Organic Fertilization Programs for Greenhouse Fresh-cut Basil and Spearmint in a Soilless Media Trough System

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ADDITIONAL INDEX WORDS. culinary herbs, protected culture, postharvest, hydroponics

SUMMARY. Greenhouse experiments were conducted in 2005 and 2006 near Live Oak, FL, to develop fertilization programs for fresh-cut ‘Nufar’ basil (*Ocimum basilicum*) and spearmint (*Mentha spicata*) in troughs with soilless media using inputs compliant with the U.S. Department of Agriculture’s National Organic Program (NOP). Four NOP-compliant fertilizer treatments were evaluated in comparison with a conventional control. Treatments and their analyses in nitrogen (N), phosphorus (P), and potassium (K) contents are as follows: conventional hydroponic nutrient solution [HNS (150 ppm N, 50 ppm P, and 200 ppm K)], granular poultry (GP) litter (4N–0.9P–2.5K), granular composite [GC (4N–0.9P–3.3K)], granular meal [GM (8N–2.2P–4.1K)], and GM plus a sidedress application of 5N–0.9P–1.7K fish emulsion (GM + FE). Electrical conductivity (EC) of the media, fresh petiole sap nitrate (NO₃-N) and K concentrations, dried whole leaf NO₃-N, P, and K concentrations, and yield and postharvest quality of harvested herbs were evaluated in response to the treatments. Basil yield was similar with HNS (340 g/plant) and GP (325 g/plant) in 2005 and greatest with HNS (417 g/plant) in 2006. Spearmint yield was similar with all treatments in 2005. In 2006, spearmint yields were similar with the HNS and GP yields (172 and 189 g/plant, respectively) and greater than the yields with the remaining treatments. In both years and crops, media EC values were generally greater with the GC than with the GP, GM, and GM + FE treatments but not in all cases and ranged from 1.77 to 0.55 dS·m⁻¹ during the experiments. Furthermore, HNS media EC values were consistently equal to or lower than the GP media EC values except with EC measurements on 106 days after transplanting in both crops in 2005. Petiole NO₃-N and K results were variable among crops and years, but provided valuable insight into the EC and yield data. We expected EC, petiole NO₃-N, and petiole K to be consistently higher with HNS than with organic treatments, but they were not, indicating a reasonable synchrony of nutrient availability and crop demand among the organic treatments. The postharvest quality of both basil and spearmint was excellent with all treatments with few exceptions.

The organic fruits and vegetables category, including culinary herbs, has consistently remained the largest single sector of the domestic organic food market since the federal organic standards were implemented in 2002 [37% in 2008 [Organic Trade Association (OTA), 2009]]. Sales of organic food reached \$22.9 billion in the United States in 2008, and sales of organic food now comprise 3.5% of the total U.S. agricultural market share (OTA, 2009). Fresh-cut organic culinary herbs can be sold in bundles at direct markets, as bulk ingredients to processors for ready-to-eat products, and in clamshells to mass-market retailers and distributors. Market data on fresh-cut culinary herbs are available at the

U.S. Department of Agriculture’s (USDA) Agricultural Marketing Service Fruit and Vegetable Market News Report (USDA, 2009). Yields and acreage of fresh culinary herbs are no longer

a category in the USDA’s census data, although some state departments of agriculture, including Hawaii and California, continue to collect herb production data.

Producers are exploring soilless greenhouse herb production systems as a means to produce high-quality crops in an efficient manner. Benefits of protected agriculture include increased protection from crop pests, enhanced control of temperature, and more efficient irrigation management. The capital expenses of establishing and maintaining greenhouses necessitate high-quality, high-volume products to justify the investment. Adoption of organic greenhouse systems has been slow because of the lack of clear regulatory language on greenhouse production from the USDA’s NOP Final Rule (USDA, 2010), the lack of readily available technical information, and the limited number of producers experienced in this area.

In subtropical Florida and the Caribbean region, greenhouse systems can provide improved water and nutrient use efficiency. In organic systems, fertilizer is generally the most expensive input, and N management is often cited as one of the more challenging aspects of this type of crop production (Gaskell and Smith, 2007). Because most synthetic fertilizers are prohibited under the NOP, plant nutrients are supplied by plant- and animal-based (organic) fertilizers and mined minerals. Nutrients from organic fertilizers must be transformed by microorganisms through mineralization and nitrification processes before plant utilization. The rate of these biological processes is highly variable and depends on a number of environmental conditions including substrate temperature and moisture. This variability can result in nutrient release patterns

Unit			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
1.1209	lb/acre	kg·ha ⁻¹	0.8922
1	mmho/cm	dS·m ⁻¹	1
28.3495	oz	g	0.0353
1	ppm	mg·L ⁻¹	1
10.7639	W/ft ²	W·m ⁻²	0.0929
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

that are inconsistent with crop nutrient demand, especially for N, but the controlled environmental conditions of protected structures may provide more even conditions for nutrient release. The season for fresh-cut greenhouse herbs in Florida lasts for several months; therefore, maintaining sufficient N availability throughout the season can be a challenge (Treadwell et al., 2007).

Few research reports have been published on greenhouse production of culinary basil (Chang et al., 2005; Copetta et al., 2006; Kopsell et al., 2005; Succop and Newman, 2004). No articles could be found on greenhouse production of spearmint. Of the published reports on basil, only Succop and Newman (2004) reported using fertilizer sources approved for use in certified organic systems for greenhouse herb production. In addition, only Succop and Newman (2004) provided fertility recommendations for greenhouse-grown basil. However, in that trial, only one organic fertilizer, a proprietary blend of poultry compost, FE, kelp extracts, and soft rock phosphate, was used. Tissue nutrient concentration thresholds for the developmental stages of basil and spearmint and recommendations for fertilizer source, rates, timing, and methods of application are currently not available in peer-reviewed literature for greenhouse production of culinary basil and spearmint. The objective of this research was to evaluate four nutrient management programs

composed of fertilizers that are approved for use in organic systems compared with a conventional HNS and identify the organic nutrient program that resulted in the highest crop quality and yields.

Materials and methods

EXPERIMENTAL DESIGN. Separate experiments for basil and spearmint were conducted between Dec. 2004 through Apr. 2005 (110 d) and Oct. 2005 through Feb. 2006 (130 d) in a double-layer polyethylene-covered greenhouse with fan and pad ventilation at the University of Florida's (UF) North Florida Research and Education Center—Suwannee Valley near Live Oak. According to the Florida Automated Weather Network, average daily solar radiation measured at 2 m above the soil over a 1-m² area in Live Oak was 143.45 W·m⁻² per steradian in 2005 and 124.86 W·m⁻² per steradian in 2006 (UF, 2010). The period of production is consistent with grower practice in our area. Greenhouse and field productions occur primarily from mid-September through mid-June in Florida. High value specialty crops are often maintained over winter months to meet buyer demand, but greenhouse producers typically avoid summer months due to the high cost of cooling during summer months. Methods for both experiments were similar with minor exceptions and are described as follows.

Open troughs were constructed with semirigid plastic (Crop King, Seville, OH) that measured 48 inches long, 20 inches wide, and 8 inches deep (Hochmuth et al., 2007). The troughs were tilted slightly end-to-end to allow leachate to drain. The troughs were filled to a depth of 6 inches with a commercially available soilless media approved for organic systems (Fafard no. 30; Conrad Fafard, Anderson, SC). The media was composed of 45% peatmoss, 25% pine bark, 15% perlite, and 15% dolomitic limestone. Media was not sterilized to ensure viability of bacteria responsible for N mineralization from organic-compliant fertilizers. Each trough comprised one experimental unit and contained ≈95 L of media and seven plants.

Four NOP-compliant fertilizer treatments were evaluated and compared with a conventional HNS typically used by greenhouse growers in

our area (Hochmuth, 2008). Compliant fertilizers were selected because they were affordable, commercially available, and certified by the Organic Materials Review Institute (Eugene, OR) (Table 1). Compliant fertilizers were in granular form, except for the liquid FE.

The five treatments and their N, P, and K analyses were as follows: 1) GP litter (4N–0.9P–2.5K; Perdue AgriRecycle, Seaford, DE), 2) GC (4N–0.9P–3.3K; Fertrell Co., Bainbridge, PA), 3) GM (8N–2.2P–4.1K, Nature Safe; Griffin Industries, Coldspring, KY), 4) GM + a sidedress application of hydrolyzed 5N–0.9P–1.7K FE (Agro-K Corp., Minneapolis, MN) (Table 1), and 5) HNS (150 ppm N, 50 ppm P, and 200 ppm K). Sources of fertility for the HNS treatment were as follows: calcium nitrate, potassium nitrate, ammonium nitrate, phosphoric acid, potassium chloride, and magnesium nitrate (Hochmuth, 2008). The HNS was supplied to treatments via fertigation with a dedicated drip tape as described later. The treatments were arranged in a randomized complete-block design, replicated six times, and repeated for 2 years.

CROP MANAGEMENT. Fertilization practices were based on available production recommendations for basil (Davis, 1997). The application rates of organic fertilizer materials (both preplant and sidedress) were calculated based on N analysis, and each organic treatment received the same amount of N at each application (Table 1). In both Davis's (1997) and this experiments, plants received ≈1 g/plant of N during the season. Granular fertilizers in the four organic fertilizer treatments were thoroughly incorporated in the media before transplanting, and a second application of fertilizer was incorporated at 58 d after transplanting (DAT) (Table 1). At sidedress, granular fertilizer was banded and incorporated to a depth of 2 inches under the drip tape. Three organic treatments (GP, GC, and GM) received the same material at preplant and at sidedress. To compare the growth response of crops when provided different sources of sidedress fertilizers, the GM fertilizer treatment was repeated so that one GM treatment received the same material at sidedress (GM), and the second GM material received hydrolyzed FE in a liquid formulation (GM + FE)

This research was supported by a grant from the USDA Cooperative State Research Education and Extension Service-Tropical and Subtropical Agricultural Research (TSTAR), Grant Nos. 00005923 and 00063651.

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Table 1. Summary of organic-compliant fertilizer treatments used to produce greenhouse fresh-cut basil or spearmint in troughs with soilless media in 2005–2006 at the University of Florida's North Florida Research and Education Center near Live Oak.

Treatment ^a	Component ingredients	Preplant + sidedress fertilizer (lb/acre) ^y	Potentially available nutrient (lb/acre) ^z		
			N	P	K
Granular poultry litter 4N–0.9P–2.5K	Poultry litter	1720 + 430 = 2150 ^x	86.0	18.8	54.0
Granular composite 4N–0.9P–3.3K	Aragonite (a carbonate mineral), bone char, composted poultry manure, sodium nitrate, feather meal, greensand, peanut meal, sulfur, and sulfate of potash	1720 + 430 = 2150	86.0	18.8	71.4
Granular meal (GM) 8N–2.2P–4.1K	Feather, meat, bone and blood meals, sulfate of potash, yeast, sugars, carbohydrates, and humus	860 + 215 = 1075	86.0	23.6	44.9
GM + fish emulsion (FE) 8N–2.2P–4.1K + 5N–0.9P–1.7K	GM (above) + hydrolyzed FE and seaweed (<i>Ascophyllum nodosum</i>)	860 + 316 = 1176	85.0	21.4	40.7

^aN, nitrogen; P, phosphorus; K, potassium; organic-compliant treatments were compared with a conventional hydroponic nutrient solution.

^y1 lb/acre = 1.1209 kg·ha⁻¹.

^zEach trough contained 95 L (25.1 gal) of media and measured 1.53×10^{-4} acre (6.192×10^{-5} ha).

applied directly to the media. The HNS treatment received fertilizer once daily throughout the experiment.

Micronutrient content in poultry litter (Edwards and Daniel, 1992; Kunkle et al., 1981; Tewolde et al., 2005) has been reported to be sufficient to support crop production at typical application rates. Feather meal and blood meal micronutrient contents can be higher than necessary for plant growth, but the phytoavailability of these meals is not known (Tewolde et al., 2005). Because poultry litter, feather meal, and blood meal were dominant ingredients in the fertilizers, additional micronutrients were not added with the organic treatments. The HNS treatment was based on conventional nutrient solution formulation for hydroponic tomato (*Solanum lycopersicum*) at the third to fifth cluster stage (Hochmuth and Hochmuth, 2008). Micronutrients in the HNS were supplied as follows: iron [Fe (2.8 ppm)], copper [Cu (0.2 ppm)], manganese [Mn (0.8 ppm)], zinc [Zn (0.3 ppm)], boron [B (0.7 ppm)], and molybdenum [Mo (0.05 ppm)]. Micronutrient contents in plant tissue from all treatments analyzed at harvest were consistent with those in other greenhouse crops (Raviv and Lieth, 2008), and, therefore, was assumed to be sufficient for basil and spearmint.

In accordance with the NOP, organically grown transplants of 'Nufar' basil and a strain of spearmint, used by local organic growers, were

used for this experiment. Seven transplants were established in each trough on 23 Dec. 2004 and 10 Oct. 2006. All plots were thoroughly irrigated by hand following transplanting to ensure that the media was uniformly wet. Each trough had drip irrigation tape (4-inch emitter spacing, John Deere Ro-Drip; John Deere Water Technologies, San Marcos, CA) that delivered water only to the organic treatments or nutrients in solution to the HNS treatment. Troughs containing organic treatments were irrigated three times daily for 5 min per irrigation event. Additional irrigation water was delivered to the HNS treatment using the line dedicated to irrigation water only as needed to compensate for moisture loss due to evapotranspiration and to maintain consistent moisture with organic treatments.

NUTRIENT MONITORING. Potentially available fertilizer was assessed by measuring the EC of the media to a depth of 3 inches with a hand-held EC probe (Spectrum Technologies, Plainfield, IL) on four dates each year. Plant petiole fresh sap was collected from 12 most recently mature petioles when 90% of the plants reached a height of 12 ± 1 inches and again at final harvest. Sap was analyzed for NO₃-N and K concentrations (Coltman, 1988; Hochmuth et al., 2007) using a hand-held ion specific electrode (Cardy Ion Meters, Spectrum Technologies), according to methods described by Hochmuth et al. (2007).

In 2006, two additional parameters were measured for basil. Basil-growing media was analyzed for water-soluble NO₃-N via colorimetric analysis; P, K, calcium (Ca), and magnesium (Mg) via inductively coupled plasma emission spectrometer; and pH (1:2 v/v) 87 DAT (2 weeks after sidedressing). To assess the influence of fertilizer source on plant nutrient status at season's end, basil leaf nutrient content was assessed at final harvest (109 DAT) by collecting 30 most recently mature leaves and drying them to a constant weight in an oven at 60 °C. Tissue and media samples were analyzed for nutrient content according to the UF Analytical Laboratory procedures (Mylavarapu and Moon, 2002).

CROP HARVEST. Basil and spearmint were harvested from Jan. to Apr. 2005 (16 weeks) and from Nov. 2005 to Feb. 2006 (18 weeks). Crops were harvested about every 14 d by cutting shoot tips 6–8 inches in length and weighed immediately after harvest. On average, fresh-cut tissue comprised 30% of the plant's total biomass. In 2005, basil was harvested eight times and spearmint was harvested four times (final harvest was 110 DAT for basil and 98 DAT for spearmint). In 2006, basil was harvested eight times and spearmint was harvested six times (128 DAT for basil and 129 DAT for spearmint). Basil and spearmint plants remained vigorous following the final data collection for these experiments both

years. In the absence of official USDA market grades for herbs, spearmint and basil were graded using market standards of a local commercial grower selling herbs in clamshells. Herbs were considered marketable if the stems and leaves were turgid, uniform in color and vigor, and free from physical defects.

POSTHARVEST QUALITY. To determine the effect of fertilizer treatments on postharvest quality of basil and spearmint, experiments were conducted on both crops 120 DAT in 2005 and 42 and 60 DAT in 2006 on spearmint and basil, respectively. For each experiment, three replicate subsamples from all five treatments were harvested in Live Oak, FL, placed in storage bags in a cooler, and transported immediately to the Postharvest Horticulture Laboratory in Gainesville, FL. Herb stems were trimmed as necessary and packed in vented polystyrene consumer packages (± 50 g) and stored flat under simulated commercial conditions for 7 and 14 d (basil at 12.5 °C and spearmint at 5 °C). Each clamshell package was randomly assigned by treatment (initial quality assessments or following 7 or 14 d storage). Samples were placed on tared, aluminum trays, weighed, covered with aluminum foil, dried at 50 °C until constant weight, and reweighed. Moisture content (fresh weight basis) was calculated as follows: moisture content (%) = [(fresh weight – dry weight) $\times$ 100] $\div$ fresh weight.

Leaf upper surface color was determined by reflectance using a chromameter (Konica Minolta, Ramsey, NJ) and recorded as lightness (L^*) or measure of light to dark, chroma value (C^*) or the color intensity, and hue angle (H^*) or the actual color. Two leaves were measured per sample with one measurement per leaf initially and after 7 and 14 d storage. Individual clamshells were subjectively rated (initially and after 7 and 14 d storage) for the following selected parameters: decay (1 = no decay and 2 = decay), blackening (1 = blackened areas present and 2 = no blackened areas present), and firmness (1 = turgid, very firm to the touch, 2 = firm, 3 = somewhat firm, 4 = barely firm, and 5 = flaccid).

DATA ANALYSIS. All data, by crop, were analyzed using SAS (version 8.2; SAS Institute, Cary, NC) analysis of variance general linear model. Basil and spearmint responses varied by

fertilizer sources and year. Therefore, data were analyzed and are presented by crop and year. When significant differences among treatments were detected at $P \leq 0.05$, means were distinguished with Fisher's least significant difference.

Results

YIELD. In 2005, total fresh-cut basil yields with the GP treatment were similar to the yields with HNS, and were at least 30% higher than remaining organic treatments (Table 2). In 2006, basil yields from the HNS treatment were 23% higher than GP, and greater than the remaining organic treatments. Organic basil yields in this trial ranged from 133 to 417 g/plant and were generally lower than basil yields reported by Succop and Newman (2004) (399 to 557 g/plant). Spearmint yields were similar among all treatments in 2005, but in 2006, yields with the GP system were similar to HNS and were at least 31% greater than remaining organic fertilizer systems (Table 2).

ELECTRICAL CONDUCTIVITY. In 2005 and 2006, basil media EC was highest in the GC treatments on five of nine occasions, similar to the HNS on two occasions, and highest in the HNS on one occasion (Table 3). In 2005 and 2006, spearmint media EC was highest in the GC treatments on six occasions, highest in the HNS on one occasion and similar to the GM + FE on one occasion when differences occurred. In both crops in 2006, media EC in the GC treatment was frequently two or more times higher than the media EC in HNS, indicating that nutrients from organic fertilizers

became soluble during the first 9 weeks (64 DAT) of production. In 2005, this trend was evident during the first 5 weeks of production, after which EC values tended to be highest in the HNS and/or GC treatments with three exceptions (Table 3).

TISSUE NUTRIENTS. Basil petiole $\text{NO}_3\text{-N}$ concentrations ranged from 1000 to 2000 ppm both years (Table 4). Basil petiole $\text{NO}_3\text{-N}$ with the HNS treatment was lower than or similar to that with the organic treatments on all occasions. Spearmint petiole $\text{NO}_3\text{-N}$ concentrations were frequently greater than 2000 ppm, although significant differences were evident only at harvest in 2006 (Table 4). Petiole K concentration was more variable among the treatments than petiole $\text{NO}_3\text{-N}$ and ranged from 565 ppm to 4133 ppm over both crops and years. Basil fertilized with the GP fertilizer had the highest K petiole sap concentration in 2005, and it was similar to the GC and HNS treatments in 2006. Spearmint petiole K concentration was similar among GP, GM + FE, and HNS at 43 DAT in 2005 and was 43% higher in GP than in the remaining organic treatments at 129 DAT in 2006.

Macronutrient concentrations (N, P, K, Ca, and Mg) from whole basil leaves at final harvest were similar among the treatments (Table 5). We expected lower concentrations from the lower-yielding organic treatments compared with the GP and HNS, but similar responses at the end of the season imply that all fertilizer programs were providing sufficient nutrition at that time. The response was

Table 2. Fresh-cut basil and spearmint yield reported as marketable fresh weight in 2005 and 2006.

Treatment ^a	Marketable fresh wt (g/plant) ^b			
	Basil		Spearmint	
	2005	2006	2005	2006
GP	325 a ^x	339 b	218	172 a
GC	237 b	221 c	233	122 b
GM	250 b	165 cd	264	118 b
GM + FE	222 b	133 d	238	105 b
HNS	340 a	417 a	270	189 a
Significance	***	***	NS	***

^aGP, granular poultry (4N–0.9P–2.5K); GC, granular composite (4N–0.9P–3.3K); GM, granular meal (8N–2.2P–4.1K); GM + FE, GM (8N–2.2P–4.1K) plus hydrolyzed fish emulsion (5N–0.9P–1.7K); and HNS, hydroponic nutrient solution.

^bBasil yield includes eight harvests each in 2005 [110 d after transplanting (DAT)] and in 2006 (128 DAT). Spearmint yield includes four harvests in 2005 (98 DAT) and six harvests in 2006 (129 DAT); 1 g = 0.0353 oz.

^xValues within a column followed by different letters are significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

NS, ***Nonsignificant or significant at $P \leq 0.0001$, respectively.

Table 3. Electrical conductivity (EC) in basil and spearmint growing media under five fertilizer treatments media in 2005–2006 at the University of Florida's North Florida Research and Education Center near Live Oak.

Treatments ^y	EC (dS·m ⁻¹) ^z								
	2005					2006			
	Days after transplanting								
	35	43	64	85	106	37	43	85	107
Basil									
GP	0.83 b ^x	0.57 b	0.38 c	0.62 b	0.42 bc	0.53 b	0.40 b	0.80 b	0.27 b
GC	1.52 a	1.23 a	0.95 ab	1.28 a	0.55 b	1.77 a	1.72 a	1.52 a	0.82 a
GM	0.85 b	0.67 b	0.48 c	0.68 b	0.22 c	0.57 b	0.43 b	0.47 b	0.27 b
GM + FE	1.40 a	0.82 b	0.80 b	1.52 a	0.38 bc	0.68 b	0.68 b	0.42 b	0.33 b
HNS	0.68 b	0.72 b	1.02 a	1.22 a	1.15 a	0.68 b	0.83 b	0.43 b	0.20 b
Significance	*	*	*	*	***	**	***	***	***
Spearmint									
GP	0.52 b	0.43 b	0.98 bc	0.82	0.45 b	0.73 b	0.72 bc	0.63 b	0.65 b
GC	1.62 a	1.02 a	1.43 a	1.27	0.60 b	1.25 a	1.27 a	1.48 a	1.05 a
GM	0.55 b	0.40 b	0.55 c	0.78	0.37 b	0.70 b	0.70 bc	0.57 b	0.57 bc
GM + FE	0.70 b	0.38 b	1.18 ab	1.23	0.38 b	0.43 b	0.40 c	0.45 b	0.28 c
HNS	0.37 b	0.32 b	0.73 bc	1.27	1.10 a	0.73 b	0.83 b	0.60 b	0.63 b
Significance	***	**	*	NS	***	*	*	***	**

^z1 dS·m⁻¹ = 1 mmho/cm.^yGP, granular poultry (4N–0.9P–2.5K); GC, granular composite (4N–0.9P–3.3K); GM, granular meal (8N–2.2P–4.1K); GM + FE, GM (8N–2.2P–4.1K) plus hydrolyzed fish emulsion (5N–0.9P–1.7K); and HNS, hydroponic nutrient solution.^xValues within a crop and column followed by different letters are significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.NS, *, **, ***Nonsignificant or significant at $P \leq 0.01$, 0.001, or 0.0001, respectively.**Table 4. Nitrate (NO₃-N) and potassium (K) content in basil and spearmint fresh petiole sap under five different fertilizer treatments in Live Oak, FL, in 2005 and 2006. Samples were collected from the most recently mature leaf petioles.**

Treatment ^x	Petiole NO ₃ -N (ppm) ^z				Petiole K (ppm)			
	2005 DAT ^y		2006 DAT		2005 DAT		2006 DAT	
	50	76	72	91	50	76	72	91
Basil								
GP	1067 bc ^w	1248 b	1103 b	1083 c	3483 a	2933 a	2527 a	2933 a
GC	1433 a	1633 a	1617 ab	1833 a	1500 b	1307 c	1750 ab	1853 ab
GM	1250 ab	1683 a	1817 a	1467 ab	982 b	1333 c	1203 b	887 b
GM + FE	1300 a	1650 a	1950 a	1683 bc	1150 b	1400 c	1490 b	817 b
HNS	1000 c	1617 a	1517 ab	1448 bc	1535 b	2000 b	2367 a	1472 ab
Significance	*	*	*	**	***	***	*	*
Spearmint								
2005 DAT		2006 DAT		2005 DAT		2006 DAT		
	43	70	70	129	43	70	70	129
GP	2183	1683	1650	1700 bc	4133 a	1320	2583	1260 a
GC	3183	1717	2317	2083 b	2967 bc	1030	1700	635 b
GM	2833	1667	1900	1950 ab	2700 c	1358	2745	582 b
GM + FE	2233	1667	2067	1650 c	3667 ab	1057	1537	565 b
HNS	2267	1800	1918	2050 a	3517 abc	1190	2667	718 a
Significance	NS	NS	NS	**	*	NS	NS	**

^z1 ppm = 1 mg·L⁻¹.^yDAT = days after transplanting.^xGP, granular poultry (4N–0.9P–2.5K); GC, granular composite (4N–0.9P–3.3K); GM, granular meal (8N–2.2P–4.1K); GM + FE, GM (8N–2.2P–4.1K) plus hydrolyzed fish emulsion (5N–0.9P–1.7K); and HNS, hydroponic nutrient solution.^wValues within a crop and column followed by different letters are significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.NS, *, **, ***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively.

variable for micronutrients, with some nutrients showing significant differences, whereas other nutrients were similar among treatments. Magnesium, Cu, and Zn were greatest in GP (Table 5) and may have contributed to that treatment's yield, but Fe

(107–126 ppm), sulfur [S (0.28–0.33 ppm)], aluminum [Al (35–47 ppm)], and B (26–29 ppm) were similar among the treatments (data not shown). All micronutrients were considered sufficient for all treatments (Raviv and Lieth, 2008).

POSTHARVEST. There were no differences due to treatment, storage period, or harvest season for moisture content (initial and post-storage) or for the subjective quality ratings. Moisture content ranged from 89% to 92% for basil and 88% to 90% for

Table 5. Basil whole-leaf nutrient concentrations (dry weight basis) in percent and parts per million at final basil harvest in 2006 (109 d after transplanting).

Treatment ^z	Nutrient concn ^y							
	N	P	K	Ca	Mg	Mn	Cu	Zn
	(%)				(ppm)			
GP	4.3	0.6	6.1	1.4	0.5	252.3 a ^x	19.2 a	160.8 a
GC	4.5	0.7	6.0	1.4	0.4	146.0 b	7.3 bc	86.5 b
GM	4.2	0.7	6.3	1.3	0.5	143.7 b	7.5 bc	86.3 b
GM + FE	4.3	0.6	6.0	1.3	0.4	92.8 c	7.0 c	71.7 b
HNS	4.1	0.7	6.1	1.4	0.5	66.5 c	9.8 b	94.2 b
Significance	NS	NS	NS	NS	NS	***	***	***

^zGP, granular poultry (4N-0.9P-2.5K); GC, granular composite (4N-0.9P-3.3K); GM, granular meal (8N-2.2P-4.1K); GM + FE, GM (8N-2.2P-4.1K) plus hydrolyzed fish emulsion (5N-0.9P-1.7K); and HNS, hydroponic nutrient solution.

^yNitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), copper (Cu), and zinc (Zn); 1 ppm = 1 mg·L⁻¹.

^xValues within a column followed by different letters are significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

NS, ***Nonsignificant or significant at $P \leq 0.0001$, respectively.

spearmint. Subjective quality ratings following storage were turgid or very firm to the touch and primarily no decay or blackening for both crops (data not shown). Although leaf color was significantly different among many treatments, particularly for basil, these differences were generally considered minor and of no commercial consequence. L^* values increased during storage and ranged from 43 to 48, indicating the leaf was slightly lighter after 14 d. Values for C^* and H^* were fairly constant for basil, whereas for spearmint H^* in 2006, the values decreased after 14 d, indicating that it was slightly less green. The subjective quality ratings, moisture content, and color retention indicate high marketable quality among all treatments.

Discussion

Plant- and animal-based amendments have been evaluated for use in greenhouse crop production in both conventional (Cheng et al., 2004; Fernandez-Luqueno et al., 2010; Liedl et al., 2004) and organic systems (Rippy et al., 2004; Zaller, 2007; Zhai et al., 2009). A variety of amendments have been tested including commercially available dry granular and liquid formulations and locally available composts and manures applied as solids or in liquid form (Gaskell and Smith, 2007). In these experiments, we evaluated four commercially available organic-compliant fertilizers that provided similar macronutrient contents to determine if fertilizer source influenced basil and spearmint quality and yield. Because the fertilizers

are composed of different ingredients (Table 1), we anticipated and observed differences in yield (Table 2).

In Succop and Newman's trial, a proprietary liquid fertilizer approved for use in organic systems was used similarly for three different planting mediums including rockwool, perlite, and a peat-perlite-compost mixture. Basil yields with perlite media were greater than yields with rockwool in 1996, but no difference in yields among planting media were reported for 1997 (Succop and Newman, 2004). In that trial, the concentration of fertilizer nutrients provided to the conventional treatment was 364, 78, and 308 ppm of N, P, and K, respectively, whereas organic treatments received 369, 78, and 280 ppm of N, P, and K, respectively. The additional yield observed by those authors compared with the yields from our trial may have been due to the higher concentrations of N (over four times higher), P (over three times higher), and K (nearly four or more times higher) they provided to organic treatments over the course of the season (Table 1). Succop and Newman explained that the high concentrations were necessary to achieve target levels of minor elements. Basil tissue nutrient content following the 2006 harvest does not substantiate that the lower yields from this experiment compared with that by Succop and Newman (2004) was due to micronutrient deficiencies (Table 5). In 2006, basil yields with the GP treatment were greater than the yields with HNS (Table 2), even though the micronutrient content was much

greater in the HNS than in the GP (Table 5).

Overall, basil and spearmint yields were lower in 2006 than in 2005, possibly due to a 2-month earlier transplanting date. Despite the similarity of average daily solar radiation between years, the distribution of solar radiation was greater in the second half of season in 2005 than in the second half of 2006. In general, yields in these production regimes were favored by a December to April season (2005) compared with an October to February season (2006).

Differences in fertilizer component ingredients likely influenced yield among the organic treatments. Basil and spearmint produced in the GP treatment yielded greater than in the remaining organic treatments. The GP fertilizer is composed primarily of poultry litter, whereas the GM is composed primarily of hydrolyzed feather and meat, bone, and blood meals. Gaskell and Smith (2007) conducted a mineralization study of several common organic fertilizers at 25 °C and observed that after 8 weeks, N mineralization rates were greatest in blood meal (70%) followed by feather meal (63%) and poultry litter (36%). The poultry litter in the GP may have released nutrients more slowly and in a rate pattern that more closely coincided with crop demand compared with the meals (GM and GM + FE). The GC fertilizer contained both poultry litter and meals, and an intermediate yield response (less than the GP and greater than the GM) was observed in basil in 2006. Mined sodium nitrate, also present in the GC, is a soluble N source allowed in organic systems but can only account for 20% of a crops' total N application rate. Its rapid solubility and relatively high N analysis (16%) in the GC did not translate to additional yields compared with the 100% poultry litter fertilizer (GP), nor did the bone and blood meals in the GM. Organic-compliant fertilizers are diverse in their composition, and their ingredients are inherently variable, changing with animal feed quality, time of year, environment, and processing methods (Gaskell and Smith, 2007). Fertilizer formulations are generally proprietary. Manufacturer's labels do not typically provide the relative mass of all the component ingredients so that it can be a challenge to predict availability

rates of complex formulations. For example, simply knowing a fertilizer contains seven ingredients is not especially helpful to producers unless the weight or volume of those ingredients in that product is also known.

Previously reported media EC values in greenhouse hydroponic vegetables receiving conventional nutrient solution include 1500 $\mu\text{S}\cdot\text{cm}^{-1}$ (1.0–1.5 $\text{dS}\cdot\text{m}^{-1}$) in tomato (Hochmuth, 2008)], 2.5 $\text{dS}\cdot\text{m}^{-1}$ in lettuce [*Lactuca sativa* var. *longifolia* (Tas et al., 2005)], and 1.8 to 2.4 $\text{dS}\cdot\text{m}^{-1}$ in ‘Afrodite’ zucchini [*Cucurbita pepo* (Rouphael and Colla, 2005)]. These authors reported that maintaining the higher EC values during the season resulted in favorable yield responses. Throughout these experiments, EC values never exceeded 1.77 $\text{dS}\cdot\text{m}^{-1}$ and were frequently less than 1.0 $\text{dS}\cdot\text{m}^{-1}$, suggesting that nutrients were used quickly (Table 3). Small increases in fertilizer rates and adjustments to the timing of application of fertilizer might result in more consistent EC levels during the production period. An increase in K content in the GC fertilizer is a partial explanation for the EC increase compared with the remaining organic-compliant fertilizers, and although the additional K may have provided some yield advantage over the GM and the GM + FE in basil in 2006, it was not enough to surpass the yields obtained in the GP.

Petiole $\text{NO}_3\text{-N}$ and K similarities among the HNS and the organic treatments indicated a sufficient level of nutrition (Table 4). The additional K provided by the GC treatment (Table 1) was not reflected in petiole K increases compared with the other treatments, except in basil in 2006 (Table 4). Petiole $\text{NO}_3\text{-N}$ and K concentrations in basil were lower, and the yields were greater in the GP and HNS both years compared with other treatments (Tables 3 and 4) and were likely related to greater biomass production in those treatments compared with the remaining treatments. This trend was not as evident for spearmint (Tables 3 and 4). Petiole nutrients were similar among the treatments during the first 8 weeks of spearmint production, although late season (129 DAT) increases in petiole K from the GP plants may explain the favorable spearmint yield in 2006 (Tables 3 and 4). In both basil and spearmint, petiole K with the GP fertilizer was greater

than with the GC on four occasions and equal to that with the GC on four, despite 24% less K applied. Petiole K with the GP could reflect an increase in K availability facilitated by increased day length early in the 2005 season and late in the 2006 season.

Based on these experiments, basil and spearmint produced using organic fertility regimes in a peat, pine bark, and perlite media in the greenhouse were best achieved with GP litter (4N–0.9P–2.5K) as preplant and sidedress fertilizer applied at a rate of 86 lb/acre N (1.1 g/plant N) when 80% is applied preplant incorporated and 20% applied 58 d later. In general, yields were favored by a December to April season (2005) compared with an October to February season (2006) likely because of greater solar radiation later in the season in 2005 when plants were well-established rather than early in the season as in 2006. During periods of extended day length, increasing the frequency of organic fertilizer application may improve synchrony of mineralized N with crop demand and limit the risk of excess N. Because organic-compliant fertilizers were exposed to the same temperatures and day length in the greenhouse, the differences in availability of nutrients can be attributed to the different source ingredients rather than environmentally mediated transformation rates. A yield response curve to a range of fertilizer application rates and subsequent determination of economically beneficial fertilizer rates based on yield and income would be of benefit to organic herb producers.

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