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Investigating the efficiency of co-composting and vermicomposting of vinasse with the mixture of cow manure wastes, bagasse, and natural zeolite

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ABSTRACT

Fermentation of ethanol as a product of sugarcane agro-industry causes the discharge of large amounts of a liquid waste called vinasse into the environment. In this study, co-composting followed by vermicomposting process of the mixtures of vinasse, cow manure, and chopped bagasse was performed for 60 days using earthworms of *Eisenia fetida* species. The results showed that the trend of changes in C/N was decreasing. The pH of the final fertilizer was in alkaline range (8.1–8.4). The total potassium decreased during the process, ranging from 0.062 to 0.15%, while the total phosphorus increased and its values ranged from 0.06 to 0.10%. The germination index (GI) for all samples was 100%, while the cellular respiration maturity index was < 2 mg C-CO_2 g^{-1} organic carbon day^{-1}, confirming a very stable compost. The results of this study indicate that the compost obtained from the co-composting-vermicomposting process could be used as a sound soil amendment.

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1. Introduction

Food and agricultural industries produce large amounts of solid and liquid wastes; if not properly managed, they create numerous problems to the environment. The residues of agro-industries are considered as the contaminants, influencing the environment significantly (Diaz et al., 2002; Siles et al., 2011). Ethanol as one of the products of sugarcane agro-industries is produced from alcohol producing factories through mesophilic fermentation of agricultural crops including sugarcane, corn, wheat, sugar beet etc. (Mota et al., 2013). Production of ethanol through fermentation results in the production of large amounts of a liquid waste called vinasse (9–14 L of vinasse is produced per one liter of ethanol) (Diaz et al., 2002; Siles et al., 2011). It contains considerable amount of biodegradable organic matter (BOD = 25,000–45,000 mg/L and COD = 70,000–120,000 mg/L) and nutrients (N = 30 g/kg, K = 30 g/kg). However, due to low pH (3–4.5), high temperature, brown color, high ash content, and electrical conductivity (250–300 dS/m), it is considered as one of the most contaminated wastewaters (Campos et al., 2014; Carvajal-Zarrabal et al., 2012; Diaz et al., 2002; Vaccarino et al., 1993; Zayas et al., 2007).

The discharge of this wastewater into the environment causes serious problems and changes in natural ecosystem including eutrophication or decreased diffusion of sunlight into aqueous environments. In addition, increasing environmental awareness coupled with more stringent regulation standards has triggered various industries to challenge themselves in seeking appropriate wastewater treatment technologies (Teh et al., 2016). In the past years, vinasse produced by Razi Alcohol Production Factory of Ahvaz city was disposed off in evaporation ponds. This treatment method generated many problems including contamination of ground and surface waters, nuisance, malodor, appearance and aggregation of insects and other disturbances to the surrounding environment (Madejón et al., 2001; Siles et al., 2011). There are different methods for the treatment of vinasse, including chemical treatment (coagulation and flocculation, chemical precipitation,

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chemical oxidation) and biological treatment (aerobic or anaerobic, trickling filter, lagoons, landfilling etc.). The majority of these methods are not very efficient due to relatively high investment and maintenance cost, the production of other hazardous compounds, and very high concentration of minerals and salts in the wastewater. Therefore, the use of advanced wastewater treatment systems is not reasonable (Eykelbosh et al., 2015; Prado et al., 2013; Siles et al., 2011). One of the suitable methods for converting agricultural wastes is composting process. Composting is regarded as a method in which aerobic mesophilic and thermophilic microorganisms consume organic matter as a substrate under controlled conditions, producing a stabilized, mature, deodorized, hygienic material, free of pathogens and plant seeds, and rich in humic substances that can be used as soil conditioner. If earthworms are applied in this process, it can be termed as an integrated composting-vermicomposting process. Earthworms can convert organic fraction of solid wastes to a nutrient rich fertilizer under aerobic conditions. *Eisenia fetida* is a species of earthworms, which under suitable environmental conditions (suitable pH, temperature, and moisture), has the potential to convert organic waste into products with a high nutritious value that can be used as conditioner for improving physical, nutritional, and biological characteristics of soil (Amouei et al., 2009; Lim and Wu, 2016; Lim et al., 2015b; Meunchang et al., 2005; Negro et al., 1999; Prado et al., 2013; Wu et al., 2014). In various studies, agricultural wastes, wastewater sludge, and industrial and municipal organic solid wastes have been used as the raw materials in composting and vermicomposting processes (Entry et al., 2005; Gigliotti et al., 1996; Molina et al., 2013; Moreno et al., 1996; Murillo et al., 1995; Yadav and Garg, 2011). Since vinasse possesses carbon and some salts including potassium and calcium, which are required for the growth of microorganisms, it may be applied in aerobic degradation processes (Mota et al., 2013). However, limited studies were conducted in this regard. For example, Molina et al. (2013) have investigated the stabilization of sewage sludge, vinasse biowastes, and rabbit manure by vermicomposting using *E. fetida*. In another study, co-composting of vinasse/grape marc has been investigated and optimized (Diaz et al., 2002). Madejón et al. (2001) also have evaluated the effect of three vinasse composts as a deep fertilizer on crops (corn and sugar-beet) and on some chemical properties of a soil by applying two successive compost applications. One of the most important requirements that must be taken into consideration for composting and vermicomposting processes is proper aeration. For this purpose, bulking materials are used to facilitate the aeration of the compost mixture. The use of agricultural and industrial wastes not only provides the required carbon but also serves as bulking agents and improves the aeration of composting mixtures. Bagasse is an agricultural waste, which over several million tons of it is annually produced in agro-industrial units in Khuzestan province; of which 100 thousand tons is used for production of animal feeds and chipboard sheet and 300–350 thousand tons is used in paper production units (Taghizadeh, 2011). The remaining amount of the produced bagasse is dumped as waste materials, which causes air pollution through frequent natural self-burning. Therefore, it is necessary to find an efficient way for managing the huge amounts of the produced bagasse in our area in an ecofriendly manner. Hence, this waste was used as bulking agent during combined composting followed by vermicomposting of vinasse. Usage of vinasse compost for increasing soil fertility is one of the economical and suitable methods. However, the high salinity caused by vinasse has significantly limited its usage as a fertilizer in agriculture. One of the solutions to decrease the salinity of final compost is the application of adsorbent materials such as natural zeolites during vermicomposting. Zeolites are porous structured compounds with an aluminosilicate framework (AlO_4 and SiO_4) that can accommodate a wide variety of cations, such as Na^+, K^+, Ca^{2+}, Mg^{2+} and others. Some studies have used zeolites for reducing the salinity as well as for removing heavy metals from fertilizers obtained from composting of poultry manure and leachate. However, no study has been reported for reducing salinity in the fertilizer obtained from different mixtures with vinasse (Armağan et al., 2004; Turan, 2008). The present study was aimed to investigate the applicability of an integrated co-composting-vermicomposting process to produce a fertilizer from vinasse, cow manure, and bagasse. Furthermore, during the process a natural calcium zeolite was used as adsorbent to improve the quality and decrease the salinity of the final product. The physical, chemical, and biological parameters affecting the maturity and quality of the final product were also evaluated for different mixtures of the raw materials.

2. Materials and methods

2.1. Feeding materials and composting system setup

In this study, the required vinasse and bagasse were obtained from Razi Alcohol Production Factory and Dabal Khazaei Agro-industry Company, Iran, respectively. The co-composting process was carried out for 3 weeks in wooden boxes ($50 \times 15 \times 25$ cm) with internal polyethylene coating. The feeding materials consisted of cow manure, vinasse ($EC_{1:10}$ = 6.44 mS/cm; pH = 4.7; moisture = 93%), and crushed bagasse (1–1.5 cm) as the bulking agent. The wet weight ratios of bagasse to cow manure during composting were 10, 25, and 50%. Thereafter, vinasse was added to the mixture of cow manure and bagasse at a ratio of 10 (V_1), 20 (V_2), and 40% (V_3) (wet weight basis) (Diaz et al., 2002; Madejón et al., 2001; Molina et al., 2013). During the composting process, aeration of the mixtures was performed through manual mixing in a periodic fashion of twice per week (Hawrot et al., 2005). The moisture content of the mixtures was measured after mixing and then it was adjusted to the optimum range (45–55%) by sprinkling required water, and the moisture content was kept in this range during the composting process (Fountoulakis et al., 2009).

2.2. Vermicomposting by the earthworm

After composting for 3 weeks, calcium zeolite was added to the mixtures at two ratios of 10% (Z_1) and 20% (Z_2). Then, 15–18 earthworms, *E. fetida*, with a mean size of 5.5 cm, were added to each kilogram of the compost to begin the vermicomposting process. A mixture without the presence of the worms was used as the control (Molina et al., 2013). The moisture and temperature of the treatments during vermicomposting were monitored and kept constant to be in the optimal range (Molina et al., 2013).

2.3. Physical and chemical analyses

On the 1st, 10th, 20th, 40th and 60th days, after complete mixing of the mixture, about 20 g homogenized wet samples (free of earthworms and cocoons) were drawn from 5 different parts of each treatment and then dried for further chemical analyses. The parameters of electrical conductivity (EC), pH, organic carbon (OC), total nitrogen content (TKN), total phosphorus (TP), and total potassium (TK) were analyzed. Monitoring of *E. fetida* worms was performed across all stages of the process as well as at the end of the process in terms of the number of the worms and the weight of the worm mass (Gandolfi et al., 2010; Molina et al., 2013). The indices of germination, cellular respiration, population of fungi and heterotrophic bacteria were measured in the final product to determine the maturity degree.

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