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Response of Hydroponically Grown Cherry and Fresh Market Tomatoes to Reduced Nutrient Concentration and Foliar Fertilizer Application under Shadenet Conditions

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Abstract*. Reduced nutrient concentration (NC) through fertigation in an open-bag hydroponic system with additional foliar fertilizer application may reduce nutrient wastage and thus decrease the production costs. A study was conducted to determine the effect of foliar fertilizer in combination with reduced NCs on the yield and quality of hydroponically grown cherry and fresh market (FM) tomatoes in a shadenet structure. In the first experiment, FM tomato plants were grown in sawdust fertigated with nutrient solutions containing 100% (control), 75%, 50%, or 25% of the recommended NC. Marketable yield and fruit mineral content were unaffected by NC, whereas the total yield decreased with a decrease in NC. The second and third experiments were on FM and cherry tomatoes, respectively, subjected to four NCs (100%, 75%, 50%, or 25%) and two foliar fertilizer applications (no foliar and foliar application). Fresh and dry weight of FM and cherry tomato plants decreased with a decrease in NC application. Marketable yield on FM tomatoes increased with 50% to 100% NC, whereas the total yield increased with 75% and 100% NC, as compared with 25% NC. Cherry tomatoes produced lower marketable yield at 25% and 50% NC, as compared with 75% and 100% NC. Foliar fertilizer application did not have an effect on FM and cherry tomato yield, but improved the plant dry weight of cherry tomatoes. Fruit and leaf Ca content of FM tomatoes were improved by the decrease in the NC. Fruit mineral content (K, P, Ca, Mg, and Zn) of cherry tomatoes increased with an increase in NC. The improvement in yield was primarily due to nutrient uptake, especially, N, P, and K, as determined in tomato leaves. Reduced NC of 50% can maintain yield and quality of FM tomatoes, whereas application of foliar fertilizer had a limited effect. In cherry tomatoes, yield and fruit mineral content were maintained at 75% NC combined with foliar fertilizer application. The findings of this research may reduce nutrient wastage and result in a cost saving of 25% and 50% on fertilizer input costs on cherry and FM tomatoes, respectively, and reduce the risk associated with water pollution.

The management of total nutrient concentration (NC) applied through fertigation is an important aspect for successful vegetable production in hydroponic systems to maximize yield and quality of produce. However, too high levels of NC increase input costs unnecessarily, and can induce osmotic stress, ion toxicity, and nutrient imbalance, whereas too low levels generally lead to nutrient deficiencies (Fallovo et al., 2009; Luna et al., 2013).

Commercial hydroponic vegetable growers use high NC in an attempt to maximize crop yield with little attention to nutrient uptake by the crop (Li et al., 2001; Sonneveld and Voogt, 2009). This practice does not present an economically optimized production method, as excessive nutrients do not necessarily translate into higher yields (Rouphael et al., 2008). Manipulating the level of fertilization was reported to be useful in meeting the specific production demands of either increased yield or quality (Lin and Ehret, 1991). Siddiqi et al. (1998) have shown that macro-NCs, commonly used by commercial greenhouse tomato growers, can be reduced by 75% without having any adverse effect on growth, fruit yield, and quality in a recirculating hydroponic system. Similarly, Breś et al. (2013) reported that it is possible to use 20% less fertilizer without any negative effects on the number and quality of gerbera flowers grown in perlite. The ideal NC in a hydroponic solution varies by hydroponic system, crop species, growth stage, and plant density, but is typically between 1 and 3 $mS{\cdot}cm^{-1}$ (Hashida et al., 2014; Rouphael and Colla, 2005).

Nutrients can be applied to the growing medium through irrigation or applied on leaves as a foliar spray, which are both recognized by some authors as a very efficient method of plant nutrition during the intensive growth stages (Giskin et al., 1984; Komosa, 1990; Mengel, 2002). Foliar fertilizer application is a technique using foliar sprays to provide the nutrients at the actual site of activity, especially micronutrients (Kolota and Osińska, 2000). It results in better nutrient absorption by the plants, thus increasing fertilizer use efficiency (Fernàndez and Eichert, 2009; Lester et al., 2006). The effect of foliar plant nutrition is highly dependent on plant species, and physical and chemical properties of the nutrient solution, as well as growing conditions (Komosa, 1990; Kolota and Osińska, 2000). Both fertigation and foliar fertilizer application were reported to be effective in increasing marketable yield by 20.3% in cabbage, 10.8% in onion, and 7.3% in cucumber (Kolota and Osińska, 2001). As a supplement, foliar fertilizer application is gaining popularity among farmers as a standard practice in agricultural crop production, because it is more purposeful and environmentally friendly as opposed to soil fertilization.

Since the optimal NC will vary by climatic conditions, hydroponic system, crop species, growth stage, and plant density (Rouphael and Colla, 2005), results from outside the country might not always be applicable to local South African conditions. In view of limited local results as well as the costs of soluble fertilizers and the negative influence of open hydroponic systems on the environment, studies have been undertaken aiming at reducing fertilizer application, whereas applying foliar fertilizers on yield and quality of hydroponically grown FM and cherry tomatoes.

Materials and Methods

The study was conducted during Sept. 2013 to Feb. 2014 (spring/summer season) and the follow-up experiments were done during Sept. 2014 to Feb. 2015 (spring/summer season) in a 40% white shadenet structure at the Agricultural Research Council-Vegetable and Ornamental Plants, Roodeplaat, South Africa (25°59′ S; 28°35′ E and at an altitude of 1200 m above sea level). The 40% white shadenet is recommended for the Roodeplaat area and popular among commercial vegetable growers in South Africa. The growing conditions in the shadenet was not controlled with a mean temperature of 33 °C day/15 °C night recorded during the growth season. Tomato seedlings (FM cultivar Dominique and cherry tomato cv. Tinker) were produced according to the method described by Maboko and Du Plooy (2008). Five-week-old seedlings were transplanted into 10-L plastic bags containing sawdust as a growing medium.

The fertilizers composition and chemical concentration as recommended by Niederwieser (2001) for tomato production were Hygroponic® (Hygrotech Pty. Limited, Pretoria, South Africa) comprising N (68 $mg{\cdot}kg^{-1}$), P (42 $mg{\cdot}kg^{-1}$), K (208 $mg{\cdot}kg^{-1}$), Mg (30 $mg{\cdot}kg^{-1}$), S (64 $mg{\cdot}kg^{-1}$),

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Fe (1.254 mg·kg^{-1}), Cu (0.022 mg·kg^{-1}), Zn (0.149 mg·kg^{-1}), Mn (0.299 mg·kg^{-1}), B (0.373 mg·kg^{-1}), and Mo (0.037 mg·kg^{-1}); calcium nitrate [$Ca(NO_3)_2$] comprising N (117 mg·kg^{-1}) and Ca (166 mg·kg^{-1}); and potassium nitrate (KNO_3) comprising K (38.6 mg·kg^{-1}) and N (13.8 mg·kg^{-1}). Fertilizers were applied per 1000 L of water (Table 1).

Expt. 1. (Sept. 2013 to Feb. 2014). FM tomato plants (Dominique cv.) were fertigated with four NCs treatment (Table 1), that is, the recommended NC (100%) (control) and reduced NCs (75%, 50%, or 25% of recommended concentration). The concentration of the nutrient solution was adopted for both macro- and micronutrients. The treatments were laid out in a randomized complete block design with four replicates.

Expt. 2. (Sept. 2014 to Feb. 2015). The follow-up experiment was conducted on FM tomato (Dominique cv.). The experimental design was a 2 × 4 factorial arrangement with two foliar fertilizer applications (with and without foliar fertilizer application) and four similar NCs as applied in Expt. 1. Treatment combinations were arranged in a randomized complete block design. Six weeks after transplanting (third flower truss), foliar fertilizer was applied every 2nd week using calcium nitrate (117 mg·kg^{-1} N and 166 mg·kg^{-1} Ca) and Multifeed® (Plaaskem (Pty) Ltd, South Africa) at the recommended application of 1 g·L^{-1} for both, whereas in the control treatment no fertilizer was added to the spray solution (water only). Multifeed® is composed of N (193 g·kg^{-1}), P (83 g·kg^{-1}), K (158 g·kg^{-1}), S (6.1 g·kg^{-1}), Mg (4.6 g·kg^{-1}), Zn (700 mg·kg^{-1}), B (1054 mg·kg^{-1}), Mo (63 mg·kg^{-1}), Fe (751 mg·kg^{-1}), Mn (273 mg·kg^{-1}), and Cu (75 mg·kg^{-1}).

Expt. 3. (Sept. 2014 to Feb. 2015). The third experiment was conducted with cherry tomato, cultivar Tinker. Application of treatments, experimental design, and planting date were similar to the second experiment.

Cultural practices. Plants were maintained at a plant population density of 2.5 plants/m^2. There were 14 plants per plot, consisting of four NCs and two foliar fertilizer application treatments maintained under a 40% white shadenet structure. FM tomatoes were trained to a single stem by twisting trellis twine around the main stem, whereas cherry tomatoes were trained to two stems and fixing them to a stray wire 2 m away from the ground to support the plant. Side branches were removed weekly to maintain a single and double stem system in FM and cherry tomatoes, respectively. When plants had reached the horizontal wire at a height of 2 m, the growing point was removed to stop further vertical plant growth as per common commercial practice in South Africa.

The pH of the nutrient solution was measured on a daily basis with a handheld 'HANNA' electrical conductivity (EC) and pH meter (HANNA Instruments, Mauritius), and maintained between pH 5.5 and 6.5 using nitric acid. Plants were irrigated, using one dripper per plant (at a discharging rate of 2.1 L·h^{-1}), at 2-h intervals, seven times daily (total daily irrigation during the growing season ranged from 490 to 2205 mL/plant equivalent to 2 to 9 min, respectively). The irrigation volume was gradually increased as plants enlarged, to ensure that 10% to 15% of the applied water leached out of the bags to reduce salt buildup in the growing medium.

Plant growth and productivity measurements. FM tomatoes were harvested weekly at the breaker stage, whereas cherry tomatoes were harvested at the full ripe stage (Jones, 2008) from December to February. Yield data were collected from 10 plants per treatment, and the performance of the treatments was evaluated using total yield, marketable and unmarketable fruit, as well as physiological disorders as parameters. All harvested fruit, excluding unmarketable fruit (fruit exhibiting cracking or falling into the extra-small size category of less than 40-mm diameter) were regarded as marketable yield (Maboko et al., 2011).

Leaf nutrient analysis. The fourth leaf from the growing point of four plants per replicate per treatment was selected to determine the leaf N, P, K, Ca, Mg, Mn, Zn, B, Cu, and Fe concentrations (Maboko et al., 2013). These leaves were oven-dried at 70 °C for 48 h and ground using a mill with a 1-mm sieve. Nitrogen was determined on dry-milled material using a Carlo Erba NA 1500 C/N/S Analyzer (Thermo Scientific, Milan, Italy). An aliquot of the digested solution was used for inductively coupled plasma optical emission spectrometry for determination of Ca, Mg, P, K, Fe, Zn, Mn, and Cu concentrations (Liberty Series II Model; Varian). All NCs were expressed on a dry weight basis.

Fruit nutrient analysis. Four ripe medium-sized fruit were harvested from the fourth truss

Table 1. Type and amount of fertilizer applied as treatments for fertigation application.

Nutrient concn (%)	Transplant to first flower		First flower truss to third flower truss		Third flower truss to end		
	Hygroponic (g)/1,000 L	Calcium nitrate (g)/1,000 L	Hygroponic (g)/1,000 L	Calcium nitrate (g)/1,000 L	Hygroponic (g)/1,000 L	Calcium nitrate (g)/1,000 L	Potassium nitrate (g)/1,000 L
25	150	122.5	200	155.0	200	155.0	50
50	300	245.0	400	310.0	400	310.0	100
75	450	367.5	600	465.0	600	465.0	150
100	600	490.0	800	620.0	800	620.0	200

Table 2. Effect of nutrient concentration on yield and quality parameters of fresh market tomatoes (Sept. 2013 to Feb. 2014).

Nutrient concn (%)	Marketable yield (kg/plant)	Unmarketable yield (kg/plant)	Total no. of fruits/plant	No. of marketable fruits/plant	Total yield (kg/plant)	Fruit firmness (kg)	Total soluble solids	pH
25	4.29	0.64 b	46.1 b	39.6	4.92 b	1.80	6.3	4.70
50	4.75	0.85 b	50.2 b	41.7	5.60 ab	1.88	5.1	4.68
75	4.60	1.39 a	58.0 a	44.4	6.00 a	1.88	6.6	4.68
100	5.24	0.96 b	56.2 a	46.7	6.20 a	1.83	5.5	4.68
LSD 0.05	NS	0.34	5.16	NS	0.85	NS	NS	NS

NS = nonsignificant; LSD = least significant difference.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected t test.

Table 3. Effect of nutrient concentration on fruit physiological disorders per fresh market tomato plant (Sept. 2013 to Feb. 2014).

	Fruit cracking		Blossom-end rot		Zippering		Rain check		Catface	
Nutrient concn (%)	No. of fruits	Mass (g)	No. of fruits	Mass (g)	No. of fruits	Mass (g)	No. of fruits	Mass (g)	No. of fruits	Mass (g)
25	4.0 c	478 b	0.11 b	6.7 b	0.61	49.9	0.8	77.9	0.06	3.0
50	5.6 bc	615 b	0.17 b	12.6 b	0.73	65.5	1.1	117.2	0.11	22.7
75	10.3 a	1153 a	0.67 a	53.1 a	0.58	52.8	0.9	92.3	0.14	20.3
100	7.4 b	803 b	0.06 b	3.5 b	0.44	50.9	0.7	72.4	0.03	8.8
LSD 0.05	2.79	328.2	0.43	37.16	NS	NS	NS	NS	NS	NS

NS = nonsignificant; LSD = least significant difference.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected t test.

of four plants per replicate per treatment for nutrient analysis (P, K, Ca, Mg, Mn, Zn, B, Cu, and Fe), as described earlier. Fruits were oven-dried at 70 °C for 72 h. NCs were expressed per gram dry fruit mass.

Statistical analysis. Data were subjected to analysis of variance using GenStat®, version 11.1 (Payne et al., 2008). Means were separated using Fisher's protected *t* test least significant difference (Snedecor and Cochran, 1980).

Results

Expt. 1. There was no significant effect on marketable yield, number of marketable fruits, fruit firmness, total soluble solids (TSS), and pH among the NCs tested. However, plants fertigated at 25% NC had a tendency toward lower marketable yield than other NCs (Table 2). Fertigation at 75% of the recommended NC increased the total number of fruit and total yield significantly, as compared with the 25% NC treatment with no significant differences, as compared with the recommended rate in this regard (Table 2). Furthermore, the 75% NC also resulted in significant higher unmarketable fruit yield, with the result that it had no significant advantage on the marketable yield, as compared with any of the other treatments. The high unmarketable fruit yield at 75% NC was mainly because of increased number of fruits exhibiting incidence of fruit cracking and blossom-end rot (BER), whereas physiological disorders such as zippering, rain check, and catface were unaffected by NC (Table 3). Fruit mineral content such as K, P, Ca, Mg, and Mn were not significantly affected by reduced NC (Table 4), although some tendencies were observed. NC of 75% had a tendency toward reduced Ca content of tomato fruits, which can be linked to the higher BER occurrence with this treatment. There was also a tendency toward reduced P and Mg fruit content at 100% NC, whereas Mn was reduced at 25% NC compared with other NC treatments.

Table 4. Effect of nutrient concentration on fruit mineral content (dry weight basis) for fresh market tomatoes (Sept. 2013 to Feb. 2014).

Nutrient concn (%)	K (%)	P (%)	Ca (%)	Mg (%)	Mn (mg·kg^{-1})
25	4.2	0.42	0.41	0.21	15.6
50	4.1	0.51	0.41	0.21	19.2
75	3.9	0.54	0.30	0.22	20.7
100	3.6	0.41	0.35	0.18	20.6
LSD 0.05	NS	NS	NS	NS	NS

NS = nonsignificant; LSD = least significant difference.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

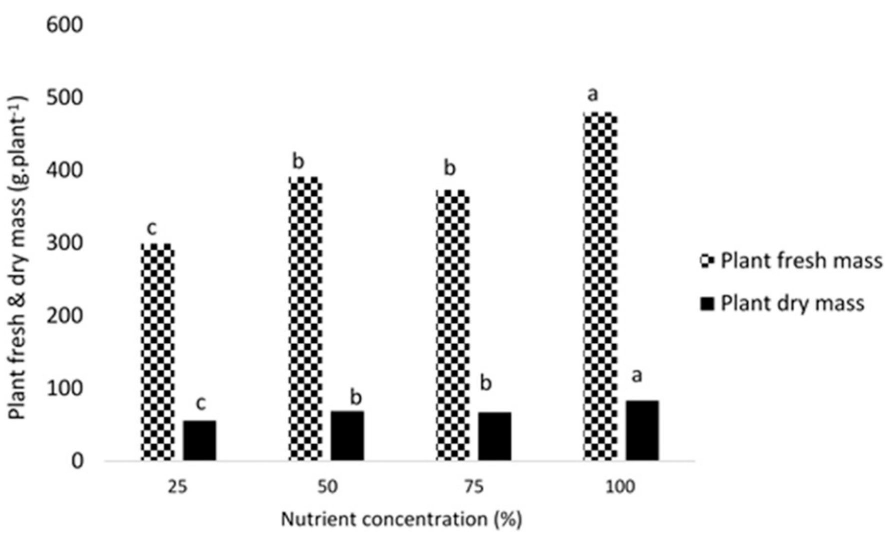

Fig. 1. Effect of nutrient concentration on plant fresh and dry weight for fresh market tomato plants. Values in bars followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

In Expts. 2 and 3, there were no interaction effect between foliar fertilizer application and NC on all parameters measured, thus only the main factors will be presented.

Expt. 2. The 100% recommended NC improved plant fresh and dry weight significantly, and the lowest plant fresh and dry weight were found on plants fertigated at 25% NC (Fig. 1). Marketable yield and number of marketable fruits of FM tomatoes were not significantly different at 50%, 75%, and 100% NC, whereas the highest total yield was obtained at 100% NC (Table 5). No significant differences could be determined with respect to unmarketable yield (Table 5) and fruit physiological disorders (data not shown) among the NCs.

TSS, pH, and EC of the extracted tomato juice were unaffected by NC (Table 5). Increasing the NC had no effect on fruit and leaf mineral content, except that an increase in NC reduced fruit (Table 6) and leaf Ca content (Table 7). Leaf N content was significantly higher at 50%, 75%, and 100% NC, even though 25% and 50% NC did not differ significantly (Table 7). Leaf P content was significantly higher at 100% NC, followed by both 50% and 75% NC, and the lowest at 25% NC. Leaf K, Ca, Zn, and B were unaffected by NC. Leaf Mg content showed decreased tendency toward an increase in NC. Leaf Fe content was significantly higher at 100% NC compared with 75%, 50%, and 25% NC. Plants fertigated with 75% and 100% NC had the highest leaf Mn content compared with 25% and 50% NC (Table 7).

Table 5. Effect of nutrient concentration and foliar fertilizer application on fresh market tomato yield and TSS, EC, and pH of tomato juice (Sept. 2014 to Feb. 2015).

Nutrient concn (%)	Marketable yield (kg/plant)	Unmarketable yield (kg/plant)	Total no. of fruits/plant	No. of marketable fruits/plant	Total yield (kg/plant)	TSS (%)	EC (mS·cm^{-1})	pH
25	3.9 b	1.6	49.9 c	34.68 b	5.5 b	3.2	3.6	5.8
50	4.4 ab	1.3	56.2 ab	42.80 a	5.8 b	3.2	3.3	5.9
75	4.5 ab	1.7	55.4 bc	40.65 a	6.1 ab	3.3	3.3	5.8
100	5.0 a	1.8	61.7 a	44.30 a	6.8 a	3.5	3.4	5.8
LSD 0.05	0.64	NS	5.98	5.1	0.78	NS	NS	NS
Foliar fertilizer application								
F_1	4.6	1.6	56.7	41.72	6.2	3.5	3.3	5.8
F_0	4.3	1.6	54.9	39.49	5.9	3.0	3.5	5.8
LSD 0.05	NS	NS	NS	NS	NS	0.4	NS	NS

TSS = total soluble solids; EC = electrical conductivity; NS = nonsignificant; LSD = least significant difference; F_1 = foliar fertilizer application; F_0 = no foliar fertilizer application.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

Table 6. Effect of nutrient concentration and foliar fertilizer on mineral content of fresh market tomatoes (Sept. 2014 to Feb. 2015).

Nutrient concn	K (%)	P (%)	Ca (%)	Mg (%)	Fe (mg·kg^{-1})	Zn (mg·kg^{-1})	B (mg·kg^{-1})	Mn (mg·kg^{-1})
25	4.11	0.38	0.27 a	0.20	72.2	46.6	36.6	20.59
50	3.96	0.43	0.25 ab	0.19	84.3	41.9	32.1	17.73
75	4.08	0.43	0.22 b	0.17	69.1	46.5	32.7	16.68
100	4.06	0.47	0.21 b	0.18	67.5	44.1	30.2	20.19
LSD 0.05	NS	NS	0.04	NS	NS	NS	NS	NS
Foliar fertilizer application								
F_1	4.20	0.431	0.25 a	0.18	71.1	48.3	34.5	18.68
F_0	3.90	0.419	0.22 b	0.18	75.4	41.3	31.3	21.70
LSD 0.05	NS	NS	0.02	NS	NS	NS	NS	NS

NS = nonsignificant; LSD = least significant difference; F_1 = foliar fertilizer application; F_0 = no foliar fertilizer application.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

Table 7. Effect of nutrient concentration and foliar fertilizer on leaf mineral content of fresh market tomatoes (Sept. 2014 to Feb. 2015).

Nutrient concn (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg·kg^{-1})	Zn (mg·kg^{-1})	B (mg·kg^{-1})	Mn (mg·kg^{-1})
25	3.63 b	0.35 c	2.39	2.38	0.54 a	177.0 b	31.9	60.0	88.6 b
50	3.89 ab	0.37 bc	2.42	2.50	0.50 ab	183.0 b	33.9	60.3	82.4 b
75	4.03 a	0.41 b	2.53	2.71	0.46 bc	206.4 b	34.9	59.1	164.3 a
100	4.14 a	0.48 a	2.90	2.63	0.42 c	263.2 a	36.3	65.1	146.9 a
LSD 0.05	0.36	0.04	NS	NS	0.05	49.52	NS	NS	23.98
Foliar fertilizer application									
F_1	4.00	0.40	2.49	2.52	0.49	220.9	34.6	61.7	125.7
F_0	3.83	0.41	2.62	2.59	0.48	193.9	33.9	60.6	115.5
LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant; LSD = least significant difference; F_1 = foliar fertilizer application; F_0 = no foliar fertilizer application.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

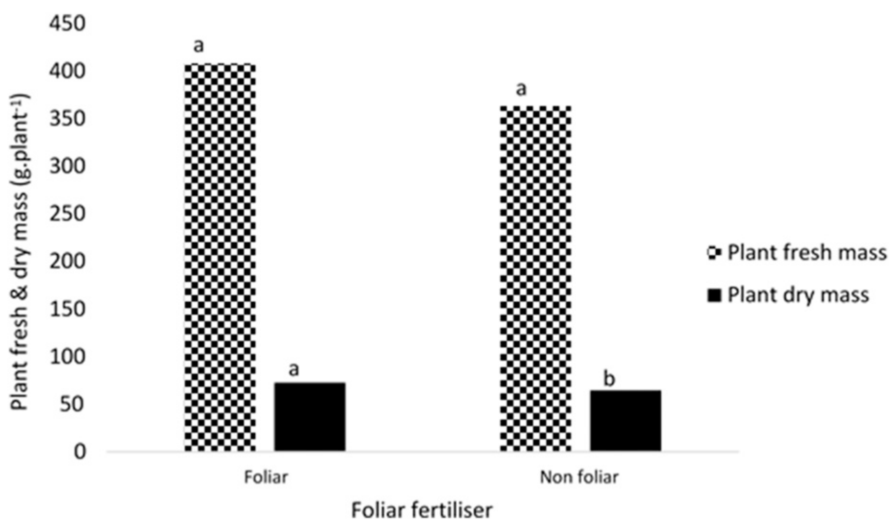

Fig. 2. Effect of foliar fertilizer on plant fresh and dry weight of fresh market tomato plants. Values in bars followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

There was an increased tendency toward plant fresh weight with foliar fertilizer application compared with untreated plants (Fig. 2). Plant dry weight was significantly improved by foliar fertilizer (Fig. 2). Neither tomato yield (Table 5) nor fruit physiological disorders (data not shown) were affected by foliar fertilizer. EC and pH of the tomato juice were unaffected by foliar fertilizer application (Table 5). Foliar fertilizer application improved TSS of tomato juice (Table 5). Foliar fertilizer application did not have an effect on fruit mineral content, with an exception of Ca, which was significantly higher on plants treated with foliar fertilizer (Table 6). Foliar fertilizer application did not have an effect on leaf mineral content (Table 7).

Expt. 3. Cherry tomato plants fertigated at 75% and 100% NC resulted in an increased in plant fresh and dry weight (Table 8). The highest total yield and marketable yield were obtained from plants fertigated at 75% and 100% NC compared with 50% and 25% NC (Table 8). Total number of fruits were reduced at 25% of the recommended NC. An increase in NC showed a tendency toward an increased number of marketable fruits, even though it was not significant. Incidence of fruit cracking was unaffected by NC (Table 8).

NC improved fruit mineral content of cherry tomatoes significantly (Table 9). The 100% recommended NC improved K and Mg fruit content significantly. In addition, both 100% and 75% NC resulted in an increase in P, Ca, and Zn fruit content compared with 50% and 25% NC, whereas 25% NC resulted in a decrease in K, P, and Mg fruit content compared with 100%, 75%, and 50% NC. Surprisingly, microelements, that is, Fe, B, and Mn fruit content were unaffected by NC. Foliar fertilizer improved the K, P, Mg, and Zn fruit content compared with untreated plants (Table 9). Other elements, that is, Ca, Fe, B, and Mn were unaffected by foliar fertilizer application.

Leaf N content was not significantly affected by NC; however, there was a trend of an increase in N as NC increased (Table 10). Leaf K content increased with an increase in NC. Leaf P content was significantly higher at the recommended NC, followed by 75%, 50%, and 25% NC. Leaf Ca and B contents on cherry tomatoes were unaffected by NC. Leaf Mg content decreased significantly with an increase in NC, whereas leaf S content was significantly reduced at lower NC (25%). Both Fe and Zn leaf contents were high at the recommended NC (100%), and low NC reduced Zn significantly. Leaf Mn content was significantly higher at 75% and 100% NC, followed by 50%, and the least was at 25% NC. Surprisingly, leaf mineral content of cherry tomatoes was not influenced by foliar fertilizer application (Table 10).

Discussion

It is well reported that crop growth and yield are negatively affected by too high or too low nutrient solution concentrations (Savvas and Adamidis, 1999). Plant growth and marketable fruit yield of zucchini plants were reported to be substantially reduced when the concentration of macronutrients in the feed solution were lowered to 50% of the control (Rouphael and Colla, 2009). At high NC levels, cucumber on the other hand produced a reduced number of marketable fruits and presented a reduction in days to harvest (Lin and Ehret, 1991). In this study with tomatoes, the highest NC was the recommended fertilizer application (control treatment). Cherry and FM tomatoes responded differently to NC. The substantial reduction in fruit yield at NC of 25% could be explained by poor plant growth (plant fresh and dry weights) as a result of low NC. Low NC, especially at 25% NC, restricted plant growth and, subsequently, yield, since nutrients were a limiting growth factor. FM tomatoes were able to produce a high marketable yield at the relatively low NC of 50% during both seasons. Cherry tomatoes responded negatively to the application of 50% and 25% NC, producing significantly lower total and marketable yields. Farmers are mainly interested in the marketable yield of produce for good profit, which was attained at 50% and 75% NC on FM and cherry tomatoes, respectively. The reduction in NC to 50% did not cause any drastic reduction in yield on both FM and cherry tomato in comparison with the recommended NC. An open-bag hydroponic system is still the most popular system in South Africa, with at least 10% to 15% of water and nutrients that leach from the rooting zone with a potential risk of pollution. Further studies need to be conducted on reduced fertilizer application on different growth media, whereas investigating the mineral composition to reduce the cost of production and to protect the environment through decreased nutrient leachates.

Application of foliar fertilizer had no effect on tomato yield in this study, which can be ascribed to application treatments such as foliar fertilizer source and the time of application, and require some further investigation. This is in contrast to the findings by Roosta and Hamidpour (2011) who reported tomato yield increase with foliar fertilizer application. Plant dry weight of FM tomatoes, however, improved significantly by application of foliar fertilizer which is in agreement with Roosta and Hamidpour (2011) who reported improved vegetative growth of tomato plants in aquaponics when foliar fertilizer was applied. In this study, foliar fertilizer application contributed toward improvement of fruit quality in terms of fruit mineral content. Foliar fertilizer application improved Ca fruit content in FM tomatoes, whereas in cherry tomato, high K, P, Mg, and Zn fruit contents were obtained. High mineral content of tomato will be beneficial to the consumers as they are

Table 8. Effect of nutrient solution and foliar fertilizer on cherry tomato yield and plant growth (Sept. 2014 to Feb. 2015).

Nutrient concn	Total yield (kg/plant)	Total no. of fruits/plant	No. of marketable fruits/plant	Marketable yield (kg/plant)	No. of fruit crack/plant	Mass of fruit crack (g/plant)	Plant fresh wt (g/plant)	Plant dry weight (g/plant)
25	3.0 b	403.0 b	389.9	2.9 b	13.2	106.8	648 c	118.4 c
50	3.0 b	458.2 a	420.1	2.9 b	12.8	105.7	759 bc	133.9 bc
75	3.6 a	432.9 ab	419.3	3.4 a	13.6	108.0	909 ab	158.2 ab
100	3.5 a	467.3 a	456.0	3.4 a	11.3	94.6	1045 a	168.7 a
LSD 0.05	0.35	44.69	NS	0.35	NS	NS	174.5	29.9
Foliar fertilizer application								
F_1	3.2	452.3	440	3.1	12.3	101.8	810	139.7
F_0	3.3	428.3	415.3	3.2	13.1	105.7	870	150.0
LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant; LSD = least significant difference; F_1 = foliar fertilizer application; F_0 = no foliar fertilizer application.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

Table 9. Effect of nutrient concentration and foliar fertilizer application on fruit mineral content of cherry tomatoes (Sept. 2014 to Feb. 2015).

Nutrient concn (%)	K (%)	P (%)	Ca (%)	Mg (%)	Fe (mg·kg^{-1})	Zn (mg·kg^{-1})	B (mg·kg^{-1})	Mn (mg·kg^{-1})
25	2.8 c	0.24 c	0.097 b	0.12 c	43.3	27.0 b	19.5	7.8
50	3.1 b	0.29 b	0.096 b	0.12 bc	40.8	27.8 b	20.0	7.2
75	3.1 b	0.32 a	0.115 ab	0.12 b	41.0	29.2 ab	18.5	8.1
100	3.3 a	0.34 a	0.118 a	0.13 a	53.0	31.9 a	20.6	8.8
LSD 0.05	0.17	0.019	0.019	0.006	NS	3.07	NS	NS
Foliar fertilizer application								
F_1	33.2 a	0.30 a	0.11	0.13 a	46.2	30.0 a	19.6	8.5
F_0	2.9 b	0.29 b	0.10	0.12 b	42.8	27.8 b	19.7	7.5
LSD 0.05	0.12	0.014	NS	0.004	NS	2.17	NS	NS

NS = nonsignificant; LSD = least significant difference; F_1 = foliar fertilizer application; F_0 = no foliar fertilizer application.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

Table 10. Effect of nutrient concentration and foliar fertilizer application on leaf mineral content of cherry tomato plants (Sept. 2014 to Feb. 2015).

Nutrient concn (%)	N (%)	K (%)	P (%)	Ca (%)	Mg (%)	S (mg·kg^{-1})	Fe (mg·kg^{-1})	Zn (mg·kg^{-1})	B (mg·kg^{-1})	Mn (mg·kg^{-1})
25	3.47	2.08 c	0.19 c	4.20	0.87 a	0.95 b	194.9 b	50.5 c	88.4	169.0 c
50	3.57	2.59 bc	0.24 b	4.62	0.76 b	1.52 a	202.5 b	62.7 b	83.5	207.5 b
75	3.62	2.90 ab	0.25 b	4.31	0.67 c	1.57 a	210.8 b	63.7 b	78.7	304.2 a
100	3.65	3.26 a	0.32 a	4.34	0.54 d	1.78 a	272.4 a	77.3 a	88.4	302.6 a
LSD 0.05	NS	0.55	0.03	NS	0.07	0.33	46.06	9.18	NS	37.24
Foliar fertilizer application										
F_1	3.61	2.64	0.25	4.33	0.72	1.46	222.1	64.9	82.9	247.3
F_0	3.54	2.77	0.25	4.40	0.70	1.45	218.1	62.2	86.6	244.4
LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS = nonsignificant; LSD = least significant difference; F_1 = foliar fertilizer application; F_0 = no foliar fertilizer application.
Values in a column followed by the same letter are not significantly different, $P \leq 0.05$, using Fishers' protected *t* test.

consuming nutritious food, and it may contribute to reducing the incidence of malnutrition. Although both FM and cherry tomatoes were treated the same in terms of growing conditions, irrigation and fertigation, and foliar fertilizer application, it seems the effectiveness of foliar spray depends on the crop species.

Calcium deficiency is known to cause BER in tomato (Ho and Adams, 1995) and it was evident in these results (Table 3). Decreasing NC increased Ca fruit content of FM tomatoes (Tables 4 and 6) (Charbonneau et al., 1988; Sonneveld and Welles, 2005). Calcium leaf content showed a tendency to decrease as NC decreased. These results are in agreement with the hypothesis that BER is related to the Ca concentration in the fruit. High NC can reduce Ca uptake in the fruit, regardless of a sufficient Ca concentration in the nutrient solution, and induce BER (Ho and Adams, 1995). Conversely, a decrease in NC decreased cherry tomatoes fruit Ca content, Ca content showed a tendency to decrease as NC increased. Generally, the study shows that fruit mineral content was higher in FM tomatoes as compared with cherry tomatoes, which could be explained by differences in the genetic makeup of the plants and fruit load. Cherry tomatoes produce many smaller-sized fruits per plant compared with FM tomatoes. Foliar fertilizer did not have a significant effect on leaf mineral content and yield of FM and cherry tomatoes, with the exception of improved P content for FM tomatoes, and K, P, Mg, and Zn for cherry tomatoes. Yield improvement of FM tomatoes could be primarily related to improved nutrient uptake, especially N, P, and K (Table 6), whereas in cherry tomatoes it was due to improved uptake of N, P, K, and S (Table 10). However, leaf mineral content values for FM tomatoes, that is, N, P, K, Ca, Mg, Zn, B, and Mn (Table 7), were acceptable across all the treatments with the exception of Fe, which was double the acceptable value (50–100 $mg \cdot kg^{-1}$) (Jones, 2008). Potassium leaf mineral content of cherry tomatoes at 25% NC was lower (2.08%) than the optimum range of 2.5% to 5% (Jones, 2008), whereas remaining treatments were falling within the range. Phosphorus leaf content of cherry tomatoes fertigated with 25% and 50% of the recommended fertilizer was below the optimum range by Jones (2008), whereas Ca, Fe, Zn, and B were above the range in all the treatments, including foliar application. Application of NC from 50% to 100% resulted in high leaf sulfur content (1.52 to 1.78), which was above the optimum range (0.3% to 1.2%) (Jones, 2008).

Fruit cracking seems to be reduced by lower concentrations of nutrient solution. Fruit cracking is generally associated with the rapid influx of water and solutes into fruit when cuticle elasticity and strength are reduced (Peet and Willits, 1995). In this study, the first experiment on FM tomatoes had a high incidence of fruit cracking (Table 3) at 75% NC, which could be related to low Ca fruit content (Table 4). Adequate transport of Ca to the fruit was reported to reduce the number and severity of cracked fruits (Lichter et al., 2002). The study was conducted during the summer season and the effects of the reduced application of NC might be related to high summer temperatures, which exacerbate rapid transpiration, therefore improved nutrient uptake.

Results showed that, compared with the recommended NC (100% NC), reduced NC had positive effects on yield and fruit mineral content of FM and cherry tomatoes. It is, therefore, recommended that the NC in the cultivation of FM tomatoes can be reduced to 50% of the recommended NC, whereas for cherry tomatoes, it can be reduced to 75% of the recommended NC for improved yield and mineral content. Foliar fertilizer improved fruit mineral content (K, P, Mg, and Zn) of cherry tomatoes, as well as the fruit Ca content and TSS of FM. The recommendation from this study to decrease NC in open-bag hydroponic system will reduce nutrient leaching, and at the same time decrease fertilizer input costs by 25% and 50% on cherry and FM tomatoes, respectively, with a reduced risk associated with soil and soil water pollution. Further studies need to be conducted on reduced fertilizer application on different growth media, whereas investigating the mineral composition to reduce the cost of production and to protect the environment through decreased nutrient leachates.

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