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Evaluation of the compost quality of vermicomposting process applied to different types of sludge using *Eisenia fetida*

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ABSTRACT

This study was carried out in 3,000 g composting containers under open test conditions, sewage and industrial sludge incubated by soil worms (*Eisenia fetida*) and vermicompost produced. For this purpose; domestic and industrial sludge were incubated with manure at 5%, 10%, 15%, 20% and control. The change in quality parameters monitored such as pH, electrical conductivity, humidity, total nitrogen, total organic carbon and C/N by taking samples from the vermicompost obtained on day 1st, day 30th, day 60th and day 90th during the times of incubation. Optimal incubation time was found to be 60 d for both sludge types and 15% (SS3) sewage sludge dose was found as optimal dose according to C/N ratio. The difference between sludge doses was statistically insignificant in the industrial sludge.

Keywords: Sewage sludge; Industrial sludge; Vermicompost; *Eisenia fetida*

1. Introduction

The spread of approaches that emphasize the concept of sustainability in agricultural production and promote organic production methods has led to the emergence of a new agricultural production sector called vermiculture in the European countries, India and the United States. Implementation of sustainable waste management policies already allowed to increase the amount of recycled wastes from 25.0 million tons in 1995 to 66 million tons in 2014 at European scale. Among different waste categories, bio-wastes have been recognized as a potential source of nutrients, carbon and energy. It was estimated that, until 2020, the European production of bio-wastes can increase by 10% from the current level of 140 million tons. Its proper management contributes the battle against climate change, problems related to energy security and scarcity of resources through resistance to global greenhouse gases emissions effect, which was expected to increase up to 70% by 2050 [1].

The increasing urbanization with drastically increasing stream of wastes forces Turkey to improve the main waste system infrastructures. Increased environmental pollution and accumulation of wastes adversely affects human and environmental health. About 65% of solid waste produced in Turkey are organic waste. Solid waste collected mixed is stored in regular landfill areas. The best method for the disposal of such organic wastes is composting and vermicomposting. Vermicomposting process low investment and operating costs are more preferred due to rapid disposal or recovery of wastes.

The textile industry is one of the fastest growing industries in Turkey, and the environmental pollution is one of the prime issues associated with this industry apart from fresh water utilization. The wastewater sludge disposal is a growing problem in textile industries and the municipality due to strict environmental norms and scarce landfill space. Most of them were untreated, and had resulted in a series of problems, for example, soil pollution. As in some other

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developing countries also. Decreasing land availability for disposals and growing public concerns over adverse impacts of insanitary disposals have drawn the attention of policy-makers to find an alternative strategy for safe disposals or meaningful utilization of such specific wastes.

Vermicompost, accelerate the process of waste recycling and better is a type of biotechnological compost generated by a particular type of worm to obtain an end product. The transformation of industrial and urban sludge into vermicompost is very important; on the one hand, waste matter is converted into a value-added product and on the other, it controls pollutants resulting from increasing industrialization or improper treatment of toxic materials. Recently, researches describe vermitechnology an effective technology in reducing the toxicity of industrial wastes. Among the available alternatives for the disposal of sewage sludge, one of the most attractive is vermicomposting, which is a simple and low-cost technique [2]. This method can be used in the removal of toxic metals and the breakdown of complex chemicals to non-toxic forms [3]. Vermitechnology is emerging as the most proficient bioconversion technique compared with aerobic or anaerobic composting [4,5]. In the recovery of domestic and industrial organic waste, vermicompost has superior properties than aerobic compost in both process and product [6].

The literature reports many studies on vermicomposting of municipal sewage sludge [7–12]. Vermicomposting of sewage sludge should require the addition of supplementary materials to ensure optimal properties for reproduction and growth of earthworms, and thus improvement of the conversion rate and properties of the obtained vermicompost. These supplementary materials can include bulking agents such as different kinds of crop straw, wood chips or saw dust as well as amendments such as soil, fly ash, tea factory coal ash and phosphate rock [13]. A few reports have been interested in the vermicomposting of different mixtures containing textile mill sludge [14,15].

According to Malińska et al. [8], to avoid the potential risk of noxious components and to biologically transform organic matter, most non-toxic, agricultural residues, animal manures, urban and industrial organic wastes can be used for composting purposes and combined composting followed by vermicomposting. Vermicomposting is one of the most feasible and environment friendly technique for the bioconversion of industrial wastes/sludges into a useful and high quality vermicompost. Bioconversion by earthworms for industrial wastes/sludges is helpful as it decreases the waste toxicity [16].

Earthworms are widely used for rapid and efficient decomposition and remediation of various industrial and organic wastes [17]. Earthworms, that are large enough to develop mutualistic relationships with microflora inside their gut proper, have also been called 'ecosystem engineers' for their ability to profoundly affect the soil structure [18]. The earthworm species *Eisenia fetida* was used for the vermicomposting as adopted in many other researches [19–22]. *Eisenia fetida* exerted high tolerance toward toxic substances in sewage sludge, as well as high stabilization efficiency in the process [23].

There have been many researches on vermicompost's effect on various plants. For example; tomato and cabbage plants [24], melon plant [25], spinach plant [26], lettuce plant [27], maize plant [28], cauliflower plant [29], onion and garlic plants [30], and wheat plant [31]. These studies indicated that vermicompost has a positive effect on the growth, quality, macro- and microelement content of plants.

The goal of this study is to obtain an efficient vermicomposting system using an earthworm, *Eisenia fetida*, contained in non-stabilized industrial sludge and sewage sludge from a wastewater treatment plant located in Ergene basin, Tekirdağ province, Turkey. The sludge was vermicomposted for 1, 30, 60 and 90 d, and the content of macroelements (C, N) and chemical properties of vermicompost determined.

2. Materials and methods

2.1. Sludge, Eisenia fetida collection and vermicomposting manure

This vermicomposted manure was collected in large-sized plastic pot containers to be taken to the laboratory in order to be mixed with sewage sludge or textile sludge after previously separating worms. The industrial sludge used was lees cake obtained from a textile industry in Ergene basin (Tekirdağ, Turkey) and the sewage sludge was a sludge cake obtained from a municipal wastewater treatment plant of Tekirdağ province. Cow manure was supplied by purchase from a special manure production company in Konya province. Fresh manure was selected as the bulking and initial substrate for worms after an appropriate vermicomposting process. In the first stage of the vermicomposting process, 300 g biowaste obtained by passing through the blender and consisted of tea truffles, banana peel, coffee grounds, lettuce and eggshells were added to the vermicomposting containers. Worms adapted well to the substrate, as visually observed by the number of individuals and cocoons [32].

2.2. Mixture preparation, vermicomposting and worm development

On the 1st day of the vermicomposting phase, four doses industrial sludge (IS) + manure and four doses sewage sludge (SS) + manure were mixed and were sampled for analysis. Eight mixtures were prepared: the vermicomposted manure alone was used as the control (Mo); Mo + sewage sludge at 5%, 10%, 15% and 20% (wet weight basis) (SS1, SS2, and SS3, SS4, respectively); Mo + industrial (textile) sludge at 5%, 10%, 15%, and 20% (wet weight basis) (IS1, IS2, and IS3, IS4, respectively). A homogenization process of the mixing materials and the mixtures was carefully carried out.

Next, 3,000 g (wet weight) of each mixture were placed into 5-L plastic containers (25 cm long; 20 cm diameter) with a fine nylon mesh at the top and pierced lids for aeration. Fifteen adult earthworms (*Eisenia fetida*) of the average total weight of 13 g were transferred to each vermicomposting container. The Red California Worms (*Eisenia fetida*) cultivated in a special worm production company in Gönen district of Balıkesir supplied by purchase. Experiment 2 different type sludge (IS and SS) × 1 type manure × 5 sludge dose = 10 composting container was prepared, from each compost container four periodic time (1st day, 30th day, 60th day, 90th day) during the incubation a total of 40 pieces sampling was carried out.

In order to survive the soil worms during the composting phase, as the moisture and temperature are important, the distilled water added to the compost container every 4 d. The moisture content was maintained at 85% throughout the vermicomposting period by periodically sprinkling adequate amounts of distilled water, and containers were kept in a dark room at 25°C. Neither manure nor biowaste was added during this vermicomposting period.

2.3. Chemical analysis

The following chemical characteristics were determined in the initial mixtures and in the final vermicomposts: pH, electrical conductivity (EC), moisture content, total kjeldahl nitrogen (TKN), total carbon content and C/N ratio. Eluate was prepared according to the Turkish regulations on the landfill and then measurement was made [33]. The solid sample was mixed with distilled water for 15 min and filtered through filter paper. The results from the eluate of the sewage sludge, industrial sludge and manure are given in Table 1.

To evaluate the changes in physico-chemical characteristics of feedstocks, various parameters were quantified including pH, electrical conductivity (EC), organic carbon (OC), total nitrogen (TKN). Before analysis, subsamples were air-dried in shade and stored in the plastic bags at room temperature. Organic carbon content was determined by oxidation with potassium dichromate as reported by Nelson and Sommers [41]. Total nitrogen was measured by the Micro-Kjeldahl method after digesting the sample in a diacid mixture of concentrated sulphuric acid and perchloric acid [42]. EC and pH were measured with a glass electrode by, respectively, using the 1:5 and 1:2.5 (w/w) sample:water ratios. EC values were referred to as a standard temperature of 25°C [43].

2.4. Statistical analysis

The SPSS statistical package (IBM Corp. Released 2011. IBM SPSS Statistics for Windows, Version 20.0. Armonk, NY: IBM Corp) was employed. The probability levels used for statistical significance were $p < 0.05$. All the results reported in the text are the mean of data. The test of independent sample t and Kruskal–Wallis was used to analyse the significant differences among mixtures.

3. Results

3.1. Chemical results

The physical and chemicals properties of the vermicomposts produced from two different type sludges are given in Table 2. As seen in this table, the difference between the sludges was found to be significant at $p < 0.05$.

Similar results on vermicomposting of sewage sludge have been reported by Kouba et al. [44]; Wang et al. [9]; Gupta and Garg [11]; Garg et al. [14]. There is not a regulation on the quality standard of vermicompost in Turkey. Both the Soil Pollution Control and Concerning Point Source Contaminated Sites Regulation and the Concerning Usage of Domestic and Municipal Treatment Sludges in Soil Regulation do not have any limitation for the usage of compost in soil. The compost usage limitations in the Control of Solid Wastes Regulation, however, are defined cursory. On the other hand, the moisture content and C/N ratio of the vermicompost is above the limit value (10–30) according to the Compost Quality Standards constituted by Turkish regulation [45].

The values of pH were found to be 6.66–7.62 (Table 3). The lower pH recorded in the final products might have been due to the production of CO_2 and organic acids by microbial metabolism during decomposition of different substrates in the feed mixtures [46]. Gradual increase in EC was recorded in both two sludges towards the 60th d in this study. This may be attributed to the freely available ions and minerals that are generated during ingestion and excretion by the earthworms [14].

Organic carbon decreased more significantly with time in two sludges as compared with control. The maximum reduction in OC was obtained in sewage sludge (110.6 to 8.41 g kg^{-1}) in comparison with industrial sludge and control (Table 4). C/N ratio in sewage sludge was higher than industrial sludge. This may be attributed to the higher nitrogen content of industrial sludge and the end of vermicomposting period in different sludge mixtures, probably due to mineralization of the organic matter.

The effect of incubation time on the physical and chemical properties of vermicompost is shown in Tables 3 and 4. The difference between incubation times was based on Kruskal–Wallis test and statistical significance level was taken as $p < 0.05$. As shown in this table, the median, minimum, and maximum values of the measured pH, EC, moisture, TKN,

Table 1
Results of the analysis of the cow manure and sludges

	Cow manure	Sewage sludge	Industrial sludge	Method
$pH_{1:2.5}$	7.03	6.70	8.77	TS EN 12457-4&SM 4500-H+B [34,35]
				TS ISO 10390 [36]
EC (dS cm^{-1})	3.38	2.15	3.10	TS 9748 EN 27888 [37]
Moisture (%)	0.7	39.0	12	SM 2540 G [35]
				TS 9546 EN 12880 [38]
TKN (%)	29	15	33	SM 4500 NO_2 B&EPA 352.1&SM 4500 Norg B [35]
Total C (%)	271.2	110.6	285	TS 8195 EN 1484 [39]
				TS 12089 EN 13137:2003 [40]
C/N ratio	9.3	7.3	8.6	–

Table 2
Effect of two different types sludge on some physical and chemical properties of vermicompost (independent sample t test)

	Sludge type	Mean ± SD	$p < 0.005$	Limit values[a]
Sludge dose	Sewage	12.5 ± 5.7	1	–
	Textile	12.5 ± 5.7	1	–
$pH_{1:2.5}$	Sewage	7.0 ± 0.4	0.15	
	Textile	7.2 ± 0.3	0.15	5.5–8.5
$EC_{1:5}$ (dS cm^{-1})	Sewage	1.76 ± 1.08	0.43	
	Textile	2.10 ± 1.06	0.43	<10 dS cm^{-1}
Moisture(%)	Sewage	41.8 ± 23.6	0.89	
	Textile	42.9 ± 24.4	0.89	<30%
TKN (g kg^{-1})	Sewage	8.2 ± 4.7	0.35	–
	Textile	9.9 ± 5.5	0.35	–
OC (g kg^{-1})	Sewage	29.2 ± 24.9	0.82	
	Textile	31.3 ± 25.4	0.82	>35%
C/N ratio	Sewage	35.5 ± 19.2	0.9	
	Textile	34.6 ± 22.4	0.9	10–30

[a]Compost Quality Standards constituted by Turkish Regulations [45].

Table 3
Effect of incubation time on the physical properties of sewage and industrial sludge (Kruskal–Wallis test results)

	Sewage sludge time				Textile sludge time			
	(day)	Median	Min & max	$p < 0.005$	(day)	Median	Min & max	$p < 0.005$
			7.11				7.45	
	1th	7.62	8.02		1	7.51	7.75	
			6.55a				6.85a	
	30th	6.66	6.77		30	7.06	7.16	
$pH_{1:2.5}$			7.02bd	0.006*			7.23d	0.024*
	60th	7.06	7.23		60	7.34	7.55	
			6.56cf				6.56c	
	90th	6.66	6.76		90	6.77	7.46	
			1.41				2.00	
	1th	1.85	2.38		1	2.21	2.30	
			2.52a				2.64a	
	30th	2.89	3.15		30	2.82	3.49	
$EC_{1:5}$ mS cm^{-1}			1.40d	0.092*			1.29bd	0.092*
	60th	1.51	1.52		60	1.47	1.59	
			0.072				0.01	
	90th	0.43	3.2		90	1.68	3.36	
			5.4				7.10	
	1th	13.7	29.2		1	8.95	62.00	
			67.6a				71.3a	
	30th	71.1	76.5		30	72.85	76.7	
Moisture (%)			24.4d	0.004			24.9d	0.012*
	60th	26.8	27		60	26.65	29.7	
			44.8cef				44.3ef	
	90th	56.9	57.2		90	49.9	54.5	

*Statistically significant at $p < 0.005$ level.

Table 4
Effect of incubation time on the chemical properties of sewage and industrial sludge (Kruskal–Wallis test results)

	Sewage sludge time				Textile sludge time			
	(day)	Median	Min & max	$p < 0.005$	(day)	Median	Min & max	$p < 0.005$
	1th	3.06	2.58 3.67		1	3.39	2.20 5.06	
TKN g kg^{-1}	30th	12.14	11.03a 15.62		30	15.61	14.22a 20.59	
	60th	4.62	4.07b 5.08d	0.005	60	6.8	6.22bd 7.64	0.004
	90th	12.36	10.65cf 14.61		90	12.88	10.23cf 15.67	
	1th	13.88	8.92 21.07		1	14.35	13.96 15.59	
OC g kg^{-1}	30th	24.35	21.30a 26.80		30	26.4	23.90a 36.40	
	60th	8.87	8.41d 9.04	0.004	60	10.63	9.74bd 10.8	0.003
	90th	70.03	66.6cef 71.96		90	72.27	66.65cef 77.2	
	1th	47.7	28.7 63.76		1	48.19	27.57 70.67	
C/N Ratio	30th	20.93	13.63a 22.30		30	17.17	15.24a 18.91	
	60th	18.9	17.61b 21.58	0.009*	60	15.63	12.75b 17.37	0.008*
	90th	57.44	48.42ef 62.92		90	54.15	45.8ef 75.46	

OC, C/N parameters are presented. According to the statistical analysis, pH, EC and C/N ratio were found to be significant and other parameters were found to be insignificant.

The change of TKN, OC and C/N ratio in the vermicomposting process is shown in Fig. 1. Accordingly, there is a decrease in OC and C/N ratio in both sludge towards the 60th day and there is an increase again towards the 90th day. Total Kjeldahl nitrogen content of the vermicompost increased with time in two sludges towards the 30th and 90th day. Decrease in pH may be an important factor in nitrogen retention as this element is lost as volatile ammonia at higher pH [14]. The increase was observed in TKN at the end of vermicomposting period in two sludge, probably due to mineralization of the organic matter. The increase in TKN for different sludge was found in the following: cow manure (control) > industrial sludge > sewage sludge.

The earthworms change the composition of waste, decreases organic carbon content, C:N ratio and retains macro and micronutrients [47]. In vermicomposting, the finished product (vermicompost) has higher nutritional content than thermal composting, which is due to the increased rate of mineralization and humification by earthworms [46].

The difference between sludge doses was only significant in the sewage sludge and it was insignificant in the industrial sludge as statically ($p < 0.005$). According to Fig. 2, the lowest C/N ratio was observed as 13.63 at 10% sewage sludge dose (SS2) while the highest C/N ratio was observed as 37.33 at 20% sewage sludge dose (SS4). The lowest TKN ratio was observed as 2.58 at 5% sewage sludge dose (SS1) while the highest TKN ratio was observed as 9.84 at 15% sewage sludge dose (SS3). If the C/N ratio exceeds 30, the biological activity slows down and more time is needed to complete the process. On the other hand, if the amount of nitrogen is high ammonia is released which damages the microorganisms and causes odour. By introducing an organic matter which is large in C/N ratio into the soil, the amount of nitrogen in the soil is not sufficient to degrade the organic matter.

Earthworms fragment the waste substrate and accelerate rate of decomposition of the organic matter, leading to a composting effect through which unstabilized organic matter becomes stabilized [14].

3.2. Economical results

The comparison of a sludge disposal plant and vermicomposting process feasibility studies is presented in Table 5. As shown in Table 5, vermicomposting is less costly than other sludge disposal methods. Agriculture is a one of the main areas of development in developing countries such as Turkey. The increasing interest in the use of vermicomposts as plant growth media, and soil amendment should extend its use in

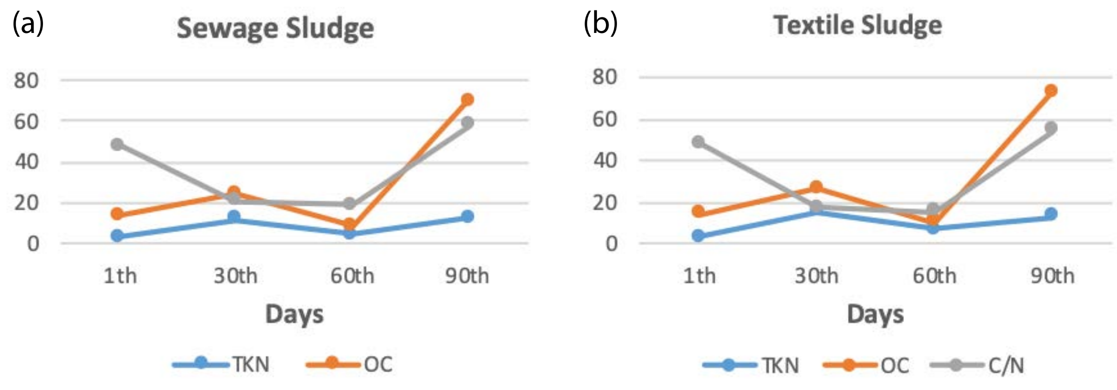

Fig. 1. Change of TKN, OC and C/N ratio in the vermicomposting process. The indicator of C/N values does not appear in Figure (a) .

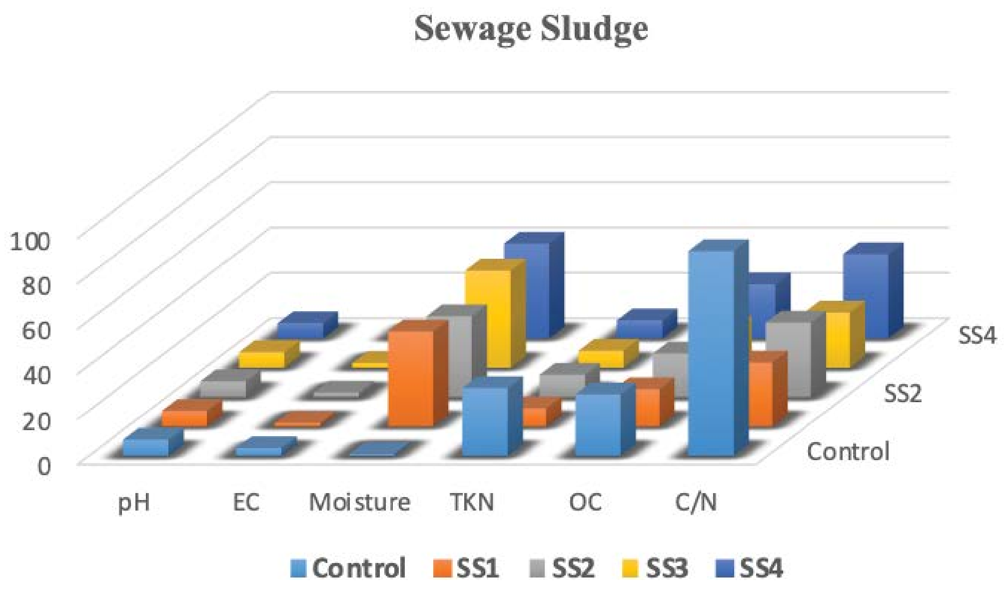

Fig. 2. Difference between sludge doses in the sewage sludge.

Table 5
Feasibility studies of disposal plant and vermicomposting process

Amount of sludge (25 t d^{-1})[a]	Solar drying	Thermal drying	Vermicompost[b]	Chemical fertilizer[b]
Investment cost (€)	390.625	781.250	25.100	2,421. 87
Operating cost (€/month)	4.531	18.750	–	–
Energy cost (€/month)	1.012	12.500	–	–
Repair and personnel cost (€/month)	625	1.562	312	312
Sludge removal cost (€/month)	2.890	4.687	–	–
Amount of sludge (t/month)	750	750	–	–
Operating cost (per ton)	6.09	25	–	–

[a]Disposal methods and operating costs of sludges [48].
[b]Calculated for 25 ton/d of vermicompost.

many purposes. Apart from environmental clean-up, other co-benefits that may arise through this practice ranges from raising soil organic matter to reduced soil problems, all of which will in the end improve soil quality and productivity within sustainable agriculture. It is thought that vermicompost usage can also be useful to other cultivars [31].

4. Conclusions

Optimal incubation time was found to be 60 d for both sludge types and 15% (SS3) sewage sludge dose was found as optimal dose according to C/N ratio. The difference between sludge doses was statistically insignificant in the industrial sludge. The efficiency of vermicomposting process using *Eisenia fetida* based on TKN and OC content of the vermicompost was found maximum for industrial sludge.

Composting is an agricultural system that aims to prevent environmental pollution. With the use of vermicompost, which has no old history for Turkey, it is aimed to prevent environmental pollution and decrease the rate of use of chemical fertilizers. Experimental data provide a sound basis that vermicomposting is a suitable technology for conversion of different types of sludge (sewage as well as industrial) into value-added material. In order to recover the treatment sludge, comprehensive researches should be carried out, reducing the sludge removal costs, encouraging the use of sludge in agricultural areas, carrying out the studies on this subject to the shortest way to the natural cycle and converting the pollution into a benefit. However, there is a need for greenhouse and field trials on how vermicomposts from the treatment sludge will affect the plant growth and the effects on soil quality in Turkey.

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