Plant Performance and Nutrient Losses during Containerized Bedding Plant Production Using Composted Dairy Manure Solids as a Peat Substitute in Substrate

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Additional index words. nursery production, potting media, *Solenostemon scutellarioides*, *Tagetes patula*, *Begonia ×hybrida*

Abstract. Recent concerns over the environmental impact of peat harvesting have led to restrictions on the production of peat in Florida and other areas. The objectives of this study were to evaluate the use of composted dairy manure solids as a substitute for sphagnum or reed-sedge peat in container substrates on the growth of *Solenostemon scutellarioides* L. Codd ‘Wizard Velvet’, *Tagetes patula* L. ‘Safari Queen’, and *Begonia ×hybrida* ‘Dragon Wing Red’ and to examine the nutrient content in leachate from pots. Plants were grown for 5 weeks in a greenhouse in 15-cm plastic pots with seven substrates containing various proportions of sphagnum peat (S) or reed-sedge peat (R) and composted dairy manure solids (C), each with 20% vermiculite and 20% perlite. Substrate composition had no effect on plant quality ratings, number of flowers, or root dry mass for any of the plant species evaluated. Substrate composition did not affect the growth index (GI) or shoot dry mass of *S. scutellarioides* ‘Wizard Velvet’ or the GI of *T. patula* ‘Safari Queen’. However, growth of *B. ×hybrida* ‘Dragon Wing Red’ (GI and shoot dry mass) and *T. patula* ‘Safari Queen’ (shoot dry mass only) was highest in the 3S:0R:0C substrate. The substrates containing sphagnum peat and/or composted dairy manure solids (3S:0R:0C, 2S:0R:1C and 1S:0R:2C) had the highest NH₄-N losses through the first 7 d of production. The 0S:3R:0C substrate had the highest initial leachate NO₃+NO₂-N losses and this trend persisted throughout most of the production cycle. Significantly more dissolved reactive phosphorus was leached from substrate mixes containing composted dairy manure solids than mixes containing only sphagnum or reed-sedge peat materials through 19 d after planting. All substrates tested as part of this study appeared to be commercially acceptable for production of container-grown bedding plant species based on plant growth and quality. However, nutrient losses from the containers differed depending on the peat or peat substitute used to formulate the substrates.

Peat is one of the fundamental components of most horticultural potting substrates because

it contributes to water-holding capacity, porosity, and cation exchange capacity of container substrates. The two most commonly used types of peat in potting substrates are sphagnum and reed-sedge peat. Recent concerns over the environmental impact of peat harvesting have led to restrictions on the production of peat in many areas. For example, extensive mitigation efforts are required to obtain permits for mining reed-sedge peat in Florida (FDEP, 2010). The nursery industry outside the United States is also looking to reduce detrimental impacts on wetlands through peat harvest. In 2005, the U.K. government set a goal to replace 90% of peat used in nursery container production and retail substrate by 2010 (Holmes, 2009).

As peat becomes more expensive and more difficult to obtain, researchers have begun to evaluate other materials as a substitute for peat in container substrate. For example, re-

searchers have evaluated coconut fibers (coir pith and dust) (Hensley and Yogi, 1997), composted biosolids (Klock-Moore, 1999; Lopez et al., 2008), municipal solid waste, and pruning waste (Lopez et al., 2008) as potential substitutes for peat in potting substrates. Beeson (1996) suggested that composted yard waste could be successfully substituted for peat during the production of *Rhododendron indicum* (L.) Sweet ‘Due du Rohan’ and *Pittosporum tobira variegata* Ail. in 10.2-L (#3) pots. Similarly, Klock-Moore (1999) reported that substrates containing composted biosolids and yard trimming could be used to produce *Begonia ×semperflorens-cultorum* Hort. ‘Oasis Scarlet’ and *Impatiens wallerana* Hook. f. ‘Super Elfin Violet’. In contrast, Lopez et al. (1998) reported that growth was significantly lower for *Pelargonium zonale* (L.) L’Hér. ‘Lucy Break F2’ produced in a substrate containing composted manure, pine bark, and cotton gin trash than in a peat-based commercial potting substrate. The authors suggested that poor performance was the result of poor substrate structure, high substrate pH, or high C:N ratio.

The significant presence of the dairy industry in Florida has generated interest in the potential for using composted dairy cattle manure solids as a substitute for peat. Reuse of the manure solids could significantly reduce the need for land application, which itself represents significant potential for environmental degradation as a result of leaching and runoff of nutrients when manures are broadcast over a large area (Davis et al., 1997; Elliott et al., 2002; Flavel and Murphy, 2006). Composting manure solids results in a uniform and stable product that is likely to have the physical properties necessary to support plant growth (Li et al., 2009). Mature composts provided adequate levels of available inorganic nitrogen (N) and were not phytotoxic to plants (Cogger, 2005; Hue and Sobieszczyk, 1999; Zucconi et al., 1981). Researchers suggest that composts should have a C:N ratio of less than 20:1 (Cogger, 2005) or 15:1 for some plants (Hue and Sobieszczyk, 1999) to provide the plant with enough available N.

Researchers have suggested that composted dairy manure solids may be an acceptable substitute for peat in container substrate (Gorodecki and Hadar, 1990; Li et al., 2009; Wang et al., 2004). Additions of composted dairy manure to soil improved growth of maize in pots compared with an untreated loamy-sand field soil (Irshad et al., 2002). Raviv et al. (2005) reported that container substrate formulated with composted cow manure and other additives (e.g., wheat straw, grape marc, orange peels) provided acceptable growth of tomato compared with control substrate formulated with sphagnum peat. Wang et al. (2004) suggested composted dairy manure solids would be an adequate substitute for sphagnum peat provided it was fully composted and fertilizer was added or wheat straw was composted with the manure. Available N was not adequate in other substrate combinations.

Received for publication 18 May 2010. Accepted for publication 5 Aug. 2010.

This work was supported by the Florida Agricultural Experiment Station, the Florida Department of Agriculture and Consumer Services, and the Florida Nursery, Growers and Landscape Association.

We thank Nancy West, Gitta Shurberg, and Tim Davis of the University of Florida Gulf Coast REC for their assistance with data collection. We also thank Speedling, Inc. for donating plant material.

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Table 1. Selected chemical properties of seven substrates formulated with Canadian sphagnum peat (S), Florida reed-sedge peat (R), and/or composted dairy manure solids (C), each with 20% vermiculite and 20% perlite.

Substrate	Dolomite rate (kg·m ⁻¹)	pH	Electrical conductivity (dS·m ⁻¹)	C/N ratio ^z	Total N ^z (g·kg ⁻¹)	Total P ^z (g·kg ⁻¹)	DTPA-NO ₃ ^z (mg·L ⁻¹)	DTPA-NH ₄ ^z (mg·L ⁻¹)	DTPA-P ^z (mg·L ⁻¹)
3S:0R:0C	4.15	6.6	0.11	60.3	3.8	1.1	1.8	2.1	0.4
0S:3R:0C	— ^y	6.1	0.12	17.9	9.2	0.4	9.1	ND ^x	0.3
2S:0R:1C	2.97	6.5	0.32	28.7	7.7	2.2	0.6	1.7	11.0
0S:2R:1C	—	6.6	0.29	17.1	11.4	1.5	0.6	0.2	11.7
1S:0R:2C	—	6.1	0.51	20.5	9.7	3.2	ND	3.5	20.1
0S:1R:2C	—	7.0	0.50	17.3	13.1	2.6	0.7	0.4	31.4
0S:0R:3C	—	7.4	0.58	16.9	12.2	3.9	ND	7.4	33.5

^zTotal nitrogen, total carbon, total phosphorus, DTPA-NO₃, DTPA-NH₄, and DTPA-P were determined on a separate substrate samples consisting of the same raw materials as the mix used in the current study.

^y—No dolomite was added to the substrate.

^xND = not detectable using EPA method 353.2.

Nutrient leaching, particularly N and phosphorus (P), is a concern with any container substrate formulation. A number of factors affect the extent of leaching from container substrate, including the substrate components (Wilson et al., 2009), species grown in the substrate (Cole and Newell, 1996), frequency of watering or rainfall (Broschat, 1995), volume of water applied (Huett, 1997; Huett and Morris, 1999; Yelanich and Biernbaum, 1994), and/or the addition of inorganic fertilizers (Beeson, 1996). Some substrates that used compost products (e.g., composted yard waste, composted recycled paper) as a peat substitute leached equal or less N (as NO₃-N and NH₄-N) (Beeson, 1996; Cole and Newell, 1996) and P (Beeson, 1996) than a comparable peat-based substrate. Similarly, a substrate containing pine bark, peat, and sand at a ratio of 3:1:1 produced less leachate NH₄-N than a comparable substrate in which peat was replaced with composted paper (Cole and Newell, 1996). Researchers suggest that managing watering schedule and moisture tension of the soil can reduce leachate of conventional substrate (Andersen and Hansen, 2000; Juntunen et al., 2002) as well as substrate containing compost components (Zhu et al., 2009).

The objectives of this study were to 1) evaluate the use of composted dairy manure solids as a substitute for sphagnum or reed-sedge peat in container substrate on the growth and quality of *S. scutellaroides* 'Wizard Velvet', *T. patula* 'Safari Queen', and *Begonia* 'Dragon Wing Red'; and 2) assess the potential for N and P leaching from substrates during production by examining the nutrient content in leachate from pots.

Materials and Methods

Formulation of potting substrate. Seven substrates were formulated by mixing Canadian sphagnum peat (S), Florida reed-sedge peat (R), and/or composted dairy manure solids (C) in the following ratios by volume: 1) 3S:0R:0C; 2) 0S:3R:0C; 3) 2S:0R:1C; 4) 0S:2R:1C; 5) 1S:0R:2C; 6) 0S:1R:2C; and 7) 0S:0R:3C, each with 20% vermiculite and 20% perlite. Canadian sphagnum peat was purchased from Fafard, Inc. (Apopka, FL); Li et al. (2009) reported a pH of 3.9, an electrical conductivity (EC) of 0.32 dS·m⁻¹, and a C:N ratio of 56.8 for Canadian sphagnum peat from the same source purchased at about the

Fig. 1. Growth index (cm³) of *Begonia xhybrida* 'Dragon Wing Red' grown from plugs in substrates containing varying proportions of Canadian sphagnum peat (S), Florida reed-sedge peat (R), or composted dairy manure solids (C), each with 20% vermiculite and 20% perlite. Mean separation by Tukey's honestly significant difference test at $P \leq 0.05$.

Fig. 2. Shoot dry mass (g) of (A) *Begonia xhybrida* 'Dragon Wing Red' and (B) *Tagetes patula* 'Safari Queen' grown from plugs in substrates containing varying proportions of Canadian sphagnum peat (S), Florida reed-sedge peat (R), or composted dairy manure solids (C), each with 20% vermiculite and 20% perlite. Mean separation by Tukey's honestly significant difference test at $P \leq 0.05$.

same time as our material. Florida reed-sedge peat was purchased from Reliable Peat Co. (Okahumpka, FL); Li et al. (2009) reported a pH of 6.9, an EC of 0.31 dS·m⁻¹, and a C:N ratio of 18.3 for Florida reed-sedge peat from the same source purchased at about the same time. Composted dairy manure solids were generated by Agrigy Co. (Clearwater, FL) at their Lake Okeechobee facility, where dairy manure solids were screened, composted in a large rotary drum composter at temperatures up to 65 °C for 3 d, and allowed to cure in static piles (Nordstedt and Sowerby, 2003). Li et al. (2009) reported a pH of 6.9, an EC of 4.8 dS·m⁻¹, and a C:N ratio of 15.1 for composted dairy manure solids from the same source that were received at about the same time as our material. Vermiculite and perlite were purchased from Verlite Co. (Tampa, FL) and S&B Industrial Materials (Vero Beach, FL).

The pH and EC of each substrate were measured using a 2:1 deionized water to substrate extract. Commercially available dolomitic lime was used to adjust substrate pH to 6.5 when necessary (Table 1). A bulk sample of substrate mixes formulated with peat and composted dairy manure solids from the sources noted was ground and sieved to pass a 0.42-mm screen. Substrate samples were analyzed for total carbon (C), N, and P. Substrates were also extracted with 2.00 mM DTPA (Australia, 1989) and analyzed for extractable NO₃-N, NH₄-N and P using a flow analyzer (Midwest Laboratories, Omaha, NE).

Plant materials and experimental design.

Three annual bedding plant species, *Solenostemon scutellarioides* L. Codd 'Wizard Velvet', *Tagetes patula* L. 'Safari Queen', and *Begonia ×hybrida* 'Dragon Wing Red' (Speedling Inc., Sun City, FL), were transplanted 20 to 26 June 2007 from plugs (received 12 June 2007) into 15.2-cm plastic pots. Three plugs of *S. scutellarioides* and *B. ×hybrida* 'Dragon Wing Red' and four plugs of *T. patula* were transplanted from 288-count trays into each pot. Additionally, each substrate treatment included four pots containing substrate mixes only (no plant material). All plants were grown for a period of 5 weeks in a greenhouse. Plant and substrate-only pots were fertilized (as a top-dress) with 10 g Osmocote + Minors (15N-3.9P-10K, 4-month continuous feed; The Scotts Co., Marysville, OH) per pot. Plants were irrigated using a drip irrigation system that was regulated to 15 psi. Each 15.2-cm pot was outfitted with a single Antelco Shrubblor® 360° adjustable-flow dripper (Antelco Corp., Longwood, FL) that was set to water at the same rate. The irrigation schedule was created to ensure that plants would have adequate water for optimum growth with initial rates based on measurements of the volume of water required to saturate the substrates in a 15.2-cm pot containing no plant material. The initial irrigation run time was set for 60 s per event to deliver ≈194 ± 5 mL. All emitters were adjusted weekly to increase the irrigation volume delivered to each pot to meet the transpiration needs of the growing plants. As the plants matured, the irrigation run time was also increased to 120 s per event to ensure adequate

water for the growing plants. Irrigation events were initiated at 0900 HR on days when the substrate surface in most pots (greater than 50%) was dry. All pots were irrigated for the same duration to ensure that irrigation volume was applied consistently to all pots. Although the irrigation schedule was not specifically designed to produce leachate, variability in substrate water-holding capacity between treatments and individual pot variability resulted in generation of leachate from pots.

Plant measurements and evaluation. Plant measurements and evaluations were conducted on all plant replicates once plants reached marketable size [35 d after potting (DAP)]. Plant quality was visually rated on a scale of 1 (dead plant, not marketable) to 5 (dense, full canopy with no dieback). The total number of flowers was evaluated as buds and flowers with visible color for *T. patula* 'Safari Queen' and flower clusters for *B. ×hybrida* 'Dragon Wing Red'. Plant growth index (GI) was used as a quantitative indicator of plant growth and was calculated for each plant as: GI (cm³) = H × W1 × W2, where H is the plant height (cm), W1 is the widest width of the plant (cm), and W2 is the width perpendicular to the widest width (cm). Shoot biomass was harvested by cutting the plant at the base and

root biomass was collected by washing the substrate from the roots. Shoots and roots were dried to a constant mass at 105 °C (minimum 48-h drying time) and dry mass (g) was recorded.

Leachate collection and analysis. Leachate was allowed to drain freely into a collection bucket positioned under each pot. The buckets were tightly fitted to the pots to reduce the potential for the evaporation of leachate between collection events. Pots were elevated to prevent them from sitting in the standing leachate water. The total volume of leachate collected from each pot was recorded 1 d after planting and then weekly until plant harvest. Leachate was thoroughly mixed and a 100-mL subsample of unfiltered leachate was collected for analysis at 1 d after potting (before fertilization) and then bi-weekly until plant harvest. Leachate samples were filtered through 0.45-μm membrane filters. Filtered samples were stored frozen until they were analyzed for NO₃+NO₂-N (USEPA, 1993), NH₄-N (USEPA, 1983), and dissolved reactive P (DRP) (Pote and Daniel, 2009) using a discrete analyzer (AQ2, Seal Analytical, West Sussex, U.K.). Nutrient loads from each pot (in mg) were determined by multiplying the concentration of NO₃+NO₂-N,

Table 2. Total load (mg per pot) of NH₄-N in leachate (n = 5) collected from bedding plant species grown in 15-cm containers with substrates composed of varying proportions of Canadian sphagnum peat (S), Florida reed-sedge peat (R), or composted dairy manure solids (C).

Substrate	NH ₄ -N load ^a			
	2 DAP ^b	5 DAP	19 DAP	32 DAP
<i>B. ×hybrida</i> 'Dragon Wing Red'				
3S:0R:0C	4.97 cd ^a	9.46 c	4.02 a	7.55 b
0S:3R:0C	0.19 a	0.48 a	2.72 a	1.28 a
2S:0R:1C	6.51 d	2.73 bc	1.58 a	1.93 a
0S:2R:1C	0.66 ab	1.00 ab	1.60 a	1.44 a
1S:0R:2C	1.80 bc	2.23 b	1.60 a	1.30 a
0S:1R:2C	1.17 b	0.39 a	1.29 a	1.39 a
0S:0R:3C	1.91 bc	0.47 a	1.18 a	0.81 a
<i>S. scutellarioides</i> 'Wizard Velvet'				
3S:0R:0C	5.73 d	15.95 c	3.61 b	4.37 a
0S:3R:0C	0.28 a	0.61 ab	2.10 ab	2.61 a
2S:0R:1C	5.32 d	1.97 ab	2.04 ab	2.20 a
0S:2R:1C	0.53 ab	0.68 ab	1.32 ab	1.77 a
1S:0R:2C	1.56 bc	4.83 b	1.38 ab	1.58 a
0S:1R:2C	0.82 abc	0.84 ab	0.93 a	1.51 a
0S:0R:3C	1.93 cd	1.55 ab	0.99 a	2.77 a
<i>T. patula</i> L. 'Safari Queen'				
3S:0R:0C	4.83 cd	5.74 c	5.09 b	2.48 a
0S:3R:0C	0.19 a	1.02 ab	2.14 ab	1.77 a
2S:0R:1C	6.18 d	2.44 bc	3.14 ab	2.24 a
0S:2R:1C	0.60 ab	0.66 a	1.45 a	1.13 a
1S:0R:2C	1.60 bc	6.05 c	3.84 ab	2.13 a
0S:1R:2C	0.74 bc	0.86 ab	1.85 ab	1.22 a
0S:0R:3C	1.40 bc	0.66 a	2.43 ab	0.94 a
No plant				
3S:0R:0C	9.30 d	18.1 b	17.4 b	4.57 b
0S:3R:0C	0.01 a	0.61 a	2.15 a	0.91 a
2S:0R:1C	8.18 d	9.84 b	2.25 a	0.67 a
0S:2R:1C	0.57 b	0.81 a	1.26 a	0.44 a
1S:0R:2C	2.23 c	7.94 b	1.69 a	0.56 a
0S:1R:2C	0.79 bc	1.11 a	1.34 a	0.43 a
0S:0R:3C	1.35 bc	1.83 a	0.72 a	0.43 a

^aNutrient loads from each pot were determined by adjusting the concentration of NH₄-N with the volume of leachate collected from each pot.

^bDAP = days after potting.

^cMean separation for each species and collection date by Tukey's honestly significant difference test at P ≤ 0.05.

NH₄-N, and DRP with the volume of leachate collected from each pot.

Statistical analysis. The experiment was designed as a randomized complete block design with seven potting substrate treatments applied randomly to five plant replicates within each species. Data were analyzed separately for each plant species. Plant quality data were analyzed using the PROC GLIMMIX program in SAS (SAS Institute, 2003) with the multinomial distribution and the cumulative logit link function. Number of flowers (*T. patula* L. 'Safari Queen' and *B. ×hybrida* 'Dragon Wing Red') was analyzed using the PROC GLIMMIX program in SAS (SAS Institute, 2003) using the Poisson distribution and the log link function. Plant size index, dry root mass, dry shoot mass, and harvest biomass ratio (mass dry roots/mass dry shoots) data were analyzed using the PROC MIXED procedure in SAS (SAS Institute, 2003). Leachate nutrient loads were log-transformed and analyzed using PROC MIXED in SAS (SAS Institute, 2003) at 2, 5, 19, and 34 DAP. Leachate samples with concentrations of NO₃+NO₂-N, NH₄-N, and DRP that were below the detection limit (MDL × 2.5) were assigned a value of half the detection limit. All pairwise comparisons were completed using the Tukey honestly significant difference test with a significance level of $\alpha = 0.05$.

Results and Discussion

Plant quality, growth, and flowers. Plant quality ratings and number of flowers for all plant species evaluated were not different among the seven substrates (data not shown). Root dry mass also did not differ (data not shown). Our results were similar to the findings of Li et al. (2009), who reported no differences in the root dry mass of *Epipremnum aureum* (Linden ex André) Bunting and *Ficus benjamina* L. 'Florida Spire' produced in 72-cell plug trays using substrate formulated with various proportions (10% to 60% by vol.) of sphagnum, reed-sedge, and composted dairy manure solids. However, Li et al. (2009) did report significant substrate effects on root growth of *Asparagus densiflora* (Knuth) Jessop and *Philodendron scandens* subsp. *oxycardium* (Schott) G.S.Bunting. The authors suggested that the differences in root dry mass reported in their study were the result of physiological differences between plant species such as differences in plant tolerance to salts or epiphytic nature of the species (i.e., *P. scandens*) (Li et al., 2009).

The GI or shoot dry mass of *S. scutellarioides* 'Wizard Velvet' and the GI of *T. patula* 'Safari Queen' were not different among substrates (data not shown). These results were similar to those reported by Li et al. (2009) for *P. scandens*, *E. aureum*, and *F. benjamina* 'Florida spire'. However, *B. ×hybrida* 'Dragon Wing Red' grown in the 3S:0R:0C substrate had larger GI than plants grown in the 0S:2R:1C and 0S:0R:3C substrates (Fig. 1) and produced more dry shoot mass than plants grown in 0S:3R:0C, 1S:0R:2C, 0S:1R:2C, and 0S:0R:3C substrates (Fig. 2). *T. patula* 'Safari

Queen' grown in the 1S:0R:2C substrate produced significantly more biomass than plants grown in the 0S:2R:1C, 0S:1R:2C, and 0S:0R:3C substrates (Fig. 2).

It is possible that the reduced growth and shoot mass of *B. ×hybrida* 'Dragon Wing Red' may be the result of higher salt content in the composted dairy manure solids-based substrates. Miyamoto et al. (2004) reported low salt tolerance (less than 3 dS·m⁻¹) for *Begonia* spp. In our study, substrate EC was highest for composted dairy manure solids-based substrates (Table 1) suggesting salts may have impacted growth of *B. ×hybrida* 'Dragon Wing Red'. In addition, reduced growth may have been the result of reduced N uptake by *B. ×hybrida* 'Dragon Wing Red' under higher salt conditions. Irshad et al. (2002) reported reduced height, shoot, and root growth of maize grown on composted cow manure substrate under high salinity conditions. The authors attribute the reduced growth to a reduced N uptake under high salinity. As salinity increased, N uptake decreased in maize plants grown on composted cow manure-amended soils (Irshad et al., 2002).

In contrast, shoot mass of *B. ×hybrida* 'Dragon Wing Red' grown in the 0S:3R:0C and *T. patula* 'Safari Queen' grown in the 1S:0R:2C substrate cannot be explained by substrate salinity. In addition, there are no obvious reasons for these results based on the substrate physical and chemical properties (Table 1) or plant physiology.

Overall, our results for quality and growth of ornamentals are consistent with other studies and suggest that mature composted cow manure can be used as an acceptable substitute for sphagnum peat when additional fertilizer is added so that N availability is appropriate for plant growth (Raviv et al., 2005; Wang et al., 2004). Several researchers have documented similar or improved growth and quality of the following ornamentals species in other compost-based substrates (e.g., municipal solid waste, biosolids, yard trimmings) when compared with the same species grown in a sphagnum peat-based substrate (Ingelmo et al., 1998; Wilson et al., 2002, 2006): *Forestiera segregata* (Jacq.) Krug & Urb. var. *pinetorum* (Small) M. C. Johnston, *Myrcianthes fragrans* (Sw.) McVaughn, *Viburnum obovatum* Walter, *Nerium oleander* L., *Rosmarinus officinalis*

Table 3. Total load (mg per pot) of NO₃+NO₂-N in leachate (n = 5) collected from bedding plant species grown in 15-cm containers with substrate mixtures composed of varying proportions of Canadian sphagnum peat (S), Florida reed-sedge peat (R), or composted dairy manure solids (C) during the production cycle.

Substrate	NO ₃ +NO ₂ -N load ^a			
	2 DAP ^b	5 DAP	19 DAP	32 DAP
<i>B. ×hybrida</i> 'Dragon Wing Red'				
3S:0R:0C	0.51 ab ^x	0.70 ab	57.2 b	3.92 b
0S:3R:0C	8.32 b	18.9 b	92.4 b	2.21 ab
2S:0R:1C	0.15 a	0.58 a	0.97 a	0.10 a
0S:2R:1C	0.24 a	0.16 a	0.40 a	1.61 ab
1S:0R:2C	0.11 a	0.56 a	1.14 a	1.62 ab
0S:1R:2C	0.09 a	0.23 a	0.93 a	2.16 ab
0S:0R:3C	0.10 a	0.41 a	0.10 a	1.16 ab
<i>S. scutellarioides</i> 'Wizard Velvet'				
3S:0R:0C	0.46 ab	1.64 a	89.3 b	9.35 bc
0S:3R:0C	7.50 b	29.8 a	194 b	14.2 c
2S:0R:1C	0.16 ab	2.12 a	0.85 a	1.95 abc
0S:2R:1C	0.04 a	0.71 a	0.14 a	0.12 a
1S:0R:2C	0.05 a	1.34 a	0.40 a	0.13 a
0S:1R:2C	0.03 a	0.70 a	1.21 a	0.19 ab
0S:0R:3C	0.10 ab	0.49 a	0.37 a	1.04 abc
<i>T. patula</i> L. 'Safari Queen'				
3S:0R:0C	0.44 bc	1.43 a	2.20 ab	2.03 a
0S:3R:0C	7.41 c	48.2 b	29.1 b	1.26 a
2S:0R:1C	0.10 ab	1.22 a	1.52 a	1.51 a
0S:2R:1C	0.02 a	0.62 a	0.31 a	1.27 a
1S:0R:2C	0.06 ab	0.76 a	1.06 a	0.47 a
0S:1R:2C	0.03 ab	0.51 a	0.32 a	0.38 a
0S:0R:3C	0.04 ab	0.58 a	0.50 a	0.93 a
No plant				
3S:0R:0C	0.62 a	1.02 a	512 c	57.4 c
0S:3R:0C	15.8 b	41.5 b	46.4 bc	37.1b c
2S:0R:1C	0.11 a	2.02 a	4.00 ab	0.38 ab
0S:2R:1C	0.10 a	0.76 a	1.90 a	3.26 ab
1S:0R:2C	0.10 a	2.13 a	0.93 a	0.90 a
0S:1R:2C	0.08 a	2.10 a	0.76 a	0.80 a
0S:0R:3C	0.07 a	1.27 a	0.72 a	0.55 a

^aNutrient loads from each pot were determined by adjusting the concentration of NO₃+NO₂-N with the volume of leachate collected from each pot.

^bDAP = days after potting.

^xMean separation for each species and collection date by Tukey's honestly significant difference test at $P \leq 0.05$.

L., *Cupressus sempervirens* L., *Gloxinia sylvatica* (Kunth) Wiehler, *Justicia carnea* Lindl., and *Lysimachia congestiflora* Hemsl. Additionally, growth and yield of cherry tomato in substrates containing separated cow manure was similar or greater than that of the same species on a comparable sphagnum peat-based substrate (Raviv et al. 2005). Similarly, growth of cucumber in a dairy-manure wheat straw substrate was similar to growth on a sphagnum peat-based substrate provided that the compost was fully mature and fertilizer was added (Wang et al., 2004).

Leachate nitrogen loads. A significant species $\times$ substrate interaction required that leachate $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{+NO}_2\text{-N}$ loads be analyzed separately for each plant species; however, trends were similar for all three plant species and pots containing substrate only (no plant) (Tables 2 and 3). The substrates containing sphagnum peat (3S:0R:0C, 2S:0R:1C, and 1S:0R:2C) had the highest $\text{NH}_4\text{-N}$ losses through 7 DAP. Substrate effect on $\text{NH}_4\text{-N}$ load was less apparent after 19 DAP, and by the end of the production cycle (32 DAP), only the 3S:0R:0C substrates produced significantly higher $\text{NH}_4\text{-N}$ loads from pots containing *B. $\times$ hybrida* or no plant (Table 2). The substrates containing sphagnum peat contained similar levels of DTPA- NH_4 as the other substrates, but they had the highest C:N ratios (greater than 20) (Table 1). The increase in leachate $\text{NH}_4\text{-N}$ loads collected from these higher C:N ratio substrates is contrary to conventional thinking regarding the mineralization of N in organic materials. For example, Hue and Sobieszczyk (1999) noted a high C:N ratio (greater than 20) increased the immobilization of inorganic nitrogen, whereas a lower C:N ratio (less than 15) resulted in greater N available for plant uptake. However, our results are consistent with other studies in which $\text{NH}_4\text{-N}$ in leachate was increased from substrates formulated with materials that traditionally have high C:N ratios (e.g., pine bark). For example, Cole and Newell (1996) reported higher $\text{NH}_4\text{-N}$ concentrations in leachate from pine bark-dominated substrates when compared with substrates containing higher volumes of recycled paper for 60 d after initiating the experiment. Additionally, storage of leachate at ambient temperature for 7 d before collection and processing may have increased the concentration (and therefore load) of $\text{NH}_4\text{-N}$ collected from each pot. Busch and McGinley (2010) reported an increase in $\text{NH}_4\text{-N}$ concentrations when agricultural runoff samples were stored at high temperature (35 °C) as a result of greater mineralization of organic N attributable to microbial activity under those conditions. Therefore, it is possible that elevated $\text{NH}_4\text{-N}$ loads from substrates containing sphagnum peat were the result of higher losses of dissolved organic N than from other substrates. Differences in $\text{NH}_4\text{-N}$ concentration in leachate were no longer different between substrates by 90 d. Similarly, Beeson (1996) reported lower $\text{NH}_4\text{-N}$ concentrations in leachate from substrates composed of 40%

to 80% (by vol.) yard waste compost when compared with substrates containing 40% to 80% pine bark fines. Curtin et al. (1998) showed that mineralization of organic N was enhanced when a soil with a C to N ratio of 10.3 was limed. Both the 3S:0R:0C and the 2S:0R:1C substrates were limed; however, the pH of these substrates was lower than the substrates containing higher proportions of composted dairy manure solids (Table 1). Cole and Newell (1996) reported ammonium concentrations in leachate were higher from plants grown on composted cow manure substrate with lower pH.

The 0S:3R:0C substrate had the highest initial leachate $\text{NO}_3\text{+NO}_2\text{-N}$ losses and the trend persisted throughout most of the production cycle (Table 3). The 0S:3R:0C substrate also had the highest levels of DTPA- NO_3 (Table 1). The only exception to this trend was for pots containing *B. $\times$ hybrida* and *T. patula*, in which there was no longer any substrate effect on $\text{NO}_3\text{+NO}_2\text{-N}$ load at the end of the production cycle (32 DAP). Based on the data collected, we suggest that $\text{NO}_3\text{+NO}_2\text{-N}$ load may be higher from pots containing only the 3S:0R:0C substrate (no plants) (Table 3). This was likely a result of

nitrification of NH_4 and subsequent leaching of $\text{NO}_3\text{+NO}_2\text{-N}$ when no plant roots were available for $\text{NO}_3\text{+NO}_2\text{-N}$ uptake. Additionally, without plant roots, release of N from Osmocote could have enhanced leachate loads of $\text{NO}_3\text{+NO}_2\text{-N}$.

Leachate dissolved reactive phosphorus loads. A significant species $\times$ substrate interaction also required that leachate DRP load be analyzed separately for each plant species; however, trends were similar for all three plant species and for pots containing substrate only (no plant) (Table 4). Substrate composition had a significant effect on DRP loads from container-grown plants. Significantly more DRP was leached from substrate mixes containing composted dairy manure solids than mixes containing only sphagnum or reed-sedge peat materials through 19 DAP (Table 4). This was the result of the higher concentrations of total P and DTPA-extractable P in the composted dairy manure solids as compared with the sphagnum or reed-sedge peat (Table 1).

P concentrations in composted dairy manure solids were elevated as a result of levels of P consumed by cattle in diet supplements. Dairy manure tends to be dominated by

Table 4. Total load (mg per pot) of dissolved reactive phosphorus (DRP) in leachate (n = 5) collected from bedding plant species grown in 15-cm containers with substrate mixtures composed of varying proportions of Canadian sphagnum peat (S), Florida reed-sedge peat (R), or composted dairy manure solids (C).

Substrate	DRP load ²			
	2 DAP ³	5 DAP	19 DAP	32 DAP
<i>B. $\times$hybrida</i> 'Dragon Wing Red'				
3S:0R:0C	0.61 ab ^x	0.11 a	1.69 a	0.69 b
0S:3R:0C	0.32 a	0.05 a	0.17 ab	0.02 a
2S:0R:1C	17.1 c	58.3 c	4.95 cd	0.08 b
0S:2R:1C	2.10 abc	7.73 b	0.24 ab	0.07 ab
1S:0R:2C	14.5 c	181 bc	32.5 d	0.20 ab
0S:1R:2C	3.83 bc	15.5 b	2.08 bc	0.11 ab
0S:0R:3C	5.69 bc	29.3 bc	8.58 cd	0.16 ab
<i>S. scutellarioides</i> 'Wizard Velvet'				
3S:0R:0C	0.45 ab	1.06 bc	0.77 ab	0.19 ab
0S:3R:0C	0.24 a	0.04 a	0.15 a	0.03 a
2S:0R:1C	16.4 c	79.1 c	3.10 bcd	0.58 b
0S:2R:1C	3.08 bc	13.0 bc	0.15 a	0.05 ab
1S:0R:2C	21.9 c	127 c	36.9 d	0.12 ab
0S:1R:2C	4.45 bc	51.7 c	1.73 abc	0.08 ab
0S:0R:3C	6.47 bc	68.3 c	13.6 cd	0.04 a
<i>T. patula</i> L. 'Safari Queen'				
3S:0R:0C	0.66 b	0.39 a	0.77 abc	0.20 abc
0S:3R:0C	0.01 a	0.09 a	0.19 a	0.01 a
2S:0R:1C	17.8 b	94.0 b	7.01 bcd	0.13 abc
0S:2R:1C	2.91 b	9.96 b	0.26 a	0.01 a
1S:0R:2C	18.2 b	129 b	63.2 d	0.99 c
0S:1R:2C	3.92 b	23.3 b	1.53 abc	0.02 ab
0S:0R:3C	5.90 b	32.7 b	19.6 cd	0.31 bc
No plant				
3S:0R:0C	0.70 ab	0.37 b	4.72 b	2.17 b
0S:3R:0C	0.20 a	0.02 a	0.12 a	0.03 a
2S:0R:1C	20.1 d	212 de	4.96 b	0.46 b
0S:2R:1C	1.91 b	19.7 c	0.29 a	0.03 a
1S:0R:2C	16.6 cd	405 e	52.0 c	2.09 b
0S:1R:2C	3.13 bc	71.3 cd	4.47 b	0.80 b
0S:0R:3C	3.98 bcd	55.3 cd	10.7 bc	1.38 b

²Nutrient loads from each pot were determined by adjusting the concentration of DRP with the volume of leachate collected from each pot.

³DAP = days after potting.

^xMean separation for each species and collection date by Tukey's honestly significant difference test at $P \leq 0.05$.

calcium phosphate minerals (e.g., brushite, β -tricalcium phosphate) that are insoluble at neutral to alkaline pH (Shober et al., 2006; Toor et al., 2005). Leachate DRP loads were highest for substrates formulated with a combination of composted dairy manure solids and sphagnum peat resulting from the dissolution of these calcium phosphate minerals that resulted when the near neutral pH of composted dairy manure solids (pH = 6.65) was mixed with the acidic sphagnum peat. Leachate DRP loads decreased with time, and as plants neared marketable size, trends in leachate DRP loads tended to be less pronounced (Table 4). This may be because most of the soluble P had already been leached from the pots or had been taken up by the growing plants.

Conclusions

All substrates tested as part of this study appeared to be commercially acceptable for production of container-grown bedding plant species. There was no evidence that replacing traditional sources of peat with composted dairy manure solids will have a significant impact on plant growth or quality. However, nutrient losses from the containers will differ depending on the peat or peat substitute used to formulate the substrates. Producers should use best management practices to control nutrient losses in leachate. N losses in leachate will be the main concern when traditional sphagnum or reed-sedge peat materials are used, whereas losses of dissolved P will be greatest when composted dairy manure solids (or other manure-based sources) are used as a peat substitute. Producers should reduce P fertilization when using composted manures in potting substrates. In addition, maintaining a near neutral pH will reduce the dissolution of calcium phosphate minerals and subsequent leaching of DRP when composted manures are used as a peat substitute.

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