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Microbial biodegradation of waste materials for nutrients enrichment and heavy metals removal: An integrated composting-vermicomposting process

Seyede Maryam Kharrazi [a], Habibollah Younesi [a,*], Javad Abedini-Torghabeh [b]

[a] Department of Environmental Science, Faculty of Natural Resources, Tarbiat Modares University, P.O. Box 46414-356, Noor, Iran
[b] Waste Management Organization of Mashhad Municipality, Mashhad, Iran

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ABSTRACT

The aim of present study was to improve the quality of vermicompost through different substrates and adding active sewage sludge as a source of N-fixing and P-solublizing bacteria in a shorter time than conventional composting process. The experiment setup included 15-L reactors used for pre-composting, a vermicomposting mixture of activated sewage sludge (control, 2000, 4000 and 6000 mg L^{-1}) and corn stalk residue (40, 60 and 80%). The physico–chemical changes in vermicompost caused by the microbial biodegradation and their combinations were measured over a period of 70 days. The results showed that the values of total organic carbon (TOC), total volatile solid (TVS), total Kjeldahl nitrogen (TKN) and carbon to nitrogen ratio (C/N) decreased in all treatments, while those of electrical conductivity (EC), total phosphorous (TP), nitrate and heavy metals increased. A minimum C/N ratio of 13.16% obtained in the 40% corn stalk waste substrate with 4000 mg L^{-1} activated sludge treatment while it was 23.44% in the 80% corn stalk waste substrate without activated sludge treatment. Results indicated that with the increase in 6000 mg L^{-1} sewage sludge and with the decrease of 40% corn waste substrate lead a decrease in TKN and an increase in nitrate, viz. 1.36–2.06% and n.d.–1889 mg kg^{-1} respectively. However, in comparison to decrease in TKN nitrogen, decrease in TOC (39.94–27.32%), TVS (63.48–43.48%), C/N ratio (63.48–13.43) and pH (7.33–3.15) and increase in EC (1.55–3.15 mS cm^{-1}) and TP (2.395–3.31 g kg $^{-1}$) was obtained. The decrease of heavy metals in the final vermicompost materials was detected by noting a low heavy metals concentration in the corn residue.

1. Introduction

Today, the growing world population and large scale urbanization has created a global environmental issue for adopting a sustainable approach in handling solid waste, with solutions such as recycle of organic waste, to promote enduring agriculture as well as a pollution-free environment. Vermicomposting is a non-thermophilic process (Elvira et al., 1996), stabilizing organic matter and converting important plant nutrients in the presence of earthworms and microflora into a more soluble state to become more available to plants (Atiyeh et al., 2002). Vermicompost is considered an excellent product since it is homogenous with desirable aesthetics, reduced level of contaminates; besides, containing plant growth hormones and high level of soil enzymes, it has a larger microbial population and tends to hold more nutrients over a longer period without adversely impacting the environment than regular compost (Sharma et al., 2005). There is growing interest in the use of an integrated systems approach, starting with pre-composting followed by vermicomposting to achieve specific technical objectives. This approach is characterized by greater microbial activity of more uniform sized microbes (Ndegwa and Thompson, 2000), hastened degradation rate (Frederickson et al., 1997; Ndegwa and Thompson, 2000) and enhanced pathogen control compared to either of the individual processes. Also, for the development of sustainable farming, waste enrichment is of interest. This could be done by treating the waste initially with certain prolific microflora. Inoculation of suitable strains have been reported to hasten the rate of vermicomposting, which leads to reduced time needed to complete the process of composting and to enrichment of nutrients in the final product (Singh and Sharma, 2002). This was revealed that inoculation of microorganisms influences the chemical and biochemical properties of organic substrates significantly during vermicomposting (Pramanik et al.,

* Corresponding author. Tel.: +98 122 625 3101 3; fax: +98 122 625 3499.
E-mail addresses: hunesi@modares.ac.ir, hunesi@yahoo.com (H. Younesi).

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2007). They demonstrated an increase in nutrient content in vermicompost and also phosphates and urease activities (Pramanik et al., 2007). Kumar and Sing reported that an increased percentage of nitrogen and phosphorus was observed when organic waste was treated with a colony of nitrogen fixing and phosphate solubilizing bacteria (Kumar and Singh, 2001). The combination of bioinoculants was best in terms of quality of the vermicompost (Saha et al., 2008). Many authors have investigated the characteristics of vermicompost derived from various feed stocks (Kaviraj and Sharma, 2003; Garg et al., 2006; Pramanik et al., 2007). Over the past decades, extensive research has been conducted to evaluate the feasibility of using corn stalk for various applications including for livestock feed, paper making, energy source, biofertilizer and direct use as soil amendment (Li et al., 2007; Ioannidou et al., 2009).

The aim of the present study was to address sustainability goals through (1) recycling corn stalk residue through vermicomposting, (2) improving the quality of vermicompost using different substrates and (3) adding activated sludge as source of N-fixing and P-solubilizing bacteria in order to speed up the composting process. Keeping all this in view, the main objective of the present research work was to study the role of inoculation of activated sludge into a corn stalk vermicompost in order to determine how the inoculation of microorganism would be able to bring about changes in the nutrient contents, and further, to evaluate the changes of heavy metal content possibly present in the substrate in order to determine potential environmental hazards. Another purpose of the study was to test the technical viability of this system, initially utilizing wheat straw to be employed later on other substrates.

2. Material and methods

The experimental setup included 15 L reactors which were used for pre-composting and vermicomposting. Four different biodegradable organic wastes, viz. corn waste, cow dung, compost of municipal solid waste and paper with variable C/N ratio were used as vermicomposting substrate. Corn residue was procured from a corn farm close to the city of Mashhad, Iran. Cow manure was procured from a dairy farm adjacent to Mashhad Compost Plant, and paper was collected from the waste collection site of the Plant. The initial chemical compositions and heavy metal concentration of the organic wastes are presented in Table 1. The activated sludge as the source of nitrifying and denitrifying bacteria was obtained from the Municipal Wastewater Treatment Plant of Bojnourd, a city west of Mashhad. The chemical properties and heavy metal concentration of the activated sludge are shown in Table 2. In this experiment an exotic epigeic earthworm, *Eisenia fetida*, used for vermicomposting. The worms were cultured at room temperature in plastic pots containing plant soil and had a pH 5.5 to 6.5 and consisted of cow dung medium. The worms in their peak health were randomly picked for use in the experiment from the stock culture maintained in the vermicomposting unit of the composting factory (Mashhad, Iran).

Table 1
Physic–chemical properties and heavy metal content (mg kg^{-1}) of raw materials (mean ± SD, $n = 3$).

Raw material	Corn stalk	Compost	Cow manure	Paper
C/N	47.72 ± 8.20	22.53 ± 5.38	21.85 ± 3.76	213 ± 12.96
TOC, %	45.81 ± 6.83	25.91 ± 6.12	11.58 ± 2.60	49.21 ± 8.89
TKN, %	0.96 ± 0.18	1.15 ± 0.27	0.53 ± 0.14	0.23 ± 0.05
TVS, %	61.00 ± 12.29	35.56 ± 8.15	15.39 ± 3.84	65.73 ± 16.60
TP, g kg^{-1}	2.73 ± 0.56	2.16 ± 0.34	3.29 ± 0.23	0.61 ± 0.10
NO_3^-, mg kg^{-1}	n.d	n.d	n.d	n.d
Cd	n.d	0.12 ± 0.03	n.d	n.d
Fe	2361 ± 256	12606 ± 575	10786 ± 436	8786 ± 279
K	10516 ± 583	2720 ± 196	3533 ± 386	950 ± 78.41
Mn	170 ± 56.48	460 ± 67.04	455 ± 56.16	55.24 ± 12.45
Na	999 ± 98.21	1164 ± 112	1430 ± 87.09	644 ± 52.55
Ni	5.00 ± 0.25	75.27 ± 8.48	41.16 ± 5.15	4.05 ± 0.42
Cr	12.09 ± 0.78	71.08 ± 8.49	38.42 ± 5.17	7.00 ± 0.85
Ca	10634 ± 529	15134 ± 541	70509 ± 1432	17009 ± 863
Zn	100 ± 16.82	900 ± 24.16	150 ± 11.69	50.20 ± 6.32
Cu	21.04 ± 4.12	196 ± 23.63	36.00 ± 6.12	31.31 ± 4.14
Mg	4634 ± 687	13334 ± 1438	7696 ± 498	1284 ± 86.12
Pb	6.01 ± 0.32	113 ± 12.52	5.00 ± 0.74	9.26 ± 0.71

n.d.: not detected.

2.1. Experimental design

The corn stalk waste was air dried and chopped. Some compost and cow manure was washed to reduce EC to improve conditions for earthworms and then air dried. Paper was shredded into small pieces and soaked in water in order to speed up composting process. Samples of 40% (M_1), 60% (M_2) and 80% (M_3) of corn stalk waste (weight ratio) were mixed with other organic waste to provide an initial favorable environment for the earthworms. The experiment was conducted with 2.5 kg of substrate each in 3 plastic pots, then subjected to 1000 ml of three doses of microbial inoculants, viz. 2000 (C_1), 4000 (C_2) and 6000 mg L^{-1} (C_3) activated sludge along with control (C_0) as treatment. Some 150 pairs of earthworms (*E. fetida)* (mean weigh 300 ± 50 mg) were put into each pot, where during the study period the temperature of the feed was not allowed to exceed 25 °C and the moisture was maintained near 70% (dry weight) by adding water when necessary. The experiment was set up following a completely randomized block design with three replicates. Each windrow substrate with the different treatment was composted for 30 days as pre-compost period and then subjected to vermicomposting for 40 days. Inoculation of active sewage sludge was done at day-0. During vermicomposting, the feed material from each treatment was analyzed for pH and EC every 10 days after initiation of the process until its stabilization. Total organic carbon (TOC), total volatile solids (TVS), total Kjeldahl nitrogen (TKN), C/N ratio, nitrate (NO_3^-) and total phosphorus (TP) content were measured in the one, 30 and 70 day samples. The heavy metals, viz. magnesium (Mg), calcium (Ca), sodium (Na), potassium (K), manganese (Mn), lead (Pb), copper

Table 2
Physic–chemical properties and heavy metal content (mg L^{-1}) of active sewage sludge (mean ± SD, $n = 3$).

Value, mg L^{-1}	2000	4000	6000
NO_3^-, mg L^{-1} TKN, mg L^{-1}	1.05 ± 0.06	1.51 ± 0.12	1.25 ± 0.08
PO_4^{3-}, mg L^{-1}	1.02 ± 0.07	1.51 ± 0.07	1.71 ± 0.13
pH	7.32 ± 0.08	7.83 ± 0.09	7.57 ± 0.11
EC, mS cm^{-1}	4.21 ± 0.07	4.05 ± 00.05	5.50 ± 0.09
COD, mg L^{-1}	28.00 ± 4.5	56.00 ± 5.51	87.00 ± 6.20
Total count, CFU mL^{-1}	$(2.08 \pm 0.09) \times 10^6$	$(9.91 \pm 0.52) \times 10^7$	$(3.81 \pm 2.15) \times 10^9$
E. coli	–	–	–
Salmonella	–	–	–
Fe	4.32 ± 0.21	12.70 ± 0.27	16.52 ± 0.18
K	2.21 ± 0.24	4.83 ± 0.16	5.57 ± 0.17
Mn	0.10 ± 0.01	0.21 ± 0.03	0.38 ± 0.05
Na	4.87 ± 0.22	12.53 ± 0.11	14.54 ± 0.15
Ni	n.d	n.d	n.d
Cr	n.d	n.d	n.d
Ca	1.87 ± 0.10	2.83 ± 0.11	4.50 ± 0.07
Zn	0.10 ± 0.02	0.27 ± 0.02	0.25 ± 0.04
Cu	0.25 ± 0.03	0.51 ± 0.02	0.72 ± 0.03
Mg	1.22 ± 0.12	1.41 ± 0.06	2.01 ± 0.09
Pb	n.d	n.d	n.d
Cd	n.d	n.d	n.d

n.d: not detected.