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Assessment of Nutrients and Stability Parameters during Composting of Water Hyacinth mixed with Cattle Manure and Sawdust

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Abstract

Water hyacinth (Eichhornia crassipes) can cause a variety of problems due to its fast spread and congested growth. Nutrient recycling through the composting of water hyacinth can reduce application of chemical fertilizers to the agricultural field and problems related to its fast growth rate. The nutrients and stability parameters were evaluated during agitated pile composting of water hyacinth mixed with cattle manure and sawdust for 30 days composting period. Five different proportions of cattle manure, water hyacinth and sawdust were prepared for the composting process. Stability of compost was evaluated using respiration techniques (CO_2 evolution and oxygen uptake rate). Results show that nutrients (Na, K, Ca, Mg, total nitrogen, phosphorus) were increased significantly during the composting process. Stability parameters (CO_2 evolution rate and oxygen uptake rate, biochemical chemical oxygen demand and chemical oxygen demand) were reduced during the process. The optimum proportion of cattle manure enhanced organic matter degradation and humification during the composting process.

Keywords: Water hyacinth, composting, nutrients, stability.

Introduction

Water hyacinth (*Eichhornia crassipes*) is a free floating macrophyte. Macrophytes are aquatic plants, growing in or near water that are emergent, submerged or free floating[1]. Its excessive growth rate may affect the aquatic environment by following problems: obstructing navigation, killing fish by depletion of oxygen in the water, habitat of variety of harmful animals etc. The control of water hyacinths is very difficult due to its regeneration from fragments of stems and seed can remain viable for more than six years[2]. Composting is the most promising technique for treatment of this weed. The organic substrates of this weed can be biodegraded and stabilized by composting and the final compost products could be applied to land as the fertilizer or soil conditioner. Water hyacinth composting can solve two problems such as reduced chemical fertilizers application to the agricultural field as a nutrient source and checked the growth of water hyacinth. The windrow or pile composting is the most popular method of a nonreactor, agitated solids bed system[3]. Some studies have been carried out on pile composting of different wastes[4,5,6].

As the composting process proceeds, the readily degradable organic matter converted into less degradable humic material[3]. Humic substances are rich of nutrients required for the plants growth. The important nutrients for the fertilizing character of the compost are nitrogen, phosphorus and potassium. During the composting process nitrogen oxidize of into nitrate, which is not normally lost from the compost pile. While phosphorus and potassium are physico-chemically less mobile than nitrogen, these compounds remain in the compost unless lost through leaching[2]. Compost is considered unstable if it contains a high proportion of biodegradable matter that may maintain high microbial activity.

Compost considered stable if it contains mainly recalcitrant or humus-like matter and it is not competent to uphold microbial activity[7]. Stability is an important characteristic of composting in relation to its field application, potential of odor generation and pathogen regrowth. The stability of composts can be defined as the degree to which the organic fractions in composts have been stabilized during the proces[8-10]. Therefore, stability evaluation it is very essential before compost has to be applying for agricultural purposes. However a very limited literature available on nutrients and stability parameters evaluation during agitated pile composting of water hyacinth with cattle manure and sawdust. Therefore, the objective of the present study was to assess the nutrients and stability parameters during pile composting of water hyacinth with cattle manure and sawdust.

Material and Methods

Feedstock materials and design of agitated pile composting: Water hyacinth, cattle (cow) manure and sawdust were used for the preparation of different waste mixtures. Water hyacinth was collected from the Amingoan industrial area near Indian Institute of Technology Guwahati campus. Cattle manure was obtained from dairy farm near the campus. Sawdust was purchased from nearby saw mill. Prior to composting, the maximum particle size in the mixed waste was restricted to 1 cm in order to provide better aeration and moisture control. The compost was prepared with five different proportioning of water hyacinth, cattle manure and sawdust and initial characterizations are detailed in table 1. Five different waste combinations were formed into trapezoidal piles (length 2100 mm, base width 350 mm, top width 100 mm and height 250 mm, having length to base width (L/W) ratio of 6. Agitated piles contained approximately 150 kg of different waste combinations and composted for 30 days. Homogenized samples were collected from five different locations in the pile on 0, 3, 6, 9, 12, 15, 18, 21, 24, 27 and 30th day after turning.

Analysis of physico-chemical and biological parameters: Temperature was monitored using a digital thermometer throughout the composting period. About 500 g of each grab samples were collected from five different points, mostly at the mid span and ends of the pile by compost sampler without disturbing the adjacent materials. Finally all the grab samples were mixed thoroughly to make a homogenized sample. Triplicate samples were collected and divided in to two sub samples. Sub-samples were dried at 105^{o}C in oven for 24 h and moisture content was calculated, dried samples were ground to pass to 0.2 mm sieves and stored for further analysis. Each sub-sample was analyzed for the following parameters: pH and electrical conductivity (EC) (1:10 w/v waste:water extract), organic matter[7]. Total nitrogen was using the Kjeldahl method, NH_4-N and NO_3-N using KCl extraction[11], available and total phosphorus (acid digest) using the stannous chloride method[12]. The Flame photometer (Systronic 128) was used for analysis of Na, K and Ca concentration and atomic absorption spectrometer (Varian Spectra 55B) was used for analysis of Mg, Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr concentration after digestion of the 0.2 g sample with 10 mL H_2SO_4 and $HClO_4$ mixture (5:1) in block digestion system (Pelican Equipments Chennai-India) for 2 h at 300^{o}C.

Remaining sub samples stored for maximum 2 days at 4$^{°}$C for following analysis: The biodegradable organic matter was measured as soluble biochemical oxygen demand (BOD) (by the dilution method)[12] and soluble chemical oxygen demand (COD)[12] (by the dichromate method). Bacterial population (1:10 w/v waste:-water extract) including total coliforms (TC) by inoculation of culture tube media using the most probable number (MPN) method[12]. The stability parameters i.e. oxygen uptake rate and CO_2 evolution as described in Kalamdhad et al.[13].

Table 1
Composition and initial characterizations of waste materials (Mean ± SD, *n* = 3)

Trial/Parameter	**Waste materials (kg)**		
	Water hyacinth	**Sawdust**	**Cattle manure**
Trial 1	120	15	15
Trial 2	105	15	30
Trial 3	90	15	45
Trial 4	75	15	60
Trial 5	150	0	0
pH	5.8±0.07	6.2±0.005	6.7±0.05
Electrical conductivity (EC) (dS/m)	4.9±0.01	0.4±0.002	3.3±0.03
Moisture content (%)	85.9±0.1	10.01±0.035	80.9±0.19
Volatile solids (%)	72.641±0.04	97.9±0.2	72.05±.224
Total phosphorus (%)	0.1±0.001	0.02±0.0	0.23±0.0005
Available phosphorus	0.058±0.002	0.01±0.005	0.04±0.001
Ammonical nitrogen (%)	0.53±0.029	0.14±0.007	0.96±0.05
Total nitrogen (%)	1.15±0.12	0.38±0.01	1.4±0.168
Soluble BOD (mg/L)	360±0.0	255±105	420±0.0
Soluble COD (mg/L)	1600±320	950±310	1920±640
CO_2 evolution rate (mg/gVS/day)	5.74±0.1	1.95±0.35	5.16±0.2
Oxygen uptake rate (mg/gVS/day)	16.26±2.08	2.38±0.24	12.99±0.43
Heavy metals (mg/kg dry matter)			
Zn	152±16	116.45±2.25	182.4±1.95
Cu	39.8±0.3	29.5±1	47.8±0.8
Mn	644.8±16.3	143±3.5	527.5±1.5
Fe	12925±10	2749.3±13.3	1860.8±2.8
Ni	179.8±10.3	278.5±1.5	235.9±2.6
Cd	43.25±0.3	57.955±0.5	47.935±1.07
Pb	1140±5	1000±5	817.5±7.5
Cr	301.2±0.2	89.23±0.23	124.485±0.5
Nutrient (mg/kg dry matter)			
Na	8875±125	1097.5±2.5	2400±5
K	18195±205	697.5±7.5	987.5±22.5
Ca	6177.5±7.5	2420±15	9892.5±17.2
Mg	8303.5±233	30206±28	75500±500

All the results reported are the means of three replicates. Repeated measures treated with analysis of variance (ANOVA) was made using Statistica software. The objective of the statistical analysis was to determine any significant difference among the parameters for different trials.

Results and Discussion

Physico-chemical analysis: As shown in figure 1, the composting pile temperature went through three typical phases (mesophilic, thermophilic and cooling phase) and ranged from 26 to 56°C during the entire period of composting. The cattle manure affected the temperatures during the composting process in five different trials. Out of all five trials, trial 4 reached the highest temperature and longer due to higher addition of cattle manure indicating quick establishment of microbial activity during the composting process[14]. In trial 1, a maximum temperature of 30°C was observed, which contains only water hyacinth. These results indicate that cattle manure enhanced the composting process by providing easily available carbon for microorganisms, but in trial 5 which contained highest amount of cattle manure shows less temperature when compared to trial 4. Cattle manure in excess may increase the available carbon but inadequate nitrogen in trial 5 thereby reducing the temperature; furthermore compost microorganisms require optimum carbon and nitrogen for their growth.

The composting material requires optimum moisture content in it for the organisms to survive. Moisture loss during the composting process in the form of vapors by the heat generation can be viewed as an index of decomposition rate[7]. Initial moisture content was 82.0, 84.6, 80.5, 77.4 and 87.5% which reduced to 61.0, 60.4, 49.9, 60.1 and 78.4% in trial 1, 2, 3, 4 and 5 respectively during the composting period (figure 2). Highest moisture loss occurred in trial 3 (37.7%) and lowest moisture loss was observed in trail 5 (10.4%), due to high heat generation in trial 3 and low heat generation in trial 5. On analyzing the results by ANOVA, the decrease in moisture content varied significantly between the days ($P < 0.05$). The pH values were within the optimal range for the development of bacteria (6.0-7.5) and fungi (5.5-8.0)[15]. The pH was increased from 6.4-7.6, 6.7-7.6, 7.1-7.8, 7.0-7.6 and 6.7-7.2 in trials 1, 2, 3, 4 and 5 respectively (figure 2). Increase in the pH level during composting resulted in increase in volume of ammonia released due to protein degradation. Ammonium formation was very low after primary stabilization due to the low rate of organic matter degradation [7]. Significant difference in pH was observed in all the trials ($P < 0.05$).

Electrical conductivity (EC) is usually measured during composting because it reflects the salinity of the composting product and its suitability for plant growth [16]. EC was increased from 4.5-10.0, 3.1-4.6 and 6.2-7.5 dS/m of the trials 1, 4 and 5 respectively; mainly due to the net loss of weight and release of soluble salts through decomposition activity in the composting process. EC was decreased from 4.9-4.3 and 7.2-4.6 dS/m in trials 2 and 3 respectively during the composting process (figure 2). The volatilization of ammonia and the precipitation of mineral salts could be the possible reasons for the decrease in EC at the later phase of composting[7]. On analyzing the results by ANOVA, EC varied significantly between the all trials ($P < 0.05$). During the composting process organic matter is decomposed and transformed to stable humic substances. The figure 2 shows the trend of organic matter degradation during 30 day composting process in five different trials. The content of organic matter was decreased as the decomposition progressed. Higher loss of organic matter was observed in trial 3 (31%) followed by trial 4 (27.6%), trial 2 (20.5%), trial 1 (18.4%) and trial 5 (9.8%). Trial 3 showed higher loss of organic matter as a result of higher temperature evolution compared to other trials. A significant variation in organic matter loss was observed in all the trials ($P < 0.05$).

Water hyacinth has exceptionally high affinity and accumulation capacity for several metals[17]. Very less quantity of trace elements are needed by plants for the normal growth. Table 2 illustrates the concentration of heavy metals (Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr) in all trials might be due to loss of organic matter during the composting process[18].

On analyzing the results by ANOVA, significant differences in total heavy metals (Zn, Cu, Mn, Fe, Pb, Cd, Ni and Cr) ($P < 0.05$) were observed between the all trials. Table 3 illustrates the variation in concentration of the nutrients (Na, K, Ca and Mg) in all trials throughout the composting process. These nutrients are required for the plant growth. The concentration of Na, K, Ca and Mg was gradually increased till the end of the composting due to the net loss of dry mass. On analyzing the results by ANOVA, significant differences in nutrients were observed between the trials ($P < 0.05$).

Phosphorus in organic material is released by a mineralization process involving micro-organisms. Concentration of total and available phosphorus was increased during the composting process (table 3). It might be due to the net loss of dry mass[19]. The total and available phosphorus was increased in the range of 22.5-53.7% and 26-71% respectively during the composting process. Increase in phosphorus content indicating the higher microbial activities during the composting process causes more mineralization. Table 3 shows that total nitrogen (TN) was increased within composting time due to the net loss of dry mass in terms of CO_2 as well as the water loss by evaporation due to heat evolution during oxidization of organic matter. Highest TN was increased in trials 2 and 3 (120%) followed by trial 4 (87.5%), trial 1 (66.7%) and trial 5 (50%) during the composting process. The concentration of TN usually increases during composting when organic matter loss is greater than the loss of NH_4-N. These results were in agreement with the data of Kalamdhad et al.[7], which showed an increase in the TN content. The concentration of NH_4-N was decreased in all trials. Higher reduction of NH_4-N was observed in trial 3 (50.7%) followed by trial 4 (46.1%), trial 1 (40%), trial 5 (37.3%) and trial 2 (36.6%)

during the composting process (table 3). It has been noted that the absence or decrease in NH_4–N is an indicator of both high-quality composting process. High pH, mixing and increased aeration have been revealed to enhance ammonia loss during maturation[7]. On analyzing the results by ANOVA, significant differences in nutrients were observed between the trials ($P < 0.05$).

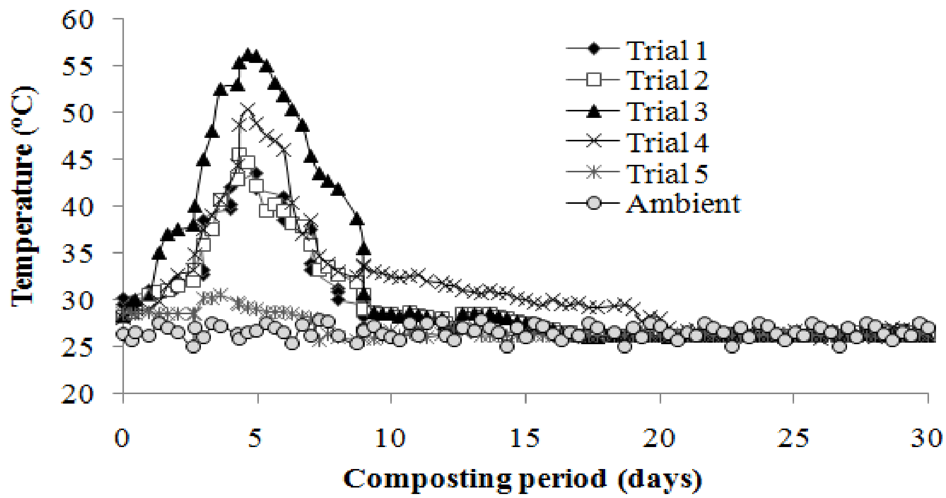

Figure 1
Variation of temperature during composting process

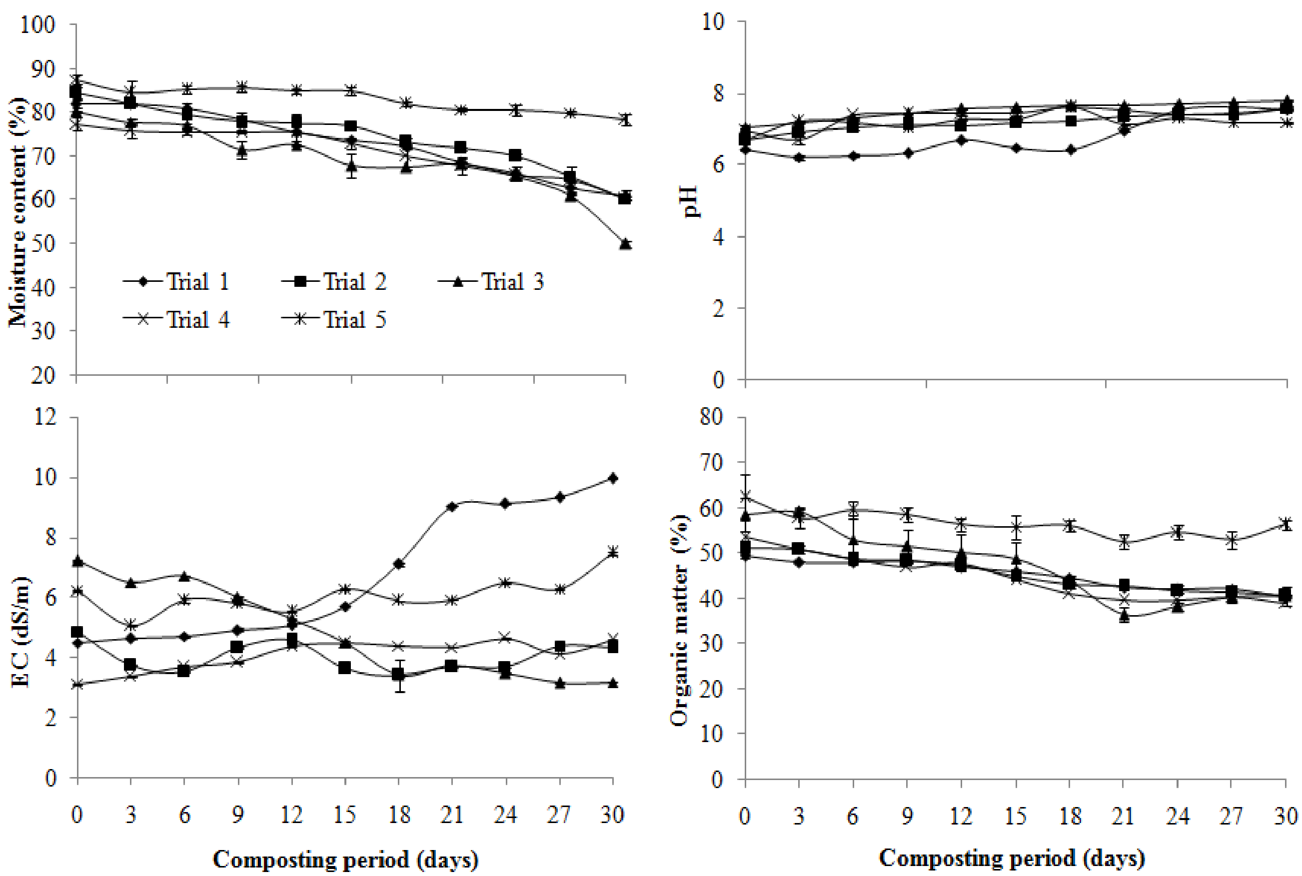

Figure 2
Variation of moisture content, pH, electrical conductivity and organic matter during composting process

Biological analysis: Respiration of biodegradable organic matter develop aerobic condition in the compost, is measured as soluble BOD and COD. As the biological organic content is reduced, BOD and COD are decreased, resulting in decreased emission of carbon dioxide, ultimately indicating stabilization of the compost[7]. Soluble BOD and COD values decreased from 540 to 180 and 960 to 224 mg/L in trial 1 and 435 to 135 and 896 to 201 mg/L in trial 2, 450 to 105 and 960 to 205 mg/L, 390 to 180 and 604.8 to 185 mg/L and 405 to 240 and 765.6 to 607.2 mg/L, respectively, during 30 days composting period (Fig. 3). Higher reduction of soluble BOD was observed in trial 3 (76.7%) followed by trial 2 (69%), trial 1 (66.7%), trial 4 (53.8%) and trial 5 (40.74%). Higher reduction of soluble COD was also observed in trial 3 (78.7%) followed by trial 2 (77.5%), trial 1 (76.7%), trial 4 (69.4%) and trial 5 (20.7%). Significant differences in soluble BOD and COD were observed between the days ($P < 0.05$). CO_2 evolution is the most direct method of compost stability because it measures carbon derived directly from the compost being tested. Thus CO_2 evolution directly correlates to aerobic respiration, the trust measure of respiration and hence aerobic biological activity during the composting process [13].

The rate of CO_2 evolution decreased during maturation (figure 3). The final values of CO_2 evolution (0.7 mg/g volatile solids (VS)/day) in trial 3 strongly recommended that the water hyacinth could produce stable quality of compost using cattle manure. The highest rate of CO_2 evolution was reduced in trial 3 (89.4%) followed by trial 1 (80.8%), trial 4 (77%), trial 2 (67%) and trial 5 (46%) during the composting process. Early in the initial phases of maturation, primary stabilized composts showed a high respiration rate due to the intense mineralization of organic matter [17]. The OUR is the most accepted method for the determination of biological activity of a materials. It measures compost stability by evaluating the amount of readily biodegradable organic matter still present in the compost through its carbonaceous oxygen demand [18]. A respirometric method is most widely accepted method for stability evaluation in the compost. Unstable compost has a strong demand for O_2 and a high CO_2 production rate as a consequence of the abundance of the easily biodegradable compounds in the compost, resulting high rates of microbial activity. For this reason, O_2 consumption or CO_2 production are indicators of compost stability[20]. The OUR was decreased in all trials significantly during the process (figure 3). The higher reduction of OUR was observed in trial 3 (68.6%) followed by trial 4 (63.7), trial 2 (62%), trial 1 (60.6%) and trial 5 (27.5%) during the process.

The presence of coliform bacteria is often used as an indicator of overall sanitary quality of the compost. Some common pathogens and parasites are destroys at high temperature. For the compost hygienization, the recommended fecal coliform density is 5×10^2 MPN/g dry weights [7]. The total coliform levels were declined from 4.3×10^6 to 9.3×10^2, 2.4×10^5 to 9.3×10^3, 9.3×10^5 to 9.3×10^3, 9.3×10^5 to 2.4×10^2 and 1.5×10^5 to 1.5×10^3 MPN/g in trials 1, 2, 3, 4 and 5 respectively. The fecal coliform levels were also declined from 2.4×10^6 to 24, 4.3×10^4 to 93, 1.1×10^6 to $2.4\text{x}10^2$, 1.1×10^6 to 15 and 4.6×10^4 to 240 MPN/g in trials 1, 2, 3, 4 and 5 respectively; during the composting process. The decrease was presumably the result of the high temperature and unfavorable conditions established during the thermophilic phase [21].

Conclusion

Addition of cattle manure provided easily available carbon sources for composting microorganisms. However, the higher or without addition of cattle manure reduced the metabolic activity of microorganisms. Highest reduction of moisture content was observed in trial 3, result of the higher temperature evolution in this trial. The pH was changed from slightly acidic to neutral at the end of composting process. Highest reduction of organic matter was observed in trial 3 (30.9%) followed by trial 4 (27.6%), trial 2 (20.5%), trial 1(18.4%) and trial 5 (9.8%). Highest reduction of BOD, COD, CO_2 evolution rate and OUR were also observed in trial 3 during the composting process. Total and fecal coliform were reduced significantly, which are pathogen indicators in the compost. This study concluded that the addition of optimum amount of cattle manure was very efficient for agitated pile composting of water hyacinth.

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Table-2
Variation in concentration of heavy metals during composting process (Mean ± SD, *n* = 3)

Days	Heavy metal concentration									
	Zn (mg/kg)					**Cu (mg/kg)**				
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**	**Trial 5**
0	114.98±0.6	241.15±0.1	161.13±1.3	222.63±0.4	180.23±2	45.75±0.75	46.75±0.8	31±0.5	49.25±0.8	77.5±1.5
6	125.75±0.7	231.4±0.0	200.8±0.2	263.5±6	222.58 ±0.8	38.75±0.3	38.75±0.3	45.5±0.5	58.75±1.3	78.75±1.3
12	104.8±1	239.75±1.8	282.7±12	282.75 ±7.3	213.7 ±0.7	31.25±0.3	64.75±0.8	51.75±0.8	65.5±0.5	72.8±1.2
18	195.83±2.9	261.7±0.8	272.475±4	272.5±2	208.83 ±1.4	44.5±0.5	63.25±1.3	46.75±0.8	65.75±0.3	57±3.0
24	179.05±1.5	242.85±0.3	245.95±1.6	235.95 ±1.2	211.18 ±0.5	74.75±7.3	61.25±0.8	49±0.5	67.25±1.8	59.25±0.8
30	217.8±0.5	291±2.0	297.75±2.8	269.65±5	197.28 ±3.8	61.5±3.5	73±0.5	103.25±0.8	61.5±0.5	79.2±1.1
Days	**Mn (mg/kg)**					**Fe (g/kg)**				
0	355.5±0.5	815.75 ±32.8	572.5±10	737.5±12.5	998.25 ±8.3	11.01±0.14	6.20±0.02	7.92±0.1	9.57±0.05	17.53±0.03
6	404.75±1.7	820.25 ±11.3	626±6	805±15	977.75 ±2.3	12.13±0.41	7.69±0.01	7.69±0.32	9.69±0.06	23.95±0.16
12	429.75±0.75	813.25 ± 2.8	906.475±11.5	852.5±17.5	1415.75 ±6.3	12.89±0.01	8.05±0.0	11.03±0.02	11.79±0.13	28.58±0.18
18	727.25±6.25	1226.25 ±1.8	776.5±16.5	970±10	1073±36.5	11.87±0.07	9.64±0.03	12.43±0.54	14.05±0.13	32.12±0.02
24	760.5±5.5	1125±75	892.5±50	801.5±1.5	1276.5±25	13.32±0.02	10.12±0.77	11.6135±0.01	13.57±0.11	30.63±0.01
30	1069.25±29.7	1368.75±45	1105±27.5	990±60	1182.5±9.0	14.19±0.03	11.67±20	13.26±0.03	14.34±0.20	20.08±0.04
Days	**Ni (mg/kg)**					**Pb (mg/kg)**				
0	157.75±7.2	249.25±10.3	187.25±1.8	268.75±1.3	192.5±2.5	1030.0±25	1185±5	872.5±12.5	867.5±7.5	1140±5
6	186.5±7	290.75±5.3	222.75±3.3	321.53±5.5	323.25±0.8	1090.0±40	1275±10	1032.5±27.5	1200±25	1200±50
12	161.25±6.7	237.5±4	293±2.0	277.25±10	306.5±19	1003.9±3.8	1160±20	1387.5±2.5	1130±5	1057.5±7.5
18	256.25±5.7	258.5±2	319.5±5.5	291.0±1	273.75±0.8	1055.0±5	1352.5±7.5	1372.5±57	1245±5	880.0±25
24	267.0±3	284.5±5.5	284.5±9	303.5±8	230.25±3.8	1250.0±5	1192.5±7.5	1250±0.0	1102.5±22	1107.5±42
30	317.25±8.2	265±5	235.75±1.8	376.25±15	302±3	1582.5±2.5	1568.5±5.5	1537.5±12.5	1207.5±17.5	1187.5±17.5
Days	**Cd (mg/kg)**					**Cr (mg/kg)**				
0	40.0±1	57.0±2	43.8±1.3	63.5±0.5	60.03±0.0	290.58±2.4	180.5±3.5	257±5	246.75±5.3	149.5±1
6	44.8±0.7	72.0±2.5	71.8±0.3	75.5±2	70.75±0.3	274.75±1.7	184.0±8	259.25±18	215±2.5	175.75±1.8
12	45.8±1.3	62.3±0.8	69.5±0.5	68±1.0	63.25±0.8	257.5±1.5	219.5±6.5	261±4	220±1	174.75±8.8
18	64.0±1.5	62.5±0.5	70.0±0.5	62.5±5	68.75±0.8	288±10	221.25±2.3	236.25±3.8	226±2	190.5±1.5
24	67.3±1.3	69.0±0.5	60.3±0.8	68±4.5	58.0±0.5	287.25 ±0.8	204.78±1.2	270.5±5.5	309±14	186.25±2.8
30	75.3±0.25	64.0±0.5	83.8±1.3	67±0.5	65±2	300.925±0.3	227.5±2.0	279.25±1.3	281±2.5	183.25±8.8

Mean value followed by different letters in columns is statistically different (ANOVA; $P < 0.05$)

Table-2
Variation in concentration of nutrients during composting process (Mean ± SD, *n* = 3)

Days	Nutrients concentration									
	Na(g/kg)					K (g/kg)				
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
0	4.80±0.05	5.18±0.13	5.35±0.0	4.47±0.43	6.13±0.01	18.34±0.06	18.76±0.01	18.68±0.07	18.25±0.05	18.19±0.20
6	5.62±0.02	5.99±0.03	7.13±0.03	4.99±0.06	6.34±0.01	15.56±0.06	19.07±0.03	24.16±0.10	20.87±0.08	23.72±0.12
12	7.61±0.14	5.61±0.06	6.62±0.12	4.72±0.18	6.12±0.12	22.72±0.03	20.37±0.03	23.11±0.01	19.61±0.06	28.37±0.18
18	5.08±0.04	5.35±0.15	6.70±0.05	4.65±0.05	5.42±0.07	21.2±0.05	21.76±0.16	26.63±0.07	20.38±0.06	29.29±0.04
24	6.37±0.08	5.74±0.06	7.83±0.03	4.75±0.10	6.79±0.0	20.03±0.03	24.64±0.14	19.35±0.05	20.01±0.01	30.34±0.01
30	5.91±0.04	5.92±0.03	5.88±0.04	5.05±0.20	6.72±0.07	21.14±0.04	25.26±0.14	22.43±0.08	19.78±0.08	35.33±0.18
Days	**Ca (g/kg)**					**Mg(g/kg)**				
0	7.13±0.03	6.69±0.09	7.18±0.02	7.35±0.10	6.17±0.01	6.28±0.21	7.59±0.28	7.54±0.06	8.041±0.02	8.30±0.23
6	8.93±0.17	7.27±0.07	5.78±0.04	7.29±0.09	10.76±0.01	7.39±0.90	6.47±0.33	9.23±0.58	9.49±0.05	10.79±0.07
12	10.81±0.14	7.22±0.03	6.85±0.06	7.27±0.07	10.88±0.06	9.83±0.12	8.25±0.07	10.65±0.43	9.91±0.07	14.17±0.16
18	7.15±0.05	7.17±0.03	5.3±0.05	7.28±0.09	13.23±0.03	9.06±0.80	8.61±0.0	11.47±0.10	10.7±0.26	10.11±0.69
24	7.25±0.05	7.25±0.03	7.34±0.14	4.81±0.31	11.77±0.08	9.38±0.84	10.39±0.06	27.10±0.53	10.34±0.34	11.61±0.63
30	7.76±0.04	7.24±0.08	8.83±0.08	7.94±0.05	14.83±0.13	11.65±0.79	9.83±0.23	21.95±0.38	11.68±0.36	10.18±0.44
Days	**Total nitrogen (%)**					**NH4-N (mg/kg)**				
0	0.63±0.07	0.49±0.07	0.49±0.07	0.77±0.07	0.84±0.00	102.99±0.03	72.02±0.5	70.67±0.1	60.3±0.05	92.87±2.4
3	0.77±0.07	0.49±0.07	0.56±0.00	0.7±0.14	0.77±0.07	102.21±0.05	75.91±0.02	74.21±0.03	77.72±0.1	88.56±0.34
6	0.77±0.07	0.63±0.07	0.63±0.07	0.77±0.07	0.84±0.00	103.84±0.02	68.76±0.02	78.78±0.06	63.21±0.05	87.67±0.11
9	0.98±0.00	0.77±0.07	0.63±0.07	0.91±0.07	0.98±0.00	100.74±0.00	68.09±0.30	60.49±0.1	52.85±0.06	84.48±0.28
12	0.63±0.07	0.77±0.07	0.77±0.07	0.98±0.00	1.12±0.00	79.4±0.08	51.55±0.11	54.24±0.08	46.03±0.03	179.75±0.17
15	0.63±0.07	0.84±0.00	0.91±0.07	0.91±0.07	1.05±0.07	80.87±0.02	51.54±0.2	51.61±0.3	38.81±0.02	136.25±0.73
18	0.91±0.07	0.77±0.07	0.98±0.00	1.12±0.00	0.91±0.07	76.03±0.3	50.61±0.04	50.84±0.03	36.18±0.00	144.41±0.73
21	0.84±0.00	0.84±0.00	0.98±0.00	1.4±0.00	0.91±0.07	76.41±0.1	48.11±0.2	50.76±0.1	34.96±0.02	163.03±0.56
24	0.98±0.00	0.77±0.07	0.98±0.00	1.47±0.07	0.91±007	61.61±0.03	47.22±0.05	42.71±0.1	33.09±0.5	100.08±0.11
27	0.98±0.00	0.91±0.07	0.98±0.00	1.47±0.07	1.05±0.07	59.99±0.01	46.56±0.03	36.275±0.3	33.02±0.01	68.71±0.2
30	0.98±0.00	1.05±0.07	1.05±0.07	1.54±0.00	1.19±0.07	61.85±0.05	45.69±0.04	34.82±0.07	32.56±0.28	58.2±0.28
Days	**Total phosphorus (g/kg)**					**Available phosphorus (g/kg)**				
0	2.72±0.00	2.28±0.01	2.18±0.0	2.97±0.04	0.99±0.01	1.72±0.0	1.57±0.0	1.34±0.05	1.93±0.0	0.58±0.02
3	2.76±0.00	2.33±0.0	2.22±0.02	2.99±0.02	1.00±0.0	2.04±0.08	1.58±0.01	1.47±0.01	2.12±0.0	0.55±0.0
6	2.77±0.01	2.37±0.01	2.51±0.0	3.49±0.02	1.23±0.0	1.79±0.05	1.6±0.01	1.47±0.01	2.21±0.4	0.56±0.0
9	2.88±0.04	2.4±0.00	2.57±0.0	3.56±0.02	1.23±0.02	2.19±0.03	1.64±0.01	1.48±0.01	2.33±0.01	0.62±0.0
12	3.23±0.00	2.44±0.0	2.73±0.01	3.61±0.03	1.01±0.02	1.63±0.0	1.65±0.0	1.61±0.01	2.39±0.02	0.59±0.0
15	3.38±0.05	2.63±0.0	2.87±0.01	3.70±0.04	1.1±0.02	2.08±0.04	1.66±0.0	1.70±0.02	2.55±0.0	0.66±0.1
18	2.97±0.00	3.0±0.05	2.95±0.0	3.84±0.02	1.11±0.07	2.01±0.01	1.69±0.0	1.72±0.02	2.66±0.0	0.68±0.0
21	2.68±0.0	3.3±0.0	3.03±0.01	3.99±0.02	1.05±0.01	2.08±0.0	1.77±0.0	1.87±0.01	2.72±0.0	0.90±0.0
24	3.08±0.0	3.3±0.02	3.16±0.00	4.08±0.03	1.21±0.0	2.36±0.0	1.8±0.0	2.06±0.05	2.77±0.0	0.74±0.02
27	3.18±0.0	3.3±0.03	3.20±0.00	4.43±0.07	1.3±0.01	2.45±0.0	2.38±0.0	2.17±0.01	2.82±0.2	0.67±0.00
30	3.32±0.03	3.34±0.02	3.36±0.0	4.50±0.03	1.28±0.00	2.43±0.01	2.47±0.01	2.29±0.02	2.87±0.01	0.73±0.02

Mean value followed by different letters in columns is statistically different (ANOVA; $P < 0.05$)

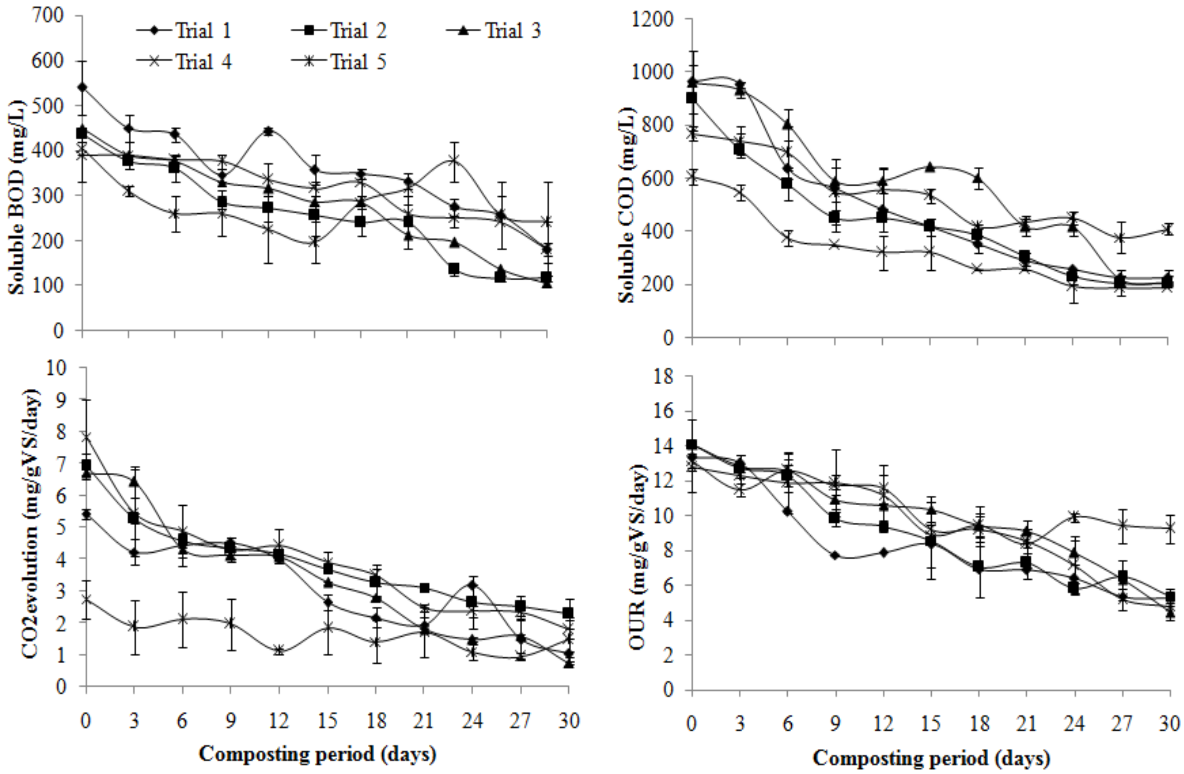

Figure 3
Variation of BOD, COD, CO_2 evolution rate and OUR during composting process

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