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Guihong Bi
Mississippi State University

William B. Evans
Mississippi State University

James M. Spiers
USDA, Agricultural Research Service

Anthony L. Witcher
USDA, Agricultural Research Service

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Effects of Organic and Inorganic Fertilizers on Marigold Growth and Flowering

Guihong Bi[1] and William B. Evans
Truck Crops Branch Experiment Station, Mississippi State University, 2024 Experiment Station Road, Crystal Springs, MS 39059

James M. Spiers and Anthony L. Witcher
USDA-ARS Southern Horticultural Laboratory, 810 Highway 26 West, Poplarville, MS 39470

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Abstract*. Two experiments were conducted to evaluate the growth and flowering responses of greenhouse-grown French marigold (*Tagetes patula* L. 'Janie Deep Orange') to two non-composted broiler chicken litter-based organic fertilizers, 4-2-2 and 3-3-3, and one commonly used synthetic controlled-release fertilizer, 14-14-14. In both experiments, fertilizer 4-2-2 was applied at four rates of 1%, 2%, 4%, and 6% (by volume); 3-3-3 was applied at four rates of 1.34%, 2.67%, 5.34%, and 8.0% (by volume); and 14-14-14 was applied at rates of 0.99, 1.98, 3.96, and 5.94 kg·m^{-3}. In general, substrate containing different rates and types of fertilizers had a pH within the recommended range of 5.0 to 6.5. Electrical conductivity (EC) was similar among substrates containing different rates of 14-14-14; however, EC increased with increasing fertilizer rate for substrates containing 4-2-2 and 3-3-3. Substrate EC within each treatment was generally higher earlier in the experiment. For the fertilizer rates used in these two experiments, increasing 14-14-14 fertilizer rate increased plant growth and flowering performance. However, low to intermediate rates of 4-2-2 and 3-3-3 in general produced the highest plant growth index, shoot dry weight, number of flowers per plant, total flower dry weight, and root rating. Plants grown at high rates of 4-2-2 and 3-3-3 showed symptoms associated with excessive fertilization. Plant tissue nitrogen (N), phosphorus (P), and potassium (K) concentrations increased linearly or quadratically with increasing fertilizer rates for all three fertilizers. In general, plants receiving 4-2-2 and 3-3-3 had higher concentrations of N, P, and K than plants receiving 14-14-14. Results from this study indicated that broiler litter-based 4-2-2 and 3-3-3 have the potential to be used as organic fertilizer sources for container production of marigolds in greenhouses. However, growers need to be cautious with the rate applied. Because different crops may respond differently to these natural fertilizers, it is important for growers to test any new fertilizers before incorporating them into their production practices.

Standard fertilization practices for greenhouse and nursery crops include the use of controlled-release fertilizer, periodic application of water-soluble fertilizer during production, or both. Recent movements toward naturally managed gardens and the growing interest in managing the environmental impacts of agriculture have led to the development of organic and natural fertilizers that may be suitable for commercial use. Many of these fertilizers are byproducts of livestock, fish, and food and other processing industries (Gaskell and Smith, 2007). Some common materials used as organic fertilizer sources include fishmeal or fish powder, processed liquid fish residues, feather meal, blood meal, meat and bone meal, and manure-based materials including chicken manure (Gaskell et al., 2006; Hartz and Johnstone, 2006).

Annual broiler chicken production in the United States was ≈50 billion pounds in 2007 (MacDonald, 2008), and broiler chicken litter (manure plus bedding) may be produced at a rate of at least 1 ton per 1000 broilers (Mitchell and Donald, 1995; Patterson et al., 1998; Vest et al., 1994); thus, there is an abundant supply of chicken litter available for fertilizer and other uses. In Mississippi, the poultry industry produces more than 730 million broiler chickens each year, and the annual chicken litter production is estimated at more than 730,000 tons (Chamblee and Todd, 2002). Several companies across the nation produce and market broiler litter-based fertilizer pellets such as a Georgia- and Mississippi-based company whose products include a balanced 3-3-3 and a more nitrogen-rich 4-2-2 formula. Despite having lower nutrient concentrations than many synthetic fertilizers, similar broiler litter-based fertilizers have been shown to be effective plant fertilizers (Hammac et al., 2007). For growers wishing to use these and other natural fertilizers in their production systems, the biggest question is how the fertilizers need to be managed.

One of the main differences between organic and inorganic fertilizers is the timing and rate of nutrient release. Unlike inorganic fertilizers, nutrients in organic fertilizers are often not immediately available to plants after application. The organic forms of nutrients must be converted by soil microbes into inorganic forms before the plants can use them (Gaskell and Smith, 2007). Among all the nutrients required for plant growth and development, nitrogen (N) is often the most limiting factor. When organic fertilizer is added to a substrate, the organic N sources in organic fertilizer need to go through a mineralization process in which soil microbes convert organic N compounds into ammonium and a subsequent process that quickly oxidizes the ammonium to nitrate (Gaskell and Smith, 2007). Mineralization determines the rate and availability of mineral N to the plants; however, it is a highly variable process that is affected by many factors such as substrate temperature and moisture, microbial activity, and the nature of the organic matter (Kraus et al., 2000; Scagel, 2005). For example, Hartz and Johnstone (2006) found in an incubation study that only 21% (at 15 °C) to 36% (at 25 °C) of the organic N in a pelleted broiler litter product they tested was mineralized in the first 8 weeks after application, whereas the University of Georgia extension service recommends growers consider 50% of the N, 90% of the phosphorus (P), and 100% of the potassium (K) in raw poultry litter as available the first year after field application (Kissel et al., 2008). How litter-based fertilizer behaves in an actual greenhouse setting remains a significant question. The objective of this study was to evaluate the growth and flowering responses of container-grown greenhouse marigold plants to different rates of two broiler litter fertilizers and one commonly used synthetic controlled-release fertilizer.

Material and Methods

Substrate, fertilizer treatments, and plant material. Two experiments were conducted in a greenhouse at the Mississippi State University Truck Crops Branch Experiment Station in Crystal Springs, MS (lat. 31°59′ N, long. 90°21′ W). The substrate used in these two experiments contained peatmoss, vermiculite, and perlite (75:10:15 by volume). The substrate was blended with 0.89 kg·m^{-3} (1.5 lb/yd^3)

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[1]To whom reprint requests should be addressed; e-mail gb250@msstate.edu.

Micromax® (Scotts-Sierra Horticultural Products Co., Marysville, OH) and 2.97 kg·m^{-3} (5 lb/yd^3) dolomitic limestone. Surfactant Aqua-Gro® L (a.i. 99% alkoxylated polyols; Aquatrols, Paulsboro, NJ) at a rate of 78 mL·m^{-3} was added to the substrates during blending.

Two non-composted broiler litter-based organic fertilizers, TOP 4-2-2 (4N–0.9P–1.7K; Organic Growing Systems, Alpharetta, GA) and TOP 3-3-3 (3N–1.3P–2.5K; Organic Growing Systems), and a synthetic controlled-release fertilizer 14-14-14 (14N–4.2P–11.6K; Osmocote® 3–4 months; Scotts-Sierra Horticultural Products Co.) were used. In both experiments, 4-2-2 was applied at rates of 1%, 2%, 4%, and 6% (by volume); 3-3-3 was applied at rates of 1.34%, 2.67%, 5.34%, and 8.0% (by volume); and 14-14-14 was applied at rates of 0.99, 1.98, 3.96, and 5.94 kg·m^{-3}. Fertilizers were uniformly incorporated into the substrates before filling the pots. A control treatment received no additional fertilizer. Because N is often the most limiting macronutrient for plant growth and development, it is important to equilibrate N levels between the organic and inorganic fertilizers. The total N from each fertilizer rate is listed in Table 1. Rates of the organic fertilizer were selected based on an estimated 50% of the total applied N being available (Kissel et al., 2008).

French marigold (*Tagetes patula* L. 'Janie Deep Orange') seedlings grown in a standard 1206-cell pack were transplanted into round azalea plastic pots (15 cm o.d., 11 cm height; one plant/pot; ITML Horticultural Products, Inc., Brantford, Ontario, Canada) on 11 Oct. 2007 (Expt. 1) and 29 Jan. 2008 (Expt. 2). In both experiments, plants were placed on benches in a single-layer polycarbonate greenhouse (16 °C night temperature/24 °C vent temperature). Plants were hand-watered (10% leaching fraction) as needed.

Sampling. For both experiments, plants were harvested 40 d after transplanting. At harvest, leaf greenness (chlorophyll content) was quantified using a SPAD-502 Chlorophyll Meter (Minolta Camera Co., Ramsey, NJ). For each plant, three recently fully expanded leaves were randomly chosen for SPAD measurement and the average of the three readings was recorded. Plant growth index [(height + widest width + perpendicular width) ÷ 3] and number of fully open flowers were also recorded. Plant height was measured from the substrate surface to the tallest plant part. The above-ground portions of plants were cut off at the surface of the substrate and separated into shoots (stems and leaves) and flowers. The samples were placed into a 60 °C forced-air oven and dried to constant weight. Dry weight was recorded for each tissue type. Immediately after above-ground harvesting, plant roots were removed from their containers and root quality was assessed using a 0 to 5 scale in which 0 = no roots present at the container substrate interface; 1 = 1% to 20% of the container substrate interface with visible roots; 2 = 21% to 40%; 3 = 41% to 60%; 4 = 61% to 80%; and 5 = more than 80% of the container substrate interface with visible roots.

Tissue nutrient analyses. Five replications of shoot tissue from each treatment in Expt. 1 were ground with a Wiley mill (40 mesh) (Thomas Scientific, Swedesboro, NJ) for nutrient analysis. Tissue nutrient analyses were conducted in the Mississippi State University Soil Testing Laboratory. Total N was determined by Kjeldahl analysis (Schuman et al., 1973). Concentrations of other nutrients were determined by inductively coupled plasma emission spectrometry 4300 Optima DV (PerkinElmer Instruments, Norwalk, CT).

Substrate pH and electrical conductivity measurements. Substrate pH and electrical conductivity (EC) were measured at 4 and 28 d after planting (DAP) in Expt. 1 and 40 DAP in Expt. 2. Plants were watered to saturation and then allowed to drain for 30 min before measurements of pH and EC. The pH was directly measured using an IQ 150 pH Meter (Spectrum Technologies, Inc., Plainfield, IL), and EC was directly measured using a Field Scout® Soil EC Probe & Meter (Spectrum Technologies, Inc., Plainfield, IL) (Scoggins and van Iersel, 2006). One reading of pH and EC was taken per pot with 10 pots (replications) per treatment. Each probe was inserted to ≈3 cm depth and 4 cm from the edge of the pot.

Substrate physical property measurements. Substrate physical characteristics were determined at the USDA-ARS Southern Horticultural Laboratory in Poplarville, MS. Substrate air space, container capacity, and total porosity were determined using the procedures described in Bilderback et al. (1982). Substrate bulk density was determined from 347.5-cm^3 samples dried in a 105 °C forced-air oven for 24 h.

Experimental design and statistical analyses. In both experiments, plants were arranged in a completely randomized design with each experimental unit (one plant/pot) replicated 10 times for each treatment. Data were analyzed by analysis of variance using Statistica (Statsoft, Inc., Tulsa, OK) separately for each experiment. Comparisons of means among treatments were conducted using Tukey's honestly significant difference test at $P < 0.05$. Plant response to each fertilizer type was evaluated using linear and quadratic polynomial contrasts based on the fertilizer rate in the substrate.

Table 1. Means of pH and electrical conductivity (EC) (dS·m^{-1}) of substrates containing different types and rates of fertilizers in Expt. 1 and Expt. 2.

		Expt. 1				Expt. 2	
	Fertilizer total	4 DAP[y]		28 DAP		40 DAP	
Fertilizer[z]	nitrogen rate (g·m^{-3})	pH	EC	pH	EC	pH	EC
Control	0	5.64	0.50	6.60	0.23	6.58	0.24
14-14-14	139	5.67	0.78	6.78	0.22	6.46	0.21
14-14-14	277	5.39	0.75	6.39	0.23	6.35	0.24
14-14-14	554	5.56	0.95	6.27	0.28	5.92	0.25
14-14-14	831	5.40	1.09	6.24	0.34	5.82	0.36
4-2-2	259	5.79	1.12	6.45	0.27	6.41	0.23
4-2-2	518	5.61	1.52	6.33	0.35	6.34	0.24
4-2-2	1036	5.97	1.93	6.05	0.83	6.31	0.36
4-2-2	1555	6.26	2.08	5.47	2.57	6.10	0.68
3-3-3	259	5.72	1.38	6.22	0.32	6.42	0.27
3-3-3	518	6.02	1.70	5.83	0.80	6.35	0.24
3-3-3	1036	6.16	2.95	5.18	2.70	6.22	0.42
3-3-3	1555	6.58	3.26	5.58	3.62	6.06	1.00
HSD[x]		0.77	0.67	0.56	0.74	0.39	0.25
		Fertilizer rate response[w]					
14-14-14		NS	NS	L**	NS	L***	NS
4-2-2		L*	L***	L***	L**Q***	L*	L***Q**
3-3-3		L***	L**	L***Q**	L**	L**	L***Q***

[z]All treatments contained 0.89 kg·m^{-3} Micromax and 2.97 kg·m^{-3} dolomitic limestone.
14-14-14 = a synthetic controlled-release fertilizer (14N–4.2P–11.6K; Osmocote® 3–4 month); 4-2-2 = a non-composted broiler litter-based organic fertilizer (4N–0.9P–1.7K); 3-3-3 = a non-composted broiler litter-based organic fertilizers (3N–1.3P–2.5K).
[y]Days after planting.
[x]Tukey's honest significant difference ($P = 0.05$, n = 10).
[w]Significant linear (L) or quadratic (Q) contrasts at *$P \leq 0.05$, **0.01, or ***0.001 across fertilizer rates in each type of fertilizer. NS = non-significant.

Results and Discussion

Substrate physical properties. Fertilizer rate and type did not significantly alter substrate air space (19.0% to 24.3%), container capacity (67.3% to 72.5%), total porosity (89.3% to 92.3%), or bulk density (0.105 to 0.146 g·m^{-3}), although there was a trend that indicated a possible increase in bulk density with increasing rates of the organic fertilizers.

Substrate pH and electrical conductivity. In Expt. 1, at 4 DAP, pH was similar among substrates containing different rates of 14-14-14; however, substrate pH increased with increasing fertilizer rate of 4-2-2 and 3-3-3 (Table 1). Substrate pH decreased with increasing fertilizer rate for all three fertilizers at 28 DAP in Expt. 1 and at 40 DAP in Expt. 2 (Table 1). In general, substrate containing different rates and types of fertilizers had a pH within the recommended range of 5.0 to 6.5 for most container substrates (Robbins and Evans, 2010) with a few exceptions in which pH was slightly above the upper end of that range.

EC measures the concentration of all soluble salts in a substrate and can be affected by the amount or type of fertilizer applied (Robbins and Evans, 2010). The EC range recommended for most container substrates is 0.5 to 1.0 dS·m^{-1} (for plants fertilized with controlled-release fertilizer only) (Robbins and Evans, 2010; Yeager et al., 2007). At both 4 and 28 DAP in Expt.1 and 40 DAP in Expt.2, there was no significant difference in EC among substrates containing different rates of 14-14-14; however, substrate EC increased with increasing fertilizer rate for substrates containing 4-2-2 and 3-3-3, likely indicating a higher release or availability of nutrients at higher organic fertilizer rates.

In Expt. 1, substrate EC within each treatment was higher at 4 DAP compared with that at 28 DAP except for substrates containing the highest rates of 4-2-2 and 3-3-3, indicating the nutrient release or availability was generally higher during the beginning of the experiment regardless of the fertilizer type. Carpio et al. (2005) found that the nutrient release as determined by leachate EC readings was high during the beginning of the growth period (10 DAP) when an organic slow-release fertilizer (Nitrell 5-3-4; 5N–1.3 P–3.3K; Fertrell Co., Bainbridge, PA) and inorganic controlled-release fertilizer (Osmocote 18-7-10; 18N–3.0P–8.3K) were used in a soilless substrate container study with bush morning glory (*Ipomoea carnea* ssp. *fistulosa*). Carpio et al. (2005) also found that the EC readings were the lowest at the final sample day (48 DAP) regardless of fertilizer source, indicating the decreased residual fertility charge over time. Research using waste byproducts, including turkey litter compost, spent mushroom compost, paper mill waste, municipal waste compost, and others, also showed that the initial EC value in substrates amended with these waste byproducts was high (up to 8.9 dS·m^{-1}); however, the high initial EC had little or no discernible effect on plant growth of many deciduous nursery species because the elevated EC declined rapidly after potting as a result of the salts leaching from the containers through irrigation water to benign levels ($\approx$1.0 dS·m^{-1}) (Chong, 2005). In our study, the initial ECs (at 4 DAP) for substrates containing different rates of 14-14-14 were below or slightly above 1.0 dS·m^{-1}, which all decreased to below 1.0 dS·m^{-1} at 28 DAP. The initial ECs (at 4 DAP) in substrates containing 4-2-2 and 3-3-3 were all above 1.0 dS·m^{-1}, then declined to below 1.0 dS·m^{-1} at 28 DAP except for substrates containing the higher rates of 4-2-2 and 3-3-3. The continuous high EC, as a result of the high salt content, in the substrates containing high rates of organic fertilizers may negatively affect plant growth.

Plant growth and flowering. In Expt. 1, in general, increasing 14-14-14 fertilizer rate increased growth index (GI), shoot dry weight, number of flowers per plant, total flower dry weight, SPAD reading, and root rating (Table 2), whereas plant GI, shoot dry weight, and root rating responded linearly or quadratically with increasing fertilizer rate for 4-2-2 and 3-3-3. Plants grown in the low to intermediate rates of 4-2-2 and 3-3-3 produced the highest GI and shoot dry weight and had higher root ratings. The root ratings were the lowest for plants receiving the highest rates of 4-2-2 and 3-3-3 in which substrates had very high ECs, suggesting a possible high salt concentration in the substrate resulting in poor root growth (Fain et al., 2008). There was no significant difference in the number of flowers among plants receiving different rates of 4-2-2. For plants receiving 3-3-3, the number of flowers responded linearly and quadratically with increasing fertilizer rate and plants grown in the lower fertilizer rates produced the highest number of flowers. For plants grown in 4-2-2 or 3-3-3, there was a trend of decreasing total flower dry weight but increasing leaf SPAD reading with increasing fertilizer rate.

Similar to Expt. 1, leaf SPAD reading increased with increasing fertilizer rate for all three fertilizers in Expt. 2, and increasing 14-14-14 fertilizer rate increased plant GI, shoot dry weight, the number of flowers per plant, total flower dry weight, and root rating (Table 3). There was no significant difference in the number of flowers among plants receiving different rates of 4-2-2 and no significant difference in plant growth indices among plants receiving different rates of 3-3-3. For plants receiving 4-2-2, plant GI, shoot dry weight, flower dry weight, and root rating responded linearly or quadratically with increasing fertilizer rate, and plants grown in the intermediate rates of 4-2-2 had the highest GI, shoot dry weight, flower dry weight, and root rating. For plants that received 3-3-3, flower number and flower dry weight decreased with increasing fertilizer rate; however, the shoot dry weight and root rating responded linearly and quadratically with increasing fertilizer rate, and plants grown with intermediate rates of 3-3-3 had the highest shoot dry weight and root rating. As expected, plants grown in substrates without fertilizer (control) had the smallest GI, shoot dry weight, the number of flowers per plant, total flower dry weight, and SPAD values in both experiments.

These results indicate that broiler litter-based 4-2-2 and 3-3-3 fertilizers have the potential to be used as organic fertilizer sources for container production of marigold in greenhouses. Studies using other commercial organic fertilizers have also shown that organic fertilizers could be used to produce crops with similar or better growth, yields, or quality than conventionally grown crops (Altland et al., 2000; Gaskell et al., 2000; Russo, 2005; Treadwell et al., 2007; Zhao et al., 2009). However, the effects of organic fertilizers on plant growth seem varied, and some studies showed decreased plant growth or yields when using organic fertilizers compared with conventional fertilizers (Ali, 1997; Peet et al., 2004). This variation could be the result of the differences in organic fertilizer sources being used and application rates and timing (Rosen and Allan, 2007). Variation may also be the result of differences in nutrient availability and mineralization rates of various nutrient fractions under

Table 2. Plant growth index (GI), shoot dry weight (DW), flower dry weight (DW), number of flowers per plant, SPAD value, and root rating of 'Janie Deep Orange' French marigold grown for 40 d in substrates containing different types and rates of fertilizers (Expt. 1).

Fertilizer[z]	Fertilizer total nitrogen rate (g·m^{-3})	GI[y] (cm)	Shoot DW (g)	Flower DW (g)	Flower number	SPAD value[x]	Root rating[w]
Control	0	15.4	1.0	1.1	4.0	35.4	3.4
14-14-14	139	18.4	2.0	3.0	8.4	41.1	4.2
14-14-14	277	20.7	2.6	3.8	11.0	43.5	4.4
14-14-14	554	22.8	3.9	4.9	11.7	47.6	4.6
14-14-14	831	22.6	4.5	5.2	12.6	49.6	4.7
4-2-2	259	21.9	4.1	4.8	12.7	44.4	4.8
4-2-2	518	22.3	5.2	4.7	12.0	48.5	4.7
4-2-2	1036	22.2	5.1	4.0	11.4	49.8	4.0
4-2-2	1555	20.1	3.7	3.5	11.9	53.5	2.3
3-3-3	259	22.8	4.7	5.1	13.3	45.8	4.6
3-3-3	518	23.2	5.9	4.8	13.4	49.6	4.3
3-3-3	1036	18.9	3.4	3.2	10.7	51.9	2.5
3-3-3	1555	15.5	1.8	1.9	7.4	53.3	1.2
HSD[v]		2.7	0.9	1.0	2.7	4.8	0.8
		Fertilizer rate response[u]					
14-14-14		L***Q*	L***	L***	L***	L***	L*
4-2-2		L*Q*	Q***	L***	NS	L***	L**Q***
3-3-3		L**Q**	L**Q***	L**Q*	L***Q***	L***	L**Q**

[z]All treatments contained 0.89 kg·m^{-3} Micromax and 2.97 kg·m^{-3} dolomitic limestone.
14-14-14 = a synthetic controlled-release fertilizer (14N–4.2P–11.6K; Osmocote® 3–4 month); 4-2-2 = a non-composted broiler litter-based organic fertilizer (4N–0.9P–1.7K); 3-3-3 = a non-composted broiler litter-based organic fertilizers (3N–1.3P–2.5K).

[y]Plant growth index = [(height + width + perpendicular width) ÷ 3].

[x]SPAD reading using SPAD-502 chlorophyll meter (average of three leaves per plant).

[w]Root rating on a scale of 0 to 5 in which 0 = no roots present at the container substrate interface; 1 = 1% to 20% of the container substrate interface with visible roots; 2 = 21% to 40%; 3 = 41% to 60%; 4 = 61% to 80%; and 5 = more than 80% of the container substrate interface with visible roots.

[v]Tukey's honest significant difference (P = 0.05, n = 10).

[u]Significant linear (L) or quadratic (Q) contrasts at *$P \leq 0.05$, **0.01, or ***0.001 across fertilizer rates in each type of fertilizer. NS = non-significant.

the environmental and horticultural conditions of each study. For the organic fertilizer rates used in this study, in general, low to intermediate rates of 4-2-2 and 3-3-3 produced the highest plant GI, shoot dry weight, number of flowers per plant, total flower dry weight, and root rating. Plants grown at high rates of 4-2-2 and 3-3-3 showed symptoms associated with excessive fertilization, including reduced plant growth, decreased root quality, and decreased number and dry weight of flowers. This is consistent with results obtained from other studies showing excessive organic fertilizer depressed plant growth compared with lower fertility levels (Carpio et al., 2005; Kelley and Biernbaum, 2000).

Tissue nutrient concentrations. Plant tissue N, P, K, iron (Fe), and zinc (Zn) concentrations increased linearly or quadratically with increasing fertilizer rates for all three fertilizers (Table 4). For plants receiving 14-14-14, tissue concentration exhibited linear or quadratic increase in calcium (Ca) and magnesium (Mg); no difference in sulfur (S), manganese (Mn), or copper (Cu); and a linear decrease in boron (B) with increasing fertilizer rates. For plants receiving 4-2-2 or 3-3-3, tissue concentration exhibited linear decrease in Ca; no difference in Mg and S; and a linear or quadratic increase in Mn, Cu, and B with increasing fertilizer rates. In general, plants receiving 4-2-2 and 3-3-3 had higher concentrations of N, P, K, Fe, Mn, Zn, and Cu than plants receiving 14-14-14. For plants that did not receive any fertilizer, in general, tissue nutrient concentrations are similar or lower

Table 3. Plant growth index (GI), shoot dry weight (DW), flower dry weight (DW), number of flowers per plant, SPAD value, and root rating of 'Janie Deep Orange' French marigold grown for 40 d in substrates containing different types and rates of fertilizers (Expt. 2).

Fertilizer[z]	Fertilizer total nitrogen rate ($g \cdot m^{-3}$)	GI[y] (cm)	Shoot DW (g)	Flower DW (g)	Flower number	SPAD value[x]	Root rating[w]
Control	0	9.4	0.8	0.5	1.9	35.0	1.6
14-14-14	139	17.1	2.0	2.7	8.4	42.4	2.4
14-14-14	277	18.2	2.8	3.2	8.9	45.2	2.5
14-14-14	554	18.9	3.7	3.3	9.0	49.3	3.1
14-14-14	831	19.3	4.4	3.6	10.0	51.1	3.4
4-2-2	259	17.9	2.3	2.8	8.7	39.9	2.6
4-2-2	518	19.4	3.1	3.1	8.9	41.4	3.1
4-2-2	1036	19.3	3.7	2.8	9.0	42.1	2.8
4-2-2	1555	18.4	3.4	2.2	8.1	44.5	2.3
3-3-3	259	17.5	2.5	3.2	10.0	40.9	3.0
3-3-3	518	17.9	3.4	2.8	8.3	42.8	3.6
3-3-3	1036	17.8	3.7	2.4	8.4	44.8	3.6
3-3-3	1555	17.6	3.3	1.8	7.5	45.8	2.1
HSD[v]		2.1	0.8	0.8	1.7	4.5	0.9
			Fertilizer rate response[u]				
14-14-14		L***	L**	L**	L**	L***	L***
4-2-2		Q*	L***Q**	L*Q*	NS	L**	Q*
3-3-3		NS	L**Q***	L***	L***	L***	L*Q***

[z]All treatments contained 0.89 $kg \cdot m^{-3}$ Micromax and 2.97 $kg \cdot m^{-3}$ dolomitic limestone.
14-14-14 = a synthetic controlled-release fertilizer (14N–4.2P–11.6K; Osmocote® 3–4 month); 4-2-2 = a non-composted broiler litter-based organic fertilizer (4N–0.9P–1.7K); 3-3-3 = a non-composted broiler litter-based organic fertilizers (3N–1.3P–2.5K).
[y]Plant growth index = [(height + width + perpendicular width) ÷ 3].
[x]SPAD reading using SPAD-502 chlorophyll meter (average of three leaves per plant).
[w]Root rating on a scale of 0 to 5 in which 0 = no roots present at the container substrate interface; 1 = 1% to 20% of the container substrate interface with visible roots; 2 = 21% to 40%; 3 = 41% to 60%; 4 = 61% to 80%; and 5 = more than 80% of the container substrate interface with visible roots.
[v]Tukey's honest significant difference ($P = 0.05$, n = 10).
[u]Significant linear (L) or quadratic (Q) contrasts at $^{*}P \leq 0.05$, **0.01, or ***0.001 across fertilizer rates in each type of fertilizer. NS = non-significant.

Table 4. Mean nutrient concentrations in shoots (stems and leaves) of 'Janie Deep Orange' French marigold grown for 40 d in substrates containing different types and rates of fertilizers (Expt. 1).

		Concn										
	Fertilizer total	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sulfur	Iron	Manganese	Zinc	Copper	Boron
Fertilizer[z]	nitrogen rate ($g \cdot m^{-3}$)	(%)						(ppm)				
Control	0	2.44	0.08	1.80	1.26	0.57	0.83	34.4	152.8	37.8	5.6	110.8
14-14-14	139	2.67	0.15	2.63	1.30	0.66	0.87	51.8	189.0	47.0	6.6	89.4
14-14-14	277	2.89	0.23	3.40	1.57	0.77	0.95	63.0	245.0	60.0	8.0	92.4
14-14-14	554	3.16	0.34	3.13	1.50	0.75	0.81	66.8	206.2	58.0	7.8	69.4
14-14-14	831	4.00	0.41	3.09	1.49	0.83	0.81	55.2	215.0	67.4	6.6	72.0
4-2-2	259	3.51	0.56	3.78	1.46	0.74	0.96	63.6	133.2	55.8	11.6	84.2
4-2-2	518	4.93	0.74	4.22	1.46	0.77	0.85	80.8	156.2	71.6	18.6	83.0
4-2-2	1036	5.49	0.84	4.14	1.26	0.66	0.81	114.2	255.0	84.8	19.8	74.6
4-2-2	1555	6.55	0.71	4.47	1.33	0.71	0.93	115.2	517.4	118.0	26.2	86.4
3-3-3	259	3.80	0.49	3.89	1.39	0.68	0.89	60.4	157.2	55.8	10.2	75.8
3-3-3	518	5.83	0.71	4.17	1.33	0.67	0.91	102.2	274.2	89.8	20.6	76.0
3-3-3	1036	6.73	0.69	3.91	1.28	0.67	0.92	112.6	475.4	104.6	20.4	85.8
3-3-3	1555	6.46	0.71	4.43	1.20	0.69	0.97	113.8	362.4	103.6	23.6	93.6
HSD[y]		0.68	0.13	0.58	0.24	0.13	0.18	21.9	77.3	14.9	4.1	12.6
						Fertilizer rate response[x]						
14-14-14		L***Q*	L***	Q**	L*Q**	L***	NS	Q*	NS	L***	NS	L***
4-2-2		L**	L***Q***	L**	L*	NS	NS	L***	L**Q***	L**Q***	L***	Q*
3-3-3		L**Q***	L***Q***	L*	L**	NS	NS	L***Q***	L***Q***	L***Q***	L***Q***	L***

[z]All treatments contained 0.89 $kg \cdot m^{-3}$ Micromax and 2.97 $kg \cdot m^{-3}$ dolomitic limestone. 14-14-14 = a synthetic controlled-release fertilizer (14N–4.2P–11.6K; Osmocote® 3–4 month); 4-2-2 = a non-composted broiler litter-based organic fertilizer (4N–0.9P–1.7K); 3-3-3 = a non-composted broiler litter-based organic fertilizers (3N–1.3P–2.5K).
[y]Tukey's honest significant difference ($P = 0.05$, n = 5).
[x]Significant linear (L) or quadratic (Q) contrasts at $^{*}P \leq 0.05$, **0.01, or ***0.001 across fertilizer rates in each type of fertilizer. NS = non-significant.

than plants that received the lowest rate of 14-14-14, except for B, which was the highest among all treatments.

As mentioned previously, we equilibrated N levels between the organic and inorganic fertilizers based on an estimate of 50% N availability from the organic fertilizers. However, the actual nutrient availability from organic fertilizers could be quite different from the estimated level. The higher nutrient concentrations seen in plants receiving organic fertilizers could be the result of higher nutrient release or availability or greater nutrient uptake efficiency. The high tissue nutrient concentrations, some of which were above plant sufficiency ranges described by Marschner (1986) and Mills and Jones (1996), along with the reduced plant growth seen at the higher organic fertilizer rates may have indicated luxury or excessive consumption of the nutrients.

The high tissue nutrient concentrations and high EC values in the substrates with higher rates of organic fertilizers may also imply high nutrient concentrations in the substrates. Leaching of N, P, and other nutrients could be significant if the litter-based fertilizers are overapplied and/or improperly watered. We also see evidence in the micronutrient data that organic fertilizer treatments elevated the concentrations of some micronutrients, including Fe, Mn, Zn, and Cu, especially at higher fertilizer rates. Broiler litter can contain significant levels of some micronutrients such as copper (Kpomblekou-A et al., 2002), which can be toxic at relatively modest levels in some plant species (Marschner, 1986). Thus, it is important to monitor the micronutrients as well as macronutrient levels when broiler litter-based fertilizers are used in the production system.

Compared with conventional fertilizers, organic fertilizers or composts have been shown to improve soil quality (Edmeades, 2003; Liebig and Doran, 1999) and are often considered more environmentally friendly (Rosen and Allan, 2007). However, it could be a challenge to develop a precise and efficient organic fertilization program because available organic fertilizers are diverse in nutrient content and physical and chemical properties. This is further complicated by differences among sources, much as one finds with limestone or other natural amendments. Furthermore, the nutrient availability and release rates from organic fertilizers are affected by many factors, including application timing and rate, microbial activity, soil temperature and moisture, substrate components, and the nature of the organic fertilizer (Rosen and Allan, 2007). It is critical and also a major challenge in organic fertilizer management to find methods to optimize synchrony between nutrient mineralization and crop demand (Treadwell et al., 2007). Also, just as with conventional fertilizer sources, different crops may respond differently to different organic fertilizers. Therefore, it is important for growers to test any new fertilizers before incorporating them into their production practices.

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