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Effects of Urban Organic Wastes, their Composts and Vermicomposts on the Growth Traits of Fenugreek (*Trigonella foenum-graecum* L.) and Tomato (*Lycopersicum esculentum* Mill.) under Field Conditions

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ABSTRACT

Three types of urban wastes – municipal solid waste (MSW), vegetable market waste (MW) and floral waste (FW) were bio-converted to composts (Cs), and vermicomposts (VCs) using three earthworm species – *Eudrilus eugeniae* (Kinberg), *Eisenia fetida* (Savigny) and *Perionyx excavatus* (Perrier). These were applied at a rate of 5 and 10 t ha^{-1} under field conditions, and their effects on various growth traits of fenugreek (*Trigonella foenum-graecum* L. South Indian cultivar) ('UM-9') and tomato plant (*Solanum lycopersicum*) (cv. 'Arka') were assessed. These experiments were conducted with a randomized complete block design. The urban organic wastes and their Cs and VCs showed significant positive effects on the growth of different traits of both plants ($P < 0.001$). There was a significant positive correlation between the number of leaves and dry biomass of both plants. The shoot length, number of leaves, number of branches, and dry biomass of both the plants increased significantly, except the root length, which decreased with the application of urban wastes and their Cs and VCs compared to the same traits of plants grown in soil. Growth traits, except for root length, were significantly higher with the application of VCs than those when Cs and urban organic wastes were used and were ranked as: VC of *E. eugeniae* > VC of *E. fetida* > VC of *P. excavatus* > C > wastes – MW > MSW > FW. This is because the VCs produced by these earthworm species possessed higher contents of nutrients – nitrogen, phosphorus, potassium, calcium and magnesium – compared to the C and urban organic wastes.

Keywords: municipal solid waste, market waste, floral waste, nutrients, growth, vermicompost, compost

Abbreviations: C, compost; **FW**, floral waste; **MW**, market waste; **MSW**, municipal solid waste; **t ha^{-1}**, tons per hectare; **VC**, vermicompost

INTRODUCTION

Urban organic waste, a potential resource of plant-nutrients is either thrown away haphazardly or burnt or buried causing environmental pollution of soil, water and air in developing countries like India. Thus, there is pressing need for disposal of escalating amounts of wastes particularly its organic component, which has encouraged the use of its compost (C) and vermicompost (VC) as soil amendment in agriculture and tree plantations (Bugbee 2002; Papafotiou *et al.* 2004). Moreover, composting and vermicomposting have been promoted as one of the suitable strategies to deal with and disposal of large quantities of organic wastes. Harnessing this waste through vermicomposting could mean disposal of the waste along with valuable manure yield, which could be added to the soil with little detrimental effects on crop growth (Hoitink 1980; Perner *et al.* 2006). Application of VC in agriculture not only boosts crop growth and enhances yield due to the presence of absorbable forms of plant nutrients and plant growth promoting hormone like substances (Arancon *et al.* 2009), but also suppresses root pathogens/soil-borne plant diseases (Arancon *et al.* 2006; Asciutto *et al.* 2006; Edwards *et al.* 2010; Villenave *et al.* 2010).

Composting generally is the aerobic microbial transformation of organic matter (Baca *et al.* 1992), and has been designated as the most adequate method of managing organic wastes or organic and mineral fraction of urban solid waste (Godden *et al.* 1986; Eghball *et al.* 1997; Maso and Blasi 2008; Elango *et al.* 2009; Domingo and Nadal 2009; Saha *et al.* 2010). In recent years, researchers have become progressively interested in using another related biological process known as vermicomposting for stabilizing organic wastes, involving the earthworms for breaking down the organic fraction of wastes (Edwards and Bohlen 1996; Edwards and Arancon 2004; Reddy and Ohkura 2004; Adi and Noor 2009; Gupta and Garg 2009; Mainoo *et al.* 2009; Suthar 2009; Bharadwaj 2010), which is a versatile natural bioreactor for biodegradation and stabilization of organic wastes in much shorter times than the composting. It is the most recommended method for treatment of organic solid wastes in many developing countries like India (NWMC 1992). It can be described as bio-oxidation and stabilization of organic material involving the joint action of earthworms and different mesophilic microorganisms (Aira *et al.* 2002). It is the process of devouring, digestion and excretion of any organic waste by earthworms, in which complex organic fractions of solid waste are broken down into good quality C, i.e., VC (EPA 1980). The nutrients locked up in the organic waste are transformed to simple and absorbable forms such as nitrate or ammonium nitrogen, exchangeable phosphorus, soluble potassium, calcium and magnesium in worm's gut during the process (Edwards and Burrows 1988; Atiyeh *et al.* 2002). The end product is usually a finely divided peat-like material having high and diverse microbes and enzymes, porosity/aeration and moisture holding capacity, rich in plant nutrients and plant growth promoting hormone-like substances (Edwards 2004; Reddy and Ohkura 2004; Arancon *et al.* 2005) compared to the substrates and normal C (Singh and Sharma 2002; Gupta *et al.* 2007; Patt-

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naik and Reddy 2009; Jouquet *et al.* 2010). It improves the soil fertility when applied favoring higher productivity (Kale *et al.* 1992; Reddy and Ohkura 2004; Padmavathiamma *et al.* 2008; Samantara and Reddy 2009). There is accumulating scientific evidence that VCs can influence the plant growth and productivity significantly (Edwards 1998), and that boosts plant growth (Reddy 1988; Rajkhowa *et al.* 2000; Fernández-Luqueño 2010; Roy *et al.* 2010; Singh *et al.* 2010). It has been reported to have a favorable influence on growth and yield parameters of different crops like cereals and legumes (Chan and Griffiths 1988; Reddy and Ohkura 2004; Pasha *et al.* 2009) and vegetables like tomato (*Solanum lycopersicum*, formerly *Lycopersicum esculentum*), brinjal (*Solanum melongena*) (Karmegam and Daniel 2008) and okra (*Abelmoschus esculentus*) (Edwards and Burrows 1988; Wilson and Carlile 1989; Atiyeh *et al.* 2000; Gutiérrez-Miceli *et al.* 2007), ornamental and flowering plants (Edwards and Burrows 1988; Atiyeh *et al.* 2000) and field crops (Garg and Bhardwaj 2000; Arancon *et al.* 2004).

There are, however, only few research studies that have examined the responses of crop plants to VCs under field conditions (Edwards and Burrows 1988; Wilson and Carlile 1989; Kale *et al.* 1992; Mba 1996; Buckerfield and Webster 1998). Field studies conducted in Ohio (USA) showed that soil amended with VC can enhance the growth and yield of crop plants (Arancon *et al.* 2004). But such studies in India are only a few (Kale *et al.* 1992; Singh *et al.* 2008; Batchman and Metzer 2008; Samantara and Reddy 2009; Roy *et al.* 2010). The present study assessed the effects of organic and mineral fractions of different urban wastes - municipal solid waste (MSW), vegetable market waste (MW) and floral waste (FW), and their respective Cs, and VCs prepared using two exotic species of earthworms, *Eudrilus eugeniae* (Kinberg) and *Eisenia fetida* (Savigny) and a local species, *Perionyx excavatus* (Perrier) on the growth traits – number of leaves and branches, shoot length (plant height), root length and biomass (dry) of fenugreek (*Trigonella foenum-graecum* L.) and tomato (*Lycopersicum esculentum* Mill.) in relation to that of sole soil under field conditions. Fenugreek is used widely as leafy vegetable in India as it has aromatic and medicinal value (Anonymous 2003) while tomato is the world's most popular and widely used fruit vegetable, which has many health benefits (Passam and Karapanos 2008).

MATERIALS AND METHODS

Experimental set up and collection of samples

Municipal solid waste was collected from one of the major garbage dumping sites – Karravadikuppam at Puducherry, a small town on the east coast of India and the erstwhile French colony, and the vegetable MW was collected from its main vegetable market, which comprises of different left over vegetables such as cabbage, brinjal, tomato, potato, onion, carrot, turnip and leafy vegetables. The FW was obtained from the *Peltophorum pterocarpum* (Family Fabaceae and sub-family Caesalpinioideae) – a widely-appreciated shade tree and a reclamation plant with dense spreading crown, planted along the road-sides of the Pondicherry University campus; it is usually planted on the road sides. Five samples each of 10 kg of each waste were collected randomly and then were mixed to form composite samples for further use. These wastes were characterized and segregated into biodegradable and non-biodegradable components. The organic along with mineral fraction of MSW, MW and FW were separated and air-dried separately for 48 h and pre-composted for three weeks prior to vermicomposting and composting processes. The details of pre-composting and VC preparation are given in Pattnaik and Reddy (2009).

Field experiment

Seeds of two crop plants of a South Indian cultivar of tomato, *S. lycopersicum* (cv. 'Arka') and fenugreek, *T. foenum-graecum* L. (cv. 'UM-9') obtained from a local market were sown on the laterite native soil with treatment of three types of urban organic wastes – MSW, MW and FW, and their respective C and VCs produced by *E. eugeniae*, *E. fetida* and *P. excavatus*. Field experiments with a randomized complete block design containing a total 36 plots (six treatments – vermicomposts of three earthworm species, compost, waste and soil without any amendment) with six replications for each waste and for each dose were conducted for both the plants separately. The test fields were set on with each plot measuring 30 × 30 cm square. Four seeds of each plant were sown in each plot of each treatment at a rate of 5 t ha^{-1} and 10 t ha^{-1} (Samantara and Reddy 2009). During each experiment the plants were watered regularly. Each plot was separated by PVC pipe of 30 × 30 cm square up to the depth of 30 cm in order to prevent the mixing of treatments with each other during watering. The harvesting was done at 90 days of experiment. The growth traits such as leaf number, plant height, number of branches and root length and dry biomass were measured.

Physico-chemical analysis

The homogenized sub-samples of each substrate material (waste) and their respective C and VC samples (on the basis of 100 g dry weight) were collected un-destructively from each replicate pot and compound samples were made, which were processed for analyses of major nutrients – total nitrogen (N), available phosphorus (P), exchangeable potassium (K), calcium (Ca) and magnesium (Mg). The details of nutrient analysis were given in Pattnaik and Reddy (2009). Both the plants were washed thoroughly with deionized water to remove adhered soil particles, and subsequently, air-dried for 24 h followed by oven-drying at 70°C for 48 h and their dry weights were recorded.

Statistical analysis

The data on plant growth traits and the nutrient contents, were computed and presented as the mean ± SD (standard deviation), and treated statistically for *t*-test, ANOVA (Analysis of Variance) and linear regression using the XLStat software package (version 2009). ANOVA tests were used to analyze the significant difference between growth traits of tomato and fenugreek plants applied with the treatments of three urban wastes and their respective C and VCs. The *t*-test was used to detect significant differences ($P < 0.001$) between the growth traits of both the plants grown in soil applied with different inputs – types of wastes, their Cs and VCs with that in soil alone. Coefficient correlations were calculated between nutrient contents of different treatments applied to the plants and their growth traits using regression analyses.

RESULTS

Nutrient status of urban wastes in relation to their VCs and Cs

The nutrient contents were higher in MW followed by that of MSW and FW. The N, P, K, Ca and Mg contents were higher in the three types of urban wastes and their respective VCs and Cs, than that in native soil. The increase in N content was 9.3–26.9-fold in VCs, 5.9–11.6-fold in Cs and 2.4–6.4-fold in wastes; for P it was 9.8–23.6-fold in VCs, 7.8–13.4-fold in Cs; 2.2–5.0-fold in wastes; for K it was 36.7–158.3-fold in VCs, 25.0–95.0-fold in Cs, 3.3–30.0-fold in wastes; for Ca it was 146.7–680.0-fold in VCs, 65.6–463.3-fold in Cs, 7.8–68.9-fold in wastes; for Mg it was 60.0–140.0-fold in VCs, 32.9–88.6-fold in Cs and 5.7–24.3-fold higher in wastes than in soil (**Table 1**).

A comparison of nutrient contents of VC and C samples with that of substrates (wastes) showed that the range of increase of N, P, K, Ca and Mg was 2.4–6.1-fold in VCs and 1.8–2.4-fold in Cs, 3.1–6.5-fold in VCs and 2.7–3.5-fold in Cs, 3.8–19.0-fold in VCs and 3.2–7.5-fold in Cs, 7.5–33.9-fold in VCs and 6.7–14.1-fold in Cs, 4.2–16.3-fold in VCs and 3.6–5.8-fold in Cs, respectively compared to that of the substrate (**Table 1**). When nutrient contents of VCs were compared to those of respective Cs, the range of increase was 1.3–2.4-, 1.2–1.8-, 1.2–2.5-, 1.1–4.0- and 1.2–

Table 1 Nutrient content of different organic inputs - three urban wastes. i.e., municipal solid waste (MSW), market waste (MW) and floral waste (FW) and their respective vermicomposts of *Eudrilus eugeniae, Eisenia fetida* and *Perionyx excavatus* and composts.

Nutri-ents	0 Days			60 Days												Native Soil
				Vermicompost									Compost			
				E. eugeniae			*E. fetida*			*P. excavatus*						
	MSW	MW	FW	MSW	MW	FW	MSW	MW	FW	MSW	MW	FW	MSW	MW	FW	
N	0.24 ± 0.01	0.45 ± 0.10	0.17 ± 0.08	1.46 ± 0.02	1.88 ± 0.14	0.99 ± 0.06	1.08 ± 0.02	1.23 ± 0.14	0.81 ± 0.05	0.88 ± 0.02	1.07 ± 0.13	0.65 ± 0.02	0.61 ± 0.03	0.81 ± 0.08	0.41 ± 0.02	0.07 ± 0.007
P	0.19 ± 0.02	0.25 ± 0.04	0.11 ± 0.06	0.91 ± 0.02	1.18 ± 0.09	0.71 ± 0.05	0.73 ± 0.03	0.96 ± 0.05	0.55 ± 0.06	0.64 ± 0.01	0.78 ± 0.06	0.49 ± 0.06	0.52 ± 0.02	0.67 ± 0.06	0.39 ± 0.08	0.05 ± 0.005
K	0.12 ± 0.04	0.18 ± 0.07	0.02 ± 0.004	0.82 ± 0.03	0.95 ± 0.08	0.38 ± 0.01	0.68 ± 0.02	0.79 ± 0.06	0.29 ± 0.08	0.57 ± 0.04	0.69 ± 0.06	0.22 ± 0.04	0.46 ± 0.04	0.57 ± 0.03	0.15 ± 0.04	0.006 ± 0.002
Ca	0.23 ± 0.02	0.62 ± 0.18	0.07 ± 0.002	4.33 ± 0.02	6.12 ± 0.26	2.37 ± 0.35	3.92 ± 0.03	5.06 ± 0.5	1.98 ± 0.24	3.61 ± 0.03	4.64 ± 0.2	1.32 ± 0.21	3.25 ± 0.01	4.17 ± 0.14	0.59 ± 0.12	0.009 ± 0.003
Mg	0.09 ± 0.03	0.17 ± 0.06	0.04 ± 0.005	0.85 ± 0.01	0.98 ± 0.03	0.65 ± 0.09	0.71 ± 0.01	0.84 ± 0.07	0.56 ± 0.06	0.62 ± 0.04	0.72 ± 0.05	0.42 ± 0.07	0.51 ± 0.02	0.62 ± 0.06	0.23 ± 0.05	0.007 ± 0.003

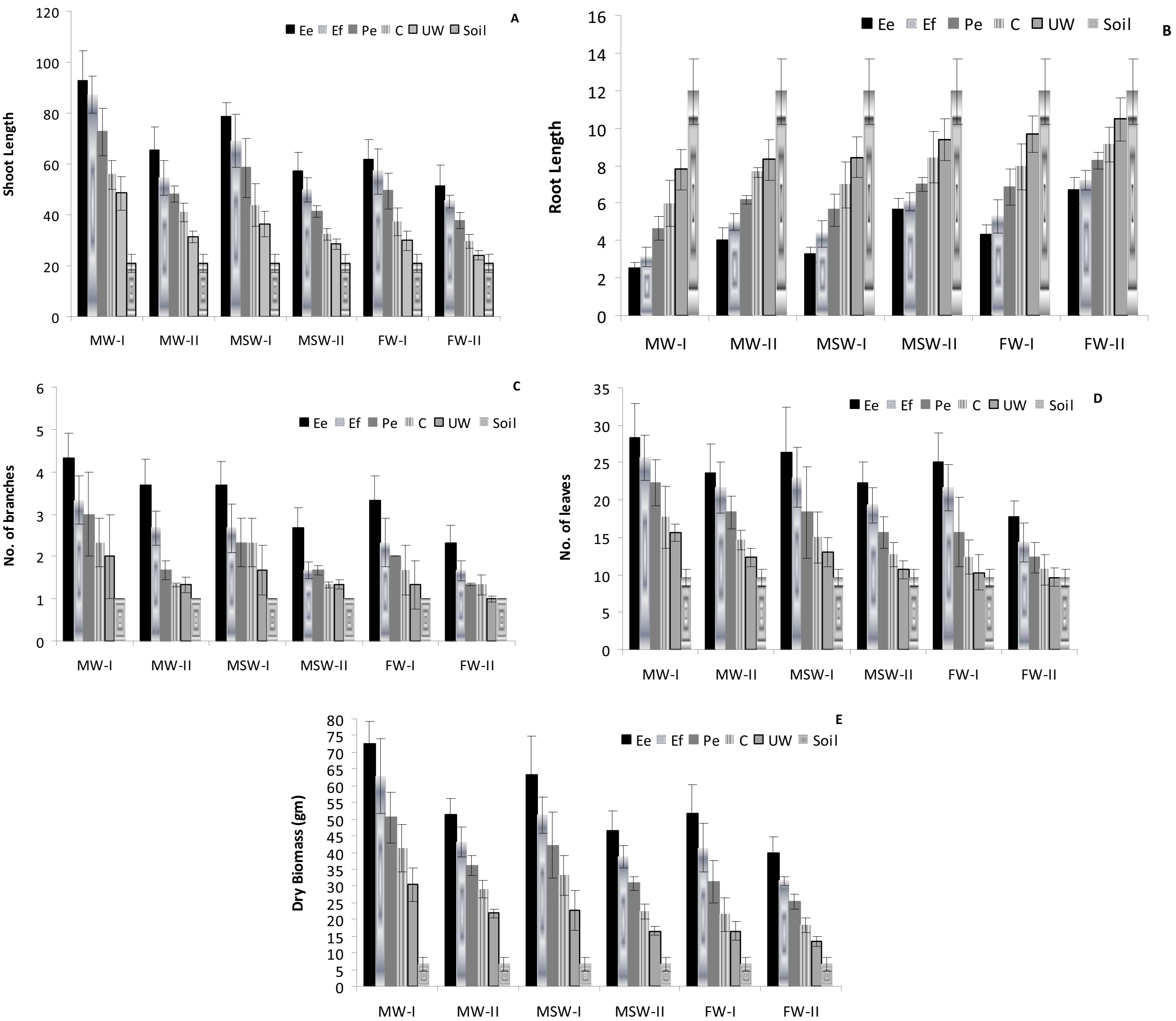


Fig. 1 Plant growth traits. (**A**) Shoot length, (**B**) Number of branches, (**C**) Number of leaves, (**D**) Dry biomass and (**E**) Root length of tomato plant treated with the organic inputs of three urban wastes (UW): MW-I (market waste at 10 t ha^{-1}) and MW-II (at 5 t ha^{-1}); MSW-I (municipal solid waste at 10 t ha^{-1}) and MSW-II (at 5 t ha^{-1}); and FW-I (floral waste at 10 t ha^{-1}) and FW-II (at 5 t ha^{-1}) and their respective composts (C) and vermicomposts of *E. eugeniae* (Ee), *E. fetida* (Ef) and *P. excavatus* (Pe) and of soil (n = 18, $P < 0.001$).

2.8-fold, in the case of N, P, K, Ca and Mg, respectively in the VCs than that of Cs of all three wastes (**Table 1**).

Comparison of plant growth traits treated with organic inputs in relation to that of soil

The plant growth traits – shoot length, number of branches, number of leaves and dry biomass of tomato and of fenugreek showed significant increase except the root length that decreased significantly in both plants treated with 10 and 5 t ha^{-1} of organic inputs i.e., three urban wastes and its VCs and Cs compared to that of soil. The increase in shoot length, number of leaves and dry biomass and the decrease in root length of both the plants –

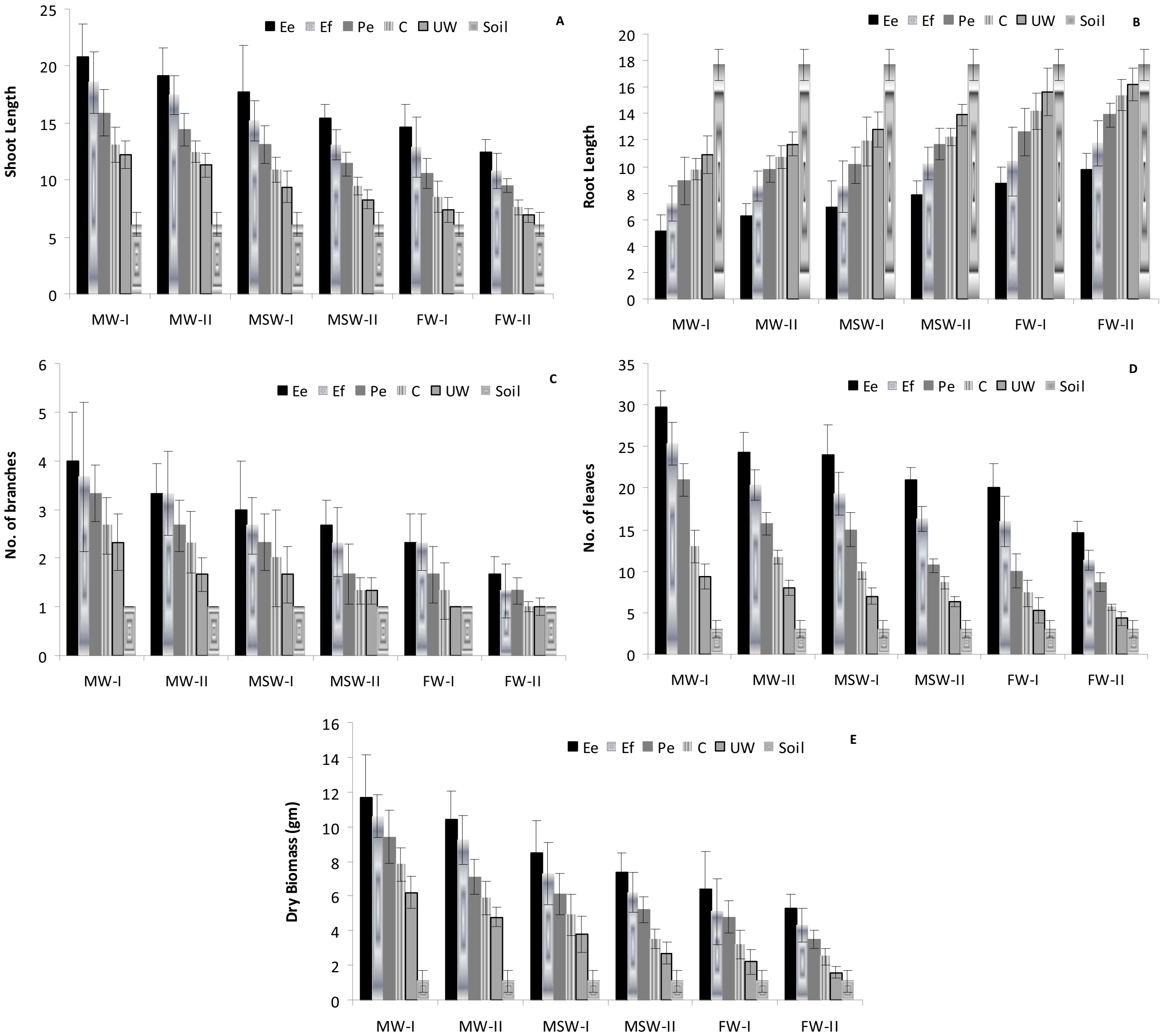


Fig. 2 Plant growth traits. (**A**) Shoot length, (**B**) Number of branches, (**C**) Number of leaves, (**D**) Dry biomass and (**E**) Root length of fenugreek plant treated with the organic inputs of three urban wastes (UW): MW-I (market waste at 10 t ha^{-1}) and MW-II (at 5 t ha^{-1}); MSW-I (municipal solid waste at 10 t ha^{-1}) and MSW-II (at 5 t ha^{-1}); and FW-I (floral waste at 10 t ha^{-1}) and FW-II (at 5 t ha^{-1}) and their respective composts (C) and vermicomposts of *E. eugeniae* (Ee), *E. fetida* (Ef) and *P. excavatus* (Pe) and of soil (n = 18, $P < 0.001$).

tomato (**Fig. 1**) and fenugreek (**Fig. 2**), was relatively higher in plants treated with VC of *E. eugeniae*, that of *E. fetida* and *P. excavatus* and sole C of MW followed by that of MSW and FW treated at the rate of both 10 as well as 5 t ha^{-1} compared to that of soil alone. The range of increase was 1.4–4.4- and 1.1–3.1-fold in the shoot length (**Fig. 1A**), 1.3–4.3- and 1.0–3.7-fold in number of branches (**Fig. 1B**), 1.1–2.9- and 1.0–2.4-fold in number of leaves (**Fig. 1C**), 2.5–11.1- and 2.0–7.9-fold in dry biomass (**Fig. 1D**), whereas the range of decrease was 0.2–0.8- and 0.33–0.88-fold in the root length (**Fig. 1E**) of tomato at 10 and 5 t/ha, respectively; in fenugreek, the range of increase was 1.2–3.4- and 1.1–3.1-fold in shoot length (**Fig. 2A**), 1.0–4.0- and 1.0–3.3-fold in number of branches (**Fig. 2B**), 1.8–9.9- and 1.4–8.1-fold in number of leaves (**Fig. 2C**), 2.0–10.6- and 1.5–6.7-fold in dry biomass (**Fig. 2D**); the decrease was 0.3–0.9- and 0.3–0.9-fold for root length (**Fig. 2E**) at 10 and 5 t ha^{-1}, respectively.

Comparison of plant growth traits applied with organic inputs in relation to that of the substrates

The growth traits of both the plants - tomato (**Table 2**) and fenugreek (**Table 3**) grown across different inputs of urban wastes and their respective VCs and Cs showed significant differences. The shoot length, number of branches and leaves, and dry biomass of tomato and fenugreek plant were significantly higher and the root length of tomato (**Fig. 1**) and fenugreek (**Fig. 2**), were lower when grown with the treatments of VC of *E. eugeniae*, *E. fetida* and *P. excavatus* and with C applied at the rate of 10 and 5 t ha^{-1}, compared to that of their respective substrate. The increase in shoot length (**Fig. 1A**), number of branches (**Fig. 1B**), number of leaves (**Fig. 1C**), and dry biomass (**Fig. 1D**) of tomato were in the range of 1.1–2.2-, 1.2–2.5-, 1.1–2.4- and 1.3–3.1-fold with the application of 10 t ha^{-1} and 1.1–2.2-, 1.0–2.8-, 1.1–2.1- and 1.3–3.0-fold at 5 t ha^{-1}, respectively and the decrease of root length (**Fig. 1E**) was 0.3–0.8- and 0.5–0.9-fold when applied at 10 and 5 t ha^{-1}, respectively; in fenugreek, the increase in shoot length (**Fig. 2A**), number of branches (**Fig. 2B**), number of leaves (**Fig. 2C**), and dry biomass (**Fig. 2D**) were 1.1–2.0-, 1.1–2.3-, 1.3–3.8- and 1.3–2.9-fold at 10 t ha^{-1} and 1.1–1.9-, 1.0–2.0-, 1.3–3.4- and 1.2–3.3-fold at 5 t ha^{-1}, respectively; the decrease in root length (**Fig. 2E**) was 0.5–0.9-fold both at 5 and 10 t ha^{-1}.

Table 2 ANOVA of different growth traits of tomato plants grown with different organic inputs - three urban wastes (municipal solid waste - MSW, market waste - MW and floral waste - FW) and their respective vermicomposts of *Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavatus* and composts (* $P < 0.001$).

Inputs	Source of variation	SS	df	MS	F*
10 t ha^{-1}	**Shoot length**				
	Treatments	6911.447	5	1382.289	42.28634
	Wastes	1233.063	2	616.5316	18.86064
	Error	326.8879	10	32.68879	
	Total	8471.399	17		
	Root length				
	Treatments	148.1646	5	29.63293	163.4299
	Wastes	8.317811	2	4.158906	22.93697
	Error	1.813189	10	0.181319	
	Total	158.2956	17		
	No. of branches				
	Treatments	13.66618	5	2.733236	54.31828
	Wastes	1.565078	2	0.782539	15.55159
	Error	0.503189	10	0.050319	
	Total	15.73444	17		
	No. of leaves				
	Treatments	619.247	5	123.8494	89.21546
	Wastes	51.02914	2	25.51457	18.37953
	Error	13.88206	10	1.388206	
	Total	684.1582	17		
	Dry biomass				
	Treatments	6086.589	5	1217.318	70.56691
	Wastes	753.3474	2	376.6737	21.83547
	Error	172.5055	10	17.25055	
	Total	7012.442	17		
5 t ha^{-1}	**Shoot length**				
	Treatments	2916.86	5	583.372	91.98846
	Wastes	231.0028	2	115.5014	18.21273
	Error	63.41796	10	6.341796	
	Total	3211.281	17		
	Root length				
	Treatments	85.60856	5	17.12171	74.64163
	Wastes	9.293344	2	4.646672	20.25704
	Error	2.293856	10	0.229386	
	Total	97.19576	17		
	Number of branches				
	Treatments	7.137867	5	1.427573	14.21178
	Wastes	0.782233	2	0.391117	3.893645
	Error	1.0045	10	0.10045	
	Total	8.9246	17		
	Number of leaves				
	Treatments	303.1608	5	60.63216	29.8559
	Wastes	57.33333	2	28.66667	14.11576
	Error	20.30827	10	2.030827	
	Total	380.8024	17		
	Dry biomass				
	Treatments	3055.006	5	611.0013	114.1332
	Wastes	234.7033	2	117.3517	21.92094
	Error	53.53403	10	5.353403	
	Total	3343.244	17		

Table 3 ANOVA of different growth traits of fenugreek plants grown with different organic inputs - three urban wastes (municipal solid waste - MSW, market waste - MW and floral waste - FW) and their respective vermicomposts of *Eudrilus eugeniae*, *Eisenia fetida* and *Perionyx excavatus* and composts (* $P < 0.001$).

Inputs	Source of variation	SS	df	MS	F*
10 t ha^{-1}	**Shoot length**				
	Treatments	264.2311	5	52.84622	41.07574
	Wastes	59.07444	2	29.53722	22.95837
	Error	12.86556	10	1.286556	
	Total	336.1711	17		
	Root length				
	Treatments	213.4517	5	42.69033	57.7677
	Wastes	32.26333	2	16.13167	21.82905
	Error	7.39	10	0.739	
	Total	253.105	17		
	No. of branches				
	Treatments	9.379517	5	1.875903	18.314
	Wastes	4.538033	2	2.269017	22.15188
	Error	1.0243	10	0.10243	
	Total	14.94185	17		
	No. of leaves				
	Treatments	995.6929	5	199.1386	44.7419
	Wastes	132.2554	2	66.12772	14.85739
	Error	44.5083	10	4.45083	
	Total	1172.457	17		
	Dry biomass				
	Treatments	116.9694	5	23.39389	21.90667
	Wastes	49.06778	2	24.53389	22.9742
	Error	10.67889	10	1.067889	
	Total	176.7161	17		
5 t ha^{-1}	**Shoot length**				
	Treatments	180.5828	5	36.11656	22.94733
	Wastes	65.18778	2	32.59389	20.70914
	Error	15.73889	10	1.573889	
	Total	261.5094	17		
	Root length				
	Treatments	165.8494	5	33.16989	42.27857
	Wastes	33.81444	2	16.90722	21.55006
	Error	7.845556	10	0.784556	
	Total	207.5094	17		
	Number of branches				
	Treatments	5.331161	5	1.066232	7.403933
	Wastes	4.111111	2	2.055556	14.27381
	Error	1.440089	10	0.144009	
	Total	10.88236	17		
	Number of leaves				
	Treatments	595.9804	5	119.1961	33.56641
	Wastes	104.0665	2	52.03327	14.65292
	Error	35.51052	10	3.551052	
	Total	735.5574	17		
	Dry biomass				
	Treatments	87.08278	5	17.41656	20.16843
	Wastes	34.59111	2	17.29556	20.02831
	Error	8.635556	10	0.863556	
	Total	130.3094	17		

Comparison of plant growth traits when grown in VCs and Cs

The growth traits of tomato (**Table 2**) and fenugreek (**Table 3**) grown in VCs were significantly higher from that of Cs applied at the rate of 5 and 10 t ha^{-1}. The range of the increase was 1.3–1.8- and 1.2–1.7-fold when applied at 10 t ha^{-1} and 1.2–1.8- and 1.2–1.6-fold at 5 t ha^{-1} for shoot length, 1.0–1.9- and 1.2–1.5-fold at 10 t ha^{-1} and 1.0–2.8- and 1.1–2.0-fold at 5 t ha^{-1} for number of branches, 1.3–2.0- and 1.4–2.7-fold at 10 t ha^{-1} and 1.2–1.8- and 1.2–2.6-fold at 5 t ha^{-1} for number of leaves, 1.2–2.4- and 1.2–2.0-fold at 10 t ha^{-1} and 1.2–2.2- and 1.2–2.1-fold at 5 t ha^{-1} for dry biomass; the decrease was in the range of 0.4–0.8- and 0.5–0.9-fold at 10 t ha^{-1} and 0.5–0.9- and 0.6–0.9-fold at 5 t ha^{-1} for root length of tomato (**Fig. 1**) and fenugreek (**Fig. 2**), respectively.

Relationship of nutrients in soil and organic inputs with the plant growth traits

The growth traits - shoot length, number of leaves and dry biomass of tomato were significantly and positively correlated to the nutrient contents – N (**Fig. 3A**), P (**Figs. 3B**), K (**Figs. 3C**), Ca (**Figs. 3D**) and Mg (**Figs. 3E**) respectively, present in the sole soil and various inputs i.e., MSW, MW and FW and their Cs, and VCs of *P. excavatus*, *E. fetida* and *E. eugeniae* ($P < 0.001$). The significant positive correlations were also found between growth traits (shoot length, number of leaves and dry biomass) of fenugreek plant and

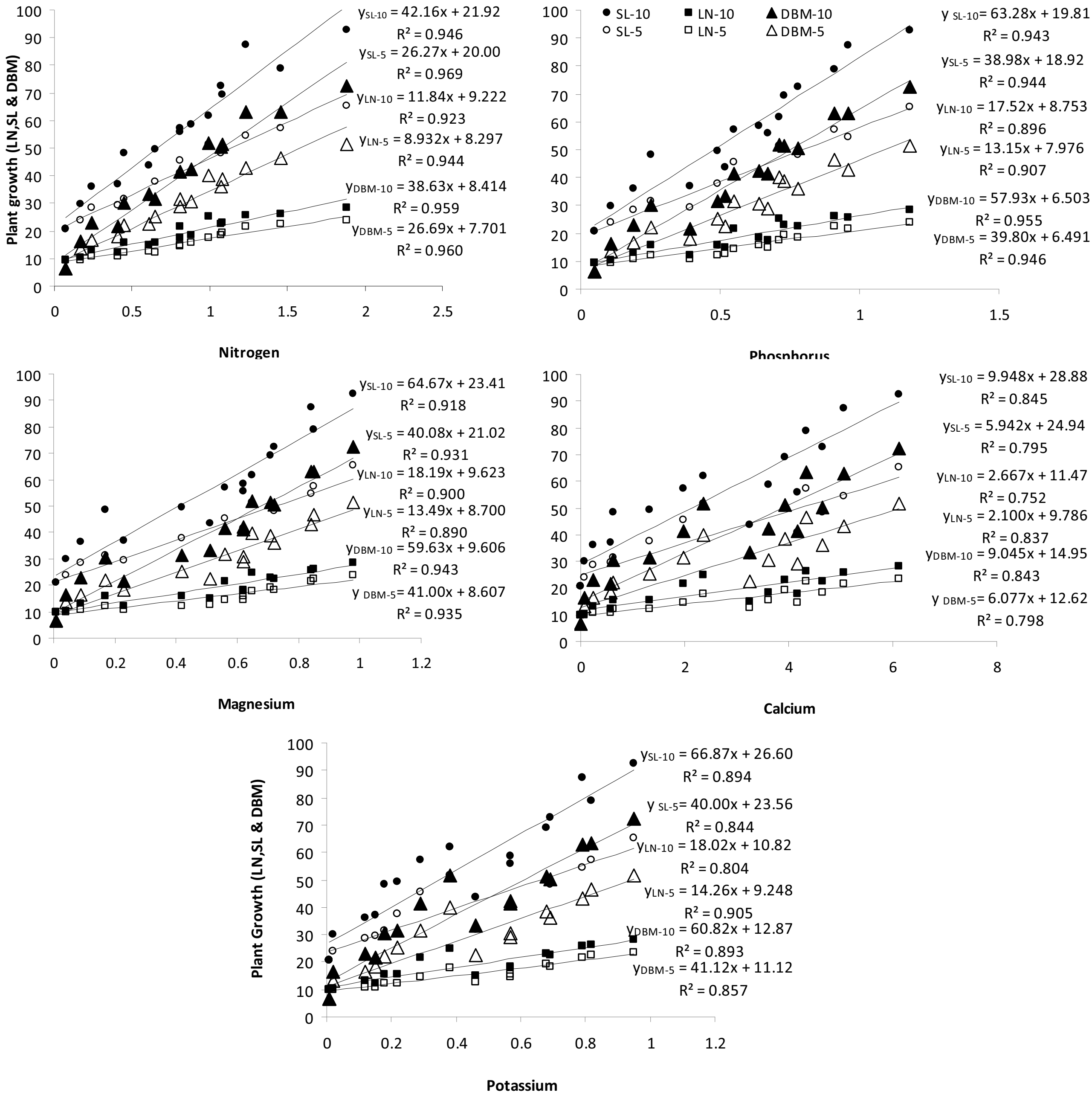


Fig. 3 Relationship between plant growth (SL - shoot length, LN - leaf number and DBM - dry biomass) of tomato plant and nutrient contents of nitrogen, phosphorus, potassium, calcium and magnesium of the inputs applied to soil, such as three urban wastes (MSW, MW and FW) and its respective composts and vermicomposts of *E. eugeniae*, *E. fetida and P. excavatus* and soil (n = 18, $P < 0.001$).

the nutrient contents – N (**Fig. 4A**), P (**Figs. 4B**), K (**Figs. 4C**), Ca (**Figs. 4D**) and Mg (**Figs. 4E**), respectively, present in different organic inputs. The number of leaves and dry biomass of tomato (**Fig. 5A**) as well as fenugreek (**Fig. 5B**) grown across the inputs and in soil applied at the rate of 10 t ha^{-1} and 5 t ha^{-1} also showed the significant positive correlations.

DISCUSSION

Plant nutrients of the urban wastes and their VCs and Cs

VCs prepared from respective organic wastes possessed considerably higher levels of major nutrients - N, P, K, Ca and Mg compared to that of the wastes (**Table 1**); these findings are in consistence with those of many earlier authors (Edwards 2004; Reddy and Ohkura 2004; Kitturmath *et al.* 2007; Pattnaik and Reddy 2009). Moreover, VCs possessed significantly higher concentrations of nutrients than that of the respective Cs ($P < 0.05$), which was probably due to the coupled effect of earthworm gut enzymatic activity as well as addition of microbial metabolites (Tognetti *et al.* 2007), making the excreta i.e., vermicast containing nutrients of more plant-available nature compared to that of Cs (Short *et al.* 1999; Bansal and Kapoor 2000). The waste materials ingested by the earthworms endured physic-chemical decomposition and bio-chemical changes due to the enzymatic and enteric microbial activities while passing through the worm's gut. The muscular gizzard and intestine masticated the ingested substrates and released nutrients in the form of microbial metabolites enriching the digested substrate in the alimentary canal with plant nutrients and plant growth promoting-like substances in an assimilated form, which is excreted in the form of vermicast (Kitturmath *et al.* 2007; Pattnaik and Reddy 2009).

Comparing the nutrients of VC of different waste substrates produced by the three earthworm species - *E. eugeniae*, *E. fetida* and *P. excavatus*, it was found that the VC of MW produced *E. eugeniae* possessed significantly higher concentrations of the nutrients followed by that MSW and FW processed by *E. fetida* and *P. excavatus* and the sole C,

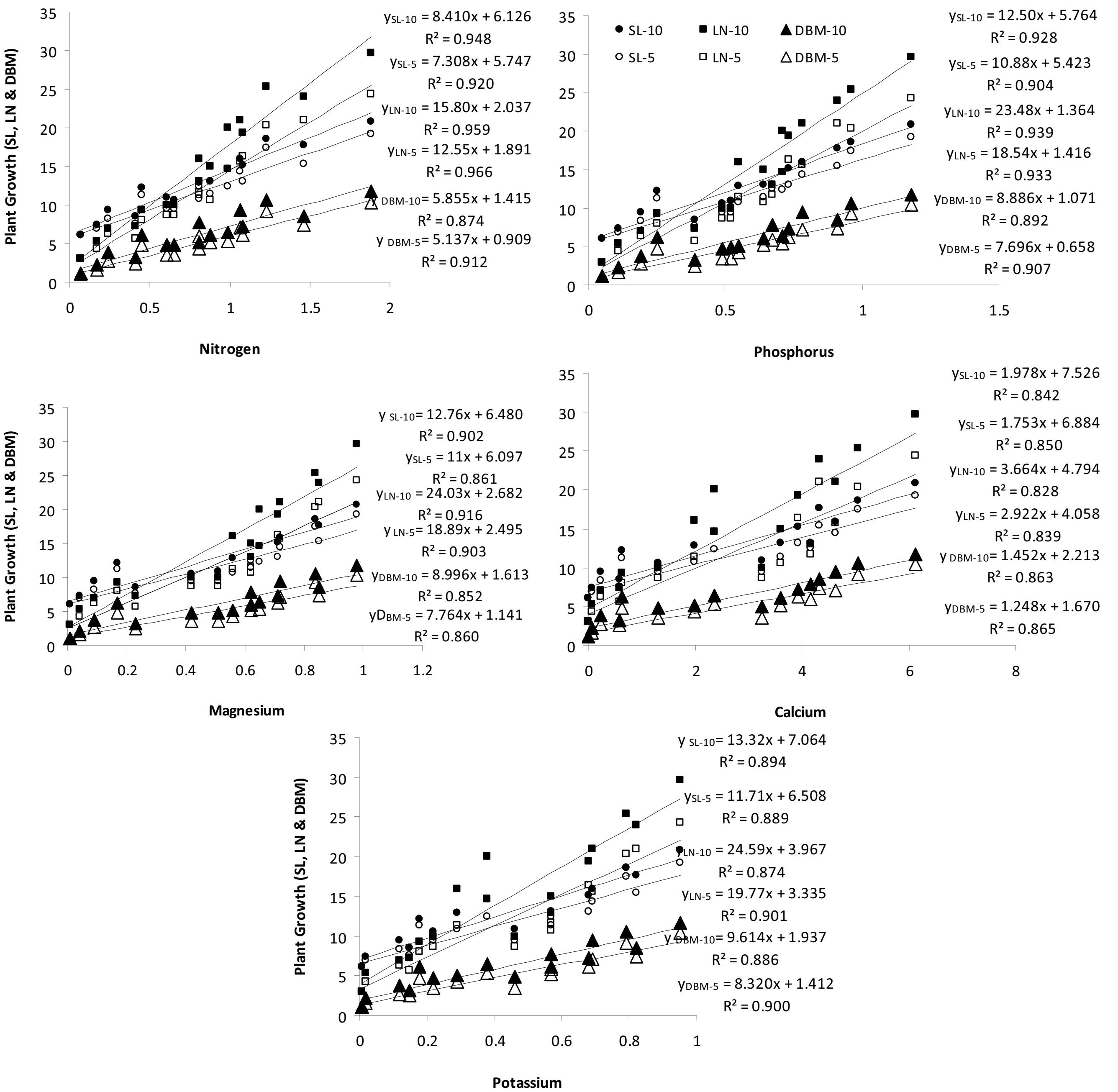


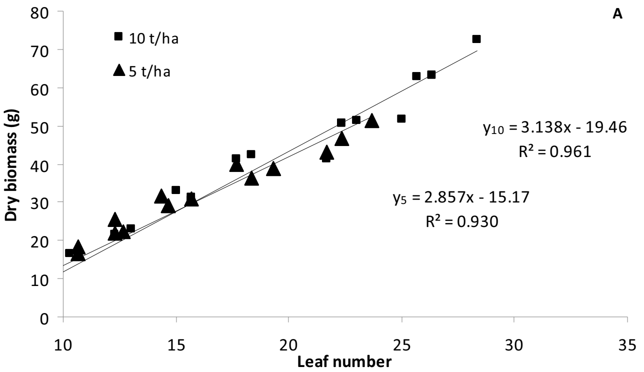
Fig. 4 Relationship between plant growth (SL - shoot length, LN - leaf number and DBM - dry biomass) of fenugreek plant and the nutrient contents of nitrogen, phosphorus, potassium, calcium and magnesium of the inputs applied to soil, such as three urban wastes (MSW, MW and FW) and its respective composts and vermicomposts of *E. eugeniae*, *E. fetida and P. excavatus* and soil (n = 18, $P < 0.001$).

in the ranking order of *E. eugeniae* > *E. fetida* > *P. excavatus* > C of MW > MSW > FW ($P < 0.05$), which indicated that the there is specific difference due to nutrient content of the waste substrate, and the better efficiency of species of earthworms in recovering nutrients from the waste through vermicomposting process (Padmavathiamma *et al.* 2008; Venkatesh and Eevera 2008).

Effect of nutrient contents of the inputs on the growth of tomato and fenugreek

Growth of both tomato and fenugreek was significantly higher with the application of urban wastes and their respective VCs and Cs compared to that the plants grown in sole soil, which is consistent with the findings of Azarmi *et al.* (2008) that VC has significant effects on growth traits like plant shoot and dry weight being higher than those of plants grown in sole soil (Reddy and Ohkura 2004; Pasha *et al.* 2009). The significant positive correlations between the increase growth traits in relation to the nutrient contents of the organic inputs i.e., wastes, Cs and VCs clearly showed that the nutrient contents present in the organic inputs applied to the plants increased growth traits of the plants, as nutritional factor is one of the important medium of plant growth (Atiyeh *et al.* 2000; Arancon *et al.* 2004).

Our findings further showed clearly that tomato (**Fig. 1**) and fenugreek (**Fig. 2**) grown with application of VCs especially that was produced by *E. eugeniae* were significantly higher than that of *E. fetida* and of *P. excavatus* in leaf and branch numbers, plant height and dry biomass compared to that of C, in the order of VC of *E. eugeniae* > that of *E. fetida* > that of *P. excavatus* > C, mainly because of VC possessed not only higher concentrations of the macronutrients but also the plant growth promoting hormone like substances that boosted the plant growth (Edwards 1998; Reddy and Ohkura 2004; Pattnaik and Reddy 2009). Further, Arancon *et al.* (2004) found similar results with maize, and tomato and cucumber and explained that auxin groups in humic acids present in VCs probably increased the stem growth in these plants significantly. The decreased root



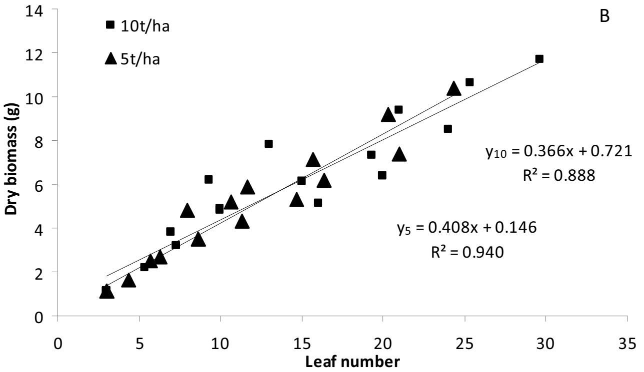


Fig. 5 Correlation between leaf number (LN) and dry biomass (DBM) of (**A**) tomato and (**B**) and that of fenugreek plant with the various inputs applied to soil such as three urban wastes (MSW, MW and FW) and its respective composts and vermicomposts of *E. eugeniae*, *E. fetida and P. excavatus* and soil (n = 18, $P < 0.001$).

length with VC was probably due to the availability of readily absorbable nutrients in the VC and their supply to the root system from the near surface rhizosphere whereas larger root length in the plants grown in sole soil was probably due to penetration of roots to deeper soil layers in search of nutrients because of the absence of readily available nutrients near the surface and sub surface areas; similar results were reported in an earlier study by Samantara and Reddy (2009).

The positive correlation between the nutrients present in the organic inputs of urban wastes and their respective VCs and Cs applied to the plants and their growth traits clearly indicated that the growth of tomato (**Fig. 3**) and fenugreek (**Fig. 4**) increased with addition of inputs – organic fraction of wastes to Cs and VCs and were associated with greater uptake of nutrients. Arancon *et al.* (2004) reported positive effects of VC on the growth and yield in strawberry, especially increase in leaf area, shoot dry weight and fruit weight under field conditions. The available nutrient status of soil was greatly enhanced by the application of VC as an organic source (Prabha *et al.* 2007). Similar studies were conducted to examine the effect of VC on growth and yield of vegetables in container growth media are in consistence to the present findings, with VC of poultry droppings increasing shoot biomass and seed yield of cowpea (Mba 1996), that of grape mare enhancing the grape yield up to 55%, and that of food waste and paper waste rising the growth, flowering and yields of field strawberries (Arancon *et al.* 2004; Reddy and Ohkura 2004; Pattnaik and Reddy 2009). These authors are of the view that large amount of beneficial microbial population in VC, and their build up and activity in the soil treated with VC probably increased the plant growth (Arancon *et al.* 2004). Azarmi *et al.* (2008) reported that growth and yield parameters such as leaf area, dry shoot weights and weight of fruits were significantly affected by applying VC. Mishra *et al.* (2005) showed that VC had beneficial effects on growth and yield of rice, especially causing significant increase of many growth parameters – seed germination, chlorophyll concentration and yield. Similar findings of increased plant growth with application of C and VC were also reported by other researchers (Atiyeh *et al.* 2001; Phasa *et al.* 2009; Samantara and Reddy 2009). Perez-Murcia *et al.* (2006) showed significant increases in the dry and fresh weights of broccoli aerial parts with the application of C, attributing the effects on the growth mainly to the great contribution of nutrients, especially N and P of Cs. These findings have been supported by other researchers (Pinamonti *et al.* 1997; Atiyeh *et al.* 2001; García-Gomez *et al.* 2002 Arancon *et al.* 2004; Reddy and Ohkura 2004; Pattnaik and Reddy 2009).

The significant positive correlation found between number of leaves and dry biomass of both the plants clearly indicated that based on simple counting the number of leaves followed by the increase in leaf number with the progress of the growth of the plants, the increase in the dry biomass of the plants can be predicted without doubt (**Fig. 5**).

CONCLUSION

Growth traits of both the plants fenugreek and tomato were higher with the organic input of VC of MW compared to that of MSW and FW produced by *E. eugeniae* as it possessed relatively higher nutrients – N, P, K, Ca and Mg followed by that of *E. fetida* and *P. excavatus*; the nutrients showed significant positive correlation with the growth traits of the plants. Both the plants showed higher growth parameters with application of VCs compared to that of Cs and the organic and mineral fraction of urban wastes as the former showed higher contents of nutrients compared to that of the sole C as well as the wastes. Besides, growth traits of both the plants were higher with the application of higher dose of MW and its VCs and Cs compared to other urban waste and their VC and C in relation to that of the soil. Thus, vermicomposting, the process of production of VC, proved to be a better technology for recovering plant nutrients from organic waste while managing the urban solid waste and thus, may be preferred as a best process for urban solid waste disposal and management. The VC can be used as an organic fertilizer, for sustainable management of agro-ecosystems.

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