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Original article

Effect of pre-composting and vermicomposting on compost characteristics

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Abstract

The aim of this study was to determine the effect of thermophilic pre-composting followed by vermicomposting on compost characteristics compared with thermophilic pre-composting and windrow composting. Source segregated household waste was thermophilically composted (14 days) to sanitise the waste. Organic matter and nitrogen losses were 9% and 5% respectively. The waste was then matured (84 days) using either vermicomposting beds ($n = 5$) or composting windrows ($n = 5$). At the end of the 98 days processing there was a significantly greater mass ($P < 0.01$) of fine particles (<10 mm) in the vermicomposting beds (65.3% m:m) compared with the compost windrows (36.9% m:m) suggesting enhanced fragmentation of the paper-based feedstock components by the earthworms. When screened, the windrow compost (<10 mm) contained significantly higher ($P < 0.01$) concentrations of total N, P and K and total Cu ($P < 0.01$), Pb ($P < 0.001$), Ni ($P < 0.05$) and Cd ($P < 0.01$). Significantly higher levels of electrical conductivity (EC) 3.08 mS.cm ($P < 0.001$) and water-soluble K 6366 mg kg^{-1} ($P < 0.01$) were recorded for the windrow compost compared with the vermicompost (1.78 mS.cm; 3328 mg kg^{-1}). The vermicompost NO_3 concentration (2660 mg kg^{-1}) was significantly higher ($P < 0.05$) than for the windrow compost (1531 mg kg^{-1}). In a programme of plant response tests based on B.S.I. PAS 100 (2005), the screened (<10 mm) vermicompost and windrow compost performed comparably when formulated into growing media based on equalising EC levels.

Keywords: Vermicompost; windrow compost; compost maturation; plant growth; combined systems; *Dendrobaena veneta*

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1. Introduction

Many authors have investigated the characteristics of vermicompost derived from various feedstocks and the effect of vermicompost on plant growth [9,13,17]. Subler et al. [27] compared the processes of thermophilic composting and vermicomposting for treating organic wastes while vermicomposts have also been compared with thermophilic composts in terms of plant growth performance [10,22]. Few studies have directly compared the characteristics and performance of thermophilic compost with vermicompost which have been derived from identical feedstocks. One example of this was Short et al. [26] who evaluated traditional windrow composting and vermicomposting for the stabilisation of waste paper sludge. Some authors have suggested combining vermicomposting with other composting methods to achieve specific objectives such as enhanced pathogen control [16]. Frederickson et al. [19] investigated the sustainability of a combined system comprising traditional windrow composting followed by vermicomposting and recommended minimising composting duration to maintain high earthworm

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populations. Tognetti et al. [29] studied end product quality for a combined system which involved thermophilic composting of mixed municipal waste followed by either windrow composting or vermicomposting. There is growing interest in the use of combined composting systems, which include vermicomposting, that are designed to achieve specific technical objectives, such as producing high specification composts or to comply with environmental legislation. For example, in the UK the introduction of Animal By-Products Regulations [15] now prohibits the use of large-scale vermicomposting to process kitchen wastes containing meat without first sanitising the waste using enclosed thermophilic composting.

This study investigated the performance of a combined system of composting, comprising in-vessel thermophilic composting followed by vermicomposting, for the production of high specification compost from source segregated household waste. This system was compared directly with a more traditional system comprising in-vessel composting and windrow composting.

2. Materials and methods

2.1. Waste and processing methods

The waste used in this study was source segregated household waste (composition as mean (%) ± S.E.; organic 77.5 ± 2.5, paper 21.5 ± 2.6, inert contaminants 1.1 ± 0.9). See Tables 1 and 2 for chemical characterisation.

In-vessel sanitisation of source segregated household waste (approximately 175 tonnes) was undertaken for 14 days with a mean pile temperature of 65 °C. A sample of sanitised material (approximately 16 tonnes) was matured using vermicomposting or windrow composting. For windrow composting, material was formed into separate, conical piles ($n = 5$). Each pile contained approximately 2.5 tonnes (dimensions: 3 m diameter × 2 m high) covered with a porous tarpaulin and was mechanically turned on days 28, 42, and 56. Vermicomposting beds ($n = 5$), each with an area of 10 m^2 contained bedding material comprising shredded wood chips (0.3 m deep). Beds were maintained at a mean temperature ± S.D. of 21.1 ± 2.6 °C. Bedding was separated from waste using wire mesh which allowed earthworm migration and beds were inoculated with *Dendrobaena veneta* at the rate of 3 kg m^{-2}. Mean individual biomass for *D. veneta* ± S.D. was 0.7 ± 0.05 g. Sanitised waste (approximately 500 kg) was applied to all beds. Beds were covered and maintained at approximately 60% moisture throughout. Chemical analyses were undertaken on the vermicomposted material only and did not include bedding. Material for chemical analyses throughout was obtained by aggregating and subsampling from 2 kg samples of material ($n = 5$) from random locations within each windrow and bed.

2.2. Laboratory analyses

Dry solid fraction was determined after drying at 103 °C and organic carbon by loss on ignition at

Table 1
Waste characterisation data for fresh input waste, sanitised output waste and for the mature material produced from windrow composting or vermicomposting

Processing phase	Days from start	pH	EC (mS.cm)	Loss on ignition (% dm)	Total N (% dm)	Total P (% dm)	Total K (% dm)	C:N Ratio
Sanitisation								
Input waste	0	6.96 ± 0.1	3.39 ± 0.3	68.4 ± 1.2	0.98 ± 0.05	0.15 ± 0.01	0.67 ± 0.08	39:1
Sanitised output	14	7.85 ± 0.15	2.39 ± 0.1	66.3 ± 0.9	1.1 ± 0.03	0.25 ± 0.01	0.94 ± 0.02	34:1
Maturation								
Windrowed material	98	9.15 ± 0.04	1.71 ± 0.15	51.96 ± 1.62	1.45 ± 0.03	0.36 ± 0.02	0.69 ± 0.03	20:1
Vermicomposted material	98	8.47 ± 0.11	1.76 ± 0.09	49.57 ± 0.72	1.40 ± 0.02	0.34 ± 0.01	0.66 ± 0.03	20:1
Significance level		***	NS	NS	NS	NS	NS	NS
Screened compost (<10 mm)								
Windrow compost	112	8.28 ± 0.04	3.08 ± 0.21	43.4 ± 0.57	1.69 ± 0.03	0.29 ± 0.01	1.28 ± 0.03	14:1
Vermicompost	112	7.80 ± 0.07	1.78 ± 0.14	40.9 ± 0.09	1.35 ± 0.06	0.22 ± 0.01	0.76 ± 0.03	17:1
Significance level		***	***	*	***	***	***	*

Also included are data for the screened (<10 mm) windrow compost and vermicompost. Results are means of 5 replicates ± S.E. for the maturation and screened compost phases.

Significance: figures in columns marked as significantly different or NS relate to individual maturation or screened compost sections only (levels $*P = 0.05$, $**P = 0.01$, $***P = 0.001$; NS = not significantly different).

Table 2

Selected total PTE and water-soluble ion concentrations for fresh input waste, sanitised output waste and for the mature material produced from windrow composting or vermicomposting

Processing phase	Days from start	Selected PTE concentrations (total) (mg kg^{-1} dm)						Selected ion concentrations (water-soluble) (mg kg^{-1} dm)				
		Cr	Cu	Pb	Zn	Ni	Cd	K	Na	Ca	Cl	NO_3
Sanitisation												
Input waste	0	8.5 ± 0.5	40.9 ± 9.4	50.6 ± 14.7	92 ± 3	11.9 ± 1.0	0.91 ± 0.03	7341 ± 442	755 ± 57	2110 ± 229	2752 ± 161	106 ± 10
Sanitised output	14	15.4 ± 1.9	38.2 ± 1.6	62.3 ± 10.5	194 ± 39	15.9 ± 2.3	0.91 ± 0.04	6793 ± 343	687 ± 38	497 ± 38	2563 ± 130	124 ± 9
Maturation												
Windrowed material	98	13.4 ± 0.3	46.8 ± 2.1	86.5 ± 8.5	177 ± 10	13.6 ± 3.3	1.26 ± 0.09	3906 ± 360	453 ± 39	450 ± 28	2931 ± 524	107 ± 48
Vermicomposted material	98	11.6 ± 0.5	47.8 ± 6.3	75.5 ± 6.4	185 ± 5	8.8 ± 0.4	1.23 ± 0.04	3250 ± 669	399 ± 83	386 ± 85	2706 ± 264	688 ± 229
Significance level		*	NS	NS	NS	NS	NS	NS	NS	NS	NS	*
Screened compost (<10 mm)												
Windrow compost	112	18.1 ± 1.6	54.0 ± 1.5	100.4 ± 4.9	196 ± 6	10.0 ± 0.6	1.59 ± 0.05	6366 ± 606	728 ± 82	130 ± 15	2725 ± 281	1531 ± 211
Vermicompost	112	14.1 ± 0.9	36.3 ± 3.5	68.5 ± 4.5	229 ± 4	7.6 ± 0.7	1.01 ± 0.14	3328 ± 333	348 ± 34	104 ± 9	1566 ± 376	2660 ± 460
Significance level		NS	**	***	***	*	**	**	**	NS	*	*

Also included are data for the screened (<10 mm) windrow compost and vermicompost. Results are means of 5 replicates ± S.E. for the maturation and screened compost phases.

Significance: figures in columns marked as significantly different or NS relate to individual maturation or screened compost sections only (levels $^{*}P = 0.05$, $^{**}P = 0.01$, $^{***}P = 0.001$; NS = not significantly different).

450 °C [3]. A Kjeldahl digestion modified to include nitrates was used for total N [5]. Aqua regia digests for total elements (BS EN 13650 [4]) were analysed for P by spectrophotometry, K by flame photometer, and Cd, Cu, Cr, Ni, Pb, Zn by atomic emission spectrometry (Varian AA240FS). Composition (organics, paper and inert contaminants) was determined by manual sorting of sieved size fractions 40, 20 and 10 mm. Water extracts for waste samples used a constant solid:liquid ratio of 1:10 [7]. Compost samples were extracted according to BS EN 13652 [6] for growing media. In addition to pH and conductivity (EC), extracts were analysed by ion chromatograph for inorganic cations (Dionex DX100) and anions (Dionex ICS2500), expressed on a dry weight basis. Conductivity for the compost extract was related to constant ratio method assuming linear correlation with dry weight of sample per litre water. For the waste samples a 4-day dynamic respiration test for waste stability was applied (adapted from ASTM D5975-96 [1]) with incubation temperature 35 °C and moisture contents adjusted to 50%. Final compost respiration was also tested [8].

2.3. *Plant growth trials*

The screened vermicompost and compost (<10 mm) were subjected to a 28 day programme of plant response tests based on B.S.I. PAS 100 Annex D [8] and variations of this method. Base fertilizer (15:10:16) at the same rate was added to all treatments and peat controls. In Trial 1 (PAS 100 Annex D) the test compost mixes had EC levels (based on BS EN 13038 [2]) adjusted to a maximum level of 300 μS.cm. The matured test composts had ECs of 1170 μS.cm (windrow) and 710 μS.cm (vermicompost) and were mixed with peat to form test mixes; 23:77 v/v windrow compost to peat and 33:66 v/v vermicompost to peat. In Trial 2 the mix ratios were windrow compost (33:66 v/v) and vermicompost (23:77 v/v). The Trial 3 variation involved the substitution of Tomato with Marigold var. Spanish Brocade and Radish var. Cherry Belle. Trial 1 had 10 replicates and Trials 2 and 3 had 5 replicates per treatment in a fully randomised whole block layout. Ratios based on mass are given as (m:m) and volume as (v:v) throughout.

2.4. *Statistical analysis*

Due to the exploratory nature of the research and the large number of parameters (continuous variables) used to characterise the material produced by the two maturation systems, the independent samples *t*-test was selected to compare mean values throughout [28].

3. Results

For the thermophilic sanitisation stage, Table 1 shows that there was a relatively small reduction (9%) in the organic matter (LOI) content of the waste and a 5% loss in nitrogen content (losses based on ash conservation). Although nitrogen was lost overall, the organic matter loss had the effect of increasing the relative level of total N, as well as P and K. From Fig. 1 it can be seen that after a total of 98 days processing, the waste respiration rates had stabilised and there was no significant difference between the rates for the vermicomposted and the windrow matured material when sampled directly from the vermicomposting beds or windrows. The type of maturation process had no significant effect on the levels of most of the physico-chemical parameters selected (Tables 1 and 2). The most notable exception was pH which was significantly lower for the vermicomposted material ($P < 0.001$). The particle size profiles (Table 3) showed that the vermicomposted material contained a significantly greater mass of fine particles (<10 mm) than the windrowed material ($P < 0.01$).

The material from each of the individual vermicomposting beds and windrows was then separately screened to produce compost (<10 mm). The effect of screening was found to produce vermicompost and windrow compost which differed significantly in terms of key physico-chemical parameters. For the windrow compost, levels of total N, P and K were significantly higher than for the vermicompost ($P < 0.001$). Electrical conductivity (EC) was also significantly higher for the windrow compost ($P < 0.001$) and this was reflected in increased levels of water-soluble K and Na ($P < 0.01$) and Cl ($P < 0.05$). The windrow compost also showed significantly higher concentrations of total Cu ($P < 0.01$), Pb ($P < 0.001$), Ni ($P < 0.05$) and Cd ($P < 0.01$), although the total Zn concentration was significantly higher in the vermicompost ($P < 0.001$). Bulk densities for the windrow compost and vermicompost were 530 and 582 g L^{-1} respectively. Respiration rates (PAS100 [8]) for the windrow compost and vermicompost were 1.2 and 1.0 mg CO_2 gVS^{-1} $24h^{-1}$ respectively, indicating high levels of maturity.

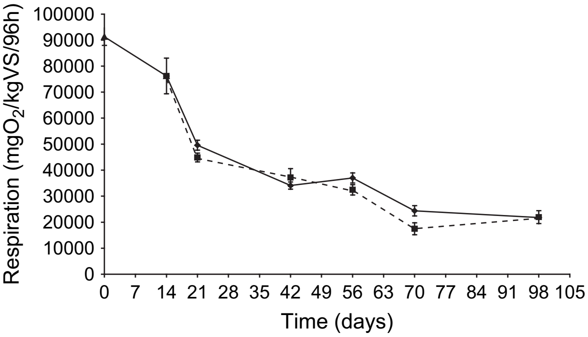

Fig. 1. Respiration rates for source segregated household waste as a result of in-vessel sanitisation for the first 14 days followed by maturation by either windrow composting or vermicomposting for a further 84 days. ▲, in-vessel sanitisation; ■, windrow maturation; ◆, vermicomposting maturation.

Table 4 gives results for the programme of plant response tests based on B.S.I. PAS 100 procedures. In Trial 1, the mean plant dry mass of tomato produced by the vermicompost mix (33:67) and the similar EC windrow compost mix (23:77) were not significantly different to the control. In Trial 2 where the ratio of windrow compost to peat was increased to 33:66 thereby increasing the EC, the mean plant dry mass of tomato was reduced compared with the 23:77 windrow compost mix used in Trial 1 and this was significantly different to the control ($P < 0.01$). Reducing the mix ratio from 33:67 to 23:77 for the vermicompost had no effect on yield. In Trial 3, for marigold, the yields for all mixes were not significantly different to the control except for the high EC (33:67) windrow mix ($P < 0.01$) which depressed yield significantly. For radish, this result was reversed with the high EC windrow

Table 3
Particle size distribution of the output sanitised material and material after maturation by either windrow composting or vermicomposting

Composted material	>40 mm (%)	20–40 mm (%)	10–20 mm (%)	<10 mm (%)
Sanitised material	25.1 ± 2.5	17.5 ± 1.7	21.4 ± 2.4	36.1 ± 2.0
(paper/card content (% m:m) of sanitised material)	(51 ± 4)	(38 ± 3)	(n.a.)	(n.a.)
Windrow composted material	9.8 ± 1.3	26.6 ± 2.7	26.6 ± 1.5	37.0 ± 3.5
Vermicomposted material	7.9 ± 1.2	6.9 ± 1.2	19.8 ± 6.8	65.3 ± 5.5
Significance level	NS	***	NS	**

Particle size fractions are given as percent mean mass ± S.E. for fresh material. n.a. = not analysed (paper in smaller fractions not discernible). Significance: figures marked as significantly different or NS relate to windrow and vermicomposted materials only (levels * $P = 0.05$, ** $P = 0.01$, *** $P = 0.001$; NS = not significantly different).

Table 4
Plant biomass yields for various mixes of windrow compost and vermicompost

Trials conducted	Growing media	Ratio compost:peat (v:v)	Fresh mass per plant (means ± S.E.) (g)	Dry mass per plant (means ± S.E.) (g)	Mean number of plants per tray
Trial 1. PAS100 test	Control	0:100	5.71 ± 0.54	0.34 ± 0.03 b	8.9
	WC	23:77	5.58 ± 0.64	0.31 ± 0.03 ab	8.7
	VC	33:66	5.80 ± 0.52	0.33 ± 0.03 ab	8.8
Trial 2. PAS100 variation	WC	33:66	4.65 ± 0.44	0.27 ± 0.03 a	8.4
	VC	23:77	5.51 ± 0.70	0.33 ± 0.04 ab	8.8
Trial 3. PAS100 variation					
Marigold	Control	0:100	3.27 ± 0.31	0.16 ± 0.02 d	7.3
	WC	23:77	2.60 ± 0.26	0.11 ± 0.02 cd	8.4
	VC	33:66	2.71 ± 0.30	0.15 ± 0.02 cd	8.2
	WC	33:66	2.47 ± 0.15	0.10 ± 0.01 c	8.4
	VC	23:77	2.84 ± 0.16	0.15 ± 0.02 d	8.0
Radish	Control	0:100	6.76 ± 0.41	0.31 ± 0.02 f	9.1
	WC	23:77	7.85 ± 0.60	0.34 ± 0.03 ef	8.6
	VC	33:66	7.46 ± 0.66	0.36 ± 0.03 ef	9.8
	WC	33:66	8.04 ± 0.24	0.39 ± 0.01 e	9.2
	VC	23:77	7.68 ± 0.31	0.35 ± 0.03 ef	9.4

Trial 1 was conducted according to PAS100 (2005). Trial 2 was a variation of PAS100 with equal volume mixes being compared with Trial 1 equal EC mixes. Trial 3 was a variation of PAS100 involving the substitution of tomato with marigold or radish. Windrow compost = WC; Vermicompost = VC.
Mean plant masses with the same letters are not significantly different ($P < 0.05$).

compost mix (33:67) being the only mix to produce a significantly greater yield compared with the control ($P < 0.01$).

4. Discussion

The relatively short duration of the sanitisation phase was not sufficient to fully stabilise the waste and only 9% of the organic matter was lost. Much greater losses in organic matter have been reported for long term composting such as 60% for food waste and leaves [24]. From the respiration data, the sanitisation phase contributed only 23% to the overall reduction in respiration rate, indicating the importance of the maturation process in stabilising as well as maturing the waste. Approximately 5% of the nitrogen content was also lost during the sanitisation phase and this is also relatively low. Witter and Lopez-Real [32] reported losses of nitrogen could amount to 50% and considered that nearly all nitrogen lost is due to ammonia volatilization. Michel et al. [25] showed that the initial C:N ratio of waste correlated significantly with the loss of total nitrogen. It is likely that the recalcitrant nature of the feedstock waste with its high proportion of paper/card (21.5%) and high C:N ratio (39:1) were responsible for the relatively small losses in C and N. The degree of pre-composting and the effect on nutrient losses is an important consideration for the subsequent compost maturation stage, in particular in terms of end product specification. Equally, Frederickson et al. [19] found a strong negative correlation between the duration of pre-composting and earthworm growth and reproduction during vermicomposting and concluded that extensive pre-composting may impact on the sustainability of these combined systems.

It was notable that the nature of the maturation process (windrow or vermicomposting) was found to have little effect on the chemical properties of the materials produced, as shown by the general absence of significant differences between the characteristics of the two types of matured materials. However, the two processes did produce materials with very different particle size profiles with the vermicomposted material containing almost twice the mass of fine particles (<10 mm), indicating the earthworm population during maturation was highly effective in reducing the particle size of the sanitized waste.

Physico-chemical differences between the materials produced by the two processes only became apparent when material from beds and windrows were individually screened to produce high specification compost (<10 mm). Total N, P, K, Cu, Pb, Ni and Cd, as well as levels of EC and water-soluble K and Cl were significantly higher for windrow compost. However, the vermicompost had a significantly greater NO_3

concentration and lower pH. Short et al. [26] composted and vermicomposted waste paper pulp and reported higher levels of total N, electrical conductivity and water-soluble nutrients (K, P, Mg and NO_3) for the vermicompost and a much lower pH. Tognetti et al. [29] subjected Municipal Solid Waste to thermophilic sanitisation prior to windrow composting or vermicomposting and reported a significantly lower pH for the vermicompost as well as higher levels of total N and P (but not K) and significantly higher levels of NO_3 and available P. EC was significantly higher for the windrow compost indicating higher levels of soluble nutrients.

In this research the windrow compost contained significantly higher levels of total and water-soluble nutrients compared with the vermicompost and in general total PTE (potentially toxic element) levels were also higher. Various mechanisms may have contributed to the decreased levels in the vermicompost. Firstly, the design of the vermicomposting beds may have promoted removal of nutrients by introducing castings directly into the bedding material and through leaching during periodic irrigation of beds. For example, Korner et al. [23] reported that leachable K concentrations in compost could range from 49% to 99%. Equally, earthworms are known to accumulate particular metals and this may have contributed to reducing specific total PTEs [18]. However, it is unlikely that these mechanisms would play a major role in lowering PTE levels in the vermicompost as the solubilities of PTEs in composted material are generally very low [12,14,20,21]. Another possible mechanism could be that vermicomposting, may have introduced significantly more paper-based material into the fine screened fraction (<10 mm). The unscreened vermicomposted material contained a much greater mass of fine particles (<10 mm) compared with the windrow material (approximately 80% more) and much of these would appear to have been derived from the fragmentation of the two largest size fractions in the sanitised input feedstock, which comprised approximately 50% and 38% paper (m:m). By contrast, for the windrow compost much of the material in the largest size fraction (>40 mm) in the input feedstock appeared to have been distributed throughout the intermediate size fractions but much of it was insufficiently fragmented to appear in the final compost (<10 mm). The significance of incorporating increased levels of paper-based material into the vermicompost is that contemporary paper and pulp based feedstocks are likely to contain reduced PTE and N, P and K levels compared with botanical or kitchen waste [26,30,31]. It is not clear why total Zn was significantly higher in the vermicompost but may be related to feedstock composition as levels of Zn in waste paper are known to be very variable and can be much greater than for botanical and kitchen waste [30].

The vermicompost and windrow compost were subjected to a programme of plant growth trials based on B.S.I. PAS 100 procedures. When equal EC mixes of vermicompost and windrow compost were tested, dry mass yields were not significantly different to the controls throughout the programme. For sensitive plants (tomato and marigold) increasing the ratio of the windrow compost mix from 23:77 to 33:67 significantly reduced yield compared to the control, whereas for radish the yields were significantly greater than the control. For the vermicompost, amending the mix from 33:67 to 23:77 had no negative effect on yields throughout. Many authors report enhanced plant growth for relatively small volumes of vermicompost in peat-based test mixes but studies tend to compare the performance of vermicompost mixes with peat-based controls only. For example, Atiyeh et al. [11] grew marigolds in vermicompost derived from pig manure and reported increased yields of shoot, weight and height compared with the peat-based control for 10%, 20%, 30% and 40% mixes plus added nutrients. However, in another study, Atiyeh et al. [10] directly compared the performance of vermicomposts (derived from pig manure and food waste) with biosolids compost in 10% and 20% mixes for the growth of marigold and tomato plants. For marigold, there was no significant difference in biomass found between the vermicomposts, compost and control. For tomato, the biosolids compost produced the highest shoot dry weight, with the 20% mix producing significantly more shoot dry mass than the vermicomposts or the control. The findings from this study showed that when formulated into growing media with appropriate and equal levels of EC plus added nutrients, the vermicompost and the windrow compost performed comparably to the peat-based control for the growth of tomato, marigold and radish plants.

5. Conclusion

Maturation of thermophilically treated waste, using vermicomposting compared with windrow composting was more effective in transforming a greater proportion of the paper-based material present in the sanitised waste into fine particulate compost. In general, the vermicompost had significantly lower nutrient and total PTE levels. When formulated into growing media with appropriate and equal levels of EC plus added nutrients, the vermicompost and the windrow compost performed comparably for the growth of tomato, marigold and radish.

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