

# Assessment of compost quality in agitated pile composting of water hyacinth collected from different sources

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## Abstract

**Background** Water hyacinth (*Eichhornia crassipes*) can cause a diversity of problems due to its fast spread and congested growth. The composting of water hyacinth can reduce the chemical fertilizer application to the agricultural field and problems related to its fast growth rate and also help in nutrient recycling. The present study was carried out on agitated pile composting of water hyacinth collected from four different areas (Bharalu River, Agriculture site, Boragaon landfill site and Industrial site). The nutrients and stability parameters were evaluated during the 30 days of agitated pile composting of water hyacinth mixed with cattle manure and sawdust. The stability of compost was evaluated using respiration techniques (CO<sub>2</sub> evolution and oxygen uptake rate).

**Results** Results showed that nutrients (Na, K, Ca, total nitrogen and phosphorus) were increased significantly in all agitated pile composting. Stability parameters such as CO<sub>2</sub> evolution rate and oxygen uptake rate, biochemical oxygen demand and chemical oxygen demand were reduced significantly during the process. Highest reduction of moisture content (35.2 %), volatile solid (40.5 %), ammonical nitrogen (75.6 %), biochemical oxygen demand (65.3 %), CO<sub>2</sub> evolution rate (78.7 %), and oxygen uptake rate (74.4 %) were observed in the agitated pile of Bharalu River site as compared to other agitated piles. The higher increase of total nitrogen

(83.5 %) and total phosphorus (76.0 %) was also observed in the agitated pile of Bharalu River site.

**Conclusion** Addition of optimum amount of cattle manure was highly efficient for making compost of water hyacinth collected from four different sites. Highest content of nutrients was found in compost of water hyacinth collected from Bharalu River site due to availability of nutrients in sewage water. In the final compost of all trials, total coliform and fecal coliform were reduced significantly, which are pathogen indicators in the compost. The best compost quality was found in water hyacinth collected from Bharalu River site.

**Keywords** Water hyacinth · Agitated pile composting · Nutrients · Stability · Bharalu River

## Introduction

Water hyacinth (*Eichhornia crassipes*) is a free-floating macrophyte, growing in or near water, that is emergent, submerged or free floating (Singh and Kalamdhad 2012). Due to very high productivity, water hyacinth has been considered as one of the worst aquatic plants of the world. It can double its size in 5 days under optimum temperature and moisture. The dense mats of water hyacinth can interfere with navigation, recreation and irrigation as well as the blockage of canals and rivers can even cause dangerous flooding. Availability of oxygen is low beneath the mats that generate good breeding conditions for mosquito vectors of malaria, encephalitis and filariasis (Gajalakshmi et al. 2002; Malik 2007). Composting is the most promising technique for the treatment of water hyacinth; composting can solve two problems: (a) reduce chemical fertilizer load and (b) check the abnormal growth of

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hyacinth. The formation of humic substances is the final product of any type of composting process; it holds sufficient quantity of nutrients (nitrogen, potassium, calcium and phosphorus) which are required for the plants growth Gajalakshmi et al. 2002; Prasad et al. 2013; Singh and Kalamdhad 2013a). Water hyacinth compost application in agriculture mainly results from its content of organic matter, plant nutrients, promoting plant growth and inhibiting root pathogens/soil-borne plant diseases (Balasubramanian et al. 2013).

As the composting process proceeds, the readily degradable organic mass is converted into stable humic substances (Haug 1993). The compost is considered stable if it contains mainly recalcitrant or humus-like matter, but some times unstable when it contains a high quantity of biodegradable matter that may maintain high microbial activity (Kalamdhad et al. 2009). Stability of compost is a key parameter 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 process (Kalamdhad et al. 2009).

A Boragaon landfill (Guwahati, India) may cause contamination of soil and water via leaching. This landfill has covered the surrounding area of the Deepor Beel Lake. Leachate is generated by landfill possibly entering into lake and pollutes fresh water resource. Growing water hyacinth in those areas may accumulate nutrient from the polluted water. Bharalu River is highly polluted by sewage of Guwahati city, India. Water hyacinth plants are growing in this River accumulating high concentration of nutrients. Loss of nutrient from agriculture field due to runoff in low-lying areas is very common phenomenon in the agricultural field. These are the most favorable conditions for the growth of the water hyacinth which are often found in developing countries. Rising water hyacinth in these sites may contain high concentration of nutrients. Some studies have been done on agitated pile composting of different wastes (Parkinson et al. 2004; Jouraiphy et al. 2005; Singh and Kalamdhad 2012, 2013a, b), but there is no information available on composting of water hyacinth collected from different sources. Therefore, the objective of the present study was to assess the nutrients and stability parameters during agitated pile composting of water hyacinth collected from Bharalu River site (BRS), agriculture site (AS), boragaon landfill site (BLS) and industrial site (IS).

## Materials and methods

### Feedstock materials and design of agitated pile composting

The composting study was carried out in the summer season (from June, 2013 to July, 2013). Water hyacinth, cattle (cow)

manure and sawdust were used for the preparation of different waste mixtures for the composting process. Water hyacinth was collected from four different places, i.e. Amingaoan industrial site (IS) near Indian Institute of Technology Guwahati (IITG) campus, Boragaon landfill site (BLS), Bharalu River site (BRS) and low-lying area near agriculture site (AS), Guwahati, India. Water hyacinth (shoot + root) was collected from 4 to 5 different places at each sampling site to ensure the grab sampling. All collected materials were processed in the laboratory before composting process. The maximum particle size of water hyacinth in the waste mixture was restricted to 1 cm by chopping to provide better aeration. Cattle manure was obtained from dairy farm near the IITG campus. Sawdust was purchased from nearby saw mill. On the basis of our previous studies (Singh and Kalamdhad 2012, 2013a, b; Prasad et al. 2013), a mixture of 90 kg water hyacinth, 45 kg cattle manure and 15 kg sawdust (6:3:1 ratio of water hyacinth, cattle manure and sawdust) was taken for the study. This was the best combination for nutrient recycling and stability analysis during water hyacinth composting; therefore, in this study same combinations have been used with water hyacinth collected from four different sources. The initial characterizations of raw materials are given in Table 1. Four different waste combinations were composted in agitated pile (length 2100 mm, base width 350 mm, top width 100 mm and height 250 mm). A length to base width ( $L/W$ ) ratio of 6 was maintained for each agitated pile. Agitated piles contained approximately 150 kg of different waste combinations and composted for 30 days. Temperature was monitored by a digital thermometer during the composting period. About 500 g of homogenized samples were collected from five different locations, mostly at the mid span and ends of the pile by compost sampler without disturbing the adjacent materials in the pile on days 0, 3, 6, 9, 12, 15, 18, 21, 24, 27, and 30 after turning. Finally all the grab samples were mixed carefully to make a homogenized sample. Triplicate samples were collected and stored at 4 °C for analysis of biochemical parameters. Sub-samples were dried at 105 °C in oven for 24 h and moisture content was calculated as given in Eq. 1. Dried samples were ground to pass to 0.2 mm sieves and stored for further analysis.

$$\text{Moisture content (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \quad (1)$$

### Analysis of physico-chemical and biological parameters

Each sub-sample was analyzed for the following parameters: pH and electrical conductivity (EC) (1:10 w/v

**Table 1** Initial characterization of waste materials collected from different sources (Mean  $\pm$  SD,  $n = 3$ )

Parameters	Water hyacinth BRS	Water hyacinth AS	Water hyacinth BLS	Water hyacinth IS	Sawdust	Cattle manure
pH	5.98 $\pm$ 0.16	5.86 $\pm$ 0.03	5.51 $\pm$ 0.04	5.79 $\pm$ 0.07	6.2 $\pm$ 0.005	6.7 $\pm$ 0.05
EC (dS/m)	6.04 $\pm$ 0.29	5.10 $\pm$ 0.14	4.44 $\pm$ 0.11	4.91 $\pm$ 0.01	0.4 $\pm$ 0.002	3.3 $\pm$ 0.03
Moisture content (%)	85.95 $\pm$ 0.35	88.95 $\pm$ 0.35	87.25 $\pm$ 0.65	85.94 $\pm$ 0.055	10.01 $\pm$ 0.04	80.9 $\pm$ 0.19
Volatile solids (%)	73.57 $\pm$ 1.4	74.85 $\pm$ 0.75	75.22 $\pm$ 1.66	72.64 $\pm$ 0.037	97.9 $\pm$ 0.2	72.05 $\pm$ 0.224
Ash content (%)	26.44 $\pm$ 1.4	25.15 $\pm$ 0.75	24.78 $\pm$ 1.66	27.50 $\pm$ 0.11	2.13 $\pm$ 0.23	27.9 $\pm$ 0.22
TOC (%)	40.87 $\pm$ 0.79	41.58 $\pm$ 0.75	41.79 $\pm$ 0.09	40.27 $\pm$ 0.06		
Total Nitrogen (%)	1.19 $\pm$ 0.16	1.33 $\pm$ 0.41	1.11 $\pm$ 0.12	1.15 $\pm$ 0.14	0.38 $\pm$ 0.01	1.4 $\pm$ 0.168
Ammonical nitrogen (mg/kg)	153.0 $\pm$ 0.77	87.9 $\pm$ 0.53	178 $\pm$ 10.001	152.8 $\pm$ 2.9	96.59 $\pm$ 7.5	135.6 $\pm$ 5.3
Available phosphorus (mg/kg)	3171 $\pm$ 0.5	2750 $\pm$ 150	3521 $\pm$ 20	5801 $\pm$ 200	1563 $\pm$ 11	3574 $\pm$ 119
Total phosphorus (mg/kg)	6089 $\pm$ 223	4975 $\pm$ 25	6075 $\pm$ 179	9967 $\pm$ 126	2214 $\pm$ 7	2277 $\pm$ 5.8
Sodium(mg/kg)	14405 $\pm$ 862	3427.5 $\pm$ 17	11723.5 $\pm$ 1488	8875 $\pm$ 125	1097.5 $\pm$ 2.5	2400 $\pm$ 5
Potassium(mg/kg)	26472 $\pm$ 1151	6047 $\pm$ 485	20483.5 $\pm$ 1831	18195 $\pm$ 205	697.5 $\pm$ 7.5	987.5 $\pm$ 22.5
Calcium(mg/kg)	5690.5 $\pm$ 454	2674.5 $\pm$ 221	8063.5 $\pm$ 500	6177.5 $\pm$ 7.5	2420 $\pm$ 15	9892.5 $\pm$ 17.2
COD (mg/L)	1440 $\pm$ 160	1120 $\pm$ 160	960 $\pm$ 160	1600 $\pm$ 320	255 $\pm$ 105	420 $\pm$ 0.0
BOD (mg/L)	480 $\pm$ 30	375 $\pm$ 15	465 $\pm$ 15	360 $\pm$ 0.0	950 $\pm$ 310	1920 $\pm$ 640
CO <sub>2</sub> evolution (mg/g VS/day)	6.07 $\pm$ 0.25	5.28 $\pm$ 0.95	5.73 $\pm$ 0.40	5.74 $\pm$ 0.1	1.95 $\pm$ 0.35	5.16 $\pm$ 0.2
OUR(mg/g VS/day)	15.33 $\pm$ 0.99	12.81 $\pm$ 0.45	14.56 $\pm$ 1.29	17.13 $\pm$ 1.5	2.38 $\pm$ 0.24	12.99 $\pm$ 0.43

BRS Bharalu river site, AS agricultural site, BLS Boragoan landfill site, IS industrial site, COD chemical oxygen demand, BOD biochemical oxygen demand, TOC total organic carbon

waste: water extract, and volatile solids (VS) (Kalamdhad et al. 2009). Volatile solid was determined by loss ignition method; 10 g sample was taken in crucible and kept in muffle furnace at 550 °C for 2 h. The total nitrogen (TN) was determined using the Kjeldahl method; 0.2 g of sample (dried) was digested with 10 ml of concentrated H<sub>2</sub>SO<sub>4</sub> and catalyst mixture (CuSO<sub>4</sub>:K<sub>2</sub>SO<sub>4</sub>, 5:1 ratio) and heated at 400 °C. After digestion, sample was diluted to 100 mL with distilled water. 10 mL of diluted sample was mixed with 20 mL of 40 % NaOH and subjected to the distillation assembly. Ammonia gas was collected in 25 mL of boric acid solution in 250 mL conical flask and then titrated with standardized H<sub>2</sub>SO<sub>4</sub> (0.02 N). Boric acid solution was prepared with mixed indicator (methyl red and methylene blue). The end point is the appearance of purple colour. NH<sub>4</sub>-N and NO<sub>3</sub>-N were determined using KCl extraction (Tiquia and Tam 2000); a 3-g oven-dried sample was taken in a 250 mL conical flask and mixed with 30 mL 2 M KCl solution. The mixture was placed in a horizontal shaker for 2 h. The analysis for NH<sub>4</sub><sup>+</sup>-N in the filtered sample was done using Phenate Method (APHA 2005). The Flame photometer (Systronic 128) was used for analysis of Na, K and Ca concentration after digestion of the 0.2-g sample with 10 mL H<sub>2</sub>SO<sub>4</sub> and HClO<sub>4</sub> mixture (5:1) in block digestion system (Pelican Equipments Chennai-India) for 2 h

at 300 °C. Above acid-digested sample was also taken for the determination of available and total phosphorus (acid digestion) using the stannous chloride method (APHA 2005). Calculations of VS and TN of compost samples are given in Eq. 2 and 3, as follows:

$$VS (\%) = \frac{\text{Initial weight} - \text{weight after burning}}{\text{Initial weight}} \times 100 \quad (2)$$

$$TN (\%) = \frac{14 \times (S - B) \times N}{\text{weight (g)}} \times 100, \quad (3)$$

where  $S$  mL of standard sulfuric acid used for sample,  $B$  mL of standard sulfuric acid used for blank,  $N$  normality of standard sulfuric acid

The biodegradable organic matter was measured as soluble biochemical oxygen demand (BOD) (by the dilution method; APHA 2005) and soluble chemical oxygen demand (COD) (by the dichromate method; APHA 2005). The population of total coliforms (TC) in the compost was determined in extract (compost:water extract, 1:10) by inoculation of culture tube media using the most probable number (MPN) method (APHA 2005).

The stability parameters, i.e. oxygen uptake rate (OUR) and CO<sub>2</sub> evolution rate were determined according to the

Kalamdhad et al. (2008). For the determination of CO<sub>2</sub> evolution rate, about 25 g of fresh compost sample was taken in 1 L of polyvinyl chloride airtight container. About 10 g of oven-dried (105 °C) soda lime (1.5–2.0 mm mesh size) was taken in a 100-mL beaker and placed in the above container. The initial weight of the soda lime was measured. The container with soda-lime beaker was kept in an incubator at 25 °C temperature for 24 h. After 24 h, the soda-lime was taken out and oven dried again; then the final weight was noted down. CO<sub>2</sub> evolution rate was calculated by the following formula Eq. (4) (Kalamdhad et al. 2008):

$$\text{Carbon dioxide evolution (mg/g VS/hr)} = \frac{(W1 - W2) \times 1000}{W \times T} \times 100, \quad (4)$$

where W1 is initial weight of the soda-lime (g), W2 is final weight of the soda-lime (g), W is weight of compost sample (g) and T is time duration of incubation (h).

The OUR was measured in a liquid suspension of 5–8 g of compost sample in 500 mL of distilled water in which CaCl<sub>2</sub>, MgSO<sub>4</sub>, FeCl<sub>3</sub> and phosphate buffer (pH 7.2) were added. The mixture was kept in suspension by placing it on the magnetic stirrer at 30 °C temperature. During this time, the dissolved O<sub>2</sub> in the suspension was continuously measured by the digital dissolved oxygen meter attached. The oxygen consumption rate was calculated by taking the difference of dissolved oxygen with the respect to the time intervals and calculated value was quoted as the OUR in mg O<sub>2</sub>/g VS/h (Kalamdhad et al. 2008).

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

## Results and discussion

### Physico-chemical analysis

The composting pile temperature went through three typical phases (mesophilic, thermophilic and cooling phase) and ranged from 22 to 52 °C during the entire period of composting (Fig. 1). The cattle manure affected the temperature during the agitated pile composting in all four different agitated piles. Addition of optimum amount of cattle manure to the composting materials may fasten the composting process by providing easily available carbon to the microorganisms present in the composting mass. Therefore, microbial metabolic activities have increased and temperature was increased in very short time (Singh and Kalamdhad 2012, 2014). In agitated pile composting of

BRS reached the highest temperature among all four piles due to quick establishment of microbial activity during the composting process (Chen et al. 2010). Although addition of cattle manure increased the composting process in all agitated piles the results indicate that the composting microbes started utilizing the easily degradable materials at the earliest in BRS. The highest temperature was observed in BRS (52 °C) followed by BLS (51.3 °C), AS (50.8 °C) and IS (48.5 °C). After 12th day, temperature in all piles was reduced and reached near-ambient temperature. Reduction in temperature indicated all piles achieved stability within 30 days of composting period.

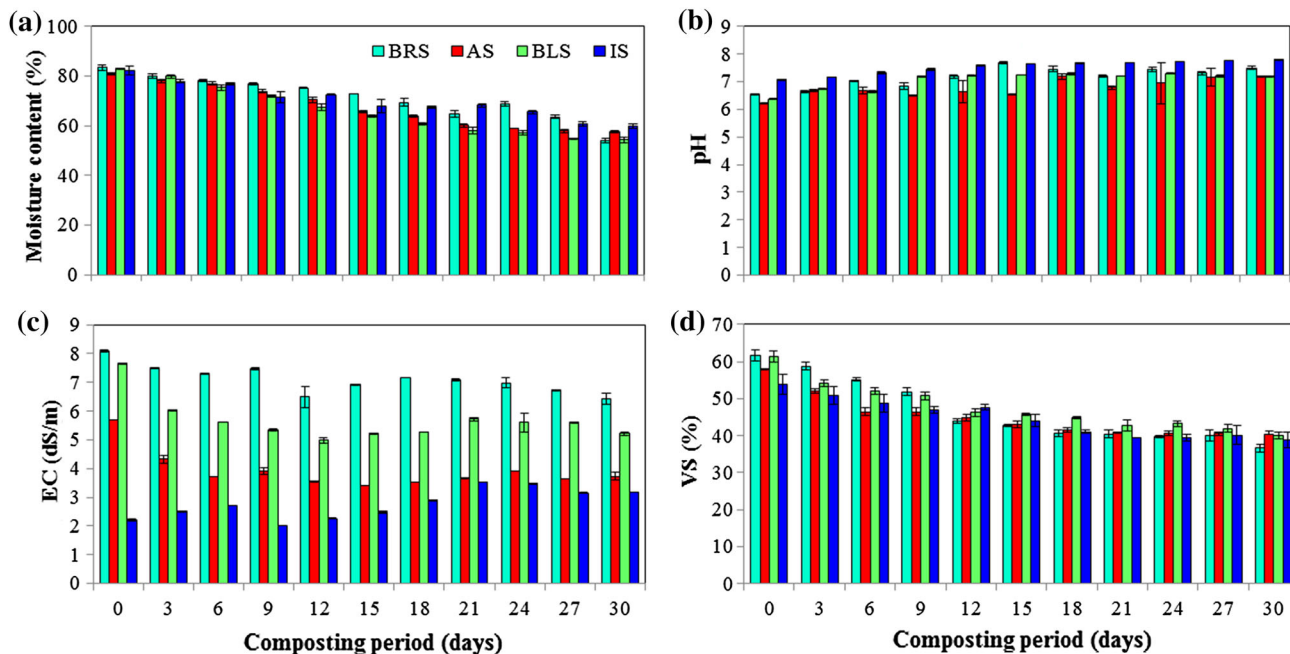
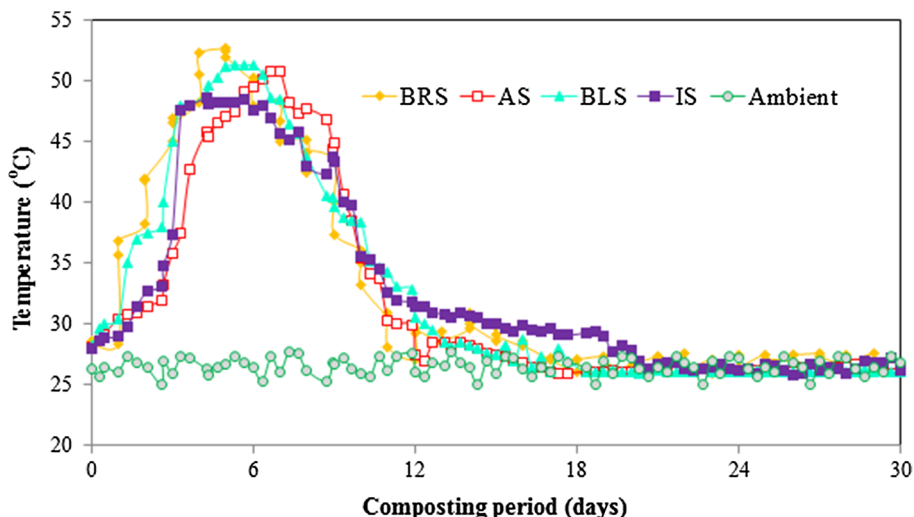
Initial composting mixture requires optimum moisture content for the survival of microorganisms. The reduction in moisture content during the composting process in the form of vapors by the heat generation can be viewed as an index of decomposition rate (Kalamdhad et al. 2009). Initial moisture contents were observed about 83.4, 80.9, 82.9 and 82.2 % which were reduced to 54.1, 57.7, 54.3 and 59.9 % during pile composting of water hyacinth collected from BRS, AS, BLS and IS, respectively (Fig. 2a). Highest moisture loss occurred in agitated pile of BRS (35.2 %) followed by BLS (34.5 %), AS (28.6 %) and IS (27.1 %). On analyzing the results by ANOVA, the decrease in moisture content varied significantly between the days ( $P < 0.05$ ).

Figure 2b illustrates that the pH was increased from 6.5 to 7.5, 6.2 to 7.2, 6.4 to 7.2 and 7.1 to 7.8 in agitated pile of BRS, IS, BLS and IS, respectively. The pH values were increased during the composting process may be due to sufficient aeration provided through the turning of piles at every 3rd day. Consequently, carbon dioxide level was reduced during the composting process (Singh and Kalamdhad 2013a). Significant difference in pH was observed in all the trials ( $P < 0.05$ ). The pH values were measured within the optimal range for the development of bacteria (6.0–7.5) and fungi (5.5–8.0) (Amir et al. 2005).

Electrical conductivity (EC) is generally measured during composting because it reflects the salinity of the compost and its appropriateness for plant growth (Singh and Kalamdhad 2013a). Fig. 2c depicts the reduction of EC from 8.1 to 6.4 dS/m, 5.7 to 3.7 dS/m and 7.7 to 5.2 dS/m in the agitated pile of BRS, IS and BLS, respectively; however, EC was increased about 2.2–3.2 dS/m in agitated pile of IS. EC was decreased during the composting process probably due to volatilization of ammonia and the precipitation of mineral salts (Kalamdhad et al. 2009). In the agitated pile of IS, EC was enhanced probably due to the net loss of weight and release of soluble salts through decomposition activity in the composting process. On analyzing the results by ANOVA, EC varied significantly between the all agitated piles ( $P < 0.05$ ).

Figure 2d shows the trend of organic matter degradation during the 30-day composting process in four different

**Fig. 1** Variation of temperature during composting process



**Fig. 2** Variation of moisture content, pH, electrical conductivity and organic matter during composting process

agitated piles. The content of organic matter was decreased from 61.7, 58.0, 61.4 and 53.7 % to 36.7, 40.2, 40.1 and 38.9 % in the agitated pile of BRS, AS, BLS and IS, respectively, as the decomposition progressed. Higher loss of organic matter was observed in agitated pile of BRS (40.5 %) followed by BLS (34.8 %), AS (30.6 %) and IS (27.6 %). BRS composting shows higher loss of organic matter as a result of higher temperature evolution as compared to other agitated piles. A significant variation in organic matter loss was found in all the agitated piles ( $P < 0.05$ ). In the composting process organic matter is

decomposed and transformed to stable humic substances (Prasad et al. 2013).

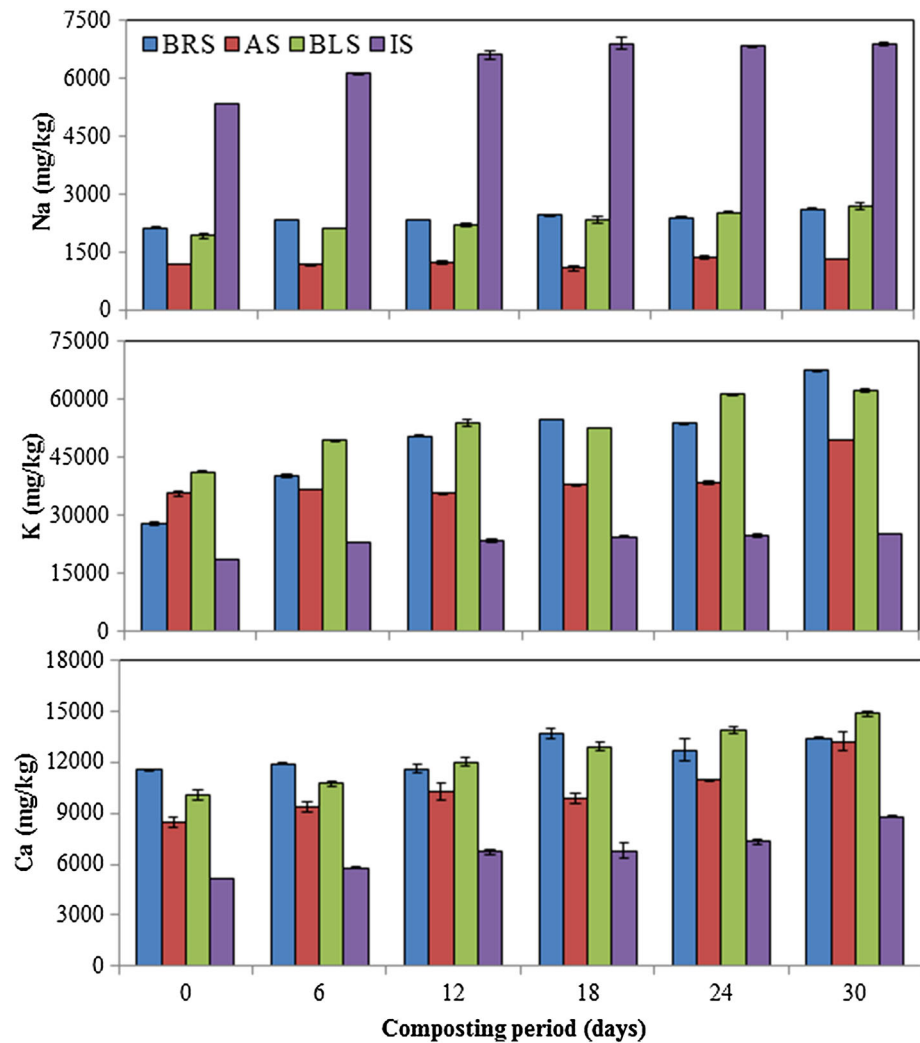
Table 2 shows that the total nitrogen was increased significantly ( $P < 0.05$ ) from 0.85, 0.83, 1.05 and 0.64 % to 1.56, 1.19, 1.47 and 1.05 % in the agitated pile of BRS, AS, BLS and IS, respectively, during the composting process. The maximum increase in total nitrogen was observed in agitated pile of BRS (83.5 %) followed by IS (64.1 %), AS (43.4 %) and BLS (40.0 %). The total nitrogen was increased from 0.9 to 1.6 %, from 0.8 to 1.2 %, from 1.1 to 1.5 % and from 0.6 to 1.1 % in BRS, AS, BLS

**Table 2** Changes in physico-chemical parameters during the composting process (Mean  $\pm$  SD,  $n = 3$ )

Days	Nutrients concentration							
	BRS	AS	BLS	IS	BRS	AS	BLS	IS
	Total nitrogen (%)				NH <sub>4</sub> -N (mg/kg)			
0	0.85 $\pm$ 0.13	0.83 $\pm$ 0.07	1.05 $\pm$ 0.07	0.64 $\pm$ 0.02	253.49 $\pm$ 0.26	42.26 $\pm$ 0.53	223.31 $\pm$ 4.38	70.67 $\pm$ 0.17
3	1.05 $\pm$ 0.21	0.74 $\pm$ 0.02	1.05 $\pm$ 0.07	0.64 $\pm$ 0.03	377.9 $\pm$ 1.23	43.33 $\pm$ 0.32	206.04 $\pm$ 1.88	74.21 $\pm$ 0.03
6	1.05 $\pm$ 0.07	0.84 $\pm$ 0.14	1.05 $\pm$ 0.21	0.68 $\pm$ 0.02	156.36 $\pm$ 0.09	42.46 $\pm$ 0.0	193.03 $\pm$ 4.52	78.78 $\pm$ 0.06
9	0.98 $\pm$ 0.14	0.81 $\pm$ 0.03	1.19 $\pm$ 0.07	0.68 $\pm$ 0.02	167.69 $\pm$ 8.88	35.61 $\pm$ 0.0	182.79 $\pm$ 2.59	60.5 $\pm$ 0.13
12	1.12 $\pm$ 0.14	0.84 $\pm$ 0.0	1.26 $\pm$ 0.14	0.77 $\pm$ 0.07	105.13 $\pm$ 6.51	32.95 $\pm$ 0.50	94.08 $\pm$ 2.59	54.24 $\pm$ 0.08
15	1.19 $\pm$ 0.07	0.98 $\pm$ 0.14	1.47 $\pm$ 0.07	0.91 $\pm$ 0.07	93.32 $\pm$ 0.06	32.48 $\pm$ 0.09	92.20 $\pm$ 1.43	51.61 $\pm$ 0.34
18	1.33 $\pm$ 0.07	0.98 $\pm$ 0.0	1.33 $\pm$ 0.21	0.98 $\pm$ 0.0	91.86 $\pm$ 0.04	26.76 $\pm$ 0.57	99.18 $\pm$ 0.54	50.85 $\pm$ 0.03
21	1.26 $\pm$ 0.14	0.91 $\pm$ 0.07	1.19 $\pm$ 0.07	0.98 $\pm$ 0.0	85.3 $\pm$ 0.04	26.79 $\pm$ 4.26	94.045 $\pm$ 1.2	50.76 $\pm$ 0.10
24	1.33 $\pm$ 0.07	1.05 $\pm$ 0.07	1.267 $\pm$ 0.01	0.98 $\pm$ 0.0	69.42 $\pm$ 0.03	29.19 $\pm$ 0.07	96.49 $\pm$ 3.76	42.71 $\pm$ 0.14
27	1.47 $\pm$ 0.07	1.12 $\pm$ 0.14	1.4 $\pm$ 0.14	0.98 $\pm$ 0.0	67.76 $\pm$ 6.41	27.12 $\pm$ 0.08	103.83 $\pm$ 4.38	36.28 $\pm$ 0.35
30	1.56 $\pm$ 0.02	1.19 $\pm$ 0.1	1.47 $\pm$ 0.07	1.05 $\pm$ 0.07	61.91 $\pm$ 0.10	21.53 $\pm$ 0.01	94.30 $\pm$ 2.82	34.82 $\pm$ 0.07
Days	Total phosphorus (g/kg)				Available phosphorus (g/kg)			
0	3.05 $\pm$ 0.24	1.57 $\pm$ 0.14	3.14 $\pm$ 0.12	2.19 $\pm$ 0.0	2.8 $\pm$ 0.05	1.32 $\pm$ 0.08	1.59 $\pm$ 0.05	1.43 $\pm$ 0.14
3	3.16 $\pm$ 0.19	1.7 $\pm$ 0.01	3.41 $\pm$ 0.01	2.22 $\pm$ 0.02	3.07 $\pm$ 0.07	1.55 $\pm$ 0.16	1.51 $\pm$ 0.03	1.52 $\pm$ 0.07
6	3.16 $\pm$ 0.23	1.96 $\pm$ 0.0	3.92 $\pm$ 0.0	2.51 $\pm$ 0.0	3.1 $\pm$ 0.05	1.52 $\pm$ 0.01	1.61 $\pm$ 0.03	1.54 $\pm$ 0.08
9	3.22 $\pm$ 0.29	2.02 $\pm$ 0.01	4.04 $\pm$ 0.01	2.6 $\pm$ 0.0	3.1 $\pm$ 0.24	1.44 $\pm$ 0.04	1.64 $\pm$ 0.02	1.6 $\pm$ 0.09
12	3.38 $\pm$ 0.51	2.26 $\pm$ 0.01	4.53 $\pm$ 0.01	2.73 $\pm$ 0.01	3.01 $\pm$ 0.03	1.28 $\pm$ 0.04	1.75 $\pm$ 0.01	1.63 $\pm$ 0.03
15	3.50 $\pm$ 0.23	2.27 $\pm$ 0.03	4.53 $\pm$ 0.05	2.87 $\pm$ 0.01	3.13 $\pm$ 0.03	1.49 $\pm$ 0.17	1.81 $\pm$ 0.01	1.67 $\pm$ 0.01
18	3.46 $\pm$ 0.2	2.28 $\pm$ 0.01	4.56 $\pm$ 0.02	2.95 $\pm$ 0.0	3.45 $\pm$ 0.07	1.57 $\pm$ 0.13	1.88 $\pm$ 0.09	1.69 $\pm$ 0.0
21	3.03 $\pm$ 0.21	2.38 $\pm$ 0.0	4.76 $\pm$ 0.01	3.04 $\pm$ 0.01	3.52 $\pm$ 0.04	1.63 $\pm$ 0.14	2.37 $\pm$ 0.02	1.8 $\pm$ 0.04
24	3.53 $\pm$ 0.26	2.54 $\pm$ 0.02	5.07 $\pm$ 0.04	3.16 $\pm$ 0.0	3.64 $\pm$ 0.05	1.57 $\pm$ 0.03	2.33 $\pm$ 0.04	1.9 $\pm$ 0.11
27	4.0 $\pm$ 0.23	2.54 $\pm$ 0.0	5.07 $\pm$ 0.0	3.2 $\pm$ 0.0	3.53 $\pm$ 0.07	1.89 $\pm$ 0.11	1.95 $\pm$ 0.0	2.28 $\pm$ 0.10
30	5.37 $\pm$ 0.79	2.76 $\pm$ 0.01	5.52 $\pm$ 0.02	3.37 $\pm$ 0.0	3.57 $\pm$ 0.07	2.2 $\pm$ 0.23	1.91 $\pm$ 0.09	2.38 $\pm$ 0.10

and IS, respectively, within the composting time. It might be due to the net loss of dry mass in terms of CO<sub>2</sub> as well as the water loss by evaporation during oxidization of organic matter (Prasad et al. 2013). The total nitrogen generally increases during composting when organic matter loss is greater than the loss of NH<sub>4</sub>-N (Sarika et al. 2014). The ammonical nitrogen was reduced significantly ( $P < 0.05$ ) from 253.5, 42.3, 223.3 and 70.7 mg/kg to 61.9, 21.5, 94.3 and 34.8 mg/kg in the agitated pile of BRS, AS, BLS and IS, respectively (Table 2). The maximum reduction of ammonical nitrogen was found in agitated pile of BRS (75.6 %) followed by BLS (57.8 %), IS (50.7 %) and IS (49.1 %) during the process. At high pH, mixing and proper aeration enhance ammonia loss during maturation (Kalamdhad et al. 2009). Table 2 demonstrates that the total and available phosphorus were increased significantly ( $P < 0.05$ ) in all agitated piles. The total phosphorus concentration was increased from 3.1, 1.7, 3.3, and 2.2 g/kg to 5.4, 2.8, 5.5 and 3.4 g/kg in BRS, AS, BLS and IS, respectively. The available phosphorus concentration was

increased from 2.8 to 3.6 mg/kg, from 1.7 to 2.2 mg/kg, from 1.6 to 1.9 mg/kg and from 1.4 to 2.4 g/kg in BRS, AS, BLS and IS, respectively, in the 30 days of composting process. The concentrations of total and available phosphorus were increased during the composting process might be due to phosphorus released by micro-organisms through the mineralization of organic matter. The results of present study were consistent with those of the other study (Sarika et al. 2014). The highest percentage of total phosphorus and available were increased in the compost of BRS (76.0 %) and IS (66.3 %), respectively. Figure 3 shows that nutrient (Na, K and Ca) concentration was increased significantly ( $P < 0.05$ ) due to degradation of organic matter during the composting process (Huang et al. 2004). The concentrations of nutrients (Na, K and Ca) were increased in the range of 1.21–6.89 g/kg for Na, 18.68–67.43 g/kg for K and 5.18–14.88 g/kg for Ca in final compost of all agitated piles. Nutrient concentrations were increased during composting process due to the net loss of dry mass (Sarika et al. 2014).

**Fig. 3** Changes in Na, K and Ca during composting process

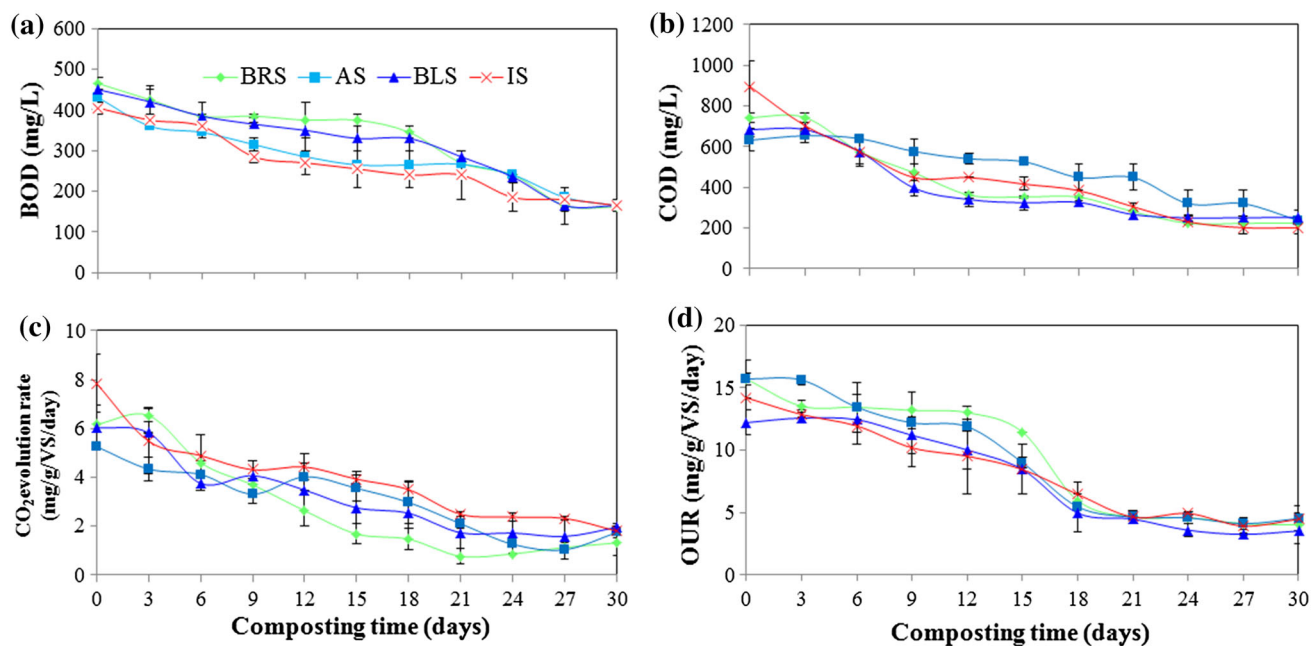
### Biological analysis

Respiration of organic matter during degradation is measured as BOD, COD, OUR and CO<sub>2</sub> evolution rate. These parameters reduced with organic matter degradation, consequently decreased the emission of carbon dioxide, ultimately indicating stabilization of the compost (Kalamdhad and Kazmi 2009). Figure 4a, b demonstrates that the soluble BOD and COD were reduced significantly ( $P < 0.05$ ). The higher reduction in BOD was found in BRS (65.3 %) followed by BLS (63.3 %), AS (61.6 %) and IS (59.3 %); however, higher reduction in COD was found in IS (77.5 %) followed by BRS (69.7 %), BLS (63.2 %) and AS (62.3 %).

The CO<sub>2</sub> evolution directly correlates to aerobic respiration, the measurement of respiration and consequently aerobic biological activity (Kalamdhad et al. 2009). The OUR is the most accepted method for the determination of biological activity of a materials; it measures compost stability by assessing the amount of easily biodegradable

organic matter still present in the compost through its carbonaceous oxygen demand (Singh et al. 2009). Significantly higher reduction ( $P < 0.05$ ) in CO<sub>2</sub> evolution rate was found in BRS (78.7 %) followed by IS (77.0 %), BLS (67.8 %) and AS (66.8 %) (Fig. 4c), while higher reduction in OUR was found in BRS (74.4 %) followed by AS (71.2 %), BLS (71.1 %) and IS (68.6 %) during the process ( $P < 0.05$ ) (Fig. 4d). The presence of coliform bacteria is generally used as an indicator of overall sanitary quality of the compost. Most of the pathogens and parasites are destroyed at high temperatures during the composting process. The fecal coliform was within the recommended limit of density  $5 \times 10^2$  MPN/g dry weights for the compost hygienization (Kalamdhad et al. 2009). The total coliform levels declined from  $2.3 \times 10^{12}$  to  $5.3 \times 10^2$ ,  $1.5 \times 10^8$  to  $2.1 \times 10^6$ ,  $9.3 \times 10^{10}$  to  $4.6 \times 10^7$  and  $1.1 \times 10^{10}$  to  $1.5 \times 10^6$  MPN/g wet weight in the agitated pile of BRS, AS, BLS and IS, respectively. The fecal coliform levels were also reduced from  $3.6 \times 10^8$  to 23,  $4.3 \times 10^2$  to 28,  $3.6 \times 10^2$  to  $1.2 \times 10^2$  and  $2.4 \times 10^2$  to





**Fig. 4** Variation of BOD, COD, CO<sub>2</sub> evolution rate and OUR during composting process

15 MPN/g wet weight in the agitated pile of BRL, AS, BLS and IS, respectively, during the composting process. The results of present study were consistent with the results reported by Prasad et al. (2013) during the agitated pile composting of water hyacinth performed with different ratios of cattle manure, sawdust and water hyacinth.

The reduction of total and fecal coliform can be attributed to pathogens killed at high temperatures during thermophilic phase (Hassen et al. 2001)

## Conclusion

Addition of optimum amount of cattle manure provides easily available carbon sources for composting microorganisms. The pH was changed from slightly acidic to neutral at the end of composting process. Highest reduction of moisture content, organic matter, ammoniacal nitrogen, CO<sub>2</sub> evolution rate and oxygen uptake rate was observed in the agitated pile of Bharalu River site as compared to industrial site, agricultural site and Boragaon landfill site during the composting process. The nutrient (nitrogen, available phosphorus, Na, K and Ca) content was increased significantly in the final compost of all agitated piles but higher increment was found in the final compost of water hyacinth collected from Bharalu River site. Total and fecal coliform were reduced significantly, which are pathogen indicators in the compost. Therefore, the present study concluded that the addition of optimum amount of cattle manure was very efficient for composting water hyacinth collected from four

different sites, but better compost quality was found in water hyacinth collected from Bharalu River site.

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