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Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse

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ABSTRACT

Vermicomposts have been shown to promote the germination, growth, and yields of plants. This paper aims to demonstrate the effects of vermicomposts produced from three types of wastes on growth and flowering of petunias which are an important U.S. flowering crop.

Vermicomposts, produced commercially from cattle manure, food wastes and paper wastes, were substituted at a range of different concentrations into with a soilless commercial bedding plant container medium, Metro-Mix 360 (MM360), to evaluate their effects on the growth and flowering of petunias (*Petunia* sp.) in the greenhouse. Seeds of petunia (var. Dreams Neon Rose F1) were sown into 100, 90, 80, 70, 60, 50, 40, 30, 20 or 10% MM360 substituted with 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 or 100% cattle manure, food waste or paper waste vermicompost. Each type of vermicompost constituted a separate sub-experiment. All plants were watered three times weekly with 200 ppm Peter's nutrient solution, containing all nutrients required, from sowing up to 79 days. Substitutions with all of the vermicomposts into MM360 increased germination significantly on almost all sampling dates. Shoot dry weights increased significantly after substituting MM360 with 10–60% cattle manure vermicompost, and 10–100% of both food waste and paper waste vermicomposts. Numbers of flowers increased significantly after MM360 substitutions with 20–40% of both cattle manure and food waste vermicomposts, and by only 40% of paper waste vermicompost. There were no positive correlations between the increases in numbers of flowers, and the amounts of mineral-N and microbial biomass-N in the potting mixtures, or the concentrations of N in the shoot tissues of petunias. Factors such as improvement of the physical structure of the potting medium, increases in populations of beneficial microorganisms, and most probably, the availability of plant growth-influencing-substances such as hormones and humates produced by microorganisms during vermicomposting, probably contributed to the increased petunia germination, growth and flowering.

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1. Introduction

Petunias (*Petunia* sp.), which belong to the family Solanaceae, are a popular annual bedding ornamental choice, for summer home gardens and commercial landscaping projects, in the U.S. Petunia seedlings are commonly produced in the greenhouse in mixtures of commercial soilless bedding plant growth media with fertilizers before transplanting outdoors. However, a growing awareness of possible adverse environmental and economic impacts of agrochemicals on ornamental plant production, has stimulated interest in the greater utilization of organic amendments such as composts or vermicomposts for producing and maintaining bedding plants for use in greenhouses, homes and commercial gardens.

Recently, there has been much interest in the potential of vermicomposts, which are products of a mesophilic, aerobic biodegradation and stabilization of organic materials, produced through interactions between earthworms and microorganisms, as plant growth media and soil amendments. Vermicomposts are finely divided peat-like materials with high porosity, good aeration, drainage, water-holding capacity and very high microbial activity, which make them excellent as soil amendments or conditioners and as plant growth media (Edwards and Burrows, 1988; Edwards, 1998; Edwards and Arancon, 2004). Metro-Mix 360 (MM360) is a commercial soil-less greenhouse bedding plant medium prepared from vermiculite, Canadian sphagnum peat moss, ash from bark and sand, which contains a starter nutrient fertilizer in its formulation. Substitutions of different proportions of vermicomposts, produced commercially from cattle manure, food waste or paper waste, into corresponding proportions of MM360, have been shown in our laboratory and greenhouses to increase the rates of germination, growth and flowering of a range of greenhouse ornamental and vegetable seedlings significantly including marigolds (Atiyeh et al., 2001a), tomatoes (Atiyeh et al., 2000a,b), and peppers (Arancon et al., 2004), even when all necessary mineral nutrients were supplied. More recent experiments in our laboratory have demonstrated that vermicomposts contain plant growth-regulating materials, including plant growth hormones and humic acids, which are probably responsible, for most of the increased germination, growth and yields of plants, in response to vermicompost applications or substitutions, independent of the nutrients they contain (Atiyeh et al., 2002; Arancon et al., 2006b; Arancon and Edwards, 2006b). The research reported here assessed and compared the effects of different rates of substitutions of three types of vermicomposts, produced from cattle manure, food waste and paper waste, into a soilless growth medium (MM360), on the germination, growth and flowering of petunias, kept under similar environmental conditions in the greenhouse.

2. Materials and methods

2.1. Experimental design

The experimental design used was a completely randomized design (CRD) with 11 treatments replicated four times. Fifty petunia seeds (var. Dreams Neon Rose F1) (Harris Seeds Co., New York, USA) were sown into polystyrene plug trays containing either 100% (control), 90, 80, 70, 60, 50, 40, 30, 20, 10, or 0% MM360 substituted with 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, or 100% (by volume) cattle manure, food waste or paper waste vermicomposts, for each experiment, respectively. Each set of 50 plugs, containing one of the MM360/vermicompost mixtures. Seeded plug trays were placed in a mist house and the numbers of seeds germinating counted after 6, 9 and 11 days. Plants were watered with tap water and fertilized three times a week with 20–10–20 (200 ppm N) Peters Professional plant nutrient solution to provide all MM360/vermicompost mixtures, and the control, with all necessary nutrients. Peters Professional which is a water-soluble fertilizer recommended for continuous liquid feed programs of greenhouse plants, contains 7.77% NH_4-N, 12.23% NO_3-N, 10% P_2O_5, 20% K_2O, 0.15% Mg, 0.02% B, 0.01% Cu, 0.1% Fe, 0.056% Mn, 0.01% Mo, and 0.0162% Zn.

2.2. Location of experiment and description of vermicomposts used

The experiments were in the Department of Horticulture and Crop Science greenhouse at the Ohio State University, Columbus, OH. The basic plant growth medium was a commercial soilless greenhouse container medium, MM360 (Scotts, Marysville, OH), with a range of substitutions with cattle manure, food waste or paper waste vermicomposts. The substitution of each different type of vermicompost into MM360 constituted a separate sub-experiment, with a total of three such sub-experiments. The commercial food waste vermicompost, which was provided by Oregon Soil Corporation (Oregon City, OR), came from supermarket food wastes processed by earthworms (*Eisenia fetida*), in indoor automated, continuous flow reactor systems (Edwards, 1998; Edwards and Arancon, 2004). Commercial paper waste vermicompost, produced from recycled cardboard and, processed by *E. fetida* in outdoor windrows was provided by the American Resource Recovery in Stockton, CA. Cattle manure vermicompost was produced at the Ohio State University from separated dairy cattle manure processed by *E. fetida* in a continuous flow reactor system (Edwards and Arancon, 2004). The basic chemical properties of the vermicomposts tested are summarized in Table 1.

2.3. Measurements and analyses

Sixteen petunias, selected at random from each MM360/vermicompost mixture, were transplanted singly into 10 cm diameter pots containing the same MM360/vermicompost mixtures that they were grown in. Pots were placed in the greenhouse in a completely randomized design (CRD) where they were watered as needed with tap water and fertilized three times a week, with 20–10–20 (200 ppm N) Peters Professional plant nutrient solution.

Forty-two days after sowing, eight plants from each treatment (MM360/vermicompost mixture) were harvested for shoot and root dry weight measurements. All leaves were removed from the stems, which were then oven-dried at 60 °C for 3 days. Dry shoots were weighed, then ground in a ball mill (Retsch, GMBH & Co., West Germany) and analyzed for tissue C

Table 1 – Initial nutrient chemical composition of vermicomposts produced from cattle manure, food waste and paper waste vermicomposts

Source of vermicomposts	C (%)	N (%)	B ($mg\ g^{-1}$)	Ca ($mg\ g^{-1}$)	Cu ($mg\ g^{-1}$)	Fe ($mg\ g^{-1}$)	K ($mg\ g^{-1}$)	Mg ($mg\ g^{-1}$)	Mn ($mg\ g^{-1}$)	Na ($mg\ g^{-1}$)	P ($mg\ g^{-1}$)	S ($mg\ g^{-1}$)	Zn ($mg\ g^{-1}$)
Cattle manure	18.0	1.9	0.06	35.07	0.35	3.86	9.39	5.94	0.17	1.65	4.71	5.71	0.26
Food waste	19.5	1.3	0.02	12.00	0.04	20.98	9.78	3.24	0.68	0.51	2.51	1.72	0.29
Paper waste	17.2	1.0	0.04	15.02	0.10	9.00	2.21	3.985	0.30	1.16	3.14	49.60	0.24

and N concentrations on a Carlo Erba NA 1500 C/N analyzer. Numbers of flowers were counted from the remaining eight plants in each treatment, 79 days after transplanting.

Samples of potting mixtures (5 g) were taken from pots for mineral-N ($NO_3 + NH_4$) analyses prior to transplanting and 79 days after sowing. The mineral-N concentrations in each potting mixtures were determined colorimetrically in 0.5 M K_2SO_4 extracts, in the ratio of 1:10 potting mixture to extractant, using a modified indophenol blue technique (Sims et al., 1995) with a Bio-Tek EL 311sx automated microplate reader (Bio-Tek® Instruments, Inc., Winooski, Vermont) at 660 nm. Microbial biomass nitrogen was measured in chloroform-fumigated soil samples (Brookes et al., 1985). Fumigated samples were extracted and digested using potassium sulfate and potassium persulfate, respectively.

2.4. *Statistical analyses*

Data were analyzed statistically by one-way ANOVA in a general linear model using SAS 9.2 (SAS Institute Inc., Cary, NC, USA, 2003). For each sampling date, and each measured parameter, the means were separated statistically using the least significant difference (LSD). Statistical significances were defined as $P \leq 0.05$. Data from sub-experiments were pooled for comparisons of differences between each type of vermicomposts.

3. Results

The initial nutrient compositions of vermicomposts from cattle manure, food waste and paper waste vermicomposts are summarized in Table 1. Although the C and N amounts were quite similar, amounts of most micro-nutrients differed between the types of vermicompost. For instance, vermicomposts from cattle manure had twice as much Ca (35.07 $mg\ g^{-1}$) as those of food waste and paper wastes, which had Ca concentrations of 12.00 and 15.02 $mg\ g^{-1}$, respectively. By contrast, the vermicompost from paper waste had more S (49.60 $mg\ g^{-1}$) compared to the amounts in cattle manure and paper waste vermicomposts which contained 5.71 and 1.72 $mg\ g^{-1}$, respectively.

The amounts of mineral-N in the cattle manure vermicompost/MM360 ranged from 5.8 to 464 $\mu g\ g^{-1}$ at transplanting to 15.7–36 $\mu g\ g^{-1}$ after 79 days (Table 2). The mineral-N in food waste vermicompost ranged from 32–161 $\mu g\ g^{-1}$ at transplanting to 9–51 $\mu g\ g^{-1}$ after 79 days (Table 3). The mineral-N in food waste vermicompost/MM360 mixtures ranged from 365–607 $\mu g\ g^{-1}$ at transplanting to 8–44 $\mu g\ g^{-1}$ after 79 days (Table 4). These amounts differed little from those in MM360 with no vermicomposts.

The microbial biomass-N in the cattle manure vermicompost/MM360 mixtures ranged from 719–1502 $\mu g\ g^{-1}$ at transplanting to 65–709 $\mu g\ g^{-1}$ after 79 days (Table 2). In the food waste vermicompost/MM360 mixtures, they ranged from 545–850 $\mu g\ g^{-1}$ at transplanting to 310–450 $\mu g\ g^{-1}$ after 79 days (Table 3). In the paper waste vermicompost/MM360 mixtures, they ranged from 118–604 $\mu g\ g^{-1}$ at transplanting to 40–925 $\mu g\ g^{-1}$ after 79 days (Table 4). These amounts of microbial biomass were much greater than those in MM360 with no

Table 2 – The concentrations (means ± S.E.) of mineral nitrogen, microbial biomass (Metro-Mix 360) substituted with different concentrations of cow manure vermicompost at transplanting and 79 days after transplanting and organic nitrogen in shoot tissues 79 days after transplanting

Percentage cow manure vermicompost in Metro-Mix 360	Mineral-N		Microbial biomass-N		Tissue-N
	At transplanting ($\mu g\,g^{-1}$)	79 days after transplanting ($\mu g\,g^{-1}$)	At transplanting ($\mu g\,g^{-1}$)	79 days after transplanting ($\mu g\,g^{-1}$)	79days after transplanting ($\mu g\,g^{-1}$)
Control	171 ± 2.5 d,e	51 ± 8 a	427 ± 34 e	329 ± 31 c,d	4.8 ± 0.5
10	8 ± 21 f	33 ± 6 a,b,c	719 ± 250 d,e	369 ± 63 c	4.9 ± 0.1
20	121 ± 6 e	19 ± 9 b,c	771 ± 48 c,d,e	471 ± 140 a,b,c	4.6 ± 0.1
30	221 ± 6 c,d	15 ± 7 c	1452 ± 249 a	421 ± 72 b,c	4.5 ± 0.2
40	236 ± 12 c	33 ± 8 a,b,c	1147 ± 31 a,b,c	109 ± 153 d,e	4.7 ± 0.3
50	340 ± 48 b,c	33 ± 2 a,b,c	1165 ± 229 a,b	95 ± 17 d,e	4.4 ± 0.3
60	292 ± 5 b	29 ± 3 b,c	1214 ± 70 a,b	709 ± 120 a	4.2 ± .2
70	408 ± 16 a	30 ± 3 b,c	1502 ± 78 a,b	100 ± 41 d,e	4.6 ± 0.2
80	423 ± 3 a	36 ± 7 a,b	1184 ± 4 a,b	65 ± 28 e	4.6 ± 0.3
90	464 ± 21 a	33 ± 4 a,b,c	1166 ± 39 a,b	658 ± 55 a,b	4.5 ± 0.2
100	459 ± 17 a	23 ± 7 b,c	1056 ± 3 b,c,d	362 ± 47 c	4.7 ± 0.2
P	***	*	***	***	ns
LSD (alpha = 0.05)	56	18	389	285	–

Means followed by the same letters do not significantly differ ($P < 0.05$).

vermicompost at transplanting, and some were still significantly greater ($P \leq 0.05$) even 79 days after transplanting.

There was a consistent tendency for the petunia seeds to germinate faster, often significantly so ($P \leq 0.5$), when there were larger amounts of vermicomposts in the mixtures, seedlings often emerging even as early as 6 days after sowing, in all types of vermicomposts (Fig. 1a–c).

Petunias germinated poorest in 80, 90 and 100% cattle manure vermicompost 20, 10 and 0%/MM360 mixtures. However, petunias grown in mixtures containing 10–60% cattle manure vermicompost, produced significantly larger ($P \leq 0.05$) shoot dry weights than those grown in MM360 only (Fig. 2a) independent of nutrient supply. Petunias grown in a mixture of 40% cattle manure vermicompost and 60% MM360 produced larger shoot dry weights, which were significantly greater than the shoot dry weights of petunias grown in MM360 with substitutions of 10, 20, 30, 50 and 0% cattle manure vermicomposts, independent of nutrient supply. Root dry weights, showed a similar trend, with petunias grown in cattle manure vermicompost substitutions ranging from 10 to 60% producing

Table 3 – The concentrations (means ± S.E.) of mineral nitrogen, microbial biomass (Metro-Mix 360) substituted with different concentrations of food waste vermicompost at transplanting and 79 days after transplanting and organic nitrogen in shoot tissues 79 days after transplanting

Percentage food waste vermicompost in Metro-Mix 360	Mineral-N		Microbial biomass-N		Tissue-N
	At transplanting ($\mu g\,g^{-1}$)	79 days after transplanting ($\mu g\,g^{-1}$)	At transplanting ($\mu g\,g^{-1}$)	79 days after transplanting ($\mu g\,g^{-1}$)	79days after transplanting ($\mu g\,g^{-1}$)
Control	171 ± 2	51 ± 8 a	427 ± 36 e	329 ± 29	5.1 ± 0.7
10	146 ± 71	18 ± 7 b	850 ± 25 a	422 ± 39	4.8 ± .03
20	161 ± 36	13 ± 3 b	842 ± 25 a	450 ± 41	4.5 ± 0.2
30	117 ± 33	17 ± 3 b	612 ± 105 c,d	325 ± 80	4.2 ± 0.2
40	66 ± 60	9 ± 3 b	778 ± 10 a,b	409 ± 8	4.7 ± 0.3
50	94 ± 34	16 ± 2 b	806 ± 72 a	383 ± 41	4.2 ± 0.4
60	163 ± 12	13 ± 2 b	636 ± 20 a,b,c	402 ± 52	4.5 ± 0.4
70	92 ± 46	16 ± 4 b	735 ± 33 a,b,c	310 ± 7	4.1 ± 0.3
80	77 ± 16	15 ± 2 b	545 ± 7 d,e	346 ± 24	4.7 ± 0.4
90	62 ± 6	17 ± 1 b	645 ± 33 b,c,d	406 ± 37	4.5 ± 0.2
100	32 ± 14	14 ± 3 b	589 ± 8 d	351 ± 24	4.6 ± 0.1
P	ns	***	***	ns	ns
LSD (alpha = 0.05)	–	13	136	–	–

Means followed by the same letters do not significantly differ ($P < 0.05$).

Table 4 – The concentrations (means ± S.E.) of mineral nitrogen, microbial biomass (Metro-Mix 360) substituted with different concentrations of paper waste vermicompost at transplanting and 79 days after transplanting and organic nitrogen in shoot tissues 79 days after transplanting

Percentage paper waste vermicompost in Metro-Mix 360	Mineral-N		Microbial Biomass-N		Tissue-N
	At transplanting ($\mu g\ g^{-1}$)	79 days after transplanting ($\mu g\ g^{-1}$)	At transplanting ($\mu g\ g^{-1}$)	79 days after transplanting ($\mu g\ g^{-1}$)	79days after transplanting ($\mu g\ g^{-1}$)
Control	171 ± 2 e	51 ± 8 a	427 ± 31 b	329 ± 2 b,c	4.9 ± 0.7
10	365 ± 27 d	25 ± 2 b	223 ± 35 c	280 ± 53 b,c	4.9 ± 0.2
20	370 ± 1 c,d	18 ± 5 b,c	236 ± 14 c	554 ± 29 a,b	4.7 ± 0.1
30	385 ± 35 b,c,d	15 ± 1 b,c	230 ± 37 c	370 ± 73 b,c	4.5 ± 0.3
40	402 ± 7 b,c,d	8 ± 2 c	220 ± 10 c	40 ± 71 d	4.7 ± 0.3
50	418 ± 19 b,c,d	9 ± 2 c	118 ± 40 d	58 ± 1 d	4.3 ± 0.3
60	424 ± 15 b,c	10 ± 4 c	161 ± 17 c,d	925 ± 495 a	4.2 ± 0.2
70	426 ± 13 b	18 ± 8 b,c	133 ± 14 d	68 ± 58 d	4.5 ± 0.2
80	607 ± 4 a	44 ± 8 a	532 ± 10 a	55 ± 18 d	4.5 ± 0.4
90	655 ± 35 a	13 ± 7 b,c	604 ± 27 a	573 ± 95 a	4.4 ± 0.2
100	656 ± 4 a	9 ± 1 c	588 ± 14 a	371 ± 42 c	4.6 ± 0.2
P	***	***	***	***	ns
LSD (alpha = 0.05)	56	15	55	212	–

Means followed by the same letters do not significantly differ ($P < 0.05$).

significantly more root dry weights ($P < 0.05$) than, those in MM360 only and those in the 70% cattle manure vermicomposts/30% MM360 substitutions (Fig. 2b) independent of availability of nutrients. Petunias grown in 30% and 40% substitutions of food waste vermicompost/MM360 mixtures, had significantly larger root dry weights ($P \leq 0.05$, Fig. 3a) but the shoot dry weights did not differ significantly between vermicompost substitution treatments (Fig. 3b). Petunias grown in substitutions of 10–60% paper waste vermicomposts into MM360 had significantly larger shoot dry weights ($P \leq 0.05$) than those grown in MM360 only, and in the range of substitutions of 70% up to 100% paper waste vermicompost into MM360 (Fig. 4a). Petunias grown in substitutions of 10–90% paper waste vermicompost into MM360 produced significantly larger root dry weights ($P < 0.05$) than those grown in 100% MM360 with no vermicompost or 100% vermicompost only (Fig. 4b). There were significantly more flowers ($P < 0.05$) on petunias grown in substitutions of 20, 30 and 40% cattle manure vermicompost into MM360 (Fig. 5a). Substitutions of 20, 30 and 40% of food waste vermicomposts into MM360 produced significantly more flowers ($P < 0.05$) than substitution of the other amounts of food waste vermicompost/MM360 (Fig. 5b). Petunias grown in a mixture of 40% paper waste vermicompost and 60% MM360 produced significantly more flowers ($P < 0.05$) than those from food waste substituted at other rates (Fig. 5c). All these increases in flower production were independent of nutrient availability.

4. Discussion

4.1. *Effects of vermicomposts on petunia germination, growth and flowering*

The data presented demonstrate considerably accelerated rates of germination of petunias, in response to all of the three types of vermicomposts produced from cattle manure, food waste and paper waste, that we tested in the current greenhouse experiments, independent of nutrient availability. Paper waste vermicompost produced the fastest seedling emergence, to even as early as 6 days after sowing, in response to substitutions of 10–90% paper waste or food waste vermicomposts into 90–10% MM360. The greatest germination of petunia seedlings in cattle manure vermicomposts was in response to substitutions of 50–100% food or paper waste vermicompost into 50–0% MM360. We have reported in previous publications that vermicomposts increased the seedling emergence of other ornamentals and vegetables compared with those grown in control commercial plant growth media, MM360 (Atiyeh et al., 2000a,b; Atiyeh et al., 2001a,b).

Edwards and Burrows (1988) also reported that a wide range of vegetables and ornamentals germinated earlier and better in mixing with vermicomposts than in commercial plant growth media. Subler et al. (1998) stated that marigolds germinated much earlier and grew faster for the first 2 weeks of growth in a standard commercial potting media substituted with 10 or 20% of vermicomposted pig manure. Buckerfield et al. (1999) reported similar increased germination trends of radishes in 0–100% mixtures of vermicompost and sand although some vermicompost application rates tended to inhibit germination initially.

In our current experiments, all three types of vermicompost caused very significant increases in rates and amounts of petunia growth in terms of shoot and root dry weights (Figs. 2–4). Increases in rates of shoot and root growth in response to all of the vermicomposts were much greater at lower substitution rates of vermicompost into MM360 than at higher ones. Atiyeh et al. (2000b) reported that marigold seedlings grown in a growth medium substituted with 20% pig manure vermicompost grew faster than those in MM360. Roots and shoot weights of marigolds were also significantly greater.

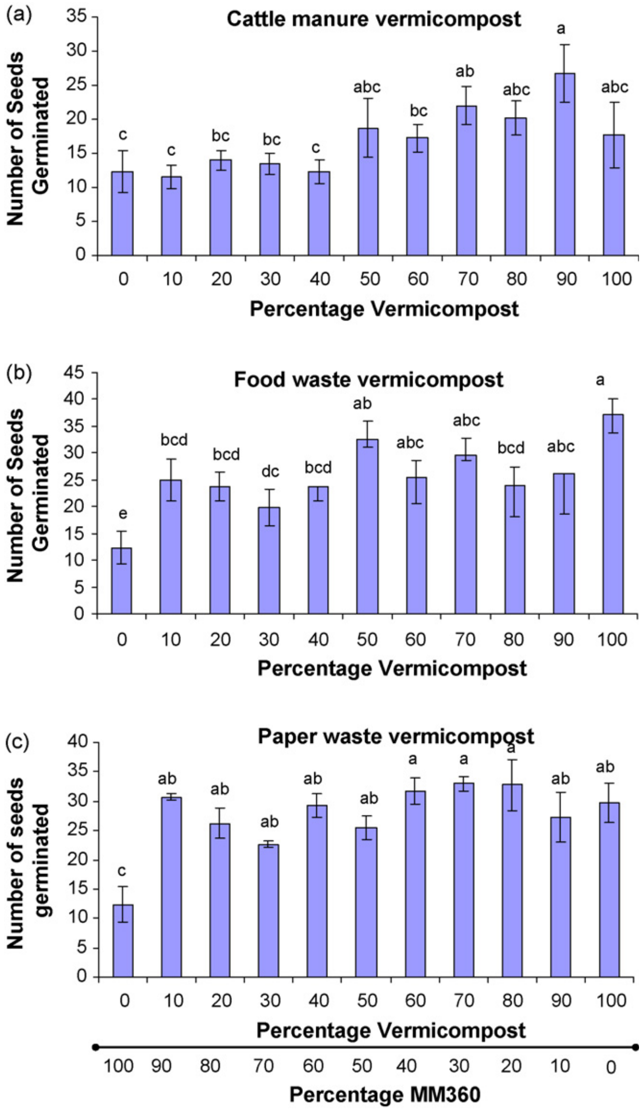

Fig. 1 – Number of petunia seeds germinating in standard commercial medium (Metro-Mix 360) substituted with different concentrations of (a) cattle manure, (b) food waste and (c) paper waste vermicompost 6 days after sowing. Columns followed by the same letter(s) do not differ significantly (P < 0.05) (increases independent of nutrient supply).

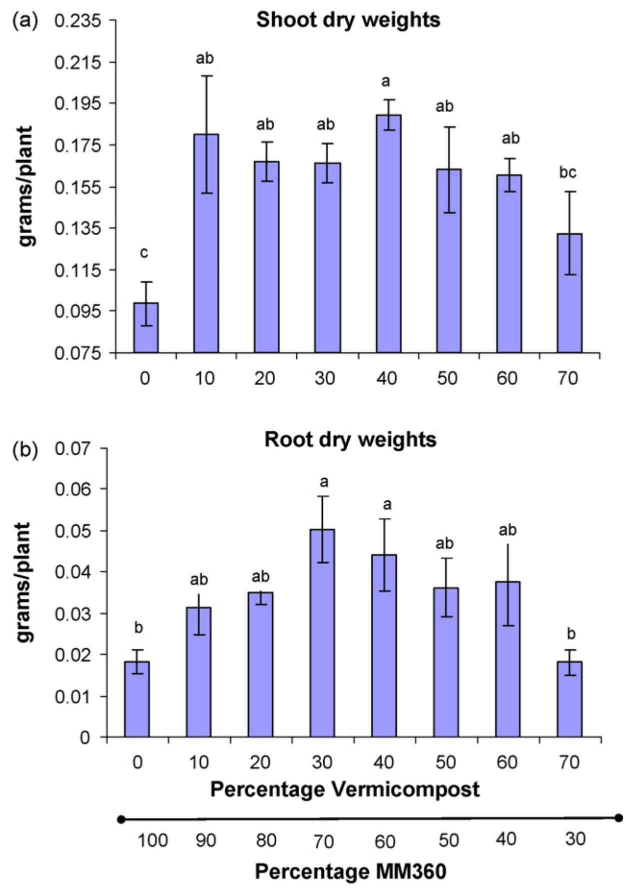

Fig. 2 – Mean petunia (a) shoots dry weight (b) and roots dry weights in a commercial medium (Metro-Mix 360) substituted with different concentrations of cattle manure vermicompost 42 days after sowing. Columns followed by the same letter(s) do not differ significantly (P < 0.05) (increases independent of nutrient supply).

Growth was slower in media with some substitution rates, such as that by cattle manure vermicompost at higher rates of substitution, but became evident only in the later stages of seedling growth where sometimes the shoot dry weights and root dry weights of petunias were affected negatively at the higher vermicompost substitution rates. For instance, shoot growth was significantly slower in petunias planted into MM360 substituted with either 70% cattle manure vermicompost, from 70 to 100% food waste vermicomposts or 70, 90 and 100% paper waste vermicomposts, compared to those that were grown in MM360 substituted with only 40% cattle manure, food waste and paper waste vermicomposts. Some of the lower growth rates in response to large rates of substitution of vermicomposts, particularly cattle vermicomposts, could be attributed to the higher salt content (i.e. electrical conductivity) or excessive nutrient levels in the more concentrated mixtures. In previous experiments we have concluded that some of slower growth rates of plants at high rates of substitution of vermicomposts was a response to higher concentrations of plant growth hormones such as auxins and humic acids produced by microorganisms in vermicomposts (Arancon et al., 2006b). When auxins are applied at high concentrations, they can reduce the rates of growth and development of plants (Hopkins and Huner, 2004) as well as increasing growth at lower concentrations.

Earlier research at OSU, substitutions of 30 or 40% pig manure vermicomposts into 70 or 60% MM360 reported increased numbers of flowers of another flowering crop, marigolds (Atiyeh et al., 2002). In the current experiments, all three types of vermicomposts produced significantly more flowers ($P \leq 0.5$) in response to substitutions of 20, 30 and 40% cattle manure or food waste vermicomposts and 40% paper waste vermicompost into corresponding amounts of MM360 and there was an overall trend for the lower substitution rates of vermicomposts to increase petunia flowering more than the

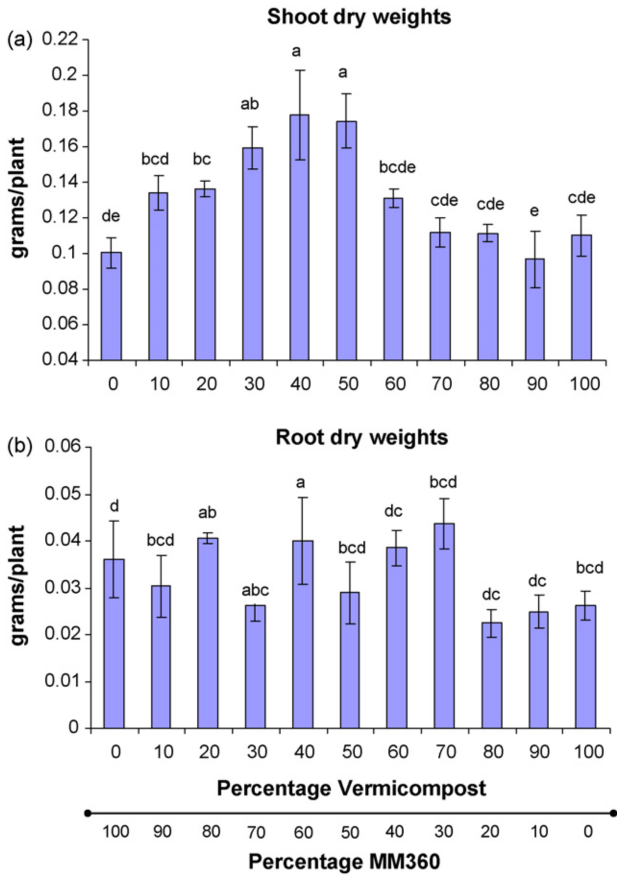

Fig. 3 – Mean petunia (a) shoot dry weights (b) and root dry weights in a commercial medium (Metro-Mix 360) substituted with different concentrations of food waste vermicompost 42 days after sowing. Columns followed by the same letter(s) do not differ significantly ($P < 0.05$) (increases independent of nutrient supply).

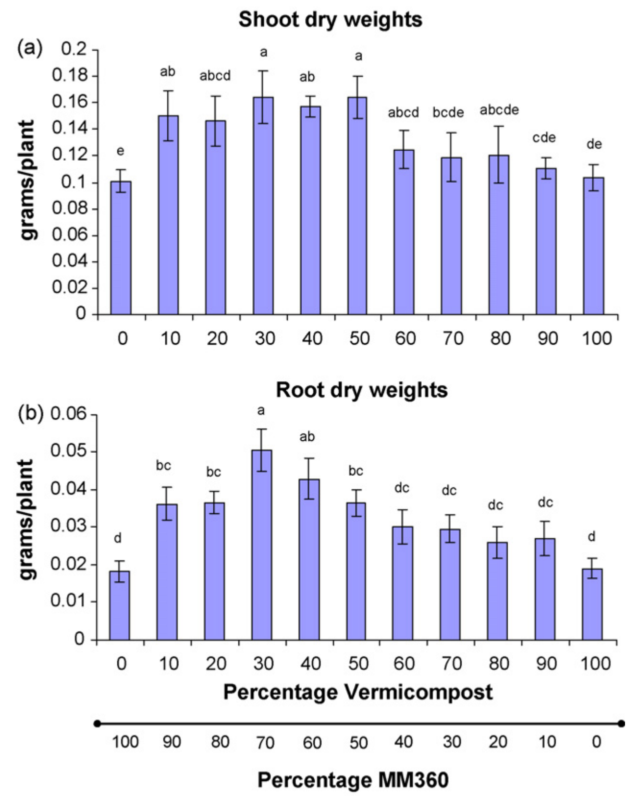

Fig. 4 – Mean petunia (a) shoot dry weights (b) and root dry weights in a commercial medium (Metro-Mix 360) substituted with different concentrations of paper waste vermicompost 42 days after sowing. Columns followed by the same letter(s) do not differ significantly ($P < 0.05$) (increases independent of nutrient supply).

higher rates. These increases in germination at lower substitution rates of vermicomposts into MM360 improved growth and flowering stages of the plant and provided economic increases in numbers of petunia flowers. Atiyeh et al. (2000c) reported more marigold flower buds in MM360 substituted with pig manure vermicompost.

4.2. *Mechanisms of beneficial effects of vermicomposts*

The increased rates of germination, growth and flowering of petunias could not have been associated with greater nutrient availability because, in all experiments, plants received all required nutrients from regular applications of Peter's Professional nutrient solution. Some possible factors that improved the germination, growth and flowering of petunias could include vermicomposts producing improvements in the physical structure of the growth medium such as aeration and drainage. It could also have been due to biological effects such as increases in beneficial enzymatic activities, increased populations of beneficial microorganisms, or the presence of biologically active plant growth-influencing substances such as plant growth regulators or plant hormones in the vermicomposts (Grappelli et al., 1987; Tomati and Galli, 1995; Subler et al., 1998) and humic acids (Arancon et al., 2006a). Krishnamoorthy and Vajranabhiah (1986) showed that earthworm activity could promote the production of cytokinins and auxins in organic waste dramatically. They also demonstrated strong positive correlations between earthworm populations and amounts of cytokinins, and auxins in field soils and reported that auxins and cytokinins produced by interactions between earthworms and microorganisms, could persist in soil for up to 10 weeks but degraded rapidly if exposed to sunlight. Atiyeh et al. (2002) suggested that plant hormones such as IAA, kinetins and gibberellins are relatively transient in soil because of their solubility and rapid breakdown in ultraviolet light.

Humic substances have been shown to increase yields of corn, oats, soybean, peanuts, clover, chicory plants and other tropical crops (Cacco and Dell'Agnola, 1984; Hayes and Wilson, 1997; Albuzio et al., 1994; Lee and Bartlett, 1976; Muscolo et al., 1993, 1996, 1999; Mylonas and Mccants, 1980; Nardi et al., 1988; Valdrighi et al., 1996). In our laboratory, we reported that applications of a range of humic acids, that had been extracted from vermicomposts, and then added to MM360, with all needed nutrients, increased the overall growth of tomatoes

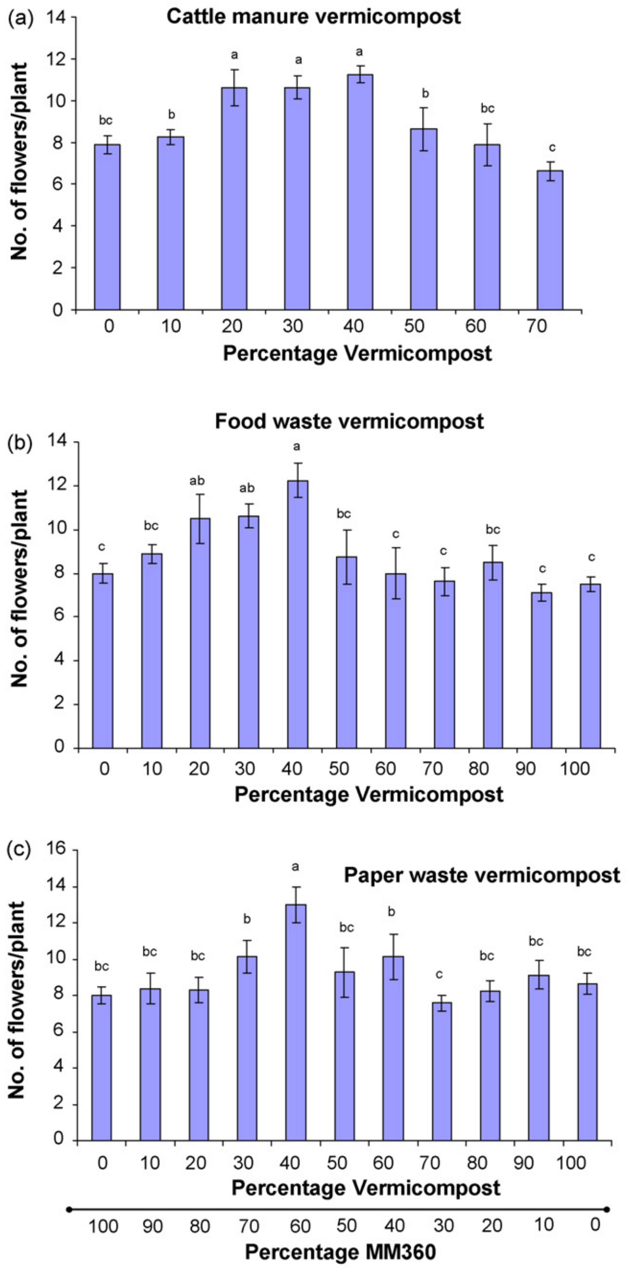

Fig. 5 – Mean numbers of flowers in the commercial medium (Metro-Mix 360) substituted with different concentrations of (a) cattle manure vermicompost, (b) food waste vermicompost and (c) paper waste vermicompost, 79 days after sowing. Columns followed by the same letter(s) do not differ significantly (*P* < 0.05) (increases independent of nutrient supply).

and cucumbers significantly in a very similar pattern to the effects of a range of vermicomposts (Atiyeh et al., 2002; Arancon et al., 2006a). However, plant growth hormones can become adsorbed onto the complex structure of humic acids that are produced very rapidly in vermicomposts (Canellas et al., 2000) and may have acted in conjunction with them to influence plant growth since humates have also been shown to increase plant growth. In this situation plant growth hormones that are adsorbed on to humates would persist in soil and would be released slowly from humates and have much more effects on plant growth over a considerably longer period. In support of this hypothesis, Canellas et al. (2000) identified exchangeable auxin groups attached to humic acids, extracted from cattle manure vermicompost, following a detailed structural analysis. These complexes enhanced root elongation, lateral root emergence and plasma membrane H+-ATPase activity of maize roots.

The overall effects of the applications of cattle manure, food waste and paper waste vermicomposts in the experiments reported here, in terms of increased germination of petunias, increased dry shoot and root weights and numbers of flowers, are economically critical since petunias are valuable bedding plants in the U.S. Since all plants received all needed nutrients, the contributions of nutrients from the mixtures, on the germination, growth and flowering of petunias can be virtually eliminated as an influence. Tissue-N did not differ in all treatments (Tables 2–4) which supports the evidence that nutritional status of the plants did not correlate with the increases in growth and flowering. It seems most likely that plant growth-influencing materials such as humic acids, with plant growth hormones adsorbed on to them, and the increased populations and diversity of beneficial microorganisms that produce hormones and enzymes, were together responsible for the accelerated rates of germination, growth and flowering of petunias. If the use of vermicompost is widely adopted, the faster germination, growth and flowering of petunias of the kind reported here would result in a much shorter retention time of plants in the greenhouse, before they are transplanted out into the field or garden soil. There are also better prospects of earlier production of other bedding plants in commercial greenhouses. This would be economically very attractive, since faster growth and flowering will inevitably minimize expensive greenhouse maintenance costs in March and April such as water, electricity, fertilizers and labor in March and April.

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