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Polynomial Trend in Short-Term Surface CO_2 Emissions during Vermicomposting of Paint Sludges with Various Organic Substrates

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ABSTRACT

Two types of sludge generated from effluent treatment plants of two different paint industries and customarily disposed in landfills were used for vermicomposting in conjunction with organic substrates like cow dung, camel dung, poultry dropping and de-oiled Karanja cake, among which poultry dropping was found to be unsuitable for earthworms and hence not used. The selected wastes were used in various ratios (1: 1: 1, 1: 1: 2, 1: 1: 4 or 1: 1: 1: 0.2) for vermicomposting for a month and half with *Eisenia fetida* Savigny after a pre-composting period of 10 days for initial breakdown of waste mixtures. Flux of CO_2 (mg m^{-2} d^{-1}) from surface of vermibeds during vermicomposting was monitored for just more than three weeks and was found to be moderately variable temporally (coefficient of variation, CV = 17-34%) with peaks appearing towards the end of two weeks, a period of maximum respiratory activity of the microorganisms and earthworms in the waste mixtures. Average daily CO_2 flux from all the treatments followed a perfect 4th degree polynomial trend. Carbon lost *via* total CO_2 emission from various treatments during the study period ranged from 0.6 to 0.9% of the total C added to these treatments.

Keywords: camel dung, carbon dioxide, cow dung, earthworm, Karanja, poultry dropping, respiration, temperature

Abbreviations: BPS, Beepee coating sludge; **CaD**, camel dung; **CD**, cow dung; **KC**, Karanja cake; **NPS**, Nerolac Paints sludge; **PD**, poultry dropping

INTRODUCTION

Vermicomposting is an excellent technology for the transformation of solid wastes to valuable products (Elvira *et al.* 1996). Earthworms fragment the substrates, increasing their surface area for further microbial action during the process of feeding (Chan and Griffiths 1988) and major plant nutrients like nitrogen, potassium, phosphorus etc. present in the substrates are converted through microbial action into more soluble forms that are much more available to plants than those in the parent substrate. The ability of earthworms to consume and break down a wide range of organic residues such as sewage sludge, animal wastes, crop residues and industrial refuse is well known (Bansal and Kapoor 2000; Gajalakshmi *et al.* 2002; Garg *et al.* 2006; Suthar 2007; Kaushik *et al*. 2008; Suthar 2008). Emissions of various greenhouse gases like CO_2, CH_4 and N_2O have been reported from vermicomposting (Hobson *et al.* 2005; Majumdar *et al.* 2006) as processes like respiration, fermentation, nitrification, denitrification etc. operate simultaneously in organic waste mixtures undergoing composting or vermicomposting. Various factors like C and N availability, water content, temperature, aeration, worm density etc. influence greenhouse gas emissions from vermicomposting of organic wastes (Frederickson and Howell 2003; Hobson *et al.* 2005). Earthworms are reported to influence CO_2 emissions from soil ecosystems (Speratti *et al.* 2007). CO_2, being the most abundant greenhouse gas in the atmosphere, is an important aspect to study and an anthropogenic practice like vermicomposting may have a C footprint and its own CO_2 emission signature.

Though several industrial wastes have been tested successfully for vermicomposting, monitoring of CO_2 emissions during vermicomposting is not done frequently. Moreover, paint industry sludges have rarely been tried or utilized for vermicomposting and CO_2 emission from its mixtures under vermicomposting is seldom reported. So, the present study was designed to estimate short-term CO_2 emission pattern during vermicomposting of a few paint sludges in conjunction with cow dung, camel dung, poultry droppings and de-oiled Karanja cake by using *Eisenia fetida* Savigny or red worm, which is the most common type of earthworm used for vermicomposting in India.

MATERIALS AND METHODS

Collection and characterization of solid wastes

Waste sludge samples from paint industries were collected from Beepee Coatings Pvt. Ltd., a subsidiary of Berger Paints India Ltd., based at Vitthal Udyognagar, Anand, Gujarat and Kansai Nerolac Paints Ltd., Vatva, Ahmedabad, Gujarat. The Beepee Coating Sludge (BPS) was collected as dried cakes from the sludge drying bed in the factory premises. The sludge is generated in the wastewater treatment plant during primary sedimentation after equalization, pH adjustment by lime and flocculation by alum. The sludge from primary sedimentation tank is sloughed off and stored in the sludge drying beds for solar drying. The dried sludge was crushed to smaller size fractions (<2 mm) and stored for final use. The sludge from Kansai Nerolac Paints Pvt. Ltd. i.e. Nerolac Paints Sludge (NPS) was also collected from sludge drying bed as dry cakes. The sludge is generated during primary and secondary sedimentation processes, sloughed off subsequently and stored in sludge drying beds for solar drying. This dried sludge also was crushed to smaller size fractions (<2 mm).

Dry cow dung (CD) cakes of approx. 4-5 inch diameter (approx. 4% moisture, w/w) were collected from a cattle shed where they were kept outside in the open for subsequent use as a fuel in

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Table 1 Characteristics of sludge and organic products used for vermicomposting.

Parameters	NPS	BPS	CD	CaD	KC	PD
pH	4.69	8.16	8.12	8.56	5.36	7.60
Conductivity (mmho cm^{-1})	3.24	2.35	1.05	1.3	1.70	4.20
Organic carbon (%)	26.1	15.3	33	31.5	78	76.5
Mineralizable N (g kg^{-1})	7.7	3.1	3.6	3.6	7.3	14.7
Available P (g kg^{-1})	9.7	1.1	5.9	1.6	2.9	5.1
K (g kg^{-1})	3.1	0.8	7.3	3.5	6.5	7.0
Ca (g kg^{-1})	30.0	29.0	70.2	48.4	6.0	140.0
Mg (g kg^{-1})	10.2	20.1	20.20	22.7	2.0	20.0
Na (g kg^{-1})	1.2	0.5	16.3	12.3	17.9	1.2
Cl$^-$ (g kg^{-1})	1.3	0.7	1.4	2.0	6.5	9.9
Fe (mg kg^{-1})	170	-	484	420	324	160
Cu (mg kg^{-1})	30.9	22.0	17.9	15.3	21.5	59.8
Zn (mg kg^{-1})	162.4	118.2	98.1	52.9	46.9	101.5
Mn (mg kg^{-1})	82.6	137.0	114.5	111.1	29.5	411.4
Pb (mg kg^{-1})	66.7	1208.4	BDL[a]	BDL	BDL	BDL
Ni (mg kg^{-1})	15.4	15.9	5.5	10.2	13.2	12.4
Cd (mg kg^{-1})	BDL[a]	BDL	BDL	BDL	BDL	BDL
Particle density (g cc^{-1})	1.20	1.90	0.94	1.17	1.19	1.77
Max. Water Holding Capacity (%)	146	95	348	287	189	122
Volume expansion on saturation (%)	78	35	34	27	99	78

[a] BDL = below detection limit, for Pb - 0.0420 mg L^{-1} and Cd - 0.0027 mg L^{-1}

Indian villages. The dung was more than a month old. The dung was crushed into small size fragments for addition during vermicomposting. Camel dung (CaD) was collected from a small hamlet of nomads camping in the outskirts of Anand town in Gujarat, India, who rear camels for milk and transportation. The dry dung was collected in its original shape and size i.e. small oblong round pieces with approx. 6% (w/w) moisture content and was crushed to small fragments for use. Poultry dropping (PD), mixed with urine was collected from a poultry farm near Anand town in semi-dry form (13% w/w moisture) with traces of feathers and wheat grains, which were carefully sorted out and dropping was made ready for use. Karanja (*Pongamia glabra* Vent) cake (KC) was collected from a local trader after oil extraction by a filter press. The cake having 5.7 (w/w) and 15.3% (v/w) oil, 41.3% crude protein, 7.1 crude fibre, 7.6% ash, 3.7% N, 0.8% P and 1.8% K was crushed (<2 mm) for use. Sludge and organic substrates were analyzed for different physicochemical parameters viz. physical properties (Mishra and Ahmed 1987); metals (USEPA 1992); chloride (Trivedy and Goel 1986); pH, EC, organic C, available P and K (Singh *et al.* 1999); mineralizable N (Subbiah and Asija 1956). The physicochemical properties of the solid wastes are presented in **Table 1**.

Collection and maintenance of earthworms

Eisenia fetida Savigny, also known as red or manure worm, was chosen for the study which is locally available and considered as one of the best worms for vermicomposting. The worm population was collected from a manure bed containing mixture of cow dung, dry leaves, straw and other crop residues in a farm run by a vermicompost producer operating in Anand town who rears this species of earthworm only. The species was further identified and confirmed in the Department of Zoology, Sardar Patel University in Vallabh Vidyanagar. The worms were brought to laboratory along with bed material and stored in a cool shaded place in earthen pots. Rotten cow dung was added to each of these pots periodically as substrate. Mixture moisture was maintained at approximately 70 ± 5% (w/w).

Study of survival of earthworms in manure and waste mixtures

This was a small preliminary study carried out to examine the suitability of various organic substrates for vermicomposting. Cow dung, camel dung, poultry dropping, de-oiled cake and paint waste were mixed in different combinations into various mixtures of approx. 100 g, in ratios of 1: 1: 1, 1: 1: 2, 1: 1: 4 (CD: CaD: BPS/NPS) and 1: 1: 1: 1, 2: 1: 1: 1 and 3: 1: 1: 1 (CD: CaD: KC: BPS/NPS or CD: PD: KC: BPS/NPS or CaD: PD: KC: BPS/NPS) and were kept in small earthen pots of 500 ml capacity for 10 days for initial breakdown and removal of volatiles. The waste mixtures were watered to a moisture content of approx. 70 ± 5% (w/w) and this moisture content was roughly maintained throughout. Subsequently, 2-3 mature (0.8 ± 0.4 g and 4-6 cm long, each) earthworms were added to each mixture and their behaviour was noted.

Vermicomposting

After the demo experiment to examine the survival of earthworms in mixtures, actual vermicomposting was carried out with different ratios *viz.*, 1: 1: 1, 1: 1: 2, 1: 1: 4 (CD: CaD: BPS/NPS) and 1: 1: 1: 0.2 (CD: CaD: BPS: KC) comprising of cow dung, camel dung, paint sludges and de-oiled cake in a total of 1 kg material in each mixture taken in earthen pots with three replicates each. Poultry dropping was rejected as the earthworms immediately fled its mixtures indicating unfavourable condition. The mixtures were mixed thoroughly and moisture content was maintained at 70 ± 5% (w/w). These mixtures were kept for 10 days with frequent turnings for initial breakdown of organic substrates and removal of volatile substances.

Before addition of earthworms into the mixtures, gut voiding was done to measure exact biomass of the worms for addition to the mixtures. Mature clitelletted earthworms i.e. worms with fully developed clitellum, the glandular swelling on the epidermis which secretes a viscous fluid in which eggs are deposited, were spread inside flooded (approx. 2 mm depth) white transparent plastic bowls and kept for 15-18 h. The earthworms cleared their gut content during this period under constant vigil. A group of 10 earthworms, each group having a combined weight of 12 ± 0.8 g were added to each pot.

Feeding the worms with waste mixtures was continued for a month in the earthen pots at approximately 70 ± 5% (w/w) moisture. Moisture was added to each pot approximately once in every 3 days after determining moisture content of the waste mixtures by rapid moisture recording meter 'Moist Sure', manufactured by Transchem Agritech Ltd., Vadodara, Gujarat, India. Moisture content in the waste governs electrical conductivity of the waste which in turn is measured by the meter. The sensing tip of the meter was inserted up to a depth of 5 cm in the waste and the readings were noted. 'Moist Sure' only showed readings under dry, moist and wet ranges and whenever the meter indicated dryness, moisture was added until it reached the 'moist' mark.

Monitoring of temperature

Temperature changes in the waste mixtures were monitored daily by a thermocouple temperature recorder at a depth of 10 cm. Ambient temperature was also recorded from a wall mounted room thermometer at the same time to understand the build up of heat inside the waste piles.

Estimation of CO_2 flux from vermibeds

During vermicomposting, CO_2 flux (mg m^{-2} d^{-1}) from the waste mixtures was monitored periodically (on 4th, 9th, 14th, 19th and 23rd day) up to 23 days. The principle of a static chamber was employed for sampling of surface flux of CO_2 and a wet chemical method was followed for CO_2 sampling as described by Anderson (1982). This method is regarded as an accurate, versatile and the easiest method for estimating CO_2 evolution from soils *in situ* (Anderson 1982) and has been used in distant as well as recent past (Kowalenko *et al.* 1978; Redmann and Abouguendia 1978; Majumdar *et al.* 2006; Serna-Perez *et al.* 2006). So, this method was followed to correctly estimate *in situ* CO_2 emissions from surface of the waste undergoing vermicomposting. A plastic chamber was inserted 5 cm deep on the surface of the waste mixtures and loose waste was packed tightly around the inserted chamber making it fully leak proof. A glass container containing 15 ml of 1 N NaOH was kept on a small and short tripod stand inside the plastic chamber and emitted CO_2 was allowed to get absorbed in NaOH for 3 h, which was then titrated with 0.1 N HCL to estimate the amount of CO_2 absorbed. A blank, also in triplicate, was simultaneously maintained by inserting the plastic chamber into the waste mixture covered with a thin polythene sheet to prevent CO_2 entry from the waste. A similar glass beaker containing 15 ml of 1 N NaOH was kept for 3 h and only ambient CO_2 inside the chamber was allowed to get absorbed in NaOH (**Fig. 1**). Blank CO_2 content was subtracted from samples to get the actual emissions from samples. The following formula was used for estimating CO_2 emissions (Stotzky 1965):

$$CO_2\ (\text{mg m}^{-2}\,\text{h}^{-1}) = [(B-S) \times N \times E]/(T \times A)$$

where B = blank titre volume, S = sample titre volume, N = normality of HCl, E= Eq. wt. of CO_2 in mg, T = incubation time in h, A = area of waste surface in m^2.

From samples, CO_2 flux was calculated on the basis of CO_2 emitted per unit time (h) and covered waste surface area, which was then extrapolated for one square meter area and 24 hour (mg CO_2 m^{-2} d^{-1}).

A temperature correction was applied on CO_2 fluxes using the general rule that biological activity increases by a factor of 2 with each 10°C increase in temperature (Parkin *et al.* 1996). The following equation was used to standardize CO_2 fluxes to 25°C for waste temperature that were between 15 and 35°C (USDA 1999):

$$\text{Standardized } CO_2 \text{ flux rate} = \text{soil respiration rate} \times 2^{[(25-T)/10]}$$

Total CO_2 emission from each treatment during the 23-day study period was calculated by extrapolating the 3-hourly flux to 24 hourly emissions on the particular sampling day and then by successive interpolation of emissions in between the sampling days i.e. for 0-3rd, 5-8th, 10-13th, 15-18th and 20-22nd day, with an assumption that CO_2 flux followed a linear trend. Further, loss of total C via CO_2 in the study period was calculated from the estimated amount of organic C added to each treatment.

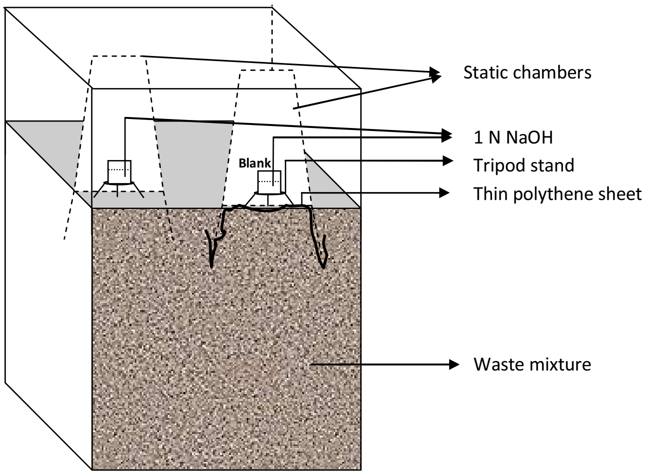

Fig. 1 Arrangement to trap CO_2 emissions from surface of solid waste mixtures undergoing vermicomposting.

Data analysis

The experiment was set up with seven treatments with a single factor completely randomized design with three replications (Gomez and Gomez 1984) used for analysis of variance (ANOVA). Single factor ANOVA was done by Microsoft Excel-2000, developed by Microsoft Corporation, USA while Duncan's Multiple Range Test (DMRT) was done by MSTAT (version 1.41), developed by Crop and Soil Science Division, Michigan State University, USA. All other descriptive statistical analyses were carried out by Microsoft Excel.

RESULTS AND DISCUSSION

Suitability of collected wastes for vermicomposting

Cow/camel dung and poultry droppings were alkaline while pH of the two sludges was alkaline and acidic and de-oiled cake was acidic. The electrical conductivity (EC) of all the raw materials was low to medium from 1.05 to 4.2 mmho cm^{-1} indicating that there was absence of high salt content in these materials. Water holding capacity ranged from 95 to 146% in sludges and 120 to 348% in dung droppings indicating that all these raw materials were capable of absorbing high amount of water during vermicomposting. Volume expansion on saturation of all these raw materials except camel dung was significant, ranging from 34 to 100% but camel dung showed almost no expansion, indicating that its bulking in waste mixtures after water addition could be minimal. Very significantly, all the raw materials had moderate to high organic carbon content ranging from 15.3 to 26.1% in sludges and 33 to 78% on dry wt. basis in the animal droppings. Concentration of major nutrients like N, P, K, Ca and Mg were appreciable in the raw materials making them nutritionally suitable for vermicomposting. Especially, Ca was very high in BPS as lime is used for pH adjustment in the water treatment facility. Micronutrients like Fe, Zn and Mn were also found in appreciable quantities in these wastes. Only in case of BPS, Fe was negligible. Except poultry manure, all other raw materials had supported the survival of earthworms for a week. Earthworms survived well and started to form vermicast in mixtures of cow dung, camel dung and sludge but were found dead within 1-2 h in mixtures of poultry droppings. The failure of earthworms to stay in poultry manure could be due to the reported prevalence of volatile organic carbons (VOCs) and ammonia (NH_3) gas generated from protein rich poultry excreta and urine. Based on this observation, poultry manure was withdrawn from vermicomposting trial.

CO_2 emissions from vermibed

There was conspicuous fluctuation in CO_2 flux from different treatments in this experiment. In some treatments, flux increased towards the end of the study while in some other they decreased towards the end. But, when average CO_2 flux from all the treatments was considered, it peaked in the middle of vermicomposting trial with the biological activity apparently at its peak and came down towards the end indicating diminishing biological activity indicated by lower respiration (**Fig. 2**). With time, substrate C depleted resulting in lower utilization of substrate and lower respiratory CO_2. Temporal trend of daily average CO_2 flux from all treatments could be perfectly fitted to a 4th degree polynomial equation with a perfect value of coefficient of determination (**Fig. 2**). The temporal variation in CO_2 flux was not very high (17-34%).

CO_2 is the most abundant greenhouse gas and thereby is implicated in the alteration of earth's heat budget and related disorders in weather and climate. CO_2 emission is taken as an index of biological activity of a system since it

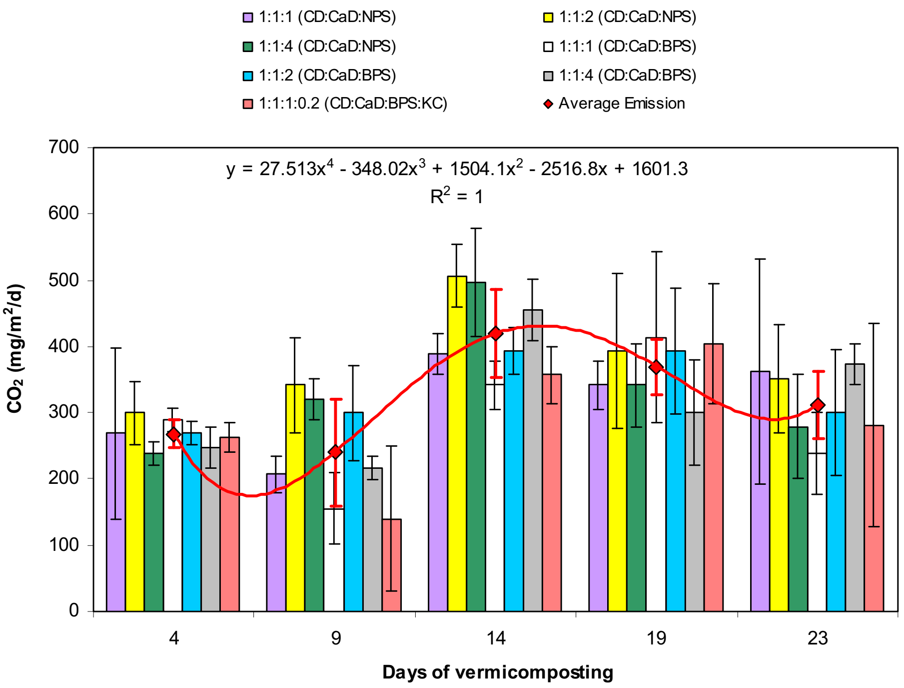

Fig. 2 CO_2 emissions (bar diagram with bars for mean ± SD of 3 replications) from various treatments and daily average CO_2 emissions (scatter diagram with bars for mean ± SD of 7 treatments), the latter fitted to a 4th degree polynomial equation.

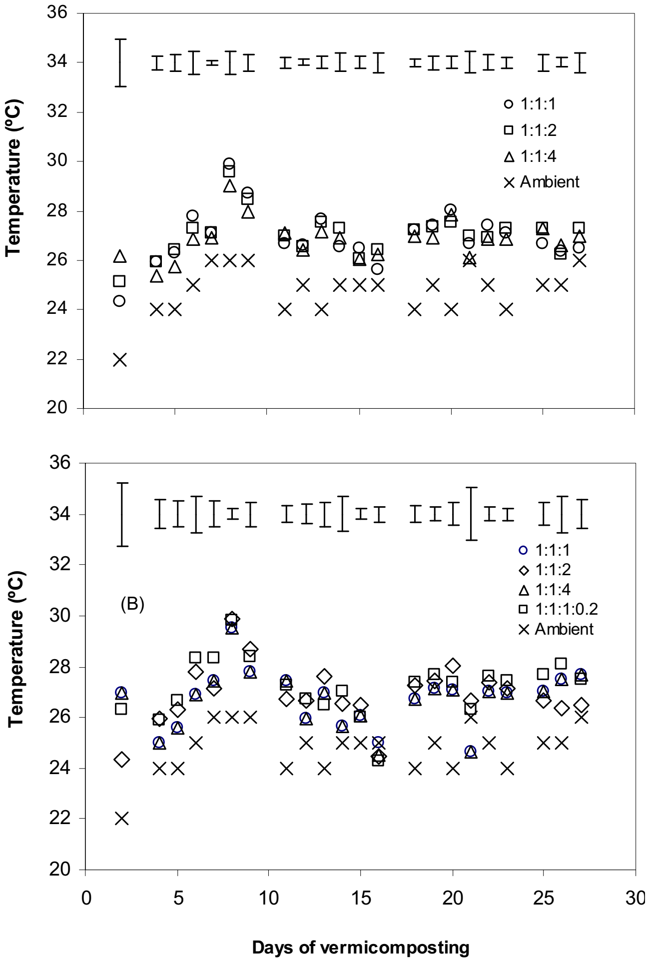

Fig. 3 Temporal variation in temperature of (a) NPS mixtures and (b) BPS mixtures and corresponding ambient temperature. Bars indicate mean ± SD of 3 and 4 treatments, respectively, for a and b, except ambient.

comes via respiration from micro and macro flora and fauna (Anderson 1982; Wilhelmi and Rothe 1990). CO_2 emission during composting and vermicomposting could be considered as an ecological footprint of these activities involving an anthropogenic signature since these are taken up under planned activities. The emissions from vermicomposting would involve CO_2 from microbial as well as earthworm respiration and could be expected to be quite higher than only composing with similar substrates *in toto* under similar circumstances.

Temperature in waste mixtures, recorded everyday during the experiment was tallied with corresponding room temperature to find out differences between ambient and waste pile temperature. Since the mixture depth was not high, heat was expected to have easily dissipated to atmosphere not allowing the heat to build up to high levels inside the waste pile. Though waste piles were small and were approximately 25 cm deep, its temperature at a depth of approximately 10 cm (23.7-29.9°C) was often more than ambient temperature (22.1-26.0°C) due to exothermic reactions during biodegradation of waste (**Fig. 3**). Earthworm respiration in these mixtures would be a combined effect of both mature and juveniles, later having a higher respiration rate. At constant temperature regimes, Q_{10} values for juvenile and mature earthworms were found to be 2.7 and 2.0, respectively, while at fluctuating temperature regimes, Q_{10} values were generally higher at 3.6 and 3.5 (Uvarov and Scheu 2004). CO_2 flux values at absolute waste pile temperature were converted to standardized flux rates at 25°C and the latter were found to deviate slightly to moderately from the former (**Table 2**).

F value generated by ANOVA to find out the difference among treatments in governing CO_2 flux was not significant, implying that difference in waste mixtures had no significant effect on CO_2 flux or that there was no treatment difference in influencing CO_2 flux. In another study conducted earlier, CO_2 emissions were always significantly higher than CH_4 emissions from pharmaceutical waste and organic residue treatments due to prevalence of aerobic condition during vermicomposting (Majumdar *et al.* 2006).

So, the total CO_2 emission during vermicomposting could be deemed as the carbon footprint of vermicomposting activity with an anthropogenic signature. Total CO_2 emission during the 23-day experimentation was variable and there was statistically significant difference between a few treatments e.g. CD+CaD+NPS (1: 1: 2) had significantly more CO_2 emission than CD: CaD: BPS (1: 1: 1) and CD: CaD: BPS: KC (1: 1: 1: 0.2). It may be reasonable to

Table 2 Standardized CO_2 flux (mg m^{-2} d^{-1}) during vermicomposting.

Treatments	4	9	14	19	23
1:1:1 (CD: CaD: NPS)	252.0 (6.3)[a]	160.0 (22.6)	348.1 (10.3)	288.2 (15.5)	312.1 (13.7)
1:1:2 (CD: CaD: NPS)	281.7 (6.0)	268.3 (21.4)	432.0 (14.7)	333.4 (15.1)	299.7 (14.7)
1:1:4 (CD: CaD: NPS)	231.3 (2.7)	260.3 (18.8)	434.0 (12.5)	298.4 (12.5)	245.8 (11.9)
1:1:1 (CD: CaD: BPS)	290.2 (-0.2)	128.0 (17.5)	325.8 (4.5)	356.7 (13.7)	208.0 (12.5)
1:1:2 (CD: CaD: BPS)	252.0 (6.3)	232.0 (22.6)	352.5 (10.3)	331.9 (15.5)	258.6 (13.7)
1:1:4 (CD: CaD: BPS)	248.7 (-0.2)	179.2 (17.5)	434.4 (4.5)	258.6 (13.7)	327.2 (12.5)
1:1:1:0.2 (CD: CaD: BPS: KC)	247.7 (6.0)	110.3 (21.0)	310.5 (12.9)	334.4 (17.1)	237.2 (15.6)

[a] Figures in parentheses are per cent reduction from absolute CO_2 flux

Table 3 Total CO_2 emission from different treatments during 23-day study period.

Treatments	Organic C added (g)	Total CO_2 emission [a] (mg/m^2)	CO_2-C loss (%)
CD: CaD: NPS (1: 1: 1)	301.9	7027 ± 237 ab	0.63
CD: CaD: NPS (1: 1: 2)	291.8	8185 ± 312 b	0.81
CD: CaD: NPS (1: 1: 4)	281.4	7744 ± 114 ab	0.75
CD: CaD: BPS (1: 1: 1)	265.9	6674 ± 144 a	0.68
CD: CaD: BPS (1: 1: 2)	237.8	7594 ± 198 ab	0.87
CD: CaD: BPS (1: 1: 4)	209.4	7134 ± 227 ab	0.93
CD: CaD: BPS: KC (1: 1: 1: 0.2)	305.1	6581 ± 308 a	0.59

[a] Letters followed by same letters are not significantly different from each other at 5% level of significance according to Duncan's Multiple Range Test (DMRT)

mention that CO_2 emissions from vermicomposting consisted of both microbial and earthworm respiration and carbon loss via CO_2-C emission per square meter amounted to 0.6-0.9% of the total organic C added to these treatments (**Table 3**).

Disposing paint sludge and the organic wastes used in this study would be a waste of resources as they could be used for vermicomposting or composting, but on the other hand, utilization of these wastes for rearing earthworms and vermicomposting might lead to more CO_2 loading to atmosphere due to the involvement of earthworm respiration as compared to their wanton dumping or even composting. The magnitude of this emission will be many folds lower than various anthropogenic activities like burning of fossil fuels for industrial production and in vehicles, domestic burning, etc. But, this emission could be higher than some other alternatives that an industrial sludge or an organic waste may be subjected to e.g. landfilling, briquetting etc. whereby they would undergo negligible microbial conversion or being composted or as manure in agricultural fields where they would go through a cycle of fluctuating microbial activities due to variation in soil thermal and moisture regimes. Speratti *et al.* (2007) have opined that earthworms, through their feeding, casting, and burrowing may lead to increased decomposition and respiration in aerobic microsites. To demonstrate whether earthworms increased CO_2 emissions or not, they reduced earthworm populations within field enclosures by repeated application of carbaryl insecticide and then introduced single and mixed populations of *Lumbricus terrestris* L. and *Aporrectodea caliginosa* Savigny in the same enclosures. Mean CO_2 fluxes tended to be greater from enclosures with added earthworms than where no earthworm was added, but fluxes were not significantly affected by earthworm treatment due to low survival rate of introduced earthworms (Speratti *et al.* 2007). In a microcosm experiment to assess the influence of inoculation with *Eisenia fetida* earthworms on CO_2 emissions from the soil, it was found that the highest total amount of CO_2-C evolved from the soil treated with composted residue and earthworms and about 40% of the total amount of CO_2 evolved came from earthworm activity (Caravaca *et al.* 2005). Further, addition of earthworms helped emit highest CO_2 from composting of a mixture of chicken manure and straw as compared to other additives like humokarbowit or biosan, both dietary additives for poultry, confirming that earthworm respiration could increase CO_2 emissions (Krawczyk *et al.* 2005). Moreover, appreciably aerating waste mixtures by burrowing, earthworms might actually help in more CO_2 emissions from composting mixtures as it has been found that increased manual aeration of composting mixtures led to more CO_2 emissions (Hao *et al.* 2001). These authors opined that periodic turning introduced fresh oxygen into windrow compost heap and also mixed well-composted material from surface to bottom and partially composted materials from bottom to surface making more material subjected to aerobic decomposition, thereby increasing the rate of the composting and CO_2 production.

Utilization of wasted paint industry sludge for manure production in conjunction with other organic substrates augers well for environment as it creates wealth from waste, minimizes the burden of waste disposal to a marginal extent, generates business potential with manure and worm production and propagates organic farming. Especially, in a country like India, where agriculture is the primary occupation of a large population and environmental awareness is growing, the practice of converting industrial waste to manure is welcome. The burden of CO_2 emissions may come with this practice, but that also holds true for a few alternative practices also e.g. composting and hence should not be taken as a deterrent.

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REFERENCES

Anderson JPE (1982) Soil respiration. In: Page AL, Miller RH, Keeney DR (Eds) *Methods of Soil Analysis. Part 2-Chemical and Microbiological Properties*, Madison, Wisconsin, American Society of Agronomy, Soil Science Society of America, Inc, pp 831-871

Bansal S, Kapoor KK (2000) Vermicomposting of crop residues and cattle dung with *Eisenia fetida*. *Bioresource Technology* **73**, 95-98

Caravaca F, Pera A, Masciandaro G, Ceccanti B, Roldán A (2005) A microcosm approach to assessing the effects of earthworm inoculation and oat cover cropping on CO_2 fluxes and biological properties in an amended semiarid soil. Chemosphere **59**, 1625-1631

Chan PLS, Griffiths DA (1988) The vermicomposting of pretreated pig manure. *Biological Wastes* **24**, 57-69

Elvira C, Goicoechea M, Sampedro L, Mato S, Nogales R (1996) Bioconversion of solid paper-pulp mill sludge earthworms. *Bioresource Technology* **57**, 173-177

Frederickson J, Howell G (2003) Large-scale vermicomposting: emission of nitrous oxide and effects of temperature on earthworm populations. *Pedobiologia* **47**, 724-730

Gajalakshmi S, Ramasamy EV, Abbasi SA (2002) High-rate composting vermicomposting of water hyacinth (*Eichhornia crassipes*, Mart. Solms). *Bioresource Technology* **83**, 235-239

Garg VK, Kaushik P, Dilbaghi N (2006) Vermiconversion of wastewater sludge from textile mill mixed with anaerobically digested biogas plant slurry employing *Eisenia foetida*. *Ecotoxicology and Environmental Safety* **65**, 412-419

Gomez KA, Gomez AA (1984) *Statistical Procedures for Agricultural Research*, International Rice Research Institute (IIRI), Wiley-Interscience, NY, USA, 625 pp

Hao X, Chang C, Larney FJ, Travis GR (2001) Greenhouse gas emissions during cattle feedlot manure composting. *Journal of Environmental Quality* **30**, 376-386

Hobson AM, Frederickson J, Dise NB (2005) CH_4 and N_2O from mechanically turned windrow and vermicomposting systems following in-vessel pretreatment. *Waste Management* **25**, 345-352

Krawczyk W, Herbut E, Walczak J, Muchacka R, Radecki P (2005) The environmental impact of composting manure. In: *International Society for Animal Hygiene* (ISAH-2005, Vol. 2), Warsaw, Poland. Available online: www.isah-soc.org/documents/2005/sections/65_vol_2.pdf

Kowalenko CG, Ivarson KC, Cameron DR (1978) Effect of moisture content, temperature and nitrogen fertilization on carbon dioxide evolution from field soils. *Soil Biology and Biochemistry* **10**, 417-423

Majumdar D, Patel J, Bhatt N, Desai P (2006) CH_4, CO_2 emissions and earthworm survival during composting of pharmaceutical sludge and spent mycelia. *Bioresource Technology* **97**, 648-658

Mishra RD, Ahmed M (1987) *Manual on Irrigation Agronomy*, Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India, 412 pp

Parkin TB, Doran JW, Franco Vizcaini E (1996) Field and Laboratory tests of soil respiration. In: Doran JW, Jones AJ (Eds) *Methods for Assessing Soil Quality*, Soil Science Society America Special Publication, 49, SSSA, Madison, WI, USA, pp 231-246

Kaushik P, Yadav YK, Dilbaghi N, Garg VK (2008) Enrichment of vermicomposts prepared from cow dung spiked solid textile mill sludge using nitrogen fixing and phosphate solubilizing bacteria. *The Environmentalist* **28**, 283-287

Redmann RE, Abouguendia ZM (1978) Partitioning of respiration from soil, litter and plants in a mixed grassland ecosystem. *Oecologia* **36**, 69-79

Serna-Perez A, Monger HC, Herrick JE, Murray L (2006) Carbon dioxide emissions from exhumed petrocalcic horizons. *Soil Science Society of America Journal* **70**, 795-805

Singh D, Chhonkar PK, Pandey RN (1999) *Soil Plant Water Analysis*, A methods manual, Indian Agricultural Research Institute (ICAR), New Delhi, India, 160 pp

Speratti AB, Whalen JK, Rochette P (2007) Earthworm influence on carbon dioxide and nitrous oxide fluxes from an unfertilized corn agroecosystem. *Biology and Fertility of Soils* **44**, 405-409

Stotzky G (1965) Microbial respiration. In: Black CA (Ed) *Methods of Soil Analysis*, American Society of Agronomy, Madison, WI, pp 1550-1570

Subbiah BV, Asija GL (1956) A rapid procedure for the determination of available nitrogen in soil. *Current Science* **25**, 159-160

Suthar S (2007) Production of vermifertilizer from guar gum industrial wastes by using composting earthworm *Perionyx sansibaricus* (Perrier). *Environmentalist* **27**, 329-335

Suthar S (2008) Metal remediation from partially composted distillery sludge using composting earthworm *Eisenia fetida*. *Journal of Environmental Monitoring* **10**, 1099-1106

Trivedy RK, Goel PK (1986) *Chemical and Biological Methods for Water Pollution Studies*, Environmental Publications, Karad, India, 215 pp

USDA (1999) *Soil Quality Test Kit Guide*, United States Department of Agriculture, Agricultural Research Service and Natural Resources Conservation Service-Soil Quality Institute, USA, pp 52-54

USEPA (1992) Inductively coupled plasma-atomic emission spectroscopy. In: *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods* (3rd Edn), SW-846

Uvarov AV, Scheu S (2004) Effects of temperature regime on the respiratory activity of developmental stages of *Lumbricus rubellus* (Lumbricidae). *Pedobiologia* **48**, 365-371

Wilhelmi V, Rothe GM (1990) The effect of acid rain, soil temperature and humidity on C-mineralization rates in organic soil layers under spruce. *Plant and Soil* **121**, 197-202