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Organic manure production from cow dung and biogas plant slurry by vermicomposting under field conditions

Anoop Yadav[1*], Renuka Gupta[2] and Vinod Kumar Garg[1]

Abstract

Background: Vermicomposting is a biological process which may be a future technology for the management of animal excreta. This study was undertaken to produce vermicompost from cow dung and biogas plant slurry under field conditions. To achieve the objectives, two vermicomposting units containing cow dung (CD) and biogas plant slurry (BPS) were established, inoculated with *Eisenia fetida* species of earthworm and allowed to be vermicomposted for 3 months.

Results: After 3 months, the vermicompost was harvested and characterized. The results showed that the vermicompost had lower pH, total organic carbon (TOC), organic matter (OM) and carbon/nitrogen ratio (C/N ratio) but higher electrical conductivity (EC), nitrogen, phosphorous and potassium (NPK) content than the raw substrate. The heavy metal content in vermicomposts was higher than raw substrates.

Conclusions: During vermicomposting, the CD and BPS were converted into a homogeneous, odourless and stabilized humus-like material. This experiment demonstrates that vermicomposting is an environmentally sustainable method for the management of animal excreta.

Keywords: Cattle dung; Vermicompost; *Eisenia fetida*; Heavy metals; C/N ratio

Introduction

Vermicomposting is as a bio-oxidative process in which earthworms interact intensively with microorganisms and other fauna within the decomposer community, accelerating the stabilization of organic matter and modifying its physical and biochemical properties. The action of the earthworms in this process is physical or mechanical. Physical participation in degrading organic substrates results in fragmentation, thereby increasing the surface area of action, turnover and aeration. On the other hand, biochemical changes in the degradation of organic matter are carried out by microorganisms through enzymatic digestion, enrichment by nitrogen excrement and transport of inorganic and organic materials. The benefits of vermicomposting in recycling of organic wastes, *viz.* animal wastes (Edwards et al. 1998; Aira et al. 2002; Loh et al. 2005; Molina et al. 2013), crop residues (Bansal and Kapoor 2000), industrial wastes (Elvira et al. 1998; Kaushik and Garg 2003; Yadav and Garg 2010; Garg et al. 2012), etc., have been reported at laboratory scale, and very little attention has been given to undertake such studies in field conditions to know the success of the method.

The selection of suitable earthworm species for vermicomposting is an important step of the overall process. Out of the thousands of species of earthworms, only a few are suitable for vermicomposting of organic wastes. The epigeic species of earthworms are widely used for vermicomposting of different organic wastes. *Eisenia fetida* is the most widely used earthworm species for vermicomposting due to its well-established potential for the vermicomposting of compostable organic materials such as agricultural wastes and animal manures (Edwards et al. 1998). Neuhauser et al. (1988) studied the overall reproductive capabilities of five earthworm species, *viz. Eudrilus eugeniae*, *Perionyx excavatus*, *E. fetida*, *Drawida veneta* and *Perionyx hawayana*, and suggested that *E. fetida* is the most appropriate species for the vermicomposting process.

* Correspondence: yadavanoop@rediffmail.com
[1]Department of Environmental Science and Engineering, Guru Jambheshwar University of Science and Technology, Hisar 125001, India
Full list of author information is available at the end of the article

Animal wastes are important resources that are used to supplement organic matters and improve soil conditions (Garg et al. 2005). Average-size cattle produces 4 to 6 tonnes of fresh dung per year. In India and some other developing nations, a significant fraction of cattle dung is used as cooking and heating fuel after making its bricks (Figure 1).

However, burning of dung cakes causes serious health and environmental problems. The burning of animal dung for heating and cooking results in higher indoor particle concentrations. Smoke from animal dung-based cooking stoves contains carbon monoxide, fine particulates, nitrogen dioxide and hydrocarbons, all at concentrations far in excess of what is considered unsafe in outdoor air. Long-term exposure to airborne particulate matter has been associated with increased rates of acute respiratory infections, chronic obstructive lung disease and cancer (USEPA 2008). On the other hand, once the dung is burnt, the nutrients present in it are lost forever.

Another important use of cattle dung is its conversion into compost to be used as manure in agricultural fields. For this purpose, cattle dung is heaped in the open and allowed to degrade naturally without any amendments. This process takes 6 to 9 months, and still dung is not stabilized which may attract termites in the fields after its application. Further, this method is a major cause of odour and fly problems in rural areas (Figure 2).

In the last few decades, the Government of India has promoted biogas production at individual and community levels using cattle dung and various other wastes. Biogas is used as cooking and heating fuel in rural areas in India. During this process, animal dung is converted into slurry which is good-quality manure and can be applied in agricultural fields as soil conditioner (Figure 3). However, it was observed that farmers are reluctant to apply it directly to agricultural fields. So some new method for pollution-free management of cattle dung and biogas plant slurry is desired.

Figure 1 Cattle dung bricks prepared for cooking and heating fuel.

Figure 2 Natural composting of animal dung in rural areas.

A bibliographic survey has indicated that vermicomposting can be an efficient technology for the management of CD and BPS. Various studies conducted on vermicomposting of animal excreta are encapsulated in Table 1. The available data indicate that most of the studies have been taken up at laboratory scale. There is paucity of data on the applicability of vermicomposting technology for the vermiconversion of animal wastes under natural environmental conditions. So this work was undertaken to study the vermicomposting of cattle dung and biogas plant slurry under field conditions.

Methods

Waste collection and earthworms (*E. fetida*)

Fresh cow dung (CD) was procured from an intensively live-stocked farm at Hisar, India. Anaerobically digested biogas plant slurry (BPS) was procured from a post-methanation storage tank of an on-farm biogas plant.

Figure 3 Biogas plant slurry disposed in the open.

Table 1 Various studies conducted on vermicomposting of animal excreta/waste

Animal waste	Earthworm	Scale	Reference
Cow dung	*Perionyx ceylanensis*	Laboratory	Karmegam and Daniel (2009)
Cow, sheep, pig and chicken wastes	*Eudrilus eugeniae*	Laboratory	Coulibaly and Zoro Bi (2010)
Cattle manure	*Eisenia andrei*	Laboratory	Lazcano et al. (2008)
Cattle manure	*Eisenia andrei*	Pilot	Elvira et al. (1998)
Cow manure	*Eisenia fetida*	Laboratory	Contreras-Ramos et al. (2005)
Cattle solids, pig solids, horse solids and turkey waste	*Perionyx excavatus*	Laboratory	Edwards et al. (1998)
Cow manure and poultry droppings	*Metaphire posthuma*	Laboratory	Bisht et al. (2007)
Cow, buffalo, horse, donkey, sheep, goat and camel wastes	*Eisenia fetida*	Laboratory	Garg et al. (2005)
Cow manure	*Eisenia fetida*	Industrial	Aira et al. (2011)
Pig manure	*Eisenia fetida*	Laboratory	Aira et al. (2007)
Rabbit manure	*Eisenia fetida*	Laboratory	Molina et al. (2013)
Rabbit manure	*Eisenia fetida*	Industrial	Gómez-Brandón et al. (2013)
Goat manure	*Eisenia fetida*	Laboratory	Loh et al. (2005)

The raw material used in the biogas plant was cow dung. The average nitrogen, phosphorous and potassium (NPK) content and other important parameters of cow dung and biogas plant slurry compiled from other studies are given in Table 2.

E. fetida earthworm species was used in the experiment. Healthy unclitellated hatchlings weighing 200 to 250 mg live weight were randomly picked up for the experiment from other vermicomposting beds maintained under field conditions.

Table 2 Average range of nutrient content of CD and BPS

Serial number	Parameters	CD	BPS
1	pH	7.5 to 8.3	7.2 to 8.1
2	EC (dS/m)	1.2 to 2.2	1.0 to 1.4
3	TOC (g/kg)	425 to 550	400 to 470
4	TKN (g/kg)	6.5 to 8.6	5.2 to 10
5	TAP (g/kg)	5.0 to 8.7	5.0 to 5.8
6	TK (g/kg)	2.8 to 7.8	1.3 to 4.2
7	TNa (g/kg)	1.38 to 5.8	1.9 to 2.8
8	TCa (g/kg)	1.87 to 2.0	1.2 to 3.0
9	Fe (mg/kg)	1,134 to 1,884	900 to 1,200
10	Cu (mg/kg)	31 to 234	20 to 50
11	Zn (mg/kg)	110 to 143	20 to 75
12	Cd (mg/kg)	2.10 to 4.5	1.0 to 10

Experimental setup

Ten kilograms of each waste (CD or BPS) was filled in circular plastic containers of 45-cm diameter and 25-cm depth without any bedding. All vermicomposting units were established in triplicate. After 3 weeks of pre-composting, 250 unclitellated *E. fetida* hatchlings were introduced in each vermicomposting unit. All the vermicomposting units were maintained at a farmer's field without any temperature control in a thatched house. The moisture content was maintained at 70% ± 10% by periodic sprinkling of canal water throughout the study period. The ambient temperature during the study period is given in Figure 4.

Chemical analysis

Homogenized samples of CD and BPS were drawn at day 0 (initial) and day 90 (at the end). Day 0 refers to the day of inoculation of earthworms after pre-composting for 3 weeks. The raw wastes and vermicomposts were air-dried at room temperature prior to physico-chemical and heavy metal analysis. The pH and electrical conductivity (EC) were determined using a water suspension of the raw waste or vermicompost in the ratio of 1:10 (*w*/*v*) after agitating for 30 min using pH and electrical conductivity meters, respectively. Total organic carbon (TOC) was determined as reported by Nelson and Sommers (1982). Total Kjeldahl nitrogen (TKN) was determined after digesting the sample with concentrated H_2SO_4 and $HClO_4$ (9:1, *v*/*v*) according to the Bremner and Mulvaney (1982) procedure. Total available phosphorus (TAP) was determined spectrophotometrically with molybdenum in sulphuric acid. Total potassium (TK) and total calcium (TCa) were determined after digesting the sample in a diacid mixture of concentrated HNO_3 and concentrated $HClO_4$ (9:1, *v*/*v*) using a flame photometer. Heavy metals (Fe, Cu, Zn and Cr) were determined using an atomic absorption spectrophotometer (AAS) after digestion of the sample with a diacid mixture of concentrated HNO_3 and concentrated $HClO_4$ (9:1, *v*/*v*). The carbon/nitrogen ratio (C/N) ratio was calculated from the measured value of TOC and TKN. The reported results are the mean of three replicates with standard deviation (mean ± SD). The probability levels used for statistical significance were $P < 0.05$ for the tests. Statistical analysis of the data was carried out with the SPSS 16.0 software program.

Results and discussion

Physico-chemical characteristics of vermicomposts

The physico-chemical characteristics of the raw materials and vermicomposts are presented in Table 3. The results showed that the pH values of vermicomposts

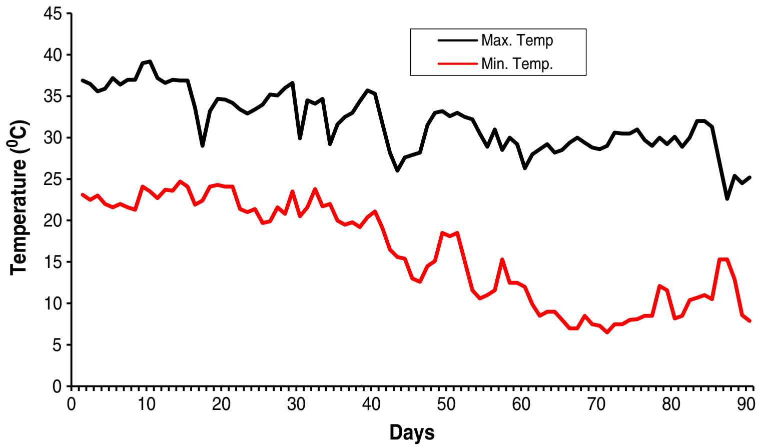

Figure 4 Minimum and maximum ambient air temperature at the experimental site during the study period.

were lower than those of their respective raw materials, i.e. CD and BPS (Table 3). Decreases in pH were significantly different after vermicomposting in both mixtures ($P < 0.05$). The pH reduction may be attributed to mineralization of nitrogen and phosphorus into nitrites/nitrates and orthophosphates and bioconversion of the organic material into intermediate species of organic acids (Ndegwa et al. 2000).

The EC of CD-vermicompost was 33.3% higher than that of CD, and that of BPS-vermicompost was 21.4% higher than that of BPS. The increase in EC is an indication of mineralization of wastes (Neuhauser et al. 1988). The differences in EC in the end products were insignificant ($P < 0.05$). Calcium (Ca) content in the vermicomposts was higher than that in CD and BPS. Maximum increment was observed in CD-vermicompost (3.10 g/kg) and minimum increment in BPS-vermicompost (2.45 g/kg) (Table 3). Spiers et al. (1986) have reported that earthworms convert calcium oxalate crystals in ingested fungal hyphae to calcium bicarbonate which is then egested in cast material, which increases calcium availability in the final vermicompost. Garg and Kaushik (2005) have also reported an increase in calcium content during the vermicomposting of industrial wastes. The earthworms drive the mineralization process and convert a fraction of calcium from binding form to free forms, resulting in its enrichment in worm casts.

Table 3 Changes in physico-chemical characteristics of CD, BPS and their vermicomposts (mean ± SD, n = 3)

Treatments	Parameters			
	pH	EC (dS/m)	TCa (g/kg)	TK (g/kg)
CD	7.9 ± 0.40 b	1.2 ± 0.10 a	2.0 ± 0.12 b	8.8 ± 0.20 b
CD-vermicompost	6.7 ± 0.10 a	1.6 ± 0.35 a	3.10 ± 0.15 d	9.7 ± 0.20 d
BPS	7.8 ± 0.35 b	1.4 ± 0.10 a	1.4 ± 0.10 a	4.2 ± 0.10 a
BPS-vermicompost	7.3 ± 0.20 ab	1.7 ± 0.12 a	2.45 ± 0.18 c	6.3 ± 0.24 c

Different letters in each column represent significant differences, and the same letters do not represent significant differences ($P < 0.05$).

The TK content was higher in vermicomposts than in raw wastes (Table 3). The initial TK content in CD and BPS was 4.2 and 8.8 g/kg, respectively, whereas the TK content in the BPS-vermicompost and CD-vermicompost was 6.30 ± 0.24 and 9.70 ± 0.20 g/kg, respectively. The differences in TK content in the end products obtained from different waste mixtures were significant ($P < 0.05$). Suthar (2007) has reported that an earthworm-processed waste material contains a higher concentration of exchangeable K due to enhanced microbial activity during the vermicomposting process, which consequently enhances the rate of mineralization. The production of acid during decomposition of organic matter by the microorganisms is the key mechanism for solubilization of insoluble TK (Adi and Noor 2009).

After vermicomposting, the TP content was 10.2 ± 0.40 and 7.0 ± 0.20 g/kg in CD-vermicompost and BPS-vermicompost, respectively (Table 4). The TP contents in both vermicomposts were significantly different from each other ($P < 0.05$). Le Bayon and Binet (2006) have reported that some amount of phosphorus is converted to more available forms partly by earthworm gut enzymes, i.e. acid phosphatases and alkaline phosphatases. Sangwan et al. (2010) have reported a 1.3- to 1.5-fold increase in phosphorus content after vermicomposting of press mud.

The TOC content of the vermicomposts was lesser than initial levels. The reduction in TOC content in vermicomposts was 35.6% and 22.7% in CD-vermicompost and BPS-vermicompost, respectively (Table 4). Aira et al. (2007) reported that earthworms modified substrate conditions, which subsequently enhanced carbon losses from the substrates through microbial respiration in the form of CO_2. Nitrogen content was higher in vermicomposts than in CD and BPS. The TKN content of BPS and CD was in the range of 6.2 and 8.5 g/kg (Table 4). The TKN

Table 4 Biochemical characteristics of CD, BPS and their vermicomposts (mean ± SD, *n* = 3)

Treatments	Parameters			
	TP (g/kg)	TOC (g/kg)	TKN (g/kg)	C/N ratio
CD	5.0 ± 0.30 a	427 ± 12 c	8.5 ± 0.33 a	50.24 ± 0.34 c
CD-vermicompost	10.2 ± 0.20 c	275 ± 16 a	28.7 ± 1.10 b	9.58 ± 0.15 a
BPS	5.6 ± 0.42 a	471 ± 33 c	6.2 ± 0.25 a	75.97 ± 1.70 d
BPS-vermicompost	7.0 ± 0.40 b	364 ± 14 b	29.9 ± 2.10 b	12.34 ± 0.50 b

Different letters in each column represent significant differences, and the same letters do not represent significant differences ($P < 0.05$).

content increased in the range of 28.7 to 29.9 g/kg after vermicomposting. There was a 3.37- and 4.82-fold increase in TKN after vermicomposting CD and BPS, respectively. The TKN contents in CD-vermicompost and BPS-vermicompost were not significantly different from each other ($P < 0.05$). Kaushik and Garg (2004) have reported a 2.0- to 3.2-fold increase in TKN during vermicomposting of textile mill sludge mixed with cow dung and wheat straw. Benitez et al. (1999) have reported that decomposition of organic materials by earthworm accelerates the N mineralization process and subsequently changes the N profile of the substrate.

The initial C/N ratio was in the range of 50.2 and 75.9 (at day 0) of CD and BPS, respectively, but after 90 days, there was a significant decrease in the C/N ratios (Table 4). The final C/N ratio of CD-vermicompost and BPS-vermicompost was 9.58 ± 0.3 and 12.2 ± 0.7, respectively. The reduction in C/N ratio was 80.9% to 83.9% during the vermicomposting process. The C/N ratio indicates the degree of stabilization of a waste as carbon is lost as CO_2 and nitrogen content is increased during the vermicomposting process, and these factors contribute to the lowering of the C/N ratio. The decrease in C/N ratio and relative increase in the TKN of vermicomposts may also be due to the loss of dry mass in terms of CO_2 (Viel et al. 1987). So a high degree of organic matter stabilization in CD and BPS was achieved after vermicomposting which proves that *E. fetida* can promote decomposition and mineralization of organic matter.

Heavy metals in vermicomposts

All vermicomposts contain trace elements and other metals which play an important role in their production, worm growth and application in agricultural fields. The potential risk of heavy metals is their transfer from the soil to food grains after vermicompost application in agricultural fields. However, the bioavailability of heavy metals to crops is influenced by several factors including the nature of heavy metals, soil properties (soil type, pH, cation exchange capacity (CEC), nutrient status, organic matter content, redox potential, texture and characteristics of the deposition/composition), plant species, agronomic conditions, etc. Heavy metal contents in raw wastes and final vermicomposts are given in Table 5. While comparing the metal concentration of the vermicomposts with initial levels, it was observed that the concentration of all the studied metals was higher in vermicomposts than initial raw materials. However, the metal concentrations in vermicomposts obtained from both raw materials (CD and BPS) were lesser than the prescribed limits for heavy metal application in agricultural soils. Total iron (Fe) content of vermicomposts was 2.3% and 3.2% higher in CD-vermicompost and BPS-vermicompost, respectively. Total copper (Cu) content was also higher after vermicomposting (14.1% to 76%). Cu content was more in BPS-vermicompost. Total zinc (Zn) content was 5.4% and 46.7% higher in CD-vermicompost and BPS-vermicompost than in CD and BPS, respectively. Chromium content was also higher in vermicomposts than in raw materials; it was 98 ± 6.8 mg/kg in CD-vermicompost and 133 ± 8.5 mg/kg in BPS-vermicompost (Table 5). The results indicate that metal content in the vermicomposted material was closely related to the metal concentration in raw materials. Gupta and Garg (2008) have reported an increase in heavy metal concentration in vermicomposts of sewage sludge after vermicomposting. Suthar and Singh (2008) have also reported a higher concentration of metals in earthworm casts collected from sewage soils and cultivated lands. The weight and volume reduction due to

Table 5 Heavy metal (mg/kg) content in CD, BPS and their vermicomposts (mean ± SD, *n* = 3)

Parameters	CD	CD-vermicompost	BPS	BPS-vermicompost	EU limit range[a]
Fe (mg/kg)	1,859 ± 19	1,902 ± 48	1,077 ± 21	1,112 ± 64	-
Cu (mg/kg)	234 ± 15	267 ± 30	22.5 ± 3	39.6 ± 5	70 to 600
Zn (mg/kg)	110 ± 9	116 ± 3.4	31 ± 2.4	45.5 ± 5.1	210 to 4,000
Cr (mg/kg)	84 ± 3.8	98 ± 6.8	127 ± 8.2	133 ± 8.5	70 to 200

[a]Source: Brinton (2000).

mineralization and decomposition of organic matter during vermicomposting may be the major factor for increase in metal concentrations in vermicomposts (Domínguez 2004).

Conclusions

The results indicate that CD and BPS can be used as a raw material in vermicomposting. The vermicomposts were rich in NPK and their C/N ratio was below 15 which indicate their agronomic importance as soil conditioner and manure. The quality of raw materials determined the physico-chemical characteristics of vermicomposts. The results suggest that vermicompost can be introduced as one of the technologies for converting organic wastes into value-added products.

Abbreviations

BPS: Biogas plant slurry; C/N: Carbon nitrogen ratio; CD: Cow dung; EC: Electrical conductivity; NPK: Nitrogen, phosphorous and potassium; OM: Organic matter; TCa: Total calcium; TK: Total potassium; TKN: Total Kjeldahl nitrogen; TOC: Total organic carbon; TP: Total phosphorus.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

AY carried out the experimentation and physico-chemical analysis and drafts the manuscript. RG performed the statistical and physico-chemical analysis. VKG carried out planned this study, supervision on the data analysis and revised the manuscript. All authors read and approved the final manuscript.

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Author details

[1]Department of Environmental Science and Engineering, Guru Jambheshwar University of Science and Technology, Hisar 125001, India. [2]Department of Humanities and Applied Science, YMCA University of Science & Technology, Faridabad - 121006 (Haryana), India.

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