Bioresource Technology 151 (2014) 306–313

Contents lists available at ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

# Evaluation of hydrothermal treatment in enhancing rice straw compost stability and maturity

Bakhtiyor Nakhshiniev[a,*], Muhammad Kunta Biddinika[a], Hazel Bantolino Gonzales[b], Hiroaki Sumida[c], Kunio Yoshikawa[a]

[a] *Department of Environmental Science and Technology, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama, Kanagawa 226-8503, Japan*

[b] *Innovative Platform for Education and Research, Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology, 4259 Nagatsuta-cho, Midori-ku, Yokohama, Kanagawa 226-8503, Japan*

[c] *Laboratory of Soil Science, Department of Chemistry and Life Science, Nihon University, 1866 Kameino, Fujisawa, Kanagawa 252-8510, Japan*

## HIGHLIGHTS

- Bin-scale composting (90 L) was performed following a pilot-scale (200 L) HTT.
- HTT with mild reaction condition (180 °C, 1.0 MPa, 30 min) enhanced rice straw composting process.
- Rice straw compost with HTT can reach stability within 6 weeks of composting.
- Rice straw compost with HTT may be phytotoxic if used as growing media for EC sensitive plants.

## ARTICLE INFO

*Article history:*
Received 5 September 2013
Received in revised form 23 October 2013
Accepted 26 October 2013
Available online 1 November 2013

*Keywords:*
Hydrothermal treatment
Rice straw
Compost
Stability and maturity

## ABSTRACT

In order to evaluate the hydrothermal treatment (HTT) in enhancing compost stability and maturity of lignocellulosic agricultural residues, a bin-scale (90 L) composting of rice straw with and without "HTT" was performed. The rice straw compost product with "HTT" after 6 weeks of composting can be considered stable and adequate for field application as expressed by pH of 8.4, "EC value" of 2.96 dS $m^{-1}$, C/N ratio of 12.5, microbial activity of <8.05 mg $CO_2$ $g^{-1}$ OM $d^{-1}$, $NH_4^+$—N content of 93.75 mg $kg^{-1}$ DM and finally, by "GI" of >83%. However, compost may prove phytotoxic if used as growing media for EC sensitive plants. As for rice straw compost product without "HTT", the high microbial activity (>12.28 mg $CO_2$ $g^{-1}$ OM $d^{-1}$) even after 14 weeks of composting suggests that the residue has not stabilized yet and is far away from stability and maturity, although a higher GI (>100%) was observed.



## 1. Introduction

The growth of global food production, increased price of energy coupled with increased production of biofuels from food crops are causing the high price of chemical fertilizers (Mueller et al., 2011). On the other hand, large volumes of crop residues which could have been converted into valuable organic fertilizers are regarded as waste each season almost everywhere in the world (Yadvinder-Singh et al., 2005). Rice (*Oryza sativa*), although the world's second most-grown crop, produces the largest amount of crop residues. According to FAO (2013), over the past ten years, the global paddy rice output on an average was about 664.3 million Mt. As rice generates about one Mt of straw per each Mt of grain, large amount of residue is accumulated annually. Rice straw is unique relative to other crop residues; it has limited use as an animal feed because of its high silica content (Van Soest, 2006). Direct incorporation of the rice straw into the soil is also limited as it may cause certain agronomic problems such as temporary immobilization of nutrients and associated crop yield reduction (Yadvinder-Singh et al., 2005). As a result, a large amount of produced straw is left unutilized, which is mostly burnt on-farm (Gadde et al., 2009), although burning of the straw *in situ* is the most discouraged option as it emits air pollutions (Gadde et al., 2009) and causes loss of valuable nutrients into atmosphere (Yadvinder-Singh et al., 2005). Fortunately, composting offers a low-cost and environmentally friendly option for recovery and recycling of nutrients in the crop residues. Composting is a process of controlling and enhancing the biological decomposition of organic residues into usable end product such as organic fertilizer (Kluczek-Turpeinen, 2007). The C/N ratio, moisture content, particle size, airflow and temperature are the key

* Corresponding author. Tel.: +81 8058931645; fax: +81 459245518.
*E-mail addresses:* bakhtiyor_nr@yahoo.com, bakhtiyor.n.aa@m.titech.ac.jp (B. Nakhshiniev).

0960-8524/$ - see front matter 
http://dx.doi.org/10.1016/j.biortech.2013.10.083

parameters influencing the process. Successful optimization of these parameters may shorten the process and result in quality product i.e. stable and mature compost (Guo et al., 2012). Nevertheless, ordinary composting of rice straw is a too slow process for farmers, and may require at least 90 days to allow transformation of the residue into stable and mature compost (Goyal and Sindhu, 2011). This is because, microbial access to cellulose (a major biodegradable component of crop residue), is known to be inhibited by hemicellulose–lignin association during the decomposition process. In native lignocellulose i.e. rice straw, lignin is intermeshed and chemically bonded with hemicellulose polysaccharides, which together form a barrier that becomes even more resistant to microbial degradation (Malherbe and Cloete, 2002). Therefore, enhancement of rice straw composting process requires disruption of this physicochemical barrier. It has been suggested that at least 50% of hemicellulose should be removed to significantly increase cellulose degradability (Agbor et al., 2011).

In order to enhance the composting process, an innovative hydrothermal treatment (HTT) technology with mild reaction conditions (180 °C, 1.0 MPa, 30 min) was selected as a pretreatment step for solubilization of hemicellulose before subsequent composting of rice straw. The HTT reaction conditions were selected from our previous bench-scale work in which a reaction temperature of 180 °C was the most favorable for solubilization of the major portion of hemicellulose polysaccharides (Nakhshiniev et al., 2012). However, stability and maturity are also the important aspects of compost quality, in particular in relation to its agronomic application. Therefore, it is essential to evaluate the stability and maturity of the compost to ensure effectiveness of the pretreatment technology.

A large variety of physical, chemical and biological parameters have been proposed for the evaluation of compost stability and maturity (Wichuk and McCartney, 2010). Biological stability index evaluated by respirometric measurements based either on $CO_2$ production rate, $O_2$ uptake or release of heat has been frequently applied in compost stability determination (Komilis and Kletsas, 2012). Compost maturity, on the other hand, which implies no toxicity to plants upon immediate application of compost, is still best determined using the plant phytotoxicity tests, such as seed germination and/or plant growth bioassays (Wang et al., 2004). In practice, phytotoxicity can also be induced by factors such as high amounts of free ammonia, excess soluble salts or certain organic acids. Therefore, the change in chemical parameters during the composting process such as pH, electrical conductivity (EC), C/N ratio, $NH_4^+$—N formation and the ratio of $NH_4^+$—N to $NO_3^-$—N have been found as the useful indicators in compost maturity determination (Wang et al., 2004). Integrated use of these parameters and indices has been shown to result in better evaluation of compost stability and maturity (Mondini et al., 2003). The objective of this research, therefore, was to measure the changes in physical, chemical and biological parameters and indexes during composting of rice straw residue with and without HTT, and evaluate HTT in enhancing the compost stability and maturity of the rice straw residue.

## 2. Methods

### 2.1. Material and HTT process

In this study, rice straw was used as the model lignocellulosic agricultural residue. It was purchased from the local gardening store. Since, the residue was already cut into small pieces ranging from 2 to 4 cm no additional cutting was required. In order to obtain sufficient amount of material for subsequent bin-scale composting experiment a pilot-scale HTT facility with reactor capacity of 200 L was employed in this study. Schematic and overall view of the HTT facility is shown in Fig. 1. First, the rice straw (about 8 kg in dry weight) was fed into the reactor, and then, saturated steam supplied from the boiler was injected into the reactor until the pre-set hydrothermal conditions (180°C, 1.0 MPa) were reached. The blades installed inside the reactor then started to mix the residue for about 30 min. After the treatment was complete, the reactor was decompressed immediately by flashing the steam through the condenser and the moist treated residue (with around 68% MC) was discharged by rotating the blades, which also act as a screw conveyor. Four batches were performed. The treated products cooled down, mixed and were preserved (10 °C) until the next experimental procedure. The chemical properties of the residue with and without HTT are shown in Table 1.

### 2.2. Compost substrate preparation

The rice straw residues, with and without HTT, were then spread on separate blue plastic sheets and microbial inoculums were applied using a bottle with water spray nozzle. Since, the residue obtained after the HTT had already a moisture content of 68%, no correction of the moisture content was required. As for the untreated residue, however, it was initially soaked in the water for 48 h to constitute the moisture content of 68%. Because the initial C/N ratios of both substrates were higher than the range considered optimum (25–30) for starting composting process, necessary amount of nitrogen was added to the substrates (8 g per each kg of DM) in order to bring the C/N ratios within the recommended range. The nitrogen was added in the form of urea solution (17% w/v) and was applied (100 ml per each kg of substrate) soon after the application of microbial inoculums. All preparations were conducted outdoor when the ambient temperature was below 15 °C, so no special care was taken to prevent the water or nitrogen loss. The amount of substrates loaded in each composting reactor was about 18 kg (wet basis). While the substrate was being loaded into each reactor, original samples were withdrawn (bottom, middle, top) immediately for subsequent analyses, and the composting process was begun; the composting time was noted as week zero (Week 0).

### 2.3. Microbial inoculum preparation

Compost microbial inoculum was prepared by means of shaking a 1:25 (w/v) compost/water mixture for 15 min in a warm water bath (32 °C). Compost was commercially produced (Wakayama Organic Productive Union, Japan) and prior to shaking, it was supplemented with glucose solution (5% w/v) and pre-incubated at 32 °C for 3 days in air-tight collapsible container in order to active the microbes. Produced gas was released and compost was mixed once daily. Because, the hydrothermally treated residue had undergone a 'sterilization' process, rice straw rinse water was also prepared in similar way to include 'native' microbial inoculums presented naturally in the untreated residue. The prepared suspensions were then mixed and diluted with 5 parts of pure water before it was applied as a compost inoculum.

### 2.4. Composting setup

Plastic dust bins with a volume of 90 L (Fig. 2) were modified and used as composting reactors. The bins were externally insulated with two layers of glass wool and aluminum foil thermal insulators to minimize the convective heat loss. A removable airtight lid was put on top of each reactor to facilitate intermittent mixing and sampling of substrate during the course of composting. The lids, however, were insulated from the inner side (foam rubber) in order to minimize the occurrence of the reflux condition.