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Co-composting of livestock manure with rice straw: Characterization and establishment of maturity evaluation system

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ABSTRACT

Composting is considered to be a primary treatment method for livestock manure and rice straw, and high degree of maturity is a prerequisite for safe land application of the composting products. In this study pilot-scale experiments were carried out to characterize the co-composting process of livestock manure with rice straw, as well as to establish a maturity evaluation index system for the composts obtained. Two pilot composting piles with different feedstocks were conducted for 3 months: (1) swine manure and rice straw (SM–RS); and (2) dairy manure and rice straw (DM–RS). During the composting process, parameters including temperature, moisture, pH, total organic carbon (TOC), organic matter (OM), different forms of nitrogen (total, ammonia and nitrate), and humification index (humic acid and fulvic acid) were monitored in addition to germination index (GI), plant growth index (PGI) and Solvita maturity index. OM loss followed the first-order kinetic model in both piles, and a slightly faster OM mineralization was achieved in the SM–RS pile. Also, the SM–RS pile exhibited slightly better performance than the DM–RS according to the evolutions of temperature, OM degradation, GI and PGI. The *C*/*N* ratio, GI and PGI could be included in the maturity evaluation index system in which GI > 120% and PGI > 1.00 signal mature co-composts.

1. Introduction

Livestock breeding and rice production are the major agricultural industries in China. The annual amounts of fattening pigs and dairy cows exceed 0.6 billion and 0.1 billion, respectively (NBSC, 2011), resulting in an annual generation of nearly 0.3 billion tons of animal manure. The large quantity of animal manure is difficult to be completely utilized in a limited nearby arable land, and fresh animal manure is also not suitable for land application not only because of its containing pathogens and unstable nutrients but also because of transportation cost issue (Hu et al., 2011). Serious environmental pollution has been triggered due to inappropriate manure disposal. According to the report on the first China Pollution Source Census issued by the Ministry of Environmental Protection in February, 2010, the annual chemical oxygen demand (COD) discharged from animal husbandry accounted for 40% of the total discharge from all pollution sources. Meanwhile, the sown area of paddy is about 30 million hectares (NBSC, 2011) with annual amount of 0.2 billion tons of rice straw being produced accordingly. Rice straw is mainly used for fuel (cooking and house heating), animal feed, fiber for pulping, and plowing into farmland. It has been reported that a very large proportion of rice straw was discarded or burned in the field due to lack of cost-effective treatment approaches, leading to severe water and air pollution (Wang et al., 2008). There is an urgent need to find appropriate methods for these wastes in order to reduce environmental pollution and recycle agricultural resources. Co-composting of livestock manure with rice straw can be one of the applicable solutions (Li et al., 2008), mostly attributable to the higher moisture and lower *C*/*N* ratio of livestock manure while lower moisture and higher *C*/*N* ratio of rice straw, especially in the areas where both two wastes are available.

Composting is a biological process in which organic matter (OM) can be utilized by aerobic thermophilic and mesophilic microorganisms as substrate and mainly converted into mineralized products (CO_2, H_2O, NH_4^+) or stabilized OM (mostly as humic substances) (Bernal et al., 2009; He et al., 2009; de Guardia et al., 2010a,b). Although composting has been widely practiced with its final products being utilized as fertilizers or soil amendments, there are still knowledge gaps in understanding it due to the high variety and heterogeneity of feedstocks (Li et al., 2008; Himanen and Hänninen, 2011). Besides, various composting systems add

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some difficulty in this understanding, probably resulting in the complexity of compost maturity evaluation system (Gao et al., 2010). Bernal et al. (2009) and Nolan et al. (2011) pointed out that compost maturity couldn't be well described by a single property or parameter. In China, the standards for composts lay stress on the physical and chemical parameters like pH, moisture, total nitrogen (TN), and OM without biological or agronomical parameters being considered, resulting in a less comprehensive and systematical assessment with respect to the maturity of composts and the potential risk of land application of unstable and immature composts (Gao et al., 2010). A prerequisite for the compost to be safely applied in agriculture is its high degree of maturity and stability (Bernal et al., 2009). Some attempts have been tried on testing the effects of different feedstocks on the performance of composting process (Paredes et al., 2000; Zhu, 2007; Li et al., 2008; Himanen and Hänninen, 2011), and on evaluating compost maturity by using different parameters (Grube et al., 2006; Ko et al., 2008; Gómez-Brandón et al., 2008). Up to now, for the co-composting of the two main livestock manures with rice straw, however, little information can be found when these two aspects (*i.e.*, physical/chemical and biological/agronomical parameters) are taken into consideration simultaneously, thus no maturity evaluation index system with agronomical parameters included is available. In addition, the relationship between the physical/chemical properties and biological/agronomical parameters is also scarce for the co-composting of the two main livestock manures with rice straw.

The objective of present study was to characterize the co-composting process of swine/dairy manure with rice straw using different parameters including pH, temperature, total organic carbon (TOC), different forms of nitrogen, OM, humus, germination index (GI) and plant growth index (PGI). A compost maturity evaluation index system was proposed and established to reveal the composting progress and the compost maturity. The relationship between the physical/chemical and biological/agronomical parameters are also discussed.

2. Materials and methods

2.1. Experimental procedure

Two pilot piles of composting were prepared with rice straw (RS) and two different livestock manures, namely swine manure (SM) and dairy manure (DM), respectively. The SM was collected from a swine farm in Pudong District, Shanghai, China with a productivity of 8000 heads per year; the DM was from a dairy farm located in Jinshan District, Shanghai, China with 5000 milk cows; and the RS was sampled from a paddy field in Qingpu District, Shanghai, China. Table 1 lists the main characteristics of the raw materials used in this study. In order to start the composting at desirable *C*/*N* ratios, the feedstock mixtures were prepared in the following proportions on fresh weight basis (w.m.): 60% SW + 40% RS for the SM–RS pile and 67% DM + 33% RS for the DM–RS pile, corresponding to theoretical *C*/*N* ratios between 35 and 40.

Besides fresh manure and rice straw, two types of commercial composts were obtained from a local market for the maturity test: (1) Commercial compost A, provided by Shanghai Yunong Composting Plant, a product from co-composting of swine manure with rice straw; and (2) Commercial compost B, provided by Shanghai Lianye Composting Plant, a product from composting of dairy manure with rice straw.

The weight of each pile was about 50 kg and each pile was conducted in quintuplicate. After being mixed completely, the feedstocks were put into foam boxes (50 cm × 50 cm × 50 cm) which were then placed in a climate chamber. The chamber was controlled at temperature of 30 ± 1 °C and humidity of 70 ± 5%, respectively. During the composting process, the pile was manually mixed every 10 d and sampled every 15 d or 30 d for the determination of the designed parameters. The compost sample was obtained by mixing 5 sub-samples from 5 random sites of the pile at the same time.

2.2. Analytical methods

The core temperature was measured by a thermometer (ZDR-21, Hangzhou Zeda Equipment Co, Ltd., China) equipped in each feedstock at the depth of 25 cm, and monitored every 24 h. The pH of the raw material or compost sample was detected by a pH meter (SenION1 portable pH meter, HACH, USA) in a 1:5 (w/v) water-soluble extract. The moisture content and dry matter of the sample was obtained by drying at 105 °C in an oven for 12 h, and the organic matter (OM) was determined by the weight loss after ignition at 430 °C for 24 h (Navarro et al., 1993). Total nitrogen (TN) and total organic carbon (TOC) were measured in accordance with the method of Yeomans and Bremner (1988). Ammonia-N was determined by the indophenol blue photometric method based on Berthelot's reaction (Sommer et al., 1992). Nitrate-N was determined by ion chromatography (WIC-II ion chromatographer, Shanghai Cany Precision Instrument Co., Ltd., China) in a 1:20 (w/v) water extract. Humic acid (HA) and fulvic acid (FA) fractionations were determined according to Ciavatta et al. (1990).

OM loss was calculated from the initial (X_1, %) and final (X_2, %) ashes contents according to Eq. (1) (Paredes et al., 2000):

$$\text{OM loss } (\%) = 100 - 100[X_1(100 - X_2)]/[X_2(100 - X_1)] \quad (1)$$

Germination index (GI) was obtained by growing the seeds of *Lepidium sativum* L. (Zucconi et al., 1981) in a 1:2 (w/v) of the water-soluble extract of the compost. The extract was achieved by centrifuge the mixture (compost + distilled water) at 3200 rpm (1147 × g) for 30 min, and then filtration through filter paper. The resultant solution was mixed with distilled water in the proportion of 100%, 75% and 50%, respectively with 100% of distilled water as control in the experiment. Two ml of the mixture was added into a petri dish (9 cm) with filter paper laid previously, and 10 seeds of garden cress (*Lepidium sativum* L.) were spread on the filter paper. Then all the petri dishes were placed in an

Table 1
Main characteristics of the three raw materials and two commercial compost products used in this study (dry weight).

Parameters	Rice straws	Swine manure	Dairy manure	Commercial compost A	Commercial compost B
Moisture (%)	11.07 ± 1.00	81.95 ± 0.56	84.25 ± 0.69	27.08 ± 0.86	37.41 ± 1.09
Total organic carbon (TOC, %, d.w.)	38.73 ± 0.99	42.20 ± 0.45	41.10 ± 1.22	36.19 ± 1.13	36.47 ± 0.95
Total nitrogen (TN, %, d.w.)	0.54 ± 0.07	3.17 ± 0.07	2.61 ± 0.13	1.63 ± 0.05	1.64 ± 0.12
C/*N* ratio (TOC/TN)[a]	71.72	13.31	15.75	22.20	22.24
Total phosphorus (TP, %, d.w.)	0.09 ± 0.02	1.28 ± 0.13	0.65 ± 0.06	2.09 ± 0.15	2.14 ± 0.27
pH	N.D.	7.64 ± 0.43	8.03 ± 0.58	7.45 ± 0.03	7.50 ± 0.06

The data are indicated by mean ± standard deviation for triplicate determinations. N.D., no determination.
[a] Average value of triplicate determinations.