

Executive Summary: Creating High Value Potting Media from Composts Made with Biosolids and Carbon-Rich Organic Wastes

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Objective:

Determine suitability of composts and blends made with biosolids and urban organic carbon sources as high value potting mixes.

Introduction:

Composted organic wastes have the potential to substitute for peat and bark as components of the growing media in containerized plant production systems. From a grower's perspective, one of the major impediments to using composts for potting media is the variation in physical and chemical characteristics between different sources of compost, and even between different batches of the same compost from the same source. Compost producers need to tailor their products to meet the needs of container growers.

Biosolids composts have the potential to be a major ingredient in locally produced potting mixes. A large number of carbon-rich materials are available in Washington State, and these could be composted with Class B biosolids to make a Class A product suitable for use in potting mixes. Woody construction debris, land-clearing debris, and horse manure are abundant in urban areas of western Washington, such as King County.

Methods:

Composts were produced in aerobic reactors providing similar conditions to full scale static aerobic piles. Composts were made from King County biosolids (1 part by volume) blended with construction debris, land clearing debris, or horse manure (3 parts by volume).

The composts produced above were screened (7/16 in.) and blended 1:1 (v:v) with aged Douglas-fir bark to produce potting mixes. They were compared with an industry standard peat-perlite mix, Tagro (Tacoma biosolids) potting mix and potting mixes made from Groco biosolids compost and from fiber from a mixed anaerobic digester (dairy manure and food waste). The growth and quality of marigolds and peppers were measured in a replicated greenhouse study comparing the potting mixes.

Results:

- Experimental biosolids composts with horse manure, construction debris, and land clearing debris mixed with Douglas-fir bark performed equal to the peat-perlite control for growing marigold and sweet pepper.

- Traditional Groco compost mixed with bark did not perform as well as the other treatments.
- Anaerobically digested dairy manure and food waste mixed with bark was intermediate between Groco and other treatments in overall performance.
- Higher nitrogen rates improved plant growth and quality across all potting mixes in pepper (a plant with higher N demand), but had fewer significant effects for marigold (a plant with lower N demand).
- Experimental composts were coarser textured than the peat-perlite or Tagro potting mixes, resulting in higher aeration porosity and lower water holding capacity, but performed well nonetheless under the overhead irrigation used in this study.

Opportunities and feasibility

- Adequate supplies of alternative C-rich materials to make compost with existing biosolids supply. King County currently uses about 10% of its biosolids production for compost (none to potting mix), and Tacoma uses 25% of its biosolids in potting mix.
- Replaces potting mixes made from non-renewable materials.
- Technology to make compost is well established and technology to make potting mixes from biosolids composts or blends is easily adopted.
- Unmet demand in home and commercial markets for potting mixes from local, renewable resources.

Barriers and challenges

- Product must have consistent high quality to be acceptable as a potting medium.
- Collection of carbon materials from decentralized sources.
- Potential saturation of demand forcing products to lower value markets.
- Products in this study performed well using drip irrigation, but they may be too coarse for some other management systems.
- Additional study may be needed done to improve the quality and consistency of the products from this study by additional compost curing and perhaps custom grinding or screening of the woody feedstocks.

Creating High Value Potting Media from Composts Made with Biosolids and Carbon-Rich Organic Wastes

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Greenhouse and nursery production of plants for landscape and interior use is a specialized segment of the horticulture industry. High value crop plants are grown with the environmental inputs required for plant growth tightly controlled (Biernbaum, 1992). Container production is the norm in the nursery and greenhouse industries with almost 80% of the plants grown in containers (Gouin, 1995). The root systems of container-grown plants are restricted to small volumes of media that must act as a reservoir for nutrients and water, provide oxygen for root respiration, and support for the plant. The growing media used in container production are typically soilless and 70 to 80% of the ingredients are organic materials (Gouin, 1995). Container media are a foundation for the successful growing of containerized plants and their quality must be assured.

The market value of potting media in the Pacific Northwest (Washington, Oregon, Idaho, and British Columbia) was recently estimated at \$130 million. The main ingredients are non-renewable resources including sphagnum peat, perlite, and/or vermiculite. Use of locally available renewable resources could provide more sustainably produced potting media while boosting the local economy.

Peat, formed by the partial decomposition of sphagnums, other mosses, reeds and sedges, and bark from various softwood and hardwood tree species, are the most widely used organic components of container media (Bundt, 1988; Fontano, 1996). Starting in the 1950's, sphagnum peat based media became the standard for container crop production due to peat's desirable characteristics, such as high cation exchange capacity, low bulk density, high water-holding capacity, good aeration porosity and resistance to decomposition (Schmilewski, 1983; Stamps and Evans, 1999). But peat is a part of wetland ecosystems and there is concern about the possible detrimental effects of peat harvesting on the wetlands. Preservation projects are increasing globally in size and in number, reducing the availability of peat resources and increasing the cost (Shmilewski, 1983). To reduce production costs for container-plant growers and ecological damage to the peat bogs, another type of organic growing medium must be found that can serve as a replacement for peat.

Composted organic wastes have the potential to substitute for peat and bark as components of the growing media in containerized plant production systems. Most of the feedstocks used for composting are widely available and are not limited in supply. The

container plant industry is an obvious choice for utilizing some of these recycled wastes because of its constant need for plant growth substrates. As plants are sold, the containers and the media inside are sold with them, resulting in the demand for more.

Growers must have a reliable source of high quality growing media that is consistent over time. From a grower's perspective, one of the major impediments to using composts for potting media is the variation in physical and chemical characteristics between different types of compost, different sources of compost, and even between different batches of the same compost from the same source (Tyler, 1993; Bettineski, 1996). Unlike plants grown in the field or landscape, containerized plants have very limited root-zone space, because compost in container media can comprise from 10 to 100% of the root zone, the requirements are much more stringent than those of land application. The media must be porous and well drained but at the same time have sufficient water and nutrient retention to sustain and nourish plants. Container growing media must be low in soluble salts and have an acceptable pH. The media must be free from diseases, pests, harmful chemicals, and objectionable odors, and be standardized, easily duplicated and consistent from batch to batch. Compost producers need to tailor their products to meet the needs of container growers (Raviv, 1998).

Previous research at WSU Puyallup has shown that a blend of Tagro mix and bark is equal to or superior than standard peat-based potting mixes for growing chrysanthemums and bedding plants (Krucker, 2003). Tagro mix is a garden amendment made from Class A wastewater biosolids from the City of Tacoma (50%), screened sand (25%), and sawdust (25%). Tacoma now produces a Tagro-based potting mix, and sells it locally as the most profitable product of their biosolids stream. It has become accepted by users as a quality potting medium. The City produced 2000 yards of potting mix in the first half of 2009, utilizing 25% of their biosolids stream.

Biosolids composts also have the potential to be a major ingredient in locally produced potting mixes. A large number of carbon-rich materials are available in Washington State (Frear et al., 2005), and these could be composted with Class B biosolids to make a Class A product suitable for use in potting mixes. Woody construction debris, land-clearing debris, and horse manure are abundant in urban areas of western Washington, such as King County (Table 1).

We conducted this research to determine suitability of composts and blends made with biosolids and urban organic carbon sources as high value potting mixes.

Methods

Preparation and analysis of experimental composts and potting media

Three composts were made from carbon-rich woody biomass and biosolids. The C-rich biomass feedstocks included ground and screened construction debris from Recovery 1 in Tacoma, ground and screened land-clearing debris from Rainier Wood Recycling in King County, and horse manure obtained as-is from a farm in Pierce County. The biosolids were dewatered class B material from the South (Renton) wastewater treatment plant operated by King County.

Composts were made in 2.5-yard composting units operated as static piles under positive aeration. The aeration system consisted of two perforated 4-inch pipes at the bottom of the composting bin connected to a 280 watt blower via a manifold. An 8-inch layer of coarse woody material was placed around the aeration pipes to serve as plenum to improve air flow into the pile.

Bulking agents and biosolids (described above) were combined in a 3:1 volume ratio on 15 May 2008. The mixed feedstocks were run through a manure spreader twice to blend them thoroughly, and then loaded into the composting units. They were capped with a layer of finished compost, and composted under forced aeration for seven weeks, on an aeration cycle of 20 seconds per hour. Temperatures were measured at three depths in each pile five times per week for four weeks, and weekly for the next 3 weeks. Temperatures reached PFRP levels for pathogen reduction in the upper two depths of each pile, but not at the lowest depth, which was located in the plenum. The bins were emptied and the composts cured in freestanding piles for an additional 15 weeks (until 17 October). A portion of the cured compost was sieved (7/16 inch) and saved for the preparation of the potting mixes.

The composts were analyzed for moisture (oven at 70°C), pH and EC (1:5 compost:water ratio; Thompson et al., 2001). Stability analyses were run using Solvita® tests (Woods End Laboratories, 2009), and particle size fractions determined by sieving samples (approx. 500 g) through a series of standard Tyler screens on a sieve shaker. Dried and ground samples were analyzed for total N, ammonium and nitrate N, total P, total K, and micronutrients, all using standard TMECC methods for compost analysis (Thompson et al., 2001).

All composts were mixed 1:1 with 100% fine-ground fresh Douglas fir bark before use as potting mixes. Previous research (Krucker, 2003) showed that mixing compost and biosolids products with bark improved their performance as potting mixes. The potting mixes were analyzed for initial pH, electrical conductivity (EC), water-holding capacity

(WHC), aeration porosity (AP), nitrate levels ($\text{NO}_3\text{-N}$), and particle-size fractions. The pour-through method, also known as the Virginia Tech Extraction Method (Wright, 1986), was used to collect leachate samples for $\text{NO}_3\text{-N}$. Media pH and EC were determined using the 1:5 method (media:water ratio) of Thompson et al. (2001). WHC and AP were determined by following the volume measurement technique described by Ingram et al. (1990).

Greenhouse trial

Seeds of marigold 'Little Hero Flame' and pepper 'California Wonder Golden' were planted in plug trays. At the 1 to 2 true leaf stage uniform seedlings were transplanted into 0.7 liter (0.74 qt) square containers 10 cm (4 in) tall and 10 cm (4 in) wide. The containers were filled with the following experimental growing media:

- 1. Land clearing (storm debris) + biosolids compost mixed 1:1 with bark (LDB)
- 2. Construction debris + biosolids compost mixed 1:1 with bark (CDB)
- 3. Horse waste + biosolids compost mixed 1:1 with bark (HWB)
- 4. Dairy manure-food waste anaerobic digester solids mixed 1:1 with bark (DDB)
- 5. Standard GroCo compost mixed 1:1 with bark (GroB)
- 6. Standard Tagro potting mix (Tag)
- 7. A bagged peat-perlite mixture as the industry standard control.

The land clearing debris, construction debris, and horse waste composts are described above. The digester solids were collected from an anaerobic digester that processes both dairy manure and food waste. Groco is a compost product currently made from King County biosolids and sawdust. Tagro potting mix is made by the Tacoma wastewater treatment plant. It consists of Tagro mix (50% class A biosolids cake, 25% sawdust and 25% screened sand) combined with Douglas-fir bark.

After transplanting, nitrogen fertilizer solutions were applied at two N rates, either 200 mg/L N every other day (high N rate), or 200 mg/L N every four days (low N rate). To insure uniformity of P and K application, a second solution containing 100 mg/L P and 200 mg/L K but no N was applied to the low N plants on the days when the solution containing N was applied to the high N plants. Thus all plants received the same amount of P and K; only the N rate varied. All media were amended with Scotts Micromax micronutrient mix at the rate of 1038 g/m³ (1.75 lb/yd³). All plants were drip irrigated as needed and grown under standard greenhouse conditions.

The experiment was a factorial treatment combination of seven growing media by two N fertilizer rates. There were eight replicate containers per treatment with one plant per

container. Plants were arranged on greenhouse benches in a randomized complete block design.

Plant growth and quality measurements

Initial plant height and the narrowest and widest canopy widths were recorded at transplanting. At the end of the production cycle, stem height and the widest and narrowest canopy width were again measured. A shoot growth index (SGI) was calculated from this data as follows: $((\text{widest width} + \text{narrowest width})/2 + \text{height})/2$.

At the end of the production cycle, color of the adaxial (upper) leaf surface of two fully expanded leaves was determined quantitatively with a Minolta CR200b Chroma Meter (Minolta, Ramsay, N. J.). The CIELAB coordinates, $L^*a^*b^*$, were recorded and the chroma (C^*) and hue angle (h°) were calculated (Mc Guire 1992). L^* measures the lightness or value of the color from black (equal 0) to white (equal 100). C^* is the degree of color from grey (equal 0) to pure chromatic color and h° is the attribute of color perceived (red, yellow, green, blue or intermediate between adjacent pairs arranged on a 360° color wheel, 0° = red, 90° = yellow, 180° =green, and 270° = blue).

After leaf color was measured, visual shoot quality of all plants was rated on a scale ranging from 5: a superior plant, to 1 a poor quality plant with a rating of 3 considered salable. Root growth, as root length and root density was also rated. Root length was rated from 4, roots circling the bottom of the container, to 1, roots growing $\frac{1}{2}$ way to the container bottom. Root density was rated on a 4 (solid root mass with little or no growing medium visible at the periphery) to 1 (no roots visible at the periphery) scale. Finally, plants were cut at the medium surface and the shoots dried for 96 hours at 60°C in a forced air oven and weighed to determine shoot dry mass.

Leachate collection and analysis

Leachate samples were collected from the pots by adding 150 ml of distilled water to the medium one hour after irrigation and collecting the resulting leachate for pH, soluble salt and nitrate evaluation. The leachate was measured and tested using a Hanna pH meter (model #EN 50081-1, Portugal), an Orion EC meter (model #128, MS) and a Hach One Laboratory pH/ISE meter (model #44700, CO) to analyze pH, EC, and nitrate levels, respectively. Leachate was collected from the marigold plots at the end of the experiment, before final plant measurements and harvest. Pepper leachate was collected twice: two weeks before the end of the experiment and at the of the experiment.

Statistical analysis

Analysis of variance (PROC GLM) was used to test the significance of growing media and fertilizer rates (SAS 8.1, SAS Institute Inc., N.C.). Mean separation for the growing media

were done with a Tukey's studentized range test (HSD). A Student's t-test was used to compare the high N to low N fertilizer treatments.

Results

Composts and potting mixes

The nutrient concentrations of the three experimental composts were similar, suggesting a strong influence of the biosolids on the nutrient profiles (Tables 2 and 3). The horse manure-biosolids compost contained slightly higher levels of P, K, and Ca and a slightly lower C:N ratio than the construction debris-biosolids or land clearing debris-biosolids composts. C:N ratios ranged from 14:1 to 16:1 (Table 3), which is a point where biological release of small amounts of available nitrogen is expected. Compost pH was at an acceptable level for potting mixes, while EC tended to be high (Table 3). Once the composts were mixed with bark to make the potting media, EC values for all materials fell into a satisfactory range (less than 2 dS/m) (Table 5).

The Solvita test estimates compost stability using a colorimetric indicator of CO₂ evolution. The Solvita results ranged from 4.6 to 5.3 for these materials (taken after 6 months of composting and curing) indicating they were less stable than desired for potting mixes (minimum Solvita measurement of 6) (Table 3). High levels of ammonium also indicated unstable material. By the time the composts were mixed with bark and used as potting media (3 months later), no problems related to compost immaturity were seen.

Particle size was similar among the composts, with the construction debris-biosolids compost having the largest coarse fraction (Table 4). The experimental media had more coarse particles and fewer fines compared with the peat-perlite standard, even after mixing with bark (Table 4). The particle size profiles in the middle of the range (between 0.42 and 2 mm) were similar between the experimental media and the peat-perlite standard. The coarseness of the experimental potting mixes was reflected in their high aeration porosity and low water holding capacity compared with the peat-perlite standard and Tagro potting mix (Table 5). Water holding capacity of the experimental media was still within the acceptable range of 20 to 60%, but less than the ideal range of 35 to 50% (Dickey et al., 1978). Aeration porosity was slightly higher than the ideal range of 10 to 20% (Bunt, 1988).

Plant response to potting media

Marigolds. Nitrogen rate had few effects on the size of marigold plants across the potting mix treatments (Table 6), but reduced nitrogen did significantly reduce the visual quality of the plants in most treatments (Table 7).

With the high N fertilization regime, marigolds grown in the Construction Debris-Biosolids based potting mix (CDB) had a significantly greater shoot growth index than the control plants (peat-perlite), but all other potting mixes produced plants with similar shoot growth index to the controls (Table 6). Under low N the Groco-based potting mix had lower shoot growth index than the controls, but all other potting mixes produced plants similar to the controls. No treatment differed from the controls for dry weight under the high N regime, but plants grown in HWB and LDB mixes had greater dry weights than the control with low N fertilization. Root length and density was not affected by any of the potting media, and was optimal in all cases (Table 8).

Plant visual quality was similar across all materials except Groco under high N, and except Groco and DDB under low N (Table 7). HWB and Tagro had greater numbers of flowers and buds than the controls for both low and high N treatments, while CDB, LDB, and Groco had greater numbers of flowers under one of the N treatments.

Leaf color is an aspect of plant quality that can be measured and compared statistically using a color meter. For most plants, higher quality is associated with darker (lower L*), less bright (lower chroma), and greener (higher hue angle) leaf color. The high N treatment significantly improved all aspects of leaf color compared with the low N treatment for nearly all of the potting media (Table 9). Within N treatments, marigolds grown in the experimental biosolids compost-bark potting media had similar leaf color to the peat-perlite control, while marigolds in the Groco-bark potting mix had lower quality for all three color factors (Table 9). Marigolds grown in the digester solids-bark potting mix and the Tagro potting mix had similar color to the control under high N conditions, but inferior color with reduced N.

Overall, the experimental biosolids compost-bark potting mixes (HWB, LDB, and CDB) performed equal to or better than the peat-perlite control and similar to the Tagro potting mix, when all factors are taken into consideration. Plants grown in Groco-bark generally showed the poorest growth and quality.

Pepper. Pepper differs from marigold in that it has a longer growth period and greater biomass production in the containers, and an expected higher nutrient demand. Nitrogen rate had a greater effect on pepper growth than on marigold, with all measurements in all potting mixes showing reduced performance with reduced nitrogen rates (Tables 10 and 11). Plants grown in Groco showed poorer performance than all of the other potting mixes in all growth and quality categories under both low and high N fertilization (Tables 10 and 11). Plants grown in digester solids (DDB) performed more poorly than the peat-perlite control in all categories under low N fertilization, and for dry weight and visual quality

under high N fertilization. Root length and density was not affected by any of the potting media, and was optimal in all cases, the same result as observed for marigold (Table 12).

Peppers grown in the construction debris- biosolids compost and land clearing debris- biosolids compost potting mixes (CDB and LDB) had superior color (L^* , chroma, and hue angle) than the control peppers under low N fertilization (Table 13). Under high N fertilization, peppers grown CDB, LDB, and horse waste-biosolids potting mixes (HWB) had similar color to the control treatment, while the Groco and Tagro potting mixes had inferior color in at least two of the color categories (Table 13). Overall, the three experimental mixes performed equal to or slightly better than the control for all growth and color categories under both N levels for pepper.

Results are not entirely consistent over both crops, but color differences in pepper at low N levels for LDB and CDB suggest a slow release of nitrogen from these materials led to measurable improvement in the quality of the pepper plants. The Groco and Tagro potting mixes also contained biosolids, but these were more highly processed and biologically stable materials, likely with a lower rate of N release, leading to less plant response.

Leachate quality

Leachate was collected on one date at the end of the marigold experiment and on two dates near the end of the pepper experiment. Electrical conductivity of the leachate collected from containers in both experiments at both N fertilization levels was low (100 to 400 $\mu\text{S cm}^{-1}$) for all treatments (Tables 14 and 15), reflecting the acceptable EC of the potting mixes at the time of potting (Table 5). Although there were some statistically significant differences among treatments, none of the differences were biologically important.

Leachate nitrate-N levels were also low across treatments (0.1 to 1 mg/pot), indicating effective N uptake by the plant roots at the time of leachate collection (Tables 14 and 15). Differences in leachate nitrate-N levels between the low and high N treatments were small, although they were statistically significant in some cases. The lack of large differences between fertility levels are further indication of effective N uptake by the plant roots. Leachate pH fell into a narrow range among media (Tables 14 and 15), with some small statistical differences among treatments. The potting mix made from dairy-food waste digester solids (DDB) had the highest pH in the medium at the time of potting (Table 5) and in the leachate, while initial media and final leachate pH of the experimental compost media (CDB, HWB, and LDB) were all similar to the peat-perlite control.

Summary

Based on the results from these two species, the experimental biosolids compost potting mixes have similar to slightly better performance overall to the commercially available peat-perlite and Tagro standards, while the dairy-food waste anaerobic digester solids and particularly the Groco mix lag behind the others. This is despite the coarseness of the alternative potting mixes compared to peat-perlite, resulting in high aeration porosity and low water holding capacity, and the relatively low stability of the composts used in the potting mixes. The drip irrigation regime may have compensated for the reduced water holding capacity of the experimental mixes. Although plants performed well under the conditions of this study, they may not perform as well under different irrigation systems or management. This suggests that additional work could be done to improve the quality and consistency of the products, perhaps by custom grinding or screening of the woody feedstocks.

Acknowledgments

The Washington State Department of Ecology provided funding for this project through the Beyond Waste Organics Waste to Resources (OWR) project. These funds were provided in the 2007-2009 Washington State budget from the Waste Reduction Recycling and Litter Control Account. OWR project goals and objectives were developed by the Beyond Waste Organics team, and were approved by the Solid Waste and Financial Assistance Program.

Beyond Waste Objectives: Turning organic wastes to resources, such as compost, bioenergy, biofuels, recovery of stable carbon and nutrients and other products promotes economic vitality in growing industries, and protects the environment. This creates robust markets and sustainable jobs in all sectors of the economy, and facilitates closed-loop materials management where by-products from one process become feedstocks for another with no waste generated.

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Table 1. Biomass inventory for biosolids and selected high carbon materials

Material	Statewide (dry tons)	King County (dry tons)
Biosolids	95,000	30,000
Land clearing debris	419,000	70,000
Wood residue	834,000*	170,000
Horse manure	407,000	27,000
Douglas fir bark	265,000**	

Table 2. Nutrient concentrations of composts made of biosolids and land-clearing debris, construction debris, and horse manure

	P	K	Ca	Mg	Na	S	Fe	Zn	Mn	Cu	B
	g kg ⁻¹							mg kg ⁻¹			
Land-clearing debris-biosolids	12	6	17	5	8	4	11	370	420	200	56
Construction debris-biosolids	12	5	17	5	13	5	10	410	320	220	92
Horse Manure-biosolids	13	12	26	6	16	5	9	410	390	220	57

Table 3. Compost nitrogen, quality, and stability measurements

	C/N	Total N	NH4-N	NO3-N	pH	EC	Bulk density	Solvita
		g kg ⁻¹				dS m ⁻¹	lb/ton (as-is)	
Land-clearing debris-biosolids	16	22	2.3	0.9	6.4	2.6	660	5.3
Construction debris-biosolids	16	24	2.2	0.7	6.3	2.5	590	4.6
Horse Manure-biosolids	14	25	1.8	1.5	6.3	3.2	630	5.3

Table 4. Compost and potting mix particle size measurements

	Sieve size (mm)							
	4.7	2.36	2	1	0.83	0.6	0.42	Pan
	% retained							
Composts:								
Land-clearing debris-biosolids	35	28	5	15	2	4	2	8
Construction debris-biosolids	46	27	4	12	2	3	2	5
Horse Manure-biosolids	33	30	5	17	3	4	3	5
Potting Mixes:								
Peat-Perlite	9	18	4	14	5	8	7	32
Land-clearing debris-biosolids:Bark	26	25	4	16	3	6	4	16
Construction debris-biosolids:Bark	31	24	4	14	3	6	4	14
Horse Manure-biosolids:Bark	24	26	4	17	3	6	5	15

Table 5. Potting mix aeration porosity, water holding capacity, and chemical properties

	Aeration porosity	Water holding capacity	pH ^z	NO ₃ -N ^y	EC ^z
	%	%		mg/L	ds/m
Peat-Perlite	9.5	42.2	5.5	3	0.7
CDB	22.3	29.6	5.3	77	1.2
HWB	21.4	31.7	5.5	87	1.4
LDB	22.8	28.0	5.1	79	1.1
DDB	16.9	31.9	6.7	21	0.7
GroB	18.4	31.8	6.4	17	0.4
Tag	11.7	34.4	5.8	47	0.9

^z 1:5 saturated paste method

^y pour through method

Potting Mix Key:

CDB = 1:1 **C**onstruction **D**ebris-biosolids compost : **B**ark

HWB = 1:1 **H**orse **W**aste-biosolids compost : **B**ark

LDB = 1:1 **L**and clearing **D**ebris-biosolids compost : **B**ark

DDB = 1:1 **D**airy **D**igester solids : **B**ark

GroB = 1:1 **G**roco biosolids compost : **B**ark

Tag = **T**agro potting mix

Table 6. Effect of potting mix and nitrogen rate on shoot growth and dry weight of Marigold ‘Little Hero Flame’

	Shoot Growth Index (cm) ^z	Shoot Growth Index (cm)		Dry Weight (gm)	Dry Weight (gm)	
Potting Mix	High N	Low N		High N	Low N	
Peat:Perlite	13.8 B ^y	14.0 AB	NS ^x	3.80 AB	3.01 CD	NS
CDB	15.4 A	13.9 AB	NS	3.75 B	3.52 ABC	NS
HWB	14.7 AB	14.0 AB	NS	4.71 A	3.90 A	***
LDB	13.8 B	14.4 A	NS	3.91 AB	3.67 AB	NS
DDB	14.5 AB	13.2 BC	*	3.47 B	3.20 BCD	NS
GroB	13.6 B	12.4 C	***	3.33 B	2.90 D	NS
Tag	14.1 AB	13.7 AB	NS	3.56 B	3.27 BCD	NS

^zShoot Growth Index= $((\text{widest width} + \text{narrowest width})/2 + \text{height})/2$.

^yMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^xNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 7. Effect of potting mix and nitrogen rate on visual quality, flower and flower bud number of Marigold ‘Little Hero Flame’

	Plant Visual Quality ^z	Plant Visual Quality		Flower & Bud Number	Flower & Bud Number	
Potting Mix	High N	Low N		High N	Low N	
Peat:Perlite	4.5 A ^y	4.0 B	* ^x	8.0 B	9.0 C	*
CDB	4.4 A	4.1 AB	NS	10.8 A	9.6 C	NS
HWB	4.9 A	4.5 A	NS	12.4 A	12.6 A	NS
LDB	4.6 A	4.1 AB	*	10.1 AB	12.3 AB	*
DDB	4.3 A	3.6 C	**	11.3 A	9.8C	NS
GroB	3.5 B	3.0 D	***	12.4 A	10.3 BC	**
Tag	4.5 A	4.0 B	*	11.9 A	13.1A	NS

^zShoot quality was rated on a 1 to 5 scale where 5 = superior, 1 = poor and a rating of 3 was considered marketable.

^yMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^xNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 8. Effect of potting mix and nitrogen rate on root length and root density of Marigold 'Little Hero Flame'.

Potting Mix	Root Length Rating ^z			Root Density Rating ^y		
	High N	Low N		High N	Low N	
Peat-Perlite	4.0A ^x	4.0A	NS ^w	3.0A	3.0A	NS
CDB	4.0A	4.0A	NS	3.0A	3.0A	NS
HWB	4.0A	4.0A	NS	3.0A	3.0A	NS
LDB	4.0A	4.0A	NS	3.0A	3.0A	NS
DDB	4.0A	4.0A	NS	3.0A	3.0A	NS
GroB	4.0A	4.0A	NS	3.0A	3.0A	NS
Tag	4.0A	4.0A	NS	3.0A	3.0A	NS

^zRoot length was rated from 4, roots circling the bottom of the container, to 1, roots growing ½ way to the container bottom.

^yRoot density was rated from 4, solid root mass with little or no growing medium visible at the periphery, to 1 no roots visible at the periphery.

^xMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^wNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 9. Effect of potting mix and nitrogen rate on leaf color of Marigold ‘Little Hero Flame’.

Potting Mix	L* ^z			Chroma ^y			Hue Angle ^x		
	High N	Low N		High N	Low N	**	High N	Low N	
Peat-Perlite	36.2 B ^w	38.0 C	*** v	14.1 B	16.3 C	NS	135.6 A	133.6 A	***
CDB	37.2 AB	38.5 C	NS	15.6 B	17.7 C	***	134.9 A	133.1 A	*
HWB	37.0 AB	38.1 C	**	14.6 B	16.9 C	***	135.3 A	133.7 A	**
LDB	36.6 B	38.3 C	***	14.5 B	17.4 C	***	135.6 A	132.7 AB	***
DDB	37.1 AB	40.3 B	***	15.7 B	21.0 AB	***	134.7 A	130.5 C	***
GroB	38.6 A	42.1 A	***	19.1 A	22.8 A	***	132.1 B	128.4 D	***
Tag	37.6 AB	39.1 BC	**	16.1 B	20.0 B	***	133.8 AB	131.2BC	***

^zL* is the color lightness or value 0 = black to 100 = white.

^yChroma is the degree of color from grey (0) to pure chromatic color.

^xHue Angle is the attribute of color perceived (red, yellow, green, blue or intermediate between adjacent pairs arranged on a 360° color wheel, 0°= red, 90°= yellow, 180°=green, and 270° = blue).

^wMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^yNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 10. Effect of potting mix and nitrogen rate on shoot growth and dry weight of Pepper ‘California Wonder Golden’

Potting Mix	Shoot Growth Index (cm) ^z	Shoot Growth Index (cm)		Dry Weight (gm)	Dry Weight (gm)	
	High N	Low N		High N	Low N	
Peat-Perlite	27.8 A ^y	25.9 A	*** ^x	7.58 A	4.93 A	***
CDB	27.3 A	23.9 AB	**	6.69 A	4.54 A	***
HWB	27.4 A	23.5 B	***	7.24 A	4.14 AB	***
LDB	26.9 A	24.0 AB	*	7.31 A	4.49 A	***
DDB	25.5 A	22.1 B	**	5.21 B	3.30 B	**
GroB	22.0B	15.6 C	***	3.16 C	1.11 C	***
Tag	27.2 A	23.0 B	***	6.64 A	4.09 AB	***

^zShoot Growth Index=((widest width + narrowest width)/2 + height)/2.

^yMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^xNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 11. Effect of potting mix and nitrogen rate on visual quality, flower and flower bud number of Pepper ‘California Wonder Golden’

Potting Mix	Plant Visual Quality ^z	Plant Visual Quality		Flower & Bud Number	Flower & Bud Number	
	High N	Low N		High N	Low N	
Peat-Perlite	5.0 A ^y	4.0A	**** ^x	19.6 A	14.5 A	**
CDB	5.0 A	4.0 A	***	19.3 A	12.5 AB	**
HWB	5.0 A	4.0 A	***	21.3 A	10.9 AB	***
LDB	4.8 A	4.0 A	**	20.8 A	12.9 AB	**
DDB	4.0 B	3.6 B	***	17.8 A	9.6 B	***
GroB	3.9 B	3.0 C	***	10.8 B	4.4 C	***
Tag	4.8 A	4.0 A	**	19.1 A	12.5 AB	*

^zShoot quality was rated on a 1 to 5 scale where 5 = superior, 1 = poor and a rating of 3 was considered marketable.

^yMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^xNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 12. Effect of potting mix and nitrogen rate on root length and root density of Pepper 'California Wonder Golden'.

Potting Mix	Root Length Rating ^z			Root Density Rating ^y		
	High N	Low N		High N	Low N	
Peat-Perlite	4.0A ^x	4.0A	NS ^w	3.0A	3.0A	NS
CDB	4.0A	4.0A	NS	3.0A	3.0A	NS
HWB	4.0A	4.0A	NS	3.0A	3.0A	NS
LDB	4.0A	4.0A	NS	3.0A	3.0A	NS
DDB	4.0A	4.0A	NS	3.0A	3.0A	NS
GroB	4.0A	4.0A	NS	3.0A	3.0A	NS
Tag	4.0A	4.0A	NS	3.0A	3.0A	NS

^zRoot length was rated from 4, roots circling the bottom of the container, to 1, roots growing ½ way to the container bottom.

^yRoot density was rated from 4, solid root mass with little or no growing medium visible at the periphery, to 1 no roots visible at the periphery.

^xMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^wNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 13. Effect of potting mix and nitrogen rate on leaf color of Pepper ‘California Wonder Golden’.

Potting Mix	L* ^z			Chroma ^y			Hue Angle ^x		
	High N	Low N		High N	Low N		High N	Low N	
Peat-Perlite	46.4 BC ^w	51.3 AB	*** ^v	30.0 D	37.1 AB	***	124.3 A	120.1 CD	***
CDB	46.1 C	48.9 CD	***	30.9 BCD	35.0 C	***	124.2 A	122.0 AB	**
HWB	47.2 ABC	50.1 BC	***	33.0 ABC	36.4 BC	***	123.0 AB	120.6 BC	***
LDB	46.1 C	48.2 D	**	30.8 CD	34.4 C	***	124.3 A	122.2 A	***
DDB	47.7 ABC	51.9 A	***	33.2 AB	38.8 A	***	122.8 AB	119.3 CD	***
GroB	48.2 A	52.8 A	***	34.0 A	39.0 A	***	122.1 B	119.0 D	***
Tag	48.1 AB	52.4 A	***	34.1 A	38.5 AB	***	122.3 B	119.8 CD	***

^zL* is the color lightness or value 0 = black to 100 = white.

^yChroma is the degree of color from grey (0) to pure chromatic color.

^xHue Angle is the attribute of color perceived (red, yellow, green, blue or intermediate between adjacent pairs arranged on a 360° color wheel, 0°= red, 90° = yellow, 180°=green, and 270° = blue).

^wMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^vNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0.1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment

Table 14. Effect of potting mix and nitrogen rate on leachate electrical conductivity (EC), pH and nitrate-nitrogen of Marigold 'Little Hero Flame'. Leachate was collected at the end of production, just prior to harvest.

Potting Mix	EC ($\mu\text{S}\cdot\text{cm}^{-1}$)			pH			NO ₃ (mg•pot ⁻¹)		
	High N	Low N		High N	Low N		High N	Low N	
Peat-Perlite	113 E ^z	127 D	NS ^y	6.39 DE	6.52 BC	**	0.213 A	0.145 A	*
CDB	175 CD	175 C	NS	6.42 CD	6.42 CD	NS	0.210 AB	0.142 A	*
HWB	237 B	220 AB	NS	6.56 B	6.60 B	NS	0.177 AB	0.160 A	NS
LDB	176 C	203 BC	*	6.52 BC	6.55 B	NS	0.167 AB	0.159 A	NS
DDB	286 A	246 A	NS	6.68 A	6.81 A	**	0.191 AB	0.124 A	**
GroB	128 DE	178 C	**	6.28 E	6.37 D	NS	0.131 B	0.127 A	NS
Tag	94 E	107 D	NS	6.50 BCD	6.56 B	*	0.149 AB	0.139 A	NS

^zMeans within a column followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^yNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0,1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment.

Table 15. Effect of potting mix and nitrogen rate on leachate electrical conductivity (EC), pH and nitrate-nitrogen of Pepper 'California Wonder Golden'. Leachate was collected twice, on April 9 and again just prior to harvest on April 23.

Collection 1, April 9									
Potting Mix	EC ($\mu\text{S}\cdot\text{cm}^{-1}$)			pH			NO₃ (mg•pot⁻¹)		
	High N	Low N		High N	Low N		High N	Low N	
Peat-Perlite	229 B ^z	221 CD	NS ^y	6.73 CD	6.94 AB	***	0.615 BC	0.189 B	**
CDB	292 B	267 BC	NS	6.72 CD	6.82 CD	**	1.018 A	0.459 B	**
HWB	206 B	202 D	NS	6.65 D	6.69 E	NS	0.308 BC	0.223 B	*
LDB	246 B	308 AB	**	6.70 CD	6.74 DE	NS	0.498 BC	0.780 A	*
DDB	390 A	352 A	NS	6.88 A	6.98 A	**	0.527 BC	0.321 B	*
GroB	273 B	282 B	NS	6.77 BC	6.85 BC	*	0.650 B	0.428 B	NS
Tag	217 B	209 D	NS	6.85 AB	6.93 AB	*	0.283 C	0.210 B	NS
Collection 2, April 23									
Peat-Perlite	174 D	224 B	**	7.10 AB	7.21 AB	*	0.217 AB	0.193 AB	NS
CDB	205 B	256 AB	NS	7.05 B	7.12 BC	**	0.261 A	0.211 AB	NS
HWB	200 BC	229 B	**	7.05 B	7.09 C	NS	0.215 AB	0.233 A	NS
LDB	180 CD	223 B	***	7.05 B	7.11 BC	NS	0.167 B	0.201 AB	NS
DDB	276 A	321 A	*	7.11 AB	7.24 A	**	0.255 A	0.232 A	NS
GroB	219 B	248 B	**	7.04 B	7.09 C	NS	0.184 B	0.171 B	NS
Tag	140 E	150 C	NS	7.19 A	7.24 A	NS	0.196 B	0.193 AB	NS

^zMeans within a column and collection date followed by the same letter are not significantly different at the 5% level using a protected Tukey's studentized range test.

^yNS, *, **, and *** are used to indicate nonsignificance and significance at the 5%, 1% and 0,1% level, respectively, as determined by Student's t test of the fertilizer effect within a treatment.