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Fertilizer potential of liquid product from hydrothermal treatment of swine manure

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ABSTRACT

Compared with composting, hydrothermal treatment (HTT) technology can dramatically shorten the duration for manure waste treatment. This study firstly investigated the effect of HTT on solubilization of N, P and organics from swine manure, and then evaluated the phytotoxicity of liquid product from hydrothermally treated manure by seed germination test. Results show that 98% of N in manure could be converted into soluble form after HTT at 200 °C for 60 min. Soluble P in hydrothermally treated manure (at 150 °C for 60 min) was 2.7 times that in raw manure. The germination indices (GI) were all greater than 100% when the liquid product (from HTT at 150 °C for 60 min) or its diluted samples being used. Results from this study suggest that HTT could be a promising technology for producing safe and value-added liquid fertilizers from swine manure.

1. Introduction

Nutrients are essential for plant growth. To insure enough food production from the limited farmland on Earth for the increasing global population, fertilizers play an important role in the increase of plant yield and remediation of soil depletion resulted from intensive farming activities. However, long-term application of chemical fertilizers shows negative effect on soil's N and C storage capacities and agronomic efficiency (Khan et al., 2007; Mulvaney et al., 2009). In addition, the production of synthetic fertilizer requires a large amount of gases, energy (Haber-Bosch process for N) and natural mineral resources (like phosphate rock) (Teenstra et al., 2014).

Nutrients recovery from organic wastes can become a prospective option if the process's environmental friendliness and sustainability could be guaranteed. As a result of the increasing global population, one important sector of food production, animal husbandry has also been rapidly developed, generating far more manure than the amount needed by local farmers for land application (He et al., 2016). Composting is a typical method widely used to convert manure waste to fertilizer that can be safely used, as the process can stabilize organics, sterilize pathogens and weed seeds in raw manure (Eghball and Lesoing, 2000). However, in terms of manure waste treatment and resources recovery, composting might be less efficient, since after 1–3 months' processing, the major beneficial and finished product is compost only. During the long period of composting process, around half of the C and N resources would be lost and emitted as harmful and greenhouse gases (GHGs) (Hao et al., 2004), demonstrating its low environmental friendliness and sustainability.

In order to reduce nutrients loss and develop a highly efficient process to convert manure waste into safe fertilizers, hydrothermal treatment (HTT) technology was attempted in this study, since the high temperature used (above 100 °C) can release high content of nutrients and sterilize pathogens (Barber, 2016). HTT as a treatment method has been applied to sewage sludge for enhanced sludge dewaterability and improved subsequent anaerobic digestion (AD) (Li et al., 2017). On the other hand, HTT coupling with AD has been demonstrated to save energy and enhance economic benefits in processing organic solid wastes for biogas production, and its high energy consumption can be compensated by enhanced dry AD process of the solid residue after the soluble nutrients being extracted from HTT treated swine manure at an appropriate temperature (Huang et al., 2017). Most recently, Huang et al. (2018) pointed out the possibility of using the water extract from hydrother-

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mally treated manure as liquid fertilizer, and the solid fraction can achieve 51% increase in CH_4 yield by dry AD. In addition, the resultant dry AD residue can be further used as solid fertilizer. In recent years, an increasing attention has been paid to the recovery of valuable compounds from solid wastes by using HTT (Suárez-Iglesias et al., 2017; Aida et al., 2017). For instance, when microalgae were hydrothermally treated at 175–350 °C for 10–90 min, 38–100% of nitrogen (N) and 57–99% of phosphorus (P) could be recovered in the water-soluble fraction (Aida et al., 2017). They also found that when HTT was performed at a lower temperature than 200 °C, organic N was the predominant N form in the water-soluble fraction. The high nutrients recovery rate with high organic N content reflects the great potential of HTT technology for nutrients recovery and liquid fertilizer production from manure waste. Idowu et al. (2017) also mentioned the fertilizer potential of process water from food waste after hydrothermal process. Restated, although previous research works have pointed out the fertilizer potential of liquid product from sludge, chicken feathers and empty fruit bunch by using HTT (Gollakota et al., 2018; Sun et al., 2014; Nurdiawati et al., 2015, 2018), the said liquid fertilizer potential has rarely been explored. In addition, limited information could be found on the feasibility of liquid fertilizer production from manure waste by using HTT, let alone the nutrients variation of treated manure at lower temperatures than 200 °C.

This study aimed to investigate the fertilizer potential of liquid product from HTT of swine manure. The effects of treatment temperature (110–200 °C) and retention time (0–60 min) on soluble N and P, soluble organics (carbohydrates, proteins and volatile fatty acids (VFAs)) were clarified. The properties of liquid product were further demonstrated by seed germination test and its pH, electric conductivity (EC), and metal ions.

2. Materials and methods

2.1. Swine manure

Swine manure used in this study was sampled from a local farm in Tsukuba, Ibaraki, Japan. The pigs were raised in traditional pig houses with cement floor. The manure was collected as solid state and stored at 4 °C before use. The main characteristics of swine manure were as follows: total solids (TS) 26.9 ± 0.53% of fresh weight, volatile solids (VS) 20.1 ± 0.42% of fresh weight, total nitrogen (TN) 27.7 ± 1.02 g N/kg-VS, soluble N 11.1 ± 0.33 g N/kg-VS, total phosphorus (TP) 25.8 ± 0.50 g P/kg-TS, and soluble P 1.7 ± 0.08 g P/kg-TS.

2.2. Hydrothermal treatment

Hydrothermal treatment (HTT) trials were conducted in an enclosed stainless reactor equipped with a propeller stirrer (OM Lab-tech MMJ-200, Japan). The reactor has a working volume of 200 ml and maximum temperature of 300 °C. These trials, each in triplicate, were performed at different temperature (110, 150, 180, or 200 °C) for different retention time (0, 10, 30, or 60 min) with agitation (60 rpm). For each trial, 80 g of raw swine manure was loaded into the reactor. After maintaining at different temperature for a designated retention time, the reactor was cooled to room temperature. Then, the treated swine manure was collected for further analysis. The schematic of experimental setup is illustrated in Fig. 1.

Soluble organic carbon (SOC), proteins, carbohydrates, volatile fatty acids (VFAs), ammonia nitrogen, orthophosphate, total solids (TS) and volatile solids (VS) contents, and pH of each sample were determined according to the procedures and methods described elsewhere (Yuan et al., 2017). Soluble N was detected with alkaline potassium persulfate digestion and UV spectrophotometric method. Soluble P was determined according to the phosphomolybdenum blue method after potassium persulfate digestion (APHA, 2012). Metal ions were analyzed by ICP-OES (Perkin Elmer Optima 7300DV, USA) after the sample being completely digested with the mixture of HNO_3 and H_2O_2 (1:1, v/v) at 98 °C.

2.3. Seed germination test

Seed germination was conducted to evaluate the phytotoxicity of swine manure after HTT. The seeds of Komatsuna were chosen for this germination test. The filtrates of treated manure after HTT at 150 °C for 60 min (150–60), 180 °C for 30 min (180–30), 200 °C for 60 min (200–60) were diluted correspondingly to a SOC concentration of 500, 1000, or 2000 mg/L. For each test, 1.5 ml filtrate or distilled water was added on the filter paper in a petri dish where 15 seeds were placed. Three petri dishes were prepared for each condition. Then, the germination test was conducted at 30 °C and 60% of humidity. After 72 h' incubation, the number of viable seeds and the root length in each test were measured and recorded. Besides, the electric conductivity (EC) and pH of each filtrate used for the germination test were measured. Germination index (GI) was calculated using the following equation (Tiquia and Tam, 1998).

$$\textit{Germination index}(\%) = \frac{n_s \times \textit{Root length in filtrate}}{n_c \times \textit{Root length in control}} \times 100$$

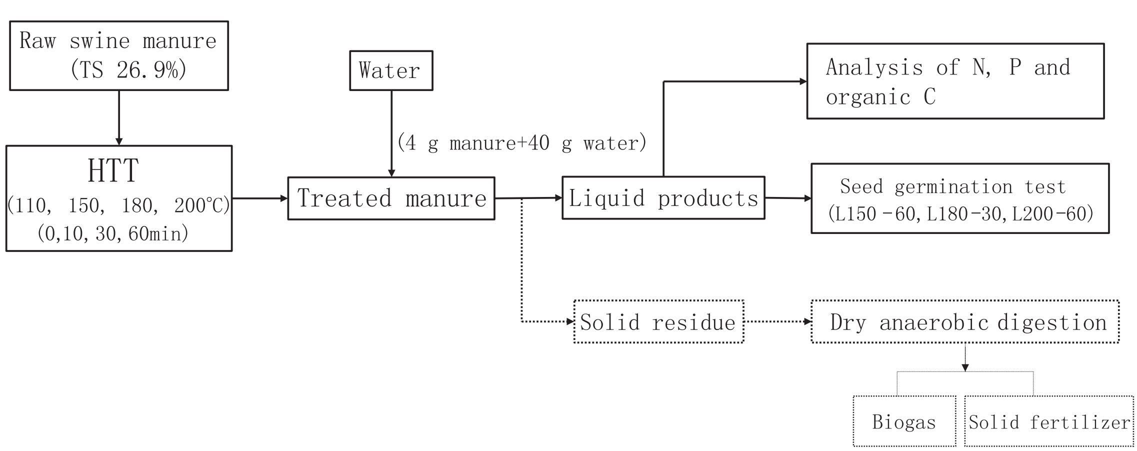

Fig. 1. Schematic of experimental setup in this study. HTT, hydrothermal treatment; Lx-y, the liquid product from HTT at temperature of x (°C) for y min. Solid line, the experiments did in this study; Dash line, the suggested treatment method for solid residue after water extraction.