Effects of Nutrient Solution Concentration and Daily Light Integral on Growth and Nutrient Concentration of Several Basil Species in Hydroponic Production

Kellie J. Walters¹ and Christopher J. Currey²,³
Department of Horticulture, Iowa State University, 106 Horticulture Hall, Ames, IA 50011

Abstract. Our objective was to quantify the effect of mineral nutrient concentration of a nutrient solution on the growth of basil species and cultivars grown under high and low photosynthetic daily light integrals (DLIs). Sweet basil (Ocimum basilicum ‘Nufar’), lemon basil (O. ×citriodorum ‘Lime’), and holy basil (O. tenuiflorum ‘Holy’) seedlings were transplanted into nutrient-film technique (NFT) systems with different nutrient solution electrical conductivities (EC; 0.5, 1.0, 2.0, 3.0, or 4.0 dS·m⁻¹) in greenhouses with a low (~7 mol·m⁻³·d⁻¹) or high (~15 mol·m⁻³·d⁻¹) DLI. Although nutrient solution EC did not affect growth and morphology, increasing DLI did. For example, when sweet basil was grown under a high DLI, the fresh and dry weight, height, and node number increased by 144%, 178%, 20%, and 18%, respectively, compared with plants grown under the low DLI, and branching was also stimulated. In contrast, DLI had little effect on tissue nutrient concentration, although nutrient solution EC did. Most tissue nutrient concentrations increased with increasing EC, with the exception of Mg and Ca. For example, N in sweet basil increased by 0.6% to 0.7% whereas Mg decreased by 0.2% as EC increased from 0.5 to 4.0 dS·m⁻¹. Across treatments and basil species, tissue nutrient concentrations were generally within recommended ranges with no visible deficiencies. Based on our results, nutrient solution concentrations for hydroponic basil production can be selected based on factors such as other species grown in the same solution or by reducing fertilizer inputs.

Received for publication 9 Apr. 2018. Accepted for publication 23 May 2018.

We gratefully acknowledge Peter Lawlor for greenhouse assistance, Brianna Vest and Jacob Smith for assistance in collecting data and cleaning, J.R. Peters for fertilizer, and Smithers-Oasis Company for substrate. The use of tradenames in this publication does not imply endorsement by Iowa State University of products named nor criticism of similar ones not mentioned.

¹Graduate research assistant.
²Assistant professor. E-mail: currey@iastate.edu.
and 203 cm long (GT50-612; FarmTek, Dyersville, IA), with a 3% slope. Nutrient solution was held in a 151-L reservoir (Premium Reservoir; Botanicare, Chandler, AZ) delivered to troughs by a submersible water pump (Active Aqua 33 Watt pump; Hydrofarm, Grand Prairie, TX), resulting in a flow of ≈1 L min−1 per trough. Plants were placed in 3.5-cm-diameter holes cut into the top of the NFT troughs, allowing the base of the phenolic foam to rest on the bottom of the trough.

**Greenhouse environment and DLI treatments.** Five hydroponic systems were in each of two independent glass-glazed greenhouses (Ames, IA; lat. 42.0°N). Radiant hot-water heating and fog cooling were used to maintain an average daily temperature of 21 ± 1 °C, with actual temperatures reported in Table 1. The target DLI for the low and high DLI treatments was 7 or 15 mol m−2 d−1, respectively (Table 1). A supplemental PPF of 180 ± 27 μmol m−2 s−1 from high-pressure sodium lamps (PL 3000; P.L. Light Systems, Seattle, WA) and quantum sensors were connected to a data logger (CR1000 Measurement and Control System; Campbell Scientific, Logan, UT), with mean values logged every 15 min. Nutrient solutions. The nutrient solutions consisted of RO water, MgSO4·7H2O, and 16N–1.8P–14.3K fertilizer (Jack’s Hydro FeED; JR Peters Inc.; Table 2), with a target N:Mg of 5:1. The pH was measured daily with a pH probe (HI 981504 pH/TDS/Temperature Monitor; Hanna Instruments, Woonsocket, RI) and adjusted to 6.0 using potassium carbonate (pH Up; General Hydroponics, Sebastopol, CA) and a combination of phosphoric and citric acids (pH Down; General Hydroponics). EC was measured with a handheld meter (HI 9813-6 Portable pH/EC/TDS Meter; Hanna Instruments) and adjusted to 0.5, 1.0, 2.0, 3.0, or 4.0 dS m−1 daily using RO water or concentrated 16N–1.8P–14.3K fertilizer. The solution was aerated constantly with four 15-cm-long air stones (Active Aqua air stone; Hydrofarm) per system attached to a 110-L air pump (Active Aqua commercial air pump; Hydrofarm). Oxygen concentrations (8.3 ± 0.2 ppm) in the nutrient solutions were measured daily with a dissolved oxygen meter (4020D; Hanna Instruments). Nutrient solutions were circulated continuously through a heater/chiller unit (SeaChill TR-10; TECO, Terrell, TX) to maintain a water temperature of 22.1 ± 0.5 °C. 

**Data collection and calculation.** Nutrient solution samples were collected from each system before transplanting and after harvesting to determine initial and final nutrient concentrations. Nitrogen was measured with a flow-injection analyzer (QuickChem 8500; Lachat Instruments, Loveland, CO). Phosphorus, K, Mg, Ca, S, Zn, Mn, Cu, Fe, and B were analyzed by inductively coupled plasma–optical emission spectroscopy (Optima 4300 DV; Perkin Elmer, Waltham, MA).

Three weeks after transplanting, relative chlorophyll concentration was measured with a handheld soil-plant analysis development (SPAD) meter (SPAD-502; Konica Minolta, Ramsey, NJ) on the second-most mature leaf, the newest fully expanded leaf, and a leaf midway between those points for five plants per treatment per replication. Height of the main stem, and node and branch (≥2.5 cm) numbers were recorded. Plants were severed at the surface of the substrate and fresh weight was recorded immediately. Shoots were rinsed in RO water three times, placed in a forced-air oven maintained at 67 °C for 3 d, then weighed, and dry weight was recorded.

Table 1. Average (mean ± s.d) daily light integral (DLI) and air temperature for hydroponic basil grown in nutrient-film technique hydroponic systems with a range of nutrient solution electrical conductivities (ECs; 0.5–4.0 dS m−1) in a greenhouse under a low (≈7 mol m−2 d−1) or high (≈15 mol m−2 d−1) actual light integral (DLI) for 3 weeks.

| Replication | Target DLI (mol m−2 d−1) | Actual DLI (mol m−2 d−1) | Air temp (°C) |
|-------------|--------------------------|--------------------------|---------------|
| 1           | 7.0                      | 6.7 ± 0.8                | 21.8 ± 0.3    |
| 1           | 15.0                     | 14.5 ± 1.6               | 21.8 ± 0.2    |
| 2           | 7.0                      | 6.6 ± 0.9                | 22.0 ± 0.3    |
| 2           | 15.0                     | 14.9 ± 1.2               | 21.6 ± 0.4    |
| 3           | 7.0                      | 7.4 ± 1.1                | 21.4 ± 0.4    |
| 3           | 15.0                     | 15.7 ± 1.4               | 21.8 ± 0.3    |

Table 2. Nutrient concentrations of hydroponic nutrient solutions with electrical conductivities (ECs) ranging from 0.5 to 4.0 dS m−1 for basil grown in hydroponic systems under low (≈7.0 mol m−2 d−1) or high (≈15.0 mol m−2 d−1) daily light integrals (DLIs) at the beginning of the experiment, and the change (Δ) in concentration from the beginning to the end of the experiment (3 weeks).

| Target DLIs | EC | Time | N | P | K | Mg | Ca | S | Zn | Mn | Cu | Fe | B |
|-------------|----|------|---|---|---|----|----|---|----|----|----|----|---|
| Low         |    | Initial | 56 | 26 | 41 | 13 | 17 | 31 | 0.2 | 0.05 | 0.04 | 0.7 | 0.1 |
|             | 0.5 | +1    | +35 | +3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 1.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 2.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 3.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 4.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
| High        |    | Initial | 57 | 29 | 50 | 14 | 17 | 33 | 0.2 | 0.1 | 0.05 | 0.8 | 0.1 |
|             | 0.5 | +1    | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 1.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 2.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 3.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |
|             | 4.0 | Initial | +35 | -3 | -3 | -4 | -4 | 0.04 | -0.04 | -0.003 | -0.003 | -0.04 | +0.003 |

**Nutrient conc (mg L−1)**
Table 3. Analysis of variance for fresh and dry weight, height, node number, branch number, soil-plant analysis development (SPAD) meter index, and nutrient concentrations for sweet basil (Ocimum basilicum ‘Nufar’), lemon basil (Ocimum × citriodorum ‘Lime’), and holy basil (Ocimum tenuiflorum ‘Holy’) 3 weeks after transplanting into nutrient-film technique hydroponic systems with a range of nutrient solution electrical conductivities (EC; 0.5–4.0 dS m⁻¹) in a greenhouse under a low (≤7 mol·m⁻²·d⁻¹) or high (≥15 mol·m⁻²·d⁻¹) daily light integral (DLI).

| Parameter             | EC          | DLI          | EC × DLI | DLI × EC | NS       |
|-----------------------|-------------|--------------|----------|----------|----------|
| Fresh weight (g)      | NS          | ***          | NS       | ***      | NS       |
| Dry weight (g)        | NS          | ***          | NS       | ***      | NS       |
| Height (cm)           | NS          | ***          | NS       | ***      | NS       |
| Node (no.)            | NS          | ***          | NS       | ***      | NS       |
| Branch (no.)          | NS          | ***          | NS       | ***      | NS       |
| SPAD                  | ***         | NS           | ***      | NS       | ***      |
| N (%)                 | ***         | ***          | NS       | ***      | NS       |
| P (%)                 | ***         | ***          | NS       | ***      | NS       |
| K (%)                 | ***         | ***          | NS       | ***      | NS       |
| Mg (%)                | ***         | NS           | NS       | NS       | NS       |
| Ca (%)                | ***         | ***          | NS       | ***      | NS       |
| Mn (%)                | ***         | NS           | NS       | NS       | NS       |
| Fe (%)                | ***         | NS           | NS       | NS       | NS       |
| B (mg·kg⁻¹)           | ***         | NS           | NS       | ***      | NS       |
| Zn (mg·kg⁻¹)          | NS          | ***          | NS       | ***      | NS       |
| Mn (mg·kg⁻¹)          | NS          | ***          | NS       | ***      | NS       |
| Cu (mg·kg⁻¹)          | ***         | NS           | NS       | NS       | NS       |
| Fe (mg·kg⁻¹)          | NS          | ***          | NS       | ***      | NS       |
| B (mg·kg⁻¹)           | NS          | ***          | NS       | ***      | NS       |

* or *** indicate significance (Sig.) at P ≤ 0.05, 0.001, respectively.
NS = nonsignificant.

Each value represents the mean of three replications.

Table 4. Fresh and dry weight, height, node number, branch number, and soil-plant analysis development (SPAD) meter index for sweet basil (Ocimum basilicum ‘Nufar’), lemon basil (Ocimum × citriodorum ‘Lime’), and holy basil (Ocimum tenuiflorum ‘Holy’) 3 weeks after transplanting into nutrient-film technique hydroponic systems in a greenhouse under a low (≤7 mol·m⁻²·d⁻¹) or high (≥15 mol·m⁻²·d⁻¹) daily light integral (DLI). Data were pooled across electrical conductivities within DLI for each species. Each value represents the mean of three replications.

| Parameter             | EC Low | EC High | DLI Low | DLI High | Sig.          |
|-----------------------|--------|---------|---------|----------|---------------|
| Sweet basil           |        |         |         |          |               |
| Fresh weight (g)      | 12.5   | 30.5    | ***     |          | ***           |
| Dry weight (g)        | 0.9    | 2.5     |         |          | ***           |
| Height (cm)           | 13.2   | 15.9    | ***     |          | ***           |
| Node (no.)            | 4.3    | 5.1     | ***     |          | ***           |
| Branches (no.)        | 0.0    | 2.3     | ***     |          | ***           |
| SPAD                  | 25.7   | 34.1    | ***     |          | ***           |
| Lemon basil           |        |         |         |          |               |
| Fresh weight (g)      | 6.2    | 18.9    | ***     |          | ***           |
| Dry weight (g)        | 0.5    | 1.9     | ***     |          | ***           |
| Height (cm)           | 16.3   | 18.5    | ***     |          | ***           |
| Node (no.)            | 5.5    | 6.3     | ***     |          | ***           |
| Branches (no.)        | 3.5    | 7.5     | ***     |          | ***           |
| SPAD                  | 30.1   | 40.2    | ***     |          | ***           |
| Holy basil            |        |         |         |          |               |
| Fresh weight (g)      | 6.4    | 19.7    | ***     |          | ***           |
| Dry weight (g)        | 0.5    | 1.8     | ***     |          | ***           |
| Height (cm)           | 14.1   | 17.8    | ***     |          | ***           |
| Node (no.)            | 5.7    | 6.3     | ***     |          | ***           |
| Branches (no.)        | 2.5    | 7.3     | ***     |          | ***           |
| SPAD                  | 32.8   | 39.9    | ***     |          | ***           |

* or *** indicate significance (Sig.) at P ≤ 0.05 or 0.001, respectively.
NS = nonsignificant.

Each value represents the mean of three replications.

Dried shoot tissue was analyzed to determine nutrient concentrations. Determination of Kjeldahl nitrogen for all tissue samples began with standard digestion in concentrated sulfuric acid at 360 °C for 1.5 h using a Tecator 40 block digestor. The resultant ammonium fraction was measured with a flow-injection analyzer (QuickChem 8500; Lachat Instruments) using a buffered salicylate–hypochlorite solution for color development. Determination of P, K, Cu, Mg, S, Zn, Mn, Cu, Fe, and B in all tissue samples began with initial digestion in concentrated nitric acid at 90 °C followed by three small additions of 30% hydrogen peroxide, with a total time for digestion of 1 h. Digested samples were filtered and analyzed by inductively coupled plasma–optical emission spectroscopy (Optima 4300 DV; Perkin Elmer).

Experimental design and statistical analyses. For each species, the experiment was organized in a randomized complete block design with a factorial arrangement. The factors included nutrient solution concentrations (five concentrations) and DLI (two DLIs) with 10 plants of each species per individual NFT system per replication. The experiment was replicated three times over time.

Analyses of variance and t tests with α = 0.05 were performed using JMP Version 11 (SAS Institute Inc., Cary, NC); regression analyses were performed using Sigma Plot 13.0 (Systat Software, San Jose, CA). To analyze the main effect of EC, data were pooled across DLI within EC for each species, and regression analyses were performed. To analyze the main effect of DLI, data were pooled across EC within DLI for each species, and t tests were performed across DLI.

Results

Nutrient solutions. Specific mineral nutrient concentrations changed from the beginning to the end of the experiment (Table 2). Concentrations of N and S changed less in hydroponic systems in low DLI treatments than those in high DLI treatments. For example, solution N in low DLI treatments decreased by 11 to 22 mg·L⁻¹ whereas concentrations in high DLI treatments decreased by 26 to 88 mg·L⁻¹. From the beginning to the end of the experiment, solution S changed with EC and DLI. Under low DLI conditions, S concentrations decreased by 4 to 12 mg·L⁻¹ whereas under high DLI treatments, concentrations decreased by 11 to 43 mg·L⁻¹.

From the beginning to the end of the experiment, S concentration increased by 11 to 43 mg·L⁻¹. As EC increased from 0.5 to 4.0 dS·m⁻¹, S concentration decreased by 7 to 32 mg·L⁻¹ from the beginning to end of the experiment. The change in
concentration of other nutrients analyzed was unaffected by DLI or EC. The N, P, Mg, Ca, S, Zn, and Mn concentrations decreased whereas K concentrations increased by 8 to 118 mg·L⁻¹ and by 35 to 141 mg·L⁻¹ under high and low DLI treatments, respectively.

Sweet basil. Plant growth of sweet basil was influenced by DLI, but not nutrient solution EC (Table 3). For example, fresh and dry weight, height, node number, branch number, and SPAD increased as DLI increased (Table 4). Sweet basil tissue N, K, Ca, Zn, Mn, Cu, Fe, and B concentrations decreased as DLI increased, whereas P, Mg, and S concentrations were unaffected by DLI (Table 5).

Nutrient solution EC affected tissue N, P, K, Mg, Ca, S, Cu, and B concentrations, but not Zn, Mn, or Fe concentrations (Table 3). Sweet basil tissue N concentration increased by 0.7% as EC increased from 0.5 to 4.0 dS·m⁻¹ (Fig. 1). Tissue K concentration decreased by 1.3% whereas B concentration increased by 10 mg·kg⁻¹ (Fig. 2). Tissue Mg and Ca concentrations decreased by 0.2% and 0.3%, respectively (Fig. 1), as EC increased from 0.5 to 4.0 dS·m⁻¹.

Lemon basil. Lemon basil growth was unaffected by EC, but was affected by DLI (Table 3). Fresh weight increased by 12.7 g (205%) whereas dry weight increased by

Fig. 1. (A–L) Tissue nitrogen (N), phosphorus (P), magnesium (Mg), and calcium (Ca) concentrations of sweet basil (Ocimum basilicum 'Nufar'), lemon basil (O. scutellarioides 'Lime'), and holy basil (O. tenuiflorum 'Holy') 3 weeks after transplanting into nutrient-film technique hydroponic systems containing nutrient solutions with 0.5, 1.0, 2.0, 3.0, or 4.0 dS·m⁻¹ electrical conductivities (ECs). Data were pooled across daily light integrals with EC. Each symbol represents the mean of six replications with 10 plants per replicate, and error bars represent the SEs of the mean of the six replicates. ** or *** indicate significance at P ≤ 0.01 or 0.001, respectively.
1.4 g (280%) with increasing DLI (Table 4). Plants grown under a high DLI were 2.2 cm taller, with 4.0 more branches, 0.8 more nodes, and a 10.1 greater SPAD index. Increasing DLI decreased K, Mn, Cu, and B lemon basil tissue concentrations by 0.5%, 27 mg·kg⁻¹, 3 mg·kg⁻¹, and 5 mg·kg⁻¹, respectively, but did not affect other tissue nutrient concentrations (Table 5). Tissue N, P, Mg, Ca, S, Zn, Cu, and B concentrations were affected by nutrient solution EC, but K, Mn, and Fe were not (Table 3). For example, as EC increased from 0.5 to 2.0 or 3.0 dS·m⁻¹, tissue N, P, S, and Cu concentrations increased (Figs. 1 and 3). Lemon basil Zn and B concentrations increased as EC increased from 0.5 and 1.0 to 4.0 dS·m⁻¹, whereas tissue Mn and Cu concentrations decreased as EC increased from 0.5 to 4.0 dS·m⁻¹ (Fig. 3). 

**Holy basil.** Nutrient solution EC did not influence holy basil growth, but DLI did (Table 3). Holy basil grown under high DLI had 13.3 g more fresh weight, 1.3 g more dry weight, and were 3.7 cm taller (Table 4) compared with plants grown under the low DLI. Branch and node numbers increased by 4.8 and 0.6, respectively, as DLI increased, whereas SPAD index increased by 7.1. As DLI increased, tissue P, K, Mn, Cu, and B concentrations in holy basil decreased, whereas tissue N and S concentrations increased (Table 5). SPAD increased by 4.5 (Fig. 4) with increasing EC (0.5–4.0 dS·m⁻¹). As EC increased from 0.5 to 3.0 dS·m⁻¹, holy basil tissue N and P increased (Fig. 1), and Zn concentrations increased as EC further increased up to 4.0 dS·m⁻¹ (Fig. 4), whereas Mg and Ca concentrations decreased by 0.5% and 0.6%, respectively (Fig. 1). Tissue concentrations of other nutrients were unaffected by EC.

**Discussion**

Nutrient solution EC had no effect on growth and development of all three basil species, although DLI did. In contrast to our findings, Suh and Park (1997) conducted an experiment to determine the optimal hydroponic nutrient solution EC for sweet, opal, and bush basil and found fresh weight was affected by EC. In their results, sweet basil fresh weight increased from 148 to 329 g as the EC decreased from three times the base solution to one-half times the base solution. Their results may differ as a result of a longer production time (8.5 weeks) compared with that of a commercial producer (3–4 weeks). This lack of EC effect on mass also contrasts with previous field and container research that found an increase in shoot mass with...
increased N fertilization (Biesiada and Kuś, 2010; Golcz et al., 2006; Nurzynska-Wierdak et al., 2012; Sifola and Barbieri, 2006). This may be attributed to constant nutrient availability in recirculating hydroponic production in which the EC of nutrient solutions is maintained constantly compared with field and container production, which receive intermittent fertilizer and water applications and have varying substrate and soil moisture levels. We found no change in height or branching in response to nutrient solution EC; however, increasing N fertilization has been reported to have mixed effects on height and branching in basil. For example, Nurzynska-Wierdak et al. (2012) reported that the height of sweet basil ‘Wala’ decreased by 6 cm and branching increased by 0.5 branch as N increased from 0.2 to 0.9 kg·m⁻³ of substrate. However, similar to our findings, Sifola and Barbieri (2006) described increasing N had no effect on height for field-grown sweet basil.

The effect of DLI on fresh and dry weight for the three basil species is consistent with previous research on sweet basil (Beaman et al., 2009; Chang et al., 2008). Dry weight of basil grown by Chang et al. (2008) increased as DLI increased from 5.3 to 24.9 mol·m⁻²·s⁻¹ whereas Beaman et al. (2009) reported edible biomass of ‘Genovese’, ‘Italian Large Leaf’, and ‘Nufar’ sweet basil was greatest under a PPF of 500 mol·m⁻²·s⁻¹ (28.8 mol·m⁻²·d⁻¹). Consistent with Chang et al. (2008), who reported increasing DLI by 19.6 mol·m⁻²·d⁻¹ increased branching by 2.5 branches per plant, increasing basil increased with DLI in our study. Increasing DLI resulted in a greater SPAD index for sweet, holy, and lemon basil, and our results on increasing DLI agree with those of Fukuda et al. (2012) in which the use of SPAD-502 chlorophyll meter for field-grown basil was evaluated for different growth conditions. We postulate that decreasing Mg concentrations in lemon basil were unaffected (data not shown), further supporting that tissue N was within sufficient ranges. Although P concentrations of basil were between 1.1% and 2.0% and exceeded the recommended range (0.6%–1.0%), no apparent toxicity symptoms were visible. The upper range for tissue K is 2.0%, but our tissue samples had K concentrations ranging from 4.2% to 7.6% across DLIs, ECs, and species. We believe the increased K concentration in the nutrient solution (Table 2) from additions of potassium carbonate to increase pH contributed to the luxury consumption of K. The Mg in holy basil was within or above the recommended range of 0.6% to 1.0%. Although lemon and sweet basil were at or below these values, they appeared healthy and we noted no visual symptoms of Mg deficiency. Although Ca concentrations declined with increasing EC, nearly all Ca concentrations across species and ECs were within the recommended ranges. We postulate that decreasing Mg and Ca concentrations in basil may be a result of the antagonistic relationship between K, Mg, and Ca (Dibb and Thompson, 1985; Johansen et al., 1968). Fageria (1983) reported that Mg and Ca uptake is diminished with increasing K fertilization, which agrees with the results of our study. Although nearly all S and B tissue concentrations were within the recommended ranges, our Cu concentrations were above recommended values. Zinc concentrations in lemon basil were within recommended concentrations, but holy and sweet basil Zn concentrations were above recommended values. Zinc concentrations for hydroponically grown basil species or cultivars, Bryson et al. (2014) recommended sweet basil tissue nutrient concentrations and, although these came from established plants grown outdoors in soil, we believe these recommendations are still valuable for interpreting the results of our study with the three basil species. Sweet basil tissue N concentrations were within the recommended concentration range of 4% to 6%, whereas holy and lemon basil N concentrations slightly exceeded the upper limit under a higher DLI (holy basil) or as DLI was ≥2.0 dS·m⁻¹ (holy and lemon basil).

Increasing DLI for all basil species. Nutrient concentrations for hydroponically grown basil species or cultivars, Bryson et al. (2014) published recommended sweet basil tissue nutrient concentrations and, although these came from established plants grown outdoors in soil, we believe these recommendations are still valuable for interpreting the results of our study with the three basil species. Sweet basil tissue N concentrations were within the recommended concentration range of 4% to 6%, whereas holy and lemon basil N concentrations slightly exceeded the upper limit under a higher DLI (holy basil) or as DLI was ≥2.0 dS·m⁻¹ (holy and lemon basil). Relative chlorophyll concentration measured by the SPAD meter correlates with N concentration (Bullock and Anderson, 1998; Choi et al., 2011; Gianquinto et al., 2001). Although the SPAD index of holy basil leaves increased with increasing EC, sweet and lemon basil were unaffected (data not shown), further supporting that tissue N was within sufficient ranges. Although P concentrations of basil were between 1.1% and 2.0% and exceeded the recommended range (0.6%–1.0%), no apparent toxicity symptoms were visible. The upper range for tissue K is 2.0%, but our tissue samples had K concentrations ranging from 4.2% to 7.6% across DLIs, ECs, and species. We believe the increased K concentration in the nutrient solution (Table 2) from additions of potassium carbonate to increase pH contributed to the luxury consumption of K. The Mg in holy basil was within or above the recommended range of 0.6% to 1.0%. Although lemon and sweet basil were at or below these values, they appeared healthy and we noted no visual symptoms of Mg deficiency. Although Ca concentrations declined with increasing EC, nearly all Ca concentrations across species and ECs were within the recommended ranges. We postulate that decreasing Mg and Ca concentrations in basil may be a result of the antagonistic relationship between K, Mg, and Ca (Dibb and Thompson, 1985; Johansen et al., 1968). Fageria (1983) reported that Mg and Ca uptake is diminished with increasing K fertilization, which agrees with the results of our study. Although nearly all S and B tissue concentrations were within the recommended ranges, our Cu concentrations were above recommended values. Zinc concentrations in lemon basil were within recommended concentrations, but holy and sweet basil Zn concentrations were above recommendations.

Conclusions

We found no interactions between the nutrient solution EC and DLI on basil growth, morphology, or tissue nutrient concentrations. Basil growth was unaffected and tissue concentrations were generally at or above recommended sufficient ranges in response to EC, whereas growth was enhanced with increased DLI for all basil species. Nutrient content for basil for plants grown under high DLI was greater than plants grown under a low DLI (data not shown). However, because the ECs for each solution were maintained at target values consistently throughout the experiment, as is commonly practiced commercially, all nutrient solutions resulted in suitable tissue nutrient concentrations for all basil species under both low and high DLIs. As a result, nutrient solution EC does not need to be adjusted for hydroponic basil production based on DLI alone. Producers are urged to conduct onsite trials to determine optimal nutrient solution concentrations for the cultivars and species they are growing in their greenhouse environment under their production practices.

Literature Cited

Beaman, A.R., R.J. Gladon, and J.A. Schrader. 2009. Sweet basil requires an irradiance of 500 mol·m⁻²·s⁻¹ for greatest edible biomass production. HorticScience 44:64–67.

Biesiada, A. and A. Kuś. 2010. The effect of nitrogen fertilization and irrigation on yielding and nutritional status of sweet basil (Ocimum basilicum L.). Acta Sci. Pol. Hortorum Cultus 23:1–12.

Bryson, G.M., H.A. Mills, D.N. Sasseville, J.B. Jones, and A.V. Barker. 2014. Plant analysis handbook III: A guide to sampling, preparation, analysis, and interpretation for agronomic and horticultural crops. Micro-Macro Publishing, Athens, GA.

Bullock, D.G. and D.S. Anderson. 1998. Evaluation of the Minolta SPAD-502 chlorophyll meter for nitrogen management in corn. J. Plant Nutr. 21:741–755.

Chang, X., P.G. Alderson, and C.J. Wright. 2008. Solar irradiance level alters the growth of basil (Ocimum basilicum L.) and its content of volatile oils. Environ. Exp. Bot. 63:216–223.

Choi, S.T., D.S. Park, S.M. Kang, and S.J. Park. 2011. Use of a chlorophyll meter to diagnose nitrogen status of ‘Fuyu’ persimmon leaves. HorticScience 46:821–824.

Currey, C.J., D.A. Kopsell, N.S. Mattson, J.K. Craver, R.G. Lopez, J.E. Erwin, and C. Kubota. 2017. Supplemental and sole-source lighting of leafy greens, herbs, and microgreens, p. 170–180. In: R.G. Lopez and E.S. Runkle (eds.). Light management in controlled environments. Meister Media Worldwide, Willoughby, OH.

De Pascale, S., A. Maggio, F. Orsini, and G. Barbieri. 2006. Nutrients influence on ready to eat sweet basil quality. Acta Hort. 718:523–530.

Dibb, D.W. and W.R. Thompson. 1985. Interaction of potassium with other nutrients, p. 515–533. In: R.D. Munson (ed.). Potassium in agriculture. American Society of Agronomy, Madison, WI.

Fageria, N.K. 1983. Ionic interactions in rice plants from dilute solutions. Plant Soil 70:309–316.

Faust, J.E. 2011. Light, p. 83–94. In: J. Nau (ed.). Ball redbook vol. 2. Crop production. 18th ed. Ball Publishing, West Chicago, IL.

Fisher, P., A.J. Both, and B. Bugbee. 2017. Supplemental lighting technology, costs, and efficiency, p. 74–81. In: R.G. Lopez and E.S. Runkle (eds.). Light management in controlled environments. Meister Media Worldwide, Willoughby, OH.

Fukuda, N., S. Nishimura, and Y. Fumiki. 2002. Micro-tip micropropagation of sweet basil (Ocimum basilicum L.). Acta Hort. 633:237–244.

Gianquinto, G., P. Sambo, and S. Bona. 2001. The use of SPAD-502 chlorophyll meter for
dynamically optimizing the nitrogen supply in potato crop: A methodological approach. Acta Hort. 607:197–204.

Gołcz, A., B. Politycka, and K. Seidler-Lozykowska. 2006. The effect of nitrogen fertilization and stage of plant development on the mass and quality of sweet basil leaves (Ocimum basilicum L.). Herba Pol. 52:22–30.

Hochmuth, R.H. and D. Cantliffe. 2012. Alternative greenhouse crops: Florida greenhouse vegetable production handbook, vol 3. Univ. Florida, Inst. Food Agr. Sci Ext. HS791.

Jensen, M.H. 2002. Deep flow hydroponics: Past, present and future. Proc. Natl. Agr. Plastics Congr. 30:40–46.

Johansen, C., D.G. Edwards, and J.F. Loneragan. 1968. Interactions between potassium and calcium in their absorption by intact barley plants: I. Effects of potassium on calcium absorption. Plant Physiol. 43:1717–1721.

Korczynski, P.C., J. Logan, and J.E. Faust. 2002. Mapping monthly distribution of daily light integrals across the contiguous United States. HortTechnology 12:12–16.

Litvin, A.G. and C.J. Currey. 2017. Daily light integral affects growth, development, and chlorophyll fluorescence of eight culinary herbs grown hydroponically. HortScience 59:S243 (abstr.).

Morgan, L. 2005. Fresh culinary herb production: A technical guide to the hydroponic and organic production of commercial fresh gourmet herb crops. Suntec NZ, Tokomaru, New Zealand.

Nurzynska-Wierdak, R., E. Rożek, E. Dzida, and B. Borowski. 2012. Growth response to nitrogen and potassium fertilization of common basil (Ocimum basilicum L.) plants. Acta Sci. Pol. Hortorum Cultus 11:275–288.

Resh, H.M. 2013. Hydroponic food production: A definitive eguidebook for the advanced home gardener and the commercial hydroponic grower. 7th ed. CRC Press, Boca Raton, FL.

Sifola, M.I. and G. Barbieri. 2006. Growth, yield and essential oil content of three cultivars of basil grown under different levels of nitrogen in the field. Scientia Hort. 108:408–413.

Simon, J.E., M.R. Morales, W.B. Phippen, R.F. Vieira, and Z. Hao. 1999. Basil: A source of aroma compounds and a popular culinary and ornamental herb, p. 449–505. In: J. Janick (ed.). Perspectives on new crops and new uses. ASHS Press, Arlington, VA.

Succop, C.E. 1998. Hydroponic greenhouse production of fresh market basil. Colo. State Univ., Fort Collins, MS thesis.

Suh, E. and K. Park. 1997. Effect of different concentrations of nutrient solutions on the growth, yield, and quality of basil. Acta Hort. 483:193–198.

Walters, K.J. and C.J. Currey. 2015. Hydroponic basil production: Comparing systems and cultivars. HortTechnology 25:645–650.

Wolf, M.M., A. Spittler, and J. Ahern. 2005. A profile of farmers’ market consumers and the perceived advantages of produce sold at farmers’ markets. J. Food Distrib. Res. 36:192–201.