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Potted Gerbera Production in a Subirrigation System Using Low-concentration Nutrient Solutions

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Abstract. **To determine whether currently used commercial nutrient solution concentrations can be reduced during the final stage (last 4 to 5 weeks) of production of potted gerbera (*Gerbera jamesonii* 'Shogun') under recirculating subirrigation conditions, plants were grown under one of four nutrient levels (10%, 25%, 50%, and 100% of full strength). Nutrient concentration levels did not affect leaf area, flower number and appearance, and plant total dry weight. There were no significant differences in the greenness (as measured by SPAD meter) of leaves from plants that received the 50% and 100% strength nutrient solutions. However, leaves from plants that received the 10% and 25% strength solution showed significantly less greenness than that of the plants that received 50% and 100% strength nutrient solutions. There were interveinal chlorosis symptoms on the younger leaves of some plants in the 10% and 25% strength nutrient treatments. It is suspected that this interveinal chlorosis was due to iron (Fe) deficiency caused by the increased substrate pH. It is concluded that the nutrient solution concentrations typically used for potted gerbera production in commercial greenhouses at the final stage (4 to 5 weeks) under recirculating subirrigation conditions, can be safely reduced by at least 50% without adversely affecting crop production. Nutrient salts accumulated in the top section of the growth substrate under all treatments levels; however, no phytotoxic effects were observed. No differences in water use (141 mL per plant per day) were observed amid the various nutrient levels. Fertilizer inputs were reduced in the 50%, 25%, and 10% treatments by 54%, 75%, and 90% respectively, relative to the 100% treatment. After 4 weeks under recirculating conditions, the qualities of the nutrient solutions were still within acceptable limits.**

Over the past decade, recirculating subirrigation has become increasingly popular in the greenhouse industry. This cultural practice has many environmental, social and economical benefits, and is particularly attractive in the face of nutrient management legislation initiatives that are occurring world-wide. Recirculating subirrigation culture has lower nutrient and water requirements, delivers nutrients in a uniform manner, avoids foliar wetting (disease prevention), offers greater flexibility in pot sizing and spacing, and reduces the discharge of nutrients to surrounding ecosystems. These benefits can lead to savings in labour, material input, and product losses (Biernbaum and Versluys, 1998; Blom, 1991; Purvis et al., 2000; Uva et al., 1998). However, salt accumulation at the substrate surface is a major drawback of this cultural technique (Argo and Biernbaum, 1996; Morvant et al., 1997). This problem can be exacerbated by high fertilizer application rates. Commercial greenhouse growers typically use high nutrient concentrations in an attempt to maximize crop yield. This practice does not represent an economically optimized production strategy, as excessive nutrients do not necessarily translate into higher yields. Siddiqi et al. (1998) have shown that macronutrient concentrations, commonly used by commercial greenhouse tomato growers, can be reduced by 75% without having any adverse effect on growth, fruit yield and fruit quality. Similarly, for NFT lettuce production, Chen et al. (1997) have shown that current nutrient concentrations can be reduced by up to 99% without having any adverse effect on growth and rates of nutrient uptake.

During our recent Ontario greenhouse nutrient management survey, some growers reported problems with root rot in the upper substrate sections when utilizing subirrigation systems. In many cases it was suspected that the root rot was, at least in part, caused by salt accumulation at the substrate surface. However, there is little scientific evidence to support this theory, as very little work has been done to quantify 1) optimum nutrient feed levels for subirrigated potted gerbera production and 2) the extent of surface salt accumulation in potted gerbera grown under subirrigation.

The objectives of the presented study were to 1) determine whether potted gerbera can be grown using lower concentration nutrient solutions than are currently used in commercial greenhouses, without having a negative influence on plant production; 2) to profile vertical salt distribution within subirrigated growth substrate; and 3) to examine nutrient solution quality changes in a recirculating subirrigation system.

Materials and Methods

Plants and growth substrate. Gerbera daisy (*Gerbera jamesonii*, 'Shogun') seedlings were potted in 1.9-L (15 cm diameter × 11 cm high) pots on 24 Apr. 2002. The substrate used was BM6 Coarse (Berger/Berger peatmoss, Quebec, Canada) containing 20% perlite and 80% Canadian sphagnum peatmoss. Commercial potted gerbera greenhouses typically use overhead fertigation for 3 to 4 weeks before switching to subirrigation. Subirrigation is then maintained for 4 to 5 weeks until plants are ready for market. To maintain this practice during this study, plants were overhead fertigated with a full strength nutrient solution for 4 weeks in a commercial greenhouse, after which, plants were moved to a subirrigation system in the research greenhouse at the University of Guelph (Guelph, Ontario, Canada). The full strength nutrient solution used in this study consisted of the following macronutrients (in mM): 11.2 NO_3-N and 1.5 NH_4-N (total N of 178 $\mathrm{mg \cdot L^{-1}}$), 1.2 P, 3.0 Ca, 5.5 K, 1.0 SO_4^{2-}, and 1.0 Mg; and micronutrients (in µM): 2.2 Mn, 4.0 Zn, 29.6 B, 0.5 Mo, 1.0 Cu, and 53.9 Fe as Fe-EDTA. The experiment was started on 22 May 2002 when plants were at the 10 to 12 leaf stage. Initial chemical composition, pH, and EC of the growth substrate (Table 1) were determined on five randomly selected pots according to the saturation media extract (SME) method (Warncke, 1986). Pot substrates were evenly divided into top, middle and bottom sections. Extracted solution ion concentrations were determined by HPLC (DX-120 for cations and DX-500 for anions, Dionex, Sunnyvale, Calif.). Plants were subirrigated for 4 weeks, at which point they had reached marketable size and were consequently harvested on 20 June.

Table 1. Vertical distribution of ions, EC, and pH of the growth substrate before subirrigation treatment.

	Ion ($\mathrm{mmol \cdot L^{-1}}$)							EC	
Section[z]	NO_3^-	$H_2PO_4^-$	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	($\mathrm{dS \cdot m^{-1}}$)	pH
Bottom	7.1	0.2	2.51	0.34	0.94	1.74	4.62	1.2	6.36
Middle	6.1	0.3	1.61	0.35	0.99	1.64	4.39	1.1	6.41
Top	9.5	0.2	1.68	0.34	1.08	2.18	5.83	1.4	6.32
ANOVA	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z] Substrate (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.

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Treatments. The experiment was a randomized complete block design with four nutrient level treatments in three blocks. In each experimental unit (trough), there were 10 plants. Plants in each trough were fertigated as required (2 to 4 times per week) by filling troughs with nutrient solutions from a reservoir tank containing 70 L of nutrient solution. Troughs were filled so that the bottom 2.5 cm of the pots were submerged for 1 to 2 min. The four nutrient levels were 10, 25, 50, and 100% of a full strength nutrient solution. All treatment solutions had the same micronutrient concentrations. After each fertigation, the pH of the solutions was restored to the target value of 5.6 with HNO_3. Additionally, the EC was restored to the original target values (1.7, 1.0, 0.5, and 0.2 $dS \cdot m^{-1}$ for the 100%, 50%, 25%, and 10% solutions respectively) by adding 100× concentrated stock solution. During the adjustment, the volumes of added water and nutrient stock solutions were recorded for calculation of water and nutrient inputs. Nutrient solution samples were collected and analysed (by HPLC) after each pH and EC adjustment. The air temperature and relative humidity set points in the greenhouse were day/night 23/19 °C and 70% respectively.

Measurements. Leaf greenness measurements were started on 25 May (2 d after start of the experiment), and once a week thereafter. Measurements were made using a SPAD-501 meter (Minolta, Osaka, Japan). Measurements were conducted on both the most recent fully expanded leaf at the time of measuring, and the most recent fully expanded leaf present at the onset of the experiment (representing old leaf chlorophyll levels). At harvest, flowers of each plant were counted. Each plant was separated into flowers, leaves, crown and roots. Leaf area of each plant was measured using an area meter (LI-3100; LI-COR, Lincoln, Neb.). 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. Specific leaf area (SLA, $cm^2 \cdot g^{-1}$) was calculated by dividing leaf area by leaf dry weight of each plant. Foliar N, P, K, Ca, Mg, and Fe contents were analysed by Laboratory Services Division, University of Guelph (for details see Zheng et al., 2004). At harvest, the substrate (with roots) of five randomly chosen pots from each experimental unit were 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 (linear or quadratic). 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., 1999).

Results and Discussion

During the 4-week experiment, gerbera plants showed vigorous growth and development. The average plant above ground dry weight increased from 2.96 to 16.61 g/plant; and leaf area increased from 532 to 1578 cm^2/plant for plants in all the treatments as a whole. Most of the flowers were developed during this period as well. Nutrient solution concentration did not affect leaf area (1578 cm^2/plant), leaf thickness (SLA, 196 $cm^2 \cdot g^{-1}$) or plant total dry weight (18.2 g/plant). There were no differences in flower number (7/plant) or flower dry weight (6.22g/plant) among all the nutrient treatments. Visual assessment of floral quality did not indicate any differences among the various treatments.

Leaf greenness measured on the most recent fully expanded leaf did not show any difference among all the nutrient levels before the third week. During the fourth week however, the most recent fully expanded leaves of plants receiving the 25 and 10% strength nutrient solutions had significantly ($P \leq 0.05$) lower SPAD

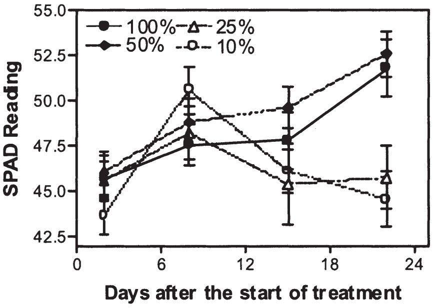

Fig. 1. Leaf greenness (SPAD readings) of the most recent fully expanded leaves, measured at 1 week intervals, after the start of the experiment. The 100%, 50%, 25%, and 10% in the figure are the nutrient levels. Values are means of 30 subsamples ± standard error.

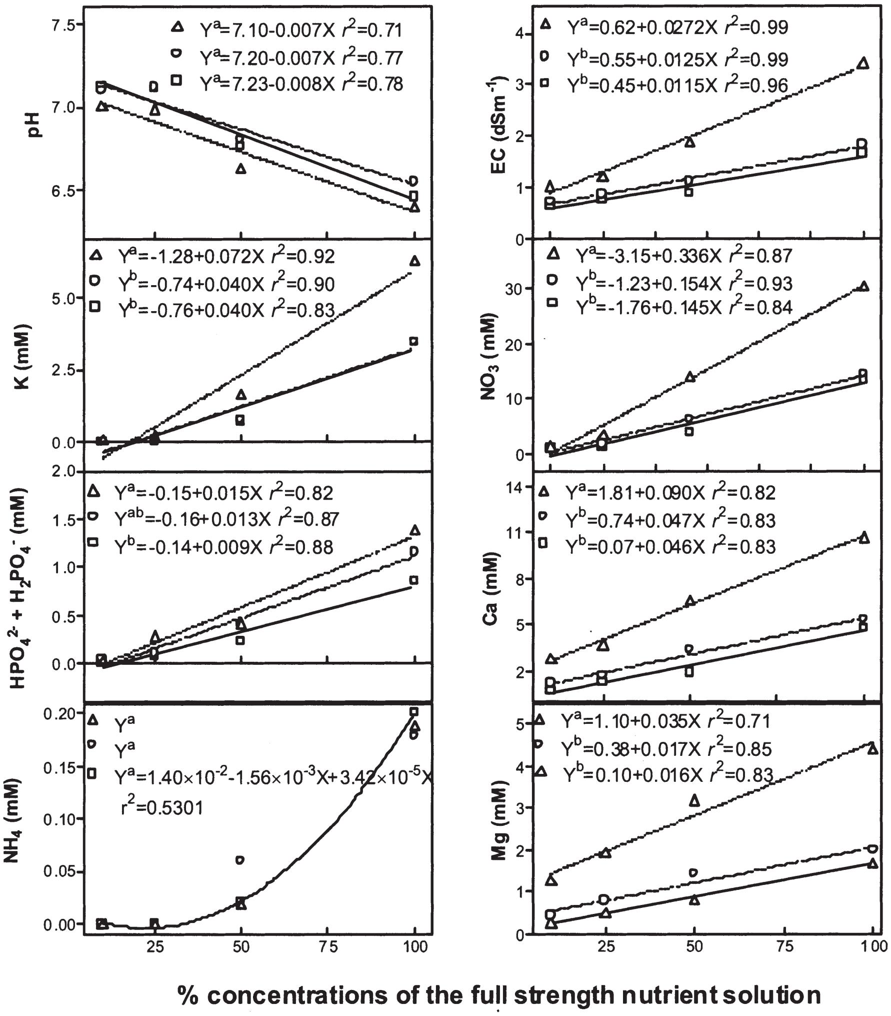

Fig. 2. Substrate nutrients, EC and pH vertical distributions after a 4-week period of subirrigation under four different concentrations (100%, 50%, 25%, and 10% of full strength) of nutrient solutions. The top, middle, and bottom sections of the pot substrate are represented by triangles, circles and squares respectively. Each point represents the mean of three replications (15 subsamples). Equations for the same ion, EC, or pH, bearing the same letter (superscript on the Y parameter) indicate that the means are not significantly different at $P \leq 0.05$ level. Where nutrient treatment effects were significant ($P \leq$ 0.05), lines indicate the calculated regression, otherwise no lines are shown.

reading than the 100% and 50% treatments (Fig. 1). Similarly, during the fourth week, some plants in the 25% and 10% treatments started to show signs of interveinal chlorosis in some of their younger leaves. It was suspected that this interveinal chlorosis was caused by iron deficiency. The leaf tissue Fe contents (Table 2) of all the treatments were within the normal range (80 to 130 mg·g^{-1}) for gerbera (OMAF, 2003). However, these results represent the average foliar Fe content of all the leaves not simply the youngest. The implication of this is that there was likely ample Fe in older leaves, but a deficiency was manifested in younger leaves, as Fe is relatively immobile within the plant. Foliar iron content measurements showed that there was a significant ($p \leq 0.05$) linear relationships between fertigation nutrient levels and foliar iron contents (mg·g^{-1}, $Y = 72.6 + 0.96X$, X as percent of the full strength, $r^2 = 0.9307$). The apparent Fe deficiency, in this study, is likely due to elevated pH levels in the growth media receiving the lower concentration nutrient solutions (Fig. 2) rather than the reduced fertilizer supply, as micronutrients were constant across treatments. This is supported by the fact that although the micronutrients remained at the 100% level in all the solutions during the experiment, interveinal chlorosis still persisted on some of the young leaves of plants fertigated with 25% and 10% strength nutrient solutions. Indeed, there was a positive linear relationship between substrate extract solution pH and EC ($pH = 7.23 - 0.295EC$, $r^2 = 0.7002$) in the present study. This trend of increased substrate pH under lower nutrient levels has also been observed by other researchers (James and van Iersel, 2001; Kang and van Iersel, 2002). If substrate pH levels can be adequately maintained under lower EC conditions, it may be possible to reduce the concentration of fertigation nutrient solutions even further than 50%, without comprising crop production; however, further research is required to elucidate this hypothesis.

Table 2. Leaf tissue nutrient contents of gerbera plants fertigated with different concentrations of nutrient solutions.

Nutrient level[z]	N[y] (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg·g^{-1})
100%	3.91 ± 0.115 a[x]	0.52 ± 0.045a	4.96 ± 0.250a	2.15 ± 0.122 a	0.75 ± 0.071 a	175 ± 21.6 a
50%	3.56 ± 0.123 a	0.43 ± 0.036 ab	4.15 ± 0.310 ab	1.94 ± 0.109 a	0.71 ± 0.054 a	107 ± 8.8 b
25%	3.66 ± 0.047 a	0.45 ± 0.020ab	3.78 ± 0.209bc	1.92 ± 0.101 a	0.83 ± 0.047 a	96 ± 5.8 b
10%	3.35 ± 0.138 a	0.33 ± 0.023b	2.91 ± 0.152 c	1.74 ± 0.127 a	0.77 ± 0.049 a	91 ± 5.2 b
Guideline[w]	3.3–4.1	0.3–0.7	3.1–3.9	0.9–4.2	0.3–2.8	80–130

[z] Percentage nutrient concentrations of the full-strength.

[y] Data (% or mg·g^{-1} of leaf dry weight) are means of 15 subsamples ± standard error.

[x] Means within a column followed by different letters are significantly different at $P < 0.05$.

[w] From OMAF, 2003 for gerbera leaf tissues analysis.

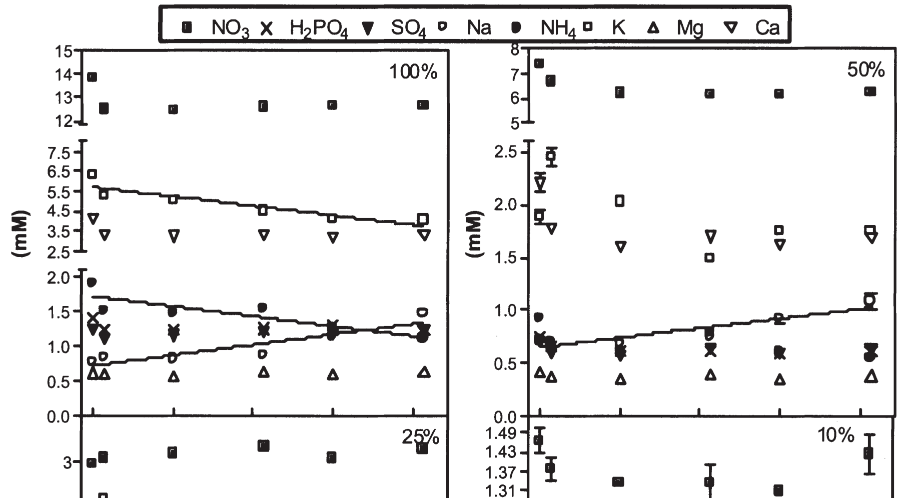

Fig. 3. Reservoir nutrient solutions ion concentrations changes with time under recycling conditions. Data were collected after each pH and EC adjustment. Values are means of three replications ± standard error. Where time effects were significant ($P \leq 0.05$), lines indicate the calculated regression, otherwise no lines are shown.

There were significant ($p \leq 0.05$) positive linear relationships between fertigation nutrient levels (X) and foliar contents (%, Y) of phosphorus ($Y = 0.35 + 0.0018X$, $r^2 = 0.7560$) and potassium ($Y = 3.0 + 0.021X$, $r^2 = 0.9164$) (Table 2). Even with a decreased foliar P and K content under lowered nutrient concentration solutions, there were no signs of P or K deficiency symptoms on any plants. In addition, both P and K foliar contents, under all fertigation nutrient levels (with the exception of K under the 10% treatment), were higher than the minimum recommended limits for gerbera (OMAF, 2003).

Analysis showed that subirrigation nutrient levels did not affect the total foliar contents of nitrogen (3.62%), calcium (1.94%) and magnesium (0.77%) (see Table 2). One of the main concerns over using low concentration nutrient solutions, in soilless crop production, is the potential for N deficiency. To further confirm whether there was any N deficiency in this study, leaf greenness (indicator of chlorophyll content) was measured every week on the old leaves (the most recent fully expanded leaves on 25 May). Results indicate that there were no chlorophyll content differences in the old leaves of plants, under all levels of nutrient solutions, through the end of the experiments (data not shown). This effectively ruled out N-deficiency, as N deficiency normally manifests itself in older leaves first. The lack of effect on N is consistent with the findings of other subirrigation nutrient studies (van Iersel, 1999; James and van Iersel, 2001) as well.

There were positive linear relationships between fertigation nutrient solution concentrations and substrate nutrient contents for NO_3^-, the sum of HPO_4^{2-} and $H_2PO_4^-$, K^+, Mg^{2+} and Ca^{2+} (Fig. 2). Subirrigation resulted in a significant accumulation of salts within the top third of the plant growth substrate across all treatments. The EC values for the top third of the growth substrate were 62% to 105% higher than those of the bottom two-thirds. Not surprisingly then, most of the measured major nutrient ion (NO_3^-, HPO_4^{2-} and $H_2PO_4^-$, K^+, Mg^{2+}, and Ca^{2+}) concentrations were higher in the top third of the media, as compared to the bottom section. The accumulation of salts in the surface layer of growth media has also been reported in numerous other studies (Argo and Biernbaum, 1995; Argo and Biernbaum, 1996; Kent and Reed, 1996; Mak and Yeh, 2001; Morvant et al., 1997). Although nutrient salts significantly accumulated in the upper section of the growth media, no detrimental effects, such as root rot, were observed in the presented study. The highest EC observed was still within the accepted range of 2.0 – 3.5 dS·m^{-1} (Warncke and Krauskopf, 1983). Figure 2 also shows that the magnitude of salt accumulation, in the top third sections of the reduced concentration treatments, was much lower as compared to the full strength treatment. This implies that to avoid phytotoxic salt accumulation in long-duration subirrigated crop production, a reduction in feed concentrations would be advisable. To further reduce the potential for phytotoxic salt accumulation, under subirrigation, it would also be advisable to periodically switch to overhead fertigation in an attempt to redistribute nutrient salts to the lower sections of the pot. Since NO_3^-, in particular, seems to accumulate in the top layer of the growth medium, washing it down would make these nutrients more available to the roots. However, when the nutrient level is too low, other problems, such as nutrient deficiency, may occur. In the present study, NH_4^+ and K^+ levels approached zero in all three sections of the substrate under the lower nutrient conditions (25% and 10% solutions). Clearly, a balance needs to be struck between providing adequate nutrients while reducing the potential for phytotoxic salt accumulations.

The results of this study clearly demonstrate that during the final stages (the last 4 to 5 weeks) of subirrigated potted gerbera production, nutrient feed concentrations can be reduced by 50% without negatively affecting production. The feasibility of reducing nutrient concentrations, while maintaining production and quality standards is, however, crop dependent. Kang and van Iersel (2002) subirrigated seedlings of alyssum [*Lobularia maritima* Desv. 'New Carpet of Snow'], celosia (*Celosia argentea* 'Gloria Scarlet'), dianthus (*Dianthus Chinensis* 'Telstar Crimson'), gomphrena (*Gomphrena globosa* 'Gnome Whitee'), stock (*Matthiola incana* R. Br 'Special Mix'), and zinnia (*Zinnia elegans* Jacq. 'Dreamland Mix') grown in cells (160 ml), with varying concentrations of nutrient solutions. While growth of zinnia was maximized with a half-strength Hoagland solution, the other species required full strength solutions (15 mM N) for maximum production. Other research has shown that under three concentrations of N (7.1, 14.3, and 28.6 mM) and K (2.6, 5.1, and 10.3 mM), over a 16-week period, poinsettia *(Euphorbia pulcherrima* V-14 'Glory') growth was maximized with the lowest concentrations in both top and subirrigation systems (Yelanich and Biernbaum, 1990).

Regression analysis (Fig. 3) of nutrient ion (NO_3^-, $H_2PO_4^-$, SO_4^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}; measured after each nutrient adjustment) concentrations in the irrigation nutrient solutions, as a function of time (days), indicated that there were no significant changes for NO_3^-, $H2PO_4^-$, Mg^{2+} and Ca^{2+} throughout the duration of the experiment, in all treatments. There were accumulation trends for SO_4^{2-} and Na^+; and depletion trends for NH_4^+ and K^+ in some solutions. The ion with the highest percentage accumulation was Na^+ with a 121% increase in the 25% strength nutrient solution. The ion with the highest percentage depletion was NH_4^+ with a 72% decrease in the 10% strength nutrient solution. While the accumulated Na^+ was not high enough to cause any phytotoxic effect; the depleted NH_4^+ in the lower level nutrient solutions may have played a role in the growth substrate pH increases (Fig. 2). During NH_4^+ uptake, one proton is exchanged for each NH_4^+ molecule taken into the roots. The result of this exchange is a net decrease in substrate pH (Marschner, 2002). In the low nutrient treatments, NH_4^+ was deficient, therefore, fewer protons were exchanged and the media pH was not lowered. Overall, these results demonstrate that the quality of the nutrient solutions was still acceptable after a 4-week recirculating period when nutrient solution composition was adjusted based solely on EC and pH.

While water consumption of the production system (avg.141 mL per plant per day) was unaffected by nutrient solution concentration, fertilizer inputs were dramatically reduced at lower nutrient feeds. Compared to the 100% treatment, fertilizer inputs for the 50%, 25%, and 10% treatments were lower by 54%, 75%, and 90% respectively.

In conclusion, our results demonstrate that current nutrient application rates at the final stage (4 to 5 weeks) of the greenhouse gerbera production, in recirculating subirrigation systems, can be reduced by at least 50% without any detrimental effect on plant growth or quality. However, when the concentration of the nutrient solution was lowered to 25%, plants started to show symptoms of Fe deficiency. The Fe deficiency was most likely due to the associated pH increase at low nutrient feeds. Although nutrient salts did accumulate in the top section of the growth substrate under all treatments, they were significantly lower in the reduced nutrient treatments. This being said, salt levels did not become phytotoxic under any of the treatments. Nutrient solution quality was still acceptable after 4-weeks of recirculation. Significant fertilizer savings were also realized by using lower nutrient solution concentrations in this subirrigation potted gerbera production system.

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