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Stability and Kinetic Analysis during Vermicomposting of Sewage Sludge

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***Abstract*—**The present study is aimed at alteration of sewage sludge into stable compost product using vermicomposting of sewage sludge mixed with cattle manure and saw dust in five different proportions based on C/N ratios (C/N 15 (R1), 20 (R2), 25 (R3) and 30 (R4); and control (R5)) by employing an epigeic earthworm *Eisenia fetida*. Higher reductions in C/N ratio, CO_2 evolution and OUR were observed in R4 demonstrated the compost stability. In addition, R4 proved to be best combination for the growth of the earthworms. In order to observe the optimal degradation, kinetics for degradation of organic matter in vermicomposting were quantitatively evaluated. An approach model was developed by assuming that composting process is carried out in a homogeneous way and the kinetics for decomposition reaction is represented by a Monod-type equation. The results exhibit comparable variations in the kinetic constants K_m and K_3 under varying parameters during vermicomposting process. Results suggested that higher R^2 value in R4, enhanced suitability towards Lineweaver-Burke plot. R4 yields higher degradability coefficient (K) reveals that the occurrence of optimal nutrient balance, which not only enhanced the affinity of enzymes towards substrate but also improved its degradation process. Therefore, it can be proved that R4 provided to be the best feed combination for vermicomposting process as compared to other reactors.

***Keywords*—**Vermicomposting, *Eisenia fetida*, Sewage sludge, C/N ratio, Stability, Enzyme kinetics concept.

I. Introduction

IN recent years, the problem in efficient disposal and management of sewage sludge has become more rigorous due to rapidly increasing of population, economic growth and increasing number of treatment plants. The major ways of disposing the sewage sludge are deposition; landfill and incineration, only part of the sludge are to be re-used in agricultural. Application of sewage sludge to agricultural land may be beneficial because it can improve the physical, chemical and biological properties of soils which may improve crop growth. Though, composting is a successful strategy for the sustainable recycling of organic wastes [1], [2]. During composting, organic wastes are transformed to a more stable and complex organic matter by the successive activities of different microbes, which can be helpful in agriculture purposes, made composting a promising alternative [3]. On the other hand, the disadvantages are the long duration of the process, regular aeration required and loss of nutrients (e.g. gassing off of nitrogen).

In this regard, vermicomposting has been reported to be a feasible, commercial and rapid process for the efficient management of the organic wastes [4]. During vermicomposting, earthworms eat, grind, and digest organic wastes with the help of aerobic and some anaerobic microflora, converting it into excreta known as casts. The generated product is stable and homogenous; may have reduced levels of contaminants [5]; and furthermore it refers as a valuable, marketable, and superior plant growth medium.

To achieve good quality compost, environmental factors such as temperature, aeration, moisture and nutrients should be appropriately controlled [6]. In addition, compost stability refers to the resistance of compost organic matter to further rapid degradation, which is related to microbial activity can be directly measured by respiration indices [7]-[9]. Unstable compost can show phytotoxic behavior and therefore affect crops. Hence, it is essential to prove the stability of compost to ensure about the technology and operational performance.

Now-a-days, respirometric techniques are well suited for compost stability measurement [10]-[12]. Respiration indices have measured both CO_2 evolution [13], [14] and oxygen uptake rate [15], [16]. These are the most accredited method for the evaluation of the biological activity of the compost material [17]-[19]. Respirometric techniques recommend accurate information on the activity of a compost sample. Until recently, limited studies have been made on compost stability using respirometric methods during vermicomposting of sewage sludge mixed with cattle manure and saw dust based on different C/N ratio. However, most published information on the composting process is qualitative; few studies on modeling of composting process have been published [20]-[23]. These complex processes require quantitative knowledge of kinetics for composting of materials. Though, kinetic studies of compost processes cannot reveal a complete scenario of the composting process, they may improve understanding of phenomena occurring in composting reactors.

Keeping in view the above facts, the present study performed a comparative analysis on vermicomposting of sewage sludge mixed with cattle manure and saw dust in four different proportions based on C/N ratios (i.e. 15; R1, 20; R2, 25; R3, and 30; R4) with blank reactor (R5). Control for each proportion was also analyzed (i.e. CR1, CR2, CR3, CR4 and CR5, respectively). This paper evaluated the feasibility of sewage sludge vermicompost using *Eisenia fetida* earthworm in terms of stability and kinetic analysis; to develop a model

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describing composting process based on Monod kinetics and to simulate the degradation in composting process.

II. Materials and Methods

A. Earthworm Culture

The required earthworm species (*E. fetida*) was brought from Central Plantation Crops Research Institute (CPCRI), Indian Council of Agricultural Research, Guwahati, India. *E. fetida* were cultured in hopper bottom Perspex bins (450mm x 300mm x 450mm), which fabricated in the laboratory. For aeration and drainage purpose 16 holes of 10mm diameter were drilled along the longer sides and 16 holes at the bottom respectively. Hopper was used to collect leachate (if any). Moderately degraded cattle manure was added for culturing the earthworms.

B. Compost Material

Sewage sludge, cattle manure, and saw dust were used for preparation of different waste mixtures. Sewage sludge was collected from the sewage treatment plant of the Indian Institute of Technology Guwahati campus. The treatment plant consists of aerated lagoon system with two units; one unit is acting in stand-by mode for maintenance purposes. Though, this treatment activity is considered to be secondary treatment. Therefore, the sludge procured from the treatment plant is called as secondary sludge. Fresh cattle manure was obtained from nearby Amingaon village. Saw dust were purchased from the nearby rice mill and saw mill, respectively. The compost material was prepared by mixing different proportions (i.e. C/N 15; R1, 20; R2, 25; R3 and 30; R4) with blank reactor (R5) of the collected waste as described in Table I. Control for each proportion was also analyzed (i.e. CR1, CR2, CR3, CR4 and CR5).

C. Experimental Setup

The experiments were conducted in triplicate, in locally made bamboo containers (reactor) of volume 90.47 x 10^4mm^3 (radius-120mm and depth-90mm). The containers were kept in the laboratory at room temperature. 10cm bedding was kept in all the containers using a mixture of hay (155g), cattle manure (375g), banana leaves and tree leaves (280g) respectively which were partially degraded for two weeks. Approximately, 120 earthworms (*E. fetida*), having both clitellated and juvenile, were inoculated in the bedding for acclimatization to the new environment then the substrate was added the next day. Control reactors were carried out in same manner for degradation the substrate without any worms.

1.5kg of three different proportions of sewage sludge, cattle manure and saw dust were added to each of the reactors and they are referred to as R1, R2, R3, R4, and R5 respectively. Control for each mixture was also kept (i.e. CR1, CR2, CR3, CR4, and CR5). The quantity of the substrate was decided based on the findings that the earthworms can consume the material half their body weight per day under favorable conditions [24]. The moisture level was maintained about 50-60% throughout the study periodically sprinkling of adequate quantity of tap (potable) water. However, the reactors were covered with gunny bags to prevent moisture loss.

D. Experimental Analysis

About 170g of homogenized wet samples (free from earthworms, hatchlings and cocoons) were taken out at 0, 15, 30, and 45 day of composting period and stored at 4^{o}C immediately for analysis. The 0 day refers to the sample taken out before earthworm inoculation. The samples were air dried immediately, ground to pass through 0.2mm sieve and stored for analysis of organic matter (OM) (ignition loss at 550°C for 2h), total organic carbon [25] and total nitrogen using Kjeldahl method [26]. The carbon-to-nitrogen (C/N) ratio was determined by dividing the total organic carbon content to the total nitrogen content. In addition earthworm biomass was also measured at the end of every 15th day of the experiment.

E. Stability Analysis

Compost stability was measured by respiration index method. Respiration indices have measured both CO_2 evolution and oxygen uptake rate (OUR). OUR was performed according to the method described by [12], [27]. A liquid suspension of compost (8g of compost in 500ml of distilled water added with $CaCl_2$, $MgSO_4$, $FeCl_3$ and phosphate buffer at pH 7.2) incubated at room temperature (24±2^{o}C) was placed in the sample bottle. A DO sensor was placed in the sample bottle at a depth of 5-7cm below the water surface. The suspension was continuously stirred by means of a magnetic stirrer. The O_2 concentration was measured continuously and this value quoted as the OUR in mg O_2/g OM/day.

CO_2 evolution rate was measured using static measurement method [12], [14]. Approximately, 10g of sample was sealed in a 0.5L vessel along with a beaker containing a known weight of oven dried soda lime (105^{o}C, 1.5–2.0 mesh) to trap CO_2. The samples were incubated at room temperature (24±2^{o}C). Blank measurement necessary for initial CO_2 calculation was determined without putting a sample in a vessel. The soda lime traps were removed after 24h, oven dried and reweighed to determine CO_2 absorbed.

F. Statistical and Kinetic Analysis

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 using Statistica software. In addition, kinetic analysis of the process was determined based on complexion of enzyme concentration with substrate concentration, resulting enzyme substrate complex. The kinetic constants K_m and K_3 can be graphically determined and correlates the initial rate of reaction and substrate concentration.

III. Results and Discussions

Table I shows the OM, C/N ratio, OUR and CO_2 evolution for individual composting substrate used. The saw dust have the highest C/N ratio, followed by the cattle manure and sewage sludge. As saw dust and cattle manure owns high carbon contents as compared to sewage sludge, it makes a

good carbon source that supplies to the microbial activity. During microbial activity, microbes use oxygen to obtain the energy to carry their activities; resulting CO_2 is evolved.

TABLE I
MIXING PROPORTIONS AND INITIAL CHARACTERISTICS OF WASTE MATERIALS

Reactors/Parameters	Waste materials (kg)		
	Sewage sludge	Cattle manure	Sawdust
R1	1.30	0.04	0.16
R2	1.04	0.07	0.39
R3	0.98	0.13	0.39
R4	0.87	0.18	0.45
R5	1.50	--	--
Organic matter (OM) (%)	38.46±0.23	70.12±3.21	97.59±0.07
Total organic carbon (%)	21.37±0.18	38.96±2.14	54.22±0.03
Total nitrogen (%)	1.91±0.22	1.47±0.20	0.40±0.02
C/N ratio	11.19±1.21	26.44±2.50	135.88±7.25
CO_2 evolution (mg/g VS/day)	12.1±0.5	17.6±0.5	10.8±0.1
Oxygen uptake rate (OUR) (mg/g VS/day)	17.9±0.2	21.8±1.3	12.5±0.7

A. Stability Analysis

The composting mass is referred "stable" when it has reached a position of decomposition at which it can be stored without giving risk to health or nuisance problems. Unstable compost can show phytotoxic behavior and therefore affect crops. Hence, it is essential to prove the stability of compost to ensure about the technology and operational performance. Compost stability was quantified by respiration index method. Respiration indices have considered both CO_2 evolution and OUR [12].

Compost stability was evaluated by CO_2 evolution because it assesses carbon derived directly from the compost being tested, caused by mineralization of the composts organic matter [28]. Therefore, the CO_2 evolution correlates to microbial respiration and aerobic biological activity. CO_2 evolution rate was higher in R4 (10.78 fold) followed by R2 (4.80), R3 (4.66), R5 (3.95), R1 (3.78), CR4 (3.95), CR2 (2.09), CR1 (2.60), CR3 (2.50), and CR5 (1.98), respectively (Table II). On analyzing the results by ANOVA, CO_2 evolution varied significantly ($p < 0.0001$) between all the reactors on all the sampling days. Higher CO_2 concentrations indicate elevated microbial respiration of the readily available carbon in the composting mixture. The decrease in the respiration rate with vermicomposting time is a result of a reduction in metabolic activity due to the decrease of readily available carbon.

The result showing higher decrease with lower final value of CO_2 evolution in R4 indicated more stabilization as compared to other reactors. OUR is the most conventional respirometric technique to assess biological activity in composts. It evaluates the amount of readily biodegradable organic matter still present in the sample through its carbonaceous oxygen demand. In all reactors, sharp reduction were observed; correlated with less availability of readily organic matter as the composting process proceeds. Higher OUR was observed in R4 with 10.83 fold followed by R1 (5.66), R3 (4.32), R2 (4.31), R5 (3.59), CR4 (3.45), CR1 (3.01), CR2 (2.88), CR3 (2.57), and CR5 (2.10) respectively (Table II). Higher respiration rates were observed in the beginning of the vermicomposting in all the reactors especially in R4 due to high availability of readily degradable cattle manure coupled with the sewage sludge and saw dust. As vermicomposting proceeds, larger organic molecules are broken down to smaller, soluble ones and temporarily more substrate may become available. Lower respiration index indicates the stability of finished compost. On analyzing the results by ANOVA, OUR varied significantly ($p < 0.0001$) between all the reactors on all the sampling days.

The C/N ratio reflects the spectra of changing carbon and nitrogen concentration of the biowaste during composting/ vermicomposting process [4]. The nitrogen increases due to nitrogenous excreta generated by earthworms and loss of carbon as CO_2 through microbial activity lowered the C/N ratio of the end products. The decreased in C/N ratio over time might also be attributed to increase in the earthworm population [5]. The change in the C/N ratios reflects the organic matter decomposition and stabilization achieved during composting. Higher reduction in C/N ratio was observed in R4 with 3.27 fold followed by R3 (1.90), R2 CR4 (1.81), CR2 (1.77), R1 (1.75), CR3 (1.62), R5 (1.58), CR1 (1.45), and CR5 (1.38), respectively. Therefore, continuous decrease was observed during all the reactors (Table II). C/N variations were observed to be significant in all the reactors ($p < 0.0001$).

CR5).

B. Kinetic Analysis

Losses of OM were calculated from the initial and final OM contents, according to the following equation [29]-[31]:

$$K = \frac{[OM_m(\%) - OM_p(\%)] \times 100}{OM_m(\%) \times [100 - OM_p(\%)]} \quad (1)$$

where OM_m is the OM content at the beginning of the process and OM_p is the OM content at the end of the process. The degradability coefficient (K) values are mentioned in Table IV. This method is a rough measure for evaluating the system. But the use of organic matter concentration data for kinetic analysis of the system provides a better understanding of the

degradation process. In this regard, kinetic analysis of the composting process was carried out by using (5).

TABLE II
VARIATION IN C/N RATIO, OUR AND CO_2 EVOLUTION DURING VERMICOMPOSTING

Reactors	CO_2 evolution (mg/g OM/day)			
	0 day	*15 day*	*30 day*	*45 day*
R1	9.48±0.41ac	7.08±0.63ab	4.96±0.22ade	2.51±0.44ade
CR1	9.83±0.35abc	7.53±0.08a	5.98±0.74bfg	3.84±0.32b
R2	9.84±0.68abc	7.05±0.22ab	4.66±0.17ae	2.05±0.10ae
CR2	10.34±0.29ab	7.31±0.13ab	6.78±0.14g	3.84±0.27b
R3	9.04±0.32c	7.91±0.62a	5.40±0.26aedb	1.94±0.07a
CR3	10.03±0.24ab	7.98±0.11a	6.23±0.32bfg	4.01±0.12b
R4	9.49±0.33ac	6.42±0.05b	3.65±0.12c	0.88±0.04c
CR4	9.96±0.19abc	7.83±0.20a	5.77±0.21bdf	2.88±0.17d
R5	10.63±0.04b	7.72±0.22a	4.64±0.24e	2.69±0.33de
CR5	9.96±0.13abc	7.68±0.38a	6.36±0.09fg	5.03±0.18f
	Oxygen uptake rate(OURs) (mg/g OM/day)			
R1	18.17±0.32ac	12.66±0.36acd	7.85±0.28a	3.21±0.52a
CR1	18.09±0.12ac	13.56±0.14ad	9.09±0.19ac	6.01±0.17b
R2	17.32±0.30ad	11.76±0.61c	7.78±0.24a	4.02±0.27c
CR2	18.19±0.24c	13.14±0.84ad	8.98±0.43ac	6.31±0.28b
R3	12.88±0.21b	9.03±0.19b	5.70±0.40b	2.98±0.10a
CR3	13.31±0.42b	9.77±0.30b	7.95±0.71a	5.17±0.11d
R4	15.50±0.22e	9.68±0.45b	4.91±0.28b	1.43±0.35e
CR4	16.69±0.22d	11.64±0.15c	8.79±0.64ac	4.84±0.18d
R5	17.85±0.41ac	13.29±0.23d	9.70±0.52cd	4.97±0.05d
CR5	17.45±0.37acd	13.87±0.39ad	10.68±0.57d	8.31±0.34f
	C/N ratio			
R1	16.58±0.61a	13.08±0.33ad	10.90±0.26a	9.46±0.33ae
CR1	17.06±0.21a	15.19±0.77ab	13.52±0.41c	11.77±0.52b
R2	21.53±0.77b	16.77±0.25bc	14.50±0.62ce	11.90±0.44b
CR2	22.77±0.59b	18.26±0.59cf	15.14±0.74ce	12.86±0.18bc
R3	25.47±0.83c	19.10±0.88cefh	16.00±0.86edf	13.38±0.53c
CR3	25.45±0.40c	21.89±0.14ehg	17.48±0.61bf	15.69±0.39d
R4	33.72±1.52d	21.05±2.39hf	15.26±1.14cde	10.31±0.41a
CR4	29.81±0.68e	24.27±0.81g	18.74±0.18b	16.43±0.74d
R5	13.55±0.67f	11.48±0.55d	10.28±0.30a	8.60±0.40e
CR5	13.69±0.02f	11.82±0.40d	10.84±0.30a	9.93±0.42ae

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey's test, $p < 0.0001$)

Composting process is carried out in a homogeneous way; in which, individual microbes are uniformly dispersed in a solution of soluble substrates. Such systems are usually analyzed by Monod kinetics to describe its process. Under controlled conditions, the microbes are attached to the substrate surface and the moisture required for microbial growth is controlled to the solid organic substrate. The composting of organic ingredients or decomposition of organic matters are examples of an enzymatic related microbe systems [23], [32]-[33].

In view of the mass-balance law, enzyme concentration forms a complex with the substrate concentration, results enzyme substrate (ES) complex. The decomposition of ES accepted out in two ways as indicated in. (2)

$$[E] + [S] \underset{K_2}{\overset{K_1}{\leftrightarrow}} [ES] \overset{K_3}{\rightarrow} [E] + [P] \quad (2)$$

where E = enzyme concentration (%); S = limiting substrate concentration (%); P = product form substrate degradation due to enzymatic reaction (%); K_1 = forward reaction rate constant to form ES; K_2 = backward reaction rate constant to form E and S; K_3 = maximum or limiting velocity rate reaction constant.

In equilibrium conditions,

$$K_1[E][S] = K_2[ES] + K_3[ES] \quad (3)$$

On solving, we get

$$(r) = \frac{K_3[S]}{K_m + [S]} \quad (4)$$

where K_m represents Michaelis-Menten constant

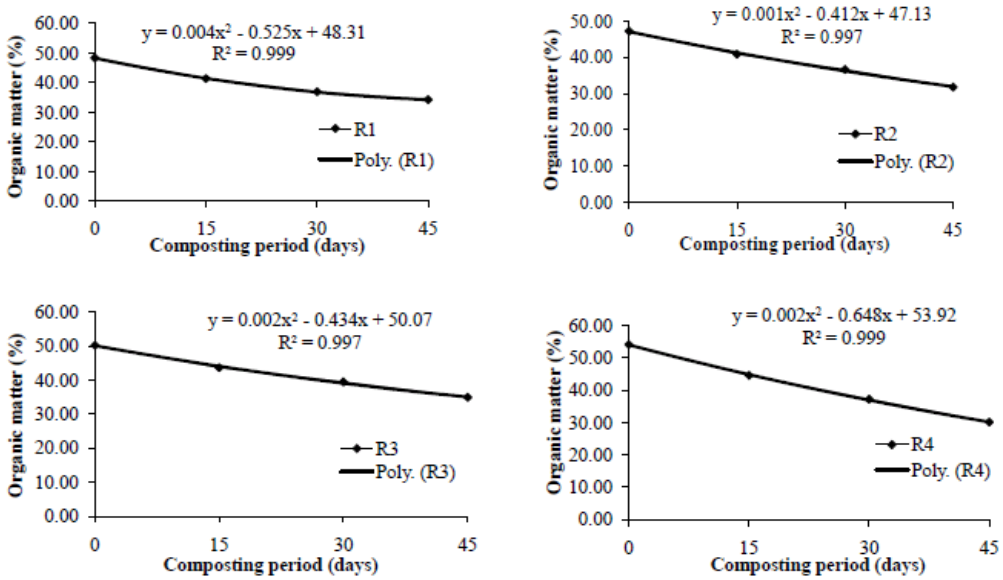

Fig. 1 Variation of organic matter with composting over time during R1, R2, R3 and R4 reactors (The resultant curve was drawn based on 2nd order polynomial (i.e., $y = ax^2+bx+c$) consideration)

Equation (4) is identified as a Michaelis-Menten equation, which resembles with Monod equation. The K_m is equal to the substrate concentration expressed as mg/L at which the reaction proceeds at half of the maximum initial rate. Equation (4) is the projected kinetic rate equation for the composting process. In order to determine the values of K_m and K_3 from the experimental data, (4) is retransformed as follows.

$$\frac{1}{r} = \frac{K_m}{K_3}\left(\frac{1}{S}\right) + \frac{1}{K_3} \quad (5)$$

The kinetic constants K_m and K_3 can be graphically determined by a Lineweaver-Burk plot using (5) incorporating 1/ r and 1/S data. It correlates the initial rate of reaction (consumption rate of substrate i.e., r) and the substrate concentration (S) relationship into a linear relation-ship. In the Lineweaver-Burke plot, the intercept on the y-axis gives the value of K_3 whereas the value of K_m is obtained from the slope of the line. The organic matter was plotted against sampling/composting time and the reaction rate (r) was determined by drawing the tangent to the resultant curve (Figs. 1, 2 and 5). The reciprocals of reaction rate (1/r) and *OM* percent (1/*OM*) were computed and the results are summarized in Table III. In addition, CR2 yielded higher K_3 and K_m values as compared to other control reactors; but it doesn't correlates with their slow degradation process. Therefore, the high degradation was achieved in R4 as compared to others due to most favorable waste proportion occurs for worm's activity; showed the sewage sludge was a better degradable material when mixed with cattle manure and saw dust in the desired proportion, which not only increased the affinity of enzymes towards substrate but also improved the degradation.

C. Earthworm Biomass

The changes in worm biomass for all reactors over the experimentation period are illustrated in Table IV. The earthworm biomass had risen during composting period up to 45 days in all reactors. Results suggested that R4 proved to be best combination for the growth and hatchlings of the earthworms as compared to other reactors. On analyzing the results by ANOVA, earthworm biomass varied significantly ($p < 0.0001$) between all the reactors during 45 days of sampling period.

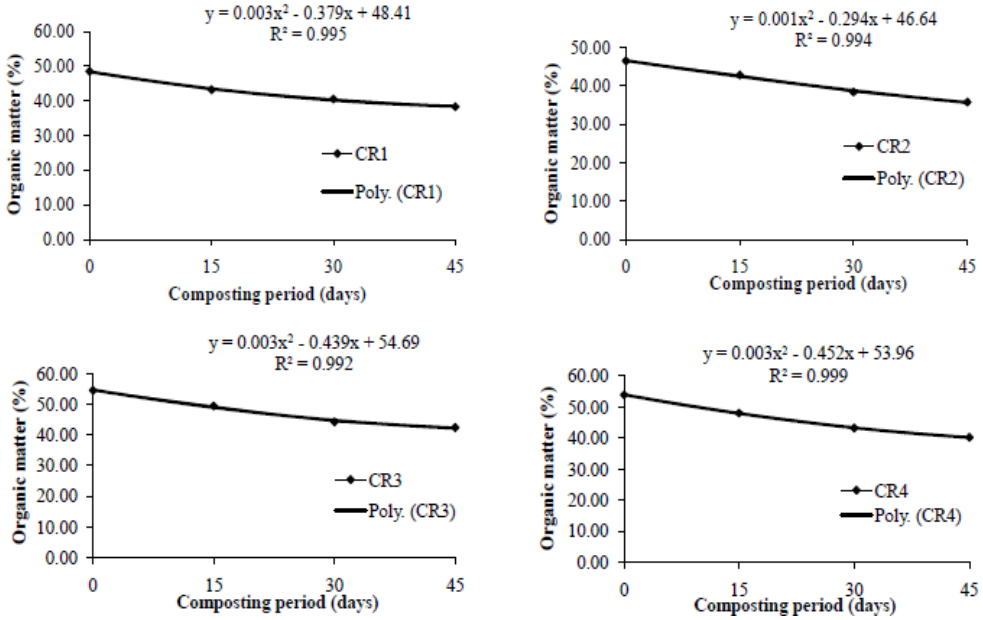

Fig. 2 Variation of organic matter with composting over time during CR1, CR2, CR3 and CR4 reactors

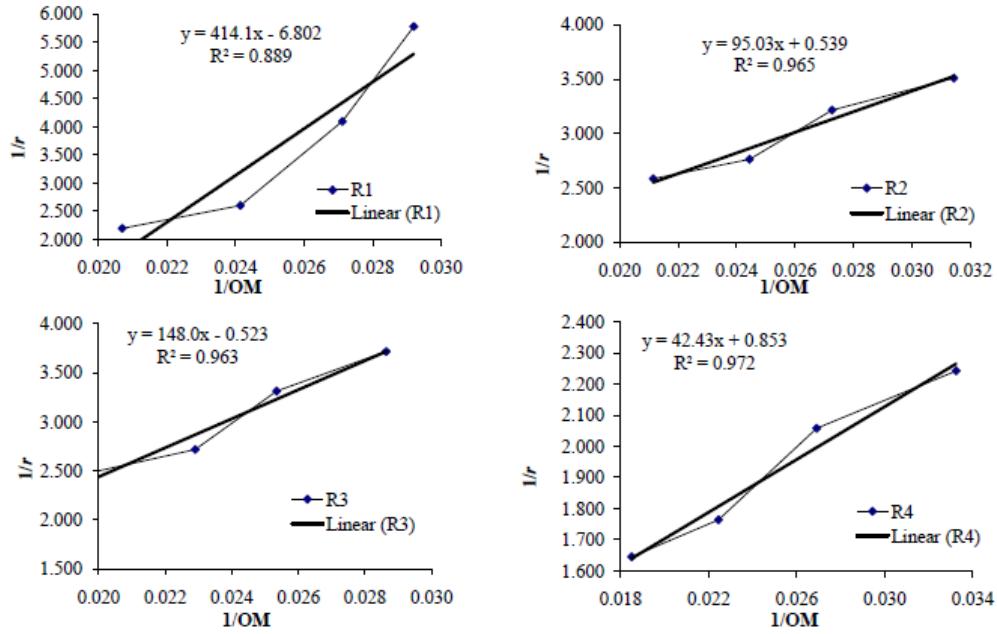

Fig. 3 Lineweaver-Burke plot for R1, R2, R3 and R4 reactors

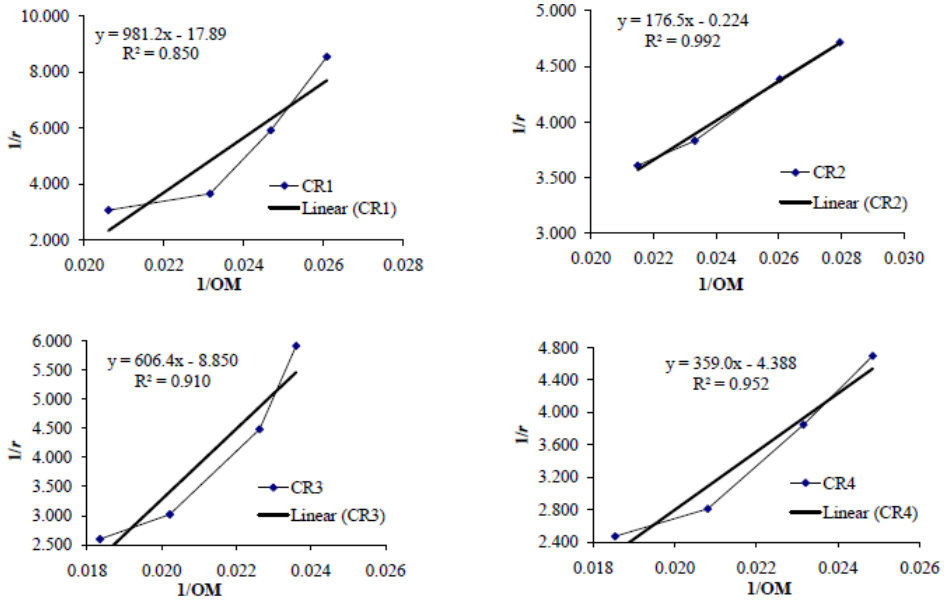

Fig. 4 Lineweaver-Burke plot for CR1, CR2, CR3 and CR4 reactors

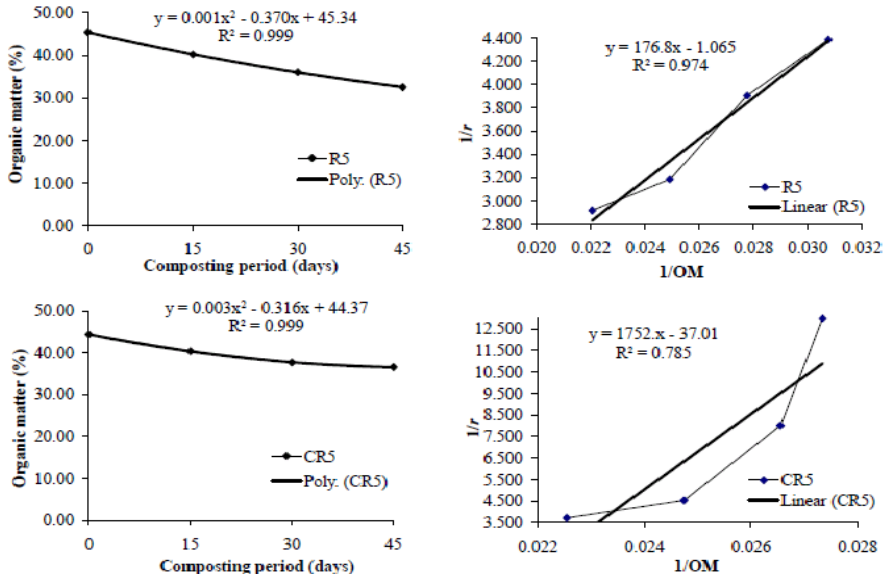

Fig. 5 Resultant curve and Lineweaver-Burke plot for R5 and CR5 reactors

TABLE III
KINETIC CONSTANTS UNDER DIFFERENT SETS OF REACTORS

Reactors	OM conc. (%)				*r* (days^{-1})			
	0 day	*15 day*	*30 day*	*45 day*	*0 day*	*15 day*	*30 day*	*45 day*
R1	48.34	41.43	36.88	34.24	0.455	0.384	0.244	0.173
CR1	48.53	43.19	40.52	38.34	0.327	0.274	0.169	0.117
R2	47.28	40.91	36.68	31.82	0.387	0.362	0.311	0.285
CR2	46.52	42.89	38.42	35.78	0.277	0.261	0.228	0.212
R3	50.21	43.67	39.45	34.92	0.401	0.368	0.302	0.269
CR3	54.52	49.46	44.20	42.37	0.385	0.331	0.223	0.169
R4	54.02	44.53	37.15	30.06	0.608	0.567	0.486	0.446
CR4	53.92	48.05	43.18	40.23	0.405	0.356	0.260	0.213
R5	45.37	40.15	36.02	32.51	0.343	0.314	0.256	0.228
CR5	44.36	40.41	37.66	36.57	0.269	0.221	0.125	0.077

TABLE IV
COMPUTED VALUES OF KINETIC CONSTANTS USING LINEWEAVER-BURK PLOTS FOR DIFFERENT VERMIREACTORS AND CONTROL REACTORS

Parameters	*R1*	*R2*	*R3*	*R4*	*R5*
R^2 *value*	0.8892	0.9650	0.9639	0.9721	0.9743
K_3	0.147	1.853	1.909	1.171	0.939
K_m	60.882	176.104	282.685	49.695	166.062
Degradability Coefficient*	0.44	0.48	0.47	0.63	0.42
	CR1	*CR2*	*CR3*	*CR4*	*CR5*
R^2 *value*	0.8504	0.9929	0.9105	0.9524	0.7851
K_3	0.056	4.458	0.113	0.228	0.027
K_m	54.952	786.971	68.533	81.863	47.309
Degradability Coefficient*	0.34	0.36	0.39	0.42	0.28

* Calculated on dry mass basis using (1)

TABLE V
VARIATION IN EARTHWORM BIOMASS DURING VERMICOMPOSTING

Reactors	Earthworm biomass			
	0 day	*15 day*	*30 day*	*45 day*
R1	120±1a	139±12a	198±8a	323±15a
R2	120±2a	153±2ab	199±2a	318±4a
R3	120±1a	156±4b	226±14b	342±17a
R4	120±1a	174±5c	262±8c	402±29b
R5	120±2a	115±5d	172±8d	315±2a

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey's test, $p < 0.05$)

IV. CONCLUSIONS

The stability analysis was carried out during vermicomposting based upon different C/N ratios (15, 20, 25 and 30). The study reveals that R4 (C/N 30) produced more stable compost after 45 days as compared to others, implying that rigorous decomposition was occurred. The decomposition decreased with increasing the sewage sludge content in the reactors due to less availability of readily biodegradable organic. Higher reductions in C/N ratio, CO_2 evolution and OUR in R4 demonstrated the stability, resulting the total biodegradable ingredients are stabilized. Higher percentage loss in OM in R4 concluded the paramount waste combination of sewage sludge, cattle manure and saw dust justified the higher degradability coefficient (*K*). On analyzing the results by Michaelis-Menten equation which resembles with Monod kinetics; yields higher R^2 value in R4 reactor, enhanced suitability towards Lineweaver-Burk plot. It reveals that the optimal nutrient balance has been occurred in R4, which not only enhanced the affinity of enzymes towards substrate but also improved its degradation process. Therefore, it can be concluded that R4 verified to be the best feed combination for vermicomposting technique followed by R3 (C/N 25), R2 (C/N 20), R5 (Control) and R1 (C/N 15) respectively.

REFERENCES

[1] T.R. Fermor, "Applied aspects of composting and bioconversion of lingocellulosic materials: An overview," *International Biodeterioration & Biodegradation*, vol. 31, pp. 87-106, 1993.
[2] M. Tuomela, M. Vikman, A. Hatakka, and M. Itavaara, "Biodegradation of lignin in a compost environment: A review," *Bioresource Technology*, vol. 72, pp. 169-183, 2000.
[3] T. He, S.J. Traina, and T. Lagan, "Chemical properties of municipal solid waste composts," *Journal of Environmental Quality*, vol. 21, pp. 318-329, 1992.
[4] M. Khwairakpam, and R. Bhargava, "Vermitechnology for sewage sludge recycling," *Journal of Hazardous Material*, vol. 161, pp. 948-954, 2009.
[5] P.M. Ndegwa, and S.A. Thompson, "Integrating composting and vermicomposting the treatment and bioconversion of biosolids," *Bioresource Technology*, vol. 76, pp. 107-112, 2001.
[6] H.B. Gotaas, *Composting-sanitary, disposal and reclamation of organic wastes*, World Health Organization, Geneva, 1956.
[7] N.V. Hue, and J. Liu, "Predicting compost stability," *Compost Science & Utilization*, vol. 3, no. 2, pp. 8-15, 1995.
[8] T. Eggen, and O. Vethe, "Stability indices for different composts," *Compost Science & Utilization*, vol. 9, no. 2, pp. 27-37, 2001.
[9] D.M. Sullivan, and R.O. Miller, "Compost quality attributes, measurements and variability," In: P.J. Stoffella & P.A. Kahn (Eds.), *Compost Utilization in Horticultural Cropping Systems*, CRC Press, 2001.
[10] FCQAO, *Methods book for the analysis of compost-in addition with the results of the parallel interlaboratory test*. Federal Compost Quality Assurance Organization, Stuttgart, Germany, 1993.
[11] Washington State, *Interim guidelines for compost quality*, Department of Ecology Solid Waste Services Program, Technical Assistance Section, Olympia, WA, 1994.
[12] A.S. Kalamdhad, M. Pasha, and A.A. Kazmi, "Stability evaluation of compost by respiration techniques in a rotary drum composter," *Resource, Conservation and Recycling*, vol. 52, pp. 829-834, 2008.
[13] T. Naganawa, K.H. Kyuma, and K. Tatsuyama, "Automatic measurement of CO_2 evolution in multiple samples in small chambers," *Soil Science & Plant Nutrition*, vol.36, no.1, pp. 141-143, 1990.
[14] J.D. Knoepp, and J.M. Vose, "Quantitative comparison of in situ soil CO_2 flux measurement method," *USDA Forest Service, Southern Research Station: Research Paper*, SRS-28, 2002.
[15] W.T. Palestky, and J.C. Young, "Stability measurement of biosolids compost by aerobic respirometry," *Compost Science & Utilization*, vol. 3, no. 2, pp. 16-24, 1995.
[16] K.E. Iannotti , E.K. Papadimitriou, and C. Balis, "Compost stability," *Biocycle*, vol. 11, pp. 62-6, 1996.
[17] D.A. Iannotti, M.E. Grebus, B.L. Toth, L.V. Madden, and H. A. J. Hoitink, "Oxygen respirometry to assess stability and maturity of composted municipal solid waste," *Journal of Environmental Quality*, vol. 23, pp. 1177-1183, 1994.
[18] F. Adani, P. Lozzi, and P. Genevini, "Determination of biological stability by oxygen uptake on municipal solid waste and derived products," *Compost Science & Utilization*, vol. 9, pp. 163-178, 2001.
[19] T. Gea, R. Barrrena, A. Artola, and A. Sanchez, "Monitoring the biological activity of the composting process: oxygen uptake rate (OUR), respirometric index (RI) and respiratory quotient (RQ)," *Biotechnology & Bioengineering*, vol. 88, pp. 520-527, 2004.
[20] D.S. Whang, and G.F. Meenaghan, "Kinetic model of composting process," *Compost Science & Utilization*, vol. 21, pp. 44-46, 1980.
[21] H. Takabayashi, T. Kanaya, and K. Karashima, "Biokinetic analysis of composting fermentation," *Environmental Technology*, vol. 11, pp. 94-100, 1992.
[22] H. Kaneko, and K. Fujita, "Realtionships among aeration, oxygen concentration and reaction efficiency in composting," *Urban Sanitary*, vol. 43, pp.383-390, 1990.
[23] P. Agamuthu, L.C. Chang, S. Hasan, and V.V. Praven, "Kinetic evaluation of composting of agriculture wastes," *Environmental Technology*, vol. 21, no. 2, pp. 185-192, 2000.

[24] J. Haimi, and V. Huhta, "Capacity of various organic residues to support adequate earthworm biomass for vermicomposting," *Biol. Fertil. Soils*, vol. 2, pp. 23-27, 1986.
[25] R. Mohee, M.F.B. Driver, and N. Sobratee, "Transformation of spent broiler litter from exogenous matter to compost in as sub-tropical context," *Bioresource Technology*, vol. 99, no. 1, pp. 128-136, 2008.
[26] M. Codell, and F.D. Verderame, "The determination of nitrogen in copper-titanium alloys," *Analytica Chimica Acta*,vol. 11, pp. 40-47, 1954.
[27] K.E. Lasaridi, and E.I. Stentiford, "A simple respirometric technique for assessing compost stability," *Water Research*, vol. 32, pp. 3717-3723, 1998.
[28] M.P. Bernal, C. Paredes, M.A. Sanchez-Monedero, and J. Cegarra, "Maturity and stability parameters of composts prepared with a wide range of organic wastes," *Bioresource Technology*, vol. 63, pp. 91-99, 1998.
[29] G. Tchobanoglolus, and H. Theisen, S. Vigil, *Integrated solid waste management*, McGraw-Hill Inc., New York, 1993.
[30] R.T. Haung, *The practical handbook of composting engineering*, Lewis publishers, Boca Raton, 1993.
[31] M.J. Diaz, E. Madejon, F. Lopez, R. Lopez, and F. Cabrera, "Optimization of the rate vinasse/grape marc for co-composting process," *Process Biochemistry*, vol. 37, pp. 1143-1150, 2002.
[32] Q.H. Bari, A. Koenig, and T. Gujhe, "Kinetic analysis of forced aeration composting reaction rates and temperature," *Waste Management & Research*, vol. 18, no. 4, pp. 303-312, 2000.
[33] D.L. Nelson, and M.M. Cox, *Lehninger principles of biochemistry*. 3rd edition, Worth Publishers, New York, 2000.