doi: 10.17221/166/2016-HORTSCI

Increasing nutrient levels promote growth and flower quality in lilies grown under soilless culture

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Abstract

Al-Ajlouni M.G., Ayd J.Y., Othman Y.A. (2017): Increasing nutrient levels promote growth and flower quality in lilies grown under soilless culture. Hort. Sci. (Prague), 44: 171–177.

This research was aimed at assessing the impact of different doses of nutrients on growth and flower quality of the Asiatic hybrid *Lilium* ((*Lilium* × *elegans* Thunb.) cv. 'Fangio') under the soilless culture. Five nutrient (fertigation) regimes were applied (T1: daily, T2: twice a week, T3: weekly, T4: twice a month and T5: control). Increasing the nutrient supply increased chlorophyll content index (SPAD, 45–93%), leaf area (30–55%), number of flowers per plant (25–67%) and substrate electrical conductivity (EC: 28–300%) compared to control. Although T3 (weekly nutrient supply) had lower shoot N, P, K^+ and Ca^{+2} concentrations than T1, this regimen increased the number of flower buds by 20% and flower longevity by 56% compared to T1. Overall, weekly nutrient application is effective at maintaining flower quality and yield in the 'Fangio' lily, and compares favourably with programs in which fertigation is more frequent and the level of total applied nutrients is higher.

Keywords: plant longevity; nitrogen; ornamental plant; bulbs; tuff

Lilium is widely cultivated as a potted and cut flower plant worldwide (Burchi et al. 2011; Barrera-Aguilar et al. 2013). In the Netherlands, the world largest cut flower exporter, the lily (*Lilium* spp.) ranks fifth of the top-selling cut flowers with annual sales of approximately 205 million pieces (Hanks 2015). To produce superior lily plants, growers need to identify the optimal nutritional requirements and the difficulties that occur during the production process (Barnes et al. 2011). Fertigation is a necessary management practice in hydroponic *Lilium* production systems because nutrients supplied by the mother bulb are not sufficient to complete the production cycle (Ortega-Blu et al. 2006). However, the demand for nutrients depends on cultivar and growth stage. For example, the demand of *Lilium* for potassium (K^+) and nitrogen (N) is higher than that for calcium (Ca^{+2}) during stem elongation and flowering stages (Marin et al. 2011). The lower and middle leaves of the *Lilium* rely more on the internal Ca^{+2} stored in the bulb, while the upper leaves and flowers depend more on Ca^{+2} supplies from the roots (Chang, Miller 2003). Marin et al. (2011) found that *Lilium* plants maintained relatively constant K^+ and Ca^{+2} levels in the shoots regardless of the nutrient levels in the nutrient solution. However, insufficient supply of Ca^{+2} from the bulb and root to the upper leaves can cause leaf necrosis (Chang, Miller 2003).

Nutrient management practices significantly impact shoot and root growth and development (Zhang et al. 1999; Barnes et al. 2011), and effective fertigation is a critical strategy to produce high quality plants able to withstand environmental stress (Leskovar, Othman 2016). Generally, plants respond to nitrate (NO_3^-) and phosphorus (P) availability in the growing media by altering their root system architecture (Linkohr et al. 2002).

Supported by the Deanship of the Academic Research at the University of Jordan.

doi: 10.17221/166/2016-HORTSCI

High levels of NO_3^- in growing media reduced primary root length, while primary roots increased with increasing P supply (Linkohr et al. 2002).

Few studies have been conducted on flower quality and yield in lilies (Goto et al. 2005; Veatch-Blohm et al. 2012). High P concentration in the growing media increased Calla lily (*Zantedeschia* spp.) tuber biomass but decreased the number of flowers per plant (Scagel, Schreiner 2006). Concentrations of 504–900 mmol/kg K^+ in the shoot and 5.6 mmol/l K^+ in the nutrient solution are associated with optimum growth and flower quality while 949 mmol/kg K^+ and 13.6 mmol/l K^+ in shoot and growing media, respectively, is harmful to *Lilium* plants (Barrera-Aguilar et al. 2013). However, nutrient demands (N, P and K^+) during stem elongation and floral initiation stages were found to be different between *Lilium* cultivars ('Fangio', 'Miami' and 'Navona'; Ortega-Blu et al. 2006).

Volcanic tuff is widely available in the Mediterranean region, including Jordan (Nawasreh et al. 2006), and has been used frequently as growing media for soilless systems. Volcanic tuff is a reliable substrate for soilless culture because it has good water holding capacity, cation exchange capacity, acidity resistance and aeration. Moreover, it is free of weed seeds and exhibits good nutrient retention, especially of N (Polat et al. 2004; Nawasreh et al. 2006). Al-Ajmi et al. (2009) found that using volcanic tuff as a growing substrate in soilless tomato (*Lycopersicum esculentum* L.) increased growth and yield markedly compared to perlite and sand. However, limited information is available on *Lilium* nutrients and water management practices, specifically for flowers grown in soilless culture systems (Barrera-Aguilar et al. 2013). The objective of this study was to assess the impact of different nutrient levels on the growth and flower quality of 'Fangio' lily under a soilless system.

MATERIAL AND METHODS

Plant material and greenhouse setup. The experiment was conducted in a greenhouse at the University of Jordan (lat. 32°0'40.4316"N, long. 35°52'20.3628"E). Min. and max. solar radiation in the greenhouse ranged from 650 to 1,150 μmol/m^2/s and min. and max. temperature ranged from 16 to 18°C and 22 to 30°C, respectively. Bulbs of Asiatic lily 'Fangio' were planted on September 14, 2015 into 4 l pots at 15 cm depth. Volcanic tuff with particle sizes of less than 4 mm was used as a growth media. The tuff had a water holding capacity of 31.4%, bulk density of 1.12 g/cm^3, air-filled porosity of 35.2%, EC of 0.3 mmhos/cm and pH was 8.15. The chemical composition for Jordanian volcanic tuff was 41.26% SiO_2, 12.41% Al_2O_3, 15.6% Fe_2O_3, 0.25% MnO, 2.86% TiO_2, 7.26% CaO, 1.94% K_2O, 0.63% P_2O_5, 7.82% MgO, 2.73% Na_2O, 7.24% LOI and 2.96% Si/Al (Almjadleh et al. 2014). Lily plants were established for two weeks after which they were fertigated (weekly) with the experimental nutrition solution.

Nutrient treatments. Nutrient treatments (fertigation) were started two weeks after planting (September 28, 2015). Five nutrient (fertigation) regimes were applied; T1: daily, T2: twice a week, T3: weekly, T4: twice a month and T5: control (fertigation carried out twice during the crop cycle; Table 1). Irrigation water was applied daily to the plants that were not fertigated. The same solution was applied with different frequencies resulting in different total amounts of fertilisers applied in the

Table 1. Total fertigation number, water volume, fertigation volume and nutrient applied during the experimental period, September 14 to December 5, 2015

Nutrient levels (fertigation)	Fertigation No.	Water applied (l/plant)	Fertigation applied (l/plant)	Total nutrient applied (mg/ plant)			
				N	P	K^+	Ca^{+2}
T1: daily	65	4.50	16.25	3,331	585	2,795	1,544
T2: twice a week	20	15.75	5.00	1,025	180	860	475
T3: weekly	11	18.00	2.75	564	99	473	261
T4: twice a month	7	19.00	1.75	359	63	301	166
T5: control	2	20.25	0.50	103	18	86	48

doi: 10.17221/166/2016-HORTSCI

five treatments. Each pot was fully saturated (nutrient solution or water) on a daily basis. The daily water or nutrient solution applied during the growing cycle was 250 ml/plant regardless of treatment. During the study, three fertiliser sources (AlQawafel Agro-Industrial, Zarqa, Jordan) were used to prepare the fertigation solutions. These fertilisers were 6N-1.8P-8.6K (An-Nebras®), micronutrient mix (Micronate 15®), and 12N-9.8Ca-3.4Mg (Micronate 34®). The final composition of the fertigation solution was 205 ppm N, 36 ppm P, 172 ppm K^+, 40 ppm Fe-EDTA, 65 ppm Mn, 15 ppm B, 95 ppm Ca^{+2}, 34 ppm Mg^{+2}, 40 ppm Zn and 5 ppm Cu. The pH and EC of the fertigation solution were 6.24 and 2.41 mmhos/cm, respectively. The final nutrient composition of the fertigation solution was determined according to the recommendations of Dole and Wilkins (2005). The nutrient solution was prepared in a 2 m^3 tank and was circulated to prevent precipitation.

Plant morpho-physiological measurements and statistical analysis. Measurements were conducted between 11:00 a.m. and 1:00 p.m. from five fully expanded and sun-exposed leaves. Plant height and chlorophyll content index (SPAD) was measured twice a month. The number of days to flowering and flower longevity were also determined. Flowering date was considered as the blooming of the first bud on each stem (plant). The number of days from the time of planting to the blooming of first bud on each stem (plant) was recorded. Flower longevity (on each stem) was determined by measuring the number of days from flowering date to the first petal falling off the plant. At the end of the experiment, chlorophyll fluorescence, total leaf area and weight, nutrient concentration and root dry weight were determined. Chlorophyll fluorescence was measured using a chlorophyll fluorometer (OS1-FL; Opti-Sciences; USA), chlorophyll content index (SPAD) with a chlorophyll meter (CCM-200 plus; Opti-Sciences; USA) and leaf area was measured using a leaf area meter (AM350 Portable Leaf Area Meter, ADC BioScientific Ltd, UK). Shoot (all of the above-ground part) P, K^+ and Ca^{+2} were determined using inductively coupled plasma mass spectrometry (ELAN ICP-MS, PerkinElmer Inc. USA) and total Kjeldahl N using a discrete analyser (Easy Chem. Plus; Analytical Technologies, Italy). Roots were oven-dried for 24 h at 70°C to determine dry weight (up until constant weight).

The design of the experiment was completely randomised with four replications and five nutrient levels. Each pot was considered as an experimental unit. The regression and analysis of variance (ANOVA) in SAS (Version 9.4 for Windows; SAS Institute, USA) were used to assess the relationship between nutrient levels and plant morpho-physiology and to identify the lowest quantity of nutrients (fertiliser) that could be applied using the soilless system.

RESULTS AND DISCUSSION

Plant morphology and physiology

Nutrient levels significantly affected chlorophyll fluorescence and content (SPAD), leaf fresh weight and area and plant height (Table 2). The chlorophyll fluorescence of lily plants that were fertigated weekly (T3) or daily (T1) was higher than those fertigated twice a month as well as the control (non-fertigated; Table 2). Additionally, regression analysis revealed a significant relationship between nutrient level and plant growth parameters (Fig. 1). However, the response of plant variables to nutrients levels was not linear.

Table 2. Chlorophyll fluorescence and content (SPAD), leaf fresh weight and area, plant height and root dry weight of 'Fangio' lilies grown under different nutrient levels

Nutrient levels (fertigation)	Fluorescence (F_v/F_m)	SPAD	Leaf fresh weight (g/plant)	Leaf area (cm^2/plant)	Plant height (cm)	Root dry weight (g/plant)
T1: daily	0.78^{ab}	61.3^{a}	31.6^{a}	978^{a}	62.6	1.11
T2: twice a week	0.79^{a}	59.^{7a}	30.4^{ab}	941^{ab}	69.9	0.96
T3: weekly	0.78^{ab}	55.1^{a}	29.2^{ab}	904^{ab}	68.3	1.09
T4: twice a month	0.76^{c}	45.8^{ab}	24.9^{bc}	771^{bc}	67.7	0.95
T5: control	0.75^{d*}	31.7^{b}	20.5^{c}	629^{c}	69.8	0.72

different letters indicate a significant difference between the different fertigation frequency treatments ($P < 0.05$)

doi: 10.17221/166/2016-HORTSCI

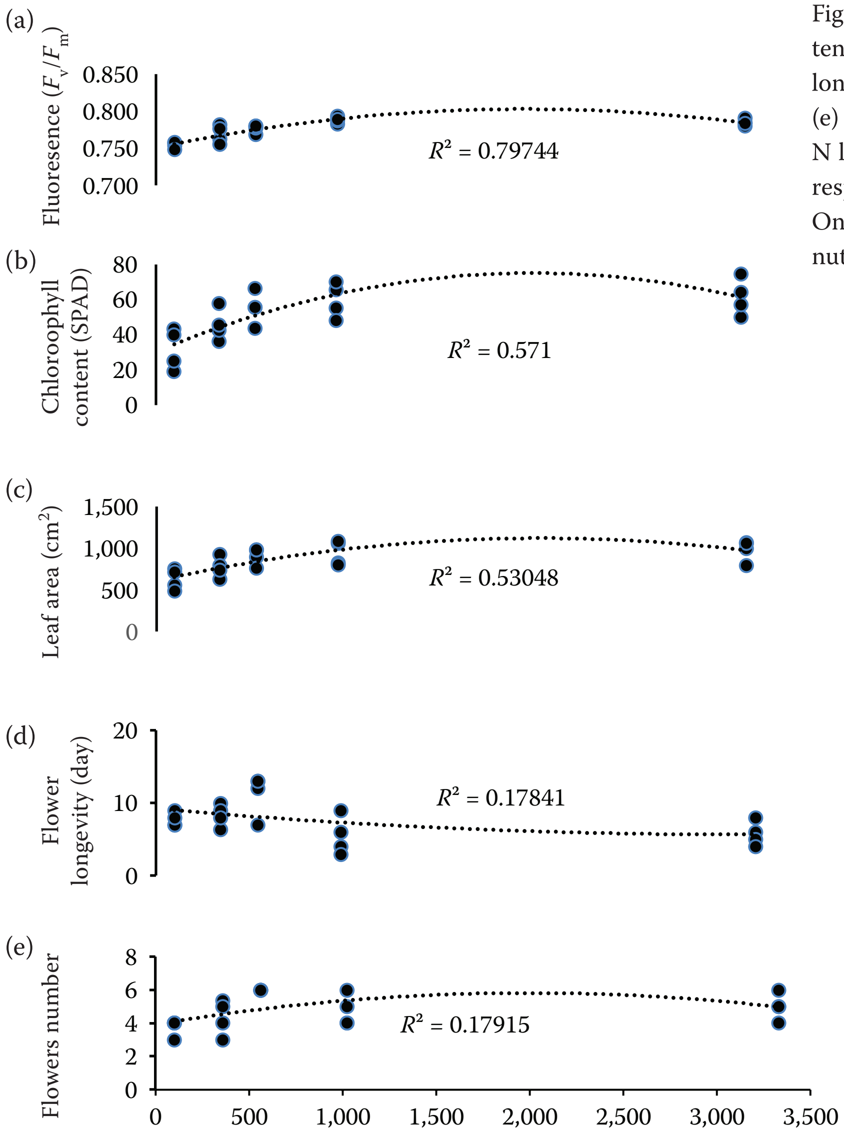

Fig. 1. Chlorophyll fluorescence (a), content index (SPAD) (b), leaf area (c), flower longevity (d) and flower number per plant (e) of 'Fangio' lilies subjected to different N levels. P, K^+ and Ca^{+2} showed the same response

Only N is depicted because all measured nutrients had the same trend

Leaf visual quality (size and greenness) is a critical factor in the marketing of *Lilium* flowers (McKenzie 1989). This study showed that increasing the nutrient levels increased leaf area by values ranging from 29.6% for the lowest nutrient level treatment (T4, fertigation twice a month), up to 55.5% for the highest nutrient level treatment (T1, daily fertigation) when compared to the control (Table 2). Meanwhile, the chlorophyll content index (SPAD) increased by 44.5% in response to twice monthly, 73.8% in response to weekly, 88.3% in response to twice weekly and by 93.4% in response to more frequent fertigation (daily). The lower leaf area measured in response to control treatments (compared to weekly and fertigation) might be attributed to lower N concentrations (Table 3). Interestingly, no significant differences in plant morpho-physiology (chlorophyll fluorescence, SPAD, leaf fresh weight and area and root dry weight) was found between 'Fangio' lilies fertigated daily, twice weekly and weekly. Overall, the application of full-strength nutrient solution to lily plants daily, twice weekly and weekly resulted in marked improvements in leaf quality variables (SPAD > 73%, and leaf area > 43%).

Generally, crop shoot nutrient concentrations for N are 2.0–4.0%, for K^+ 2.0–4.5%, for Ca^{+2} 0.2–0.6% and for P they are 0.15–0.35% (Barrera-Aguilar et al. 2013; Marschner 2011). Although plants that received the highest nutrient levels during the study (daily fertigation) had higher shoot nutrient concentrations than plants receiving other treatments, shoot nutrient content in weekly fertigated plants was within an adequate range (Table 3). In-

doi: 10.17221/166/2016-HORTSCI

Table 3. Shoot nutrient and substrate analysis for nutrient treatments at the end of the experimental period, December 5, 2015

Nutrient levels (fertigation)	Shoot nutrient content (%)				Substrate	
	N	P	K^+	Ca^{+2}	EC (mmhos/cm)	pH
T1: daily	3.35[a]	0.43[a]	4.92[a]	0.31[a]	1.01[a]	6.81[d]
T2: twice a week	3.04[ab]	0.35[ab]	4.09[b]	0.28[ab]	0.59[b]	7.07[cd]
T3: weekly	2.55[c]	0.29[d]	3.86[c]	0.20[c]	0.36[c]	7.26[bc]
T4: twice a month	2.16[d]	0.27[c]	3.39[d]	0.19[c]	0.32[c]	7.72[a]
T5: control	1.67[e*]	0.23[e]	2.97[e]	0.17[d]	0.25[c]	7.50[ab]

different letters indicate a significant difference between the different fertigation frequency treatments ($P < 0.05$)

terestingly, increasing the nutrient levels in shoots through increasing the fertigation frequency (T1, daily treatment) did not improve flower quality (number of flowers, flower longevity or plant height) compared to lily plants that received less nutrients (weekly fertigation treatment) during the growing cycle (Table 4). Additionally, increasing the nutrient levels increased substrate EC from 28% (T4) to 300% (T1) when compared to the control (Table 3). Therefore, mitigating salinity by reducing nutrient levels (while maintaining flower quality) appears to hold great promise.

Flower quality

Flower colour, scent, size, architecture, number per stem and longevity are the most important qualitative characteristics of cut flowers (Burchi et al. 2010; Woodson 1991). Recent studies showed that the application of exogenous chemicals and hormones, plant nutrition and cultivar breeding improved cut flower growth and quality (Burchi et al. 2005, 2010; Treder 2005). For example, foliar application of potassium sulphate and sucrose onto Asiatic lily (cvs. 'Fangio' and 'Brindisi') 30–10 days before harvest significantly improved flower colour quality and reduced flower abortion (Burchi et al. 2010). In this study, the relationship between nutrient levels and flower quality variables was not linear (Fig. 1d and 1e). For example, increasing the application of N-P-K^+-Ca^{+2} from 359-63-301-166 mg/plant (T4, fertigation twice a month) during the growing cycle to 546-99-473-261 mg/plant (T3, weekly fertigation) had a positive effect on flower number per plant, but higher levels of N-P-K^+-Ca^{+2}, i.e., 3,331-585-2,795-1,544 mg/plant (T1, daily fertigation), did not show the same positive linear trend. However, a significant difference among nutrient levels was found in flower number and flower longevity variables (Table 4). Daily (T1) and weekly (T3) fertigation resulted in higher flower numbers per plant than in the control. However, flower number in response to daily fertigation was 20% less than that in response to weekly fertigation. The decrease in the number of flowers per plant in parallel with excess nutrient supply (daily fertigation) is consistent with previous results in Calla (excess P, (Scagel, Schreiner 2006)) and *Ranunculus asiaticus* (excess N, (Bernstein et al. 2005)).

Flower longevity denotes the length of time that the flowering bud lasts before showing symptoms of wilting or curling (Hashemabadi 2015). Flower longevity is related to chemical and physiological processes which affect senescence and exerts a significant influence during long-distance transportation and on subsequent marketing (Alaey et al. 2011). This study showed that lily plants receiving 564-99-301-261 mg/plant N-P-K^+-Ca^{+2} (T3, weekly fertigation) during the growing cycle had significantly increased flower longevity (56%) compared to those plants that received a lower or higher amount of nutrients (i.e., T1, T2, T4 and T5; Table 4). This is might be attributed to excess nutrient supply to the shoot. Growing *Ranunculus asiaticus* under a soilless culture system and low N levels (50 ppm) resulted in higher flower numbers and sizes and flower longevity was approximately twice as long as for those grown in high N (100 ppm) growing medium (Bernstein et al. 2005).

In floriculture, efficient production systems require knowledge of how resources are partitioned

doi: 10.17221/166/2016-HORTSCI

Table 4. Flower number, flower longevity, number of days to flowering and flowering bud length of 'Fangio' lilies in response to different levels of nutrients

Nutrient levels (fertigation)	Flowers (No./plant)	Flower longevity (day/plant)	No. of days to flowering	Flowering bud length (cm)
T1: daily	5.0^{ab}	9.8^{b}	62.6	10.34
T2: twice a week	4.8^{bc}	9.5^{b}	61.2	10.32
T3: weekly	6.0^{a}	15.3^{a}	66.5	10.15
T4: twice a month	4.5^{bc}	12.3^{ab}	62.3	10.28
T5: control	3.6^{c}	11.8^{b}	66.0	10.13

different letters indicate a significant difference between the different fertigation frequency treatments ($P < 0.05$)

during the growing cycle (Scagel, Schreiner 2006). Such knowledge allows growers to maximise flower production and reduce input costs within a specific frame of time. *Lilium* can maintain a relatively constant K^+ and Ca^{+2} level in its shoots regardless of the concentration in the nutrient solution (Marin et al. 2011). Additionally, *Lilium* requires an intermediate concentration of N (136–170 ppm) and K (116–136 ppm) and low amounts of Ca^{+2} (34–88 ppm; MARIN et al. 2011). This may be because *Lilium* plants remobilise the nutrients stored in the bulbs at early growth stages, especially Ca^{+2} (Chang, Miller 2003; Marin et al. 2011). This study revealed that monitoring nutrient levels can help *Lilium* growers to lower the amount of fertiliser applied and to reduce input costs while maintain plant growth and flower quality.

CONCLUSION

Total nutrient levels during the growing season significantly affected 'Fangio' lily morphology, physiology, flower quality and flower yield. 'Fangio' lilies that received 103N-18P-86K$^+$-48P mg/plant during the growing cycle had lower leaf area, chlorophyll content (SPAD) and flower quality than those receiving higher amounts of nutrients. However, no significant difference in plant morpho-physiology parameters was found between lily receiving 3331N-585P-2795K$^+$-1544P mg/plant per cycle (daily fertigation) and those receiving lower amounts of nutrients, i.e., 564N-99P-301K$^+$-261 Ca^{+2} mg/plant per cycle (weekly fertigation). In fact, a higher supply of nutrients (daily fertigation) reduced flower number per plant by 20% and reduced flower longevity by 56% when compared to weekly fertigated lilies. The total fertiliser applied is a key factor in floriculture production and landscaping. Reducing nutrient application by reducing the fertigation frequency will lower input costs. This study showed that weekly fertigation with a full-strength nutrient solution (total N-P-K$^+$-Ca^{+2} per cycle was 546-99-473-261 mg/plant) is sufficient to maintain the quality and yield of 'Fangio' *Lilium*. Additional research is required to determine the impact of different types of soilless media on internal nutrient composition and flower quality in the lily (colour and longevity).

Acknowledgment

We thank our staff Hassan Munir, Tala Assaf and Mahmoud Abadi for their assistance in the greenhouse measurements.

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Received for publication September 29, 2016
Accepted after corrections March 6, 2017