Research Journal of Chemical Sciences ____ ISSN 2231-606X
Vol. **1(8),** 49-56, Nov. **(2011)** *Res.J.Chem.Sci.*

Vermicomposting of Vegetable Wastes Amended With Cattle Manure

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Available online at: www.isca.in
(Received 30th August 2011, revised 12th September 2011, accepted 22nd September 2011)

Abstract

Three different earthworm species Eisenia fetida, Eudrilus eugeniae and Perionyx excavatus in individual (Monocultures) and combinations (Polycultures) were utilized to compare the suitability of worm species for vermicomposting of vegetable waste amended with cattle manure. Eight different reactors including three monocultures and four polycultures of Eisenia fetida, Eudrilus eugeniae and Perionyx excavatus and one control were used for the experiment. Compost stability studies revealed that compost from monoculture reactors became very stable with final oxygen uptake rate and CO_2 *evolution of 2.60-1.53 mg/g volatile solids (VS)/day, 1.38-1.88 mg/g VS/day respectively. However, the compost obtained from the polyculture reactors attained maturity faster than the monoculture reactors as confirmed by the oxygen uptake rate results, with a reduction of 70 to 80%. The results show that vegetable waste amended with cattle manure produced high quality stable compost free from pathogens but the waste is not ideal for the growth and reproduction of earthworms.*

Keywords: vermicomposting; *Eisenia fetida; Eudrilus eugeniae; Perionyx excavates*; vegetable waste.

Introduction

For the past decades, the environmental pollution problems originated from municipal solid waste (MSW) call for more sustainable waste management systems. As shown in table 1 vegetable waste comprises as major portion of the Indian MSW[1]. The vegetable waste in MSW is mainly contributed by waste from vegetable markets, restaurants, canteens and household kitchens. All cities, towns, districts have major vegetable markets producing significant amount of this waste. At present, the collection, transportation and disposal of this waste is a big problem. The organic kitchen waste produced, form a major component of organic waste that end up in landfill sites or disposed off into roadsides and waterways in many developing countries. All these valuable organic wastes need to be fully utilized by vermicomposting before final disposal at the landfills. Owing to its high organic content and moisture content it can be looked upon as a very useful and promising feedstock for vermicomposting. The main problems encountered with kitchen waste composting are its high moisture content, need of bulking substrate and constituents unacceptable for worms.

Vermicomposting has been identified as one of the potential activities in managing MSW since it is a natural process, cost effective and only shorter duration needed to accomplish. Vermicompost in recent years has gained importance because of its higher nutrient value such as nitrogen, phosphorous, potassium etc. Most vermicomposting experiments have used epigeic earthworm species because they possess higher composting potential. The introduction of foreign species has been justified by a few scientists[2, 3] though it is extremely unnecessary and undesirable to tamper with local biodiversity[4]. Native species of earthworms are well-adapted to local conditions[5]. Hence choosing local or native species is a first pre-requisite for launching a vermicomposting programme.

Table - 1
Typical MSW components from Indian cities

Waste components	Percentage amount
Vegetable, fruit and animal matter	27.0
Dry grass and leaves	5.6
Paper and paper products	10.9
Plastic materials	5.4
Leather, foam and human hair	3.7
Cotton, jute and burlap	6.1
Rubber including cycle and auto tyres	2.9
Metals (tin, iron and aluminium)	2.0
Concrete, pebbles, earth, sands and dust	25.0
Ash and coal	9.0
Wood	0.4
Glass and ceramics	2.0
Total	100.0

Therefore, vermicomposting of vegetable waste was carried out amended with cattle manure and blended with saw dust. And keeping in view about the use of local species of earthworm, the present study was carried out using two exotic species (*Eisenia fetida, Eudrilus eugeniae*) and one local species (*Perionyx excavatus*).

Material and methods

Three composting species of earthworms two exotic (*Eisenia fetida* and *Eudrilus eugeniae*) and one indigenous (*Perionyx excavatus*) were chosen for the experiment. In the present study exotic earthworms *E. fetida* and *E. eugeniae* were cultured in the laboratory and were randomly picked for experimentation. The indigenous species, *P. excavatus* was collected from the drainage area in Indian Institute of Technology Roorkee campus by hand sorting method. The species were identified at National Zoological Survey of India, Solan, India, before culturing in the field laboratory. Vegetable waste was procured from the hostels of Indian Institute of Technology Roorkee, India. After size reduction of fresh vegetable waste to 1-2 cm, it was kept in shade for 2-3 weeks before using for the vermicomposting process. The partially degraded vegetable waste (0.85 kg) was then blended with saw dust (0.1 kg) and cattle manure (0.25 kg) to improve the C/N ratio. The obtained vegetable waste mixture (VWM) is used as the raw material for the vermicomposting process. The main characteristics of VWM are: pH, 8.47±0.2; electrical conductivity (EC), 0.24±0.05 S/m; ash content, 23 ±0.3 %; total organic content (TOC), 1.61±0.2%; total nitrogen (TN), 1.74±0.11%; total phosphorous (TP), 6.09±0.1 g/kg; C/N, 25.70±1.5; sodium (Na), 0.6±0.05%; potassium (K), 1.60±0.5%; calcium (Ca), 3.02±0.75%. The experiments were conducted in triplicate, in perforated cylindrical plastic containers of capacity 6 L. The containers were kept in temperature controlled experimentation room of 25±1^{o}C which is the optimum temperature range for all the three species[6]. Bedding (10 cm) was kept in all the containers using old vermicompost. Approximately 50 g (~100-120 in numbers) of earthworms, having both clitellated and juvenile, were inoculated in the bedding for acclimatization of the earthworms to the new environment for 15-20 days then VWM was added the next day. Eight different reactors including three monocultures and four polycultures of *E. fetida, E. eugeniae* and *P. excavatus* and one control were used for the experiment which are: i) *E. fetida* (R_1), ii) *E. eugeniae* (R_2), iii) *P. excavatus* (R_3), iv) *E. fetida* + *E. eugeniae* (R_4), v) *E. fetida* + *E. eugeniae* + *P. excavatus* (R_5), vi) *E. eugeniae* + *P. excavatus* (R_6), vii) *E. fetida* + *P. excavatus*(R_7), viii) Control (R_8). The polycultures were prepared using the earthworm species in equal proportions and one control (without any worms) was kept for degradation. Initial substrate (1.2 kg, VWM) was added to each of the reactors. The quantity of VWM was decided based on the findings that the earthworms can consume the material half their body weight per day under favorable conditions[7]. The moisture level was maintained about 50-60% throughout the study period by periodic sprinkling of adequate quantity of tap (potable) water. To prevent moisture loss, the reactors were covered with gunny bags. Homogenized wet samples (free from earthworms, hatchlings and cocoons; 110 g) were taken out at zero day and 15th, 30th and 45th day of composting period. The zero day refers to the sample taken out before earthworm inoculation. Triplicate samples were collected and stored at 4^{o}C for stability parameters i.e. oxygen uptake rate (OUR) and CO_2 evolution[8] bacterial population (1:10 w/v waste:water extract) including total coliforms (TC), fecal streptococci (FS) and fecal coliforms (FC) was measured by multiple fermentation method using lactose broth[9]. Sub-samples were air dried, ground to pass to 0.2-mm sieve and stored for further analysis. Each sub-sample was analyzed for the following parameters: pH and (EC) (1:10 w/v waste:water extract), ash content (550^{o}C for 2 h) (loss on ignition), TN using Kjeldahl method, ammonical nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) using KCL extraction[10], TOC determined by Shimadzu (TOC-VCSN) Solid Sample Module (SSM-5000A), TP by acid digestion using stannous chloride method, K, Ca and Na by acid digestion using Flame Photometer. In addition earthworm growth related parameters like earthworm biomass; and total mortality were measured at the end of the vermicomposting process.

All results reported are the means of three replicate. The results were statistically analyzed at 0.05 levels using one way analysis of variance (ANOVA) and Tukey's HSD test was used as a post-hoc analysis to compare the means (SPSS Package, Version 16).

Results and Discussion

pH: The changes in pH from the initial alkaline (8.47) to a more neutral condition was observed for all the reactors as shown in table 2. pH reduced in all the reactors during the vermicomposting period. The maximum pH reduction was for R_1 followed by R_2, R_5, R_4, R_7, R_3, R_6 and R_8 respectively. The decrease in pH was caused by the volatilization of ammonical nitrogen and H+ released due to microbial nitrification process by nitrifying bacteria[11]. The great reduction in pH level for monoculture reactors (R_1, R_2) and polyculture reactors (R_5, R_4) suggests the greater mineralization rate in it. Other researchers[12] have shown higher reduction in pH in the polyculture reactors. On analyzing the results by ANOVA, the pH value varied significantly ($P<0.05$) on 15th, 30th and 45th days of vermicomposting period.

Electrical conductivity (EC): Increment in EC was observed for all the reactors on 15th day of the composting. With the increase in time EC was observed to be reduced on 30th and 45th day of composting as shown in table 2. The increase in EC might have been due to release of different mineral salts in available forms. As the composting process further progressed the available salts were converted into insoluble salts which may be the reason for the reduction of EC at the latter stage. There was no significant variation ($P>0.05$) on 15th day of sampling for all the reactors. But as composting progressed, significant variation ($P<0.05$) was observed for all the reactors on 30th and 45th days of sampling as per ANOVA.

Table - 2
Variation in pH and EC during vermicomposting of vegetable waste

Reactors	pH			EC (S/m)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	7.84±0.15a	7.65±0.1a	7.32±0.1a	0.31±0.09a	0.27±0.09ac	0.17±0.08a
R_2	7.93±0.1a	7.67±0.1a	7.52±0.1ab	0.38±0.09a	0.21±0.06ad	0.13±0.08ab
R_3	8.28±0.2a	8.03±0.2ab	7.64±0.1bcd	0.41±0.1a	0.29±0.07abc	0.19±0.08ab
R_4	8.12±0.2a	7.91±0.15ab	7.60±0.1bc	0.25±0.1a	0.14±0.05bd	0.11±0.09ab
R_5	8.06±0.1a	7.88±0.1ab	7.62±0.1bcd	0.34±0.1a	0.28±0.04d	0.18±0.08a
R_6	8.28±0.15a	8.10±0.1b	7.88±0.1cd	0.33±0.1a	0.21±0.05bd	0.16±0.08ab
R_7	8.22±0.2a	8.01±0.2ab	7.82±0.1bcd	0.36±0.1a	0.26±0.05c	0.14±0.08a
R_8	8.28±0.1a	8.13±0.1b	7.94±0.2d	0.48±0.1a	0.39±0.09d	0.32±0.1b

Values followed by the same letter within each column are not significantly different

Table - 3
Variation in ash content and TOC during vermicomposting of vegetable waste

Reactors	Ash content (%)			TOC (%)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	25.2±1.4a	31.4±2.4ah	36.0±2.4ah	44.8±3.8a	41.1±3.8a	38.4±2.5ah
R_2	38.0±1.5b	42.1±2.4bc	50.2±3.5bd	37.2±2.8bfd	34.8±2.7b	29.8±1.4bd
R_3	39.8±1.4c	41.6±2.4c	62.4±3.4c	36.1±2.9b	35.0±2.9ab	22.5±1.5c
R_4	33.4±1.3def	34.0±1.5dg	51.8±3.5d	39.9±3cfgde	39.6±2.8ab	28.8±2.3dg
R_5	34.0±1.6e	36.1±1.9ef	45.2±3.0e	39.6±3.5fde	38.4±2.2ab	32.8±2.3e
R_6	34.0±1.3fe	36.0±1.8f	69.0±3.8f	39.6±3de	38.4±2.6ab	18.6±1.5f
R_7	32.0±1.3g	34.2±1.6d	52.8±3.6gd	40.8±3.9e	39.6±2.7a	28.3±2.4g
R_8	30.1±1.3h	32.0±1.3h	33.9±2.4h	42.0±4e	40.8±3.8a	39.6±2.7h

Values followed by the same letter within each column are not significantly different

Ash Content: The ash content increased till the last day of observation in all the reactors with similar trend. The increment in ash content for monoculture reactors were 1.6 (R_1), 2.2 (R_2) and 2.7 (R_3) folds while in polyculture reactors 2.2 (R_4), 1.9 (R_5), 3 (R_6) and 2.3 (R_7) folds were observed as shown in table 3. Similar results were observed for the substrate filter mud. Minimum increment was observed in control reactor with 1.5 (R_8) fold while maximum increment was observed in polyculture reactor R_6 (3 fold). Significant variation ($P<0.05$) was observed on 15th, 30th and 45th days of composting for all the reactors as per ANOVA.

Total organic carbon (TOC): Table 3 shows the TOC losses amount to 16.66 (R_1), 35.32 (R_2) and 51.16% (R_3) for monoculture reactors, 37.51 (R_4), 28.83 (R_5), 59.74 (R_6) and 38.78% (R_7) for polyculture reactors and 14.15% (R_8) for control respectively. Maximum reduction was observed in R_6 (59.74%) which indicates a high organic matter mineralization when compared to other reactors. The observed results are supported by those of other researchers[13,14] who have reported 20-45% and 40-50% reduction of TOC as CO_2 during vermicomposting of municipal or industrial wastes and filter mud respectively. Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA.

Nitrogen dynamics: Total nitrogen (TN) was 1.61% before composting and increased by 1.4 (R_1), 1.8 (R_2) and 1.6 (R_3) folds in monoculture and 1.9 (R_4), 2.0 (R_5), 1.4 (R_6) and 2.1 (R_7) folds for polyculture reactors, respectively. Earthworm activity enriches the nitrogen profile of vermicompost through microbial mediated nitrogen transformation, through addition of mucus and nitrogenous wastes secreted by earthworms. Decrease in pH may be an important factor in nitrogen retention as N_2 is lost as volatile ammonia at high pH values. The maximum increment was observed in R_5 and minimum was observed in R_8 with 1.1 fold. Other researchers[12, 15] have also observed similar nitrogen profile during the vermicomposting process. NH_4-N showed a declining trend and correspondingly an increase in NO_3-N was also observed which clearly indicated the nitrification of the feedstock as depicted in table 4 and 5. Decrease in NH_4-N occurred which corresponded with an increase in NO_3-N at the end of the vermicomposting process. Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA for TN, NH_4-N and NO_3-N respectively.

Table - 4
Variation in TN and NH_4-N during vermicomposting of vegetable waste

Reactors	TN (%)			NH_4-N (%)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	1.906±0.22a	2.07±0.41ac	2.52±0.52ac	0.28±0.03a	0.24±0.03ac	0.14±0.01a
R_2	2.06±0.18a	2.51±0.32ac	3.19±0.38ab	0.39±0.02b	0.38±0.02b	0.37±0.03b
R_3	1.80±0.21a	2.63±0.28ab	2.79±0.33abc	0.40±0.02b	0.35±0.03bc	0.31±0.02bc
R_4	1.76±0.19a	2.72±0.33ab	3.27±0.42ab	0.40±0.02b	0.38±0.02b	0.36±0.02b
R_5	1.78±0.21a	3.46±0.29b	3.58±0.39b	0.39±0.03b	0.38±0.04b	0.37±0.04b
R_6	2.10±0.22a	2.36±0.26ac	2.48±0.33ac	0.27±0.03a	0.21±0.01a	0.12±0.01a
R_7	1.89±0.11a	2.74±0.23ab	3.71±0.32b	0.2±0.03c	0.17±0.04a	0.10±0.01a
R_8	1.77±0.12a	1.82±0.31c	1.86±0.22c	0.32±0.01a	0.29±0.02c	0.25±0.02c

Values followed by the same letter within each column are not significantly different

Table – 5
Variation in NO_3-N and TP during vermicomposting of vegetable waste

Reactors	NO_3-N (%)			TP (g/kg)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	nil	0.05±0.01a	0.09±0.03a	4.78±0.52a	7.88±0.71a	11.55±0.92a
R_2	0.15±0.01b	0.20±0.05bc	0.21±0.03abc	4.06±0.58b	6.95±0.62b	9.09±0.78bd
R_3	0.09±0.01cd	0.12±0.03ab	0.23±0.05abc	3.87±0.31b	6.02±0.58d	8.24±0.73b
R_4	0.13±0.03bc	0.18±0.03bc	0.25±0.06bc	4.19±0.49b	7.57±0.63ab	10.89±0.82a
R_5	0.15±0.04bc	0.23±0.05c	0.30±0.05c	4.36±0.41ab	7.83±0.69a	10.81±0.89ad
R_6	0.07±0.01d	0.11±0.04ab	0.21±0.07abc	3.87±0.32b	6.98±0.66b	9.14±0.83bd
R_7	0.04±0.01d	0.15±0.02bc	0.23±0.06abc	4.01±0.41b	6.72±0.63bd	9.78±0.82d
R_8	nil	0.05±0.01a	0.11±0.03ab	2.84±0.22c	3.28±0.31c	4.18±0.42c

Values followed by the same letter within each column are not significantly different

Total phosphorous (TP): The amount of TP increased gradually with increase in composting period because of the gradual mineralization of organic matter as shown in table 4. TP increased by 5.2 (R_1), 4.1 (R_2), 3.7 (R_3) folds for monoculture reactors while the increment was 4.9 (R_4), 4.9 (R_5), 4.1 (R_6) and 4.4 (R_7) folds for polyculture reactors. The minimum increment was observed in control (R_8) with just 1.9 fold increase. The result obtained has much lower increment in TP as compared with other studies by researcher[16]. The earthworm affects phosphorus mineralization in wastes if reared for long periods in it[17]. In the present study, vermicomposting was done only for 45 days whereas in other studies it was done for 105 days. Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA.

C/N ratio: Variation in C/N ratio is given in figure 1. If the C/N ratio of compost is more, the excess carbon tends to utilize nitrogen in the soil to build cell protoplasm. This results in loss of nitrogen of the soil and is known as robbing of nitrogen from the soil. On the other hand if C/N ratio is too low the resultant product does not help improve the structure of the soil. It is hence desirable to control the process so that the final C/N ratio is less than or equal to 20[18, 19]. The reduction of organic C as CO_2 and total N increase has led to a decreasing trend in C/N ratio with increase in composting time. C/N ratio reduced by 42.62 (R_1), 64.73 (R_2) and 69.59% (R_3) for monoculture reactors while for the polyculture reactors the reduction was 66.76 (R_4), 65.44 (R_5), 71.78 (R_6) and 71.29% (R_7) respectively. The maximum reduction was observed in R6 of the polyculture and minimum in control (R_8) with 19.69%. Significant variation ($P < 0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA.

Other nutrients (K, Na, Ca and Fe): Nutrients i.e. K, Na, Ca and Fe increased with the composting time for all the reactors. Potassium increased by 1.25 (R_1), 1.82 (R_2) and 1.92 (R_3) folds for monocultures and 1.9 (R_4), 2.2 (R_5), 1.9 (R_6) and 2.2 (R_7) folds for polyculture reactors respectively as shown in table 6 and 7. Significant variation ($P < 0.05$) was observed only on 30th and 45th days of composting for all the reactors as per ANOVA. Sodium increased by 0.8 (R_1), 2.5 (R_2) and 2.8 (R_3) folds for monoculture reactors and 3.4 (R_4), 3.6 (R_5), 2.5 (R_6) and 1.5 (R_7) folds for polyculture reactors. Significant variation ($P < 0.05$) was observed on 15th, 30th and 45th days of composting for all the reactors as per ANOVA. Calcium increased by 3.38 (R_1), 1.9 (R_2) and 2.0 (R_3) folds for monocultures and 3.9 (R_4), 2.1 (R_5), 2.3 (R_6) and 2.9 (R_7) folds for polyculture reactors respectively. Significant variation ($P<0.05$) was observed on 15th, 30th and 45th days of composting for all the reactors as per ANOVA. Iron increased by 86.42 (R_1), 52.5 (R_2) and 50% (R_3) in monoculture reactors and 50 (R_4), 67.79 (R_5), 52.5 (R_6) and 51.28% (R_7) for polyculture reactors. Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA.

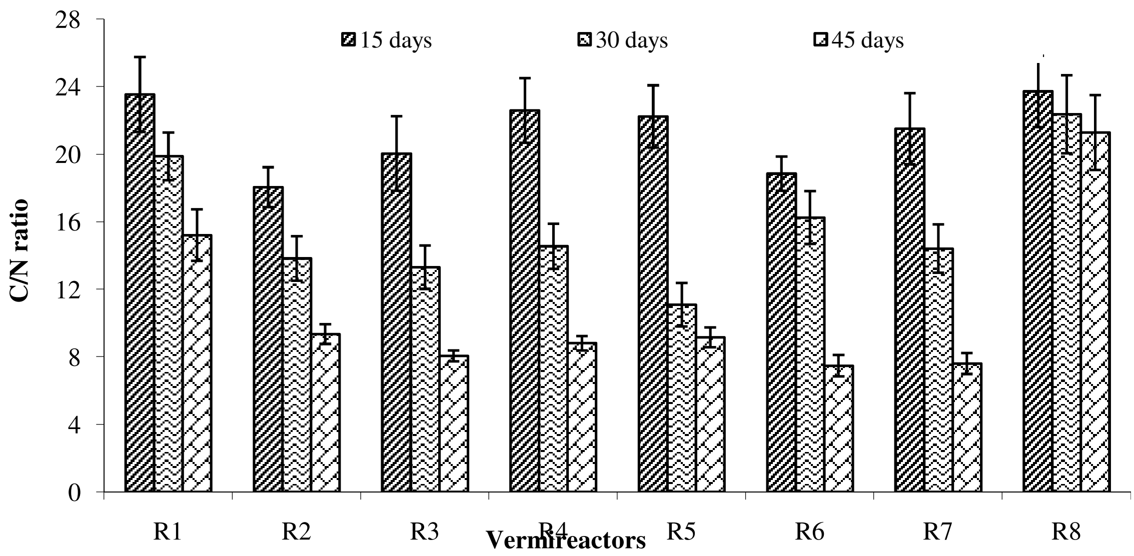

Figure - 1
Variation in C/N ratio during vermicomposting

Table - 6
Variation in K and Na during vermicomposting of vegetable waste

Reactors	K (%)			Na (%)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	11.22±1.34a	12.11±1.37a	13.72±1.72a	1.33±0.11a	1.58±0.12a	2.08±0.22a
R_2	11.62±1.45a	15.68±2.42ab	20.02±3.77ab	2.20±0.22b	2.63±0.22b	3.24±0.33bf
R_3	12.50±1.67a	16.84±2.71ab	21.12±3.56ab	3.30±0.32d	3.46±0.33c	3.58±0.33c
R_4	14.40±1.88a	18.60±2.93ab	21.70±4.81ab	2.60±0.22bd	2.71±0.22d	4.46±0.44d
R_5	15.24±2.1a	19.40±3.13b	24.40±4.17b	4.50±0.43c	4.62±0.43e	4.70±0.44e
R_6	11.80±1.5a	16.51±1.89ab	21.72±2.28ab	2.84±0.23ed	3.04±0.33f	3.28±0.33f
R_7	13.56±2.31a	17.66±1.97ab	24.22±2.86b	1.79±0.12ab	1.86±0.11g	1.97±0.12g
R_8	11.46±1.32a	12.86±1.56ab	13.52±1.28a	1.37±0.12a	1.41±0.11h	1.44±0.11h

Values followed by the same letter within each column are not significantly different

Table - 7
Variation in Ca and Fe during vermicomposting of vegetable waste

Reactors	Ca (%)			Fe (%)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	0.93±0.08ac	1.69±0.42ab	2.61±0.65ab	0.031±0.001a	0.077±0.003a	0.140±0.01a
R_2	0.89±0.06ac	1.02±0.21a	1.51±0.23a	0.025±0.001b	0.037±0.002b	0.042±0.003b
R_3	0.95±0.10ac	1.08±0.18a	1.60±0.54a	0.020±0.001cd	0.031±0.001cef	0.038±0.001b
R_4	1.33±0.31a	1.69±0.51ab	3.06±0.86b	0.021±0.001cd	0.025±0.001dg	0.037±0.001b
R_5	1.15±0.23acb	1.19±0.13ab	1.68±0.19ab	0.021±0.001cd	0.031±0.002ef	0.059±0.007c
R_6	1.43±0.12b	1.61±0.17ab	1.84±0.13ab	0.022±0.001c	0.031±0.002f	0.040±0.001b
R_7	1.55±0.17b	1.88±0.19b	2.30±0.74ab	0.020±0.001cd	0.025±0.002g	0.039±0.001b
R_8	0.86±0.02c	1.02±0.15a	1.33±0.12a	0.019±0.001d	0.020±0.001h	0.017±0.001d

Values followed by the same letter within each column are not significantly different

Coliforms: Coliforms reduced for all the reactors as the composting time increased. Total coliform reduced by 2 log (R_1, R_3), 3 log (R_2) in monocultures and 3 log reduction in all the polyculture reactors as shown in table 8. The reduction in control was comparatively very less that is 1 log reduction. Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA. Fecal streptococci reduced by 4 log for monoculture reactors (R_1, R_2, R_3) and polyculture reactors (R_4, R_5, R_6, R_7), while only 2 log reduction was observed in the control (R_8). Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA. Fecal coliform reduced by 2 log for monoculture reactors (R_1, R_2, R_3) and 2 log (R_4, R_7), 3 log (R_5, R_6) for polyculture reactors respectively (table 6). Significant variation ($P<0.05$) was observed on 15th, 30th and 45th day of composting for all the reactors as per ANOVA.

Growth and reproduction of earthworms: The changes in worm biomass for all reactors with mono as well as polycultures over the experimentation period are illustrated in table 9. In monocultures the increase in biomass was 26 and 4% for R_1 and R_2, but there was no change in biomass for R_3. In polyculture reactors the percentage increase in earthworm biomass was 36, 29, 14 and 4 (R_4, R_5, R_6, R_7) respectively. The lower reproduction of earthworms as compared to previous study may be due to addition of higher proportion of earthworms to the substrate. In the present study, as substrate was consumed, the earthworm castings may have become dominant and would likely not have supported the growth of the earthworms.

Oxygen uptake rate (OUR): Oxygen uptake rate was observed to reduce for the reactors with monocultures by 66.88, 73.14 and 74.79% (R_1, R_2, R_3) where as the percentage reduction for the reactors with polycultures was observed to be 72.81, 70.67, 75.94 and 80.06% (R_4, R_5, R_6, R_7) as shown in figure 2. A low decrease (20-32%) was observed in the initial 15- 30 days for all the reactors however, a higher decrease was observed in the last 30-45 days for R_7 with 65.02%. The compost obtained from the polyculture reactors attained maturity faster than the monoculture reactors as confirmed by the OUR results. Similar results were also observed in other studies[13]. On analyzing the results by ANOVA, decrease in OUR varied significantly ($P<0.05$) for all the reactors on 30th and 45th day sampling however, no significant difference was observed for the sample on 15th day.

Table - 8
Variation in FS and FC during vermicomposting of vegetable waste

Reactors	Ca (%)			Fe (%)		
	15 days	30 days	45 days	15 days	30 days	45 days
R_1	2.3×10^5^±822a	9.3×10^4^±541a	230±32a	9.3×10^4^±402ae	9.3×10^3^±181a	7.5×10^3^±154a
R_2	8.0×10^4^±618b	2.3×10^3^±132b	230±29a	4.3×10^5^±615c	2.3×10^4^±312bf	2.3×10^3^±108bc
R_3	9.3×10^4^±721c	2.3×10^4^±528cde	750±43b	7.5×10^4^±351b	2.3×10^4^±358bf	2.3×10^3^±93c
R_4	4.3×10^5^±791d	2.3×10^4^±433de	230±36a	7.5×10^5^±613d	4.3×10^5^±673c	9.3×10^3^±162dg
R_5	2.3×10^5^±784a	2.3×10^4^±480e	750±54b	7.5×10^4^±265b	4.3×10^4^±360d	230±36e
R_6	2.3×10^5^±802a	7.5×10^3^±356f	430±34ab	9.3×10^4^±356e	7.5×10^4^±449e	930±34f
R_7	2.3×10^4^±511e	4.2×10^3^±243g	750±47b	2.3×10^5^±661fg	2.3×10^4^±323f	9.3×10^3^±145g
R_8	9.3×10^5^±812f	7.5×10^4^±531h	2.3×10^4^±422c	2.3×10^5^±688g	9.3×10^4^±444g	7.5×10^4^±232h

Values followed by the same letter within each column are not significantly different

Table - 9
Live biomass production during vermicomposting of vegetable waste

Vermireactor	Mean weight of Earthworms (g)		Live biomass (% change)	Cocoons/worm/day	No. of Juveniles hatched/100g
	Initial	Final			
R_1	50	63	26	0.01	2
R_2	50	52	4	0.25	11
R_3	50	50	0	0.02	3
R_4	50	68	36	0.01	2
R_5	50	60	29	0.01	5
R_6	50	57	14	0.01	0
R_7	50	52	4	0.01	0

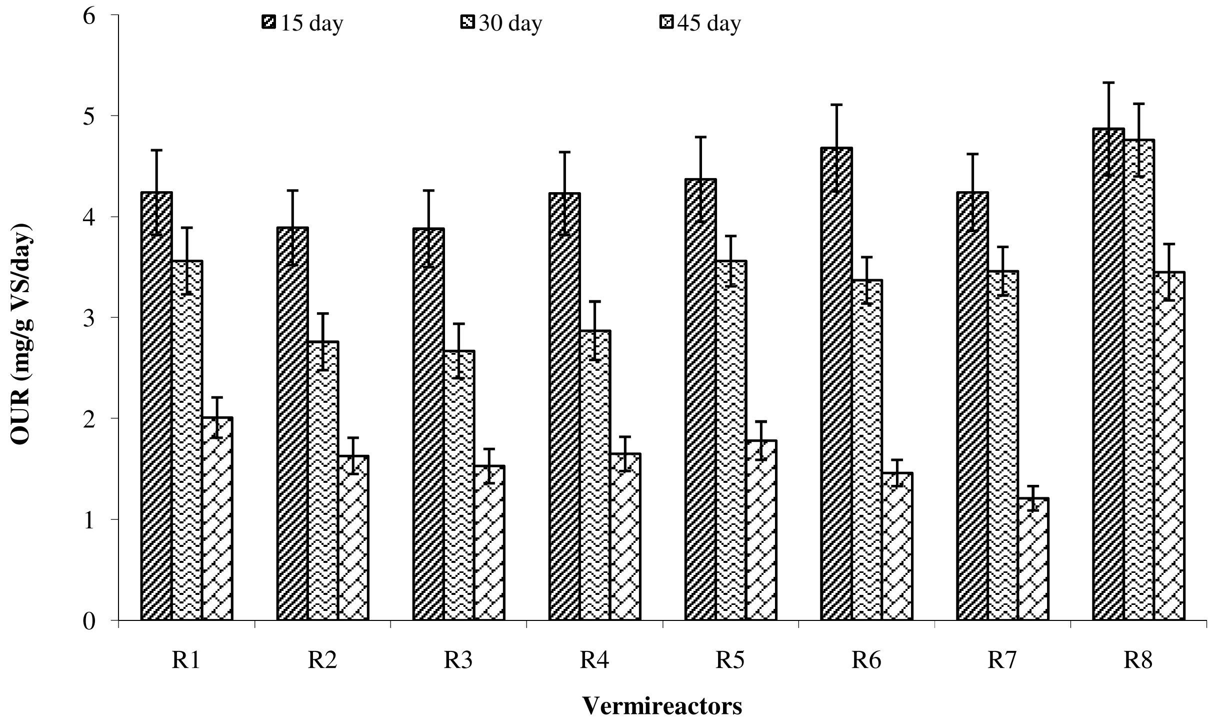

Figure – 2
Variation in OUR during vermicomposting

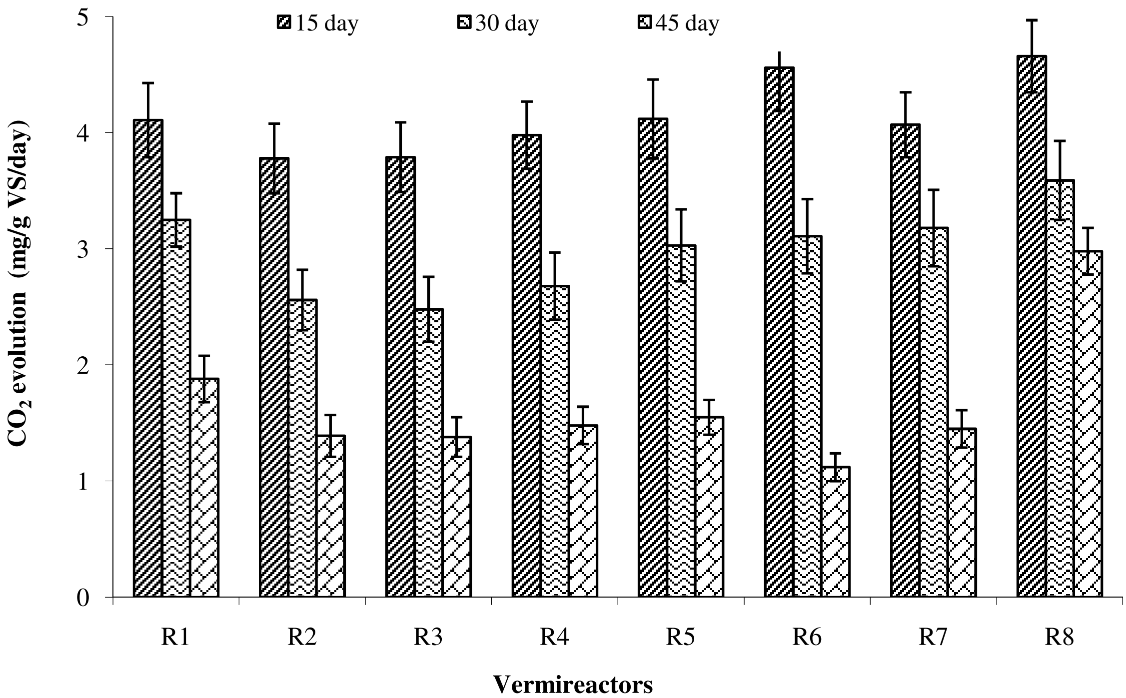

Figure - 3
Variation in CO_2 evolution during vermicomposting

CO_2 evolution: Carbon dioxide evolution rates was observed to reduce for the reactors with monocultures with 68.02, 76.36 and 76.53% (R_1, R_2, R_3) where as the percentage reduction for the reactors with polycultures was observed to be 74.82, 73.63, 80.95 and 75.34% (R_4, R_5, R_6, R_7) as shown in figure 3. ANOVA results showed significant variation ($P<0.05$) in CO_2 evolution among reactors. The greatest decrease in CO_2 evolution (80.95%) was observed in R_5 after 45 days of composting period. The highest decrease in rate of respiration activity occurred during between 30-45 days for R_6.

Conclusions

The results obtained prove the potential of vermitechnology for degradation of vegetable waste amended with cattle manure. The earthworms have enriched the end product with high nitrogen profile as confirmed by many fold increases in TN. Many fold increases in other essential plant nutrients i.e. TP, K, Na, Ca and Fe were also observed in the end product. On the other hand reduction in coliforms (TC, FS, and FC), C/N ratio and CO_2 evolution confirms that vegetable waste amended with cattle manure produced high quality stable compost free from pathogens. However, lower number of cocoons and hatchlings may be due to addition of higher number of earthworms. Hence, separate culture pits will be required to start and make up the loss in between if any. It was observed that based on the physico-chemical, biological and stability parameters, the performance of the reactors were in the order R_5 (*E. eugeniae* + *P. excavatus*) > R_7 (*E. fetida* + *P. excavatus*) > R_6 (*E. eugeniae* + *P. excavatus*) > R_4 (*E. fetida* + *E. eugeniae*) > R_3 (*P. excavatus*) > R_2 (*E. eugeniae*) > R_1 (*E. fetida*) > R_8 (Control) respectively.

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