HORTSCIENCE 48(5):637–644. 2013.

Sustainable Production of Marigold and Calibrachoa with Organic Fertilizers

Touria E. Eaton[1], Douglas A. Cox, and Allen V. Barker
Stockbridge School of Agriculture, University of Massachusetts, Amherst, MA 01003

Additional index words. organic, fertilizer, marigold, calibrachoa, sustainable

***Abstract*. Experiments were conducted to evaluate organic fertilizers in production of greenhouse-grown calibrachoa (C*alibrachoa ×hybrida* Llave & Lex) and marigold (*Tagetes erecta* L.) and nitrogen (N) leaching from containers during production. Calibrachoa was grown with five fertilizer treatments: one chemical, one organic-based, and three organic (liquid fish, oilseed extract, and a combination of oilseed extract and liquid fish). Marigold was grown with seven fertilizer treatments: one chemical and three organic (liquid fish, oilseed extract, and alfalfa pellets) used either alone or in combination. Chemical or organic-based fertilizers produced the best quality calibrachoa based on plant appearance and size. Liquid fish fertilizer produced healthy plants but smaller plants than those grown with chemical or organic-based fertilizers. Plants grown with oilseed extract were stunted and showed chlorosis. If oilseed extract was combined with liquid fish, the plants were similar to those grown with the chemical or organic-based fertilizers in size and quality. Chemical or liquid fish fertilizers produced the highest quality marigold based on plant appearance. Plants fertilized with alfalfa pellets were sparse and pale green. Oilseed extract produced the poorest growth and quality. If oilseed extract was combined with liquid fish or alfalfa, marigold plants were close in size and development to chemical-fertilized plants without nutrient deficiency and with some enhancement of nutrient levels in the leaves. The combination of alfalfa and liquid fish produced similar results. The highest N leaching resulted from plants fertilized by liquid fish, mostly in the form of ammonium nitrogen (NH_4-N). Combining liquid fish with alfalfa or oilseed extract reduced the amount of N leached from the pots. The results suggest that organic fertilizers can be used successfully to grow commercial greenhouse crops but should be combined for good plant quality and environmental sustainability.**

Consumer awareness of the environment and sustainability has increased in recent years. Market research shows that consumers are increasingly willing to pay premium prices for environmentally friendly products (Behe et al., 2010; Lopez et al., 2009, 2011). Commercial greenhouse operations that produce organic or sustainable crops have a new niche or specialty crop market.

As more greenhouse producers consider implementing organic production practices, questions arise about the use of organic media, fertilizers, and pest management methods for greenhouse crops. Organic media are available in the market, and pest management practices using organic pesticides and biological control agents are being established. However, cultural information about using organic fertilizers in a commercial greenhouse operation lags behind that available for other management areas. Specifically, information about the different organic fertilizers available in the market and their effects on plant growth and quality and substrate pH and electrical conductivity (EC) in comparison with inorganic fertilizers is needed.

Received for publication 5 Nov. 2012. Accepted for publication 8 Mar. 2013.
[1]To whom reprint requests should be addressed; e-mail eaton@umext.umass.edu.

Many organic fertilizers are byproducts of livestock, fish, food, and other processing industries (Gaskell and Smith, 2007). Some common materials used as organic fertilizer sources include fishmeal or fish powder, processed fish residues, feather meal, blood meal, meat and bone meal, and manure-based materials (Gaskell et al., 2006; Hartz and Johnstone, 2006).

Fish fertilizers are made from waste products of the ocean-fish processing industry. Fish fertilizers supply mostly NH4-N (Cox, 2010), which could be a disadvantage for some plants. Also, fish fertilizers can be a problem to store because they spoil and can be difficult to inject through some systems (Cox, 2010). Neptune's fish hydrolysate 2-4-1 is the most commonly available fish fertilizer (Cox, 2010), and it is approved by the Organic Materials Review Institute (OMRI) for organic greenhouses (OMRI, 2012).

Some organic fertilizers are derived from residues (meals) of oilseeds such as soybean or from extracts during processing of oil from the seeds (Nelson et al., 2012). Among these fertilizers, some are OMRI-approved for organic use. Some soybean-based commercial preparations supply nutrients derived from inorganic salts and therefore are not OMRI-approved for organic use.

Other organic fertilizers are derived from alfalfa plants, in which the plant material (leaves) is dehydrated and pelletized (Fasina et al., 1997).

Although organic fertilizers are available in the market, little information is available on their performance, their influence on plant growth and quality, or their N leaching characteristics. Therefore, the objective of this work was to evaluate liquid fish, oilseed extract, and alfalfa pellets, used either alone or in combination, for plant growth and N leaching from two commonly grown floricultural crops, marigold (*Tagetes erecta* L. 'First Lady') and calibrachoa (*Calibrachoa ×hybrida* Llave & Lex 'Million Bells Cherry Red'). Calibrachoa was particularly useful in this study because of its high fertility and acidic pH requirements and its tendency to demonstrate nutritional problems (Dole et al., 2002).

Materials and Methods

Two experiments, one with calibrachoa (*Calibrachoa ×hybrida* Llave & Lex 'Million Bells Cherry Red') and one with marigold (*Tagetes erecta* L. 'First Lady'), were conducted in a greenhouse at the University of Massachusetts Amherst (lat. 42.37° N, long. 72.53° W). The substrate used in these two experiments was a sphagnum peatmoss-based organic medium (Fafard FOF#30, Agawam, MA).

Expt. 1: Calibrachoa. Conventional rooted liners of calibrachoa, ≈6.0 cm in length and harvested for rooting on 22 Feb. 2010, were potted on 8 Mar. 2010 in round plastic pots (15 cm o.d., 11 cm height), one plant/pot. On 22 Mar. 2010, after a 2-week establishment period, plants were watered with treatment solutions. Plants received no fertilization during the establishment period and were watered with tap water when the medium was dry. To assess dryness, plant pots were lifted and if they felt light, they were assumed dry. This method has been recently described as the "lift" test method (LaLiberte, 2013).

Four water-soluble fertilizers (Table 1) were used for five fertilizer treatments: chemical [Plantex High Nitrate 20-2-20 (20N–0.5P–6K); Plant Products Co., Ltd., Brampton, Ontario, Canada], organically based Daniels [Daniels 10-4-3 (10N–1.8P–2.5K); Daniels AgroSciences, East Greenwich, RI], organic oilseed extract [Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), Daniels AgroSciences], organic liquid fish [Hydrolyzed Fish Fertilizer 2-4-1 (2N–1.8P–0.8K); Neptune's Harvest, Gloucester, MA], and one treatment alternating application of oilseed extract and liquid fish.

Each fertilizer treatment was applied twice a week with 200 mL of solution supplying 175 $mg \cdot L^{-1}$ N during the first 30 d after transplanting and 225 $mg \cdot L^{-1}$ N from 30 d after transplanting to the end of the experiment (Table 2). Fertilizer treatments were applied 14 times during the course of the experiment and a total of ≈0.6 g N was applied to each pot. Between applications of treatments, plants were hand-watered with 100 mL tap water if dry according to the "lift" test method (LaLiberte, 2013). To limit the number of

Table 1. Materials used in this investigation, including fertilizers and their grade [nitrogen (N), phosphorus (P), potassium (K)] and composition.

Material	Fertilizers	Term used in the article	Grade (N–P–K) (%)	Composition
Chemical	Plantex 20-2-20	Chemical	20–0.5–6.0	Ammonium phosphate, ammonium sulfate, potassium nitrate, boric acid, sodium molybdate, iron EDTA, zinc EDTA, copper EDTA, and manganese EDTA
Organic-chemical	Daniels 10-4-3	Daniels	10–1.8–2.5	Oilseed extract (soybean), potassium (Daniels) phosphate, potassium sulfate, ammonium phosphate, sulfate of ammonia, ammonium nitrate, and urea
Organic	Daniels Pinnacle 3-1-1	Oilseed extract	3.0–0.4–0.8	Oilseed extract (soybean) and sodium nitrate
Organic	Neptune's Fish Fertilizer 2-4-1	Liquid fish	2.0–1.8–0.8	Fish protein
Organic	Planet Natural Alfalfa Pellet 5-1-2	Alfalfa	5–0.4–1.7	Dehydrated compressed alfalfa leaves

Table 2. Weight of fertilizers used to provide 175 or 225 mg nitrogen (N)/L of solution.

	Grams of fertilizer/L water	
Fertilizers[z]	175[x]	225[w]
Chemical	0.9	1.1
Daniels	1.8	2.3
Oilseed extract	5.8	7.5
Liquid fish	8.8	11.3
Alfalfa[y]	N/A	N/A

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble, organic-based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer; Alfalfa = Planet Natural Alfalfa Pellet 5-1-2 (5N–0.4P–1.7K), water-soluble organic fertilizer.
[y]Alfalfa was incorporated in the substrate (30 g/pot) before transplanting.
[x]Fertilizers were applied at 175 mg N/L during the first 30 d after transplanting.
[w]Fertilizers were applied at 225 mg N/L from 30 d after transplanting to the end of the experiment.
N/A = not applicable.

variables in the experiment and to eliminate the irrigation volume as a variable, all pots were watered if at least one of them was dry. Each plant in all five treatments received the same volume of solution, whether it was fertilizer solution or plain water, during the experiment.

Plants were placed on benches in a glass greenhouse under a natural photoperiod (≈11/13 h day/night). The temperatures were 24/16 °C day/night. The experiment was laid out as a completely randomized design with five fertility treatments and eight single-plant replicates.

Plants were harvested 60 d after transplanting. At harvest, leaves from the terminal 5 to 8 cm of each shoot were harvested for nutrient analysis. Shoots (stem and leaves including the leaves harvested for tissue analysis) were placed into a 60 °C forced-air oven and dried to constant weight. Dry weight was recorded for each plant shoot. Samples of the growth medium were collected at harvest to determine EC and pH as described later in this section.

Expt. 2: Marigold. Purchased 3-week-old plug seedlings of conventional marigold were transplanted into round, plastic pots (15 cm o.d., 11 cm height), one plant/pot, on 15 Jan. 2011. Pots were suspended through the lids of larger containers (Fig. 1) to collect the leachate for NH_4-N and nitrate (NO_3-N) analysis at 10-d intervals during the experiment. Before transplanting, the seedlings were watered daily with tap water and received no fertilization. Fertilizer treatments started at transplanting. Three liquid fertilizer treatments were applied to plants, chemical, oilseed extract, or liquid fish (Table 1). In one treatment, oilseed extract and liquid fish were applied in alternating weekly applications. Three more treatments involved the use of alfalfa pellets 5N–0.4P–1.7K (Planet Natural, Bozeman, MT) incorporated into the growth medium before planting at 30 g/pot. In one treatment, alfalfa pellets were the sole source of nutrients for the plants. In two treatments, the alfalfa pellets were supplemented with liquid fish or oilseed extract applied at every fourth watering.

Liquid fertilizer concentrations for marigolds were 175 mg N/L during the first 30 d after transplanting and then 225 mg N/L from 30 d after transplanting to the end of the experiment (Table 2), because marigold requires more N during the second half of the life cycle than during the first half (El-Jaoual and Cox, 1998). In treatments in which the liquid fertilizers (chemical, oilseed extract, liquid fish, and liquid fish + oilseed extract) were the sole sources of nutrition, 150 mL of fertilizer solution was applied at regular intervals (three times per week). Plants were hand-watered with 100 mL tap water between fertilizer applications when at least one pot needed irrigation according to the "lift" test commercial practice of watering of greenhouse plants (LaLiberte, 2013). Each plant in all seven treatments received a total of 6650 mL of solution, whether it was fertilizer solution or plain water, during the experiment.

A total of 0.8 g N/pot was applied during the experiment to the liquid fertilizer treatments. In the treatment in which alfalfa pellets were used alone, 1.50 g N/pot was potentially available to the plants during the experiment, whereas in the treatments in which the alfalfa pellets were supplemented by liquid fertilizer, 1.72 g N/pot was potentially available.

Plants were placed on benches in a glass greenhouse, under a natural photoperiod (9/15 h day/night), in a completely randomized design with seven fertility treatments and six replicates. The temperature in the greenhouse was 24/16 °C day/night.

Plants were harvested 62 d after transplanting. At harvest, plant height was measured from the substrate surface to the tallest plant part. Plant width (the widest part of the plant) was recorded as the average of two measurements, the second being made at a right angle to the first. Flower height was measured from the substrate surface to the tallest plant flower, and three fully open flowers were chosen randomly for flower diameter measurement. The average of the three measurements was recorded. Leaves from the terminal 5 to 8 cm of each plant shoots were harvested for nutrient analysis (Issac and Johnson, 1998). Immediately after aboveground harvesting, shoots (stems and leaves, including the leaves harvested for tissue analysis) were placed into a 60 °C forced-air oven and dried to constant weight. Dry weight was recorded for each plant shoot. Samples of the growth medium were collected at harvest to determine EC (Scoggins and van Iersel, 2006; Sonneveld, 1990) and pH.

Ratings of plant quality. The rating data were taken at the end of each experiment. Plants were evaluated according to their appearance (presence or absence of symptoms of nutrient deficiencies and the overall plant size and fullness of foliage). Plants that were visually appealing with full foliage and big size were rated 1. Plants that were visually not appealing or were thin or small and showed symptoms of nutrient deficiencies were rated 5. Ratings between 1 and 5 were used for intermediate qualities.

Tissue nutrient analyses. For both experiments, replicates of dry leaf tissue (eight replications for calibrachoa and six replications for marigold) were ground with a Wiley mill (40 mesh) (Thomas Scientific, Swedesboro, NJ) for the analysis of nutrients [N, phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), copper (Cu), manganese (Mn), iron (Fe) or boron (B)]. Tissue nutrient analyses were conducted at the University of Massachusetts Soil Testing Laboratory by plasma spectrophotometry (Issac and Johnson, 1998). Total N was determined by Kjeldahl analysis (Nelson and Sommer, 1980).

Leachate collection and nitrogen analysis. To collect the leachate, pots of marigold were placed over 2-L opaque containers (10-cm rim), through square Styrofoam lids (20 cm side) with openings to accommodate the pots (Fig. 1). The leachate was collected in stoppered 125-mL glass

Fig. 1. To collect the leachate, pots of marigold were placed over 2-L opaque containers (10-cm rim), through square Styrofoam lids (20-cm side), with openings to accommodate the pots.

Fig. 2. Close-up of iron (Fe) deficiency induced chlorosis occurring on calibrachoa grown with oilseed extract fertilizer.

Fig. 3. Calibrachoa plant grown with chemical fertilizer (left) and plant grown with oilseed extract (right).

Fig. 4. From left to right, 'First Lady' marigold grown with individual fertilizers, chemical, liquid fish, oilseed extract, and alfalfa.

Fig. 5. From left to right, 'First Lady' marigold grown with combined organic fertilizers, fish and oilseed extract, alfalfa and oilseed extract, and alfalfa and liquid fish.

flasks at 10-d intervals, six times throughout the course of the experiment. Total leachate volume was determined by the addition of all volumes of liquid leached from the pots throughout the experiment. Leachate fraction (LF) was determined as the fraction of total leachate/total volume of applied liquid × 100.

The NH_4-N and NO_3-N concentrations in the leachate were determined potentiometrically with an ammonia gas-sensing ion selective electrode (Cole-Parmer S27502-00, Vernon Hills, IL) and nitrate ion-selective electrode (Cole-Parmer S27504-22), respectively (Mills, 1980). The N leached was determined by multiplying the concentration of N in the leachate by the volume of leachate.

Substrate pH and electrical conductivity measurements. Substrate pH and EC were measured at 60 and 62 d after transplanting in Expts. 1 and 2, respectively. The EC was measured using the substrate solution extraction "1:2 dilution" method (Sonneveld, 1990). This method consisted of mixing 20 cc of medium and 40 mL of deionized water. The mixture was filtered with #1 filter paper. The filtrate was used to read the pH and EC with standardized pH and EC electrodes, respectively (Oaktan 300 Services pH/EC meter; Euteck Instrument, Singapore). In both experiments, the pH and EC measurements were made on growth medium samples from five random pots in each treatment.

Statistical analyses. Data were processed by analysis of variance (SAS Institute Inc., 2002; Steel and Torrie, 1980). Means of treatments were separated with Duncan's new multiple range test at P = 0.05 (SAS Institute Inc., 2002; Steel and Torrie, 1980).

Results

Expt. 1: Calibrachoa

Plant growth and quality. In term of plant quality, chemical, Daniels, and liquid fish resulted in the best quality plants (rating 1) (Table 3). Oilseed extract produced the worst quality (rating 5). If oilseed extract was combined with liquid fish, plant quality was the same as that of chemical, Daniels, or liquid fish (Table 3).

Calibrachoa fertilized with chemical, Daniels, or oilseed extract + liquid fish fertilizers produced the greatest shoot dry weight (Table 3). Plants grown with liquid fish had similar shoot dry weight as those grown with Daniels but less dry weight than those grown with chemical fertilizer (Table 3). Plants grown with oilseed extract or liquid fish alone had less dry weight than those grown with chemical. Combining oilseed extract with liquid fish resulted in the same dry weight as that of plants grown with chemical. Plants grown with oilseed extract, in addition to being small, had severely chlorotic terminal leaves and branches (Figs. 2 and 3).

pH and electrical conductivity. Except for oilseed extract, all treatments resulted in a substrate pH between 5.2 and 5.6 (Table 3). Oilseed extract resulted in the highest pH of 7.2, but if combined with liquid fish fertilizer, it resulted in a substrate pH within the pH range of other treatments 5.2 to 5.6 (Table 3).

Chemical fertilizer and oilseed extract + liquid fish resulted in the highest substrate EC (Table 3). Oilseed extract resulted in the lowest EC (Table 3).

Leaf analysis. The effect of fertilizers on leaf composition was diverse among fertilizers and among nutrients (Table 4). Chemical, Daniels, or liquid fish resulted in higher N concentration in the leaves than oilseed extract combined with liquid fish (Table 4). Oilseed extract resulted in the lowest N concentration in the plant tissue (Table 4).

Liquid fish resulted in higher concentration of P in the plant tissue than oilseed extract combined with liquid fish (Table 4). Daniels or oilseed extract resulted in the lowest P concentration in the plant tissue (Table 4).

Fertilization with chemical or oilseed extract resulted in higher concentrations of K in the plant tissue than liquid fish or oilseed extract combined with liquid fish (Table 4). The lowest K concentration in the plant tissue occurred with Daniels (Table 4).

Fertilization with liquid fish resulted in a higher concentration of Ca in the plant tissue than with chemical, Daniels, or oilseed extract combined with liquid fish (Table 4). The lowest Ca concentration in the plant tissue was with oilseed extract (Table 4).

The lowest concentration of Mg occurred with oilseed extract with no significant difference occurring among the other treatments (Table 4).

Oilseed extract, used either alone or combined with liquid fish, resulted in a higher concentration of B in the plant tissue than chemical or liquid fish (Table 4). Daniels or oilseed extract combined with liquid fish resulted in similar concentrations of B in the plant tissue (Table 4).

Use of chemical, Daniels, or oilseed extract combined with liquid fish resulted in higher concentration of Fe in the plant tissue than oilseed extract or liquid fish applied alone.

In general, among organic fertilizers, use of liquid fish resulted in the best quality calibrachoa (rating 1) and in high concentrations of most nutrients (Tables 3 and 4). Use of oilseed extract resulted in the worst quality plants (rating 5) and in low concentrations of most nutrients in the plant tissue (Tables 3 and 4). Compared with the use of oilseed extract alone, combining oilseed extract with liquid fish improved the plant quality and increased the nutrient concentrations in the plant tissue (Tables 3 and 4).

Expt. 2: Marigolds

Plant growth and quality. Plants fertilized with chemical or liquid fish fertilizers resulted in the best quality plants (rating 1) (Table 5; Fig. 4). Plants were normal in appearance with dark green foliage associated with this type of marigold (Fig. 4). Fertilization with alfalfa resulted in a reduced quality of plants (rating 2) (Table 5; Fig. 4). The plants were pale green and the foliage was sparse. The use of oilseed extract resulted in the worst quality of plants (rating 5) (Table 5; Fig. 4). The foliage was chlorotic and the plant size was suppressed markedly relative to the other treatments. Plants grown with fertilizer combinations (oilseed extract + liquid fish, alfalfa + liquid fish, or alfalfa + oilseed extract) were close in growth and appearance to those receiving chemical or liquid fish fertilizer alone (Figs. 4 and 5). The quality of plants was rated 1 with alfalfa + liquid fish, 1.3 with oilseed extract + liquid fish, and 1.5 with oilseed extract + alfalfa. Heights of plants in all treatments were about the same, but plants fertilized with liquid fish or liquid fish + oilseed extract were slightly, but significantly, shorter than the others (Table 5). Chemical, liquid fish, alfalfa pellets, or all combination treatments produced plants with similar flower diameter (Table 5). Chemical fertilizer produced the greatest shoot dry weight (Table 5). The smallest flower diameter, smallest plant width, and the least dry weight resulted with the use of oilseed extract alone (Table 5).

pH and electrical conductivity. Growth medium pH ranged between 5.0 and 5.9 in all treatments except oilseed extract either alone or combined with alfalfa, where pH was high at 7.4 and 6.9, respectively (Table 6). Chemical or liquid fish fertilizers resulted in the highest substrate EC, whereas oilseed extract resulted in the lowest (Table 6). All treatments, except oilseed extract (EC = 0.69 $dS·m^{-1}$), had an EC within the range of 0.88 and 1.99 $dS·m^{-1}$.

Leaf analysis. Significant differences in the nutrient concentration of leaf tissue occurred among fertilizer treatments (Table 7). Nitrogen level in chemical or fish-treated plants exceeded the N level in plants of other treatments. Among all treatments, oilseed extract, alfalfa, or their combination resulted in low tissue N. Concentrations of Ca, P, Mg, Zn, and Mn were high in fish-treated plants and low in plants treated with oilseed extract, alfalfa, or their combination (Table 7). Iron was highest in chemical-grown plants and lowest in plants fertilized with oilseed extract, alfalfa, or the combination of the two.

Table 3. Ratings of plant quality and means of shoot dry weight (SDW) of calibrachoa and pH and electrical conductivity (EC) of substrates treated with different fertilizers.

			Substrate	
Fertilizers[z]	Ratings of plant quality	SDW g/plant	pH	EC ($dS·m^{-1}$)
Chemical	1 b[y]	9.8 a[x]	5.2 b	1.57 a
Daniels	1 b	8.0 ab	5.6 b	0.83 bc
Oilseed extract	5 a	6.0 c	7.2 a	0.62 c
Liquid fish	1 b	7.5 bc	5.3 b	1.06 b
Oilseed extract + liquid fish	1.5 b	8.1 ab	5.4 b	1.21 a

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble, organic-based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble, organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer.

[y]Plant quality is rated from 1 to 5, with 1 being highest quality (free of symptoms of nutrient deficiencies, full foliage, and good plant size) and 5 being worst quality (showing symptoms of nutrient deficiencies, sparse foliage, and/or small plant size).

[x]Means followed by different letters within columns are significantly different by Duncan's new multiple range test (P = 0.05).

Table 4. Nutrient [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), boron (B), and iron (Fe)] concentrations in leaves of calibrachoa grown for 60 d with different fertilizers.

	Nutrient						
	N	P	K	Ca	Mg	B	Fe
Fertilizers[z]	(% dry wt)					($mg·kg^{-1}$ dry wt)	
Chemical	5.19 a[x]	0.47 c	4.06 a	1.05 b	0.79 a	36 c	124 a
Daniels	5.03 ab	0.46 c	2.54 c	1.11 b	0.91 a	41 bc	100 a
Oilseed extract	3.86 c	0.35 c	4.28 a	0.54 c	0.48 b	47 a	80 b
Liquid fish	5.20 a	1.81 a	1.61 d	1.61 a	0.93 a	37 c	77 b
Oilseed extract + liquid fish	4.57 b	0.98 b	3.46 b	0.89 b	0.76 a	44 ab	94 a
Optimal range[y]	3.85 to 7.60	0.47 to 0.93	3.13 to 6.65	1.20 to 2.81	0.36 to 1.37	18 to 43	84 to 168

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble organic based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer.

[y]Range of optimal concentrations of nutrients in petunia leaf tissue [Data for petunia is used because calibrachoa is a relative of petunia and is called trailing petunia, *Petunia calibrachoa* (Ellis, 1999; Mills and Jones, 1996)].

[x]Means followed by different letters within columns are significantly different by Duncan's new multiple range test (P = 0.05).

Table 5. Ratings of plant quality and means of plant height, flower height, plant width, flower diameter, and total dry weight of marigold grown for 62 d in substrates treated with different fertilizers.

Fertilizers[z]	Ratings of plant quality[y]	Plant growth parameters: Plant ht (cm)	Flower ht (cm)	Plant width (cm)	Flower diam (cm)	Total dry wt g/plant
Chemical	1 c	24.4 a[x]	30.1 ab	37.5 a	7.1 a	19.9 a
Oilseed extract	5 a	24.1 a	30.6 ab	29.3 d	4.7 b	8.5 e
Liquid fish	1 c	22.0 c	28.3 c	36.7 ab	7.5 a	16.0 c
Alfalfa[w]	2 b	23.6 ab	30.7 ab	35.1 bc	6.6 a	14.7 d
Liquid fish + oilseed extract	1.3 c	22.8 bc	29.4 bc	34.5 c	7.3 a	16.4 c
Alfalfa[w] + oilseed extract	1.5 c	23.1 abc	31.0 a	35.4 bc	6.8 a	15.0 d
Alfalfa[w] + liquid fish	1 c	23.3 ab	31.1 a	37.7 a	7.6 a	17.5 b

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble organic based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer; Alfalfa = Planet Natural Alfalfa Pellet 5-1-2 (5N–0.4P–1.7K), water-soluble organic fertilizer. Fertilizers other than alfalfa were applied at 175 mg nitrogen (N)/L during the first 30 d after transplanting, then at 225 mg N/L from 30 d after transplanting to the end of the experiment.

[y]Plant quality is rated from 1 to 5 with 1 being highest quality (free of symptoms of nutrient deficiencies, full foliage and good plant size) and 5 being worst quality (showing symptoms of nutrient deficiencies, sparse foliage, and/or small plant size).

[x]Means followed by different letters within columns are significantly different by Duncan's new multiple range test ($P = 0.05$).

[w]Alfalfa was incorporated in the substrate (30 g/pot) before transplanting.

Table 6. Means of pH and electrical conductivity (EC) of substrates containing different types of fertilizers at the end of the experiment at 62 d after transplanting of marigold.

Fertilizers[z]	Substrate pH	Substrate EC ($dS\cdot m^{-1}$)
Chemical	5.1 d[x]	1.48 a
Oilseed extract	7.4 a	0.69 c
Liquid fish	5.0 d	1.99 a
Alfalfa[y]	5.9 c	0.90 bc
Liquid fish + oilseed extract	5.9 c	1.09 b
Alfalfa[y] + oilseed extract	6.9 b	0.88 bc
Alfalfa[y] + liquid fish	5.7 c	0.88 bc

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble organic based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer; Alfalfa = Planet Natural Alfalfa Pellet 5-1-2 (5N–0.4P–1.7K), water-soluble organic fertilizer. Fertilizers other than alfalfa were applied at 175 mg nitrogen (N)/L during the first 30 d after transplanting, then at 225 mg N/L from 30 d after transplanting to the end of the experiment.

[y]Alfalfa was incorporated in the substrate (30 g/pot) before transplanting.

[x]Means followed by different letters within columns are significantly different by Duncan's new multiple range test ($P = 0.05$).

Leachate analysis. Fertilizer type had a significant effect on the type (NO_3-N or NH_4-N) and amount of N leached from the pots (Tables 8 and 9). The largest amount of N leached occurred with liquid fish, mostly in the form of NH_4-N. Lesser amounts of N leached with oilseed extract, mostly as NO_3-N, followed by chemical mostly as NO_3-N and with liquid fish combined with oilseed extract, mostly as NH_4-N. Alfalfa, either alone or combined with oilseed extract or liquid fish, resulted in the least leaching of N. Equal amounts of NH_4-N and NO_3-N leached from the pots of alfalfa or alfalfa combined with oilseed extract. More NH_4-N than NO_3-N leached from the pots of alfalfa combined with liquid fish.

Discussion

Plant growth and quality. Calibrachoa and marigold grew best if fertilized with chemical fertilizer. The plant size was greatest, and the foliage was full and did not show any symptoms of deficiencies. In calibrachoa treated with chemical fertilizer, except for Ca, all tested nutrients were within or exceeded the range of optimal concentrations of nutrients for petunia (Mills and Jones, 1996). The range of optimal concentrations of nutrients in petunia leaf tissue is used in this article to assess the nutrients' sufficiency because there are no similar data available for calibrachoa and because calibrachoa is a relative of petunia (Ellis, 1999). The slightly low concentration of Ca (1.05%) in calibrachoa fertilized with chemical fertilizer did not affect the size or quality of the plants.

With marigold fertilized with chemical fertilizer, most of the tested nutrients were within or exceeded the range of optimal concentrations for marigold (Mills and Jones, 1996). Phosphorus, Ca, S, and Mn were slightly below the sufficiency concentrations of these nutrients for marigold, probably because of the fertilizer composition. The low concentrations of P, Ca, S, and Mn in marigold did not affect the size or the quality of plants.

The substrate EC was highest with chemical or liquid fish fertilizers indicating high availability of nutrients to plants (Robbins and Evans, 2010). The EC range recommended for most container substrates is 0.76 to 3.50 $dS\cdot m^{-1}$ (Cavins et al., 2000). In both experiments, the ECs of all treatments, except for oilseed extract, were within the recommended range. Fertilization with oilseed extract resulted in a low EC that is below the recommended range, indicating low availability of nutrients to plants (Robbins and Evans, 2010).

The pH of the growth substrate affects the availability of nutrients, especially micronutrients (Mills and Jones, 1996). For most container plants, a substrate pH between 5.0 and 6.5 is recommended (Robbins and Evans, 2010). Higher pH may result in deficiency of micronutrients, especially Fe (Fisher et al., 2003). In both experiments, the pH of the substrates of all evaluated fertilizers was within the recommended range of substrate pH, except for oilseed extract, in which the pH was above the optimal range. This high substrate pH apparently induced symptoms of nutrient deficiencies expressed in plants grown with oilseed extract (Mills and Jones, 1996).

Second to chemical fertilizer, the organic-based fertilizer, Daniels, produced the best quality plants. Except for K, the tissue nutrient concentrations of Daniels-treated plants were similar to those of plants grown with chemical fertilizer. Also, the substrate pH and EC of Daniels-treated pots were similar to that of the chemical-fertilized pots and were within the recommended range of substrate pH and EC for container substrates (Argo and Fisher, 2002; Fisher et al., 2003; Robbins and Evans, 2010).

Among organic fertilizers, liquid fish produced the best results in marigold and calibrachoa. Plants treated with liquid fish were smaller than but had similar quality as those fertilized with chemical fertilizer. The substrate pH and EC of liquid fish pots were within the recommended range of pH and EC for container substrates (Argo and Fisher, 2002; Fisher et al., 2003; Robbins and Evans, 2010). With calibrachoa, except for K and Fe, all tested nutrients were within the sufficiency concentrations range of these nutrients for petunia (Mills and Jones, 1996). With marigold, except for K, Cu, and B, all of the tested nutrients were within the sufficiency concentrations range of these nutrients for marigold.

Liquid fish resulted in adequate tissue Fe in marigold and low Fe concentration in calibrachoa. These results may be related to substrate pH or to the nature of the plants. The substrate pH of calibrachoa (5.5) was higher than that of marigold 5.0. Also, calibrachoa is an Fe-inefficient plant based on its limited ability to accumulate Fe under conditions of high substrate pH (Römheld, 1987).

Marigolds fertilized with alfalfa were sparse and pale green, suggesting deficiency of nutrients such as N (Mills and Jones, 1996). Indeed, the concentrations of N, P, Ca, S, Zn, Cu, Mn, and Fe in the plant tissue were below the optimal range of these nutrients for marigold (Mills and Jones, 1996). Alfalfa plants had the lowest concentration of N among all treatments. Although the EC (0.9 $dS\cdot m^{-1}$) of alfalfa substrate was within the recommended EC range for container substrate (Cavins et al., 2000), it was among the lowest values of the range and was considerably lower than the substrate EC of chemical or liquid fish,

Table 7. Means of nutrient [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B)] concentrations in leaves of marigold grown for 62 d in substrates treated with different fertilizers.

	Nutrient										
	N	P	K	Ca	Mg	S	Zn	Cu	Mn	Fe	B
Fertilizers[z]	(% dry wt)						($mg\cdot kg^{-1}$ dry wt)				
Chemical	5.7 a[w]	0.3 e	3.2 b	1.9 de	1.0 c	1.0 b	180 b	23 a	156 cd	233 a	53 a
Oilseed extract	3.2 d	0.5 d	5.3 a	1.7 e	0.7 e	1.1 b	70 d	15 b	44 f	78 cd	44 b
Liquid fish	5.4 a	2.6 a	0.9 e	3.6 a	1.9 a	1.3 a	229 a	8 d	541 a	101 b	30 d
Alfalfa[y]	2.4 e	0.3 e	2.9 bc	2.2 c	0.6 ef	0.6 c	68 d	10 cd	128 de	65 d	36 c
Liquid fish + oilseed extract	4.5 b	1.4 b	2.0 d	2.7 b	1.5 b	1.1 b	115 c	15 b	242 b	108 b	36 c
Alfalfa[y] + oilseed extract	2.5 e	0.4 e	3.2 b	2.1 cd	0.6 f	0.8 c	67 d	11 c	101 e	61 d	32 cd
Alfalfa[y] + liquid fish	3.7 c	0.9 c	2.6 c	2.6 b	0.8 d	0.7 c	83 d	15 b	187 c	90 bc	35 cd
Optimal range[x]	3.32 to 3.62	0.49 to 0.54	2.79 to 2.88	2.36 to 2.72	0.33 to 1.44	1.34 to 1.44	76 to 97	19 to 25	275 to 558	92 to 115	34 to 40

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble organic based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer; Alfalfa = Planet Natural Alfalfa Pellet 5-1-2 (5N–0.4P–1.7K), water-soluble organic fertilizer. Fertilizers were applied at 175 mg N/L during the first 30 d after transplanting, then at 225 mg N/L from 30 d after transplanting to the end of the experiment.
[y]Alfalfa was incorporated in the substrate (30 g/pot) before transplanting.
[x]Range of optimal concentrations of nutrients in the leaves of marigold (Mills and Jones, 1996).
[w]Means followed by different letters within columns are significantly different by Duncan's new multiple range test ($P = 0.05$).

Table 8. Means of leachate volume, leachate fraction, and ammonium nitrogen (N), nitrate N, and total N concentration in the leachate of marigold grown for 62 d in substrates containing different organic fertilizers.

	Leachate		Nitrogen leached		
	Volume[x]	Fraction[w]	NH_4-N	NO_3-N	Total
Fertilizers[z]	(mL)	(%)	(mg N/L^{-1})		
Chemical	511 d[v]	8 d	21 cd	52 a	72 bc
Oilseed extract	2216 a	33 a	15 d	45 a	60 c
Liquid fish	1298 b	20 b	185 a	7 c	192 a
Alfalfa[y]	1178 b	18 b	14 d	14 c	27 d
Liquid fish + oilseed extract	886 c	13 c	67 b	12 c	80 b
Alfalfa[y] + oilseed extract	1168 b	18 b	18 cd	22 b	39 d
Alfalfa[y] + liquid fish	726 cd	11 cd	34 c	7 c	41 d

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble organic based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer; Alfalfa = Planet Natural Alfalfa Pellet 5-1-2 (5N–0.4P–1.7K), water-soluble organic fertilizer. Fertilizers other than alfalfa were applied at 175 mg N/L during the first 30 d after transplanting, then at 225 mg N/L from 30 d after transplanting to the end of the experiment.
[y]Alfalfa was incorporated in the substrate (30 g/pot) before transplanting.
[x]Leachate volume is the total of all the leachates collected in the course of the experiment.
[w]Leachate fraction is calculated as the fraction of leachate volume/irrigation volume $\times$ 100.
[v]Means followed by different letters within columns are significantly different by Duncan's new multiple range test ($P = 0.05$).

Table 9. Means of NH_4-N, NO_3-N, and total nitrogen (N) amounts in the leachate of marigold grown for 62 d in substrates containing different organic fertilizers.

	Nitrogen leached		
	NH_4-N	NO_3-N	Total N
Fertilizers[z]	(mg)		
Chemical	11 c[x]	28 b	40 d
Oilseed extract	33 c	100 a	132 b
Liquid fish	242 a	10 c	251 a
Alfalfa[y]	17 c	16 bc	33 d
Liquid fish + oilseed extract	63 b	11 c	74 c
Alfalfa[y] + oilseed extract	21 c	25 b	46 cd
Alfalfa[y] + liquid fish	27 c	5 c	32 d

[z]Chemical = Plantex High Nitrate 20-2-20 (20N–0.5P–6K), synthetic water-soluble fertilizer; Daniels = Daniels 10-4-3 (10N–1.8P–2.5K), water-soluble organic based fertilizer; Oilseed extract = Daniels Pinnacle 3-1-1 (3N–0.4P–0.8K), water-soluble organic fertilizer; Liquid fish = Neptune's Harvest Hydrolyzed Fish 2-4-1 (2N–1.8P–0.8K), water-soluble organic fertilizer; Alfalfa = Planet Natural Alfalfa Pellet 5-1-2 (5N–0.4P–1.7K), water-soluble organic fertilizer. Fertilizers other than alfalfa were applied at 175 mg N/L during the first 30 d after transplanting, then at 225 mg N/L from 30 d after transplanting to the end of the experiment.
[y]Alfalfa was incorporated in the substrate (30 g/pot) before transplanting.
[x]Means followed by different letters within columns are significantly different by Duncan's new multiple range test ($P = 0.05$).

indicating lower availability of nutrients to plants (Robbins and Evans, 2010). This low availability of nutrients likely was the result of fertilizer composition because the substrate pH was 5.9, which is within the recommended pH range for container plants (Robbins and Evans, 2010).

Combining alfalfa with liquid fish did not affect the substrate pH or EC, which were still within the recommended range for container plants (Cavins et al., 2000; Robbins and Evans, 2010). The combination did, however, improve the size and quality of the plants significantly and increased the foliage width and total dry weight. It also increased the concentrations of N, P, Ca, Mg, Cu, Mn, and Fe in the plant tissue. Because there was no pH change in the substrate that would affect the availability of nutrients to plants (Robbins and Evans, 2010), the increase in the concentrations of plant nutrients likely is the result of the higher concentrations of nutrients in liquid fish than in alfalfa.

Both calibrachoa and marigold grew poorly when fertilized with oilseed extract. Calibrachoa grown with oilseed extract, in addition to being the smallest among plants grown with all treatments, had severely chlorotic terminal leaves and developing branches. These results suggest that plants grown with oilseed extract were deficient in some nutrients (Bennett, 1994), a suggestion that is supported by the EC of oilseed extract medium and by the concentration of mineral nutrients in the plant tissue. The EC of oilseed substrate was lowest among all treatments and was below the optimal substrate EC range for container plants, a reading that suggests lowest availability of nutrients to plants (Cavins et al., 2000; Robbins and Evans, 2010). This low nutrient availability may also be explained by the high substrate pH of 7.22 (Robbins and Evans, 2010). Argo and Fisher (2002) and Bailey and Nelson (1998) recommended a pH range of 5.8 to 6.2 for calibrachoa plants to provide adequate nutrient solubility to meet plant requirements.

Leaf analysis of calibrachoa indicated that plants grown with oilseed extract suffered from multiple deficiencies. Leaves contained ≈50%, 30%, and 60% of the sufficiency concentrations of P, Ca, and Fe, respectively (Mills and Jones, 1996). Plants differ in their capacity to accumulate Fe. Bedding plants can be classified as Fe-efficient or Fe-inefficient based on their ability to accumulate Fe under conditions of limited supply, usually caused by high substrate pH (Römheld, 1987). At high pH, Fe-efficient plants can increase Fe uptake by using various strategies (Bienfait, 1988; Guerinot and Yi, 1994; Römheld, 1987). Calibrachoa is an Fe-inefficient species (Argo and Fisher, 2002; Bunt, 1988; Fisher et al., 2003), and its Fe uptake is not enhanced if Fe availability in the medium is limited.

With marigold, oilseed extract resulted in the smallest flower diameter, smallest plant diameter, and the least dry weight compared with all other treatments. The foliage was chlorotic, suggestive of nutrient deficiencies (Mills and Jones, 1996). Nutrient deficiencies in marigold fertilized with oilseed extract are supported by the substrate EC and the concentrations of nutrients in the leaves. With marigold, oilseed extract resulted in the lowest substrate EC, which was below the recommended EC range for container substrates (Cavins et al., 2000). Leaf analysis of marigold indicated that plants grown with oilseed extract contained less than the sufficient concentrations of N, Ca, S, Zn, Cu, Mn, and Fe for marigold (Mills and Jones, 1996).

The deficiencies of nutrients in marigold, and low substrate nutrient availability, may be the result of the substrate pH, the nature of the fertilizer itself, or the rate of fertilization (Bi et al., 2010). The substrate pH of oilseed treatment was highest (7.4) among all treatments. High substrate pH may have caused deficiency of some nutrients including N. Although N is absorbed at all pH levels, NO_3^- is absorbed better at an acidic pH than at an alkaline pH (Mills and Jones, 1996). In the case of oilseed extract, not only the high pH may have suppressed NO_3^- uptake, but it may also have caused N losses from the substrate. Losses of N as gaseous dinitrogen (N_2) or as one of oxides of N (N_2O or NO) are high when the pH level is between 7.0 and 7.5 (Mills and Jones, 1996).

If oilseed extract was combined with liquid fish, the substrate pH decreased, and the substrate EC increased. Substrate pH and EC were within the optimal pH and EC range for calibrachoa or marigold (Cavins et al., 2000; Robbins and Evans, 2010). In calibrachoa, N, P, Ca, and Fe concentrations in the plant tissue increased to levels that are within or exceed the sufficiency concentrations of these nutrients in petunia (Mills and Jones, 1996). In marigold, N, P, Ca, Mg, Zn, Mn, and Fe concentrations in the plant tissue increased to levels that are within or exceed the sufficiency concentrations of these nutrients in marigold (Mills and Jones, 1996). These data explain the size and quality of plants grown with oilseed extract combined with liquid fish. The plants grown with a combination of oilseed extract and liquid fish were comparable to those grown with chemical fertilizer.

If oilseed extract was combined with alfalfa, the substrate pH decreased from 7.4 to 6.9 but was still slightly higher than the optimal pH for container plants (Robbins and Evans, 2010). The substrate EC was similar to that of oilseed extract. The tissue concentrations of N, P, K, Mg, S, Cu, and B decreased and those of Ca and Mn increased but were still lower than the sufficient concentrations of these nutrients in marigold (Mills and Jones, 1996). Alfalfa likely has more Ca than oilseed extract, and when combined with oilseed extract, it increased the concentration of Ca in the medium and consequently in the plants.

So, combining oilseed extract with liquid fish or alfalfa gave better results than using oilseed extract alone. Combining oilseed extract with liquid fish gave better results than combining it with alfalfa.

Nitrogen losses to leaching. Although liquid fish produced the best quality plants among organic fertilizers, it contributed to the highest N leaching among all treatments. Nitrogen losses to leaching from liquid fish pots were six times the amount of N leached from chemical pots. Nitrogen leaching from a container is influenced by medium type and LF (Bunt, 1988; Wright and Niemiera, 1987). Liquid fish resulted in the second highest LF after that of oilseed extract, which was highest. Combining liquid fish with oilseed extract reduced the LF by ≈40% and the total leached N by ≈60%. Combining liquid fish with alfalfa reduced the LF by ≈45% and reduced leached N by ≈80%. Also, plants grown with combinations of liquid fish and oilseed extract or liquid fish and alfalfa were comparable to those grown with liquid fish alone in quality and size.

Most of the N leached from liquid fish was as NH_4^+. Ammonium is not as a major concern in groundwater pollution as NO_3^- (Morey, 1987). Ammonium is less mobile in soil because of its positive charge. However, in warm, well-drained soil, NH_4^+ transforms rapidly to NO_3^-, which leaches easily. Not only does NO_3^- cause eutrophication, but, at high concentrations in drinking water, it can cause chemical suffocation disease in babies (Sukreeyapongse et al., 2001). Liquid fish is thus not environmentally sustainable unless combined with oilseed extract or alfalfa.

Oilseed extract resulted in the highest LF and the highest NO_3^- leaching. These results make oilseed extract not environmentally sustainable. It also resulted in the poorest quality of plants. Combining oilseed extract with alfalfa or liquid fish reduced its LF by ≈53% and 40%, respectively. It also reduced leached N by ≈56% and increased the quality of plants.

Our results indicate that organic fertilizers can be used successfully in greenhouse crop production. Used alone, organic fertilizers have either environmental limitations as is the case for liquid fish or performance limitations as is the case for oilseed extract and alfalfa. Combining organic fertilizers yields good-quality plants and supports environmental sustainability.

Literature Cited

Argo, W.R. and P.R. Fisher. 2002. Understanding pH management for container-grown crops. Meister Publishing, Willoughby, OH.

Bailey, D.A. and P.V. Nelson. 1998. Managing micronutrients in the greenhouse. NCSU Hort. Info. Leafl. 553.

Behe, B., B. Campbell, J. Ennis, C. Hall, R. Lopez, and C. Yue. 2010. Gardening consumer segments vary in eco-practices. HortScience 45: 1475–1479.

Bennett, W.F. 1994. Nutrient deficiencies and toxicities in crop plants. Amer. Phytopath. Soc., St. Paul, MN.

Bi, G., W.B. Evans, J.M. Spiders, and A.L. Witcher. 2010. Effect of organic and inorganic fertilizers on marigold growth and flowering. HortScience 45:1373–1377.

Bienfait, H.F. 1988. Mechanisms in Fe-efficiency of higher plants. J. Plant Nutr. 11:605–629.

Bunt, A.C. 1988. Media and mixes for container-grown plants. 2nd Ed. Unwin Hyman, London, UK.

Cavins, T.J., B.E. Whipker, W.C. Fonteno, B. Harden, I. McCall, and J.L. Gibson. 2000. Monitoring and managing pH and EC using the pourthru extraction method. NCSU Hort. Info. Leafl. 590.

Cox, D.A. 2010. Calibrachoa response to chemical and organic fertilizers. Floral Notes 23:2–4.

Dole, J.M., A. Williams, J.L. Gibson, B.E. Whipker, P.V. Nelson, B.R. Cleveland, and F.R. Walls. 2002. Nutrient deficiencies of calibrachoa. 16 Apr. 2013. <http://wwvv.ces.ncsu.edu/dpts/hort/floriculture/deficalibrachoa.htm>.

El-Jaoual, T. and D. Cox. 1998. Effects of plant age on nitrogen uptake and distribution by greenhouse plants. J. Plant Nutr. 21:1055–1066.

Ellis, B.W. 1999. Taylor's guide to annuals. Houghton Mifflin Co., Boston, MA.

Fasina, O., S. Sokhansanj, and R. Tyler. 1997. Thermodynamics of moisture sorption in alfalfa pellets. Drying Tech. 15:1553–1570.

Fisher, P.R., R.M. Wik, R.R. Smith, C.C. Pasian, M. Kmetz-Gonzalez, and W.A. Argo. 2003. Correcting iron deficiency in *calibrachoa* grown in a container medium at high pH. HortTechnology 13:308–313.

Gaskell, M. and R. Smith. 2007. Nitrogen sources for organic vegetable crops. HortTechnology 17:431–441.

Gaskell, M., R. Smith, J. Mitchell, S.T. Koike, C. Fouche, T. Hartz, W. Horwath, and L. Jackson. 2006. Soil fertility management for organic crops. UC Publ. Bull. l7249.

Guerinot, M.L. and Y. Yi. 1994. Iron: Nutritious, noxious, and not readily available. Plant Physiol. 104:815–820.

Hartz, T.K. and P.R. Johnstone. 2006. Nitrogen availability from high-nitrogen containing organic fertilizers. HortTechnology 16:39–42.

Issac, R.A. and W.C. Johnson, Jr. 1998. Elemental determination by inductively coupled plasma atomic emission spectrophotometry, p. 165–170. In: Kalra, Y.P. (ed.). Handbook of reference methods for plant analysis. CRC Press, Boca Raton, FL.

LaLiberte, K. 2013. When to water. 16 Apr. 2013. <http://www.gardeners.com/When-to-Water/8108,default,pg.html>.

Lopez, R., J. Dennis, B. Behe, C. Hall, C. Yue, and B. Campbell. 2011. Demand for sustainability, Part 2: What are growers doing about sustainability? Greenhouse Grower 29:32–36.

Lopez, R.G., J.H. Dennis, D.M. Camberato, J.T. Smith, B. Behe, and C. Hall. 2009. Consumer perceptions of sustainably produced poinsettias. Greenhouse Grower. 16 Apr. 2013. <http://www.greenhousegrower.com/article/11990/consumer-perceptions-of-sustainably-produced-poinsettias>.

Mills, H.A. 1980. Nitrogen specific ion electrodes for soil, plants and water analysis. J. Assoc. Off. Anal. Chem. 63:797–801.

Mills, H.A. and J.B. Jones. 1996. Plant analysis handbook II. MicroMacro Publ., Inc., Athens, GA.

Morey, D. 1987. Could fertilizer pollution of groundwater be the coming "big issue" for nursery growers? Nursery Business 32:44–46.

Nelson, D.W. and L.E. Sommer. 1980. Total N analysis of soil and plant tissues. J. Assoc. Off. Anal. Chem. 63:770–777.

Nelson, P., C. Niedziela, and D. Pitchay. 2012. Daniels plant food: Does it work? GrowerTalks 76.

OMRI. 2012. OMRI product list. Crop fertilizers and soil amendments. Organic Materials Review Institute. 16 Apr. 2013. <http://www.omri.org/sites/default/files/opl_pdf/crops_category.pdf/>.

Robbins, J.A. and M.R. Evans. 2010. Growing media for container production in a greenhouse or nursery, part II (physical and chemical properties). 16 Apr. 2013. <http://www.uaex.edu/Other_Areas/publications/PDF/FSA-6098.pdf/>.

Römheld, V. 1987. Existence of two different strategies for the acquisition of iron in higher plants, p. 445–476. In: Winkehnann, G., D. van der Helm, and J.B. Neilands (eds.). Iron transport in microbes, plants and animals. VCH Verlagsges, Weinheim, Germany.

SAS Institute Inc. 2002. SAS/STAT user's guide, version 9.1 for Windows. SAS Institute, Inc., Cary, NC.

Scoggins, H.L. and M.W. van Iersel. 2006. In situ probes for measurement of electrical conductivity of soilless substrates: Effects of temperature and substrate moisture content. HortScience 41:210–214.

Sonneveld, C. 1990. Estimating quantities of water soluble nutrients in soils using a specific 1:2 by volume extract. Commun. Soil Sci. Plant Anal. 21:1257–1265.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. McGraw-Hill, New York, NY.

Sukreeyapongse, O., S. Panichsakpatana, and J. Thongmarg. 2001. Nitrogen leaching from soil treated with sludge. Water Sci. Technol. 44: 145–150.

Wright, R.D. and A.X. Niemiera. 1987. Nutrition of container-grown woody nursery crops. Hort. Rev. 9:75–101.