Physical and Chemical Properties of Substrates Containing Earthworm Castings and Effects on Marigold Growth

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Abstract. The effects of various substrates with or without earthworm [*Eisenia fetida* (Savigny, 1826)] castings on growth of marigolds were evaluated. In addition, the physical and chemical properties of such substrates were determined. Castings had a greater nutrient content than the remaining substrates. The 4 pine bark: 1 sand treatment (v/v) (PBS) had higher P, K, and Zn than 7 peat moss: 3 perlite (v/v) (PP). PP had the lowest nutrient content of all substrates. Castings (C) had the highest pH followed by 1 PBS: 1 C (v/v), 2 PBS: 1C (v/v) and 3 PBS: 1C (v/v). Sunshine Mix 1 and PP had the lowest pH. EC (ER) was increased by castings, which had high ER. Castings and PP had the greatest percentage pore space. Water-holding capacity was greatest for 2 PBS: 1C (v/v) compared with Sunshine Mix 1 followed by castings. Earthworm castings increased plant growth index, stem diameter, root growth, dry weight, and flower number of marigolds compared with PP, Sunshine Mix 1, and PBS. All mixtures of castings (C) with PP, PBS, except 3 PBS: 1C (v/v), increase the growth index of plants. 1 PP: 1 C (v/v), increased flower number compared with all substrates without castings. Castings alone increased number of open flowers, but did not differ from 1 PP: 1 C or 3 PP:1 C.

It has been established that earthworms are one of the most useful and active agents in introducing suitable chemical, physical, and microbiologic changes in the soil. New Zealand did not have native earthworms, and when European species were introduced, grass production doubled (Logsdon, 1994). Growth improvement of specific plants, compatibility with technology, and low cost of production were among the reasons given to support the use of earthworm castings (vermicompost) as a growth medium (Grappelli et al., 1985).

Kang and Ojo (1996) found that higher rice shoot dry weight, lower fertilizer response, and higher nutrient uptake were obtained when rice plants were grown in earthworm castings compared with surface soils. *Eisenia fetida* is one of the most frequently recommended earthworm species for vermicompost production (Edwards, 1995; Orozco et al., 1996). According to

Lee (1985), N-containing products of earthworm metabolism are returned to the soil in casts, urine, mucoproteins, and dead earthworm tissue. Growth of annatto (*Bixa orellana*) in plastic bags containing soil inoculated with earthworms was superior to plants grown without earthworms (Pashanasi et al., 1992). Orozco et al. (1996) found that after ingestion of coffee pulp by *E. fetida*, an increase in available P, Ca, and Mg and a decrease in K were detected.

Earthworms influence soil structure by forming macropores, which allow O₂ to enter the soil, whereas micropores between the aggregates give good water-holding capacity (Lavelle, 1988; Willems et al., 1996). In addition to forming macropores and increasing water infiltration, earthworms have been shown to increase soil aggregate stability (Li and Ghodrati, 1995) and water-holding capacity (Stockdill, 1982). The objectives of this study were to evaluate the suitability of using earthworm castings (vermicompost) as an amendment in substrates used to grow potted marigold plants and determine the physical and chemical properties of such substrates.

Materials and Methods

This research was conducted at the Mississippi State University Horticulture Greenhouses. African Marigold 'Marvel Orange' (*Tagetes erecta*) were seeded (two seeds per hole) into 1030 plastic flats using Sunshine Mix 1 (75% Canadian sphagnum moss, 25% perlite, nutrients with gypsum, dolomitic

lime, and a wetting agent) as germination substrate. Flats were watered and covered with a transparent plastic cover, and placed on a bench with artificial light. Seedlings were relocated to the greenhouse when they had four true leaves. Then, 100 mg·L⁻¹ N of 20–4–4–16.6 N-P-K fertilizer was applied to the seedlings to promote growth and prepare seedlings for transplanting.

Plants of uniform size were chosen from the flats and transplanted into 10 cm × 10 cm square plastic pots filled with the substrates to be tested. After transplanting, plants were placed on a greenhouse bench in a completely randomized design and irrigated daily. No additional fertilizer was applied to the plants to compare the effect of substrates on plant growth without the effect of external fertilizer application.

Substrates evaluated were: Sunshine Mix 1, 7 peat: 3 perlite (v/v) (PP), 4 pine bark: 1 sand (v/v) (PBS), and earthworm castings (C) sieved to 6 mm. In addition, mixtures of (PP) and (PBS) with castings (C) at 1:1, 2:1, and 3:1 (v/v) ratios were evaluated for a total of 10 treatments. Castings were produced using cow manure as the only food source for the earthworms. Vermicomposting methodology involved harvesting cow manure from fields of grazing animals feeding on grass. Five liters of manure and 170 g of mostly adult earthworms (≈425 specimens) were placed in 6.9-L plastic containers. Containers were placed in the shade to ensure favorable temperature and light for earthworm growth (Hidalgo and Harkess, 2002a). Sixteen containers were used in the production of castings. After 30 d, the worms were removed and castings were air-dried and passed through a 6-mm sieve. Substrates with peat moss: perlite and pine bark: sand were buffered using 4.5 kg m⁻³ of calcium carbonate provided by dolomitic limestone (52% CaCO₃).

Data were collected weekly and included stem height and diameter. The plant growth index was calculated using the formula $GI = \pi \cdot r^2 \cdot h$, where GI = growth index, $\pi = 3.1415$, r = ratio of foliage, and h = stem height. Other parameters evaluated were: number of flowers per plants, number of opened flowers per plants, and root growth on a scale from 5 (excellent growth) to 1 (poor growth). In addition, plant dry weight (roots not included) was determined by drying plant parts in an oven at 60 °C for 48 h. Bulk density, percent pore space, percentage air space, water-holding capacity, electric conductivity (EC), and pH of the treatment substrates were determined using three samples of each substrate (Hidalgo and Harkess, 2002a, 2002b). EC and pH were analyzed using a 1:2 dilution. Samples of the treatment substrates were delivered to the Mississippi State University Soil Testing Laboratory (Mississippi State, Miss.) to determine nutrient content using the Lancaster Soil Test Method (Cox, 2001).

The experimental design was a completely randomized design with 10 treatments and 10 replications (10 plants per treatment). Data

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were analyzed by analysis of variance using SAS (SAS Institute, Cary, N.C.). Treatment means were separated using Duncan's multiple range test, 5% probability.

Results and Discussion

Substrate nutrient analysis showed that castings had a greater nutrient content than the remaining substrates. As anticipated, when castings were mixed with other substrates, nutrient content decreased as a result of dilution. The 4 pine bark: 1 sand (v/v) treatment (PBS) had higher P, K, and Zn than 7 peat moss: 3 perlite (v/v) (PP). PP had the lowest nutrient content of all substrates (Table 1). Similar to our findings, Parkin and Berry (1994) found that earthworm castings were enriched in mineral N, relative to surrounding soil, and the amount of N accumulated in earthworm castings was a reflection of the N content of the organic matter used as a food source by the earthworms. It was previously reported that sheep or cattle castings had greater initial nutrient content than castings from horse manure and substrates with castings (Hidalgo and Harkess, 2002b).

Earthworm castings (C) had the highest pH followed by 1 PBS: 1 C (v/v), 2 PBS: 1 C (v/v), and 3 PBS: 1 C. Sunshine Mix 1 and PP had the lowest pH. Research with poinsettia showed that leachate pH of earthworm castings and peat: perlite substrates ranged from 4.69 to 8.0 depending on the type and amount of castings (Hidalgo and Harkess, 2002a). In this experiment, PP without castings had a pH between 3.85 and 4.69.

Earthworm castings had a greater amount of soluble salts as indicated by EC compared with the control (Sunshine Mix 1) followed by 1 PBS: 1 C (v/v), 1 PP: 1 C (v/v), and 2 PP: 1 C (v/v) (Table 2). Substrates with low EC were PBS and PP. These results are associated with higher nutrient levels (Table 1) in the treatments with castings. As previously reported, electrolyte conductivity (EC) was increased by castings based on the type of castings and EC decreased with time after transplanting (Hidalgo and Harkess, 2002a).

Earthworm castings, 1 PBS: 1 C, and PP had the greatest percentage pore space followed by 2 PBS: 1 C, 2 PBC: 1 C, and Sunshine Mix 1 (control). PBS, 3 PBS: 1 C, and 1 PP: 1 C had the smallest percentage pore space (Table 2). Percent air space was greatest for PP followed by earthworm castings as compared with Sunshine Mix 1. Mixtures 3 PBS: 1 C, and 2 PBC: 1 C had the smallest percentage air space. These are expected results, because perlite is a good substrate to improve aeration of container mixes (Davidson et al., 1994).

Water-holding capacity was greatest for 1 PBS: 1 C as compared with Sunshine Mix 1 followed by earthworm castings. PBS and 1 PP: 1 C had the least water-holding capacity. All treatments containing pine bark: sand had the highest values for bulk density, followed by 1 PP: 1 C, 2 PP: 1 C, and earthworm castings. Sunshine Mix 1 and 7 peat moss: 3

Table 1. Extractable nutrient levels of the treatment substrates used to grow marigolds.

Substrates	Extractable Nutrient Levels (mg·kg ⁻¹)					
	N	P	K	Ca	Mg	Zn
Sunshine	4.0 g ^z	23.0 d	89.5 i	818.5 h	252.5 f	13.8 b
Castings	65.0 a	165.5 b	567.5 a	2431.5 a	577.5 a	17.9 a
4 Pine bark: 1 sand (PBS)	0.5 h	15.0 e	91.5 h	789.5 i	79.5 i	2.7 h
7 Peat moss: 3 perlite (PP)	0.5 h	2.5 f	10.5 j	193.0 j	55.5 j	1.1 i
1 PP: 1 C	12.5 d	166.5 a	445.5 c	1333.5 e	349.0 c	9.2 d
2 PP: 1 C	9.0 e	161.5 c	331.5 e	1246.0 d	247.5 g	8.1 e
3 PP: 1 C	17.5 b	161.5 c	281.0 g	1173.0 e	222.5 h	6.6 fg
1 PBS: 1 C	15.0 c	161.0 c	531.0 b	1820.5 b	390.0 b	11.6 c
2 PBS: 1 C	6.5 f	161.0 c	367.5 d	1061.0 f	294.0 d	7.0 f
3 PBS: 1 C	4.5 g	161.0 c	300.5 f	966.0 g	261.5 e	5.9 g

^zMeans in column separated by Duncan's multiple range test, 5% significance level.

Table 2. Percentage pore space, air space, water-holding capacity, bulk density, pH, and EC of the different substrates used to grow marigold plants.

Substrate	Pore Space (%)	Air Space (%)	Water-Holding Capacity (%)	Bulk Density (g·cm ⁻³)	pH	EC (mmhos·cm ⁻¹)
Sunshine Mix ¹	66 b ^z	13 c	53 bcd	0.10 e	5.67 f	0.42 de
Castings	82 a	22 b	60 b	0.22 c	7.59 a	0.90 a
4 Pine bark: 1 sand (PBS)	45 c	6 de	39 e	0.47 a	6.59 c	0.1 bg
7 Peat moss: 3 perlite (PP)	80 a	36 a	44 de	0.13 de	5.80 f	0.15 g
1 PP: 1 C	52 c	13 c	39 e	0.26 b	6.37 d	0.50 bc
2 PP: 1 C	62 b	8 c	54 bc	0.24 bc	6.17 d	0.50 bc
3 PP: 1 C	52 b	11 cd	41 e	0.16 d	6.11 e	0.38 ef
1 PBS: 1 C	82 a	10 cd	72 a	0.44 a	6.80 b	0.55 b
2 PBS: 1 C	62 b	5 de	56 bc	0.46 a	6.63 c	0.39 ef
3 PBS: 1 C	50 c	3 e	46 cde	0.48 a	6.56 c	0.34 f

^zMeans in columns separated by Duncan's multiple range test, 5% significance level.

perlite had the lowest bulk density. Davidson et al. (1994) stated that peat moss is difficult to wet, but when wetting, it possesses good water-holding capacity and good aeration. In this study, treatments containing peat moss showed reduces water-holding capacity, possibly as a result of a short wetting period of 30 min. Syers and Springett (1983) found that earthworm castings generally have higher water-holding capacity compared with soil without castings.

Castings alone and 1 PP: 1 C resulted in the greatest growth index (GI), but did not differ from 2 PP: 1 C or 1 PBS: 1 C (Table 3). All treatments except PP and 3 PBS: 1 C resulted in a greater GI compared with Sunshine Mix 1 (control). PBS resulted in the lowest growth index. Greater amount of nutrients, higher pH, and increased water-holding capacity found in castings may have resulted in a greater plant growth index of plants. In plant growth trials with vegetables, fruits, and ornamental plants, vermicompost outperformed both traditional compost and commercial plant growth substrates in almost every experiment. The author stated that this may be explained, partially by circumstantial evidence, that vermicomposts have better structure and may contain plant growth hormones, enhanced levels of soil enzymes, and high microbial populations (Edwards, 1995).

Castings alone resulted in greater marigold stem diameter each week after transplanting as compared with the remaining substrates (Table 3). Greater nutrient content

of the castings when compared with the rest of substrates may explain the increase in stem diameter. PBS resulted in smallest stem diameter. Earthworm castings and Sunshine Mix 1 resulted in greater number of roots and were equally effective compared with the remaining treatments (Table 3). The number of roots in Sunshine Mix 1 did not differ from pine bark castings mixtures (PBS: C).

Earthworm castings increased plant dry weight followed by 1 PP: 1 C, 1 PBS: 1 C, and 2 PP: 1 C when compared with Sunshine Mix 1 (control). PP and PBS resulted in least dry weight of marigolds. The remaining treatments showed intermediate values not different from the control (Table 3).

Earthworm castings increased the number of flowers compared with the remaining substrates (Table 3). When substrates were mixed with castings at 1:1, 2:1, or 3:1 (v/v), performance was related to the amount of castings in the mixtures; the greater the amount of castings, the greater the growth response. This improvement could have been associated with increasing amount of nutrients obtained when castings were increase in the mixture in addition to the physical and chemical properties of castings. Castings had a greater nutrient content than the other substrates, particularly nitrogen. PP had the lowest nutrient content of all substrates. In addition, castings had the highest pH and EC and contributed to greater air space and water-holding capacity, thus resulting in improved plant growth. Castings were found

Table 3. Growth index (GI), root growth, plant dry weight, stem diameter, number of flowers per plant, and number of flowers opened per plant of marigold as influenced by substrates 9 weeks after transplanting.

Substrates	GI (cm ³)	Root Growth (1–5) ^y	Dry Weight (g)	Stem Diameter (mm)	Flowers (#)	Open Flowers (#)
Sunshine	2164.7 d ^z	4.0 ab	4 cd	5 ef	1 cde	0.0 c
Castings	3449.2 a	4.8 a	10 a	7 a	3 a	0.8 a
4 Pine bark: 1 sand (PBS)	1461.7 e	2.6 cd	2 e	4 g	0 e	0.0 c
Peat moss: 3 perlite (PP)	2253.1 d	2.6 cd	3 de	4 de	1 de	0.0 c
1 PP: 1 C	3450.1 a	2.8 cd	6 b	6 b	3 ab	0.6 ab
2 PP: 1 C	3078.1 ab	2.2 d	5 c	6 bcd	2 bcd	0.2 bc
3 PP: 1 C	2884.9 bc	2.0 d	4 cd	5 de	2 abc	0.0 c
1 PBS: 1 C	3031.0 ab	3.8 b	6 b	6 bc	2 bcd	0.4 abc
2 PBS: 1 C	2721.8 bc	3.6 c	5 bc	5 cde	1 cde	0.0 c
3 PBS: 1 C	2418.1 cd	3.6 bc	4 c	5 de	2 bcd	0.0 c

^zMeans in columns separated by Duncan's multiple test, 5% significance level.^yVisual scales from 1 to 5 in which 5 = excellent number of roots and 1 = poor number of roots.

to be a suitable substrate amendment for growing potted marigolds.

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