The rose modeling work is continuing in two areas related to root-zone dynamics in hydroponic rose production: (1) modeling nutrient uptake by the plant from the root zone and (2) studying and modeling the effect of oxygen deficiency in the root zone.

**Modeling nutrient uptake in rose**

In the previous progress report we described the collaborative work with Professor Moshe Silberbush. In the past 6 months we have carried out validation work to confirm that the model that we constructed predicts nutrient uptake correctly. In particular, we need to know: are N, K uptake trends really as closely linked as they appear to be in model simulations? How do model predictions for uptake compare to actual results?

The objective of this part of the project was to study nitrogen and potassium usage of rose plants grown in an aero hydroponic system. Results from this will be used to validate our existing computer model for nutrient uptake.

The rose plants used in the experiment (*Rosa hybrida* ‘Kardinal’) were 1-year old rose plants which were removed from containers and the roots were washed to remove all substrate particles. Each of the five plants were placed in aero hydroponic units containing 5 L of nutrient solution. Plants were allowed to grow and adjust to the new environment for two weeks before uptake measurements commenced.

The nutrient solution contained 1.5 mM Ca(NO₃)₂, 0.5 mM K₂SO₄, 0.25 mM Ca(H₂PO₄)₂, 1 mM MgSO₄, 40 mg/L Fe-EDDHA chelate, 1 ml/L of micronutrient solution (prepared according to Hoagland and Arnon, 1950). A data logger (Campbell Scientific 23X) was set up to record greenhouse air temperature, light (photosynthetic photon flux density), and temperature of the solution in each hydroponic unit. The initial leaf area of each plant was assessed using a ruler to measure length of each leaf. The mathematical equation:

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A = 1.019 (0.234 x^2 + 2.294x - 10.35)
\]

was used to calculate leaf area (A) from leaf length (x) (Lieth, unpublished). Leaf area was estimated weekly to assure that the plants in the simulation work would correspond in size to the plants that were measured.

Each day the weight of each hydroponic unit was be determined using an electronic scale. Given the weight of the plant and empty container, the volume of the solution was adjusted to 5 L with the addition of de-ionized water. A sample of the solution (about 20 mL) was taken after each time the solution volume was adjusted (every 3-4 days). Samples were analyzed for nitrate concentration using a Carlson nitrogen analyzer. Initially an ion-specific electrode was used to determine concentration of K in the solution, later we used an Atomic Absorption Spectrophotometer to gain greater accuracy.
The simulation model was set up so that it would calculate the simulation of the plants in the experimental conditions. Having the simulation represent plants of a size close to the ones being measured is critical since plant size, especially total amount of foliage, may have a significant effect on nutrient uptake. Fig 1 shows that the simulated whole plant leaf areas were representative of the leaf areas of the plants being observed.

Actual results of nitrogen and potassium uptake (converted to mg/day) were compared with predictions. The observed data were compared with two separate simulation models. The first simulation used the simulation program developed by Lieth and Silberbush to simulate just the N and K uptake dynamics. In this simulation a fixed dry matter growth pattern was assumed. The second simulation used the whole rose shoot simulation model.

**Figure 1** Leaf area of simulated and actual plant
developed in previous years. The nutrient uptake model was combined with this model so that simulations could be done where the nutrient uptake would drive the biomass accumulation along with the various other environmental variables (light, temperature, etc).

There was considerable variation in the uptake data from day to day for both nitrate and potassium (Fig 2). Given this large variability, the predicted uptake rates for both nutrients from the Silberbush model is fairly good for these data. In general there was an underprediction of the uptake rates by the combined model.

Due to the large variation and our lack of understanding as to what is causing this, we will carry out further experiments so that our model can account for such fluctuations.

One of our concerns is that our current nutrient uptake model (either as implemented by Silberbush or by the whole (combined) rose growth model, has nitrate and potassium uptake in near-perfect synchrony. The collected data allow us to investigate whether this is the correct pattern. The uptake patterns of N and K over time (Fig 3) suggest that this is the case.

On average these data represent a ratio of 1.06 mg nitrate per 1 mg of potassium. The model predicts 1.23 mg nitrate per mg potassium.

Our future work in this area will focus especially on uptake rates as plants get older. In our study there is considerable underprediction of uptake rates.

Uptake of nitrate in our experiment ranged from 28-64 mg/d. This compares with rates found by Cabrera of 29-146 mg/d. We will likely see these increased levels of uptake as our plants reach later growth stages.

We are currently gearing up to begin work on other nutrients (phosphorous, calcium, etc).

**Oxygen in the root zone of roses**

Our work over the last few months has focused on building a set-up that would allow us to implement specific root zone temperature conditions. In related collaborative project with Dr Micheal Raviv in Israel, he designed and custom-built hydroponic units in Israel with built-in temperature controls (for both heating and cooling). Although this ultimately resulted in suitable research equipment, it was very costly and there were a number of failures. Thus we set out to look for a better way to obtain temperature control. We found that using normal household refrigeration equipment would allow us to build a chilling unit with far greater capacity than we would obtain with custom-built scientific equipment.
Our design includes a normal household freezer, in which we installed a large water tank (Fig 4). The temperature in the freezer is controlled by a Johnson Controls thermostat designed to operate freezers or refrigerators at temperatures higher than normally possible with the built-in thermostat. Furthermore it allowed us to specifically control the temperature of the water in the tank, rather than the air in the cabinet. Our design has the water temperature set at 1C.

Another part of the system has copper tubing wrapped around a hydroponic bucket set into a larger bucket (Fig 5). The space between the two buckets is filled with water. Chilled water is pumped with small submersible pumps from the tank in the freezer, through the tubing, and back into the tank in the freezer. Initially our plan was to circulate chilled ethylene glycol as this would allow colder temperatures, but our initial tests showed that we could accomplish our objectives with plain water. As we add more hydroponics units to the experiment we may need to use colder liquid; in that case we will add ethylene glycol and run the chiller at colder temperatures.

Thermocouples are used to sense the temperature in the hydroponic buckets. In this study the buckets are aerohydroponics units that contain no substrate. This unit is typically half full with water.

A Campbell Scientific CR21X data logger is used to measure all the temperatures in all the hydroponics units and control the valves and pumps to maintain the desired temperatures in the hydroponics units.

In cases where temperatures greater than air temperature are needed, aquarium heaters in the hydroponics

Figure 4 Freezer used as chilling unit to create cold liquid for cooling the root zone of the hydroponic units.

Figure 5 Three hydroponic units, each with temperature control and instrumentation for data collection.

Figure 6 Oxygen analyzer - blue lines are fiberoptic cables to the oxygen probe; while lines lead to temperature sensors. Both sensors consist of stainless steel probes that are inserted in the root zone.
units are used to implement the desired set-point.

The dissolved oxygen concentration in the hydroponics units is measured using Ocean Optics FOXY instrumentation. Figure 6 shows the probes and the analyzer. The tip of the oxygen probe contains a chemical that fluoresces in proportion to the amount of oxygen that is present. Through proper calibration and temperature compensation, this device allow measurement of oxygen at the tip of the probe. It can measure it in either liquid or in gas.

We recently completed assembly of this set-up and are currently carrying out the first round of experiments. The objective of the current round of experiments is to quantify how roots consume oxygen and how temperature affects this process.

Experimental Protocol:

One or two rose plants were placed in one of three hydroponic units (see photo in Fig 5). Each unit was sealed with duct tape to prevent oxygen entry. In each, oxygen saturation was initially imposed by bubbling air in the nutrient solution. Each of three temperature treatments were imposed in subsequent 24 hour periods: 12C, 24C or 33C. Additional temperature treatments are currently being added.

Once the temperature in the hydroponics solution was stable, the air bubbling stopped and oxygen depletion was monitored using the oxygen analyzer as the roots consumed the available oxygen. The same plants were used for each of the treatments so the root biomass was constant during this experiment.

Dissolved oxygen (DO) always depleted over time, rapidly at first, declining over time. This indicated high rates of consumption at high dissolved oxygen concentrations and lower consumption rates at low concentrations.

At each temperature, as the oxygen is depleted, the final DO concentration does not reach zero but rather approaches a low asymptotic level. While it is possible that this is due to Oxygen leaking back into the system, 

**Figure 7** Draw-down of oxygen concentration by the rose plants in the three temperature treatments
we feel that this is unlikely since we took precautions to seal the hydroponics units as much as possible. It is more likely that the respiration is essentially shut down due to the very low gradient of oxygen concentration between the inside and the outside the root.

When we started to look at the effect of dissolved oxygen (DO) in the rhizosphere of hydroponically grown roses we noticed that the concentration of oxygen changes very rapidly. In fact, the dynamics are much faster than was previously known. We attributed the results from our earlier findings to inadequate instrumentation, since conventional methods for measuring dissolved oxygen in the root zone are (1) very slow, (2) require that the liquid be in motion, and (3) consume oxygen in the measurement-process. This meant that measurement in hydroponic rose systems could not be conducted in the substrate. It could only be carried out during the recirculation process. Since this process introduces oxygen into the solution, the results were always skewed. By using our spectrophotometric analyzer we can get instantaneous DO measurements that are not affected by the measurement process.

When the DO concentration levels dip into the hypoxic range, oxygen becomes a limiting factor to the root respiration. When the roots are subjected to hypoxia, the rate of respiration and oxygen absorption decreases. Observed dissolved oxygen rates reached between 1 and 2 ppm, but generally not lower. This suggests that no further oxygen is consumed, indicating that respiratory processes in the roots are shut down. Thus, while there is still some small amount of oxygen present in solution, the roots are not able to use it.

The data suggest a general pattern for oxygen depletion but are not adequate as yet to completely formulate or calibrate a model. We anticipate a model that declines exponentially with oxygen concentration and perhaps linearly with temperature (Fig 8).

![Graph](image_url)

**Figure 8** Proposed model for oxygen depletion in relation to root zone temperature and oxygen concentration.