Yield and Mineral Content of Hydroponically Grown Mini-Cucumber (*Cucumis sativus* L.) as Affected by Reduced Nutrient Concentration and Foliar Fertilizer Application

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Abstract. Nutrient application is one of the major inputs required for hydroponic production of cucumbers. Reduced nutrient solution concentration with supplementary foliar fertilizer application may maintain yield and quality of mini-cucumber, while decreasing the production costs. An experiment was conducted to determine the effect of foliar fertilizer in combination with reduced nutrient concentrations on the yield and quality of hydroponically grown mini-cucumber in a plastic tunnel. Mini-cucumber plants were grown in sawdust, fertigated with nutrient solutions containing 100% (control), 75%, 50%, or 25% of the recommended nutrient concentration (NC) and two foliar fertilizer applications (no foliar and foliar application). The highest fresh and dry weight of mini-cucumber plants were obtained with 75% and 100% NC and decreased with 50% to 25% NC application. The number of marketable fruit and marketable yield on mini-cucumbers increased with 75% to 100% NC, followed by 50% NC, as compared with 25% NC. Deformed fruit were significantly lower at 25% NC than at 50%, 75%, and 100% NC. Foliar fertilizer application did not have an effect on mini-cucumber yield, but reduced the yellowing of fruit. Fruit mineral content (P, Fe, and Mn) was significantly improved by 100% NC. Improvement in yield at 75% and 100% NC was as a result of improved plant height, leaf chlorophyll content, plant fresh and dry weight, and the increase in nutrient uptake of N, P, K, and Mn, which was evident in the analysis of cucumber leaves. The reduced NC of 75% can maintain yield and quality of mini-cucumbers, whereas the application of foliar fertilizer had a limited effect.

The most important aspect in successful management of soilless produced vegetables is the management of total NC (Maboko and Du Plooy, 2017). For optimal growth and development of the crop, it is essential that all the nutrient elements required for plant growth are present in optimal quantities in the nutrient solution. Nutrient solution concentration plays an important role in determining yield and quality of vegetable crops (Fallovio et al., 2009; Siddiqi et al., 1998). Many growers continue to adopt a liberal approach to fertilizer management, by applying high NC in an attempt to maximize crop yield with no attention to nutrient uptake by the crop (Li et al., 2001; Sonneveld and Voogt, 2009). Excessive application of NC results in saline or iron toxicity and nutrient excess or imbalance and increases osmotic pressure, whereas too

low NC generally leads to nutrient deficiencies (Savvas and Adamidis, 1999; Sonneveld and Welles, 2005).

The environmental sustainability of open hydroponic systems has been questioned because a less consistent fraction of applied nutrient solution is discharged into the environment (Sonneveld, 2002). This fraction varies largely as a function of several parameters, but in normal growing conditions, it ranges between 20% and 50% (Grewal et al., 2011). Niederwieser and Du Plooy (2014) recommended that 10% to 20% of the volume of irrigated nutrient solution must drain freely out of the growing medium to leach excessive fertilizer and salts that might otherwise build up to toxic levels. This leads to an uncontrollable leakage of concentrated nutrient solution to the soil and then to the ground- or surface water, causing severe environmental pollution (Breš et al., 2013; Kläring, 2001).

As a supplement, foliar fertilizer application is gaining popularity among growers as a standard practice in agricultural crop production because it is more purposeful and environmentally friendly as opposed to soil

fertilization (Maboko and Du Plooy, 2017). Foliar fertilization is mostly used to correct nutritional deficiencies in plants caused by improper supply of nutrients to plant roots (Ling and Silberbush, 2002). It offers a complementary means of providing nutrients during a critical phase of restricted nutrient supply (Mengel, 2002). The effects of strong binding of plant nutrients in soils and the difficulties in the acquisition of nutrients because of a particular soil condition can be alleviated by foliar fertilizer application (Kolota and Osińska, 2001; Mengel, 2002; Santos, 2013). It is also recognized that supplementary foliar fertilization during crop growth can improve the mineral status of plants and increase the crop yield and quality (Fageria et al., 2009; Kolota and Osińska, 2001). The beneficial effects of applying foliar plant nutrients, expressed as an increase in yield and improvement of crop quality, have been noted in many vegetable species such as gherkin (*Cucumis sativus*) (Abeyrathna et al., 2013) and tomatoes (*Solanum lycopersicon*) (Maboko and Du Plooy, 2017; Roosta and Hamidpour, 2011). Other advantages of foliar fertilizer application over soil application include a lower input of fertilizers due to improved utilization of nutrients and reduced risk of leaching from the soil (Kolota and Osińska, 2001; Komosa, 1990). However, the use of foliar nutrition with the aim of reducing NC through fertigation in hydroponic/soilless systems is limited.

The objective of this study was to decrease the NC used for fertigation while applying foliar fertilizer on mini-cucumber grown in sawdust growing medium.

Materials and Methods

Trial location. The experiment was carried out during Nov. 2014 to Mar. 2015 (Summer/Autumn season) in a non-temperature controlled plastic tunnel at the Agricultural Research Council-Vegetable and Ornamental Plants, Rodeplaat, South Africa (lat. 25.59°S, long. 28.35°E, altitude 1200 m). The non-temperature controlled tunnel relied on natural ventilation by means of a flap and door system that could be opened on each side. The 10 m × 30 m (width × length) tunnels were covered with a 200-μm light diffusive plastic (Evadek Green Tint) and a 200-μm white plastic was placed on the floor, which is popular with commercial vegetable growers in South Africa. The growing condition in the non-temperature controlled tunnel was a mean temperature of 33 °C day/16 °C night as recorded during the growth season.

Treatments and cultural practices. Seeds of indeterminate mini-cucumber ‘Sunami’ were directly sown in 10-L plastic bags containing sawdust as a growing medium. ‘Sunami’ is an early maturing Beit Alpha type hybrid, and the fruit are dark green, 15–18 cm long, uniform, and cylindrical in shape with a slight neck (Sakata Seed Southern Africa Pty. Limited, Johannesburg, South Africa).

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The fertilizer composition and chemical concentration as recommended by Hygrotech Pty. Limited, Pretoria, South Africa, and Niederwieser and Du Plooy (2014) for cucumber production were Hygroponic® (Hygrotech Pty. Limited) comprising nitrogen (N) (68 mg·kg⁻¹), phosphorus (P) (42 mg·kg⁻¹), potassium (K) (208 mg·kg⁻¹), magnesium (Mg) (30 mg·kg⁻¹), sulfur (S) (64 mg·kg⁻¹), iron (Fe) (1.254 mg·kg⁻¹), copper (Cu) (0.022 mg·kg⁻¹), zinc (Zn) (0.149 mg·kg⁻¹), manganese (Mn) (0.299 mg·kg⁻¹), boron (B) (0.373 mg·kg⁻¹), and molybdenum (Mo) (0.037 mg·kg⁻¹), and calcium nitrate [Ca(NO₃)₂] comprising N (117 mg·kg⁻¹) and calcium (Ca) (166 mg·kg⁻¹). These fertilizers were applied per 1000 L of water (Table 1).

Cucumber plants were fertigated with four NC treatments, i.e., the recommended NC of 100% (control) and then at reduced NCs of 75%, 50%, and 25% of the recommended NC (Table 1). The four NC treatments were started on one-week-old cucumber seedlings that emerged from direct seeding [12 d after direct seeding (DADS)]. The concentration of the nutrient solution was adopted for both macro- and micronutrients. Three weeks after direct seeding, foliar fertilizer was applied every second week using calcium nitrate (117 mg·kg⁻¹ N and 166 mg·kg⁻¹ Ca) and Multifeed® (Plaaskem Pty. Ltd, Johannesburg, 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). Spraying was performed by the conventional 'runoff' method with a HH5-Handheld sprayer (Jacto Inc., Tualatin, OR). Multifeed® is composed of N (193 mg·kg⁻¹), P (83 mg·kg⁻¹), K (158 mg·kg⁻¹), S (6.1 mg·kg⁻¹), Mg (4.6 mg·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). The experimental design was a 2 × 4 factorial arrangement with two foliar fertilizer applications (with and without foliar fertilizer application) and four NCs. Treatment combinations were arranged in a randomized complete block design with four replications.

Plants were maintained at a plant population density of 2.5 plants/m². There were 14 plants per plot. Cucumber plants were trained to a single stem by twisting trellis twine around the main stem and fixing to a stray wire 2 m away from the ground to support the plant. Side branches were removed weekly to maintain a single stem. When plants had reached the horizontal wire at a height of 2 m, plants were lowered down to continue growing. The pH of the nutrient solution was measured on a daily basis with a handheld "HANNA" electrical conductivity (EC) and pH meter (HANNA Instruments, Port Louis, Mauritius) and maintained between pH 5.5 and 6.5 using nitric acid. The 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 280 to 2205 mL/plant, equivalent to 1 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, leaf chlorophyll, and yield measurements. Plant height, leaf number, and leaf chlorophyll content were evaluated on six plants per plot during the plant growth. At 28 DADS, plant height and leaf number were recorded every 14 d until the plants reached 2 m; thereafter, plants were lowered down for continuous vertical growth. No further plant height measurements were taken. Leaf chlorophyll content was measured nondestructively concurrently with the aforementioned plant height parameter on the fourth youngest leaf from the growing point with a SPAD 502 chlorophyll meter (Konica Minolta, Osaka, Japan). At the final harvest/termination of the experiment, plants were cut above the growing medium level and weighed for plant fresh weight. Plants were dried in an oven at 70 °C for 36 h for dry weight determination.

Harvesting started 49 DADS and finished 119 DADS. Cucumber plants were harvested twice a week from 10 data plants when the cucumber fruit reached 15–18 cm in length. Yield parameters that were measured or evaluated for crop performance include marketable yield, unmarketable yield, deformed fruit, and fruit exhibiting a yellowish color. Deformed fruit and fruit exhibiting a yellowish

color were regarded as unmarketable yield.

Total soluble solids, pH, and EC of cucumber fruit juice. Total soluble solids (TSS), pH, and EC of cucumber juice were determined. The cucumber fruit were sliced into small pieces and placed in a laboratory blender to produce a puree. The puree was then filtered through cheesecloth to produce cucumber juice. The pH and EC of the cucumber juice were measured using a Combo pH and EC meter (Hanna Instruments® Inc., Mauritius). The TSS of the cucumber juice was determined using a refractometer PAL-1 (ATAGO®, Kobe, Japan).

Leaf and fruit mineral analysis. At 84 DADS, four plants per plot were selected and the fourth youngest leaf from the growing point was used to determine N, P, K, Ca, Mg, Mn, Zn, B, Cu, and Fe concentrations of cucumber leaves. The leaves were oven-dried at 70 °C for 48 h and ground using a mill with a 1-mm sieve. Ten fruit of uniform size per plot were selected to determine the aforementioned mineral content with the exception of N. Fruit were sliced and oven-dried for 72 h at 70 °C. Nitrogen was determined on dry-milled material using a Carlo Erba NA 1500 C/N/S analyzer (Thermo Scientific, Milan, Italy) according to Jimenez and Ladha (1993). An aliquot of the digest solution was used for inductively coupled plasma-optical emission spectrometry for the determination of Ca, Mg, P, K, Fe, Zn, Mn, and Cu concentrations (Liberty Series II Model; Varian, Mulgrave, Australia). All NCs were expressed on a dry weight basis.

Table 1. Type and amount of fertilizer applied as treatments per 1,000 L of water.

Nutrient concentrations (%)	Transplant to first 3 weeks		From 4 weeks to end of trial	
	Hygroponic	Calcium nitrate	Hygroponic	Calcium nitrate
	(g/1,000 L)			
25	125	125	200	200
50	250	250	400	400
75	375	375	600	600
100	500	500	800	800

Table 2. Effect of nutrient solution and foliar fertilizer on mini-cucumber plant fresh weight, plant dry weight, total soluble solids (TSS), pH, and electrical conductivity (EC) of extracted cucumber juice at the Agricultural Research Council-Vegetable and Ornamental Plants, Pretoria, South Africa, in Nov. 2014 to Mar. 2015.

	Plant fresh wt (g/plant)	Plant dry wt (g/plant)	TSS (%)	pH	EC (mS·cm ⁻¹)
Nutrient concn (%)					
25	465.0 b ^z	63.9 b	2.9	5.0 b	4.1
50	604.4 a	76.7 a	3.1	5.1 a	4.1
75	619.7 a	81.5 a	3.3	5.2 a	3.9
100	620.9 a	80.8 a	3.0	5.2 a	3.7
LSD 0.05	54.21	7.17	NS	0.09	NS
Foliar fertilizer application					
F0	581.5	74.6	3.1	5.1	4.0
F1	590.9	76.8	3.1	5.1	3.9
LSD 0.05	NS	NS	NS	NS	NS

^zValues in a column followed by the same letter are not significantly different ($P \leq 0.05$), using Fisher's protected *t* test.

F0 = no foliar fertilizer application; F1 = foliar fertilizer application; NS = not significant; LSD = least significant difference.

Results and Discussion

Leaf N content decreased significantly with a decrease in NCs (Table 4) and this can be ascribed by reduced leaf chlorophyll content at the reduced NC (Table 3). Leaf N contents at 50%, 75%, and 100% NC were within the recommended level (3.5% to 6%) by Hochmuth et al. (2012). Leaf K and P contents were significantly higher at 100% and 75% NC than at 50% and 25% NC. In accordance with the recommendation by Hochmuth et al. (2012), both leaf K and P contents were within the optimum adequate

Table 3. Effect of nutrient concentration and foliar fertilizer application on leaf chlorophyll content and leaf number of cucumber at the Agricultural Research Council - Vegetable and Ornamental Plants, Pretoria, South Africa, in Nov. 2014 to Mar. 2015.

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Values in a column followed by the same letter are not significantly different ($P \leq 0.05$), using Fisher's protected t test. 0=0 no foliar fertilizer application; F1 foliar fertilizer application; NS = not significant; LSD = least significant difference

Fig. 1. Effect of nutrient concentration of plant height over plant growing period. Least significant difference at $P \leq 0.05$.

Table 4. Effect of nutrient concentration and foliar fertilizer application on leaf mineral content of cucumber at the Agricultural Research Council-Vegetable and Ornamental Plants, Pretoria, South Africa, in Nov. 2014 to Mar. 2015.

	N ²	K	P	Ca	Mg	Fe	Zn	Mn	B	Cu
	(%)					(mg·kg ⁻¹)				
Nutrient concn (%)										
25	3.2 d ³	2.2 b	0.34 b	2.69 a	0.8 a	146.6	57.6	43.2 b	54.7 a	15.88
50	3.9 c	2.3 b	0.36 b	2.39 ab	0.7 ab	125.6	57.4	64.3 a	53.3 a	14.95
75	5.3 b	3.0 a	0.53 a	2.15 bc	0.6 bc	145.0	61.9	68.1 a	46.7 b	15.50
100	5.7 a	3.0 a	0.58 a	1.69 c	0.5 c	177.6	52.5	73.4 a	43.3 b	14.45
LSD 0.05	0.40	0.28	0.10	0.49	0.16	NS	NS	14.3	5.88	NS
Foliar fertilizer application										
F0	4.6	2.6	0.45	2.22	0.65	142.2	57.8	64.2	49.0	15.23
F1	4.5	2.6	0.45	2.24	0.72	155.3	56.9	60.3	50.0	15.31
LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

²N = nitrogen; K = potassium; P = phosphorus; Ca = calcium; Mg = magnesium; Fe = iron; Zn = zinc; Mn = manganese; B = boron; Cu = copper.

³Values in a column followed by the same letter are not significantly different ($P \leq 0.05$), using Fisher's protected *t* test.

F0 = no foliar fertilizer application, F1 = foliar fertilizer application; LSD = least significant difference.

Table 5. Effect of nutrient concentration on fruit mineral content of cucumber at the Agricultural Research Council-Vegetable and Ornamental Plants, Pretoria, South Africa, in Nov. 2014 to Mar. 2015.

	K (%) ²	P	Ca	Mg	Fe	Zn	Mn	B
		(mg·kg ⁻¹)						
Nutrient concn (%)								
25	3.11	4,040 c ³	5,805	3,746 a	149.8 b	82.3	16.98 c	37.7
50	3.05	4,302 bc	4,806	3,086 b	121.5 b	80.7	22.63 b	35.6
75	3.04	5,465 b	4,695	2,577 b	128.0 b	79.7	23.76 b	29.7
100	3.82	7,457 a	5,090	2,853 b	201.1 a	85.8	36.27 a	36.5
LSD 0.05	NS	1,224.5	NS	607.7	39.52	NS	5.47	NS
Foliar fertilizer application								
F0	3.28	5,282	4,968	2,973	149.1	80.5	24.59	34.8
F1	3.23	5,351	5,230	3,158	151.1	83.8	25.23	34.9
LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS

²K = potassium; P = phosphorus; Ca = calcium; Mg = magnesium; Fe = iron; Zn = zinc; Mn = manganese; B = boron.

³Values in a column followed by the same letter are not significantly different ($P \leq 0.05$), using Fisher's protected *t* test.

F0 = no foliar fertilizer application, F1 = foliar fertilizer application; NS = not significant; LSD = least significant difference.

range of 1.6% to 3.0% and 0.3% to 0.6%, respectively. Leaf Ca and Mg contents tended to decrease with an increase in NCs, with the highest leaf Ca and Mg

contents at 25% NC, even though 25% and 50% NC did not differ significantly (Table 4). Calcium leaf mineral content of cucumber at 100% NC was lower than the

optimum adequate range of 2% to 4.0% (Hochmuth et al., 2012). Decrease in Ca leaf content with an increase in NC concurs with the findings reported on tomatoes (Charbonneau et al., 1988; Maboko and Du Plooy, 2017; Sonneveld and Welles, 2005). Magnesium leaf content fertigated with 100% NC was below the optimum adequate range of 0.58% to 0.7% by Hochmuth et al. (2012).

Foliar fertilizer application did not have a significant effect on leaf mineral content (Table 4); however, leaf N, P, K, Ca, and Mg contents were within the optimum range as reported by Hochmuth et al. (2012). Leaf Fe, Zn, and Cu contents were unaffected by NC. Leaf Fe and Zn contents for all treatments were above the optimum range of 40–100 mg·kg⁻¹ and 20–50 mg·kg⁻¹, respectively (Hochmuth et al., 2012). Leaf Mn content was significantly higher at 50%, 75%, and 100% than at 25% NC. Leaf B content was significantly higher at 25% and 50% NC than at 75% and 100% NC. Leaf Mn, B, and Cu contents across all the NC treatments were within the optimum adequate range (Hochmuth et al., 2012).

Fruit mineral content of cucumber, such as K, Ca, Zn, and B, were unaffected by reduced NC (Table 5), although some tendencies were observed. NC of 50%, 75%, and 100% had tendencies toward reduced Ca content of the cucumber fruit (Table 5), which could be attributed to the reduced leaf Ca content (Table 4). Fruit P content was significantly higher at 100% NC, followed by both 75% and 50% NC, and the lowest was at 25%. The NC of 25% increased Mg content significantly compared with 50%, 75%, and 100% NC. The 100% recommended NC improved Fe and Mn contents significantly (Table 5).

Foliar fertilizer application showed some tendency toward an increase in P, Ca, Mg, Fe, Zn, Mn, and B contents (Table 5). Foliar fertilizer was reported to be beneficial for greenhouse tomato production (Chapagain and Wiesman, 2004) and improve the fruit mineral content (K, P, Mg, and Zn) of cherry tomatoes (Maboko and Du Plooy, 2017).

The highest number of marketable fruit, marketable yield, and deformed fruit were obtained from plants fertigated with 75% and 100% NC compared with 25% and 50% NC (Table 6). This finding is in agreement with Maboko and Du Plooy (2017) who found that NC of 25% on tomatoes reduced plant growth and, subsequently, yield as a result of nutrients being the limiting factor. On the other hand, the use of a reduced NC in a closed hydroponic system for sweet pepper cultivation did not influence the total yield (Giuffrida and Leonardi, 2012). Improved yield in cucumber at 75% and 100% NC in the open hydroponic system could be as a result of improved plant height, plant fresh and dry weight, leaf number, and leaf chlorophyll content as well as improved uptake of

Table 6. Effect of nutrient concentration and foliar fertilizer application on cucumber yield at the Agricultural Research Council-Vegetable and Ornamental Plants, Pretoria, South Africa, in Nov. 2014 to Mar. 2015.

	Number of marketable fruits/plant	Marketable yield (g/plant)	Number of deformed fruits/plant	Wt of deformed fruits (g/plant)	Number of yellowish fruits/plant	Wt of yellowish fruits (g/plant)
Nutrient concn (%)						
25	19.25 c ^z	3,059 c	10.01 b	1,329 b	3.41 b	459 b
50	28.10 b	4,666 b	12.82 a	1,762 a	5.17 a	844 a
75	36.91 a	5,672 a	12.49 a	1,619 a	3.72 b	535 b
100	36.42 a	5,498 a	13.45 a	1,685 a	4.15 b	576 b
LSD 0.05	3.058	480.0	1.719	205	0.925	158.4
Foliar fertilizer application						
F0	30.82	4,810	12.17	1,601	4.46 a	661 a
F1	29.52	4,637	12.22	1,597	3.77 b	546 b
LSD 0.05	NS	NS	NS	NS	0.654	112.0

^zValues in a column followed by the same letter are not significantly different ($P \leq 0.05$), using Fisher's protected *t* test.

F0 = no foliar fertilizer application, F1 = foliar fertilizer application; NS = not significant, LSD = least significant difference.

Fig. 2. Interaction effect of nutrient concentration and foliar fertilizer application on unmarketable yield of cucumbers. Least significant difference (LSD) at $P \leq 0.05$; F0 = no foliar fertilizer application, F1 = foliar fertilizer application.

mineral elements such as N, P, K, and Mn which were evident on cucumber leaves. The higher leaf chlorophyll concentration in plants grown at 75% and 100% NC indicates that plants were able to photosynthesize more effectively than those with low NC (25% NC), and, thereby, supply assimilates for fruit development and plant growth, contributing to the higher marketable yield. Nutrient concentration of 25% significantly produced the lowest marketable yield, which is directly related to deficit nutrition. Incidences of yellowing of fruits were only observed toward the end of the experiment, which could be as a result of maturity or aging of the plant. Deformed fruit might have exacerbated by the temperature fluctuations in the non-temperature controlled tunnel. Cucumber plants fertigated with 50% NC without foliar fertilizer application increased unmarketable yield compared with other treatments (Fig. 2). Foliar fertilizer application did not have a significant effect on cucumber yield, which could be due to fertilizer source and time of application (Maboko and Du Plooy, 2017). Furthermore, an understanding of the factors that influence the ultimate efficacy

of foliar nutrient applications is, however, incomplete (Fernández and Brown, 2013; Fernández et al., 2013; Kannan, 2010) and requires further investigation. According to Fernández and Brown (2013), there are many factors that influence the performance of foliar nutrient sprays, which are grouped under physicochemical properties of the formulation, the environment under which sprays are applied, or the characteristics of the plant to which the spray is applied.

The results indicated that the NC of 75% improved yield, which was comparable/similar to that of plants fertigated with the recommended NC of 100%. This study revealed that it is possible to use about 25% less fertilizer without any negative effects on cucumber yield and quality when grown in an open hydroponic system using sawdust as a growing medium. Foliar fertilizer application did not have a significant effect on cucumber yield and quality. Further studies should be conducted to analyze the potential of saving fertilizer in the cultivation of other vegetable species in different environmental growing conditions and growing media.

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