Changes in Root Surface Area, Nutrient Absorption Activity, and Root Carbohydrate Concentration during Crop Cycles of *Rosa hybrida* ‘Kardinal’ Plants Grown in Solution Culture

N.S. Mattson¹, J.H. Lieth¹, Gyeong-Lee Choi² and Wan-Soon Kim³

¹Dept. of Plant Sciences, University of California, One Shields Ave., Davis, CA 95616, USA
²Protected Horticulture Experiment Station National Horticulture Research Institute, Rural Development Administration, Busan 618-800, Korea
³Research Management Bureau, Rural Development Administration, Suwon 441-707, Korea

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**Abstract**

Cut flower rose production is often managed to produce a flush of harvestable flowers in time for particular holiday. Such crops go through cycles of vegetative and reproductive growth. Cyclical patterns of nutrient absorption are generally shifted in time with a decline in uptake rates as new flower shoots appear and increasing rates of uptake as shoots reach harvestable maturity. The objective of this experiment was to determine how root surface area (RSA), N, P, K absorption activity (uptake per unit root area), and root total nonstructural carbohydrate (TNC) concentration varies over such crop cycles under conditions of high or low light. A sequential harvest experiment was conducted using one-year old *Rosa hybrida* ‘Kardinal’ plants on ‘Natal Briar’ rootstock in solution culture. Plant RSA did not change significantly during the high light crop cycle and averaged 14400 cm² plant⁻¹. Under low light, RSA declined following a previous harvest until day 15/20, followed by an increase until shoot maturity. N absorption activity declined from 8.6 pmol cm⁻² s⁻¹ just prior to cycle initiation (day 0) to 3.1 pmol cm⁻² s⁻¹ at day 15. Absorption rates steadily increased as flower shoots reached maturity to 8.2 pmol cm⁻² s⁻¹ at day 30. K and P followed similar patterns of absorption. Root TNC concentration did not change during the high light cycle. Under low light, root TNC concentration dropped by half (from 40 to 18 mg g⁻¹ during days 0 to 5) then remained relatively stable until the last five days of the crop cycle when the concentration increased to 36 mg g⁻¹. Overall, variation in N, P, K absorption was primarily dependent on changes in physiological root activity rather than changes in RSA.

**INTRODUCTION**

Commercial cut flower rose (*Rosa hybrida* L.) production is typically conducted in hydroponics using soil-less media that is kept moist through irrigation with a nutrient solution (fertigation). Cut flower roses are often managed to produce a flush of harvestable shoots in time for a particular holiday. These crop cycles are initiated by forcing new buds to develop through breaking apical dominance by harvesting, cutting back, or bending existing shoots. New flower shoots generally take 4-8 weeks to reach harvestable maturity depending on variety and environmental conditions.

Rose plants exhibit cyclical patterns of NΟ₃⁻, H₂PO₄⁻, K⁺, Ca²⁺ and Mg²⁺ absorption, coinciding with the crop cycle (Cabrera et al., 1995). The general pattern is a decrease in uptake rate following a previous harvest (initiation of a new cycle) until the minimum absorption rates are reached as new flower shoots begin to elongate rapidly, followed by increased uptake rates until flower shoots reach commercial maturity. A similar pattern was reported for NΟ₃⁻, H₂PO₄⁻, and K⁺ by Lorenzo et al. (2000); although addition of NH₄⁺ decreased K⁺ uptake early in the cycle and increased H₂PO₄⁻ uptake across the entire crop cycle. Rose plants also exhibit daily patterns of NO₃⁻ uptake (Bougoul et al., 2000). Uptake rates were 2.0 μmol h⁻¹ g⁻¹ aerial dry weight during the middle of the day and decreased by ten-fold during the middle of the night.
For ‘Kardinal’ roses, NO$_3^-$ and K$^+$ absorption activity (uptake per unit root surface area per unit time) has been reported to vary from 1.8 to 8 and 0.5 to 3 pmol cm$^{-2}$ s$^{-1}$, respectively (Silberbush and Lieth, 2004). However changes in root system dimensions over crop cycles were not considered in their research. Root segment age also influences physiological root absorption activity (Bouma et al., 2001). Dark coloration of older fine roots is reported to occur due to senescence and browning of the root cortex (Wells and Eissenstat, 2003). These dark-colored roots often exhibit reduced nutrient uptake rates as senescence of cortical and epidermal tissues reduces the overall membrane surface area available for uptake. Changes in rose plant root system size and growth over a crop cycle have not been reported in relationship to nutrient uptake, so it is unknown whether the cyclical patterns of nutrient absorption in roses are due to changes in plant root surface area (RSA), physiological root absorption activity, or both.

It has been hypothesized that decreased nitrogen absorption during the middle of a rose crop cycle may be due to competition within the plant for photoassimilates. New flower shoots may be a strong sink for carbohydrates during the stage of rapid shoot elongation and thus may limit carbohydrates available for root growth or ion uptake (Cabrera et al., 1995). Seasonal fluxes in rose root carbohydrate levels have been reported by Zieslin et al. (1975). For rose plants pruned in the fall, the highest starch levels of 18 mg g$^{-1}$ were found in May/June, this declined during the summer and reached a minimum level of 2 mg g$^{-1}$ by September which persisted until January when starch accumulation began again. Reducing sugar content increased during the summer from 12 mg g$^{-1}$ in June to a peak of 40 mg g$^{-1}$ in November, with a decrease during the winter. No information is available on root carbohydrate changes during a crop cycle.

The objectives of this project were to (1) quantify changes in rose plant root surface area (RSA), N, P, and K root absorption activity, and total nonstructural carbohydrate (TNC) concentration of roots during a crop cycle, and (2) determine the influence of light on RSA and TNC.

**MATERIALS AND METHODS**

**Experiment 1: Root Surface Area, N, P, K Absorption Activity and TNC Concentration under High Light**

A sequential harvest experiment was conducted to collect data on RSA, N, P, K absorption activity, and root TNC content during a thirty-day rose crop cycle under high light conditions. Thirty-five one-year old ‘Kardinal’ rose plants on ‘Natal Briar’ rootstock were established in solution culture in 8 L containers and trimmed back to achieve uniformity. The nutrient solution contained: 0.5 mM NH$_4$H$_2$PO$_4$, 3 mM KNO$_3$, 2 mM Ca(NO$_3$)$_2$, 1 mM MgSO$_4$, 0.018 mM Fe as Fe-DTPA, and Hoagland’s micronutrient concentration (Hoagland and Arnon, 1950). The solution was kept aerated by continuously bubbling air into the solution. Plants were grown in solution culture for one-month before the experiment was initiated.

At the start of the experiment (day 0) plants were trimmed by cutting back existing shoots to the second basal five-leaflet leaf. Plants were randomly divided into seven groups of five plants. Plants were placed in a controlled environment chamber (18h photoperiod at 700 µmol m$^{-2}$ s$^{-1}$ PAR with average daily temperature of 25°C). Every five days, one group of five plants was selected for destructive harvest. Methods of analysis included: NO$_3^-$ and NH$_4^+$ by the diffusion conductivity method; K$^+$ by flame emission with an ion absorption spectrophotometer; and H$_2$PO$_4^-$ by the stannous chloride colorimetric method with a Brinkman PL800 colorimeter.

At each harvest, approximately half of each plant’s fine roots (roots less than 1 mm in diameter) were reserved for root scanning, the other half were reserved for TNC analysis. The procedure for root scanning was similar to recommendations by Bouma et al. (2000) where, root samples were stained with 0.5 g L$^{-1}$ of neutral red (Sigma Chemical Co., St. Louis, MO, USA) for 24h to achieve a uniformly dark color. Sub-samples were then rinsed and spread in a glass tray with a thin layer of water. A black and white image
was obtained with a desktop scanner at 400 dpi resolution and a brightness threshold of 180. Images were analyzed using Delta-T Scan software (release V2.03, Delta-T Devices Ltd., Cambridge, UK) to determine length, diameter and RSA. Following scanning, root sub-samples were dried in an oven at 70°C for five days. RSA of each sub-sample in relationship to its dry weight was used to estimate root surface area of the plant’s whole root system. Nutrient solution samples were taken and solution volume was recorded two days prior to harvest and at harvest to determine N, P, and K absorption by each of the five plants. Nutrient absorption activity was calculated by dividing N, P, and K uptake rates by plant RSA.

Prior to TNC analysis, roots were dried as above, weighed, and ground to pass through a 40-mesh screen. Fructose, glucose, and sucrose were analyzed via hot water extraction and detection with HPLC (Johansen et al., 1996). Starch was determined via enzymatic hydrolysis with amylglucosidase and subsequent determination of glucose.

**Experiment 2: Root Surface Area of Dark and Light Roots under Low Light**

During the first experiment we found that roots could be qualitatively separated into “light-colored” and “dark-colored” groups, suggesting different levels of biological activity. A second sequential harvest experiment was conducted to determine changes in RSA and root TNC concentration during a crop cycle under low light conditions. The methods were as before except that light levels in the controlled environment chamber were 260 µmol m⁻² s⁻¹ PAR, with a 14h photoperiod; average daily temperature was 25°C; crop cycle length was 35 days; and plants were grouped into five size classes based on fresh weight prior to the experiment to control plant-to-plant variation. One plant from each size class was randomly selected for each of eight groups of five plants. At harvest, root samples for scanning were divided into groups of “dark-colored” and “light-colored” fine roots, which were subsequently stained and scanned separately.

All statistical analysis were conducted with Statistical Analysis System (SAS version 9.1, SAS Institute Inc., Cary, NC, USA). Analysis of Variance tests (SAS Proc GLM) were conducted to identify differences in the measured parameters by harvest date. When significant differences were found, Tukey’s Honestly Significant Difference method (P=0.05) method was used to conduct pairwise comparisons.

**RESULTS**

**Root Growth**

Plant RSA did not change significantly during the crop cycle for experiment 1 and averaged 14400 cm² plant⁻¹ (Fig. 1A). Large plant-to-plant variation was noted; RSA ranged from 7300 to 23600 cm² plant⁻¹. Root dry weight did not change significantly during the crop cycle and averaged 11.4 g plant⁻¹; root dry weight ranged from 6.0 to 16.3 g plant⁻¹ (data not presented).

RSA of “dark-colored” roots did not change significantly during experiment 2 and averaged 1200 cm² plant⁻¹ (Fig. 1B). There were significant quadratic relationships between “light-colored” and total RSA versus days in the crop cycle (Fig. 1B). RSA of “light-colored” roots declined following cycle initiation (day 0), till the minimum RSA was found at day 15/20. Between days 20 and 35 RSA of light-colored roots increased from 2500 to 4600 cm² plant⁻¹. Consequently, total plant RSA (“dark-colored” plus “light-colored” roots) showed a similar pattern of declining RSA until day 15 and increasing RSA between days 20 to 35. Root dry weight followed similar patterns to total RSA and varied from 3.1 to 4.4 g plant⁻¹ during the crop cycle (data not presented).

**Nutrient Absorption Activity**

Root nitrogen absorption activity declined from 8.6 ρmol cm⁻² s⁻¹ just prior to harvest (day 0) to 3.1 ρmol cm⁻² s⁻¹ at day 15. Absorption activity then steadily increased as flower shoots reached harvestable maturity to 8.2 pmol cm⁻² s⁻¹ at day 30 (Fig. 2A). Similar patterns were found for phosphorus and potassium. Absorption activity varied
from -0.24 to 0.73 \( \text{pmol cm}^{-2} \text{ s}^{-1} \) for phosphorus and from 0.65 to 3.3 \( \text{pmol cm}^{-2} \text{ s}^{-1} \) for potassium.

Root Total Nonstructural Carbohydrate Content

Under high light, the root TNC concentration did not vary during the crop cycle and averaged 44 mg g\(^{-1}\) (Fig. 3A). Under low light, The TNC concentration of roots dropped by half, from 40 to 18 mg g\(^{-1}\) during days 0 to 5 (Fig. 3B). Root TNC then remained relatively stable until the last five days of the crop cycle when the concentration increased from to 20 to 36 mg g\(^{-1}\) during days 30 to 35 (Fig. 3B).

DISCUSSION

In experiment 1, the changes in plant N, P, K absorption rates during a crop cycle could be primarily attributed to changes in physiological root absorption activity as changes in RSA were not found. However, in experiment 2, RSA, and in particular RSA of “light-colored” (younger) roots, showed a significant pattern of decline following a previous harvest until day 15/20 and a later increase in RSA.

A large plant-to-plant variation existed in experiment 1. It is possible the pattern of declining RSA could have been found in experiment 1 if there was a stricter control of plant to plant variation. Alternatively, the lower light levels and reduced TNC concentration of roots under low light may have been responsible for the declines in RSA in experiment 2. Fuchs (1986) found a similar pattern of rose root fresh weight decline following a previous harvest until a minimum was reached at day 16 in a crop cycle. This decline was more pronounced on plants that had half of their remaining leaves removed at harvest. If the pattern of RSA from experiment 2 is superimposed on N, P, K uptake rates from experiment 1, and then changes in nutrient uptake rates could be attributed to changes in both root surface area and physiological absorption activity.

Interestingly, in the high light experiment root TNC concentration did not vary significantly during the entire crop cycle; whereas in the low light experiment TNC concentration was reduced from initial levels for much of the crop cycle. In the high light experiment, the lowest rates of nutrient absorption activity occurred at day 10 for K and day 15 for N and P. While, this period coincides with the stage of rapid stem elongation of flower shoots (shoots appeared at day 8 and buds became visible on shoots around day 16), there was no evidence of decreased root TNC concentration during this period. This implies that photoassimilate availability to the roots does not itself directly control nutrient uptake rates. Other factors such as root system age (Bouma et al., 2001) and internal plant nutrient demand may play a larger role in uptake dynamics. For example, Siddiqi et al. (1990) found decreased rates of barley plant nitrate uptake as plant N content increased.

Knowledge about the dynamics of rose root surface area during a crop cycle and its relationship to N, P, and K absorption is important in our efforts to develop predictive models for rose plant nutrient uptake. Root system size and physiological absorption activity are important parameters in such a model which may serve as a tool to help identify methods of optimization of fertigation and minimization of waste water. More experimentation is needed to determine the influence of environment and rhizosphere conditions on root growth rates during rose crop cycles. Overall, these experiments provide evidence against the hypothesis that reduced rates of nutrient absorption during the middle of a crop cycle are due to decreased carbohydrate supply.

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Literature Cited


Fig. 1. Root surface area (RSA) of rose plants grown under high (A) and low (B) light crop cycles. *P*-values from Analysis of Variance were 0.718, 0.075, 0.014, and 0.918 for total roots in the high light experiment; and total, light-colored, and dark-colored roots in the low light experiment, respectively. Data are means (± SE) of five plants harvested every five days. Letters denote mean separation comparisons of light-colored RSA across days in the crop cycle for light-colored roots utilizing Tukey’s HSD (*P*=0.05). For the low light experiment, significant quadratic relationships existed between total and light-colored RSA and days into the crop cycle (x). Roots are fine roots (<1 mm in diameter).
Fig. 2. Rose plant root absorption rates for nitrogen (A), phosphorus (B), and potassium (C) over a thirty-day crop cycle under high light. Data are means (± SE) of five plants harvested every five days. *P*-values from Analysis of Variance were 0.002, <0.001, and <0.001 for N, P, and K, respectively. Letters denote mean separation comparisons of absorption rates across days in the crop cycle for each nutrient utilizing Tukey's HSD (*P*=0.05).
Fig. 3. Total nonstructural carbohydrate concentration (glucose, fructose, sucrose, and starch; TNC) of roots of rose plants over a thirty day crop cycle under high light (A) and a thirty-five day cycle under low light (B). Data are means (± SE) of five plants harvested every five days. $P$-value from Analysis of Variance was 0.295 for the high light experiment and <0.001 for the low light experiment. Letters denote mean separation comparisons of root TNC concentration across days in the crop cycle utilizing Tukey’s HSD ($P=0.05$).