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Utilization of Agrowastes for Vermicomposting and its Impact on Growth and Reproduction of Selected Earthworm Species in Puducherry, India

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ABSTRACT

Ecofriendly vermicomposting technology is used for utilizing the locally available agrowastes. Three different combinations of locally abundant agrowastes- banana waste (BW), mixed farm waste (MFW) and cow dung (CD) were fed to two different earthworm species, *Perionyx excavatus* and *Eudrilus eugeniae* in vermibins under controlled laboratory conditions for 90 days. Standard physico-chemical parameters of vermicompost were evaluated for seven different treatments along with the impacts on growth and reproduction of the selected earthworm species. The decomposition rate of substrate in *E. eugeniae* in T3, T5 and T7 (70.3±2.1 days, 76.3±2.5 days and 75.7±1.5 days respectively) and in *P. excavatus* in T2, T4 and T6 of same combination of substrates (81.7±1.2, 84.3±2.5 and 83.7±1.5 days) have been recorded. Earthworm growth and biomass production by weight of *E. eugeniae* was higher (68.5%) than *P. excavates* (66.9%). Further, the individual weight gain was higher in *E. eugeniae* than *P. excavatus* in all the three wastes with a significant difference ($p<0.05$). The production of cocoons and juveniles at the intervals of 30^{th}, 60^{th} and 90^{th} days were found higher in *E. eugeniae* than *P. excavatus* in all the three agrowaste combinations. The results indicate that *Eudrilus eugeniae* outperformed *Perionyx excavatus* in growth and decomposition rate of substrates and proves to be a better species for vermicomposting. Therefore, vermicomposting may be an efficient management approach for the locally available agrowastes to convert them into enriched manure for sustainable agriculture.

INTRODUCTION

Globally, 998 million tonnes (Fauziah et al. 2013) of agricultural waste is produced annually that accounts for one fourth of the biomass of post-harvest agricultural production. Considerably, they form the majority of organic supplements to the soil microorganisms (Akavia et al. 2009). Recycling of organic matter helps in improvement of soil physical, chemical and biological properties. Efficient agrowastes management will help in resolving the reduced availability of organic manure to agricultural sector and prevent/reduce the negative environmental impacts from agrochemicals. In the agricultural sector, organic wastes were considered useless and threat to the environment if left untreated but now it is realized that they can be converted to useful materials and provide benefits without causing damage to the environment (Singh 2014). Scientific investigations have established the use of earthworms for the conversion of biomass into manure, as a low-cost technology system (Das et al. 2016).

Vermicomposting has been identified as one of the potential composting methods, since it is a natural process, cost effective, and needs only shorter duration (Adi & Noor 2009). Vermicomposting is an appropriate alternative for the safe, hygienic and cost-effective disposal of many degradable waste materials (Lim et al. 2011). Vermicomposting has an advantage of reducing the total volume and particle size of the biomass waste and simultaneously increases its relative manurial value. Furthermore, the availability of macronutrients and micronutrients is generally higher in vermicompost than in the traditional compost and inorganic fertilizer, indicating that vermicompost is a better supplement to improve and stimulate plant growth (Lim & Wu 2015).

Based on ecological niches, earthworms are broadly grouped into three categories viz. endogeics, anecics and epigeics (Bouché 1977, Chattopadhyay 2012). Endogeic earthworms are geophagous in nature, which live deep inside the soil. Anecics reside just below the soil surface and feed on the organic materials mixed with the soils. Of these three categories of earthworms used in vermicomposting, epigeics which live on upper surface of soils feeding mainly on plant litter and other organic debris available on the soil surface play an important role in the decomposition process (Gómez-Brandón et al. 2012). As these earthworms can consume a variety of organic matter, they are more suitable for converting organic wastes into useful organic manures. These epigeic earthworms being voracious feeders can consume large quantities of different organic materials than anecics and endogeics (Chattopadhyay 2012, Varma et al. 2016). In spite of their high rate of consumption, they utilize only a very small part of the consumed food for their body synthesis and excrete about 90% to 95% of the ingested materials as vermicast (Chattopadhyay 2012). Hence epigeic earthworms with predominantly humus consuming and surface dwelling nature are considered to have higher potential in metabolic process of composting (Varma et al. 2016). It induces the higher frequency of reproduction and faster rate of growth to adulthood than most other species; these two factors make them efficient utilizers of humus, manure, and other forms of organic carbon. For all these reasons *E. eugeniae* and *P. excavatus* have been extensively used in vermicomposting throughout the world (Tian et al. 1995, Manna et al. 1997, Reinecke & Pieters 1998) and have proved to be efficient converters of organic feed, especially manure, into vermicast. Hence, they are selected for vermicomposting in our study.

Banana is one of the most extensively consumed fruits in the world and India is one of the largest producers of Banana, and Tamilnadu leads in banana production followed by Maharashtra in India. Most of the Banana farms generate huge quantities of biomass all of which goes as waste due to non- availability of suitable technology for its value addition in several states including Puducherry region. After the harvest of the fruits, the whole plant (leaves, pseudostem and rhizome) is left in the agricultural field for natural degradation, which takes several months that would potentially release Green House Gases (GHG) too (Khoshnevisan et al. 2014, Nayak et al. 2015). Cultivation of paddy, banana, sugarcane and vegetable crops account for 70% of the cropping area in Puducherry region (Directorate of Economics and Statistics 2016). Hence, this study was designed to assess the suitability of earthworm species for vermicomposting of dominant agrowastes in the region.

MATERIALS METHODS

Selection and collection of Earthworms: To compare the suitability of species for degrading agrowastes, we have chosen two different species of earthworms for the experiment one each from exotic (*Eudrilus eugeniae*) and indigenous (*Perionyx excavatus*) species which are epigeic in nature and well recognized in vermicomposting process. Indigenous species *P. excavatus* and exotic species *E. eugeniae* (Fig. 1) were randomly picked from an earthworm culture unit in Perunthalaivar Kamaraj Krishi Vigyan Kendra (PKKVK) Puducherry for the present study.

Collection of waste and blending: Cropping pattern practiced by the farmers in the study area is dominated by banana, sugarcane and other vegetables. Hence, dried leaves and pseudostem of banana, cattle waste, sugarcane trash and other crop residues were procured for Vermicomposting. Banana Waste (BW) (pseudostem) and Mixed Farm Waste (MFW) were selected for the experiment. Banana waste from banana field sites after post harvesting was collected and chopped into pieces of size 5-7cm and allowed for partial decomposition (10days). Mixed farm wastes comprising compost, paddy husks, sugarcane trash, leaves, etc. were collected from farm back yard in Pillaichavadi village, Puducherry.

In order to improve the C: N ratio of the partially decomposed wastes, cow dung (CD) was added at a ratio of 1:1 and 0.5:0.5:1 by weight respectively. Earthworms are sensitive to heat generated by fresh dung and hence fresh dung from a local cattle shed and dried separately for a week in order to reduce the generation of heat during decomposition process (Chauhan & Joshi 2010).

Experimental design: Based on the abundantly available banana pseudostem waste (BW) and mixed farm waste (MFW), we set seven treatments in 6L plastic containers of size 30×10 (diameter×depth) with 2kg of substrates i.e., combination of wastes and cow dung at 1:1 ratio .i.e., 1kg of wastes and 1kg of CD and also in 0.5:0.5:1 ratio where combination of wastes i.e., BW with MFW and CD (Fig. 1). Vermibed was prepared by placing 3mm thick double layered jute cloth moistened with water at the bottom of the reactor and laying the feed over it (Gajalakshmi & Abbasi 2004). We designed a batch of seven treatments with three replicates for each treatment (Table 1).

Total of 11Kg each of BW and MFW and 21 kg of CD were used in the experiment. Each trial was carried out for

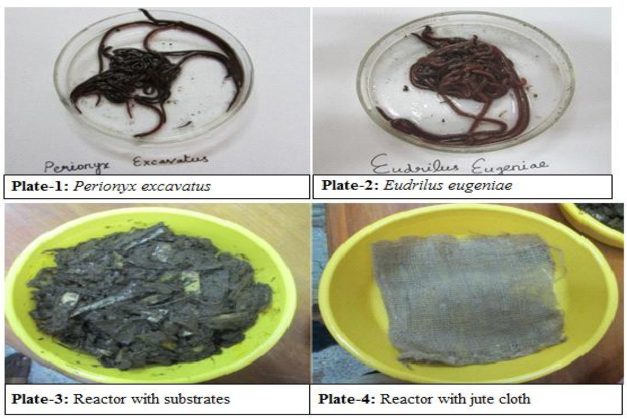

Fig. 1: Earthworm species and preparation of reactor with substrates.

Table 1: Treatments with different substrates composition and earthworm species.

Treat-ments	Substrates (Ratio)	Earthworm species
T1	BW+MFW+CD (0.5:0.5:1)	Control (no earthworm)
T2	BW+CD (1:1)	*P. excavatus* (20)
T3	BW+CD (1:1)	*E. eugeniae* (20)
T4	MFW+CD (1:1)	*P. excavatus* (20)
T5	MFW+CD (1:1)	*E. eugeniae* (20)
T6	BW+MFW+CD (0.5:0.5:1)	*P. excavatus* (20)
T7	BW+MFW+CD (0.5:0.5:1)	*E. eugeniae* (20)

the two earthworm species *P. excavatus* and *E. eugeniae*. Treatment (T1), reactors were prepared by mixing the two types of wastes together with partially decomposed cow dung in equal amounts (w/w) without earthworms and kept as a control. The treatment (T2), reactors of banana waste along with cow dung in equal amounts (w/w) were prepared with *Perionyx excavatus*. In the treatment (T3), reactors of similar as in treatment (T2) but with *Eudrilus eugeniae* and in treatment (T4), reactors of mixed farm wastes along with cow dung in equal amount (w/w) were prepared with *P. excavates*. In treatment (T5), reactors were similar as in treatment (T4) but with *Eudrilus eugeniae* in treatment (T6), reactors of both types of wastes i.e., banana waste, mixed farm wastes with cow dung in equal amount (w/w) were prepared with *Perionyx excavates*. In treatment (T7), reactors were similar as in treatment (T6) but with *Eudrilus eugeniae*. Twenty adult earthworms were introduced for each experimental treatment (T2)-(T7). The moisture contents of the treatments were maintained between 60-80% throughout the experimental period by sprinkling adequate quantities of water in a well aerated culturing room with a room temperature maintaining less than 25°C.

Sample collection and physicochemical analysis of vermicompost: After 90 days of vermicomposting process we recorded the total earthworm biomass, number of adults, cocoon and mortality rate at zero day, 30^{th}, 60^{th}, and 90^{th} day to evaluate the growth performance of both earthworms inoculated. Analysis of nitrogen (N), phosphorus (P), potassium (K), organic carbon (OC), electrical conductivity (EC) and pH of harvested vermicompost were done after the end of vermicomposting period (90 days). Total N and total P contents were determined by Micro Kjeldahl method and phosphorus by spectrophotometer at 690 nm (Bremner & Mulvaney 1982) while K was estimated by dry ashing flame photometric method respectively (Tandon 2005). The OC was determined by wet combustion method. The pH and EC were estimated by potentiometry with the help of digital pH meter and conductivity meter respectively.

Statistical analysis: The results were statistically analysed at 0.05 levels using one way analysis of variance (ANOVA) and tested using *t*-test. Tukey's HSD test was used as a post hoc to compare the means of nutrient content using SPSS package, Version 16.

RESULTS AND DISCUSSION

Growth and productivity of earthworms: Overall the growth parameters of two earthworm species cultured in BW, MFW and BW+MFW treatments have shown increase in size of *P. excavates* ranging between (84-86%) than *E. eugeniae* (59-68%). It shows no significant difference among the length of the *P. excavates* across all the substrates, whereas, *E. eugeniae* grown in mixed farm wastes exhibit reduced growth when compared to banana wastes with cow dung waste compost. Net individual weight of the two earth worm species displayed contrasting variations across the substrates as given in Table 2. The weight gain of *P. excavates* was between 16% and 66.9%, while *E. eugeniae* exhibited a weight gain range between 35.3% and 68.5%. The results show that the individual weight gain was higher in *E. eugeniae* than *P. excavatus* in all the three substrate combinations with a significant difference ($p<0.05$) (Table 2).

We have observed ferocious feeding of organic feed by *E. eugeniae* than normal soil explicitly. Due to availability of abundant food and space, they grow to a maximum weight of 2.5 g in 8 to 10 weeks. This is in agreement with the findings of Gajalakshmi et al. (2001) who have established that earthworms grew well when fed with water hyacinth: cow dung mixture, with a weight increase by more than 250%. Ranganathan & Vinotha (1998) reported maximum net gain of weight (average 30.7 g) by *E. eugeniae*, followed by *P. excavatus*, *L. mauritii* and *D. willsi*. *E. eugeniae* was found to have a faster feeding rate, higher moisture content in the casts, high microbial population and high enzymatic rate in both gut and casts. The difference between biomass and cocoon production in different treatments could be related to the biochemical quality of the feed, which was one of the important factors in determining onset of cocoon production (Flack & Hartenstein 1984).

The production of cocoons and juveniles at the intervals of 30^{th}, 60^{th} and 90^{th} days was found to be higher in *E. eugeniae* than that for *P. excavatus* in all the waste combinations. *E. eugeniae* is a tropical earthworm with a high reproduction rate (Gajalakshmi et al. 2001) and the organic content of the substrate (Viljoen & Reinecke 1989) and quality of the substrate (Edwards et al. 1998) might have promoted growth and cocoon production in *E. eugeniae*. Our results show that T3 and T7 are the preferred combination of substrate for *E. eugeniae* based on the cocoon and

Table 2: Growth performance of *P. excavatus* and *E. eugeniae* in different wastes during the process of vermicomposting (90 days).

Growth Parameters	*Perionyx excavates*			*Eudrilus eugeniae*		
	BW + CD	MFW + CD	BW + MFW+ CD	BW + CD	MFW + CD	BW + MFW+ CD
Average Individual Length:						
Initial size (cm)	7.07 ± 0.12	6.93 ± 0.12	6.87 ± 0.12	10 ± 0.30	10.2 ± 0.36	9.83 ± 0.47
Final size (cm)	13.13 ± 0.23	12.8 ± 0.2	12.73± 0.31	16.3 ±0.36	16.27 ± 0.06	16.6 ±0.26
Length increment (%)	85.8%	84.6%	85.4%	63.0%	59.5%	68.8%
Average Individual Weight:						
Initial weight (g)	0.44 ± 0.06	0.48 ± 0.03	0.50 ± 0.02	1.43 ± 0.1	1.48 ± 0.07	1.47 ± 0.09
Final weight (g)	0.73 ± 0.02	0.59 ± 0.03	0.58 ± 0.06	2.40 ± 0.08	2.01 ± 0.03	2.43 ± 0.05
Weight gain (%)	66.9%	22.4%	16%	68.5%	35.3%	65.7%

Each value represents the mean (Mean ± SD) of three replicates. Significance at: $p<0.05$

Table 3: Reproduction rate of earthworm species (in numbers) in different treatments.

Treatments	Adults				Cocoons			Juveniles		
	0^{th} day	30 days	60 days	90^{th} day	30 days	60 days	90^{th} day	30 days	60 days	90^{th} day
T2	20a	20.67± 0.58b	24.33± 1.53c	33±2d	3.33± 0.58a	13.67± 2.08b	26.67± 2.08c	6.33± 2.52a	16.67± 2.08b	24.33± 2.52c
T3	20a	21.33± 0.58b	29.33± 1.53c	42±3d	15.33± 1.53a	70.67± 14.15b	154.33± 9.07c	13±3.6a	48± 12.28b	124.33± 17.5c
T4	20abc	20.33± 0.58bac	22.33± 1.53cab	29.67± 2.08d	1.67± 1.15a	10.67± 1.53b	53±28b	1±1a	7±2b	17.67± 3.05c
T5	20abc	20.67± 0.58bac	21.33± 0.58cb	26.33± 1.53d	7.33± 1.53a	23.33± 2.52b	36.33± 4.16c	5±1a	25.33± 3.21b	39.67± 6.03c
T6	20abc	20.67± 0.58bac	24± 2cb	26.33± 2.52dc	2.67± 1.15a	11.33± 2.52b	21±2c	3.67± 1.15a	13.33± 3.51b	17.33± 1.53c
T7	20ab	21± 1ba	24.33± 1.53	27.33± 0.58	10.67± 1.53a	37.67± 4.04b	101.33± 24.11c	9.67± 3.05a	58.67± 7.37b	103± 25.16c

Values followed by same letters with in rows are not significantly different (mean ± SD) ($p>0.05$);
*T1 - Control without earthworm species

juvenile production rate. After 90 days, there was an increase in the numbers of both the earthworm species in T2-T7 from their initial number, and *E. eugeniae* has the highest number in T3 followed by T7 (Table 3). At the end of vermicomposting for 90 days, there was no case of mortality of earthworms each in *E. eugeniae* and *P. excavatus*.

Moisture content of substrates: Moisture content and dry weight of fresh materials before undergoing vermicomposting process was recorded. BW exhibited the highest moisture content percentage (92.78 %) and CD and MFW portrayed the highest dry weight percentage (29.64 and 30.44 % respectively) (Fig. 2).

Decomposition rate: A comparison of waste consumption rate between two earthworm species in six treatments with three replicates each was done by recording the number of days required to decompose the 2kg wastes with cow dung in proportion of 1:1 (T2-T5) and 0.5:0.5:1 (T6-T7) provided within 90 days period under observation. *E. eugeniae* in T3, T5 and T7 (70.3±2.1 days, 76.3±2.5 days and 75.7±1.5 days respectively) were able to utilize the combination of substrates at significantly shorter period of time before the 90 days, compared to *P. excavatus* in T2, T4 and T6 for the same combination of substrates (81.7±1.2, 84.3±2.5 and 83.7±1.5 days) (Fig. 3). The time required for composting was significantly reduced for *E. eugeniae* due to the higher feeding rate. *E. eugeniae* was able to work on larger pieces of substrate but favoured those that were pre-composted, spent, in smaller pieces, and are with cow dung and exhibited faster rate of composting (Gajalakshmi et al. 2002). Subsequently, Lim et al. (2015) confirmed that higher decomposition rate was due to the higher nutrient uptake by *E. eugeniae* for its body synthesis.

Physical characteristics of vermicompost: The bulk density of vermicompost at the end of the study period was recorded accordingly with a range of 0.61±0.01 g/cm^3, 0.75 ± 0.02 g/cm^3, 0.81 ± 0.02 g/cm^3, 0.73 ± 0.02 g/cm^3, 0.75 ± 0.02 g/cm^3, 0.79±0.05 g/cm^3, and 0.83 ± 0.03 g/cm^3 in T1, T2, T3, T4, T5, T6 and T7 respectively. In comparison among the treatments highest bulk density was recorded in T7 which was not significantly different from T3 and T6 but was sig-

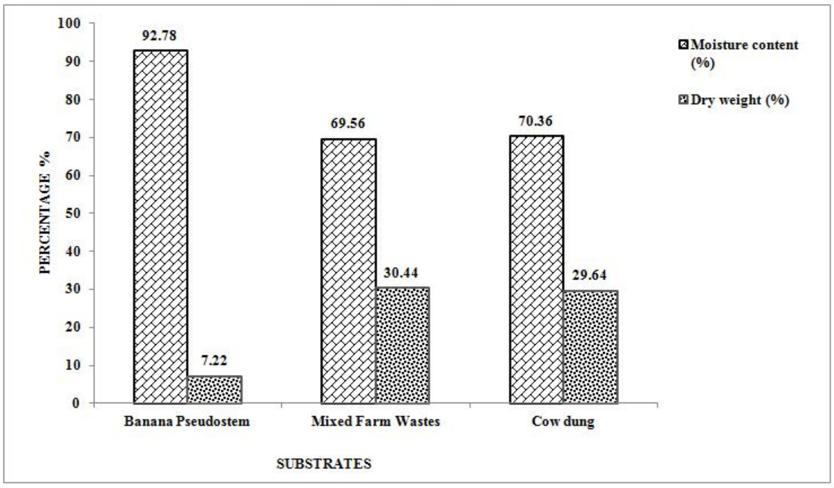

Fig. 2: Moisture content and dry weight of the substrates used.

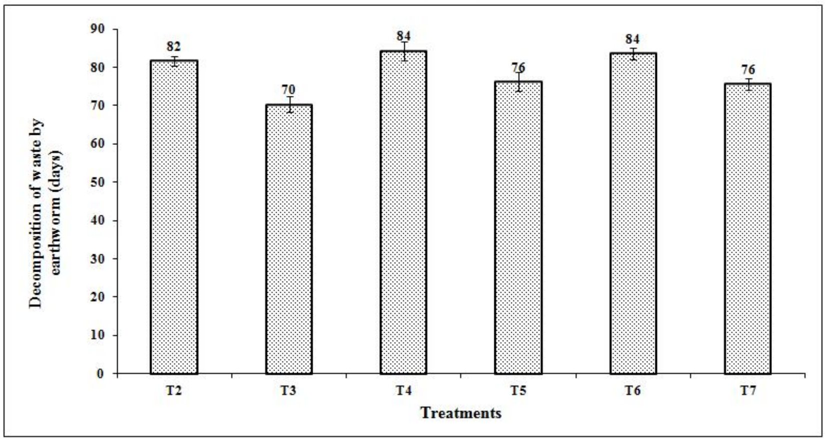

Fig. 3: Number of days taken by earthworm to decompose the substrates.

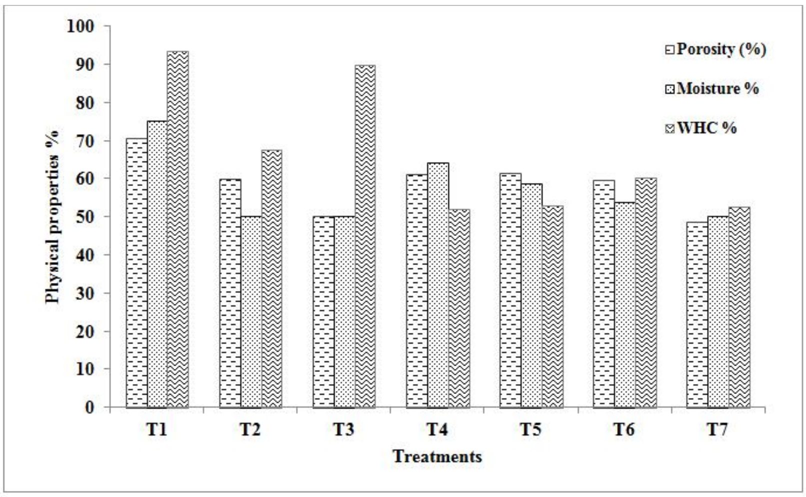

Fig. 4: Comparison of physical properties among the treatments.

Table 4: Physical characteristics of vermicomposting after 90 days.

Physical parameter	T1	T2	T3	T4	T5	T6	T7
Percent pore space (%) (PP)	70.4 ± 0.04	60.02 ± 0.01	50.06 ± 0.04	61.02 ± 0.03	61.3 ± 0.04	59.51 ± 0.07	48.61 ± 0.01
Bulk Density (g/cc) (BD)	0.61 ± 0.01	0.75 ± 0.02	0.81 ± 0.02	0.73 ± 0.02	0.75 ± 0.02	0.79 ± 0.05	0.83 ± 0.03
Particle Density (g/cc) (DP)	2.11 ± 0.35	1.88 ± 0.1	1.63 ± 0.16	1.89 ± 0.19	1.95 ± 0.23	2.01 ± 0.48	1.62 ± 0.07
Moisture content (%) (MC)	75.06 ± 0.15	50.03 ± 0.08	50 ± 0.13	64.29 ± 0.03	58.62 ± 0.15	53.84 ± 0.03	50 ± 0.4
Water holding Capacity (%) (WHC)	93.59 ± 0.01	67.55 ± 0.01	89.67 ± 0.03	52.13 ± 0.02	52.88 ± 0.01	60.33 ± 0.01	52.46 ± 0.01

Each value represents the mean (Mean ± S.D) of three replicates. No significant difference in DP (p>0.05), significance difference in PP (p<0.05) between vermicompost and control, significant difference in BD (p<0.05) between vermicompost and control.

Table 5: Parameters: pH and EC of different treatments after vermicomposting process.

Parameters	T1	T2	T3	T4	T5	T6	T7
pH	7.7±0.1	8.0±0.15	7.3±0.05*	7.9±0.15	8.1±0.15*	7.9±0.15	7.4±0.06*
EC(μS/cm)	1600±20	1650±20	2300±20*	1710±20*	2360±20*	2200±30*	2450*

Each value represents the mean (Mean ± S.D) of three replicates, for pH Values with (*) are significantly different (p<0.05) to T1 control, and for EC significant difference (p<0.05) occurred with control (*).

nificantly different (p<0.05) from T1 (Control) (Table 4). The observed bulk density for T3, T6 and T7 are closer to the optimum bulk density (1.0057g/cm^3) reported by Mckenizie et al.(2004). The final vermicompost depicted uniform granular structure with good dark brown colour (Das et al. 2016).

The porosity of vermicompost was found to vary in different treatments. Highest porosity was found in T5 with a narrow variation to T4 in contrast to T1 (control) and the lowest was observed for T7 with low porosity (Table 4). The porosity was found to be insignificant (p>0.05) between vermicompost but highly significant (p<0.05) between vermicompost and control. Das et al. (2016) reported a similar trend for porosity.

Particle density was examined at the end of the study. It was found to be slightly varying among the treatments and was found to be insignificant (p<0.05) to each other, except between T2 and T7 that were found to significantly varying (p<0.05) (Table 4). In comparison, vermicompost with the control exhibited no significant difference. Bulk density (DB), particle density (DP), and water-holding capacity are inversely correlated with total porosity (PT) and air volume (Abad et al. 2005).

Moisture content at the end of the vermicomposting process was found to be highest in the T4 (MFW) among the vermibins but T1 (control) has the highest moisture content than all the treatments (Fig. 4). This can be explained with nature of the substrates which has the high moisture content at its initial stage (Table 4). Since T1 (control) does not undergo any vermicomposting process i.e., earthworm was not present to consume the substrates, the decomposition process was only by the microbial activities which requires more time and the substrates will still hold moisture, like it does in the initial stage as it has not been decomposed completely within the study period.

Water holding capacity of the vermicompost was analysed at the end of the study period and it was noted that T3 (BW) had the highest water holding capacity percentage

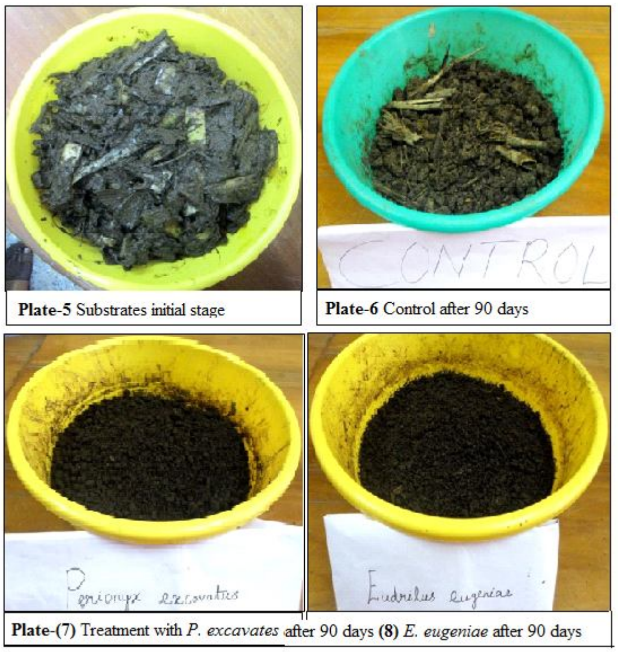

Plate-5 Substrates initial stage **Plate-6** Control after 90 days

Plate-(7) Treatment with *P. excavates* after 90 days **(8)** *E. eugeniae* after 90 days

Fig. 5: Observation of appearance at different stages of treatments.

Table 6: Variation in macro-nutrients from different treatments including control after vermicomposting process for 90 Days.

Macronutrients	T1	T2	T3	T4	T5	T6	T7
N (%)	1.79±0.01	1.55±0.02	1.63±0.01	2.12±0.02	1.72±0.02	1.98±0.01	1.85±0.01
P (%)	0.29±0.01	0.27±0.01	0.38±0.02	0.45±0.02	0.35±0.01	0.48±0.01	0.42±0.01
K (%)	0.9±0.03	1.12±0.02	1.23±0.01	0.88±0.01	1.05±0.01	1.05±0.02	0.97±0.01
OC (%)	3.8±0.1	7.21±0.01	6.73±0.05	3.99±0.02	5.07±0.01	5.36±0.02	4.19±0.01
OM (%)	6.76±0.03	12.83±0.05	11.98±0.01	7.1±0.01	9.02±0.03	9.55±0.01	7.45±0.02

Each value represents the mean (Mean ± S.D) from three replicates and were found significantly different at ($P<0.05$)

among the vermibins; whereas in comparison to the control it was low as the compost T1 control still has partial decomposed wastes (size 2mm) that can still store water like fresh substrates which is more than the vermicompost that has passed through the earthworms gut and fully decomposed (Table 4). Since the waste in control showed high moisture and high porosity content, it can be the reason for higher water holding capacity. Fig. 4 shows the comparative graphical presentation of porosity, moisture content and water holding capacity between the treatments. A similar finding was reported by Das et al. (2016), with water holding capacity of vermicompost as 65.75%.

Chemical properties in vermicompost pH: The maximum pH value (8.1) was observed in T5 while minimum pH value of 7.3 was found in T3. In comparison with the control T1 significant variation ($p<0.05$) was found in three treatments T3, T5 and T7 of *E. eugeniae* (Table 5). The pH values of vermicompost in all the treatments were taken only at the end of the study period. Suthar (2010) reported that the range of pH in vermicomposted material was 8.0±0.05 to 7.4±0.01 at the end. However, the decrease in pH values at the end was related to the loss of ammonia, producing the stabilized vermicompost (Fatehi & Shayegan 2010). Some researchers have reported decrease in pH during vermicomposting (Ndegwa & Thompson 2000, Khwairakpam & Bhargava 2009). Singh et al. (2005) attributed decrease in pH to enhanced earthworm and microbial activity on bioconversion of complex organic compounds into simpler forms and the production of humic acids. An increase in the pH of final vermicompost maybe due to excess of organic nitrogen not required by microbes, released as ammonia which gets dissolved in water and increases the pH of the vermicompost (Singh & Kalamdhad 2013).

Electric conductivity (EC): The EC values of all the treatments were analysed at the end of the study period and found highest in T7 (2450 $\mu S/cm^2$), the values of each treatments varied accordingly and significant difference was not found ($p>0.05$) in T2 with that of the control (Table 5). From the values recorded from all the treatments T7, T5 and T3 have the highest value 2450 $\mu S/cm^2$, 2360 $\mu S/cm^2$ and 2300 $\mu S/cm^2$ respectively. All the three treatments received vermicompost produced by *E. eugeniae.* Hence, it can be concluded that more exchangeable Ca, Mg, K and P was released during the vermicomposting period from *E. eugeniae* than P. *excavatus.* Similar findings were reported by Guoxue et al. (2001) and Tognetti et al. (2005) for these two species. The increased EC value during vermicomposting may be due to loss of organic matter and release of mineral salts like ammonium, phosphate, potassium, etc. (Gupta & Garg 2008). Das et al. (2016) have concluded that increase in electrical conductivity may be due to the soluble salt levels resulting from mineralization action of earthworms and microorganisms present in the gut of earthworms. Gradual decrease in the organic carbon content in the raw feed material also seems to be responsible for the increase in electrical conductivity.

Nutrient content: The major nutrients viz., N, P, K in all the treatments at the end of the study (Table 6) significantly varied ($p<0.05$) among the treatments. ANOVA was done for comparison between different substrates with same earthworm species and *t*- test for comparison between the substrates effectiveness. In the present study, N content was found highest in T4 (2.12±0.02), a combination of MFW and CD. Increase in N content in the soil could enhance the vegetative growth of the crops as evident from the work of Bansal & Kapoor (2000). Earthworms can increase N content of substrate during digestion in the gut adding their nitrogenous excretory products, mucus body fluid, and enzymes and decaying dead tissues of worms (Suthar 2007, Das et al. 2016). N content increased due to the net loss of dry mass in terms of CO_2, as well as water loss by evaporation due to heat evaluation during oxidation of organic matter (Fang et al. 1999). Earthworm activity enriches the nitrogen profile of vermicompost due to nitrogenous material secreted by earthworms (Varma et al. 2016).

Phosphorus content increased gradually in all the treatments except T2 in comparison to control T1. The worms during vermicomposting convert the insoluble P into soluble forms with the help of P solubilizing microbes through the enzymes phosphatase present in the gut of the earthworm which results in higher level of phosphorus at the end of vermicomposting (Suthar & Singh 2008). Increase in phosphorus content in vermicompost clearly indicated earthworm-mediated phosphorus mineralization, and further, it was observed that an increase in the rise of phosphate content of vermicompost may be due to the presence of alkaline phosphates in the worm cast (Suthar 2009, Bayon & Binet 2006).

Potassium (K), one of the important plant growth nutrients, was found to be higher in T3. The reason for such higher value of potassium might be due to physical decomposition of organic matter of waste due to biological grinding during passage through the gut, influenced by the enzymatic activity in worm's gut (Rao et al. 1996).

T2 (BW) was found to be high in organic carbon (7.21±0.01) and also in organic matter (12.83±0.05), and the lowest among the vermibins in organic carbon and organic matter was found in T4 (MFW). Highest values in T2 (BW) can most probably be due to the nature of the wastes that store high carbon content and organic matter. In relation to this T3 (BW) with *E. eugeniae* shows a slight variation in OC (6.73±0.05) and OM (11.98±0.01) to that of T2 (BW) with *P. excavatus*. Variations in organic carbon might be responsible for relative increase in nitrogen (Bertoldi et al.1987). During the vermicomposting process organic matter is decomposed and transformed to stable humic substances (Varma et al. 2016).

CONCLUSION

From the results obtained in the present study, the productivity of *E. eugeniae* was found to be better in the production of cocoons and juveniles with respect to the two treatments - banana waste with cow dung (T3) and combination of BW+MFW with cow dung (T7). On the other hand, *P. excavatus* was found to have the higher growth rate than *E. eugeniae* in MFW with cow dung alone (T5). In decomposing the waste, *E. eugeniae* seems to be faster and take lesser days (70-76 days) than *P. excavatus* (82-84 days) as per the time schedule of 90 Days to convert 2kg of substrates to vermicast. In terms of nutrient content *P. excavatus* seems to have the upper hand when compared to E. *eugeniae* in N and P fixing in MFW (T4) with N (2.12±0.02) and P (0.45±0.02) and in BW+ MFW (T6) vermibins with N (1.98±0.01) and P (0.48±0.01) in comparison to that of *E. eugeniae*. In taking into account the overall data and observations made in the study, it could be concluded that *E. eugeniae* is more efficient in decomposing the wastes than *P. excavatus*, BW and MFW can be effectively utilized for vermicomposting as nutrients supplier and in terms of growth and reproduction of locally available earthworm. Thus, vermicomposting is proved to be a better ecotechnology than that of natural composting or burning of farm wastes and may be preferred for the sustainable agro-waste management and nutrient recovery from the farm and agricultural wastes particularly banana waste, mixed farm waste and cow dung in developing countries like India.

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