Introduction

The research funding provided by the ICFGA has impacted my program in several ways. While providing the necessary funding to do research, it has also served as a catalyst for other related funding that effectively enlarges my research program substantially (nearly 5 fold). It is sometimes difficult to identify exactly which dollars went to which facet of the research. This report addresses only those areas of the research program that are specific to the rose model development.

Modeling nutrient uptake by roses

The availability of nutrients to rose plants is a key facet of rose production. An adequate supply of nutrients is essential to insure flower productivity and quality (Nielsen and Starkey 1999, Mortensen et al. 2001). While a number of recommendations exist for optimal fertilization, there is still a lack of knowledge about the actual consumption of the various nutrients during the production cycle. While some information exists in this area, little is available for rose plants.

Traditionally there has been an easy way to deal with this lack of knowledge. The standard horticultural best-management practice has been to over-irrigate and overfertilize. This was made possible by the use of rooting media with high porosity which eliminated (or reduced) the penalty associated with excessive irrigation (e.g. water logging). As a result, growers tend to over-fertilize and over-water their crops, which results in waste and environmental contamination. In the last few years it has become evident that this cannot continue. Many growers are being forced to eliminate the discharge of excess water.

Characterization of nutrient uptake by perennial plants using simulation models is a complicated task (Le Bot et al. 1998). Most the existing models of nutrient uptake deal with annual plants, whose root systems could be assumed as young and uniformly active (Tinker and Nye 2000). It has, however, been observed that the average uptake rate per unit of root decreases during plant growth (Barber 1995, Van Noordwijk and de Willigen 1991). Recent models, which do account for this decrease, use simplified assumptions regarding root age and uptake, such as linear decrease in time, or morphology (i.e., root position or hierarchy) of the root system (Somma et al. 1998). Such simplifications might not be valid to describe nutrient uptake by perennials. These plants are characterized by a wide diversity of roots, of various ages, thickness, and suberization. Also, the shoot-root interactions are complex and their effect on nutrient uptake by the roots is barely understood (Tani et al. 2001). The complex lifespan during the year and among years, and the relatively large storage capacity for nutrients in their tissues, induce internal transports, which make the use of mechanistic quantification difficult (Eissenstat and Yanai 2002).

Rose production consists of a pattern of biomass production that consists of growing shoots and periodic harvests. At any point in time there are shoots on the plant at various stages of
development. Nutrient uptake synchronizes, to some extent, with the plants construction of biomass (in the form of new tissue, usually flowering shoots). Thus there is a cyclical pattern of nutrient uptake induced by flower harvests (Cabrera et al. 1995a, Takeda and Takahashi 1998). This pattern makes any attempt to model nutrient uptake by roses rather unique in comparison with other agricultural crops where biomass production and nutrient uptake have been modeled. Also, the root system consists of roots of a wide range of hierarchy, age and uptake characteristics. Yet, as new roots would emerge on new shoot growth after a flower-cut, there may be a balance in grown-up rose plants between root emergence and the decay of old ones, so that the root system would achieve approximately constant dimensions. As a result, uptake may be accounted for as being induced by the demand of the shoot, while the root system adjusts itself to take up nutrients to satisfy that demand by changing its uptake capacity per root unit, while keeping its size unchanged with time.

One of the biggest problems in modeling nutrient dynamics in plants is that there are so many different nutrients to account for. These range in concentration from macronutrients (N, P, and K) to micronutrients. At the start of any modeling project it is necessary to restrict the scope so as to make the complexity manageable. Thus we restrict this project at this point to dealing with just two nutrients (N and K) with the intent of adding additional nutrients as the information becomes available.

In the present study we measured the changes in uptake rates of nitrate (NO3) nitrogen (N) and potassium (K) along a flower-cut cycle of roses, and the relationships between these changes and plant morphology. We currently developing a model that describes this process; this report describes the current state of this model.

Model Theory

The equations and theory behind the model will be published elsewhere. Here only a brief overview is provided.

There are a number of underlying assumptions in this modeling work. As with our previous work, the basic unit of rose production is the growth of one shoot. A model that describes how one shoot grows can then be applied several times to model the growth and development of a set of shoots. So as to keep things simple (at least initially) our current work models the status of a rose plant that consists of 5 shoots growing on a base of biomass. The plant is assumed to be growing in a hydroponic production system.

While the ultimate goal is to link this model into the existing rose shoot model, that model is currently akin to a construction zone as many different areas are being worked on. Thus it was decided that we would characterize the approximate growth pattern using a simple set of growth curves so as to give us the opportunity to build the model. In the future, once the model is finalized, it will be added to the main shoot model. Thus in this work, the shoot biomass is assumed to increase in a sigmoid pattern that has been described elsewhere and the leaf area on the plant also follows a logistic pattern. The simulation model uses this pattern, along with a specification of how many shoots are simulated, and when each is initiated and harvested, to simulate nutrient uptake.

The uptake rate of N (net influx into the root) is assumed to be a function of the nutrient
concentration in the growth medium, according to a Michaelis-Menten formula. This formula has a maximal rate that varies over the production cycle relative to leaf area. Our implementation also compensates for shoot nutrient deficiency or surplus.

In our approach, N and K uptake are simulated resulting in a pattern of concentrations in the solution and in the plant tissue. These are the state variables that are currently the focus of the modeling work.

Model implementation into a simulation model

A computer program was written to carry out the simulation. It runs under Windows 95/98/ME/NT. Figure 1 shows the various parameters that the user can adjust. Many of these are horticultural (e.g. nutrient concentrations, volume, etc) while others are physiological parameters. This implementation assumes that there are a pre-specified number of flowering shoots which will

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**Figure 1** The computer software implementation of the simulation model showing the parameters and variables that can be manipulated at this time. The figure shows the graphical output of a sample run.
grow on the base of the plant. This base has a pre-set amount of leaf area on it (1600 cm² in the example); each growing shoot adds additional leaf area to the total.

The simulation program instantly displays all pertinent information in both graphical or textual format.

Data collection and model calibration

Considerable work was needed to calibrate various facets of this model. For this work, Rosa hybrida ‘Kardinal’ was used. Plants were grown in aero-hydroponic systems in growth chambers, allowing us to observe the root system and manipulate all facets of the plant.

Simulation results

While we have just begun to work with the simulation model, it is interesting to use it to

**Figure 2** Example of a simulation run for 100 days. The zig-zag pattern represents the pattern of nutrient concentration including replenishment. The jagged portions of the tissue concentration curves represent the changes associated with harvesting shoots. In this simulation the five shoots are harvested at 2-day intervals.
simulate over longer periods of time and for various scenarios that are of interest. In the example in Figure 2, a simulation was run which assumed that water is replenished hourly to top the solution off to the full 5 liters and the entire nutrient solution is replaced with fresh solution once the solution concentration of nitrate reaches 500 micromoles/liter or potassium reaches 100 micromoles/liter.

Currently we are still in the phase where we are building the model and adding important elements to this. At the same time we are testing the model sensitivity to each of the parameters. This helps us identify which parts of the model have to be focused on so as to be particularly accurate.

**Predicting the length of rose stems at harvest**

Stem length is an important variable in rose cultivation and thus is also an important variable to be built into the rose model.

Previous work characterizing patterns of stem elongation revealed a correlation with stem development. Stem length increases with time in a sigmoid pattern, but the number of leaves that unfold increases linearly. Because these patterns are present, it may be possible to develop tools to predict stem length at harvest. The objective of this project is to produce a model that can be used

**Figure 3.** The regression of the number of leaves and stem length shows a strong correlation. However, there is a tendency to under predict the lengths in the early developmental stages and over predict during midstage. Data collected during the summer of 2001.
to predict the length of a rose stem at harvest based on measurements made while the leaves are unfolding on that stem.

Preliminary studies on 'Kardinal' show that there is a strong correlation of the number of leaves unfolded and stem length (Fig. 3). But when using a linear relationship, there is a tendency to underpredict the length of the stems during the early stages of development and then over predict the lengths during the mid stage. To increase the prediction accuracy, a method using two models are used: one model for leaf unfolding to determine the developmental stage of a stem and a second model, describing stem elongation, to predict the final stem length based on the developmental stage. The objective is to link the two models to directly determine length from leaf unfolding. However, exploratory work shows there may be a seasonal influence on the predictions.

Three data sets of stem elongation collected for during the early summer, early fall, and late fall were used for exploratory analysis. During each season, at least ten stems were selected and the length was measured and the number of leaves were counted daily from bud break through harvest. The lengths were transformed so that the length at harvest was set to a value of 1.0 (100% of the total length) and the time (number of days since bud break) to harvest was also set to 1.0. These values were then fitted to a Richards function used to describe stem elongation (Fig. 4). When the converted data from the other data sets were similarly fitted to the Richards function, a seasonal trend seemed to appear.

To characterize this seasonal trend, three more data sets were collected during the winter, early spring, and late spring. These data are currently being analyzed and will be combined with the earlier data to obtain a complete information set spanning the entire year. This will be used to explore the seasonal patterns. This should enable the reaching the objective of a tool to predict stem

\[ \text{Richards Function Fit} \]
\[ \text{Sep 30 Data Set} \]

\[ \text{Figure 4. Fitting of the Richards function to stem length data normalized to relative time (days to harvest=1.0) and relative length (length at harvest = 1.0).} \]
length that will be functional throughout the year. The resulting model should be usable in the rose model.

We also plan to build a tool that growers can use in greenhouse production to forecast final stem length. We will then conduct test in commercial production to test the tools accuracy and feasibility.

References


