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The preferential composting of water fern and a reduction of the mobility of potential toxic elements in a rotary drum reactor

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ABSTRACT

Studies were conducted to undertake a physico-chemical analysis and to examine the bioavailability as well as the leachability of potential toxic elements during the rotary drum reactor composting of water fern with rice husk and cattle manure in different combinations. The highest temperature (54.2 °C) was measured in trial 3 (water fern, cattle manure and rice husk at a ratio of 6:3:1) during the process. The highest reductions of the moisture content and volatile solids were observed approximately 31.4 and 32.9%, respectively, in trial 3. The soluble biochemical oxygen demand (BOD) and the oxygen uptake rate of the compost in trial 3 indicated that the compost was stable after the process. The total concentrations of potential toxic elements (Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr) were increased in the process of composting. The total concentrations of the macronutrients in the final composts of different trials were increased by 1.4–2.0% for K, 1.1–1.3% for Ca and 0.76–0.82%. The highest reduction in the soluble BOD was found to be 82.4% in trial 3. Composting of water fern biomass with the appropriate ratio of cattle manure decreased the bioavailable and leachable forms of the potential toxic elements greatly.

1. Introduction

Water fern (*Salvinia natans* L.) is a free floating freshwater macrophyte, which grows very fast in the ponds, lakes, ditches, and constructed wetland mostly in southern Asian countries. There are many species of water ferns found in tropical and temperate regions of the world. They show a fast growth rate and great capability to survive under adversative environmental conditions (Fuentes et al., 2014). All species of water fern can accumulate heavy metals from the water bodies (Dhir et al., 2009). The accumulation of heavy metals in water fern is usually fast and comprises the passive uptake via adsorption of metal ions onto the plant surface and/or active absorption into plant cells (Sune et al., 2007). Aquatic plants are an abundant bio-resource that retains an enormous capacity to accumulate heavy metals (Dhir et al., 2009). Aquatic plants have been applied worldwide in the development of eco-friendly wastewater treatment technologies for heavy metal remediation (Dhir and Srivastva, 2011; Prado et al., 2012). Aquatic plant species including free-floating Eichhornia, Lemna, Azolla, and water fern (*Salvinia*) have shown potential applications for toxic heavy metal removal from wastewater (Malik, 2007; Dhir et al., 2009). Similar to water hyacinth (*Eichhornia crassipes*), fresh water fern (*S. natas*) is also a free-floating macrophyte. It has been used in constructed wetlands due to its fast growth rate and large uptake of nutrients and toxic heavy metals (Singh and Kalamdhad, 2012). Water fern has been used for phytoremediation purposes due to its high ability and accumulation capacities for several metals (Dhir and Srivastva, 2011; Prado et al., 2012). The conservation of the wetlands through removing aggressive weeds are important in whole world, because wetlands the supports valuable bio-diversity. It plays an important role in providing regional ecological and economic security as well (Trisal and Manihar, 2004).

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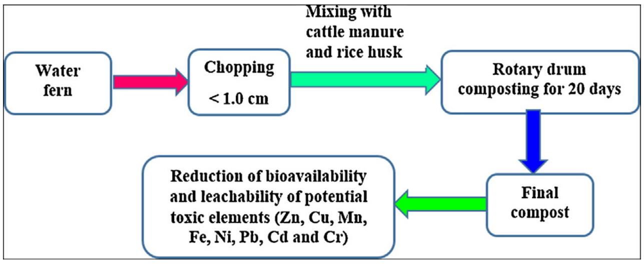

Fig. 1 – Preparation of raw materials and composting of water fern composting in a rotary drum reactor.

Composting is the best-known process for the biological stabilization of green waste, as it transforms this type of waste into compost which can be applied for agricultural purposes (Gabhane et al., 2012). Unfortunately, the presence of non-biodegradable toxic heavy metals at high levels in the composting biomass is not acceptable. This problem can restrict applications in the agricultural field. The accumulation of heavy metals by plants and following increase along the food chain is a possible risk to the human health (He et al., 2009; Singh and Kalamdhad, 2013a). Useful information is needed about the risk of bioavailability of heavy metals, which depends on the water solubility and plant availability of heavy metals rather than on the total contents of metals found after strong acid digestion of a compost (Singh and Kalamdhad, 2014).

The bioavailability of any element can be considered as the portion of the total concentration of the element easily available to plants and soil microorganisms which will consequently enter our tissues due to bio-magnification. Water soluble forms of heavy metals are the one of the most biologically active heavy metals. They have the highest potential to contaminate the environment (Hait and Tare, 2012). They can also include heavy metals extractable by diethylenetriamine pentaacetic acid (DTPA); these are plant-available metal forms at regular or higher concentrations (Samuel et al., 2013). Therefore, the objectives of the present study are (i) to treat fresh water fern by converting it into the compost using a highly efficient rotary drum reactor, (ii) to check the compost quality by assessing the biological oxygen demand and oxygen uptake rate, (iii) to determine the total potential toxic elements and nutrient concentrations in the final compost and (iv) to decrease the water solubility, plant availability and leachability of potential toxic elements by means of fast rotary drum composting.

2. Materials and methods

2.1. Materials

Fig. 1 shows an outline of composting of water fern in a rotary drum reactor. The floating water fern (WF) were collected from the Loktak Lake near Thanga village in the Bishnupur district of Manipur in India. The composting of collected biomass was at Manipur Pollution Control Board in Imphal, Manipur, India. Cattle manure (CM) and rice husks (RH) were collected from Central Agriculture University in Imphal, India. The *S. natans* were kept for 1 day to drain out excess moisture and were prepared for composting by cutting/shredding (10 mm) and constant premixing with cattle manure and rice husk at five dissimilar combination, as detailed in Table 1.

2.2. Rotary drum composting

A pilot-scale rotary drum composter with a capacity of 550 L was operated in batch mode. The details design of composter given elsewhere (Singh and Kalamdhad, 2013a). A 150 kg waste materials was composted for 20 days. Reactor was turned manually after each 24 h through one complete rotation of the rotary drum, which ensure that the material on the top portion shifted to the central portion, where it was exposed to a higher temperature. Afterward, an aerobic condition was continued by opening the top-half side doors of the two circular faces.

2.3. Sampling

The samples were collected by means of grab-sampling from different locations, mainly from the mid-span and end terminals of the pilot-scale rotary drum composter with a compost sampler. All of the grab samples were thoroughly mixed together to create a homogenized sample. Triplicate homogenized samples were collected on day 0, 4, 8, 12, 16 and 20. The collected samples were air-dried immediately and ground to pass through a 0.2 mm sieve.

2.4. Analysis

The temperature was monitored with a digital thermometer during the composting. All samples were analyzed for its moisture content (MC) (wet loss of wet sample after 105 °C for 24 h), pH, electrical conductivity (EC) (from 1:10, w/v, waste:water extract) and organic matter in terms of volatile solids (VS) (loss on ignition at 550 °C for 2 h in a muffle furnace). Readily decomposable organic matter was measured as the soluble biochemical oxygen demand (BOD) by a dilution method from the supernatant of a mixture of 10 g of wet sample in 100 mL of deionized water (APHA, 2005). For OUR, a dissolved oxygen (DO) probe was inserted 5–7 cm below the surface of a liquid suspension of compost (8 g of wet sample in 500 mL of distilled water with $CaCl_2$, $MgSO_4$, $FeCl_3$ and phosphate buffer added at pH 7.2 and incubated at room temperature, 24 ± 2 °C) contained in an airtight flask (APHA, 2005). The suspension mixture was uninterruptedly stirred by a magnetic stirrer, and the decrease in the DO concentration was measured continuously until it reached zero to determine OUR in mg O_2/g VS/day. Content of total nitrogen was measured using the Kjeldahl method, and ammoniacal nitrogen (NH_4-N) was analyzed by means of KCl extraction (Tiquia and Tam, 2000).

A flame photometer (Systronic 128) was used to analyze the Na, K and Ca concentrations and an atomic absorption spectrometer (AAS) (Varian Spectra 55B) was used to analyze the Mg, Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr concentrations after the digestion of 0.2 g of sample with 10 mL of a H_2SO_4 and $HClO_4$ (5:1) mixture in a block digestion system (Pelican Equipment, Chennai, India) for 2 h at 300 °C. Water-soluble potential toxic elements and nutrients were determined after the extraction of 2.5 g of sample with 50 mL of distilled water (solid-to-liquid ratio of 1:2) at room temperature for 2 h in a shaker operated at 100 rpm (Singh and Kalamdhad, 2013a). Plant available potential toxic elements were achieved by mechanically shaking 4 g of ground sample (screened through a 0.22 mm sieve) with 40 mL of 0.005 M DTPA, 0.01 M $CaCl_2$ and 0.1 M (triethanolamine) buffered to pH 7.3 at 100 rpm (Guan et al., 2011). The standard toxicity characteristic leaching procedure (TCLP) (US EPA, 1992) was adopted to measure the prospective leachability of the potential toxic elements. All results were replicates at least 3 times. Repeated measures of the parameters were subjected to an analysis of variance (ANOVA) test using SPSS software to determine the significance of the parameters amongst different trials.

Biodegradability is a parameter that relates the initial and final content of the organic matter during composting. The