Optimum Feeding Nutrient Solution Concentration for Greenhouse Potted Miniature Rose Production in a Recirculating Subirrigation System

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Abstract. To determine the optimum feeding nutrient solution concentrations for the production of potted miniature roses (*Rosa chineensis minima* ‘Fall Festival’) under recirculating subirrigation conditions, plants were grown under four different nutrient solution concentrations [25%, 50%, 75%, and 100% of the full strength with an electrical conductivity (EC) of 1.756 dS·m⁻¹]. Nutrient solution concentrations affected the stem, root, and plant total dry weight and flower and branch number. Under the 75% strength nutrient solution, these growth parameters were equal to or better than the 100% strength solution. No difference was detected in the chlorophyll content of leaves from plants that received the 50%, 75%, and 100% strength solutions during the experiment but at Day 35; only the 25% treatment had significantly lower leaf chlorophyll content than the other treatments. There were no treatment effects on the measured total foliar nutrient contents [except potassium (K)] of plants under the 75% strength solution compared with those under the 100% treatment, but nitrogen (N), phosphorus (P), and/or iron (Fe) of plants under the 25% strength solutions were below that of the acceptable range. Interveneal chlorosis and/or reddish leaves and branches were also apparent in plants under the 25% and 50% strength solutions. It is suspected that these are symptoms of N, P, and Fe deficiencies caused by the reduced nutrient solution concentrations and increased pH of the growing substrate. There were significant depletions of N and P nutrients in the 25% and 50% strength solutions at the end of the experiment, which was consistent with visual symptoms and deficiencies. Nutrient salts accumulated in the top section of the growing substrate under all treatments, but no phytotoxic effects were observed. The EC values for the top third of the growing substrate were much higher than those of the bottom two-thirds. EC for the top layer of the 100% treatment exhibited a fourfold increase compared with the bottom layer of that treatment. The NO₃⁻, K, magnesium, and calcium for the top layer of the 100% treatment were 235%, 149%, 287%, and 245%, respectively, higher compared with the bottom layer of the 100% treatment. It was concluded that the nutrient solution concentrations typically used for potted miniature rose production in most of the Canadian greenhouses under recirculating subirrigation conditions can be safely reduced to 75% and produce better plants.

The use of a recirculating subirrigation system is becoming increasingly popular in the greenhouse industry. In a survey on the status of nutrient solution recirculation in Ontario, Canada, Richard et al. (2006) found that almost half of the surveyed vegetable greenhouses and 30% of the ornamental crop greenhouses were recycling their nutrient solution. The use of recirculating subirriga-

tion systems has been adopted for many reasons, including environmental, social, and economical benefits. In 2002, the government of Ontario introduced the Nutrient Management Act to regulate the discharge of nutrients and pesticide pollution and reduce water consumption (Ontario Ministry of Agriculture, Food and Rural Affairs, 2007). The use of a recirculating subirrigation system allows growers to comply with the Nutrient Management Act because it lowers nutrient and water requirements. It also allows for nutrients to be delivered in a uniform manner, avoids foliar wetting to reduce disease incidence, offers greater flexibility in pot sizing and spacing, and reduces the discharge of nutrients to surrounding ecosystems. These benefits can lead to savings in labor, material input, and product losses (Richard et al., 2006; Uva and Weiler, 1998).

Subirrigation, however, leads to salt accumulation at the substrate surface, which is

a major drawback to the practice (Argo and Biernbaum, 1996; Kent and Reed, 1996; Morvant et al., 1997; Zheng et al., 2004a, 2005). In subirrigation, salts are not leached out of the containers like in overhead irrigation; as a result, water evaporates from the surface of the growing substrate leaving behind fertilizer salts on the top layers of the growing substrate causing salt accumulation (Zheng et al., 2004a, 2005). Salt concentration can quickly reach toxic levels resulting in visible damage in crops. This problem is further exacerbated by high fertilizer application rates (Zheng et al., 2004a, 2005).

Commercial greenhouse growers typically use high nutrient concentrations in an attempt to maximize crop yield, but this practice is not an economically optimized production strategy because excessive nutrients do not always result in higher crop yields (Zheng et al., 2004a, 2005). Siddiqi et al. (1998) showed that macronutrient concentrations, commonly used by commercial greenhouse tomato growers, can be reduced by 50% without having any adverse effect on growth, fruit yield, and fruit quality of tomato plants. For NFT lettuce production, Chen et al. (1997) showed that current nutrient concentrations can be reduced by up to 99% without having any adverse effect on growth and rates of nutrient uptake.

Our prior research (Zheng et al., 2004a, 2005) has shown that nutrient solution concentrations for potted gerbera production can be safely reduced by at least 50% without adversely affecting crop production over a 4- to 5-week period; however, many plants (such as miniature roses) may be subirrigated for up to 10 weeks before they are ready for the market (Beytes and Hamrick, 2003). The objectives of the present study were to: 1) determine the optimum feeding nutrient concentration for greenhouse potted miniature rose production; and 2) to profile vertical salt distribution within subirrigated growing substrate in the pot over the production period.

Materials and Methods

Plants and growing substrate. Miniature rose (*Rosa chineensis minima* ‘Fall Festival’) plants were obtained from an Ontario commercial greenhouse, which were rooted on 27 May 2004 in 1.9-L (15 cm diameter × 11 cm high) pots. Each pot contained five plants and the substrate used was Pro-Mix BX (Pro-Mix, St. Catherine’s, Ontario, Canada). The initial chemical composition, pH, and electrical conductivity (EC) of the growing substrate (Table 1) were determined on four randomly selected pots using the saturation media extract method (Warncke, 1986) before the start of the experiment. Pot substrates were evenly divided into top, middle, and bottom sections. Extracted solution ion concentrations were determined by high-performance liquid chromatography (DX-120 for cations and DX-500 for anions; Dionex, Sunnyvale, CA). The experiment was started on 9 June

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Table 1. Initial chemical composition, pH, and electrical conductivity (EC) of the growing substrate before subirrigation treatment.

Section ²	Ion (mmol·L ⁻¹)										EC (dS·m ⁻¹)	pH
	F ⁻	Cl ⁻	NO ₃ ⁻¹	PO ₄ ⁻³	SO ₄ ⁻²	Na ⁺	NH ₄ ⁺	K ⁺	Mg ²⁺	Ca ²⁺		
Bottom	0.01	0.16	4.1	0.86	0.86	0.49	0.21	2.77	0.50	1.06	0.639	5.81
Middle	0.02	0.16	3.5	0.63	0.69	0.35	0.36	2.50	0.45	0.95	0.657	5.85
Top	0.03	0.20	3.9	0.63	0.88	0.44	0.49	2.46	0.57	1.25	0.703	6.02
Analysis of variance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

²Substrate (with roots intact) in the pots was evenly divided into bottom, middle, and top sections.

NS = nonsignificant differences among sections at $P \leq 0.05$ level.

2004 and subirrigated with nutrient solution for 10.5 weeks when the plants reached marketable size and were harvested on 21 Aug. 2004.

Treatments. The experiment was conducted in the research greenhouse at the University of Guelph (Guelph, Ontario, Canada). The air temperature and relative humidity set points in the greenhouse were day/night 24/18 °C and 75%, respectively. The experiment was a randomized complete block design with four treatments of varying nutrient solution concentration (25%, 50%, 75%, and 100% full strength) in three blocks. There were 11 pots in each experimental unit (trough). Pots in each trough were fertigated as required (two to three times per week) by filling troughs with nutrient solutions from a reservoir tank containing 50 L of nutrient solution. Troughs were filled so that the bottom 8 cm of the pots was submerged for 1 to 2 min. All treatment solutions had the same micronutrient concentration. The full-strength (100% concentration) nutrient solution consisted of the following macronutrient (in mM): 11.7 NO₃-N and 4.7 NH₄-N [total nitrogen (N) of 229.6 mg·L⁻¹], 1.5 phosphorus (P), 1.5 calcium (Ca), 5.5 potassium (K), 0.7 SO₄²⁻, and 0.7 magnesium (Mg); and micronutrients (in mM): 0.005 manganese, 0.0035 zinc, 0.02 boron, 0.0005 molybdenum, 0.0008 copper, and 0.13 iron (Fe) as Fe-EDTA. After each fertigation, the pH of the solutions was restored to the target value of 5.6 with HNO₃ or KOH. Additionally, the EC was restored to the original target values (1.756, 1.320, 0.902 and 0.479 dS·m⁻¹ for the 100%, 75%, 50%, and 25% solutions, respectively) by adding 100× concentrated stock solutions A and B. The volumes of stock solutions A and B added were the same. Stock solution A consisted of (in M): 1.5 Ca(NO₃)₂·4H₂O and 3.2 NH₄NO₃; and stock solution B consisted of (in M): 0.7 MgSO₄·7H₂O, 5.5 KNO₃, and 1.5 NH₄H₂PO₄. During the adjustment, the volumes of added water and nutrient stock solutions were recorded for calculation of water and nutrient inputs.

Measurements. Nutrient solution samples were collected from each nutrient solution tank and analyzed using a Dionex ion chromatography (DX-120; Dionex Canada Ltd., Oakville, Ontario, Canada) after each pH and EC adjustment. Leaf chlorophyll index (CCI) of the most recent fully expanded leaf at the time of measurement was measured on 15 June 2009 (7 d after the start of the treatments) and once a week thereafter using a CCM-200 (Opti-Sciences, Tyngsboro, MA). Leaf chlorophyll fluorescence of plants from

seven randomly selected pots from each trough was measured on 19 Aug. 2004 (Day 72) with a Fluorescence Monitoring System FMS 2 (Hansatech Instruments, Norfolk, U.K.) between 1400 and 1600 HR. The minimal level of fluorescence (F_0) was obtained under modulated red light (2 μ mol·m⁻²·s⁻¹, frequency 20 kHz) and maximal fluorescence yield (F_m) was recorded after exposure to a saturating light pulse (0.8 s) of 8000 μ mol·m⁻²·s⁻¹ provided by an 8-V/25-W halogen lamp (Bellaphot; Osram). The maximum (or potential) quantum efficiency of photosystem (PS) II [$F_v/F_m = (F_m - F_0)/F_m$] was measured after a 40-min period of dark adaptation (Zheng et al., 2004b).

Five randomly selected pots from each trough were harvested on 22 Aug. 2009 (Day 75). The number of branches and flowers from each pot was counted. The plants from each pot were separated into flowers, leaves, stems, and roots. Plant parts were dried to a constant weight in a forced-air oven at 65 °C. Total dry weight was calculated as the sum of dry weights for all the plant parts. Foliar N, P, K, Ca, Mg, and Fe contents were analyzed by the Laboratory Services Division, University of Guelph (for details, see Zheng et al., 2004a). The substrate (with roots) was evenly divided into top, middle, and bottom sections; and the pH, EC, and nutrient ion concentrations of each section were determined as described previously.

Statistical analysis. Responses were analyzed as an orthogonal partition and regression analysis (Bowley, 1999). If the partitioning variance analysis indicated a significant ($P < 0.05$) treatment effect, then the treatment effects were partitioned into one or more regression effects followed by an estimation of regression parameters for the best-fit regression. If there was no significant treatment effect, then data were presented as the average of all the treatments. Contrast analysis was used to test whether there were significant ($P < 0.05$) differences between salt concentrations in different pot substrate sections and among leaf tissue nutrient contents under different nutrient treatments. Statistical analysis was conducted using SAS (SAS Institute Inc., Cary, NC).

Results and Discussion

The 75% treatment resulted in the highest numbers of branches and flowers per pot; stem and total plant dry weights increased linearly with the increased nutrient concentration; however, no differences (according

to t test) were observed in stem, root, and total plant dry weights between the 75% and 100% treatments (Fig. 1). Plants in both the 75% and 100% treatments were healthy and with dark green foliage throughout the entire experiment. Leaf CCI measurement also showed no significant difference among the 50%, 75%, and 100% treatments at the late stage of the experiment (Fig. 2). The average foliar nutrient levels (N, P, K, Ca, Mg, and Fe) in the 50%, 75%, and 100% treatments were all within or above Ontario Ministry of Agriculture and Food (2003) tissue analysis guideline for roses (Table 2). Nutrient treatments did not have any effect on leaf maximum quantum efficiency of PS II ($F_v/F_m = 0.85 \pm 0.009$). Overall, the 75% treatment produced better miniature roses than the 100% treatment.

During the last week of the experiment, there was interveinal chlorosis on 90% of the leaves of the plants in the 25% treatment. The remaining 10% of leaves of the plants were light green with reddish branches. The edges of the younger leaves of the 50% treatments were red with reddish branches. Leaves of the 75% and 100% treatments were dark green. Leaf CCI of the plants in the 25% treatment during the last week of the experiment were 38% to 58% below that of the other treatments (Fig. 2). Signs of interveinal chlorosis with reddish branches are typical symptoms of N, P, and Fe deficiency (Beytes and Hamrick, 2003; Salisbury and Ross, 1992). It is suspected that the plants in the 25% treatment were deficient in N, P, and Fe because the average foliar N, P, and Fe contents of this treatment were below or close to the lower limits of the normal ranges for roses (Table 2).

Foliar Fe content measurements showed that there was a significant ($P < 0.05$) linear relationship between fertigation nutrient levels and foliar iron contents (mg·g⁻¹; $Y = 41 + 0.42X$, X as percent of the full strength; $r^2 = 0.9625$). The Fe deficiency was most likely caused by the increased pH values in the lower nutrient level treatments (Fig. 3), because the micronutrient levels were the same in all the treatments. The 75% treatment had a desirable growing substrate pH range (Fig. 3) that was within the accepted range of 5.5 to 6.2 (Beytes and Hamrick, 2003); however, the growing substrates of the 25% and 50% treatments increased to between 6.4 to 6.9 (Fig. 3). The trend of increased substrate pH under lower nutrient levels was also observed in our previous research (Zheng et al., 2004a, 2005) and by several other researchers (James and van Iersel, 2001; Kang and van Iersel, 2002; van Iersel, 1999). Leaf Fe deficiency in the lower-level nutrient treatments was also observed in our previous study on potted gerberas (Zheng et al., 2004a). In our previous study on gerberas, the N and P levels in the 100% treatment were 12.7 mM and 1.2 mM, respectively, which were lower than 16.4 mM (N) and 1.5 mM (P) used in this experiment. However, no N and P deficiency was observed in any of the treatments in the studies on gerberas (Zheng et al., 2004a,

Fig. 1. Stem, root, leaf, flower, and plant total dry weight, number of flowers, and branches of miniature roses after a 10.5-week period of subirrigation under four different concentrations (25%, 50%, 75%, and 100% of full strength) of nutrient solution. A regression line was shown only when there was a significant treatment effect. Each data point represents the means of three replications (15 subsamples) $\pm$ the SE of the mean.

Fig. 2. Leaf chlorophyll content index (CCI) of the most recent fully expanded leaf at the time of measurement measured at 1-week intervals after the start of the treatments. The 25%, 50%, 75%, and 100% in the figure are the nutrient solution concentrations. Each point represents the mean of three replications (30 subsamples). Points for the same day bearing the same letter (beside the symbol) indicate that the means are not significantly different at the $P \leq 0.05$ level.

Table 2. Leaf tissue nutrient contents of miniature rose fertilized with different concentrations of nutrient solutions.

Nutrient level ^a	Nitrogen ^y	Phosphorus	Potassium (%)	Calcium	Magnesium	Iron (mg·g ⁻¹)
100%	3.37 $\pm$ 0.070 a ^x	0.38 $\pm$ 0.020 a	4.49 $\pm$ 0.104 a	1.68 $\pm$ 0.051	0.32 $\pm$ 0.013	81 $\pm$ 3.6 a
75%	3.24 $\pm$ 0.070 ab	0.37 $\pm$ 0.020 a	3.79 $\pm$ 0.104 b	1.57 $\pm$ 0.051	0.31 $\pm$ 0.013	74 $\pm$ 3.6 a
50%	2.96 $\pm$ 0.070 b	0.32 $\pm$ 0.020 a	3.42 $\pm$ 0.104 b	1.40 $\pm$ 0.051	0.31 $\pm$ 0.013	65 $\pm$ 3.6 ab
25%	1.76 $\pm$ 0.070 c	0.14 $\pm$ 0.020 b	2.53 $\pm$ 0.104 c	1.71 $\pm$ 0.051	0.38 $\pm$ 0.013	49 $\pm$ 3.6 b
Guideline ^w	3.0–5.0	0.2–0.3	1.8–3.0	1.0–1.9	0.2–0.4	50–150

^aPercentage nutrient concentrations of the full strength.

^yData are means of 15 subsamples $\pm$ SE.

^xMeans within a column followed by different letters are significantly different at $P < 0.05$.

^wFrom Ontario Ministry of Agriculture and Food (2003) for rose leaf tissues analysis.

2005). Also, the studies concluded that the nutrient concentration currently used in gerbera production can be reduced by 50% without any negative effect and also produce better potted gerbera plants. The difference between these studies could be because 1) different species have different nutrient requirements; and 2) the studies on gerbera were for 4 to 5 weeks and the study on miniature roses was 10.5 weeks. Kang and van Iersel (2002) subirrigated seedlings of *Lobularia maritima*, *Celosia* spp., *Dianthus chinensis*, *Gomphrena globosa*, *Matthiola incana*, and *Zinnia elegans* grown in cells (160 mL) with varying concentrations of nutrient solutions. Although growth of *Zinnia* was maximized with a half-strength Hoagland solution, the other species required full-strength solutions for maximum production. Yelanich and Biernbaum (1990) showed that poinsettia growth under three concentrations of N (7.1, 14.3, and 28.6 mM) and K (2.6, 5.1, and 10.3 mM) were maximized with the lowest concentrations in both top and subirrigation systems.

There were positive correlations between nutrient solution concentrations and substrate nutrient contents for NO_3^- , K, Mg, and Ca (Fig. 3). Subirrigation resulted in a significant accumulation of salts within the top third of the plant growing substrate across all treatments. The EC values for the top third of the growing substrate were much higher than those of the bottom two-thirds. For example, EC for the top layer of the 100% treatment exhibited a fourfold increase compared with the bottom layer of that treatment. Most of the measured major nutrient ion (NO_3^- , K, Mg, and Ca) concentrations were also much higher in the top third of the substrate as compared with the bottom section. The NO_3^- , K, Mg, and Ca for the top layer of the 100% treatment were 235%, 149%, 287%, and 245%, respectively, higher compared with the bottom layer of the 100% treatment. The accumulation of salts in the surface layer of growing substrate has also been reported in our previous study and in numerous other studies (Argo and Biernbaum, 1995, 1996; Kent and Reed, 1996; Mak and Yeh, 2001; Morvant et al., 1997; Zheng et al., 2004a, 2005). The EC range of the 100% treatment went as high as $10.5 \text{ dS}\cdot\text{m}^{-1}$, which was above the acceptable range of 2.0 to $3.5 \text{ dS}\cdot\text{m}^{-1}$ (Argo and Biernbaum, 1995; Warncke and Krauskopf, 1983; Fig. 3). The top layer of the 75% treatment was above the accepted EC range, but the accumulation of salts in the upper section of the 75% growing substrate had no observable detrimental effects (i.e., root rot). The magnitude of salt accumulation in each growing substrate section of the reduced concentration treatments (25%, 50%, and 75%) was much lower as compared with each growing substrate section of the full-strength treatment (100%; Fig. 3). Because the major nutrient ions (NO_3^- , K, Mg, and Ca) accumulated in the top layer of the growth medium, they might not be available to the roots, which are mostly distributed in the lower two-thirds of the substrates, thus

Fig. 3. Substrate nutrients, electrical conductivity (EC), and pH vertical distributions after a 10.5-week period of subirrigation under four different concentrations (25%, 50%, 75%, and 100% of full strength) of nutrient solution. The top, middle, and bottom sections of the pot substrate are represented by circles, squares, and triangles, respectively. Each point represents the mean of three replications (15 subsamples). Where nutrient treatment effects were significant ($P \leq 0.05$), lines indicate that calculated regression; otherwise, no lines are shown.

resulting in nutrient deficiency (such as the N deficiency observed in this study) in the lower nutrient level treatments. To avoid phytotoxic salt accumulation in long-duration

subirrigated crop production, a reduction in feed concentrations would be advisable (Zheng et al., 2004a, 2005). This study and our previous studies (Zheng et al., 2004a,

2005) suggested that to reduce the potential phytotoxic salt accumulation in the top layer and to avoid nutrient deficiency in the lower nutrient level treatments, it would be advisable

Fig. 4. Reservoir nutrient solutions ion concentrations changes with time under recycling conditions. Data were collected after each pH and electrical conductivity (EC) adjustment. Values are means of three replications $\pm$ SE. Where time effects were significant ($P \leq 0.05$), lines indicate the calculated regression; otherwise, no lines are shown. $\bullet$ $\text{NO}_3^- + \text{NH}_4^+$ $\blacksquare$ PO_4 $\blacktriangle$ SO_4 $\circ$ K $\square$ Mg Δ Ca

to periodically switch to overhead fertigation in an attempt to redistribute nutrient salts to the lower section of the pot.

Potassium was the only element accumulated with a 124% to 158% increase from the start to the end of the experiment in the lower concentrations of nutrient solution (25%, 50%, and 75%; Fig. 4). There was a depletion for all other nutrient ion concentrations ($\text{NO}_3^- + \text{NH}_4^+$, PO_4^{3-} , SO_4^{2-} , Ca, and Mg). The ion with the highest percentage depletion was $\text{NO}_3^- + \text{NH}_4^+$ with a 59% decrease in the 25% strength nutrient solution. A depletion of nitrogen was also observed in our previous study (Zheng et al., 2004a, 2005). The ion with the second highest percentage depletion was PO_4^{3-} with a 32% decrease in the 25% strength nutrient solution. Depletion of the PO_4^{3-} in the 25% strength nutrient solution would also result in the lack of P provided to the plants resulting in reddish branches and below normal foliar P content (Table 2). Overall, the results suggest that for long-term (e.g., 10 weeks) recirculating, it is necessary to adjust nutrient concentrations based on individual element analysis result rather than solely based on EC and pH, especially for

lower-level (e.g., 25% and 50%) nutrient solutions.

Water consumption of the production system (average 147 mL per pot per day) was unaffected by nutrient solution concentration, but fertilizer inputs were reduced at lower nutrient feeds. Compared with the 100% treatment, fertilizer inputs for the 75%, 50%, and 25% treatments were lower by 23%, 52%, and 80%, respectively. These results are similar to our previous study on gerbera, which showed that the average water consumption is 141 mL per plant per day, and fertilizer input is reduced by 54% and 75% for the 50% and 25% treatments, respectively (Zheng et al., 2004a).

The results of this study clearly demonstrated that in potted miniature rose production using subirrigation, nutrient feed concentrations can be reduced to 75% of the full-strength concentration without negatively affecting production and quality. However, when the concentration was lowered to less than 50%, plants started to show symptoms of N, P, and/or Fe deficiency, which was most likely the result of the decreased concentration of nutrient solution and increased

pH in the growing substrate. Nutrient salts did accumulate in the top section of the growing substrate under all treatments, but they were significantly lower in the reduced nutrient treatments and salt levels were not phytotoxic under any of the treatments.

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