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Research article

Feasibility of medical stone amendment for sewage sludge co-composting and production of nutrient-rich compost

Mukesh Kumar Awasthi [a, b], Quan Wang [a], Sanjeev Kumar Awasthi [a], Ronghua Li [a], Junchao Zhao [a], Xiuna Ren [a], Meijing Wang [a], Hongyu Chen [a], Zengqiang Zhang [a, *]

[a] *College of Natural Resources and Environment, Northwest A&F University, Yangling, Shaanxi Province 712100, PR China*
[b] *Department of Biotechnology, Amicable Knowledge Solution University, Satna, India*

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ABSTRACT

The feasibility of medical stone (MS) amendment as an innovative additive for dewatered fresh sewage sludge (DFSS) co-composting was assessed using a 130-L vessel-scale composter. To verify successful composting, five treatments were designed with four different dosages (2, 4, 6, and 10) % of MS with a 1:1 mixture (dry weight) of DFSS + wheat straw (WS). The WS was used as a bulking agent. A control without any amendment treatment was carried out for the purpose of comparison. For DFSS co-composting, the amendment with MS improved the mineralization efficiency and compost quality in terms of CO_2 emissions, dehydrogenase enzyme (DE), electrical conductivity (EC), water-solubility, and total nutrients transformation. The DTPA-extractable Cu and Zn were also estimated to confirm the immobilization ability of the applied MS. Seed germination and plant growth tests were conducted to ensure the compost stability and phytotoxicity for Chinese cabbage (*Brassica rapa chinensis* L.) growth and biomass, as well as chlorophyll content. The results showed that during the bio-oxidative phase, DOC, DON, AP, NH_4^+-N, and NO_3^--N increased drastically in all the MS-blended treatments, except the application of 2% MS and the control treatment; significantly lower water-soluble nutrients were observed in the 2% MS and control treatments. A novel additive with 6–10% MS dosages considerably enhanced the organic matter conversion in the stable end-product (compost) and reduced the maturity period by two weeks compared to the 2% MS and control treatments. Consequently, the maturity parameters (e.g., EC, SGI, NH_4^+-N, DOC, and DON) confirmed that compost with 6–10% MS became more stable and mature within four weeks of DFSS co-composting. At the end of composting, significantly higher DTPA-extractable Cu and Zn contents were observed in the control treatment, and subsequently, in the very low application (10%) of MS. Higher MS dosage lowered the pH and EC to within the permissible limit compared to the control, while increased concentrations of water-soluble nutrients diminished the DTPA-extractable Cu and Zn contents. In addition, plant growth experiments demonstrated that the addition of compost with 150 kg ha^{-1} TKN improved the Chinese cabbage biomass and chlorophyll level. The highest dry weight biomass (2.78 ± 0.02 g/pot) was obtained with 6% MS-blended compost while the maximum chlorophyll content was found with application of 4% MS compost (41.84 SPAD-unit) for Chinese cabbage. Therefore, 6–10% MS can be recommended to improve DFSS composting and to reduce the period to maturity by two weeks when considering its composting effect on Chinese cabbage growth, biomass yield, and chlorophyll level. However, amendment with 6% MS is a more economically feasible approach for DFSS co-composting.

1. Introduction

Human society is facing serious environmental challenges in the form of wastewater treatment and production of large amount of sewage sludge (SS). However, in the last few decades many advanced economically viable biotechnologies have been employed for wastewater treatment. With these, it has become possible to reduce the quantity of SS generated as well as to reduce the risk of environmental pollution (Ingelmo et al., 2012; Awasthi et al.,

* Corresponding author.
E-mail address: zhangzq58@126.com (Z. Zhang).

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2016a; Meng et al., 2017). However, looking at enrichment with essential nutrients of treated SS characteristics and its enriched essential nutrients (organic matter and N: P: K) in China, it is clear that new ecofriendly technology is required to the manage more than 30 million tons of SS generated annually by the treatment of ~129 million tons of municipal wastewater per day (National Bureau of Statistics of the People's Republic of China, 2014). However, the recycling of this huge quantity of SS is a challenge for the Chinese government because it contains high concentrations of potentially toxic metals, infectious microbes and organic micropollutants (Banegas et al., 2007). These require-rigorous enforcement of SS regulations directly relevant to agriculture (Zhang et al., 2014; Awasthi et al., 2016b). Hence, there is an urgent need for sustainable and environment -friendly technology to manage the progressively large quantities of sludge generated from wastewater treatment plants in China. Analysis of the published literature indicate that composting is effective for treating of organic solid waste prior to land application (Liu et al., 2007; Wong et al., 2009; Wu et al., 2014; Lim et al., 2016; Awasthi et al., 2017).

Many alternative methods for the disposal of SS have been proposed, but composting has the potential to provide a sustainable alternative technology to destroy the pathogens present in these wastes and convert the SS to a stable humus-like end product; this can be applied as a grow medium or organic amendment to soil with substantial benefit (Biederman and Harpole, 2013; Malinska et al., 2014; Villasẽnor et al., 2011; Lim et al., 2015; Meng et al., 2017). Nevertheless, it has been reported that the management of raw SS in composting involves several issues such as low C/N ratio, high moisture and the presence of heavy metals (HMs). These properties of SS makes it difficult to decompose and can inhibit the mobilization and volatilization of essential macro nutrients (Garcia et al., 1991; Zhang et al., 2016). However, promising nation for altering SS to create a marketable end product or organic soil conditioner is co-composting.

This involves mixing SS with organic bulking agents such as agricultural residues, yard waste or sawdust. These help to achieve optimum C/N ratio (~25) and moisture (~55%) content, making it possible to create a humus-like material (Gallardo et al., 2007; Awasthi et al., 2017). The co-composting of raw SS with such a bulking agent may also provide adequate air space, particle density, and physical structure needed to enhance the aerobic microbial activity in the composting mass as well as improve the rate of decomposition. In this sense, SS mixed with ligno-cellulosic by-products such as wheat straw, sawdust or wood chips provide more efficient composting than SS alone (Maboeta and van Rensburg, 2003; Pasda et al., 2005; Venglovsky et al., 2005; Neves et al., 2009). In addition, such agricultural wastes are easily obtained due to the extensive agricultural activities required in various countries (Loow et al., 2015).

However, during composting of SS, active mineralization of the readily available organic matter causes intensive acidification of the composting matrix, which ultimately inhibits the growth of aerobic microbe's and the composting process. Hence, amendment with alkaline additives such as lime can balance the acidic pH and this help to buffer the composting mass, and enhance the humification of organic matter but also enhances the loss of nitrogen as NH_3 (Zorpas et al., 2003; Wong et al., 2009; Awasthi et al., 2016b). Consequently, the loss of total nitrogen via NH_3 emissions could account for more than 65% of the original total N in the composting mass and reducing both its market demand and nutrient level. Therefore it is necessary to buffer the composting mass during the early thermophilic phase and then reduce NH_3 emissions in the later stage of SS composting. A review of the published literature confirmed that SS amendment with additives amendment such as zeolite (Zorpas and Loizidou, 2008; Villasẽnor et al., 2011; Awasthi et al., 2016a,b), kaolin (Himanen and Hänninen, 2009), bentonite (Li et al., 2012; Wang et al., 2016a), biochar (Zhang et al., 2016; Li et al., 2015; Awasthi et al., 2017), phosphogypsum (Gabhane et al., 2012; Yang et al., 2015), ash (fly, wood and bottom) (Lau et al., 2001; Gabhane et al., 2012; Fang et al., 1999; Kuba et al., 2008; Kurola et al., 2011; An et al., 2012), and supplementation of Mg and P salts (Chan et al., 2016; Wang et al., 2013) conserved nitrogen, immobilized the HMs and improved the humification of organic matter during SS composting. In the last few years, many kind of additives have been widely used as amendment to improve composting efficacy by mitigating the loss of nitrogen and reducing the bioavailability of HMs (Prost et al., 2013; Sánchez-García et al., 2015; Awasthi et al., 2016a). Jindo et al. (2012) and Zhang et al. (2016) investigated the impact of application of 2%–10% (v/v) wood biochar and 5%–15% (v/v) wheat straw biochar for composting with poultry manure. They found a 10% increase in the TOC concentration in the end product, with 30% decrease in the dissolved carbon content. Wang et al. (2016a,b) described that the addition of medical stone (MS) not only reduced NH_3 emission but at the same time could buffer the composting mass during the early phase of pig manure composting. It also enhanced the organic matter degradation as well as restrained the mobility of Zn and Cu in the compost.

Therefore, finding more economically feasible and effective novel additives to reduce the nitrogen loss and mobility of HMs as well as to increase the market demand for compost is still an area of progressive composting research. In this sequence, MS is a new mineral additive that has been commonly applied in waste water treatment and medical care due to its large surface area and porous properties as well as its high cation-exchange capacity (Wang et al., 2016b). However, there has been very limited research on the impact of MS on (water soluble and total nutrient transformation, and compost quality during SS co-composting. MS is similar to zeolites a large group of hydrated aluminosilicate microporous minerals that has the ability to trap gases and to decrease the bioavailability of trace elements during composting of pig manure (Wang et al., 2016b, 2017). To address the research gaps and potential of medical stone (MS) as a novel additive, we hypothesized that study of the MS amendment in the SS composting might provide comprehensive knowledge regarding nutrient transformation and HMs immobilization during SS composting. In addition, the correlation of the parameters analyzed was investigated using redundancy analysis (RDA), while compost quality was assessed using plant growth experiment to confirm the toxicity and total nitrogen content of the compost.

2. Materials and methods

2.1. Feed stock collection, processing and experimental design for composting

Dewatered fresh sewage sludge (DFSS) and wheat straw (WS) were used in the present experiment. They were collected from the Yangling Wastewater Treatment Center and from the farm house on the university campus. Chopped WS (2–5 cm) was mixed with DFSS 1:1 (dry weight) as a bulking agent to obtain the optimum moisture and C/N ratio. Medical stone (MS) was used as amendment in the present study and was procured from a private company (Zhejiang Shenshi Mining Industry Co., Ltd, China). The characteristics of the selected DFSS, WS and mixture of the two revealed in our previous study (Awasthi et al., 2017). To conduct the composting experiment, a 130 L reactor was filled with 50.0 kg of fresh DFSS mixed with WS either 1:1 dry weight (d-wt) or ~ 5:1 fresh weight basis). To these, one of five dosages of MS [0, 2, 4, 6 and