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Use of Vermicomposts Produced from Various Solid Wastes as Potting Media

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Summary

Vermicompost is a suitable alternative for peat and other organic substrates as potting media. To examine the quality of this material with respect to plant growth requirements, vermicomposts were produced from different organic wastes including yard leaf (YL), sewage sludge + woodchips (SW), municipal wastes (MW), saw dust (SD), wheat straw + urea (SU), sugar cane filter cake (FC) and dairy cattle manure (CM). The chemical characteristics of the vermicomposts and the organic wastes were determined. The carbon to nitrogen ratio (C:N) and the electrical conductivity of wastes decreased during vermicomposting. For the materials with initial low C:N ratio (SW and MW), the N content decreased. Total concentrations of other nutrients in the vermicomposts were much higher than that of the original solid wastes. Some physical characteristics of potting mixes produced from mixing of 0, 15, 30, and 45 % (w/w) of the vermicomposts, soil, and sand were determined. Mixing of vermicomposts to potting media decreased the bulk density and particle density but increased the water holding capacity. In a greenhouse trial, the growth of tomato seedlings on the potting mixes was investigated by determination of the shoot dry matter yield, the nutrient uptake, and nutrient content of leaves at flowering stage. Tomato growth in pots containing SW, MW, and SU was higher than for other mixtures. Except N, the nutrient concentrations of the leaf samples were in the sufficiency range.

Zusammenfassung

Verwendung von Wurmkompost aus verschiedenen Festabfällen als Topfsubstrat. Gegenüber Torf und anderen organischen Substraten stellt Wurmkompost sicherlich eine geeignete Alternative als Pflanzerde dar. Um die Qualität dieses Materials hinsichtlich der Erfordernisse für das Pflanzenwachstum zu untersuchen, wurden Wurmkomposte aus verschiedenen organischen Abfällen wie Blattstreu (YL), Klärschlamm + Holzschnipsel (SW), Hausmüll (MW), Sägemehl (SD), Weizenstroh + Harnstoff (SU), Zuckerrohrfilterkuchen (FC) und Kuhmist (CM) hergestellt. Es wurden die chemischen Eigenschaften dieser Wurmkomposte und der organischen Abfälle bestimmt. Das Kohlenstoff-Stickstoffverhältnis (C:N) und die elektrische Leitfähigkeit des organischen Abfalls verringerte sich während der Wurmkompostierung. Für die Materialen mit anfänglich niedrigem C:N (SW und MW) nahm der N-Gehalt ab. Die Gesamtkonzentrationen der anderen Nährstoffe in den Wurmkomposten waren viel höher als in den ursprünglichen organischen Abfällen. Von Pflanzerdemischungen aus Sand mit 0, 15, 30 und 45 % (w/w) Wurmkompostanteil wurden einige physikalische Parameter bestimmt. Die Zugabe des Wurmkompostes zur Pflanzerde verringerte die Lagerungsdichte und die Partikeldichte, erhöhte jedoch die Wasserhaltekapazität. In einem Gewächshausversuch wurde das Wachstum von Tomatensamen in den verschiedenen Pflanzerdenmischungen untersucht, indem man das Trockengewicht der Schösslinge bestimmte. Des Weiteren wurden die Nährstoffaufnahme, und der Nährstoffgehalt in den Blättern während der Blütezeit erfasst.

Das Wachstum der Tomatenpflanzen in Töpfen mit SW, MU und SU war stärker als für die anderen Mischungen. Mit Ausnahme des Stickstoffs lagen die Nährstoffkonzentrationen in den Blattproben in einem Bereich der für die optimale Versorgung ausreicht.

Key words. *Eisenia foetida* – potting mixes – solid wastes – tomato growth – vermicomposts

Introduction

Organic wastes disposal represents a serious environmental problem that requires immediate attention. With increase of world population and development of large cities, a very large quantity of organic waste is produced daily. Most of the waste produced around the world is presently land filled. The availability of sites for landfill

is, however, decreasing and the cost for their maintenance and development is increasing. In addition, substances leaching from landfills may be hazardous to ground and surface water resources (SHELTON 1991).

There are several treatments of organic wastes to convert them to a suitable form for land application and agricultural uses. Composting and vermicomposting are among the common practices that have proven to be efficient. Vermicompost is formed after non-thermophilic, aerobic biodegradation and stabilization of organic residues into finely divided earthworm casting. For vermicompost production, mixing and aeration of beds is not necessary because the earthworms are the agent of turning, fragmentation, and aeration (DOMINGUEZ et al. 1997).

In recent years, use of earthworms in breaking down organic residues, including sewage sludge, animal manures, plant residues, and industrial refuses to produce vermicompost, has increased tremendously (EDWARDS 1998). The earthworm species, most often utilized for the treatment of organic wastes are *Eisenia foetida* (Savingy) and its related species *Eisenia anderi* (Bouché) (ATIYEH et al. 2000b). The reason for their common use is their higher reproduction rate and wider temperature tolerance (BAKER and KAPLIN 1992).

Vermicompost is finely divided peat-like material with high porosity, aeration, drainage, and water holding capacity (EDWARDS and BURROWS 1988; DOMINGUEZ et al. 1997). When processed by earthworms many of the nutrients in the waste materials (including N, P, K, Ca, and Mg) are changed into forms readily available by plants (ATIYEH et al. 2000a).

In contrast to conventional compost, the quality of vermicomposts is less variable and its chemical composition is much more stable (DOMINGUEZ et al. 1997). Greater reduction of heavy metals' bio-availability (as compared to composting), increased microbial population and biologically active metabolites such as plant growth regulators (DOUBE et al. 1997), and higher degree of humification are other advantages of vermicompost (ATIYEH et al. 2002b).

Mixing of biosolids with other organic materials, such as shredded green wastes, accelerates the rate of composting and facilitates the maintenance of vermicomposting system under aerobic condition that in turn improves the quality of the products (DOUBE and BROWN 1998). Vermicomposting may be used as an alternative method for eliminating pathogens from waste to obtain USEPA (United States Environmental Protection Agency) approved class A stabilization in domestic wastewater residues (biosolids) (VIGUEROS and CAMPEROS 2002; EASTMAN et al. 2003).

Incorporation of vermicompost into commercial potting mixes results in a faster plant growth and seed germination, increases height as well as fresh and dry weight of a variety of bedding plant species, but also plant quality (SHERMAN-HUNTOON 1997). The best responses were obtained when worm castings constitute only 10 to 40 % of the pot volume of the mixes (ATIYEH et al. 2002a). Greater proportions of vermicomposts, usually, have not increased plant growth, possibly because of higher salts content (ARANCON et al. 2002).

Because of large variation in the chemical and physical properties of different solid waste, we hypothesized that those differences affect the composition and therefore the quality of various vermicomposts as a component of potting media. In most of previous researches, effects of one or two types of vermicompost on the growth of horticultural plants were investigated (ATIYEH et al. 2000a, 2000c, 2002a; ARANCON et al. 2002). The objectives of this study were i) to investigate the suitability of vermicomposts derived from various sources of organic wastes for potting mixes, and ii) to determine the optimum mixing proportion of vermicomposts in pots.

Material and Methods

Material

Solid waste used for this study included yard wastes from Isfahan municipality centre, sewage sludge from Isfahan south sewage treatment plant, municipal waste from Isfahan municipal compost factory, sugar cane filter cake from Hafttapeh Agro-industry company, cow manure and wheat straw from the Lavark farm of the Isfahan University of Technology (IUT), and saw dust and wood chips from IUT campus.

Soil that was used for preparation of potting mixtures derived from the horticulture department of IUT and was taken from farmland around Isfahan. The main classification of this soil was Argid. Washed sand within the particle size range of 0.1–2.0 mm was also used for potting mixture.

Preparation of vermicomposts

The solid wastes including yard leaf (YL), Sewage sludge + woodchips (SW), (1:1 v/v), municipal waste (MW), saw dust (SD), sugar cane filter cake (FC), wheat straw + urea (SU)(C:N=20), and dairy cattle manure (CM) were placed in wooden containers (0.4 m×0.6 m×0.4 m). Before addition of earthworms (*Eisenia foetida*), the wastes except SU were washed once with tap water (pH=7.5) to remove the excess of salts and subsequently stored for two weeks to volatilise free ammonia (NH_3). Preliminary experiments showed that leaching of excess salt and volatilisation of free NH_3 is necessary for a successful vermicomposting process. Moisture content was controlled to remain at approximately 60 % of water saturation and the temperature was maintained between 20 and 30 °C. After three months, the vermicomposts were harvested and air-dried. The exception was SD that was harvested after six months because the activity of earthworms was very low during its treatment.

Preparation of mixtures

For the pot experiment, potting mixes containing four rates of vermicompost (0, 15, 30, and 45 percent of pot volume), one rate of soil (33 percent of pot volume) and sand (remaining pot volume) were prepared. Experimental pots (total 66 pots) were filled by potting mixes prepared from vermicomposts (i.e. seven vermicomposts × three rates plus control) in three replicates. The statistical design was randomised complete block.

Analysis

The pH values of the waste and the vermicomposts were measured in a 1:5 (w/v) suspension of vermicomposts with de-ionised water. The soil pH was measured in the soil suspension (THOMAS 1996). The electrical conductivity (EC) of waste and vermicomposts was determined in 1:5 (w/v) extract (JONES 2001) and EC of soil was determined in the saturation extract (RHOADES 1996). Total nitrogen of the materials (wastes, vermicomposts, soil, and plant tissues) was measured in the oven dried (65 °C) samples after sulphuric acid digestion using Se, $CuSO_4$, and K_2SO_4 as the catalyst mixture and Autokjeltic instrument model Foss Tecator 2300 (BOLTZ and HOWELL 1978). Total organic carbon of wastes, vermicomposts and soil was determined by the Walckly Black method, applying potassium dichromate and sulphuric acid for digestion and ammonium ferrous sulphate for titration (NELSON and SOMMERS 1996). For the analysis of total P, 1 g of waste, vermicompost or plant tissue was dry-ashed at 560 °C in a muffle furnace and the ash was extracted with 2 M HCl and subsequently phosphorus concentration was measured using ammonium molibdate-ascorbic acid method (MURPHY and RILEY 1962). The extract was also used for total K determination (flame photometry) and total Ca, Mg, Fe, Zn, Mn, Cu, Pb, Ni, and Cd determination (atomic absorption spectrometry) (Perkin Elmer, model 3030) (WRIGHT and STUCZYSKI 1996). Available P and K of soil were extracted by 0.5 M sodium bicarbonate and 1 M ammonium acetate, respectively. Phosphorus and K concentrations in the extract were determined by the methods described above. Available Fe, Mn, Zn, and Cu were extracted by AB-DTPA (ammonium bicarbonate-diethylene triamin penta acetic acid) and measured by atomic absorption spectrometry (JONES 2001). Soil texture was measured by the hydrometer method (GEE and BAUDER 1996).

Some physical properties of the potting mixes used in the study were also determined (Table 4). Bulk density (BD) was determined by measuring the dry weight of 100 cm^3 of mixes. The mixes were passed through a 3 mm sieve and filled in the 100 cm^3 glass cylinder. Compaction of material was carried out by tapping of the cylinder bottom on the laboratory bench (20 times). Particle density (PD) was measured by pycnometer method. Total porosity was calculated using the following formula:

Total porosity (%) v/v = (1–BD/PD) × 100

Water retention was determined by measuring the water content of pot mixes at 0, –30 and –1500 kPa using a pressure plate apparatus (BARUAH and BRATHAKUR 1998).

Greenhouse trial

A pot experiment was conducted in the greenhouse at the Isfahan University of Technology, Isfahan, Iran. Tomato seeds (*Lycopersicon esculentum*) were sown in washed sand, and seedlings were transplanted into experimental pots after one month at four-leaf stage. Tomato plants were then thinned to three plants per pot 10 days after transplanting. Periodically, pots received equal water to ensure that plants did not suffer from water stress condition. When the seedlings were about 10 cm tall and one month later, all pots received 30 mg kg^{-1} of N as urea. The plant shoots and leaf samples were harvested at early blooming stage and then were dried at 65 °C for 48 hours, and finally weighed and ground to pass a 40-mesh screen (JONES et al. 1991). Sub samples of the plant material were dry-ashed at 560 °C and extracted with 2 M HCl for total nutrient analysis.

Table 1. Initial chemical properties of solid wastes before vermicomposting used for the experiment.

Properties *	Yard Leaves	Sewage Sludge	Municipal Waste	Saw Dust	Filter Cake	Wheat Straw	Cow Manure
pH	7.30	6.40	8.10	7.80	7.20	7.90	8.70
EC (dS m^{-1})	2.01	4.61	5.90	0.19	1.96	0.54	13.30
OC (%)	37.26	22.24	38.29	44.85	30.70	41.00	33.15
N (%)	1.12	2.08	1.40	0.11	1.82	0.64	1.73
P (%)	0.13	1.10	0.38	0.25	0.95	0.10	0.85
K (%)	0.64	0.44	0.23	0.48	0.53	1.40	1.55
Na (%)	0.37	0.38	0.20	0.24	0.06	0.10	0.42
Ca (%)	6.80	5.70	8.00	3.40	4.80	0.56	4.56
Mg (%)	1.82	1.68	2.85	1.20	2.88	0.21	2.93
Fe (mg kg^{-1})	1550.00	6464.00	3450.00	313.00	4900.00	720.00	1700.00
Zn (mg kg^{-1})	350.00	487.00	300.00	350.00	150.00	73.00	63.00
Cu (mg kg^{-1})	74.00	246.00	58.00	374.00	64.00	26.00	53.00
Mn (mg kg^{-1})	252.00	531.00	239.00	238.00	278.00	443.00	74.00
Pb (mg kg^{-1})	39.00	140.00	90.00	154.00	–	–	–
Cd (mg kg^{-1})	2.00	6.00	3.00	2.00	–	–	–
Ni (mg kg^{-1})	91.00	27.00	23.00	6.00	–	–	–
C:N	33.26	10.69	27.35	407.70	16.87	64.00	19.16

*Total concentration of the elements.

Statistics

The data were analysed by one-way ANOVA in a general linear model, using SAS statistical software (SAS 1990). Duncan's Multiple Range Test was used to compare the average of shoot dry matter. Correlation analysis was carried out to establish the relation between the amount of nutrients added to pots via vermicomposts and the nutrient uptake by plant shoots.

Results and Discussions

Chemical properties

Chemical properties of solid wastes as well as vermicomposts produced from them are shown in Table 1 and Table 2, respectively. The pH of SU, MW, and CM decreased during vermicomposting while that of SW, YL, SD, and FC increased. In general, the pH changes were small (maximum one unit) and the final pHs were neutral to slightly alkaline with a general trend of the changes towards neutral. A comparable trend was observed by MITCHELL (1997). Increase of the pH of YL, SD and FC might be due to the addition of bicarbonate from tap water with high pH (pH=7.65). On the other hand, there are contradictory reports in literature about pH changes during vermicomposting process. ATIYEH et al. (2000b) pointed out that pH of cow manure decreased slightly during vermicomposting but increased in composting. SHINDE et al. (1992) reported an increase of the pH of farmyard manure during vermicomposting by *Eisenia foetida* but a decrease when *Prionyx excavatus* was applied. GRANATSTEIN and DAUER (1999) found that composting decreased the pH of straw but increased the pH of sawdust. These reports show that the mechanism of pH change is not clear yet and may be due to the differences in chemical composition and initial pH of materials.

With the exception of SD and SU, the electrical conductivity (EC) of the samples decreased during vermicomposting, which was likely the result of excess salts being leached during washing of wastes by tap water before the addition of the worms. The decline of EC was greater for CM, MW, and SW than for FC and YL. This may be due to the differences in the initial EC of the materials. Increase in EC of SU was likely due to the urea supplement added to this material after washing with tap water. Mineralisation of nutrients during vermicomposting can also add to the EC. The latter may explain the slight increase in EC of SD.

The C:N ratios of the vermicompocts (except SW) were lower than those of solid waste indicating breakdown of decomposable organic matter in the waste during vermicomposting. Increase of the C:N ratio of the SW vermicompost in comparison with the original sewage sludge is probably due to the addition of wood chips to this mixture before treatment.

Total nitrogen content of vermicomposts increased for YL, SD and SU and decreased for SW, MW, FC and CM during vermicomposting (Tables 1 and 2). The increase was probably due to the low initial total N content of the starting materials and the decline of organic carbon (mass) of the materials during vermicomposting. The decrease occurred only for wastes with a high initial total N content and was likely due to the leaching or volatilisation of mineralised N forms produced during the process of vermicomposting.

The potassium content of materials decreased with exception of MW and SD during vermicomposting,

Table 2. Chemical properties of vermicomposts used in the study.

Properties *	YL	SW	MW	SD	FC	SU	CM
pH	8.10	6.90	7.80	8.20	8.20	7.80	8.10
EC (dS m^{-1})	0.57	1.37	0.85	1.32	0.78	1.18	0.88
OC (%)	30.20	26.22	17.94	33.81	21.05	32.43	25.70
N (%)	1.59	1.78	1.07	0.70	1.35	1.20	1.36
P (%)	0.27	1.90	0.65	0.41	0.35	0.03	1.05
K (%)	0.16	0.22	0.34	0.71	0.30	0.18	0.86
Na (%)	0.11	0.17	0.25	0.38	0.22	0.08	0.40
Ca (%)	8.02	5.28	7.74	3.96	8.10	1.64	6.40
Mg (%)	2.98	3.40	2.53	1.74	3.88	0.43	2.94
Fe (mg kg^{-1})	4379.00	9912.00	8350.00	1898.00	6480.00	1576.00	3300.00
Zn (mg kg^{-1})	338.00	1064.00	710.00	825.00	338.00	206.00	700.00
Cu (mg kg^{-1})	51.40	323.60	641.30	72.60	114.70	48.60	136.00
Mn (mg kg^{-1})	334.80	295.70	394.70	239.30	429.80	594.00	324.00
Pb (mg kg^{-1})	59.40	152.00	373.00	16.50	54.00	7.00	34.00
Cd (mg kg^{-1})	4.05	4.48	3.78	1.65	2.70	1.30	2.00
Ni (mg kg^{-1})	32.00	31.00	10.00	17.00	7.00	52.00	45.00
C:N	18.88	14.73	16.76	48.30	15.95	27.30	18.43

*Total concentration of the elements.
Vermicomposts prepared from YL: yard leaf; SW: sewage sludge + wood chips; MW: municipal waste; SD: saw dust; FC: sugar cane filter cake; SU: wheat straw + urea; CM: dairy cattle manure.

Table 3. Some Characteristics of soil used in pot mixes.

Properties	Value	Properties	Value
pH	7.5	Sand (%)	22.0
EC_e (dS m^{-1})	1.5	Clay (%)	42.0
T.N.V.*	12.3	Ava. Fe (mg kg^{-1})	16.0
TN (%)	0.1	Ava. Zn (mg g^{-1})	0.7
Ava. P (mg kg^{-1})	58.0	Ava. Cu (mg g^{-1})	10.5
Ava. K (mg kg^{-1})	240.0	Ava. Mn (mg g^{-1})	46.0
Silt (%)	36.0	–	–

*Total neutral value equivalent to $CaCO_3$.

possibly due to the fact that mineralised K has little tendency to be assimilated into the organic molecules. Concentrations of other nutrients were generally higher in vermicomposts compared to the original solid wastes likely due to the decrease in organic carbon content (mass) of compounds and CO_2 evolution (ATIYEH et al. 2000b).

Concentrations of heavy metals including Pb, Ni, Cd, Cu, and Zn in vermicompost were lower than United State Environmental Protection Agency (USEPA) permitted limits (LOGAN et al. 1999). On the other hand, cadmium content of all vermicomposts; Pb content of SW and MW; Ni content of SU; Cu and Zn content of SW, MW, SD, and CM exceeded the limits suggested by some European countries including Germany, Netherlands, UK, and Belgium but were lower than limits established by some other European countries (Italy, Spain, France, and Portugal) as well as New Zealand, Canada and Australia (WILKINSON et al. 2000; HOGG et al. 2002).

The results of the soil analysis (Table 3) indicated that the amount of sodium bicarbonate extractable P in soil used for experiment was very high (more than 40 mg kg^{-1}), ammonium acetate extractable K was high (more than 250 mg kg^{-1}), AB-DTPA extractable Mn and Cu were in the sufficiency range (1.5 and 0.6 mg kg^{-1}, respectively), and Zn was in deficiency

Table 4. Total nutrient concentration of tomato leaves in different treatments.

Treatments		N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})
Control		3.68**	0.40**	5.18***	2.08**	0.84**	90**	71**	23**	48**
SW	15 %	3.29*	0.52**	6.66***	2.05**	0.70**	95**	72**	20**	35**
	30 %	3.56**	0.46**	7.03***	2.05**	0.66**	102**	37**	17**	37**
	45 %	4.06**	0.42**	6.66***	2.25**	0.69**	91**	37**	25**	29**
MW	15 %	3.93*	0.44**	6.66***	2.15**	0.73**	98**	31**	23**	50**
	30 %	3.67**	0.52**	7.03***	3.08**	0.99**	72**	51**	27**	38**
	45 %	4.11**	0.42**	7.04***	2.36**	0.69**	78**	36**	22**	26**
YL	15 %	3.34*	0.42**	5.92***	2.71**	0.85**	84**	90***	18**	63**
	30 %	3.04*	0.46**	6.29***	2.31**	0.88**	74**	22**	12**	64**
	45 %	1.93*	0.42**	8.14***	2.98**	0.72**	107**	29**	12**	78**
CM	15 %	3.11*	0.42**	6.66***	1.60**	0.65**	90**	20**	13**	47**
	30 %	3.23*	0.52**	7.03***	1.64**	0.74**	97**	21**	15**	55**
	45 %	3.67**	0.52**	7.03***	2.52**	0.78**	109**	18**	18**	54**
FC	15 %	3.42*	0.52**	7.03***	2.00**	0.72**	91**	87***	13**	50**
	30 %	2.52*	0.40**	5.92***	1.71**	0.63**	187**	50**	15**	44**
	45 %	3.42*	0.42**	7.03***	2.02**	0.74**	93**	25**	12**	53**
SU	15 %	3.67**	0.46**	5.92***	2.34**	0.69**	85**	25**	15**	54**
	30 %	3.32*	0.36**	6.29***	2.32**	0.67**	94**	75**	12**	56**
	45 %	2.22*	0.40**	5.55***	2.29**	0.62**	98**	24**	13**	48**
SD	15 %	3.00*	0.24*	6.17***	3.02**	0.92**	123**	33**	23**	83**
	30 %	1.92*	0.28*	6.17***	3.65***	0.98**	226**	27**	43***	100**
	45 %	1.72*	0.28*	3.70**	4.21**	1.06**	147**	33**	23**	107**

*Deficiency; **Sufficiency; ***Excess (According to CAMPBELL 2002).
Vermicompost prepared from: SW: sewage sludge + wood chips; MW: municipal waste; YL: yard leaf; CM: dairy cattle manure; FC: sugar cane filter cake; SU: wheat straw + urea; SD: saw dust.

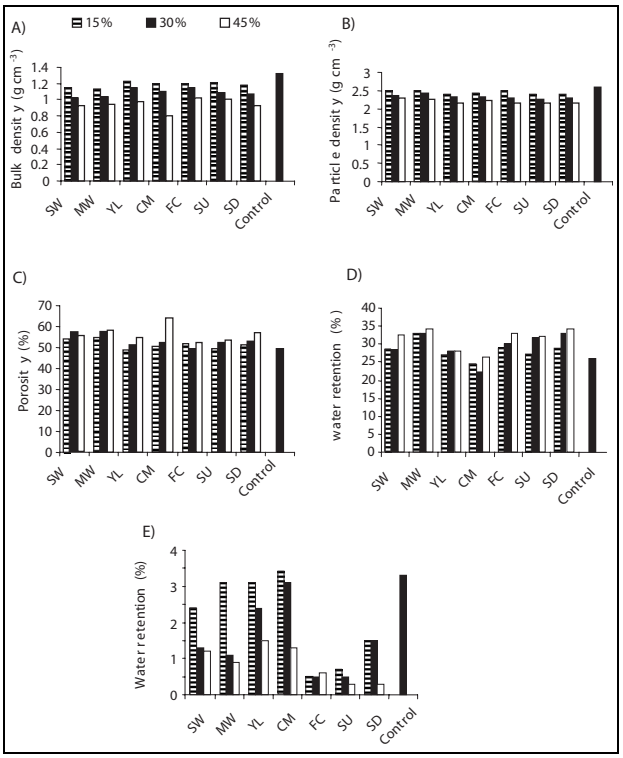


Fig. 1. Physical properties of potting mixes used for the experiment: A) Bulk density B) particle density C) porosity D) water retention of potting media between 0 and –30 kPa E) water retention of potting media between –30 and –1500 kPa. Vermicomposts were prepared from SW: sewage sludge + wood chips; MW: municipal waste; YL: yard leaf; CM: dairy cattle manure; FC: sugar cane filter cake; SU: wheat straw + urea; SD: saw dust.

range (lower than 1.0 mg kg^{-1}) (MARX et al. 1999). Because of poor relationship between soil test results, and plant uptake, the soil test for determination of available Fe usually is not recommended (MARX et al. 1999).

Physical properties of potting mix

Some physical properties of the potting mixes are depicted in Fig. 1. Bulk and particle densities of the mixtures decreased with increasing proportion of the vermicompost, indicating an improvement in porosity relative to the control. STEWART et al. (1998) reported that organic sludge, manure, and compost, when applied at high rates, raise soil pH, decrease the soil bulk density, improve the aggregation stability, and increase soil organic carbon content. The water content held at 0, –30, and –1500 kPa proportionally increased with the amounts of added vermicomposts to the pots. Water retention between 0 and –30 kPa was improved with the increasing of vermicomposts mixing proportion. This result showed the beneficial effect of vermicompost on the water holding capacity of substrate. MW, SW, SD, FC, and SU had higher water retention capacity between 0 to –30 kPa than YL and CM, while the YL and CM had greater water holding capacities from tensions of –30 to –1500 kPa. Water holding capacities between –30 and –1500 kPa even declined with increase in mixing proportion of vermicomposts. This probably showed the stronger absorption of water by organic substrate in comparison with inorganic constituents. FONTENO (1989) described portions of the water retention curve as air space (0 to –1 kPa), easily available water (–1 to –5 kPa), and water buffering capacity (–5 to –10 kPa). Water retention between –30 and –1500 kPa was very low (0.3 to 3.4 % of the pot volume). KARLOVICH and FONTENO (1986) confirmed that available water content at tensions <–30 kPa is very small in peat, bark, and soil based substrates. RICHARDS et al (1964) pointed out that container suctions during commercial plant production normally do not exceed 30 kPa. DRZAL et al. (1999) reported that the volumes of water held between –30 and –1.5 MPa may be viewed as a type of water stress "buffer" not commonly used under normal irrigations but extracted by plant roots when suctions exceed –30 kPa. Considering constant limits for available water content of media is doubtful, for example KEIHL et al. (1992) found that *Chrysanthemum* fresh and dry weight decreased as the constant moisture tension, the plants were grown at, increased from –0.8 to –16 kPa. However, if the moisture tension were allowed to cycle between these suctions, the growth of the *Chrysanthemums* was similar to –0.8 kPa treatment.

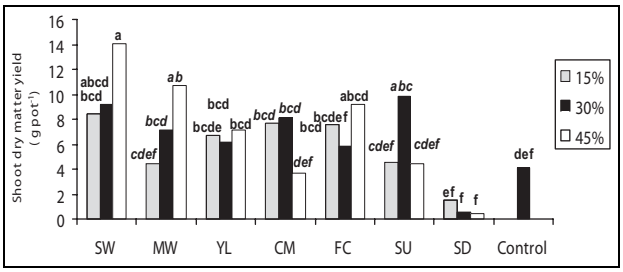


Fig. 2. Effect of vermicompost treatments on shoot dry matter yield of tomatoes; treatments with similar letter were not significantly different at 5 % level.
Vermicomposts were prepared from SW: sewage sludge + wood chips; MW: municipal waste; YL: yard leaf; CM: dairy cattle manure; FC: sugar cane filter cake; SU: wheat straw + urea; SD: saw dust.

Plant bioassay

Effect of treatments on tomato shoot dry matter is shown in Fig. 2. The highest and the lowest shoot dry matter (SDM) of tomatoes were obtained for SW and SD, respectively. This may be explained by the high nutrient content, in particular N and the low C:N of SW as opposed to the low N and the high C:N of SD (Table 2). SDM in SW 45 % and MW 45 % were significantly higher than 15 % mixing proportion of these treatments. However, the differences, between 30 and 45 % rates were not significant. POOLE and CONOVER (1990) reported that potting media composed of 10 to 40 % of woodchip + sewage sludge compost can be used without risk of reducing the quality of tested plants. On the other hand, addition of composted biosolids (including sewage sludge compost) in rates higher than 20 % by volume resulted in excessive nutrient application or even ammonium toxicity ((HOITINK et

Table 5. Reference sufficiency range for plant analysis results for greenhouse tomato plants.

Element[a]	Range (%)	Element	Range (mg kg^{-1})
N	3.5 – 5.0	Fe	50 – 300
P	0.3 – 0.7	Mn	25 – 200
K	3.5 – 4.5	Zn	18 – 80
Ca	1.0 – 3.0	Cu	5 – 35
Mg	0.4 – 1.0	–	–

[a]According to CAMPBELL (2002).

al. 1994). Mixing sewage sludge with wood chips before vermicomposting might decrease phytotoxicity.

Higher SDM in the pots amended with YL, SD, FC, and CM were not significantly different from the control indicating the possible lower suitability of these vermicomposts for potting media. ATIYEH et al. (2000a) showed that raspberry shoot growth in soil amended with yard leaf or bark composts was poorer than that in the unfertilised control soil. STORK (1997) reported that the use of mature yard trimming compost in field experiments did not increase crop yields, nor did un-composted yard trimmings led to a reduction. SDM of 30 % SU was greater than 15 % SU and 45 % SU. High rates of CM and SU, on the other hand, decreased SDM indicating the interconnecting impact of kind and rate of vermicomposts on the yield. Substitution of commercial potting media (Metro-Mix 360) with 20 to 50 % of pig manure vermicompost increased growth of tomato seedlings (ATIYEH et al. 2001, 2002a), but the largest marketable yield was obtained from 20 % rate (ATIYEH et al. 2000c). Most flower buds of marigold (*Tagetes putala*) occurred in potting mixture containing 40 % pig manure vermicompost (ATIYEH et al. 2002b). LINDSAY and METZGER (2002) showed that no difference in plant quality (tomatoes, pepper and *Chrysanthemums*) was obtained by mixing 0–20 % (by volume) of worm worked cattle manure with soil.

All mixing proportions of SD significantly lowered SDM below control. Low SDM of SD can be explained by the high C:N ratio (48.3:1) and nutrient imbalances in this vermicompost. High C:N ratio can result in immobilization of N in growth media. BURGER and HARTZ (1999) indicated that immaturity of composted

Table 6. Nutrient uptake of tomato shoots in different treatments (mg pot^{-1}).

Treatments		N	P	K	Ca	Mg	Fe	Zn	Cu	Mn
Control		115.0	15.57	197.70	116.0	39.7	3.93	1.35	0.53	1.97
SW	15 %	137.1	32.16	438.38	252.2	71.1	10.92	7.62	1.18	3.13
	30 %	182.3	32.99	508.55	240.1	71.0	16.13	4.21	0.92	3.16
	45 %	399.3	47.80	780.33	441.5	113.9	14.90	8.15	2.53	3.52
MW	15 %	98.1	12.38	261.66	127.7	38.7	4.26	1.81	0.80	1.72
	30 %	161.1	25.76	423.69	191.8	60.1	5.01	3.43	0.79	2.29
	45 %	259.5	29.90	671.58	323.5	98.9	8.43	5.98	3.41	3.31
YL	15 %	150.0	22.76	371.66	186.8	61.3	5.49	1.67	0.74	3.88
	30 %	119.8	20.89	363.66	205.2	54.4	7.19	1.72	0.68	3.56
	45 %	110.0	20.12	372.29	193.6	55.0	7.66	2.16	0.93	3.66
CM	15 %	114.1	30.83	484.77	178.0	62.0	5.63	1.54	0.54	3.93
	30 %	160.1	29.11	568.52	189.2	74.4	5.34	1.94	0.65	3.88
	45 %	84.9	15.25	255.19	77.3	33.0	3.03	0.84	0.93	2.00
FC	15 %	116.0	28.63	445.95	156.7	50.5	9.94	2.79	0.60	3.16
	30 %	110.7	19.81	323.40	137.5	44.9	4.14	1.11	0.58	2.80
	45 %	142.3	42.49	478.48	232.8	81.8	7.20	2.30	0.74	4.80
SU	15 %	85.2	18.23	202.33	128.1	36.5	3.55	3.46	0.55	2.37
	30 %	234.5	37.29	617.24	322.9	90.8	8.54	5.43	0.69	6.08
	45 %	66.3	15.03	228.96	127.7	32.9	3.09	3.54	0.44	2.30
SD	15 %	32.8	6.68	92.51	39.5	16.1	1.47	0.55	0.16	1.09
	30 %	8.2	2.52	36.22	25.1	8.3	1.00	1.49	0.13	0.42
	45 %	5.3	1.20	28.57	22.4	6.9	0.63	1.09	0.34	0.24

Vermicompost prepared from: SW: sewage sludge + wood chips; MW: municipal waste; YL: yard leaf; CM: dairy cattle manure; FC: sugar cane filter cake; SU: wheat straw + urea; SD: saw dust.

green wastes decreased availability of mineral N by immobilization.

Shoot dry matter yield of 45 % SW, 45 % MW, and 30 % SU were significantly greater than that of control. It seems that optimum mixing proportion is different for various vermicomposts.

The nutrient concentrations of tomato leaves are shown in Table 4. Despite of inorganic nitrogen application, nitrogen content of plants in most of treatments was in the deficiency range (Table 5). This showed that >30 mg kg^{-1} of inorganic nitrogen fertilizer was needed for optimal plants growth. ATIYEH et al. (2002b) reported that when all necessary nutrients were provided and in addition, 200 mg kg^{-1} of N was added three times, nitrate concentration of marigold leaf tissues increased at flowering stage. Nitrogen concentration of tomato leaves in 30 % SW, 45 % SW, 30 % MW, 45 % MW, 45 % CM, 15 % SU, and control supplied enough N to meet plants' requirement for nitrogen. This indicated that application of 30 mg kg^{-1} of urea was enough for tomato plants grown in soil, however, application of vermicomposts enhanced plant growth that in turn lead to a higher nitrogen demand. This explains the nitrogen deficiency observed in pots amended with vermicomposts low in nitrogen content. Results also showed that SW, MW, and CM treatments contributed to the nitrogen nutrition of plants. HANDRECK et al. (1986) reported that vermicompost would supply full requirements of plants for trace elements and P, probably initial requirements for K and S, and little or no N for plant growth. DONALD and VISSER (1989) showed that seedlings of *Acacia mearunssii, Eucalyptus grandis*, and *Pinus patula* required additional supplement of inorganic fertilizers for satisfactory growth regardless of the compost mixture used.

Concentrations of Mg, Fe, and Mn in plants grown in vermicompost mixes were in the sufficiency range (Table 5) and concentration of K was in the excess range. No evidence of K toxicity was found in literature. It seems that excess K concentration did not have any adverse effect on plants. Concentrations of Ca, P, and Cu in all treatments except SD were in the sufficiency range. Deviation from sufficiency for some nutrients in this treatment (N, P, Ca, and Cu) maybe explained by the fact that immobilization of N and its consequent deficiency decreased plant growth and caused nutrients imbalances. No correlation between nutrient concentration of plants from treatments and control was observed, however, nutrients uptake increased in all vermicomposts amended pots except SD as compared to the control (Table 6). PERMUIZIC et al. (1998) observed that tomatoes grown on organic substrates including vermicompost contain significantly more Ca, vitamin C and less Fe compared to those grown on hydroponics' media. Concentration of P and K, however, did not differ greatly between tomatoes grown on organic versus hydroponics substrates.

Despite of excess level of Zn in some treatments (15 % YL and 15 % FC) and Cu (30 % SD), a decline in SDM was not observed. This may indicate that reported sufficiency ranges for these elements are not accurate. KORZENIOWSKA and STANISLAWSKA-GLUBIAK (2003) reported that Cu concentration in plant top or in grain is not a sensitive or reliable indicator of phytotoxicity. Competition between micronutrients in plants is too complex and judgment is very hard.

Table 6 shows nutrient uptake of tomato shoots in different treatments. Results of a regression analysis ("r" value) between nutrients uptake by plants and total amount of nutrient added to pots by vermicompost were in the following order: Cu (r=0.796**) > Fe (r=0.539**) > N (r=0.372**) > Mg(r=0.296**) > K (r=0.290**) > P (r=0.0.267**) > Zn (r=0.151**) > Mn (r=0.082**) > Ca (r=0.080**). High correlation coefficients ("r" value) for Fe and Cu may be taken as an indication of sufficient supply of these elements by vermicomposts. Poor correlation of P and K, on the other hand, may have resulted from greater contribution of soil in supplying of these elements to plants.

Conclusion

Different solid wastes have the potential to be converted to high quality vermicomposts. Vemicomposts had more nutrients compared to the original solid waste. Application of vermicomposts to container medium improved porosity and water holding capacity but decreased bulk and particle density of substrate. The amounts of heavy metals in examined vermicomposts were in allowed level of USDPA. Vermicomposts obtained from sewage sludge + woodchips, municipal waste and N-enriched straw are suitable organic substrates for potting mixes. Proper mixing proportions of vermicompost as potting media depend on different vermicomposts and vary from 30 to 45 % of pot volume and relate to the kind of vermicompost. Nutrients concentration of tomatoes leaves except N was in the sufficiency range. Application of inorganic fertilizer especially N is necessary for suitable growth of greenhouse plants in vermicompost media.

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