TO: Members, NCR101 Committee on Controlled Environment Technology and Use
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1. Fault Detection in Hydroponic Systems

Knowledge of the root dynamics of a hydroponically grown plant is relatively limited. Hydroponic systems can be monitored with a level of detail that permits one to collect extensive sets of data about the dynamics of root interactions with the surrounding nutrient solution and provide an opportunity to monitor and control the growing process of plants and their interactions with their surrounding microenvironments. Three deep trough hydroponic systems were constructed and EC, pH, DO and temperature were monitored with lettuce growing in them. A Neural Network (NN) was trained to predict EC and pH changes for normally growing plants as a first step to developing a fault detection system to detect the onset of abnormal growth. A 9-node NN proved capable of predicting EC within 5 microS/cm and pH within 0.01 over a 20 minute time step. The predictions are considered accurate enough to be used as additional inputs to other systems that could use information of the possible future state of a process, such as fault detection systems.

2. Development of a Water Uptake Model for Hydroponically-Grown Lettuce

Preliminary experiments were completed to determine how water uptake can be measured on an hourly time step in a lettuce hydroponic production system. In the deep trough hydroponic system used for this research, 621 ml of cumulative evapotranspiration per plant per gram of cumulative dry weight was calculated. An inclined manometer was used to measure daily water level change in a deep trough hydroponic system. The change in water level data did not appear to have a strong correlation with greenhouse temperature or relative humidity, but measurement precision was less than desired. Hourly data using the inclined manometers did not show an intuitive increase of evapotranspiration with increased hourly light integral or plant age. A scale was used with an 8-plant deep trough hydroponic system to capture the daily evapotranspiration pattern. The hourly data showed evapotranspiration increased with a higher hourly light integral and with plant age. Evapotranspiration per plant increased showed an increase around the day 21 re-spacing. On the other hand, evapotranspiration per gram dry weight increase did not show an increase at the day 21 re-spacing.

3. HPS Lighting Analysis and Design for the BIO-Plex Plant Growth Chamber

The purpose of this project was to propose and evaluate a design for the high-pressure sodium lighting to be used in the BIO-Plex plant growth chamber. A standard 400-watt HPS lamp was used. The water-jacketed lamp initially suggested for this design could not be incorporated into this project due to manufacturing problems. Photopia, a 3D luminaire analysis and design program created by Lighting Technologies, Inc., was used to analyze the designs. A target mean illuminance value of 1500 _mol/m^{2}s was desired while maintaining as much uniformity in the output as possible across a plane situated beneath the light box. Lamp placement and reflector design were considered. After 29 simulations, an acceptable design was determined for a single light box. Several important issues were brought up over the course of the project. First, a total of 5 lamps per light box satisfied the lighting requirement, instead of the initial 8 that were used. Second, a decrease of 400 _mol/m^{2}s was observed across a 10 cm distance beneath the light box. Third, exclusion of the outer edges of the illuminance plane gave more realistic interpretations of the majority of the data. Finally, it became apparent that at least some loss in uniformity should be accepted due to the difficulty in reflecting light to certain areas of the lamp bank.

4. Plant Lighting System Evaluation

A computer model was developed to simulate the decision process of selecting a lighting system for plant growth and development. The model uses an additive utility equation to combine 43 attributes of the decision process, resulting in a utility value for the lighting system. The rank spread weighting equation was developed for use in the model, as was the inverse partial utility function. Expert input is required both for the attribute weights and for the partial utility functions. The model was applied to two plant growth scenarios - a greenhouse scenario and a BLSS scenario - and the output was tested using variation of parameters and Monte-Carlo simulations. The model successfully simulated the lighting system decision process, giving higher utility values to systems that are more desirable for use. However, additive independence was not strictly maintained among attributes, resulting in erroneously high utility values for a few lighting scenarios. The rank spread weighting equation gave lower errors that other weighting equations tested. Expert input, in the form of rank order data, showed agreement among expert panelists, and suggested normality of perceived weights. Testing of the model output form the two scenarios showed that output agrees with common understanding of system performance, and that differences between the utilities calculated are statistically significant.

5. Modeling the Relationship Between NO_3^- Conc. and Carbohydrate Partitioning in Hydroponic Lettuce

Cornell is informally included in a European Union project (Israel, Netherlands, Belgium) to develop data and a model that will be usable to control greenhouse root and shoot environments to limit nitrate accumulation in lettuce and other leafy crops. Cornell's contribution has been to grow three hydroponic (deep trough) lettuce crops (nine experimental treatments) to maturity to study the dynamics of nitrate uptake when the nutrient solution nitrate concentration is changed (two concentrations, 0.5 and 125 ppm). Through the generosity of the USDA Federal Nutrition Laboratory at Cornell and the Kennedy Space Center of NASA, tissue nitrogen, nitrate and carbohydrate data have been obtained and are currently being analyzed and will be incorporated into a mechanistic model being developed by the Israeli cooperator.

6. Controlled Environment Agriculture Commercial Lettuce Production Demonstration

A 840 m^2 greenhouse to produce 945 heads/day of butterhead lettuce has been operated since June of 1999. Many start-up problems have arisen, some of which have been solved. Light control to a daily integral (using supplemental lights and movable shade) is working relatively well, and the overall floating hydroponics system works. Problems yet to solve include the production of uniform seedlings using rockwool cubes, preventing aphid infestations using only biological controls, and tailoring a commercial greenhouse environmental control program to achieve the tight control required for optimum production. Marketing studies have shown the distinct advantages of developing value-added products, and producing a crop of the same quantity and quality every day of the year. This is the ultimate goal of the demonstration.