

Modeling Macronutrient Absorption of Hydroponically-Grown Cut Flower Roses

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Abstract

Regulations increasingly limit the water run-off allowed from agricultural facilities. A better understanding of appropriate irrigation and fertilization regimes are needed to comply with these regulations. The objectives of this project were to determine how macronutrient absorption by roses varies in relationship to growth of new flower stems and test whether an existing mathematical model is suitable for describing nitrogen and potassium uptake across a crop cycle. Absorption of ammonium (NH_4^+), nitrate (NO_3^-), potassium (K^+), calcium (Ca^{2+}), and magnesium (Mg^{2+}) by rose plants (*Rosa × hybrida* ‘Kardinal’) were measured during three crop cycles. Following a harvest, the rate of total nitrogen (N) uptake decreased to $0.15 \text{ mmol d}^{-1} \text{ g}^{-1}$ harvested dry weight (HDW) where it remained for the first five days, decreased during days 8-10, and then increased in synchrony with flower stem elongation. K^+ uptake rates gradually declined for the first 12 days following a harvest cycle, then increased in synchrony with stem elongation to maximum uptake rates of 0.05 to $0.09 \text{ mmol d}^{-1} \text{ g}^{-1}$ HDW as stems reached maturity. Prior to harvest, the rate of Ca^{2+} uptake decreased and remained low until day 7 of the new cycle (appearance of new shoots), then increased until just prior to stem maturity. Mg^{2+} uptake rate increased in synchrony with stem elongation and then decreased just prior to harvest. Simulations of the N/ K^+ model accurately predicted the increase in N and K^+ uptake rates beginning around day 10-12 and proceeding until harvest as well as the drop in N and K^+ uptake occurring at harvest. The simulation does not predict the somewhat sustained uptake rates for the first 7-10 days following harvest and the decline in uptake during early stem elongation. The most likely reason for the discrepancy is that the model does not yet have mechanisms for handling redistribution of these nutrients from perennial tissues to new growing shoots or account for changes in root growth across a crop cycle.

INTRODUCTION

Nutrient Use

Current management practices of field, greenhouse, and nursery crops generally use luxuriant amounts of fertilizers in relation to the amount actually consumed by the crops. In intensely managed systems, such as greenhouse crops, excessive fertilization can lead to greater than 2,000 kg of nitrogen (N) leached per hectare per year (Cabrera et al., 1993). Government regulations are increasingly regulating such run-off. To comply with these regulations, greenhouse and nursery growers need to optimize the fertilizer application rates and/or develop closed irrigation systems. This requires a greater understanding of the nutrient supply necessary for crop production.

Cut flower rose production typically uses hydroponics where soil-less substrate is kept moist through irrigation several times a day with a nutrient solution. Roses are valuable for studying dynamics of nutrient uptake, storage, and remobilization in woody crops as they exhibit many flushes of vegetative growth every year, coinciding with flushes of flower shoot growth (Cabrera et al., 1995a).

Most of the work with nutrient uptake in roses has focused on NO₃⁻; less information is available on uptake of the other macronutrients. Cabrera et al. (1995a) reported NO₃⁻ absorption of *Rosa hybrida* ‘Royalty’ over seven flower shoot growth cycles (393 days) and PO₄³⁻, K⁺, Ca²⁺ and Mg²⁺ over two crop cycles.

An important concept in our work is the ratio of nutrient uptake to water consumption calculated as nutrient uptake per day divided by daily plant transpiration. This leads to our ability to calculate the concentration of nutrients sufficient for plant consumption that need to be provided during an irrigation event. In this way, if the supplied amount of water and nutrients are equal to the amounts required for transpiration and growth, then there should be no build-up of nutrients in the container or result in excess losses of nutrients (i.e. the proportion of nutrients to water taken up is similar). While such an approach would be applicable in soil-less production, it may not be applicable in soil where higher concentrations of nutrients may be required to overcome limitations to diffusion and mass flow (Cabrera et al., 1993). If the irrigation solution is recycled and reused, then this approach can also be used to predict the nutrient composition of the solution in the containment reservoir following successive irrigations.

Modeling Nutrient Absorption

Bougoul et al. modeled *Rosa hybrida* ‘Sweet Promise’ transpiration and NO₃⁻ over 4 days given light and temperature, but not across a growth cycle. Silberbush and Lieth (2004) developed mathematical models to predict NO₃⁻ and K⁺ uptake of *Rosa hybrida* ‘Kardinal’ plants growing in solution culture across a growth cycle, where the ‘driving force’ for uptake is the growth of new flower shoots. In the model, a logistic equation describes the growth of flower shoots (increase in dry weight and leaf surface area over time), while the other plant parts (roots, leaves and stems on the base of the plant) are assumed to have a constant dry weight (equilibrium between new growth and senescence). Absorption of NO₃⁻ and K⁺ is expressed as a product of root influx via Michaelis-Menten kinetics, plant root surface area (RSA), and the time step of the simulation (Δt).

$$J = \frac{J_{\max}(C - C_{\min})}{K_m + (C - C_{\min})} \bullet RSA \bullet \Delta t \quad [1]$$

where J is nutrient influx and J_{max}, K_m, C, and C_{min} are Michaelis-Menten parameters. The plant’s relative demand for nitrogen and potassium is expressed by varying J_{max} according to the plant’s current nutrient concentration and the current stage into a growth cycle.

The objectives of the current research were to determine how macronutrient absorption by roses varies in relationship to growth of new flower stems, and to test whether the existing mathematical model by Silberbush and Lieth (2004) is suitable for describing nitrogen and potassium uptake across a crop cycle.

MATERIALS AND METHODS

Eight eighteen-month old plants of *Rosa hybrida* ‘Kardinal’ (own-rooted, i.e. no rootstock) were established in hydroponic units (solution culture) in a controlled environment chamber (20 hour photoperiod at 250 $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ PAR with day temperature of 25°C and night temperature of 18°C). Each plant was pruned back to synchronize the growth stage. To maintain uniformity, three flower stems were allowed to grow on each plant; all other bud breaks were pinched off. Each hydroponic unit contained 10 L of nutrient solution. The nutrient solution was mixed to a concentration (in mM) of 11 NO₃⁻, 1.25 PO₄³⁻, 1.25 NH₄⁺, 4.5 K⁺, 3.5 Ca²⁺, 0.75 Mg²⁺, 1.0 SO₄²⁻, and micronutrients according to Hoagland and Arnon (1950). The nutrient solution was replaced once a week. At the replacement time the pH of the new nutrient solution was adjusted to 6.0 with the addition of NaOH.

From December 16, 2003 until March 15, 2004 (i.e. three harvestable cut flower cycles) solution samples were taken from each container twice weekly. At each sampling, the volume of the nutrient solution remaining was determined by weighing each unit and

subtracting the weight of the empty container and the weight of the plant. Electrical conductivity (EC) and pH were recorded, and a 55 mL sample of the solution was taken.

The samples were analyzed for total nitrogen, NO_3^- , and NH_4^+ using a diffusion conductivity method; and for K^+ , Ca^{2+} , Mg^{2+} with an ion atomic absorption spectrometer. To equilibrate for some plants yielding a larger flower stem harvest (in grams of dry weight), the calculated nutrient uptake rates (mmol d^{-1}) were divided by grams of flower stems harvested from each plant for each cycle. Hence, the rate of nutrient uptake rate in this paper is reported in $\text{mmol d}^{-1} \text{g}^{-1}$ harvested dry weight (HDW).

To compare predicted versus actual NO_3^- and K^+ uptake; a simulation was set up using the equations and parameters as described by Silberbush and Lieth (2004) with the parameter modifications as described in table 1 to reflect the conditions of our experiment.

RESULTS

The length of each crop cycle (i.e. the time from the previous harvest/cut back) until new flower shoots reached harvest was 29, 30, and 29 days for cycles one, two, and three, respectively. Following replacement of the nutrient solution the pH decreases by about 2.2 during the next seven days until another replacement occurs (Fig. 1). During the first three to four days following replacement, the decrease in pH was greater than the decrease seen during the following three days. Following a replacement of the nutrient solution, the electrical conductivity increases by 1-2 dS m^{-1} in a linear fashion. The greatest increases in EC correspond to dates with high transpiration rates as stems reach maturity (Fig. 1).

Mean plant transpiration increased in synchrony with flower stem elongation for cycles one and three, and slightly ahead of stem elongation for cycle one (Fig. 1). Following harvest/cut back, plant transpiration decreases rapidly from about 0.46 L d^{-1} to about 0.2 L d^{-1} . As new shoots appear around day seven, plant transpiration and total shoot length per plant increases in a logistic nature until harvest to 0.46 L d^{-1} and 95 cm d^{-1} , respectively at around day twenty-nine.

Nutrient Absorption

Following the harvest of flower stems, total N uptake of the plant remained constant for the first five days and then dropped to the lowest uptake levels at day seven, then increased until a peak was reached around day nineteen, followed by a sharp decrease at harvest (Fig. 2). The N uptake cycles are somewhat out of synchrony between crop cycles: in cycles one and three the increase in stem length seems to lag behind N uptake, whereas in cycle two the increase in N uptake lags behind the increase in stem length. Note that for many nutrients, uptake values were greatest in cycle one and somewhat decreased in cycles two and three. NO_3^- and NH_4^+ uptake patterns were similar to those for total-N (Fig. 2).

The highest rates of Ca^{2+} uptake precede flower stem maturation and harvest (Fig. 3). Just prior to harvest, Ca^{2+} uptake drops and remains low until about day seven of the new cycle (appearance of new shoots), then increases sharply until the peak uptake rate is reached prior to harvest.

K^+ uptake rates gradually decline for the first twelve days following a harvest cycle, and reach their lowest rates during early shoot elongation (Fig. 3). Following early shoot development, the rate of K^+ uptake increases in synchrony with stem elongation to maximum uptake rates of 0.05 to $0.09 \text{ mmol d}^{-1} \text{g}^{-1}$ HDW. Uptake rates decrease rapidly just prior to harvest.

Mg^{2+} uptake during cycles two and three is erratic. During cycle one, Mg^{2+} uptake increases in synchrony with stem elongation and then drops just prior to harvest (Fig. 3).

The nutrient concentrations that would provide the adequate amounts required for plant consumption in our growth chamber experiments are presented in Table 2.

Model Comparison

Simulated NO_3^- uptake using the method described by Silberbush and Lieth (2004) accurately predicted the increase in N uptake rates beginning around day ten and proceeding until harvest as well as the drop in N occurring at harvest. The model did not accurately predict the somewhat sustained rates of uptake during the first seven days of a crop cycle or the decrease in N uptake beginning seven days prior to flower stem harvest (Fig. 4). The model simulations accurately predicted the increased rates of K^+ uptake beginning at day thirteen and continuing until day twenty-five as well as the drop in K uptake occurring at harvest. The simulation does not predict the sustained uptake rates for the first seven days following harvest and the decline in uptake to day thirteen.

DISCUSSION

Nutrient Absorption

Total nitrogen uptake corresponds well with results of Cabrera et al. (1995a) who found a similar oscillatory pattern. In their nitrate uptake data over the course of a 393 day experimental period the increase in N uptake was in synchrony with shoot elongation for four crop cycles, and lagged behind shoot elongation for three crop cycles. In our experiment, total N and NO_3^- uptake occurred synchronous with stem growth for cycles one and three and lagged behind stem growth for cycle two. Ammonium uptake also had an oscillatory pattern that lagged behind stem growth.

The increase in K^+ uptake and Mg^{2+} uptake rates also occurred synchronous with flower stem growth, while the increase in Ca^{2+} uptake rates occurred slightly ahead of stem growth. The K^+ and Mg^{2+} results correspond well with data presented by Cabrera et al. (1995a) over two growth cycles; while in their cycles, Ca^{2+} uptake lagged behind stem growth.

Current fertilization practices for commercially grown greenhouse roses often supply 150-200 ppm of nitrogen and potassium through liquid feeding (Cabrera et al., 1993). For the plants in our experiment, this high rate of fertilization would be required for only five days during a thirty day cycle for N, and rates greater than 70 ppm were never required for K. Indeed, Cabrera et al. (1993) found no significant differences in dry weight yield or number of flowers harvest for rose plants grown with 77, 154, and 231 ppm N. The results of our experiment can help guide fertilization decisions for NH_4^+ , NO_3^- , K^+ , Ca^{2+} and Mg^{2+} based on crop growth stage. If fertilization rates are adjusted periodically during a crop cycle, adequate amounts of nutrients can be continuously provided to plants while reducing the potential for run-off of excess nutrients.

Model Comparison

The predicted uptake of the Silberbush-Lieth model does not accurately reflect K and N absorption during an entire crop cycle, though the model does reasonably well during the period of increasing uptake for K and N. Therefore, some of the model assumptions may not be suitable or the model may need to account for additional components. These inaccuracies have provided motivation for further research. The Silberbush-Lieth model assumes that root surface area is constant over the cropping cycle, but maximum root absorption ability changes.

Another factor that needs to be accounted for is the capacity of older plant tissues (roots, old stems, old leaves) to store nutrients (phloem mobile nutrients such as N, K, and P) and redistribute these nutrients during growth of flowering shoots. Cabrera et al. (1995b) found that N mobilized from older stems and leaves provided the majority of the N to the growing shoots during rapid flower stem elongation of roses; but as stems reached flower maturity, N uptake from the media provided N to the shoots and to replenish older tissues (Cabrera et al., 1995b). Currently, no information is available on the size of K and P storage pools in roses.

We are currently working on mathematical equations that extend the Silberbush-Lieth model to one that takes into account nutrient demand, storage, and reallocation by

perennial plant parts as well as the dynamic nature (change in dry mass over a crop cycle) of these perennial parts. We are also conducting experiments to determine how root growth and activity of N, P, and K change across a growth cycle.

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Tables

Table 1. Parameter values given in Silberbush and Lieth (2004) that were adjusted for running a NO_3^- and K^+ uptake simulation based on the current experiment.

Parameter	Silberbush and Lieth value	current experiment value
Leaf area of plant base	1600 cm ²	400 cm ²
Root surface area	7841 cm ²	5000 cm ²
No. of flower shoots per plant	5 flower stems	3 flower stems
Maximum leaf area per shoot	622 cm ²	292 cm ²
Maximum dry weight per shoot	10.9 g	5.1 g
Shoot age at harvest	37 days	28 days
Volume of nutrient solution	5 L	11 L
Solution [NO_3^-]	3 mM	11 mM
Solution [K^+]	1 mM	4.5 mM

Table 2. Nutrient concentrations required in irrigation water (mM) for rose plants in this experiment calculated as daily nutrient absorption divided by transpiration. Values are means across eight plants and three crop cycles.

day	[N] mM	[Ca] mM	[K] mM	[Mg] mM
0-5	6.80	0.72	1.29	0.15
6-10	6.03	0.89	1.65	0.28
11-15	7.33	0.92	0.65	0.28
16-20	13.38	1.08	1.32	0.21
21-25	6.16	1.10	1.80	0.22
26-30	3.99	0.40	1.08	0.13

Figures

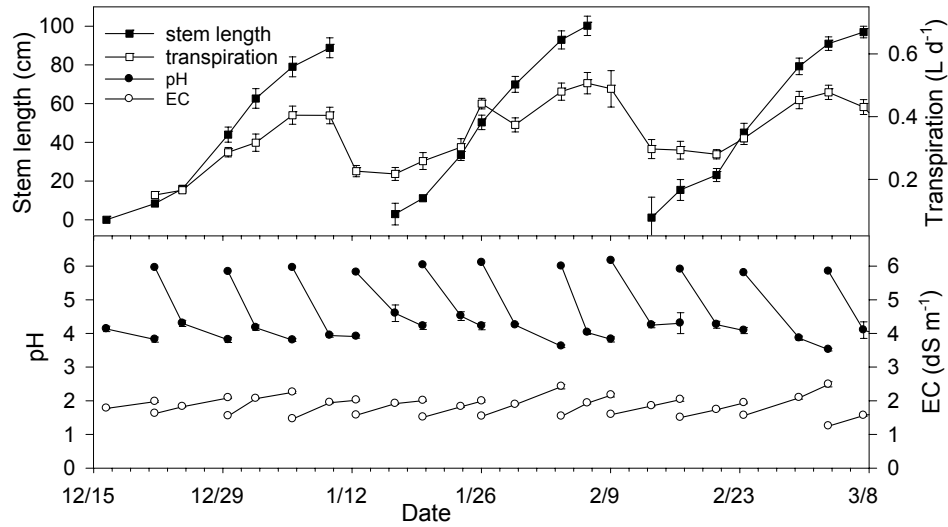


Fig. 1. Total flower stem length (cm), plant transpiration (L d⁻¹), pH and electrical conductivity of nutrient solution (EC in dS m⁻¹) (\pm SE). Spikes in pH and EC represent weekly replenishment of the nutrient solution.

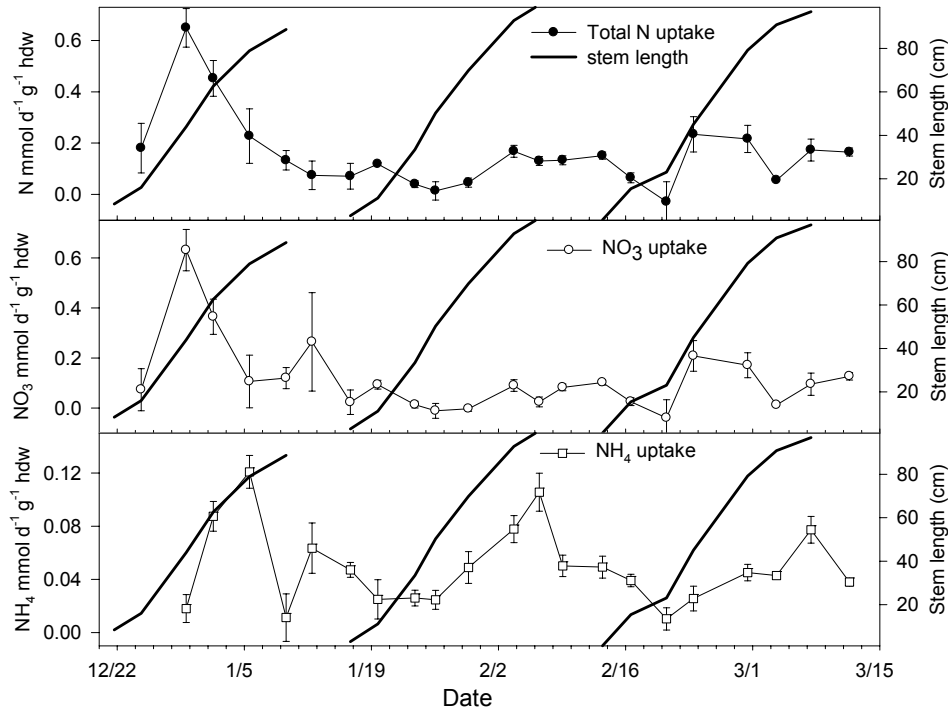


Fig. 2. Mean plant uptake (\pm SE) of total N, NO₃⁻-N, and NH₄⁺-N in mmol d⁻¹ g⁻¹ harvested dry weight (hdw); and mean total flower stem length (cm) across three crop cycles.

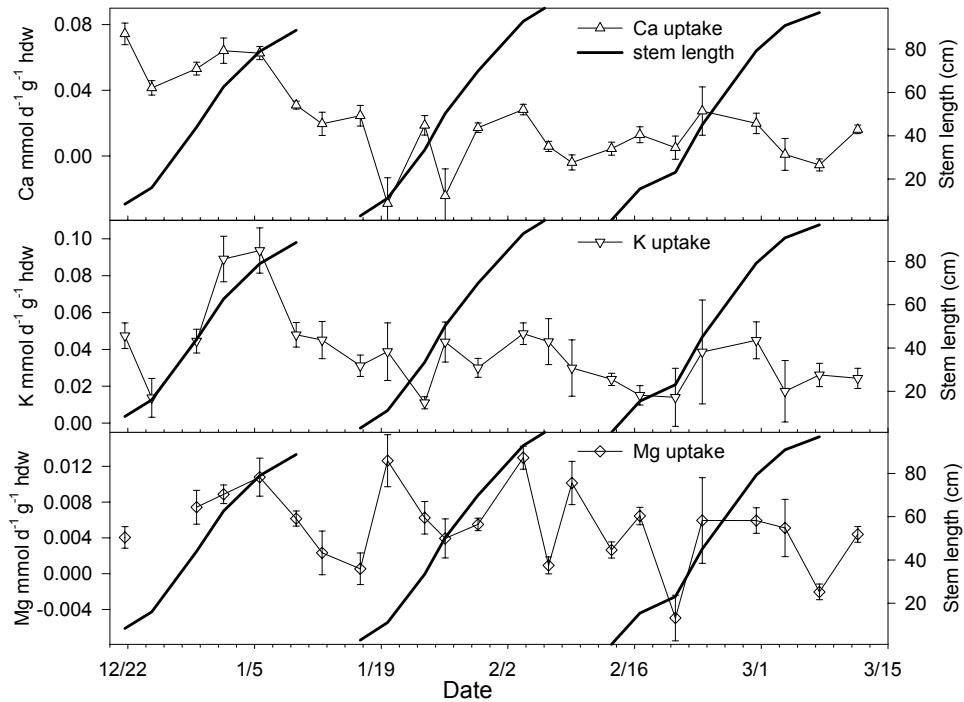


Fig. 3. Mean plant uptake (\pm SE) of Ca^{2+} , K^+ , and Mg^{2+} in $\text{mmol d}^{-1} \text{g}^{-1}$ harvested dry weight (hdw); and mean total flower stem length (cm) across three crop cycles.

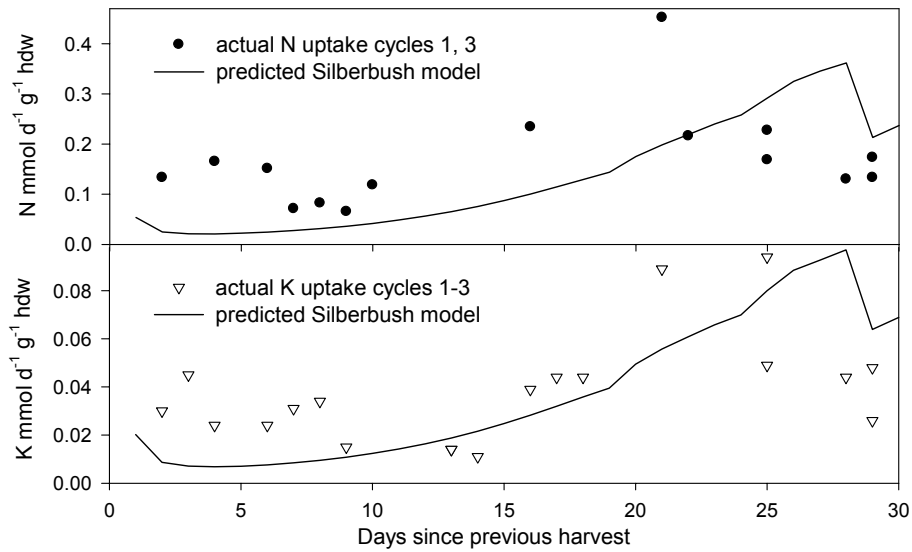


Fig. 4. Measured and predicted N and K uptake. Actual values compiled from three crop cycles. Predicted values from the Silberbush-Lieth model; simulated as described in Table 1.

