature of the water can thus be used for evaluation of changes in  $\text{CO}_2$  concentration.

An earlier nutritional study<sup>5</sup> suggested that the range of tolerance of plants in solution culture to the nutrient supply is sufficiently large to be monitored by measurements of electrical conductivity as a quantitative estimation for nutritional conditions. We have used the conductivity sensor to measure the concentration of  $\text{K}^+$  and  $\text{NO}_3^-$  during the growing season. The linear relationship between conductivity and concentration was found to be:

$$\text{for K : } C_K = 143.0 \text{ EC} - 90.2 \quad (1)$$

$$\text{for NO}_3: C_{\text{NO}_3} = 500.9 \text{ EC} - 132.4 \quad (2)$$

According to Figure 3, the concentrations were 67.1 ppm for K and 418.6 ppm for  $\text{NO}_3$  throughout the entire measuring day. Although a slight increase of conductivity is associated with the increase in water temperature, correction coefficients show that these differences are negligible. This means that no significant changes

of nutrient concentration occurred during the sampled period. It further supports the assumption that the changes in pH are due to CO<sub>2</sub> and not to other chemical changes.

#### CONCLUSION

Application of a monitoring system has demonstrated the importance of continuous measurements of DO, Ta and Tw in addition to the detection of pH and EC. The last two variables are sampled periodically with some hydroponic systems, but it may be insufficient for complete control of the nutrient solution within a greenhouse. Large differences between air and water temperature frequently occurred in the greenhouse throughout daytime hours. These differences resulted in a daily cycle of DO concentration and pH values. These significant fluctuations should be taken into account when optimal conditions are required for controlling the rootzone environment.

#### REFERENCES

1. Associate Professor, Department of Electrical Engineering.
2. Senior Lecturer, The Jacob Blaustein Institute for Desert Research and the Department of Biology.
3. I W O S C (1976). The proceedings of the Fourth International Congress on Soilless Culture. Wageningen, The Netherlands.
4. I S O S C (1980). The proceedings of the Fifth International Congress on Soilless Culture. Wageningen, The Netherlands.
5. Cooper, A.J. (1976). NFT culture. And here is the feeding. The Grower, Suppl. Hart. in the '70s.
6. Schwarz, M. (1975). Guide to Commercial Hydroponics. Israel Universities Press, Jerusalem.
7. Sopher, H. (1980). Unpublished data.

8. Ben-Yaakov, S. and J. Ben-Asher. (1980). Continuous measurements of dissolved oxygen in water culture by a self calibrating monitor. Water Research (in press).
9. Ben-Yaakov, S. and J. Ben-Asher. (1980). A method for estimating  $\text{NO}_3^-$  and  $\text{K}^+$  uptake rate in hydroponics by a four-electrode conductivity sensor. Agronomy J. (submitted).
10. Ben-Yaakov, S. (1979). A portable dissolved oxygen analyzer for the fish farming industry. Bamidgeh 31(3): 69-77.
11. Ben-Yaakov, S. and Y. Sanandagi. (1979). An analogue isolator is simple and reliable. Electronic Engr. S1(625): 23-24.
12. Hoagland, D.R. and D.I. Arnon. (1950). The water culture method for growing plants without soil. Calif. Agric. Expl. Stn. No. 347.

