Physical and Chemical Characteristics of a Commercial Potting Substrate Amended with Vermicompost Produced from Two Different Manure Sources

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ADDITIONAL INDEX WORDS. **worm castings, compost consistency, uniformity**

SUMMARY. **Interest in using alternative materials for potting substrate is increasing in response to availability and rising costs of peat and other conventional materials. Vermicompost (VC) is one such material. It is important to understand physical and chemical changes in potting substrate when amended with VC produced from different waste sources, pig (PVC) and beef cattle (BVC) manure in this study. Distribution of particles greater than 2 mm decreased, particles 0.5 to 1 mm increased, and particles less than 0.5 mm remained unchanged as PVC and BVC amendment increased. Dry bulk density and water-holding capacity increased with increasing PVC and BVC amendment. Porosity and air volume were inversely related to VC amendment, decreasing with increasing VC amendment. Saturated substrate extract sampling revealed nitrate nitrogen, phosphorus, calcium, magnesium, zinc, copper, iron content as well as electrical conductivity increased with increasing PVC and BVC amendment.**

Floriculture crops are mostly grown in lightweight potting substrates (Poole and Conover, 1979). These substrates are frequently composed of mixtures having sphagnum peatmoss combined with other materials such as vermiculite or perlite and formulated to achieve desirable physical and chemical properties. There are many different substrate formulations used for floriculture crops, and thus there is not a universal substrate formulation. Most research on potting substrate has focused on the manner in which different media compositions affect plant growth (Bunt, 1971; Fonteno, 1993).

Concerns of future availability, excessive environmental degradation, and higher prices have generated much interest in sphagnum peat alternatives (Barkham, 1993; Buckland, 1993; Robertson, 1993). Materials being evaluated include seaweed and biosolid composts (Vendrame and Moore, 2005), composted urban plant waste (Benito et al., 2005), spent mushroom compost (Szmidt and Chong, 1995), and vermicompost (VC) (Atiyeh et al., 2000, 2001; Handreck, 1986).

Vermicomposts are produced using earthworms (*Eisenia foetida*) to break down and stabilize organic wastes. During feeding, earthworms fragment the waste, increase microbial activity, and result in a composting or humification effect on waste material. The VC is obtained as the organic waste passes through the earthworm gut and is oxidized by associated microorganisms. VC, as a result of their fine particle size and structure, are being used as organic fertilizers, soil amendments, and potting substrate components. The specific physical and chemical characteristics of VC are dependent on the material consumed by the earthworms; however, VC from similar origins have similar characteristics (Tomati et al., 1990). Besides serving as a source of organic matter, VC increase moisture-holding capacity and provide nutrients (Atiyeh et al., 2001; Galli et al., 1990; Tomati et al., 1988).

Characterizations of changes in potting substrate properties that occur with the incorporation of VC are needed. This is especially true because VC can be produced from many different types of wastes. The objective of this research was to determine the differences in physical characteristics and available plant nutrient content of a commercial peat-based substrate amended with VC from two different agricultural sources and the potential suitability as a potting substrate.

Materials and methods

A commercial greenhouse substrate, Metro Mix 360 [MM360 (O.M. Scotts Co., Marysville, Ohio)] was amended with pig (PVC) or beef cattle (BVC) manure. MM360 is a potting substrate formulated from Canadian sphagnum peatmoss, horticultural-grade vermiculite, ground bark, processed bark ash, dolomitic lime, and a starter fertilizer charge. PVC consisted of separated pig solids processed by *E. foetida* in indoor flow through reactors and provided by Vermicycle Organics, Charlotte, N.C. BVC consisted of feedlot beef cattle manure, processed by *E. foetida* in upward migration bin reactors, and produced at Illinois State University, Normal. Processing manure wastes in these types of reactors typically takes ≈30 to 60 d.

PVC or BVC and MM360 were loaded into a rotary substrate mixer and blended for 3 min to ensure complete dispersal of the various components for each VC type and mix ratio: 0% VC (control), 10% VC, 20% VC, 40% VC, and 100% VC by volume.

This research was supported by funds from the Kiplinger Endowment for Floriculture. Salary and additional research support supported by State and Federal funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Manuscript HCS 06-15.

This paper is based on a portion of the dissertation submitted by GRB in partial fulfillment of the requirements for the PhD degree in horticulture.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
1	%	1 mL/100 mL	1
2.5400	inch(es)	cm	0.3937
25.4000	inch(es)	mm	0.0394
1	mmho/cm	$mS \cdot cm^{-1}$	1
1.7300	$oz/inch^3$	$g \cdot cm^{-3}$	0.5780
1	ppm	$mg \cdot kg^{-1}$	1
(°F − 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

Particle size distribution was obtained by screening three 100-g air-dried samples of each VC type and ratio using U.S. standard sieves with screens having openings of 5, 4, 2, 1, 0.5, and 0.25 mm. The particle fractions retained on each sieve and the amount that passed through the smallest sieve and retained were weighed. The percentage of each sieve fraction was determined by dividing each retained particle fraction by the total weight of the substrate sample.

Physical property characteristics were determined using a modified procedure described by Gabriels et al. (1993) and included dry bulk density (DBD), porosity (POR), water-holding capacity (WHC), and air volume (AV). Samples from each of the VC types and mix ratios were thoroughly wetted in bulk batches. Substrate was placed into 10-cm-diameter round containers with a collar added to the top of the container. The containers were tapped three times on the countertop after each addition of substrate until filled. The collar was removed and excess substrate was sliced off carefully with a sharp knife so the level of the substrate was even with the top of the container. The container and wet substrate were weighed and the weight of the container subtracted. The substrate was placed into a forced-air drying oven and dried for 24 h at 80 °C and weighed.

The baseline nutrient levels, substrate pH, and electrical conductivity (EC) of the 0%, 10%, 20%, 40%, and 100% amended substrates were determined for PVC and BVC through analysis performed at the Ohio State University Research and Extension Analytical Laboratory, Wooster (PVC) and A&L Analytical Laboratories, Memphis, Tenn. (BVC). Five separate samples were collected within each substrate mix. Substrate sampling was performed using the saturated substrate extraction (SME) method for the macronutrients (Yeager et al., 1983). Substrate sampling for micronutrients also used the SME method with the exception that the water was substituted with a 0.005 M diethylenetriamanepenta acetic acid solution (Berghage et al., 1987). The SME samples were analyzed using inductively coupled plasma analysis for phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), manganese (Mn), zinc (Zn), copper (Cu), and iron (Fe), whereas nitrate nitrogen (NO_3-N) was measured using an ion-specific electrode. Statistical analysis of all data was performed using analysis of variance and means were separated by Fisher's least significant difference.

Results and discussion

Particle size distribution. The effect of the addition of PVC and BVC to MM360 on particle size distribution is shown in Figures 1 A and B, respectively. Because amendment of MM360 with either of the two VC produced nearly identical particle size distribution, the data are discussed in terms of the composite effects. The addition of VC to MM360 resulted in an increase in the percentage of particles less than 1 mm in diameter. There were 33% more particles with diameters less than 1 mm in 20% VC compared with MM360. Particle sizes of 1.0 to 0.5,

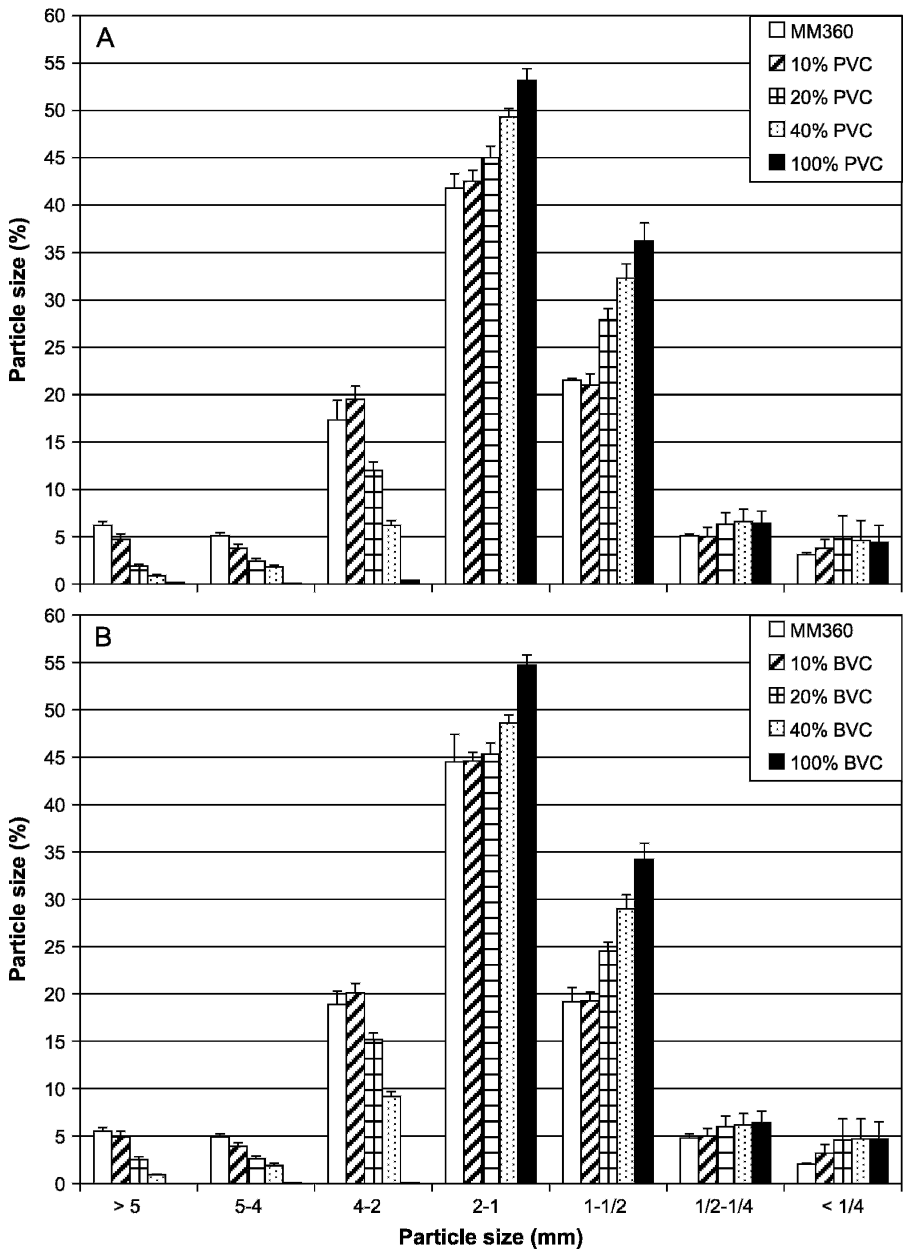

Fig. 1. Distribution of particle size ranges for a commercial potting substrate, Metro Mix 360 [MM360 (O.M. Scotts Co., Marysville, Ohio)], amended at five different levels by volume with vermicompost of (A) separated pig solids (PVC) or (B) feedlot beef cattle (BVC). Error bars represent SE, n = 3.

0.5 to 0.25, and less than 0.25 mm diameter increased 29%, 25%, and 88% for 20% VC; 47%, 25%, and 80% for 40% VC; and 65%, 27%, and 69% for 100% VC compared with unamended (0% VC) MM360 (Fig. 1). The proportion of particles with diameters greater than 1 mm decreased 15%, 20%, and 24% in 20% VC; and 40% VC, and 100% VC, respectively. The greatest increases in particle size were those particles 1.0 to 0.5 mm in substrates with VC percentages above 20%. The increases in 1.0- to 0.5-mm particles corresponded with an inverse decrease in particle sizes 2 mm or greater. There was little difference between MM360 and 10% VC in the proportion of particles with diameters between 0.25 mm and 2.0 mm.

PHYSICAL PROPERTIES. DBD and WHC increased as the proportion of VC was increased (Table 1). DBD increased 7%, 19%, 23%, and 29% for 10% VC, 20% VC, 40% VC, and 100% VC, respectively over unamended 0% VC. Incorporation of VC increased

Table 1. Differences in physical properties of a commercial potting substrate, Metro Mix 360 [MM360 (O.M. Scotts Co., Marysville, Ohio)], amended at five different levels by volume with vermicompost (VC) of separated pig solids (PVC) or feedlot beef cattle (BVC).

Substrate mix	Bulk density ($g\cdot cm^{-3}$)[z]	Porosity (mL/100 mL)[y]	Water holding capacity (mL/100 mL)[x]	Air volume (mL/100 mL)[x]
Separated pig solids vermicompost (PVC)				
MM360 (control)	0.13 c[w]	93.32 a	36.53 d	56.79 a
10% PVC	0.13 c	92.63 b	40.18 c	52.45 b
20% PVC	0.15 b	91.74 c	48.17 b	43.57 c
40% PVC	0.16 ab	91.20 cd	52.63 ab	40.63 c
100% PVC	0.16 a	90.68 d	56.85 a	35.25 d
Feedlot beef cattle vermicompost (BVC)				
MM360 (control)	0.12 c	91.23 a	35.68 e	55.55 a
10% BVC	0.14 bc	87.75 b	45.45 d	42.30 b
20% BVC	0.16 b	84.72 b	52.02 c	32.70 c
40% BVC	0.20 a	82.21 b	55.87 b	26.34 d
100% BVC	0.22 a	78.45 c	58.87 a	19.58 e
Significance				
VC treatment	**	*	*	**
Manure source	*	**	*	*

[z]1 $g\cdot cm^{-3}$ = 0.5780 oz/inch^3.
[y]Gravity equilibrated, drained wet substrate; 1 mL/100 mL = 1%.
[x]Wet substrate.
[w]Mean separation among substrate mixes within each VC source.
*,**Significant at $P \leq 0.05$ or 0.01, respectively.

Table 2. Analysis of saturated substrate extract samples for a commercial potting substrate, Metro Mix 360 [MM360 (O.M. Scotts Co., Marysville, Ohio)], amended at five different levels by volume with vermicompost of separated pig solids or feedlot beef cattle.

	pH	EC[z] ($mS\cdot cm^{-1}$)[y]	NO_3-N[z] (ppm)[y]	P[z] (ppm)	K[z] (ppm)	Ca[z] (ppm)	Mg[z] (ppm)	Mn[z] (ppm)	Fe[z] (ppm)	Cu[z] (ppm)	Zn[z] (ppm)
Separated pig solids vermicompost (PVC)											
MM360 (control)	6.3[z]	2.25	125	11	271	183	93	7.4	6	0.4	1.4
10% PVC	6.2	2.80	179	38	294	273	114	8.9	9	1.7	3.6
20% PVC	6.1	3.04	217	48	247	312	124	7.7	10	2.3	4.4
40% PVC	6.1	3.75	339	48	247	379	137	8.9	13	5.5	8.3
100% PVC	6.2	7.32	795	48	410	576	176	10.8	23	11.6	19.8
Feedlot beef cattle vermicompost (BVC)											
MM360 (control)	6.2	2.15	131	9	191	101	125	5.1	9	1	0.9
10% BVC	6.1	2.86	195	22	303	133	146	6.2	15	2.3	1.4
20% BVC	6.2	3.48	265	36	361	241	162	9.1	19	3.1	3.6
40% BVC	6.2	4.72	405	42	382	271	171	11.2	22	4.9	5.9
100% BVC	6.5	10.73	700	48	698	412	310	19.1	35	7.3	13.9
Significance											
Vermicompost treatment	NS	***	***	***	**	*	*	*	*	*	*
Manure source	NS	*	*	NS	*	*	*	NS	*	**	NS

[z]EC = electrical conductivity; NO_3-N = nitrate nitrogen; P = phosphorous; K = potassium; Ca = calcium; Mg = magnesium; Mn = manganese; Fe = iron; Cu = copper; Zn = zinc.
[y]1 $mS\cdot cm^{-1}$ = 1 mmho/cm; 1 ppm = 1 $mg\cdot kg^{-1}$.
NS,*,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

WHC 10%, 31%, 44%, and 55% in 10% VC, 20% VC, 40% VC, and 100% VC, respectively. Both AV and POR were inversely related to DBD and WHC (Table 1). As the percentage of VC incorporated increased, both AV and P decreased. The AV was lowered by 8%, 24%, 29%, and 38% for 10% VC, 20% VC, and 40% VC, and 100% VC, respectively. Amendment with VC resulted in lower substrate POR by 1%, 2%, 3%, and 3% for 10% VC, 20% VC, and 40% VC, and 100% VC, respectively.

Nutrient content. Macronutrient content increased with increasing VC content regardless of VC type when compared with the unamended control substrate (Table 2). NO_3-N increased by 43%, 73%, and 270% (PVC) and 48%, 202%, and 309% (BVC) in the 10%, 20%, and 40% amended substrates compared with the control substrates, respectively. P was greater by 245%, 336%, and 336% (PVC) and 144%, 400%, and 466% (BVC), whereas Ca increased 49%, 70%, and 107% (PVC) and 37%, 238%, and 268% (BVC), respectively, in 10%, 20%, and 40% amended substrate. K increased 8% in the 10% PVC and then decreased 9% compared with the control substrate for 20% and 40% PVC. K increased 16%, 29%, and 37% compared the control substrate 10%, 20%, and 40% BVC-amended substrate, respectively.

The amendment of the control substrate with either PVC or BVC resulted in little change in substrate pH regardless of amendment volume (Table 2). EC conductivity increased with increasing amendment volumes of both PVC and BVC, 24%, 35%, and 67%, and 53%, 61%, and 219%, respectively (Table 2). Substrate levels of Mn, Fe, Cu, and Zn increased as both PVC and BVC amendment increased (Table 2).

Particle size distribution affects all physical properties within a potting container substrate (Spomer, 1975). In this study, there was an increase in the proportion of particles with diameters less than 2 mm in 20% VC compared with unamended 0% VC control, although there was little difference between 10% VC to 0% VC. DBD and WHC increased in the 20% treatment as well as decreases in porosity and air volume. VC added at volumes above 20% resulted in substrate physical characteristics that may be optimal to produce quality floriculture crops. Gartner et al. (1974) reported that a favorable physical environment for plant growth resulted in a substrate having 20% to 40% particles less than 0.8 mm and 10% to 20% greater than 6.4 mm. Tilt et al. (1987) reported that substrate particle size had significant effects on physical properties and plant growth of three species of woody ornamental plants. Substrate amended with peanut hulls increased particle size, porosity, and air space and decreased available water and bulk density (Bilderback et al., 1981). The increased particle size resulted in greater dry shoot weight, dry root weight, and percentage of growth. Substrate amended with peatmoss resulted in decreased particle size, porosity, and air space and led to reduced growth in azalea [*Rhododendron* sp. (Bilderback et al., 1981)].

Researchers have reported that the available P in earthworm castings (VC) is usually greater than in surrounding soil (Lunt and Jacobson, 1944; Tiwari et al., 1989). The levels of P in VC are routinely five to 10 times greater than surface soils (Lee, 1985). Increased availability of P in VC compared with surrounding soil is proposed to be attributable to enhanced phosphatase activity in the VC (Satchell and Martin, 1984). This increased phosphatase activity is thought to be attributable to increased microbial activity. Evidence for this was reported by Sharpley and Syers (1976). Because P levels increased during the warmer seasons and decreased during winter, it was suggested that cool temperatures are responsible for reduced microbial activity.

The other macronutrients, particularly Ca, also increased with increased addition of VC (Tiwari et al., 1989). The chemistry of fecal material of earthworms is most likely responsible for the increased Ca found in VC. Earthworms have specialized glands that encapsulate the fecal material in calciferous deposits as it leaves the worms after passing through the worm gut (Piearce, 1972).

The micronutrient levels in the 100% VC were great enough that in some species of bedding plants, there would be the threat of developing micronutrient toxicities. The concentrations that are considered optimal for potting substrate are 0.3 to 3.0 ppm Fe, 0.1 to 3.0 ppm Mn, 0.01 to 0.3 ppm Cu, 0.1 to 0.3 ppm Zn, and 0.05 to 0.5 ppm B (Fafard Analytical Services, Anderson, S.C.). These levels decreased when less VC was added, although levels were still greater than what is considered optimal.

VC has the potential to be a beneficial amendment to potting media. Based on particle size analysis and physical properties, VC may be the most beneficial when used as an alternative supplemental component for peat or coir. Most potting substrates are composed of materials that contain a variety of particle sizes. This leads to changes in physical properties resulting from "nesting" of various particle sizes uniquely associated with soilless substrate components. The uniform particle size distribution of VC could provide predictable physical properties when blended with other substrate components. Changes in physical properties can result in growth enhancement or inhibition; therefore, additional studies must be conducted to determine optimal mix ratios with a variety of substrate components. Thus, the use of VC may reduce supplemental fertilizer applications or the need for the incorporation of nutrients ("starter charge") in media formulations. Incorporation of VC also increases WHC, which in turn could have a positive impact on water conservation and reduced water runoff.

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