Vermicomposting of Coffee Processing Wastes Using Exotic (*Eudrilus Eugeniae*) and Native Earthworm (*Perionyx Ceylanesis*) Species

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Summary: Coffee pulp is the main solid residue from the wet processing of coffee berries. Recent stringent measures by Pollution Control authorities, made it mandatory to treat all the solid and liquid waste emanating from the coffee farms. A study was conducted to evaluate the efficiency of an exotic (*Eudrilus eugeniae*) and a native earthworm (*Perionyx ceylanesis*) from coffee farm for decomposition of coffee pulp into valuable vermicompost. Exotic earthworms were found to degrade the coffee pulp faster (112 days) as compared to the native worms (165 days) and the vermicomposting efficiency (77.9%) and vermicompost yield (389 kg) were found to significantly higher with native worms. The multiplication rate of earthworms (280%) and worm yield (3.78 kg) recorded significantly higher with the exotic earthworms. The percentage of nitrogen, phosphorous, potassium, calcium and magnesium in vermicompost was found to increase while C:N ratio, pH and total organic carbon declined as a function of the vermicomposting. Vermicompost and vermicasts from native earthworms recorded significantly higher functional microbial group's population as compared to the exotic worms. The study reveals that coffee pulp can be very well used as substrate for vermicomposting using exotic (*Eudrilus eugeniae*) and native earthworm (*Perionyx ceylanesis*).

Keywords: coffee pulp; eudrilus eugeniae; microbial population; nutrients; perionyx ceylanesis; vermicomposting

Introduction

Coffee requires higher nutrients for its growth and productivity compared to other crops. The availability of organic manures particularly the Farm yard manure (FYM) is a major problem in coffee plantations because of non-availability of cattle's, but the FYM can be substituted by application of composts if composting is practiced at onfarm level in coffee farms.[1] Coffee pulp and husk are probably the major residues from the handling and processing of coffee and they are lignocellulosic enriched residues that can be used as soil fertilizers, providing a high content of macro- and micronutrients for crop growth and represent a low-cost alternative to mineral fertilizers.[2,1] However, the direct and inappropriately-timed application of these residues to agricultural fields can cause serious environmental problems, including the release of excessive amounts of tannins and phenols in soils, which could inhibit root growth. Therefore, it is necessary to find a suitable methodological alternative to reduce the environmental problems associated with their management.[3] The vermicomposting process is one of the best-known processes for the biological stabilization of solid organic wastes by

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transforming them into a safer and more stabilized material that can be used as a source of nutrients and soil conditioner in agricultural applications (Paoletti 1999; [4]). Recently attempts have focused on its application as substrate in bioprocess and vermicomposting.[1]

Vermicomposting is an accelerated process of bio-oxidation and stabilization of the organic matter that involves complex interactions between earthworms and microorganisms.[5,4] Efforts to recycle the coffee pulp include activities such as composting,[6] feeding to animals, the production of organic fertilizers, single-cell protein and biogas.[7,8,9] Application of vermicompost prepared using many organic wastes, has been shown to enhance microbial and enzymatic activities in soils.[10] But the use of coffee pulp as substrate for vermicomposting has not been well studied in India due to less attention given for soil waste management in coffee plantations. But, recent stringent measures taken by Pollution Control authorities, made it mandatory to treat all the solid and liquid waste emanating from the coffee farms. Hence, vermicomposting surely will come in way for management of coffee pulp in coffee farms for better pollution control and enhancing soil fertility. In India, there are no studies related to vermicomposting of coffee pulp using earthworms and information of nutrient and microbial dynamics during coffee waste vermicomposting is also lacking. Considering the significance of the circumstances and shortage of organic manure and pollution problems in coffee plantations, an experiment was conducted to evaluate the efficiency of exotic (*Eudrilus eugeniae*) and native earthworm species (*Perionyx ceylanesis*) on bioconversion of coffee pulp into vermicompost.

Material and Methods

The coffee pulp for experimentation were obtained from the pulper house of Coffee Research Sub Station, Chettalli, Kodagu, Karnataka (Farm-1) and another two coffee plantations in Kodagu (Farm-2 and Farm-3). The exotic African earthworms (*E. eugeniae*) were obtained from University of Madras, Tamil Nadu, India, and the native earthworms (*P. ceylanesis*) were isolated from the coffee processing waste compost pit near pulper house.

Vermicomposting – Experimental Layout

Experiments were performed in brick tanks measuring 1 m × 1 m × 0.75 m (length x breadth x depth) with a capacity to hold 500 kg of coffee processing wastes, with a hole at the bottom and overhead shade. Partially dried coffee pulp (10 days old) was used as raw material along with cow dung slurry and FYM as starter. Initially the tanks were smeared with cow dung slurry and filled with a layer of dried coffee husk (15 cm) over which cow dung slurry was sprinkled and weed biomass (10 cm) was spreaded. Partially composted coffee pulp was used as next two layers and sprinkled with cow dung slurry. Third and fourth layer is of partially composted coffee pulp mixed with partially composted weeds. 75% composted coffee pulp with dry FYM was used as fifth layer. Exotic (*E. euginae*) and native (*P. ceylanesis*) earthworms were inoculated separately on the top of the heap at one kg worms per tank. The tanks were covered with gunny bags and the moisture was maintained by periodical sprinkling of water. For subsequent vermicomposting of the pre-decomposed waste, the earthworm's *E. eugeniae* and native earthworms were cultured in cow dung employing the windrow method. There were 3 tanks (3 replicates) each for native and exotic earthworms; a treatment without earthworm inoculation was also included as control. Sampling has been done at initial and at the end of vermicomposting process. The completion of vermicomposting process was judged by visual observation and physical measurement (Sieving) under farmers field. The composting efficiency was calculated based on the quantum of un-degraded material left in the tank by sieving method.

Chemical Analysis of Vermicompost

Vermicompost samples for chemical analysis were drawn at the end of vermicomposting process. The earthworms were removed manually at the end of the experiment and the worm yield and compost yield per tank were quantified separately. Determination of pH was done by a digital pH meter. Total organic carbon and total Khjeldahl nitrogen were estimated by Walkley and Black rapid titration method[11] and Kjeldhal method, respectively.[12] Available phosphorus and total potassium were estimated by Bray and Krutz method[13] and by Flame emission technique, respectively. Exchangeable Calcium and Magnesium were estimated by method as outlined by.[14] All the determinations were carried out in triplicate.

Microbiological Analysis of Vermicompost and Vermicasts

Samples of 10 g (fresh weight) of vermicompost and vermicasts at the end of vermicomposting process from tanks inoculated with exotic and native worms were serially diluted in 90 ml Ringers solution up to 10^{-4} dilution and 1 ml of aliquot was poured plated in selective media (Nutrient agar for bacteria,[15] Martin's rose Bengal agar for fungi,[16] Ken knights and Munaier's agar[15] agar for actinomycetes and buffered yeast agar for yeast and the plates were incubated at optimum temperature in triplicates. The functional groups from the soil samples were enumerated using Pikovskaya agar[17] for phosphorus solubilizing microbes (PSM), No. 77 media for *Azotobacter* spp., Beckings media for *Beijerinckia* spp. [18] and Kings-B for fluorescent pseudomonad's.[19] The other physiological groups viz., cellulolytic, pectinolytic, starch hydrolytic, proteolytic and chitinolytic microbes were enumerated by following standard microbiological methods.[20] The microbial colonies appearing after the stipulated time period of incubation were counted and expressed as Colony Forming Units (Cfu)/g fresh weight of the sample.

Statistical Analysis

All the reported data are the means of 3 replicates. Statistical analysis of all the parameters was carried out through analysis of variance (ANOVA).[21]

Results and Discussion

The Coffee processing wastes and its composition is presented in Table 1. The chemical and microbiological characteristics of coffee pulp used in the experimentation are presented in the Table 2 and the data on nutrient status of vermicompost prepared using exotic and native earthworms are summarized in Table 3. The pH of the vermicomposting material found to fall from its initial value in both the trials with exotic and native worms. The vermicompost which was prepared using native and exotic earthworm recorded a mean pH value of 7.18 and 7.21, respectively, as compared to control treatment (7.18). The lower pH recorded in the final vermicompost might have been due to the production of CO_2 and organic acids by microbial metabolism during decomposition of different substrates in the feed mix-

Table 1.
Coffee processing wastes and its composition.

Processing methods	Weight in kgs
Wet processing (for 100kg of coffee cherries)	
Beans with mucilage	60–62
Pulp/fruit skin	38–42
Wet parchment	43–46
Mucilage	17–20
Dry processing (for 100 kg of dry cherries)	
Cherry husk	46–48
Constituents (Coffee pulp)	% by weight
Moisture content	12.7
Ash	8.30
Crude protein	9.30
Ether extracts	11.7
Soluble carbohydrates	56.0

Table 2.
Chemical and microbiological characteristics of coffee pulp.

Chemical parameters	
pH	7.6
Organic carbon %	53.5
C:N ratio	35.5:1
Nitrogen %	1.03
Phosphorus %	0.13
Potassium %	0.12
Calcium %	0.28
Magnesium %	0.10
Microbiological parameters (cfu x 10^4/g)	
Bacteria	42.0
Fungi	14.0
Yeast	37.5
Actinomycetes	12.0

tures.[22,23,24,25] Similar results on vermicomposting of cattle manure, fruit and vegetable wastes have been reported by Mitchell [26] and Gunadi and Edwards.[27] This pH shift could also be attributed to the bioconversion of the organic material into other various intermediate species of organic acids.[28]The pH-shift towards acidic conditions is believed to occur because of the resulting higher mineralization of the nitrogen and phosphorus into nitrites/nitrates and the orthophosphates, respectively.

Organic carbon of vermicompost found to reduce significantly from the initial value and the decrease was more pronounced with the native earthworm as compared to exotic. The C:N ratio of the coffee pulp after vermicomposting found to reduce significantly with both the worms to the extent of 75% as compared to control (10.2:1) (Table 4). Various studies have shown that earthworms utilize microorganisms in their substrates as a food source and can digest them selectively.[29,30] The increase in earthworms' growth may also be attributed to a low C:N ratio.[31] Loss of organic carbon (20–43%) as CO_2 was also observed during vermicomposting of paper mill and dairy sludges.[25]

The nutrients, nitrogen, phosphorus and potassium content found to increase significantly in the compost produced using native earthworms as compared to the initial values, while the calcium and magnesium content found to increase significantly in exotic worm produced compost. Kaushik and Garg [32] observed increase in total nitrogen in textile mill sludge along with cow dung and agricultural residues. Decrease in pH may be an important factor in nitrogen retention as this element is lost as volatile ammonia at higher pH. [33] Increase in nitrogen content in the final product in the form of mucus, nitrogenous excretory substances, growth stimulating hormones and enzymes from earthworms have also been reported.[34] According to Viel et al. [35] loss in organic carbon might be responsible for nitrogen enhancement. Earthworms also have a great impact on nitrogen transformations in manure, by enhancing nitrogen mineralization, so that mineral nitrogen may be retained in the nitrate form.[36] Mansell et al. [37] observed that plant litter was found to contain more available P after ingestion by earthworms, which may be due to the physical breakdown of the plant material by worms. Satchell and Martein [38] also found an increase of 25% in P of paper waste sludge,

Table 3.
Nutrient status of coffee pulp vermicompost prepared using exotic and native earthworms [a].

	pH [b]	Organic carbon	C:N Ratio	N	P_2O_5	K_2O	Ca	Mg
Exotic	7.21	14.67	8.73	1.66	0.41	0.70	0.52	0.31
Native	7.33	16.78	8.71	1.86	0.51	0.78	0.51	0.29
Control	7.18	11.24	10.2	1.26	0.32	0.64	0.42	0.25
$p > 0.01$	0.461*c	0.941*	0.979*	0.993*	0.794*	0.585*	0.997*	0.954*

[a]All the values are mean of three replicates.[b]All the values are given in percentage except pH and C:N ratio. [c]* Significant at 1%.

Table 4.
Vermicomposting on nutrient status and microbiological properties of coffee pulp [a].

	Chemical parameters									Microbes (cfu x 10^4/g)		
	pH [b]	OC	C:N ratio	N	P_2O_5	K_2O	Ca	Mg	Bacteria	Fungi	Yeast	Actinomycetes
Coffee pulp (Before composting)	7.60	53.5	35.5:1	1.03	0.13	0.12	0.28	0.10	42.0	14.0	37.5	12.0
After composting (Exotic worms)	7.21	14.67	8.73:1	1.66	0.41	0.70	0.52	0.31	75.4	21.1	56.2	25.1
After composting (Native worms)	7.33	16.78	8.71:1	1.86	0.51	0.78	0.51	0.29	76.4	17.4	64.3	27.0
Control	7.18	11.24	10.2:1	1.26	0.32	0.64	0.42	0.25	51.0	15.2	42.0	16.2
$p > 0.01$	0.894* [c]	0.999*	0.993*	0.984*	0.986*	0.980*	0.981*	0.305*	0.919*	0.636*	0.916*	0.692*

[a]All the values are average of three replicates.[b]All the values are given in percentage except pH and C:N ratio. [c]* Significant at 1%.

after worm activity. They attributed this increase in P to direct action of worm gut enzymes and indirectly by stimulation of the microflora. The vermicompost has more available nutrients per kg weight than the organic substrate from which it is produced.[39] The biological activity of earthworms provides nutrient rich vermicompost for plant growth thus facilitating the transfer of nutrients to plants.[40]

The data pertaining to vermicomposting efficiency and vermicompost yield are presented in Table 5. There found to be significant differences between vermicomposting efficiency of exotic and native earthworms on coffee pulp as compared to control treatment. Exotic worms found to degrade the coffee pulp faster (112 days) as compared to the native worms (165 days). The control treatment without earthworm inoculation took 205 days for complete degradation of coffee pulp. Native worms took 53 days excess to that of exotic worms to complete the vermicomposting process. However, the compost yield found to significantly higher in case of native worms. The multiplication rate and worm yield recorded significantly higher with the exotic earthworms and it was almost double the population as compared to native earthworms. Use of vermicomposting technology in coffee waste management have been reported by many workers in coffee producing countries.[41,3,42] Suthar [43,44] have reported production of vermifertilizer from guar gum industrial wastes by using composting earthworm *Perionyx sansibaricus* (Perrier), while Benitez et al. [45] reported production of vermicompost from olive oil industry waste.

Table 5.
Vermicomposting efficiency and yield [a].

	Days for composting	Compost yield (Kg)	Composting efficiency (%)	Earthworm yield (Kg)	Worm multiplication (%)
Exotic earthworms					
Farm-1	114.00	356.67	71.24	3.74	274.0
Farm-2	110.67	362.33	72.09	3.47	247.6
Farm-3	111.67	349.33	69.62	4.12	317.0
Native earthworms					
Farm-1	157.00	401.67	80.61	2.46	150.6
Farm-2	165.33	393.33	78.72	2.11	116.3
Farm-3	173.33	371.67	74.64	2.31	135.3
Control	205.00	270.33	54.06	–	–
$p > 0.01$	0.998* [b]	0.994*	0.980*	0.958*	0.999*

[a]All the values are average of three replicates.[b]* Significant at 1%.

Table 6.
Microbiology of raw vermicompost.

	General microflora (cfu x 10^4/g)						Functional/Physiological groups (cfu x 10^3/g)					
	Bacteria	Fungi	Yeast	Actino-mycetes	N2 fixers	P-Solubilisers	Fluorescent Pseudomonads	Cellulo-lytic	Pectino-lytic	Starch hydrolytic	Proteo-lytic	Chitino-lytic
Exotic worms												
Farm-1	83.0	23.7	61.3	26.0	11.7	7.3	12.0	7.0	15.7	8.0	3.0	1.7
Farm-2	75.3	24.0	53.0	25.7	8.3	5.0	12.7	8.3	19.7	10.7	5.0	1.7
Farm-3	68.0	15.7	54.3	23.7	6.0	5.3	14.3	9.7	19.0	11.3	5.3	2.3
Native worms												
Farm-1	67.0	18.3	62.0	23.7	8.7	4.7	14.3	9.7	21.3	15.7	8.0	2.7
Farm-2	80.7	17.0	69.3	27.0	12.0	7.0	19.0	10.7	20.3	12.0	6.7	2.7
Farm-3	81.7	17.0	61.7	30.3	10.7	7.3	21.3	9.3	19.7	8.7	9.0	4.0
Control	51.0	15.2	42.0	16.2	3.9	3.0	9.40	5.4	14.0	5.5	2.8	1.6
$p > 0.01$	0.425* [b]	0.452*	0.144*	0.924*	0.178*	0.523*	0.865*	0.05*	0.09*	0.698*	0.977*	0.232*

[a] All the values are average of three replicates.[b]* Significant at 1%.

The data on general and functional microflora of vermicompost prepared using exotic and native earthworms are presented in Table 6. In general microflora, except fungi, found to be significantly higher in compost prepared using native worms as compared to exotic species. Similar is the case with functional microbial groups, vermicompost prepared using native earthworms recorded significantly higher counts as compared to the exotic worms. Kristufek et al. [46] have reported that the number of bacteria, microfungi, and micromycetes increased in the guts of *Lumbricus rubellus.* While, Edwards and Burrows [47] have reported that vermicompost was richer in fungi, bacteria, and actinomycetes compared to the soil. This could be attributed to the fact, as reported by Pedersen and Hendriksen [48] that in the guts, there could have been an increase in the number of vegetative cells as well as germination of the spores of this bacterial community due to an increase in nutrient availability by the release of nutrients from ingested material.

The data on microbiological properties of vermicasts from exotic and native earthworms are summarized in Table 7. Bacteria, fungi and yeast population found to significantly higher in the vermicasts from the native earthworms as compared to exotic, while the actinomycetes counts found to significantly higher with the vermicasts of exotic worms. Vermicasts are rich sources of macro and micronutrients, vitamins, enzymes, antibiotics,

Table 7.
General and functional microflora of coffee pulp vermicasts [a].

	General microflora (cfu x 10^4/g)						Functional/Physiological groups (cfu x 10^3/g)					
	Bacteria	Fungi	Yeast	Actino-mycetes	N2 fixers	P-Solubil-isers	Fluorescent Pseudo-monads	Cellulo-lytic	Pectin-olytic	Starch hydrolytic	Proteolytic	Chitin-olytic
Exotic worms												
Farm-1	165.3	31.3	127.7	38.0	14.7	11.0	22.7	16.0	38.3	18.0	7.3	4.7
Farm-2	148.3	34.0	123.3	42.0	13.7	12.0	17.3	12.7	34.0	27.3	9.7	6.3
Farm-3	134.7	39.7	118.0	33.0	8.30	12.0	20.0	13.7	32.3	17.7	7.0	4.7
Native worms												
Farm-1	185.7	25.7	132.3	23.7	14.3	8.0	28.3	12.0	43.3	25.3	5.0	5.3
Farm-2	181.7	31.3	152.7	43.3	16.0	16.0	28.3	18.7	36.0	34.3	7.3	4.7
Farm-3	164.0	48.7	132.3	37.0	20.0	15.0	34.7	18.3	32.7	33.3	12.3	4.0
Control	120.6	16.3	98.60	16.4	5.80	5.50	14.4	8.0	21.2	12.5	3.6	2.4
$p > 0.01$	0.795* [b]	0.963*	0.997*	0.676*	0.739*	0.619*	0.215*	0.219*	0.215*	0.989*	0.835*	0.382*

[a]All the values are average of three replicates.[b]* Significant at 1%.

growth hormones and immobilized microflora.[49] The nutrients present in vermicasts are readily soluble in water for the uptake of plants.[50] Syers and Springett [51] found an increase in the number of bacteria and actinomycetes with enhanced phosphatase activity in earthworm casts. Earthworm gut is having many beneficial microbes including polymer degraders, phosphorus solubilizers, and nitrogen fixers. In functional microbial groups, except chitinolytic microbes all other microbes found to significantly higher with the vermicasts of native worm. Gopal et al. [52] has reported similar results on the occurrence of beneficial microflora in vermicompost prepared from coconut leaves. Vermicompost not only increase the soil fertility through the addition of plant growth hormones and increased levels of soil enzymes;[53] they are also responsible for the dissemination of important microorganisms as they are rich in microbial diversity, population, and activity.[54,55]

Conclusion

The current work clearly proved that coffee pulp can be very well used as substrate for vermicomposting using native and exotic earthworm species. The data from this study provides a sound basis that vermicomposting is a suitable technology for onfarm bioconversion of coffee pulp into value-added compost and reduction of solid waste pollution in coffee growing regions of India. Analysis of chemical and microbiological properties of vermicompost obtained from coffee pulp clearly indicates the enhancement in nutrient value and microbiological quality of compost and its utility as a good source for plant nutrients and soil fertility improvement in coffee farms.

Acknowledgements: Authors are thankful to Dr. Jayarama, Director, Central Coffee Research Institute, Chikmagalur, Karnataka for his encouragement and valuable suggestions during the study. Thanks are also due to Mr.Promod and Mr. Dilip Appachu, Coffee planters, Kodagu District, Karnataka to accept our request to conduct experiment in their plantation.

[1] H. R. Muralidhara, I. B. Biradar, G. K. Manonmani, K. Velmourougane, S. Bhat. Sudhakar, Enhancement of composting the cherry husk for value added organic manure production in coffee plantations. *Journal of Coffee Research* **2006**, *34*, 19–33.
[2] J. S. Nagaraja, D. R. Shanmukappa, K. Velmourougane, P. Panneerselvam, R. P. A. Alwar, Production of compost from coffee pulp. *Proceedings on recent advances in plantation crops research*, **2000**, pp 121–124.
[3] A. Marnyye, Velaozquez-Cedeñ, M. Gerardo, S. Jean-Michel, Waste-reducing cultivation of Pleurotus ostreatus and Pleurotus pulmonarius on coffee pulp: changes in the production of some lignocellulolytic enzymes. *World Journal of Microbiology and Biotechnology* **2002**, *18*, 201–207.
[4] P. Lavelle, T. Decaens, M. Aubert, S. Barot, M. Blouin, F. Bureau, P. Margerie, P. Mora, J. P. Rossi, Soil invertebrates and ecosystem services. *European Journal of Soil Biology* **2006**, *42*, 3–15.
[5] B. K. Senapati, In-soil earthworm technologies for tropical agro ecosystems. In: P. Lavelle,, L. Brussaard,, P. Hendrix, (Eds) *Earthworm Management in Tropical Agroecosystems*, CABI Publishing, New York, **1999**. pp 199–237.
[6] F. H. Orozco, J. Cegarra, L. M. Trujillo, A. Roig, Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: Effects on C and N contents and the availability of nutrients. *Biology and Fertility of Soils* **1996**, *22*, 162–166.
[7] C. Rolz, J. Menchu, F. Calzada, R. de Leon, R. Garcıa, Biotechnology in washed coffee processing. *Process Biochemistry* **1982**, *17*, 22.
[8] M. Adams, J. Dougan, Biological management of coffee processing wastes. *Tropical Science* **1981**, *23*, 177–197.
[9] C. Pulgarin, J. Schwitzguebel, R. Tabacchi, Comment blancher les residus du cafe noir? *Biofutur* **1991**, *102*, 43–50.
[10] P. Lavelle, A. Martin, Small-scale and large-scale effects of endogeic earthworms on soil organic matter dynamics in soils of the humic-tropics. *Soil Biology and Biochemistry* **1992**, *12*, 149–1498.
[11] A. Walkley, I. A. Black, Chromic acid titration for determination of soil organic matter. *Soil Science* **1934**, *63*, 251.
[12] R. Singh, K. Pradhan, Determination of nitrogen and protein by Khjeldahl method., In: *Forage Evaluation Science*, Pvt. Publishers Ltd, New Delhi **1981**. pp 23.
[13] R. H. Bray, L. K. Krutz, Determination of total organic and available forms of phosphorous in soil. *Soil Science* **1945**, *59*, 39–45.

[14] M. L. Jackson, *Soil Chemical Analysis*, Prentice Hall of India, Pvt. Ltd, New Delhi **1973**. 111–204 pp.
[15] O. N. Allen, *Experiments in soil bacteriology* (Ed., Burgess, Minneapolis, MN, USA **1959**. 117 pp.
[16] J. P. Martin, Use of acid rose Bengal and streptomycin in the plate method for estimating soil fungi. *Soil Science* **1950**, *69*, 215–232.
[17] R. I. Pikovskaya, Mobilization of phosphorus in soil in connection with vital activity of some soil microbial species. *Mikrobiologiya* **1948**, *17*, 362–370.
[18] J. H. Becking, Nitrogen fixing bacteria of the genus *Beijerinckia* in South African soils. *Plant Soil* **1959**, *11*, 193–206.
[19] E. O. King, M. N. Ward, D. E. Raney, Two simple media for the demonstration of pyocyanin and fluorescein. *Journal of Laboratory and Clinical Medicine* **1954**, *44*, 301–307.
[20] A. L. Page, R. H. Miller, D. R. Keeney, (Ed., *Methods of soil analysis-Part-2-chemical and microbiological properties*, American Society of Agronomy, Madison **1982**.
[21] K. A. Gomez, A. A. Gomez, *Statistical procedures for agricultural research* (Ed., Wiley and Sons, USA **1984**. 680 pp.
[22] E. Albanell, J. Plaixats, T. Cabrero, Chemical change during vermicomposting (*Eisenia foetida*) of sheep manure mixed with cotton industrial waste. *Biology and Fertility of Soils* **1988**, *6*, 266–269.
[23] P. L. S. Chan, D. A. Griffiths, Chemical composting of pretreated pig manure. *Biological Wastes* **1988**, *24*, 57–69.
[24] J. Haimi, V. Hutha, Capacity of various organic residues to support adequate earthworm biomass in vermicomposting. *Biology and Fertility of Soils* **1986**, *2*, 23–27.
[25] C. Elvira, L. Sampedro, E. Benitez, R. Nogales, Vermicomposting of sludges from paper mill and dairy industries with *Eisenia andrei*: A pilot scale study. *Bioresource Technology* **1998**, *63*, 205–211.
[26] A. Mitchell, Production of *Eisenia foetida* and vermicompost from feedlot cattle manure. *Soil Biology and Biochemistry* **1997**, *29*, 763–766.
[27] B. Gunadi, C. A. Edwards, The effect of multiple applications of different organic wastes on the growth, fecundity and survival of *Eisenia foetida* (Savigny) (Lumbricidae). *Pedobiologia* **2003**, *47*, 321–330.
[28] P. M. Nedgwa, S. A. Thompson, K. C. Das, Effects of stocking density and feeding rate on vermicomposting of Biosolids. *Bioresource Technology* **2000**, *71*, 5–12.
[29] C. A. Edwards, Breakdown of animal, vegetable, and industrial organic wastes by earthworms., In: C. A. Edwards,, E. Neuhauser, Eds., *Earthworm in waste and environmental management*, SPB, Academic Press, Netherlands **1988**. pp 21–31.
[30] C. A. Edwards, P. J. Bohlen, *Biology and Ecology of Earthworms*, Chapman and Hall, London, UK **1996**.
[31] P. M. Nedgwa, S. A. Thompson, Effects of C-to-N ratio on vermicomposting of biosolids. *Bioresource Technology* **2000**, *75*, 7–12.
[32] P. Kaushik, V. K. Garg, Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cowdung and agricultural residues. *Bioresource Technology* **2004**, *94*, 203–209.
[33] R. Hartenstein, F. Hartenstein, Physicochemical changes in activated sludge by the earthworm *Eisenia foetida*. *Journal of Environmental Quality* **1981**, *10*, 377–382.
[34] G. Tripathi, P. Bhardwaj, Comparative studies on biomass production life cycles and composting efficiency of *Eisenia foetida* (Savigny) and *Lampito mauritii* (Kinberg). *Bioresource Technology* **2004**, *92*, 275–283.
[35] M. Viel, D. Sayag, L. Andre, Optimization of agricultural, industrial waste management through in-vessel composting. In: M. de Bertoldi, (Ed) *Compost: Production, Quality and Use*, Elsevier Applied Science, Essex, pp **1987**. 230–237.
[36] R. M. Atiyeh, J. Dominguez, S. Subler, C. A. Edwards, Changes in biochemical properties of cow manure during processing by earthworms (*Eisenia andrei* Bouche) and the effects on seedling growth. *Pedobiologia* **2000**, *44*, 709–724.
[37] G. P. Mansell, J. K. Syers, P. E. H. Gregg, Plant availability of phosphorous in dead herbage ingested by surface-casting earthworms. *Soil Biology and Biochemistry* **1981**, *13*, 163–167.
[38] J. E. Satchell, K. Martein, Phosphate activity in earthworm faeces. *Soil Biology and Biochemistry* **1984**, *16*, 191–194.
[39] M. A. Buchanam, E. Rusell, S. D. Block, Chemical characterization and nitrogen mineralization potentials of vermicompost derived from differing organic wastes., In: C. A. Edwards,, E. F. Neuhauser, Eds., *Earthworms in Environmental and Waste Management*, SPB Academic Publishing, The Netherlands **1988**. pp 231–240.
[40] S. A. Ismail, Organic waste management., In: *Technology Appreciation Programme on Evaluation of Biotechnological Approaches to Waste Management*, held on 26th October 2000. Industrial Associationship of IIT, Madras **2000**. 28–30 pp.
[41] E. Aranda, I. Barois, Coffee pulp in vermicomposting treatment., In: T. Sera,, C. R. Soccol,, A. Pandey,, S. Roussos, Eds., *Coffee Biotechnology and Quality*, Kluwer Academic Publishers, Dordrecht **2000**. pp 489–506.
[42] R. Nogales, C. Cifuentes, E. Benitez, Vermicomposting of winery waste: a laboratory study. *Journal of Environmental Science and Health B* **2005**, *40*, 659–673.
[43] S. Suthar, Potential utilization of guargum industrial waste in vermicompost production. *Bioresource Technology* **2006**, *97*, 2474–2477.
[44] S. Suthar, Production of vermifertilizer from guar gum industrial wastes by using composting earth-

worm *Perionyx sansibaricus* (Perrier). *Environmentalist* **2007**, *27*, 329–335.

[45] E. Benitez, H. Saizn, R. Melayar, R. Nogales, Vermicomposting of a lignocellulosic waste from olive oil industry: A pilot scale study. *Waste Management Research* **2002**, *20*, 134–142.

[46] V. Kristufek, K. Ravasz, V. Pizl, Changes in densities of bacteria and microfungi during gut transit in *Lumbricus rubellus* and *Aporrectodea calignosa* (Oligochaeta: Lumbricidae). *Soil Biology and Biochemistry* **1992**, *24*, 1499–1500.

[47] C. A. Edwards, I. Burrows, The potential of earthworm compost as plant growth media., In: C. A. Edwards,, E. Neuhauser, Eds., *Earthworm in waste and environmental management*, SPB, Academic Press, Netherlands **1998**. pp 21–32.

[48] J. C. Pedersen, N. B. Hendriksen, Effect of passage through the intestinal tract of detrivore earthworms (*Lumbricus* spp.) on the number of selected gram-negative and total bacteria. *Biology and Fertility of Soils* **1993**, *16*, 227–232.

[49] R. D. Kale, K. Bano, M. N. Sreenivasa, D. J. Bhagyaraj, Influence of worm cast (Vee Comp. E. UAS, 1983) on the growth and mycorrhizal colonization of two ornamental plants. *South Indian Horticulture* **1987**, *35*, 433–437.

[50] U. S. Bhawalkar, U. V. Bhawalkar, Vermiculture biotechnology., In: P. K. Thampan, (Ed., *Organics in Soil Health and Crop Production*, Peekay Tree Crops Development Foundation, Cochin **1993**. pp 65–85.

[51] J. K. Syers, J. A. Springett, Earthworm and soil fertility. *Plant and Soil* **1984**, *76*, 93–104.

[52] M. Gopal, A. Gupta, E. Sunil, G. V. Thomas, Amplification of plant beneficial microbial communities during conversion of coconut leaf substrate to vermicompost by *Eudrilus* sp. *Current Microbiology* **2009**, *59*, 15–20.

[53] H. I. Chaoui, L. M. Zibilske, T. Ohno, Effects of earthworm casts and compost on soil microbial activity and plant nutrient availability. *Soil Biology and Biochemistry* **2003**, *35*, 295–302.

[54] R. D. Kale, B. C. Mallesh, K. Bano, D. J. Bagyaraj, Influence of vermicompost application on the available macronutrients and selected microbial population in a paddy field. *Soil Biology and Biochemistry* **1992**, *24*, 1317–1320.

[55] S. Subler, C. A. Edwards, J. Metzger, Comparing vermicomposts and composts. *Biocycle* **1998**, *39*, 63–66.