Composting of water hyacinth using Saw dust/Rice straw as a bulking agent

Ganesh Chandra Dhal\textsuperscript{1}, Roshan Singh.W\textsuperscript{1}, Meena Khwairakpam\textsuperscript{2}, Ajay S. Kalamdhad\textsuperscript{1}

\textsuperscript{1} Department of Civil Engineering, Indian Institute of Technology Guwahati (IITG), Guwahati – 781039, India
\textsuperscript{2} Department of Civil Engineering, Malaviya National Institute of Technology (MNIT), Jaipur - 302017, India

kalamdhad@gmail.com
doi:10.6088/ijes.00202030009

ABSTRACT

The water hyacinth (\textit{Eichhornia crassipes}) is a free floating aquatic weed generally observed in the 23.15\% wetland area of north east region of India. Due to its fast growth and the robustness of its seeds, it has caused major problems in the whole area. However, the composting has the advantage of producing a product that is easy to work into the soil compared with dried water hyacinths, because of the decomposed structure. Therefore, the aim of this study was to investigate the evolution of some physico-chemical parameters during high rate pile composting of water hyacinth in combination with cattle manure and saw dust/rice straw as a bulking agent. Results suggested that the optimal degradation of water hyacinth can be possible in the presence of large amount of cattle manure; and rice straw could be a better option as a bulking agent in comparison with saw dust.

Keywords: Water hyacinth, Pile composting, Cattle manure, Rice straw, Saw dust.

1. Introduction

Agriculture is the mainstay of the north east India and people mainly depend on agriculture for their sustenance and livelihoods. The region does not enjoy technological advancement in terms of agriculture and road connectivity etc. as compared to mainland India. However, the indigenous people of this region are hard working and have been managing their agricultural activities especially in the upland with their traditional know-how since ages. Farmers, especially the marginal ones often do not get access to chemical fertilizers and pesticides (Husain 2003). Therefore, quality organic compost is the basic requirement of the motivation of effective and beneficial agricultural system of the region.

The water hyacinth (\textit{Eichhornia crassipes}) is a free floating aquatic weed originated in the 23.15\% wetland area of north east region of India, where it was kept under control by natural predators (Abbasi, 1998; Husain, 2003). The water hyacinth has caused major problems in the whole area, e.g., a reduction of fish, due to its rapid growth and the robustness of its seeds. It forms dense mats that avert river traffic, block irrigation canals, interfere with hydel power projects and destroy rice fields (Gupta et al., 2007). As water hyacinth decays, there is a sharp increase in nutrient levels in water body, which ultimately creates the problem of eutrophication in aquatic system. At an average annual productivity of 50 dry (ash-free) tones per hectare per year, water hyacinth is one of the most productive plants in the world (Abbasi and Nipaney, 1986). Since the weed covers the water surfaces faster than most other plants;
Composting of Water Hyacinth Using Saw Dust/Rice Straw as a Bulking Agent

Ganesh Chandra Dhal, W. Roshan Singh, Meena Khwairakpam, Ajay S. Kalamdhad
International Journal of Environmental Sciences Volume 2 No.3, 2012

leads to rapid decline of the quantity and the quality of water contained in the wetlands, eventually causing the loss of the wetlands.

Efforts to control the weed have caused high costs and labor requirements, leading to nothing but temporary removal of the water hyacinths (Malik, 2007). Since the most favorable conditions for the growth of the water hyacinth often are found in developing countries, very limited resources have been put into curbing them. Scraping the water hyacinth is not generates income, therefore it left to cover the lakes. Conversely the water hyacinth would have a great potential if seen as raw material for industries or if incorporated into agricultural practice (Gunnarsson and Petersen, 2007). Much work has been carried out in different parts of the world to develop environmentally sound and appropriate methods for the management and control of this weed. In this background authors studied the utilization of water hyacinth as substituting bean straw with water hyacinth as animal feed (Tag El-Din, 1992), feed for solid-phase fermentation (Chanakya et al., 1993), raw material for making pulp, paper and paper board (Goswami and Saikia, 1994) and the vermicomposting of water hyacinth (Gajalakshmi et al., 2001; Gupta et al., 2007). However, a novel technology with ecological sound and economically viable is urgently required to solve the problem of aquatic weed disposal and management.

Composting as an alternative treatment has the advantage of producing a product that is easy to work into the soil compared with dried water hyacinths. The windrow or pile composting method the most popular example of a nonreactor, agitated solids bed system (Haug, 1993). Mixed feedstocks are placed in rows and turned periodically, usually by mechanical equipment. Height, width, and shape of the windrows vary depending on the nature of the feed material and the type of equipment used for turning. Oxygen is supplied primarily by natural ventilation resulting from the buoyancy of hot gases in the windrow, and to a lesser extent, by gas exchange during turning. Periodic agitation by turning is used to restructure the windrow. As a result, considerable mixing can be expected along the height and width of the row but little mixing will occur along the length. Several successful studies were conducted on pile composting of cattle manure, swine manure, municipal bio-solids, animal mortalities and food residuals (Huang et al., 2004; Parkinson et al., 2004; Jouraiphy et al., 2005). However, Limited investigations have been made on high rate windrow/agitated pile composting of water hyacinth in combination with cattle manure, saw dust and rice-straw, though a few studies have been made on vermicomposting of water hyacinth.

Therefore, in order to understand the compost dynamics of high rate agitated pile composting, studies are required under different waste combinations. The aim of this study is to investigate the evolution of some physico-chemical parameters during high rate pile composting of water hyacinth in various combinations with cattle manure, saw dust and rice straw as bulking agents.

2. Materials and Method

2.1 The Compost Materials

Water hyacinth, cattle (Cow) manure, saw dust and rice straw/husk were used for preparation of different waste mixtures. Water hyacinth was collected form the lakes situated near the Indian Institute of Technology Guwahati campus. Cattle manure was obtained from nearby Amingaon village. Rice straw and saw dust were purchased from farmers of nearby village and saw mill, respectively. The compost will prepare with different proportioning of waste composition as described in Table 1.
Table 1: Waste composition and characteristics of waste materials

| Trials/parameter | Waste materials | Water hyacinth | Cattle manure | Saw dust | Rice straw |
|------------------|-----------------|----------------|---------------|----------|------------|
| Moisture content (%) | 90.2±1.7 | 85.3±1.9 | 38.1±2.1 | 13.2±1.1 |
| pH | 6.9±0.1 | 7.2±0.2 | 5.6±0.2 | 5.2±0.1 |
| Electrical conductivity (EC) (dS/m) | 8.4±0.2 | 4.5±0.3 | 0.4±0.1 | 2.3±0.2 |
| Ash content (%) | 23.2±1.1 | 12.2±1.4 | 5.1±1.2 | 13.4±1.3 |
| Total organic carbon (TOC) (%) | 33.8±1.3 | 35.2±0.8 | 38.1±1.2 | 34.6±0.9 |
| Ammonical nitrogen (NH₄-N) (%) | 0.38±0.02 | 0.35±0.03 | 0.16±0.01 | 0.26±0.02 |
| Total phosphorus (g/kg) | 2.2±0.3 | 0.3±0.1 | 0.09±0.02 | 0.3±0.1 |
| Available phosphorus (g/kg) | 0.35±0.03 | 0.11±0.01 | ND | 0.14±0.02 |
| K (g/kg dry matter) | 6.16±0.24 | 5.96±0.35 | 1.72±0.18 | 5.70±0.28 |
| Na (g/kg dry matter) | 1.86±0.08 | 3.51±0.12 | 0.78±0.07 | 0.45±0.07 |
| Ca (g/kg dry matter) | 4.59±0.34 | 3.72±0.28 | 2.01±0.19 | 2.28±0.37 |
| Mg (g/kg dry matter) | 3.96±0.24 | 8.12±0.21 | 0.69±0.17 | 4.07±0.32 |
| Fe (g/kg dry matter) | 3.63±0.38 | 3.10±0.31 | 0.72±0.24 | 0.61±0.16 |
| Pb (mg/kg dry matter) | 74.3±1.3 | 0.94±0.32 | 0.32±0.13 | 0.43±0.11 |
| Cr (mg/kg dry matter) | 38.2±2.1 | 8.1±1.4 | 1.6±1.1 | 1.4±0.3 |
| Cu (mg/kg dry matter) | 78.1±2.3 | 24.8±2.4 | 0.8±0.1 | 11.2±0.7 |
| Mn (mg/kg dry matter) | 566±12 | 867±11 | 10±2 | 516±15 |
| Cd (mg/kg dry matter) | 1.12±0.07 | 0.38±0.04 | 0.07±0.01 | 0.21±0.03 |
| Zn (mg/kg dry matter) | 734±15 | 232±11 | 45±9 | 86±7 |
| As (mg/kg dry matter) | 0.41±0.03 | 0.62±0.08 | ND | 0.52±0.05 |

*ND-Not detected

2.2 Agitated Pile Composting

Initially 3 trials (Phase 1: Trial 1, 2 and 3) have performed on pile composting of water hyacinth in combination with cattle manure and saw dust as a bulking agent; subsequently (Phase 2: Trial 4, 5 and 6) saw dust have replaced with rice straw in the same proportion with water hyacinth and cattle manure. All waste combinations was 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 100 kg of different waste combinations and were manually turned on 3, 6, 9, 12, 15, 18, 21, 24, 27 and 30 days. Composting period of total 30 days was decided for agitated pile composting.

2.3 Measuring Techniques

Temperature was monitored using a digital thermometer throughout the composting period. Four grab samples from the piles were collected after mixing the whole pile thoroughly by
hand; when the piles were made (0 day) and the piles were turned. All the grab samples were mixed together and considered to be a homogenized sample. Triplicate homogenized samples were collected and air dried immediately, ground to pass through a 0.2 mm sieve and stored for further analysis.

Each air dried and grounded sample was analyzed for the following parameters: pH and electrical conductivity (EC) (1:10 w/v waste:water extract), ash (550°C for 2 h) (loss on ignition), total nitrogen using the Kjeldahl method, NH₄-N and NO₃-N using KCl extraction (Tiquia and Tam, 2000), total organic carbon (TOC) determined by Shimadzu (TOC-VCSN) Solid Sample Module (SSM-5000A), available and total phosphorus (acid digest) using the stannous chloride method (APHA, 1995), potassium and sodium and calcium (acid digest) using flame photometry, trace elements including Fe, Pb, Cr, Cu, Mn, As, Zn and Cd (acid digest) were analyzed using atomic absorption spectroscopy (APHA, 1995). The loss of organic matter (expressed in %) was from the initial (A₁) and final (A₂) ash contents (in fraction) according to the equation:

\[
\text{Loss of organic matter} = \frac{(A₂ - A₁)}{(1 - A₁) \times A₂} \times 100
\]

All results reported are the means of three replicates. The results were statistically analyzed at \( P = 0.05 \) using one-way analysis of variance (ANOVA) and Tukey’s HSD test was used as a post-hoc analysis to compare the means (SPSS Package, v. 16).

3. Results and discussion

3.1 Temperature

The variation in temperature of composting materials with time is illustrated in Figure 1. The temperature determines the rate at which many of the biological processes take place and plays a selective role on evolution and succession on the microbiological communities (Hassen, 2001). Trial 4 containing large amount of cattle manure and rice straw was reached 60°C (maximum in all 6 trials) and enters into thermophilic phase within a day indicating quick establishment of microbial activities. Higher rise in temperature at the beginning of composting was attributed to higher content of easily biodegradable carbon (Kalamdhad and Kazmi, 2009). Afterwards cooling period was observed until the end of the composting process. Trial 1 was also observed maximum 57.3°C temperature which was highest in 3 trials of phase 1. Trial 2, 3, 5 and 6 achieved lower maximum temperature of 54.4, 50.8, 56.7 and 56.1°C respectively could be due to high amount of water hyacinth as compared to cattle manure. Higher rise in temperature in phase 2 trails at the beginning of composting as compared to phase 1 was attributed to addition of rice straw in place of saw dust enhanced the degradation process.
Moisture loss during the composting process can be viewed as an index of decomposition rate, since heat generation which accompanies decomposition drives vaporization or moisture loss is there (Liao et al., 1996). Higher initial moisture content of 90.5% was observed in trial 1 due to large proportion of cattle manure and water hyacinth with saw dust which further dropped to 70.5% at the end of 30 days of pile composting (Table 2). Lower initial moisture contents were observed in phase 2 trials. Moisture content was dropped up to 72.2, 75.2, 67.4, 66.7 and 70.5% respectively in trial 2, 3, 4, 5 and 6. Percentage decrease in moisture content was 22, 18.8, 13.5, 22.1, 20.6 and 15.5 during trial 1, 2, 3, 4, 5 and 6 respectively justified the higher temperature evaluation trials of phase 2. The moisture content was not found to be within an acceptable range of 50% to 60% because of higher initial moisture in composting material i.e. water hyacinth and cattle manure. Therefore, compost should be dried in natural environment before application in the agriculture field. On analyzing the results by ANOVA, the decrease in moisture content were significant ($P < 0.05$) between the trials.
### Table 2: Moisture content, pH and EC of composting mixtures

| Days | Phase 1       | Phase 2       |
|------|---------------|---------------|
|      | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
| 0    | 90.5±2.2a | 89.0±2.4a | 87.0±1.8a | 86.0±1.4a | 84.2±1.6a | 83.5±2.2a |
| 3    | 89.0±2.4a | 88.0±1.8a | 85.0±1.6ab | 80.5±1.6b | 78.5±1.0b | 82.5±1.8ab |
| 6    | 87.5±1.6ab | 87.0±1.6a | 84.0±1.2abc | 77.5±1.4bcd | 76.5±1.4bcd | 78.1±1.6abc |
| 9    | 83.0±1.4bc | 81.0±2.2b | 82.0±1.6bcd | 76.0±1.8bcd | 75.1±1.6bcd | 7bcd7.3±1.8cdef |
| 12   | 81.5±1.6cd | 80.0±1.8bc | 80.5±1.0cde | 74.5±1.4cdef | 73.2±1.8cdef | 76.0±2.2cdef |
| 15   | 78.0±1.4def | 79.0±1.6bcd | 79.0±1.4def | 73.5±1.6cdef | 72.3±1.5cdef | 75.5±1.6cdef |
| 18   | 76.5±1.8efg | 78.0±1.8bcd | 78.5±1.6defg | 72.0±1.3efgh | 71.3±1.2efgh | 74.0±1.6cdef |
| 21   | 74.0±1.4fgh | 77.0±2.2bcde | 77.5±1.8efg | 70.1±1.4fghi | 69.5±1.6fgh | 72.5±2.2defg |
| 24   | 73.0±1.6gh | 74.5±1.6cde | 76.5±1.5efg | 69.2±2.2ghi | 68.4±1.8gh | 71.5±2.4ef |
| 27   | 71.5±1.3h | 73.5±1.6de | 75.7±1.2fg | 68.3±2.4hi | 67.0±1.6h | 71.2±1.8f |
| 30   | 70.5±1.4h | 72.2±2.2e | 75.2±1.6g | 67.4±1.7i | 66.7±1.8h | 70.5±1.3f |

#### pH

| Days | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|------|---------|---------|---------|---------|---------|---------|
| 0    | 7.3±0.3abc | 7.0±0.2abc | 6.4±0.2a | 7.4±0.2abcd | 7.1±0.2ac | 6.6±0.3ab |
| 3    | 7.0±0.2a | 6.7±0.1a | 6.2±0.2a | 7.3±0.1abc | 6.8±0.2ab | 6.2±0.2a |
| 6    | 7.1±0.2ab | 6.8±0.1ab | 6.3±0.1a | 7.0±0.1a | 6.4±0.1b | 6.5±0.2a |
| 9    | 7.4±0.3abcd | 7.3±0.2abc | 7.6±0.3b | 7.3±0.2abc | 6.8±0.3abc | 7.2±0.3bc |
| 12   | 7.5±0.1abcd | 7.3±0.3abced | 7.7±0.1b | 7.4±0.3abc | 7.2±0.1acd | 7.5±0.1cd |
| 15   | 7.5±0.2bcd | 7.3±0.2bcde | 7.8±0.2b | 7.5±0.2abced | 7.4±0.2cde | 7.6±0.2cd |
| 18   | 7.6±0.3bcde | 7.4±0.1cdef | 7.8±0.1b | 7.5±0.1abcde | 7.7±0.1def | 7.7±0.3cd |
| 21   | 7.7±0.2bcde | 7.5±0.3def | 7.8±0.1b | 7.6±0.3bcde | 7.8±0.1ef | 7.8±0.2cd |
| 24   | 7.8±0.1cde | 7.8±0.1ef | 7.9±0.2b | 7.8±0.1cde | 7.8±0.2ef | 7.9±0.1cd |
| 27   | 8.1±0.1de | 8.0±0.3ef | 7.9±0.1b | 7.9±0.2de | 7.9±0.2f | 7.9±0.2d |
| 30   | 8.2±0.2e | 8.1±0.2f | 8.0±0.2b | 8.0±0.1e | 8.1±0.1f | 8.0±0.3d |

#### EC (dS/m)

| Days | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|------|---------|---------|---------|---------|---------|---------|
| 0    | 6.8±0.4a | 7.3±0.3a | 7.1±0.3a | 6.9±0.1a | 6.7±0.2a | 7.1±0.3a |
| 3    | 6.1±0.3ab | 6.7±0.2a | 5.9±0.2b | 6.1±0.3b | 5.8±0.1b | 6.4±0.2ab |
| 6    | 5.7±0.3bc | 4.7±0.4b | 5.6±0.4bc | 5.0±0.3c | 5.3±0.3bc | 5.8±0.4bc |
| 9    | 5.2±0.2cd | 4.3±0.3bc | 5.4±0.5bc | 4.5±0.2cd | 4.9±0.2cd | 5.1±0.3cd |
| 12   | 4.8±0.1de | 3.8±0.3c | 5.6±0.3bc | 3.8±0.4de | 4.2±0.4de | 4.8±0.3de |
| 15   | 4.7±0.3de | 3.7±0.4c | 5.4±0.2bc | 3.4±0.3efh | 3.8±0.3e | 4.6±0.2def |
| 18   | 4.6±0.4de | 3.6±0.2c | 5.4±0.3bc | 3.0±0.3efgh | 3.0±0.3ef | 4.2±0.1ef |
| 21   | 4.5±0.3de | 2.7±0.3d | 5.3±0.2bc | 2.8±0.2fgh | 2.9±0.4fg | 4.0±0.3f |
| 24   | 4.3±0.2e | 2.2±0.2d | 5.2±0.3bc | 2.6±0.3gh | 2.8±0.2g | 3.9±0.4f |
| 27   | 3.1±0.1f | 2.3±0.3d | 5.2±0.3bc | 2.8±0.2h | 2.7±0.3g | 3.8±0.3f |
| 30   | 2.8±0.3g | 2.2±0.4d | 4.8±0.2c | 2.6±0.3h | 2.6±0.2g | 3.7±0.2f |

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey’s test, \( P < 0.05 \))
3.3 pH and EC

Table 2 displays the results of the monitored pH of the composting mixtures. During the nitrification process, the nitrifying bacteria lower the pH of the medium due to the liberation of hydrogen ions and once nitrification had begun after the thermophilic stage, pH decreases and pH values of the compost were directly related to nitrification (Sanchez-Monedero et al., 2001). As composting proceeds, the organic acids become neutralized and compost material tends toward a neutral pH (Ko et al., 2007). Similar observations were found in all trials as pH reduced during initial 6 days, further increased up to 8. Increased rates of aeration will tend to decrease CO$_2$ level in the compost, which in turns will tend to increase pH (Haug, 1993). Lower initial pH were observed in trial 3 and 6 may be due to higher amount of water hyacinth and saw dust/rice straw which show acidic pH. Significant differences in pH were observed between the trials (P < 0.05).

The EC value reflected the degree of salinity in the compost, indicating its possible phyto-toxic/phyto-inhibitory effects on the growth of plant if applied to soil (Huang et al., 2004). Table 2 shows the reduction of EC during all three trials. 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 (Wong et al., 1995). For the improvement of agricultural soils, the acceptable level of EC required in compost is > 4 dS/m (Bhamidari and Pandey, 1996). Results indicated the required EC values in compost of trial 1, 2, 4 and 5 compared to trial 3 and 6. On analyzing the results by ANOVA, EC varied significantly between the trials (P < 0.05).

3.4 Ash Content and TOC

Table 3 shows the ash contents increased with composting time by about 58, 55, 37, 61, 47 and 43% during trial 1, 2, 3, 4, 5 and 6 respectively, owing to the loss of organic matter through microbial degradation (Kalamdhad and Kazmi, 2009). The decrease in organic matter synchronized with an increase in the mass ash of trials. The loss of organic matter was about 53 and 61% in trial 1 of phase 1 and trial 4 of phase 2 respectively, which contained higher amount of cattle manure compared to 51, 36, 52 and 50% in trial 2, 3, 5 and 6 respectively, which indicated that intensive decomposition had taken place during trial 1 and 4. Phase 2 showed higher organic matter decomposition could be due to rice straw in place of saw dust.

Organic matter becomes fully mineralized after composting, mostly due to the degradation of easily degradable compounds such as proteins, cellulose and hemi-cellulose, which are utilized by microorganisms as C and N sources. While degrading organic compound, microbes utilize 60 to 70% of the carbon as CO$_2$ and incorporate (immobilize) only 30 to 40% of the carbon into their body as cellular components. Thus, TOC content is useful for estimating the age and physical properties of the compost. Changes in TOC during the composting period are detailed in table 3. The content of organic carbon decreased as the decomposition progressed. Initially, the amounts of TOC were 41.3, 42.9, 44.8, 41.2, 41.6 and 42.1% which then reduced to 30.3, 31.8, 39.1, 23.5, 25.7 and 26.7%, respectively in trial 1, 2, 3, 4, 5 and 6. Results indicated higher carbon degradation during phase 2 trials (trial 4, 42.9%; trial 5, 37.9% and trial 6, 36.5% due to presence of rice straw as a result of higher temperature evaluation compared to phase 1 trials (trial1, 26.6%, trial 2, 25.8% and trial 3, 12.7%). Significant variations in ash content and TOC were observed between the trials (P < 0.05).
Table 3: Ash content, TOC and C/N ratio of composting mixtures

| Days | Phase 1 | Phase 2 |
|------|---------|---------|
|      | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|      | Ash content (%) | TOC (%) | C/N ratio |
| 0    | 31.1±1.2a | 30.1±1.3a | 25.2±1.1a | 37.6±1.4a | 38.6±1.5a | 39.5±1.3a |
| 3    | 32.9±1.3ab | 38.6±1.4b | 26.1±1.2ab | 41.6±0.2b | 42.2±1.2a | 42.1±1.4a |
| 6    | 33.7±1.4abc | 39.6±1.5b | 27.2±1.3abc | 43.4±0.1b | 48.2±1.2b | 47.2±1.3b |
| 9    | 35.7±1.2bcd | 40.3±1.2b | 28.0±1.1abc | 48.1±0.2c | 49.5±1.3bc | 50.1±1.4bc |
| 12   | 36.1±1.1bed | 41.3±1.1bc | 28.5±0.9abcd | 51.4±0.3cd | 52.4±1.4cd | 52.3±1.5c |
| 15   | 36.7±1.3cd | 41.9±1.3bc | 29.5±1.4bcd | 53.2±0.1de | 52.8±1.2cd | 53.0±1.2cd |
| 18   | 37.8±1.4d | 42.4±1.4bcd | 29.8±1.5bcd | 54.1±0.9de | 53.7±1.1de | 53.2±1.5cd |
| 21   | 41.8±1.2ef | 44.9±1.2decd | 29.9±1.3cd | 55.4±1.4ef | 54.6±1.3de | 53.3±1.3cd |
| 24   | 44.2±1.3fg | 45.2±1.3cde | 30.8±1.4eced | 58.2±1.5fg | 55.6±1.4de | 56.4±1.2d |
| 27   | 47.8±1.4gh | 46.1±1.4de | 32.2±1.5de | 59.1±1.3fg | 56.1±1.2de | 56.8±1.3d |
| 30   | 49.5±1.2h | 46.9±1.2e | 34.7±1.3e | 60.8±1.4fg | 57.0±1.3e | 58.2±1.4d |

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey’s test, P < 0.05)
3.5 Nitrogen Dynamics

Table 4 shows the time course of the total nitrogen consisting of inorganic forms of nitrogen (NH$_4$-N and NO$_3$-N). Total nitrogen content in water hyacinth was higher than other composting materials. Hence, initial total nitrogen content of trials (trial 3 and 6) containing higher amount of water hyacinth was higher than other trials. The initial total nitrogen content all trials were in the range of 1.41-1.72%. Total nitrogen increased within agitated pile composting due to the net loss of dry mass in terms of CO$_2$ during oxidization of organic matter. Higher increase was observed in trial 1 and 4 shows that the percentage of water hyacinth in the initial mixture has no impact on the final total nitrogen content (Gupta et al., 2007). Results also indicated that trials with rice straw observed higher final total nitrogen content compare to trials with saw dust.

The changes in concentration of NH$_4$-N and NO$_3$-N in all trials followed the general trend during pile composting. During the first 3 days of composting, NH$_4$-N concentration decreased from 0.31-0.49% to 0.25-0.45% in all trials. An increase was observed for around 6$^{th}$ day, afterwards sudden drop was noticed during all trials and then stabilized after 18$^{th}$ day at around 0.07, 0.07, 0.08, 0.08, 0.07 and 0.09% in trial 1, 2, 3, 4, 5 and 6 respectively by the end of the pile composting. The increase in NH$_4$-N concentration could be due to the conversion of organic nitrogen to NH$_4$-N through volatilization and immobilization by microorganisms (Haung et al., 2004). It has been noted that the absence or decrease in NH$_4$-N is an indicator of both high quality composting process (Hirai et al., 1983).

Nitrate was almost absent in the cattle manure and straw dust but higher concentration was observed in water hyacinth, so in the all mixtures found the initial nitrate concentration (Table 4). The high temperature and excessive amount of ammonia inhibited the activity and the growth of nitrifying bacteria in the thermophilic phase (Morisaki et al., 1989). This seems to suggest that organic nitrogen mineralization is the limiting step in nitrification since such mineralization was extremely low during the last phase of composting, when the supply of ammonium available to the nitrifying bacteria would have been reduced (Sanchez-Monedero et al., 2001). Therefore, a slight increase was observed in NO$_3$-N concentration all trials at later phase of composting. Significant differences in total nitrogen, NH$_4$-N and NO$_3$-N were observed between the trials (P < 0.05).

3.6 C/N Ratio

The change in the C/N ratios reflects the organic matter decomposition and stabilization achieved during composting. The decomposition of organic matter is brought about by living organisms, which utilize the carbon as a source of energy and the nitrogen for building cell structures. Therefore, continuous decrease was observed during all trials (Table 3). Significant differences in C/N ratio were observed between the trials (P < 0.05). Results also indicated the initial C/N ratio was lesser in those trials which had higher percentage of water hyacinth similar to Gupta et al. (2007). If the C/N ratio of compost is more, the excess carbon tends to utilize nitrogen in the soil to build cell protoplasm. This results in loss of nitrogen of the soil and is known as robbing of nitrogen in the soil. If on the other hand the C/N ratio is too low the resultant product does not help improve the structure of the soil, hence it is desirable to achieve optimum C/N ratio for prepared compost. Lower final C/N ratio attained in trial 1 of phase 1 and trial 4 of phase 2, which content higher amount of cattle manure.
Table 4: Total nitrogen, NH₄-N and NO₃-N of composting mixtures

| Days | Phase 1 | Phase 2 |
|------|---------|---------|
|      | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|------|---------|---------|---------|---------|---------|---------|
| Total nitrogen |         |         |         |         |         |         |
| 0    | 1.41±0.08a | 1.57±0.07a | 1.72±0.06a | 1.44±0.06a | 1.58±0.09a | 1.70±0.10ab |
| 3    | 1.43±0.07a | 1.61±0.09a | 1.73±0.09ab | 1.50±0.10a | 1.57±0.07a | 1.68±0.08ab |
| 6    | 1.52±0.10a | 1.65±0.06a | 1.74±0.07ab | 1.52±0.12a | 1.57±0.09a | 1.63±0.06ab |
| 9    | 1.63±0.08ab | 1.77±0.10ab | 1.75±0.09ab | 1.52±0.08a | 1.58±0.12a | 1.60±0.09ab |
| 12   | 1.87±0.06bc | 1.91±0.12b | 1.85±0.12abc | 1.59±0.07abc | 1.60±0.08a | 1.52±0.07a |
| 15   | 2.08±0.09cd | 2.01±0.08bc | 1.97±0.08bcd | 1.70±0.05bc | 1.62±0.07ab | 1.55±0.09ab |
| 18   | 2.26±0.07de | 2.25±0.07cd | 2.06±0.07cde | 1.83±0.09cd | 1.76±0.05ab | 1.69±0.10ab |
| 21   | 2.46±0.09ef | 2.34±0.05de | 2.16±0.05def | 1.99±0.10de | 1.86±0.09bc | 1.80±0.11bc |
| 24   | 2.51±0.1ef | 2.38±0.09def | 2.28±0.09fg | 2.18±0.07e | 2.05±0.07c | 2.00±0.08c |
| 27   | 2.59±0.11f | 2.52±0.10ef | 2.38±0.09fg | 2.50±0.09f | 2.45±0.08d | 2.33±0.07d |
| 30   | 2.62±0.08f | 2.59±0.07f | 2.47±0.08g | 2.84±0.10g | 2.68±0.08d | 2.51±0.09d |

NH₄-N

| Days | Phase 1 | Phase 2 |
|------|---------|---------|
|      | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|------|---------|---------|---------|---------|---------|---------|
| 0    | 0.31±0.02ab | 0.38±0.02ab | 0.41±0.01ab | 0.39±0.02a | 0.43±0.03a | 0.49±0.02a |
| 3    | 0.25±0.01a | 0.32±0.03a | 0.35±0.03a | 0.37±0.01a | 0.42±0.02a | 0.45±0.03a |
| 6    | 0.35±0.03b | 0.38±0.01b | 0.43±0.02b | 0.52±0.02b | 0.55±0.02b | 0.55±0.03b |
| 9    | 0.35±0.01b | 0.39±0.02b | 0.45±0.03b | 0.54±0.03b | 0.56±0.03b | 0.57±0.02b |
| 12   | 0.25±0.02a | 0.18±0.02c | 0.18±0.03c | 0.46±0.01c | 0.52±0.02b | 0.51±0.01ab |
| 15   | 0.13±0.02c | 0.11±0.02d | 0.16±0.01c | 0.15±0.02d | 0.11±0.01c | 0.13±0.03c |
| 18   | 0.09±0.03c | 0.09±0.03d | 0.09±0.02d | 0.09±0.03e | 0.09±0.02c | 0.09±0.02c |
| 21   | 0.09±0.01c | 0.08±0.01d | 0.08±0.03d | 0.09±0.02e | 0.08±0.01c | 0.09±0.02c |
| 24   | 0.09±0.02c | 0.08±0.01d | 0.08±0.02d | 0.09±0.01e | 0.08±0.02c | 0.09±0.01c |
| 27   | 0.08±0.03c | 0.07±0.02d | 0.08±0.01d | 0.08±0.01e | 0.07±0.01c | 0.09±0.02c |
| 30   | 0.07±0.01c | 0.07±0.03d | 0.08±0.02d | 0.08±0.01e | 0.07±0.01c | 0.09±0.01c |

NO₃-N

| Days | Phase 1 | Phase 2 |
|------|---------|---------|
|      | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|------|---------|---------|---------|---------|---------|---------|
| 0    | 0.29±0.01a | 0.34±0.01a | 0.41±0.01a | 0.31±0.01a | 0.33±0.01a | 0.39±0.02a |
| 3    | 0.30±0.02a | 0.37±0.02a | 0.44±0.02ab | 0.35±0.02ab | 0.39±0.02b | 0.43±0.02ab |
| 6    | 0.37±0.03b | 0.42±0.02b | 0.49±0.01bc | 0.36±0.01b | 0.40±0.02bc | 0.44±0.02a |
| 9    | 0.42±0.01bc | 0.45±0.01bc | 0.53±0.02cd | 0.42±0.02cd | 0.44±0.02cd | 0.47±0.03bc |
| 12   | 0.44±0.02c | 0.47±0.02bc | 0.55±0.02de | 0.42±0.01d | 0.48±0.01d | 0.50±0.02cd |
| 15   | 0.49±0.01d | 0.50±0.02cd | 0.55±0.02de | 0.52±0.01ef | 0.54±0.02ef | 0.54±0.02de |
| 18   | 0.49±0.02d | 0.54±0.02de | 0.57±0.03def | 0.57±0.01f | 0.57±0.01f | 0.54±0.01de |
| 21   | 0.50±0.01d | 0.55±0.01def | 0.59±0.02defg | 0.62±0.02g | 0.59±0.02g | 0.57±0.02ef |
| 24   | 0.52±0.01de | 0.58±0.02efg | 0.61±0.02efg | 0.64±0.03gh | 0.62±0.02gh | 0.58±0.01ef |
| 27   | 0.56±0.02ef | 0.60±0.02fg | 0.62±0.03fg | 0.65±0.02gh | 0.63±0.02gh | 0.61±0.03f |
| 30   | 0.58±0.01f | 0.62±0.02g | 0.64±0.02g | 0.67±0.01h | 0.66±0.01h | 0.62±0.02f |

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey’s test, P < 0.05)
3.7 Total and Available Phosphorus

Phosphorous content gradually increased during the composting process. The water solubility of phosphorous decreased with the humification thereby showing that phosphorous solubилиed during the decomposition was subjected to further immobilization by the compost accelerator microorganisms. The higher initial available phosphorus in trial 3 than trial 1 and 2 was due to the higher content of water hyacinth in trial 3. The change of total and available phosphorus with a gradual increase throughout the composting period (Table 5), which was due to the net loss of dry mass and losses of organic carbon, hydrogen, nitrogen and oxygen from piles as CO$_2$, H$_2$S and H$_2$O during composting. Final total phosphorus of trial 1 of phase 1 was higher than that of trial 2 and 3; but the increase in total phosphorus in trial 1 and 2 depicted 4.1 folds compared to 3.1 fold in trial 3, indicating the higher microbial activities during trial 1 and 2 resulting in more mineralization. Similarly, final total phosphorus of trial 4 and 5 of phase 2 was higher than trial 6. Results indicated that phase 2 trials undergo more comparable mineralization due to the presence of rice straw as compared to phase 1. On analyzing the results by ANOVA, total and available phosphorus varied significantly between the trials (P < 0.05).

3.8 Nutrients

Table 5 and 6 illustrate the concentration of the macronutrients such as total K, Na, Ca and Mg in all trials throughout the pile composting process. These nutrients are used as mineral fertilizers in the compost. All mixtures showed similar pattern of changes in macronutrients. K, Na, Ca and Mg of the all mixtures showed steady increase till the end of the composting. Higher final concentration of nutrients was observed in trial 3 and 6 due to large amount of water hyacinth which depicted comparatively higher concentration of nutrients particularly Ca and K. Significant differences in macronutrients were observed between the trials (P < 0.05).

3.9 Trace elements

Aquatic plants are known to accumulate metals from their environment and affect metal fluxes through those ecosystems. Water hyacinth has exceptionally high affinity and accumulation capacity for several metals (Zaranyika et al., 1994). It has proved by initial characterization of water hyacinth which indicated higher concentration of Cu, Zn and Mn. Many of trace elements are actually needed by plants for normal growth, though in limited quantities. Certain trace elements are not biodegradable and become toxic at some concentration, therefore, measuring the concentration of these elements can provide fertilizer requirements of plants. Results showed a steady increase in all metal contents especially in trial 3 and 6 due to higher content of water hyacinth. The increase of metal level is due to weight loss in the course of composting followed by organic matter decomposition, release of CO$_2$ and water, and mineralization processes (Amir et al., 2005). The total metal content of final compost of all three trials was lower and is considered as soil fertilizer with good quality according to the standards to ensure safe application of compost laid down in Municipal Waste Management and Handling Rules notified by the Ministry of Environment and Forest, Government of India (CPHEEO, 2000) and Canadian Council of Ministers of the Environment (CCME, 1995) (Table 7).
Table 5: Available phosphorus, total phosphorus and potassium of composting mixtures

| Days | Phase 1 | Phase 2 |
|------|---------|---------|
|      | Trial 1 | Trial 2 | Trial 3 | Trial 4 | Trial 5 | Trial 6 |
|      | Available phosphorus (g/kg) | Total phosphorus (g/kg) | Potassium (g/kg) |
| 0    | 0.41±0.06a | 2.6±0.2a | 7.5±0.23a | 0.53±0.08a | 2.5±0.1a | 8.3±0.42a | 12.9±0.38a |
| 3    | 0.57±0.05ab | 3.5±0.3b | 7.6±0.34a | 0.66±0.07a | 3.2±0.2ab | 9.5±0.53ab | 13.3±0.42ab |
| 6    | 0.76±0.06b | 3.7±0.2b | 7.8±0.56a | 0.96±0.09b | 3.2±0.3b | 9.9±0.34b | 13.6±0.46abc |
| 9    | 1.02±0.07c | 4.1±0.2b | 8.8±0.43ab | 1.08±0.08b | 4.6±0.2c | 6.6±0.2ef | 12.6±0.42ab |
| 12   | 1.27±0.06d | 4.7±0.1c | 8.3±0.2c | 1.39±0.08c | 4.6±0.2c | 6.6±0.2ef | 12.6±0.42ab |
| 15   | 1.42±0.05d | 5.1±0.2c | 8.5±0.35abc | 1.65±0.07d | 5.3±0.3d | 7.1±0.3f | 14.5±0.51bc |
| 18   | 1.62±0.07e | 5.1±0.2c | 8.7±0.35abc | 2.13±0.06e | 2.8±0.3ab | 6.1±0.2de | 14.5±0.51bc |
| 21   | 1.97±0.06f | 5.7±0.1e | 8.9±0.36c | 2.19±0.05e | 2.7±0.11ef | 7.1±0.3f | 15.7±0.52c |
| 24   | 2.29±0.09g | 6.4±0.3f | 9.0±0.43ab | 2.24±0.06e | 2.8±0.08ef | 7.1±0.3f | 16.0±0.45bed |
| 27   | 2.40±0.08gh | 6.9±0.36d | 9.4±0.54abc | 2.32±0.04ef | 2.9±0.07f | 7.2±0.3d | 17.0±0.45bed |
| 30   | 2.59±0.07h | 7.3±0.2g | 9.7±0.45abc | 2.49±0.06f | 3.17±0.08g | 7.3±0.2g | 18.0±0.45bed |

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey’s test, \(P < 0.05\))
### Table 6: Sodium, calcium and magnesium of composting mixtures

| Days | Sodium (g/kg) | Calcium (g/kg) | Magnesium (g/kg) |
|------|---------------|----------------|------------------|
|      | Trial 1       | Trial 2        | Trial 3          | Trial 4       | Trial 5       | Trial 6       |
|      | Phase 1       | Phase 2        | Phase 1          | Phase 2       | Phase 3       | Phase 4       |
|      | Phase 1       | Phase 2        | Phase 3          | Phase 4       | Phase 5       | Phase 6       |
| 0    | 2.0±0.09a     | 2.0±0.11a      | 2.1±0.13a        | 2.0±0.13a     | 2.0±0.12a     | 2.1±0.08a     |
| 3    | 2.1±0.08a     | 2.1±0.13ab     | 2.1±0.11ab       | 2.1±0.14a     | 2.1±0.13a     | 2.3±0.12ab    |
| 6    | 2.2±0.09abc   | 2.2±0.08abc    | 2.1±0.08abc      | 2.2±0.15a     | 2.2±0.14a     | 2.4±0.09bc    |
| 9    | 2.4±0.11b    | 2.4±0.13b     | 2.4±0.12bcd     | 2.7±0.13b     | 2.6±0.11b     | 2.5±0.11bc    |
| 12   |               |               |                  | 2.7±0.13b     | 2.6±0.11b     | 2.5±0.13bcd   |
| 15   | 2.5±0.13cd   | 2.5±0.14cde   | 2.5±0.09cde      | 2.9±0.13bc    | 2.7±0.09bc    | 2.7±0.08cde   |
| 18   | 2.5±0.08d    | 2.6±0.15de    | 2.5±0.13de       | 2.9±0.11bc    | 2.7±0.13bcd   | 2.8±0.12def   |
| 21   | 2.7±0.12de   | 2.8±0.11ef    | 2.7±0.14ef       | 2.9±0.08bc    | 2.7±0.08bcd   | 2.9±0.11ef    |
| 24   | 3.0±0.13ef   | 3.2±0.13g     | 3.1±0.11g        | 3.1±0.12c     | 3.0±0.13cd    | 3.0±0.12fg    |
| 27   | 3.1±0.14f    | 3.3±0.08g     | 3.2±0.13g        | 3.1±0.13c     | 3.1±0.14d     | 3.2±0.11g     |
| 30   | 3.8±0.52a    | 6.0±0.47a     | 8.1±0.52a        | 3.0±0.46a     | 3.3±0.34a     | 5.8±0.61a     |
| 3  | 4.4±0.67a    | 7.1±0.63ab    | 8.5±0.55a        | 3.3±0.53a     | 3.6±0.46ab    | 6.3±0.57a     |
| 6  | 5.2±0.53ab   | 7.9±0.54bc    | 8.9±0.34a        | 4.1±0.54a     | 5.0±0.48bc    | 7.4±0.49a     |
| 9  | 6.3±0.63bc   | 8.4±0.62bc    | 10.7±0.46b       | 4.6±0.62ab    | 6.1±0.71c     | 9.4±0.52b     |
| 12 | 7.2±0.47cd   | 8.7±0.71bc    | 13.4±0.48c       | 5.8±0.71bc    | 6.3±0.64c     | 13.0±0.67c    |
| 15 | 8.2±0.81de   | 9.6±0.46bcd   | 15.4±0.71d       | 7.0±0.46c     | 7.9±0.61de    | 15.4±0.53de   |
| 18 | 9.1±0.74ef   | 10.5±0.48d    | 17.5±0.64e       | 9.4±0.48d     | 8.9±0.58e     | 16.5±0.63e    |
| 21 | 9.7±0.73efg  | 13.4±0.38e    | 18.4±0.61e       | 9.9±0.38d     | 12.9±0.47fg   | 19.7±0.47fg   |
| 24 | 10.2±0.56fg  | 16.1±0.78f    | 20.9±0.58f       | 10.7±0.78de   | 13.3±0.63g    | 20.5±0.81gh   |
| 27 | 11.2±0.43gh  | 19.4±0.65g    | 22.9±0.43g       | 11.5±0.62e    | 15.0±0.54h    | 22.0±0.74hi   |
| 30 | 12.4±0.54h   | 21.1±0.77g    | 25.1±0.73h       | 11.6±0.54e    | 17.6±0.47i    | 23.3±0.73i    |

Mean value followed by different letters in columns is statistically different (ANOVA; Tukey’s test, \( P < 0.05 \)
Table 7: Trace elements in the final compost (30 d) of trial 3 and 6, and limit values for Class A of composts “which have no restrictions in use” and Class B of compost “which can be used on forest lands and road sides and for other landscaping purposes according to Canadian normalization CCME (1995) and Indian normalization (CPHEEO, 2000)

| Trace elements | CCME guidelines (mg/kg dry matter) | CPHEEO guidelines (mg/kg dry matter) | Final compost content in Trial 3 (mg/kg of dry matter) | Final compost content in Trial 6 (mg/kg of dry matter) |
|----------------|-----------------------------------|-------------------------------------|------------------------------------------------------|------------------------------------------------------|
|                | Class A                            | Class B                             |                                                      |                                                      |
| As             | 75                                 | 15                                  | 20                                                   | 19±1                                                 |
| Cr             | 210                                | --                                  | 300                                                  | 67±3                                                 |
| Cu             | 400                                | --                                  | 500                                                  | 78±2                                                 |
| Zn             | 1850                               | 370                                 | 2500                                                 | 795±12                                               |
| Cd             | 20                                 | 4                                   | 20                                                   | 14±1                                                 |
| Mn             | --                                 | --                                  | --                                                   | 1250±13                                              |
| Pb             | 500                                | 100                                 | 500                                                  | 150±8                                                |

4. Conclusions

Trial 1 and 4 observed higher temperature compared to other trials due to high amount of water hyacinth as compared to cattle manure, which did not provide favorable conditions for growth and biological activity of microorganisms. Percentage decrease in moisture content during trial 1 and 4 justified the higher temperature evaluation. Lower initial pH were observed in all trials especially in trial 3 and 6 due to higher amount of water hyacinth and saw dust/rice straw which show acidic pH. Lower final EC, NH$_4$-N and TOC and higher final phosphorus in trial 1 and 4 concluded the optimal waste combination of water hyacinth, cattle manure with straw dust and rice straw. Higher loss of organic matter in trial 1 and 4 verified the obtained results. Higher final concentration of nutrients and limited metal content ensured the quality of compost prepared from water hyacinth in combination with cattle manure and saw dust. It suggested that the optimal degradation of water hyacinth can possible in the presence of carbonaceous material i.e. cattle manure, saw dust and rice straw. The presence of rice straw significantly influenced the results. Higher degradation was achieved during trial 4, 5 and 6 in which rice straw added as bulking agent as compare to saw dust addition. Therefore it can be concluded that the combination of water hyacinth, cattle manure and rice straw (especially trial 4 mixture) suitable for agitated pile composting.

Acknowledgement

The authors gratefully acknowledge the financial support of the Indian Institute of Technology Guwahati (IITG), Government of India.

5. References

1. Abbasi, S.A. (1998), weeds of despair, and hope. In: Abbasi, et al. (eds): Wetlands of India, Discovery Publishing House, New Delhi, pp 12-21.

2. Abbasi, S.A., and Nipaney, P.C (1986), infestation by aquatic weeds of the fern genus salvinia: its status and control. Environmental Conservation, 13, pp 235-241.
3. Amir, S., Hafidi, M., Merlina, G., and Revel, J. C (2005), sequential extraction of heavy metals during composting of sewage sludge. Chemosphere, 59, pp 801-810.

4. APHA (1995), standard methods for the examination of water and wastewater. 17th edition, American Public Health Association, Washington DC.

5. Bhamidari, S.M.R., and Pandey, S.P (1996), aerobic thermophilic composting of piggery solid wastes. Water Science & Technology, 33, pp 889-894.

6. CCME (1995), guidelines for compost quality. Canadian Council of Ministers of the Environment, Manitoba.

7. Chanakya, H.N., Borgaonkar, S., Meena, G., and Jagadish, K.S (1993), solid-phase biogas production with garbage or water hyacinth. Bioresource Technology, 46, pp 227-231.

8. CPHEEO (2000), manual on municipal solid waste management. Central Public Health and Environmental Engineering Organization, New Delhi.

9. Gajalakshmi, S., Ramasamy, E.V., and Abbasi, S.A (2001), potential of two epigeic and two anecic earthworm species in vermicomposting water hyacinth. Bioresource Technology, 76, pp 177-181.

10. Goswami, T., and Saikia, C. N (1994), water hyacinth- a potential source of raw material for greaseproof paper. Bioresource Technology, 50, pp 235-238.

11. Gunnarsson, C.C., and Petersen, C.M (2007), water hyacinths as a resource in agriculture and energy production: A literature review. Waste Management, 27, pp 117-129.

12. Gupta, R., Mutiyar, P.K., Rawat, N.K., Saini, M.S., and Garg, V.K (2007), development of a water hyacinth based vermireactor using an epigeic earthworm Eisenia foetida. Bioresource Technology, 98, pp 2605-2610.

13. Hassen, A., Belguith, K., Jedidi, N., Cherif, A., Cherif, M., and Boudabous, A. (2001), microbial characterization during composting of municipal solid waste. Bioresource Technology, 80, pp 217-225.

14. Haug, R.T. (1993), the practical handbook of composting engineering. Lewis publishers, Boca Raton

15. Hirai, M.F., Chanyasak, V., and Kubota, H. (1983), a standard measurement for compost maturity. Biocycle, 24, pp 54-56.

16. Huang, G.F., Wong, J.W.C., We, Q.T., and Nagar, B.B. (2004), effect of C/N on composting of pig manure with sawdust. Waste management, 24, pp 805-813.

17. Husain, Z. (2003), environmental issues of North east India. Regency Publication, New Delhi.

18. Jouraiphy, A., Amir, S., El Gharous, M., Revel, J-C., and Hafidi, M. (2005), chemical and spectroscopic analysis of organic matter transformation during
Composting of water hyacinth using saw dust/rice straw as a bulking agent. Composting of sewage sludge and green plant waste. International Biodeterioration & Biodegradation, 56, pp 101-108.

19. Kalamdhad, A.S., and Kazmi, A.A. (2009), rotary drum composting of different organic wastes mixtures. Waste Management & Research, 27, pp 129-137.

20. Liao, P.H., Jones, L., Lau, A.K., Walkemeyer, S., Egan, B., and Holbek, N. (1996), composting of fish wastes in a full–scale in-vessel system. Bioresource Technology, 59, pp 163-168.

21. Malik, A. (2007), environmental challenge vis a vis opportunity: The case of water hyacinth. Environment International, 33, pp 122-138.

22. Morisaki, N., Phae, C.G., Nakasaki, K., and Shoda, M. (1989), Nitrogen transformation during thermophilic composting. Journal of Fermentation and Bioengineering, Vol 67, pp 57-61.

23. Parkinson, R., Gibbs, P., Burchett, S., and Misselbrook, T. (2004), effect of turning regime and seasonal whether conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. Bioresource Technology, 91, pp 171-178.

24. Sanchez-Monedero, M.A., Roig, A., Paredes, C., and Bernal, M.P. (2001), Nitrogen transformation during waste composting by the Rutger system and its effects on pH, EC and maturity of the composting mixtures. Bioresources Technology, 78, pp 301-308.

25. Tiquia, S. M., and Tam, N. F. Y. (2000), fate of nitrogen during composting of chicken litter. Environmental Pollution, 110, pp 535-541.

26. Wong, J.W.C., Li, S.W.Y., and Wong, M.H. (1995), coal fly ash as a composting material for sewage sludge: Effects on microbial activities. Environmental Technology, 16, pp 527-537.

27. Zaranyika, M.F., Mutoko, F., and Murahwa, H. (1994), uptake of Zn, Co, Fe and Cr by water hyacinth (Eichhornia crassipes) in Lake Chivero, Zimbabwe. Science of the Total Environment, 153, pp 117-121.