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Original Research Paper

Vermicomposting of Municipal Solid Waste: A Biophysicochemical Characteristics

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The aim of this applied-analytical study is to investigate the feasibility of using selected raw waste mixtures after biological treatment using batch rectangular plastic boxes for vermicomposting (VC). We test various operating variables; these include biophysicochemical characteristics before and after vermicomposting, biophysicochemical characteristics of selected raw waste mixtures, earthworm biomass, and time to VC maturity. We pour selected raw waste mixtures+farm animal manure+agricultural wastes (as bulking agent) about 300 g, and 300-600 g of *Eisenia fetida* (as foreign earthworm) for 45-60 days in rectangular plastic containers (40 × 60 cm^2). Characteristics of selected raw waste mixtures show that cotton industry waste+horse manure (M4) is the best medium for *Eisenia fetida* activity and has the best physicochemical characteristics. The findings indicate that copper, electrical conductivity, phosphorus, potassium, relative moisture, and zinc amounts are decreased with increasing time to VC maturity. Calcium, ferrous, manganese, magnesium, nitrogen, organic matter, pH amounts, and carbon to nitrogen ratio are increased with increasing time to VC maturity. The best conditions for VC production are obtained to be selected raw waste mixtures, T4, 600 g of *Eisenia fetida,* and time to VC maturity 60 days. We conclude that the physicochemical characteristics of produced VC follows the A class standard.

Keywords: Biophysicochemical characteristics, Earthworm, Manure Vermicomposting.

Nomenclature	
BET	Specific Surface Area, BET ($m^2 . g^{-1}$)
C	Compost
C/N	Calcium to nitrogen
Ca	Calcium
Cu	Copper
EB	*Eisenia fetida* biomass
EC	Electric conductivity
EDEX	Element Dispersive X-ray
HA	Humic acid
IARC	International Agency for Research on Cancer
INS	Iranian National Standard
K	Potassium
Mg	Magnesium
M 1	Pine sawdust + poultry litter
M 2	Cotton industry waste + poultry litter
M 3	Pine sawdust + horse manure

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M 4	Cotton industry waste + horse manure
Mn	Manganese
OC	Organic carbon
OM	Organic matter
P	Phosphorus
RT	Response time
pH_{pzc}	Point zero charge
SEM	Scanning Electron Microcopy
VC	Vermicomposting
XRD	X-ray Dispersive
Zn	Zinc

INTRODUCTION

The potential of Annual vermicomposting (VC) production in 2011 was estimated to be 5.2 million tons in Iran country. Annual chemical fertilizer distribution in 2011 was estimated to be about 2700000 tons in Iran country. The International Agency for Research on Cancer (IARC) had defined that the annual mortality rate due to a variety of cancers in 2011 was 34000 people in Iran country, of which about 30000 people had been inhabited in the north provinces of Iran country (IANCRR, 2009). Annual chemical fertilizer distribution in 2011 was estimated to be about 1430 tons in the north provinces of Iran country. Tehran province ranked as the largest province in wastes producing. These wastes showed biodegradable properties in the environment, and were transformed into fertilizers (Baffi et al., 2005; Bouallagui et al., 2004). The humified matter was generated after decaying chemical and microbiological agricultural wastes [4]. Natural humification was very slow (Pereira and Arruda, 2003).

The most important advantage of biological treatment of these wastes was the little negative environmental impact (Coker, 2006; Paraskeva and Diamadopoulos, 2006). The production of humic matter was increased by composting (C) technology (Pereira and Arruda, 2003). The main disadvantage of C techniques was controversial microbial inactivation standards. Biotechnology processes such as VC, transforms wastes into a cost effective organic fertilizer in shorter periods of time. VC utilized earthworm for ingesting and metabolizing organic residues in a complex mechanism consisting of the following five steps: (i) softening of remains by saliva in the mouth of earthworm; (ii) neutralization by calcium secreted in the inner wall of the esophagus; (iii) powdering of particles in the muscular gizzard; (iv) digestion of a mixture of different kinds of organic matter (OM) by proteolytic enzyme of the stomach, and (vi) dissociation of pulped material by the action of a number of enzymes such as protease, amylase, and lipase (Fornes et al., 2012).

The advantages of VC biotechnology were: a rich source of advantageous microorganisms and nutrients, a soil conditioner agent, a fertilizer agent, increase in crop yield, having many hydrophilic groups (-OH, -COOH, and -SH), high specific surface area, remarkable porosity, significant absorption, and socio-economic benefits (saving time, electricity power, and man power) (Hattenschwile and Gaser, 2005; Klavins and Purmalis, 2013; Paul, 2000; Roberts et al., 2007). Effective factors on the optimal performance of VC were: aeration, earthworm biomass, moisture content, pH value, particle size, raw waste mixture, and time to VC maturity. Many of novel reactor arrangements were experimented by many researchers. (Bohen et al., 2007; Petiot and Guardia, 2004; Smith et al., 2006). The aim of this applied-analytical study is to investigate the feasibility of using selected raw waste mixtures after biological treatment using batch rectangular plastic boxes for VC. The variables under study involved bio physicochemical characteristics before and after VC, biophysicochemical characteristics of selected raw waste mixtures, earthworm biomass, and response time (RT).

MATERIALS AND METHODS

Earthworms used

Eisenia fetida, the exotic varieties of earthworms was selected for the VC procedure. *Eisenia fetida* was spread on bedding materials. All the reagents used were of analytical grade (Merck, Germany).

Determination of VC particle characteristics

Scanning Electron Microcopy **(**SEM) image was prepared from VC. VC composition was obtained by Dispersive X-ray (EDX) analysis. The zeta potential was analyzed with a Nano Zetasizer.

Experimental setup

The batch VC reactor was a 0.1 m^3 perforated rectangular plastic container (60 × 30 × 30 cm). To evaluate the effect of selected raw waste mixtures, on the VC generating process, samples underwent with different masses of *Eisenia fetida* (as foreign earthworm, 300-600 g), different times (45-60 days), types of agricultural wastes (as bulking agent, pine sawdust, and cotton industry waste), types of farm animal manure (as regulator agent, poultry litter, and horse manure), and municipal solid waste of Tehran city (as nutrient source for earthworm). The drying of selected raw waste mixtures was done by drying in an oven (Dyna, Iran) at 105 ˚C for 1 h. For each test, 300 g of raw waste mixture was poured into the reactor. All tests were performed at laboratory temperature (20 ˚C).

Analytical methods

All tests were performed in triplicate, and the mean data values were reported. The measurement of biophysicochemical characteristics of VC was performed according to Iranian National Standard (INS) method 13320 (INS, 2009). The VC samples were tested for electric conductivity (EC) by using a conductivity meter (Hach, America); mixture by using the gravimetric method at 105 ˚C for 1 h; organic carbon (OC) by using the titration method; pH by using a pH meter (Hach DR5000, America), total nitrogen by using the semi-micro kjeldal method (Hach, America), extractable phosphorus (P) by using a spectrophotometer (Hach DR5000, America); potassium (K) by using a flamephotometer (Hach, America); iron (Fe), manganese (Mn), magnesium (Mg), calcium (Ca), copper (Cu), and zinc (Zn) content by using an atomic absorption spectrophotometer (Perkin Elmer, America) (AWWA, 2005). Descriptive analysis and paired t-test were carried out using SPSS 18 software.

RESULTS AND DISCUSSION

The characterization of VC particles

Fig. 1 illustrates an SEM image of the VC particles. As observed, the average diameter size of VC particles was 60 nm. VC particles were of small diameter and high specific surface area (BET). Table 1 illustrates EDX analysis of the VC particles. As found in Table 1, the analyzed VC particles were composed of elements, including Ca, Cu, Fe, K, Mg, Mn, N, P, Zn, and so on. As observed, the calcium to nitrogen (C/N) ratio of VC particles was 10.42. It was concluded that humic acid ($C_{10}H_{12}O_5N$ (HA)), as a macro constituent of VC, had numerous chemical groups, interacted with surface of clays, and produced stable structures. Subramanian et al. reported that the composition of VC particles consisted of C/N ratio (Subramanian et al., 2010). Therefore, these elements confirmed that the main component of VC was HA. Mane and Raskar reported that the most compound in the VC particles was C/N ratio (Mane and Raskar, 2012). It was concluded that VC was a very heterogeneous material. Application of VC led to vaster porosity of soil due to an increase in the content of pores.

The characteristics of VC particles are shown in Table 1. BET measurements had also been performed, and the highest BET obtained for VC particles was 31 $m^2.g^{-1}$. Similar results were demonstrated by Landgraf et al., who reported that VC particles had a high surface area (Landgraf et al., 1998). Taylor et al. reported that VC particles had the numerous negative charged groups (Taylor et al., 2003). Similar results were demonstrated by Atiyeh et al., who reported that VC particles had particle density, 1.888 g. cm^{-3} (Atiyeh et al., 2001).

The effect of raw wastes physicochemical characterization

The characteristics of selected raw waste mixtures are shown in Table 3. The different treatments consisted of 300 grams of pine sawdust + poultry litter (M 1), cotton industry waste + poultry litter (M 2), pine sawdust + horse manure (M 3), cotton industry waste + horse manure (M 4). VC experiments were carried out as a function of the time levels in the range of 4 to 16 days in the experimental conditions such as amount of selected raw waste mixtures (300 g). The results are indicated in figure 2. Excluding the T 1, the temperature fluctuations as a function of time levels consisted of the following three phases:

(i) mesophilic phase;
(ii) thermophilic phase, and
(iii) stabilization phase.

The physicochemical characteristic variations as a function of time levels in the range of 45 to 60 days at the experimental conditions such as amount of selected raw waste mixtures (300 gr) are shown in Table 4. The final maturation occurred in 60 days by using M 4. It was seen that 300 g of M 4 raw west mixture was the best treatment. This phenomenon could be due to a gradual change of temperature during the process. It was seen that 300 g of M 2 raw west mixture was the worst treatment. This phenomenon could be due to a rapid change of pH during the process. This was in agreement with Castillo et al. (Castillo et al., 2005).

The Effect of different masses of Eisenia fetida

VC experiments were carried out with different masses of *Eisenia fetida* in the range of 300 to 600 g at the experimental conditions such as the amount of selected raw waste mixtures (300 g). The results are indicated in Table 5. The RT for *Eisenia fetida* adaptation to the selected raw waste mixtures (300 g) was the least in M4. The *Eisenia fetida* biomass was the greatest in M 4. This effect is attributed to an increase in the *Eisenia fetida* biomass (EB) and a decrease in the *Eisenia fetida* mortality rate by using M 4 process.

The volume loss was the greatest in the M 4. This phenomenon could be attributed to the production of carbon dioxide, evaporated water, and particle size reduction during the process. This was in agreement with Castillo et al., who reported that the slowest volume loss occurred in pine sawdust + poultry litter (Castillo et al., 2005). The tendency of VC toward lower pH than compost was reported by Subler et al. (Subler et al., 1998).

The physicochemical characterization of VC

VC experiments were carried out with a mass of *Eisenia fetida* (600 g), as redworm, at the experimental conditions such as amount of selected raw waste mixtures (300 g). The results are presented in Table 6. The C/N ratio was the least in M 3. This phenomenon was in agreement with the combination of its raw material. The selected raw waste mixtures with a low C/N ratio led to the destruction of *Eisenia fetida* due to the production of ammonia and therefore M 3 is considered as a cause for concern due to the increased potential for ammonia production. The raw waste mixture of M 4 was the best bed for *Eisenia fetida* multiplication. This phenomenon could be due to its high moisture amount.

The physicochemical characterization was the best in M 3. This was in agreement with Castillo et al., who reported that the least of volume reduction happened in pine sawdust + poultry litter (Castillo et al., 2005). It was seen that the high C/N ratio was led to effecting deleterious on the number of *Eisenia fetida*. Therefore, increasing of *Eisenia fetida* populations happened after decreasing C/N ratio. A C/N ratio in the range of 10 to 12 was a stability indicator. The pH of *Eisenia fetida* cast was about neutral. The P availability in soil was lower than in VC. The higher emission of P from *Eisenia fetida* cast was attributed to enhancing microbial activity such as phosphatase activity.

Kale and Bano found that the VC had the high concentration of P as P_2O_5 (19.58%) in worm's vermicast (Kale and Bano, 2002). Lee purposed that the transit of OM through the gut of *Eisenia fetida* led to transforming P to forms which were more bioavailable to plant (Lee, 2002). The pH values were the most in M 4. This phenomenon was attributed to passing out ammonia into the *Eisenia fetida* intestine and the VC N concentration. *Eisenia fetida* fed selectively on OM, and *Eisenia fetida* took in the small amounts of elements available.

Table 1: Characterization of VC particles

Particle	pH_{ZPC}	Density ($g.cm^{-3}$)	Specific Surface Area, BET ($m^2. g^{-1}$)	Diameter (nm)
VC particle	8.1	1.9	31.0	60.0

Table 2: EDX analysis of VC particles

Component separation	Quantity ($g. kg^{-1}$)	Quantity (%)
C/N	13.9	-
Ca	16.3	19.2
Fe	26.2	30.8
K	10.2	12.0
Mg	6.8	8.0
Mn	0.3	0.4
OC	4.2	4.9
P	3.1	3.6
pH	8.1	-
Zn	0.4	0.5
Others	17.5	20.6
Total	85	100

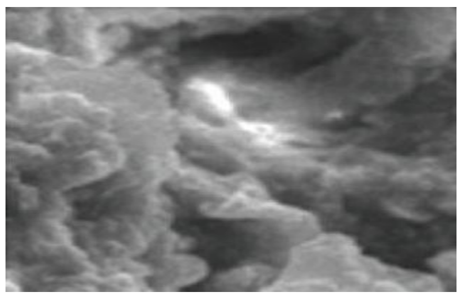

Figure 1: SEM images of vermicomposting particles

Table 3: Characterization of the original raw wastes

Number	wastes	C/N ratio	N ($g. kg^{-1}$)	OC ($g. kg^{-1}$)
1	Pine sawdust	402.0	0.014	5.600
2	Cotton industry waste	572.0	0.012	6.800
3	Poultry litter	10.5	0.190	2.000
4	Horse manure	12.4	0.200	2.300

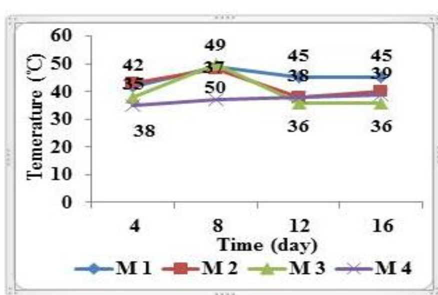

Figure 2: The effect of time on the temperature during process (pine sawdust + poultry litter (M 1), cotton industry waste + poultry litter (M 2), pine sawdust + horse manure (M 3), cotton industry waste + horse manure (M 4)

Table 4: Physicochemical variations in during process

Wastes	Parameter (mg. kg^{-1})	Time (Day)			
		45	50	55	60
M 1	NH_4^+	63.0	63.0	63.0	63.0
	pH	8.2	8.0	7.8	7.7
M 2	NH_4^+	70.0	10.0	5.0	Nd
	pH	8.1	7.7	7.3	6.9
M 3	NH_4^+	13.0	8.0	5.0	2.0
	pH	7.9	7.8	7.3	8.0
M 4	NH_4^+	nd	Nd	nd	Nd
	pH	8.1	8.0	8.2	8.1

Table 5: The Effect of different masses of *Eisenia fetida*

Wastes	Parameter	Mass of *Eisenia fetida* (g)			
		300	400	500	600
M 1	RT (Day)	95	90	87	85
	EB (%)	-104	-99	-71	-67
M 2	RT (Day)	74	69	67	66
	EB (%)	-93	-87	-82	-78
M 3	RT (Day)	70	66	63	62
	EB (%)	+18	+26	+31	+35
M 4	RT (Day)	69	65	62	60
	EB (%)	+87	+93	+98	+102

Table 6: Biological variations in during VC process

Number	Parameter	VC process			
		M 1	M 2	M 3	M 4
1	C/N	95.00	90.00	87.00	13.90
2	Ca	24.30	20.30	17.30	16.30
3	Fe	126.70	56.30	30.20	26.20
4	K	9.80	10.30	9.50	10.20
5	Mg	14.80	10.80	7.80	6.80
6	Mn	2.20	0.50	0.40	0.30
7	OC	3.40	3.60	3.70	4.20
8	P	2.80	2.90	3.00	3.10
9	pH	7.80	7.00	8.00	8.10
10	Zn	0.49	0.39	0.30	0.40

CONCLUSION

Several operational variables were examined for the effects on VC process. The following conclusions were obtained from the experiments:

1. The final maturation was occurred in 60 days by using M 4.
2. BET VC particles were 31m^2.g^{-1}.
3. 300 g of M 4 raw west mixture was the best treatment.
4. The *Eisenia fetida* biomass was the greatest in M 4.
5. The volume loss was the greatest in the M 4.
6. The C/N ratio was the least in M 3.
7. The raw waste mixture of M 4 was the best bed for *Eisenia fetida* reproduction.
8. The VC developed was found to have high value of nutrient.
9. The quantitative and qualitative analysis of other characteristics was proposed.

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