ELSEVIER

Bioresource Technology 76 (2001) 107–112

BIORESOURCE TECHNOLOGY

Integrating composting and vermicomposting in the treatment and bioconversion of biosolids

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Received 20 April 2000; received in revised form 21 July 2000; accepted 22 July 2000

Abstract

Traditional thermophillic composting is commonly adopted for treatment of organic wastes or for production of organic/natural fertilizers. A related technique, called vermicomposting (using earthworms to breakdown the organic wastes) is also becoming popular. These two techniques have their inherent advantages and disadvantages. The integrated approach suggested in this study borrows pertinent attributes from each of these two processes and combines them to enhance the overall process and improve the products qualities. Two approaches investigated in this study are: (1) pre-composting followed by vermicomposting, and (2) pre-vermicomposting followed by composting. The substrate was biosolids (activated sewage sludge) with mixed paper-mulch as the carbon base. *Eisenia fetida* (red wigglers) was the species of earthworms used in the vermicomposting processes. The results indicate that, a system that combines the two processes not only shortens stabilization time, but also improves the products quality. Combining the two systems resulted in a product that was more stable and consistent (homogenous), had less potential impact on the environment and for compost–vermicomposting (CV) system, the product met the pathogen reduction requirements.

Keywords: Integrated approach; Biosolids; Thermophillic composting; Vermicomposting; *Eisenia fetida*; Treatment; Organic fertilizers

1. Introduction

The problem of waste disposal from a myriad of industries, is becoming increasingly acute, the world over. Some of the measures that have been adopted to solve these problems have created more serious problems. The burning of such wastes in open dumps or in poorly designed incinerators could be a major source of air pollution. On the other hand, open dumps and poorly designed sanitary landfills can pollute surface and ground waters causing public health hazards. Meanwhile, the unavailability and rising cost of land near urban areas have made dumps and landfills increasingly expensive and impractical. The production of both livestock and grain on the other hand has increasingly relied on enormous chemical and energy inputs, leaving soils depleted of indigenous nutrients and organic matter, and resulting in wide-scale surface and groundwater contamination (DeLuca and DeLuca, 1997).

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The processing of organic wastes into organic fertilizers via traditional thermophillic composting is a technique that has been used to address the issues of environmental pollution, non-reliance on chemical fertilizers, sustainable natural soil fertility, and minimizing the development of new dumps and landfills. The major problems associated with traditional thermophillic composting are the long duration of the process, the frequency of turning of the material, the material sometimes needs to be reduced in size to provide the required surface area, loss of nutrients during the prolonged composting process, and the heterogeneous nature of the product. One advantage of thermophillic composting is that, during the composting process, the temperatures reached are normally high enough to provide adequate pathogen kill, especially for highly susceptible materials like biosolids. The rate of composting has been found to greatly affect the cost effectiveness and prevention of odors at both processing and process residue levels. A high rate implies lower capital and operational costs, a better-oxygenated ecosystem, and the production of a more stable end-product (Papadimitriou and Balis, 1996).

0960-8524/01/$ - see front matter
PII: S0960-8524(00)00104-8

In recent times, interest in the use of a closely-related technique, known as vermicomposting (using earthworms to breakdown organic materials) has increased (Hand, et al., 1988; Raymond et al., 1988; Edwards, 1988; Harris et al., 1990; Logsdon, 1994; Edwards and Bohlen, 1996). In its basic form, this is a low-cost technology system that primarily uses earthworms in the processing or treatment of organic wastes (Hand et al., 1988). Certain species of earthworms can consume organic material residuals very rapidly and fragment them into much finer particles by passing them through a grinding gizzard, an organ that all worms possess. The earthworms derive their nourishment from microorganisms that grow upon these materials. At the same time they promote further microbial activity since the fecal material or 'casts' that they produce is much more fragmented and microbially active than what they consume (Edwards, 1988; Edwards and Bohlen, 1996). During this process, the important plant nutrients in the material (particularly the nitrogen, potassium, phosphorus and calcium) are released and converted through microbial action into forms that are much more soluble and available to plants than those in the parent compounds.

In the traditional thermophillic composting process, the organic material has to be turned regularly or aerated in some other way to maintain the aerobic conditions. This often involves heavy and expensive equipment to process on a large scale the residuals as rapidly as possible. In vermicomposting, the earthworms, which survive only under aerobic conditions, take over both the roles of turning and maintaining the material in an aerobic condition, thereby reducing the need for expensive equipment. Besides this obvious advantage, the product (vermicompost) is homogenous, has a characteristic desirable aesthetics and may have reduced levels of contaminants.

The major drawback in the vermicomposting process is that, in contrast to traditional thermophillic composting (where thermophillic bacteria can raise the material temperature to more than 70°C), the vermicomposting processes must be maintained at temperatures below 35°C. Exposure of worms to temperatures above this will kill them. The vermicomposting process temperature is therefore not high enough for acceptable pathogen kill and hence the product does not pass EPA rules for pathogen reduction. In some cases, depending on the feed-substrate, some form of quick composting will be needed for the vermicompost to meet the EPAs process to further reduce pathogens (PFRPs) guidelines for pathogen destruction for class-A compost (class-A compost is said to be satisfactory for general distribution). These guidelines (contained in US-EPAs 40 CFR Part 503) require that, during composting, the materials reach temperatures of: (a) 40° C for at least five consecutive days and 55°C for at least three consecutive days, or alternatively; (b) temperatures of 55°C maintained for at least three consecutive days in the coolest part of compost undergoing aeration (Hay, 1996).

An integrated system approach that borrows pertinent attributes from both the traditional thermophillic composting process and the vermicomposting process would be necessary to provide a product free of pathogens, and a product with desirable characteristics at a faster rate than either of the individual processes. As the worms are able to enhance the rate of decomposition of organic materials by fragmenting the substrate material and by providing the more microbially active casts (the fecal material), if vermicomposting was used in combination with the traditional composting, the required temperature for ensuring adequate pathogen kill would be achieved. The resulting compost will not only be of high quality (with respect to pH, acceptable pathogen kill, homogeneity, higher nutrients, etc.) but also cheaper to produce if composting and curing time is effectively reduced. In England, Fredrickson and Butt in a report summarized by Logsdon (1994), reports successful addition of worms 'after' the heat of the initial decomposition subsides. The worms worked well in this situation and shortened the time for curing and stabilization of the compost.

Such an integrated system may take one of two forms, pre-vermicomposting followed by composting or pre-composting followed by vermicomposting. Pre-vermicomposting produces casts that are more microbially active besides being of more uniform size. This material would be expected to undergo the remaining stabilization process faster, thus resulting in shorter overall stabilization time. Pre-composting results in materials high in microbial biomass. Earthworms thrive on this microbial biomass and their expected improved activity may equally hasten degradation rate. In both cases, the material is ground up to a more uniform size and has the characteristic earthy appearance. These two integrated processes are examined in this paper.

2. Methods

2.1. System I: vermicomposting–composting (VC)

From preliminary studies (Ndegwa et al., 1999), an optimal worm stocking density of 1.60 kg-worms/m^2 and an optimal feeding rate of 0.75 kg-feed/kg-worm/day were used in the setup of this experiment. Biosolids were blended with mixed paper-mulch to provide a suitable C-to-N ratio of 25 (Ndegwa and Thompson, 1999). Effects or responses to be investigated were product stability, worm biomass, pH, ash content, total solids (TS), and nutrients; N and P (both total and soluble components).

Experiments were performed in worm-bins measuring $0.56 \times 0.38 \times 0.25$ m^3 (Length × Width × Depth). This provided 0.21-m^2 of exposed top surface. Earthworms (*Eisenia fetida*, commonly known as red wigglers) were introduced into each of the respective similar worm-bins, to provide the optimal stocking density. In this case, earthworm live-biomass loading was 0.34 kg for all three replicates. Each of the three replicates was fed at 0.75 kg-feed/kg-worm/day. The arrangement of the units, the loading of earthworms into each unit and the feeding of each unit were done in such a way that the concept of "complete randomization" was adhered to, as much as possible.

All the replicates were fed in a single batch with enough feedstock for the entire four weeks in which the experiment was conducted. The experiments were conducted in an environment whose temperature was 25 ± 6°C. The substrate material was maintained moist at approximately 80% (Wb) by spraying/sprinkling the surface with water every two days using a spray can.

At the time of loading, the following parameters were determined for the feed: moisture content (MC); pH; volatile solids (VS); the ash contents. These analyses were either carried out on samples immediately after they were obtained or after refrigeration at 4°C, to minimize microbiological decomposition, until analyzed.

Solid matter was determined as residue on drying at 80°C for 23 h (APHA et al., 1989). VSs were obtained by ashing the dried samples at 550°C for 8.5 h (APHA et al., 1989). Determination of pH was made potentiometrically in a 1:10 suspension of the sample in de-ionized water, this is a modification of the procedure adopted from Erhart and Burian (1997). This suspension was placed on a mechanical shaker at 230 rpm for 30 min prior to pH measurement. In the Erhart and Burian procedure, a 0.01 M calcium chloride solution was used instead of de-ionized water. Determinations of nutrients (N and P) were made in an independent laboratory, using a Perkin–Elmer total C-, N-, S-analyzer. For these determinations, representative samples were dried at 80°C for 23 h (APHA et al., 1989) and then ground to provide a homogenous sample. To obtain water extracts, 4 g of this homogenous sample was placed in 60 cm^3 of de-ionized water and the mixture placed on a mechanical shaker for 30 min. The mixture was then centrifuged at 4000 rpm for 10 min and the supernatant filtered through a number 40 Whatman filter paper to obtain the water extracts.

The vermicomposting process was terminated at the end of the fourth week after which the worms were separated from the vermicompost and total biomass of the worms was determined. Earthworm biomass growth was taken as the increase in total live earthworm biomass collected from the vermicomposted material and the bedding. Values were determined as live weight after hand sorting and removal of all extraneous material. The vermicompost was analyzed for the VS, ash content, moisture content, pH, and the nutrients (N and P) using the methods already described.

The vermicompost was then loaded into composting vessels for the composting process. All the vessels were unloaded every week for thorough turning and mixing of the material. Every day during the period of composting, the O_2 and CO_2 levels were monitored. Whenever the CO_2 levels increased or the O_2 levels decreased beyond their levels in air, aeration was manually increased to reverse this trend, and vice versa. The only other control parameter to the composting process was temperature. Temperatures were taken continuously for the entire period of composting (28 days). If the temperature exceeded 65°C, then aeration was automatically increased. The VS, TS, ash, MC, and nutrients N and P (both total and soluble proportions) were determined prior to composting and after the composting processes were terminated.

2.2. System II: composting–vermicomposting (CV)

Everything was done the same as in system I above except that the composting process was done before the vermicomposting process and two replicates were made instead of three. Biosolids blended with mixed paper-mulch to provide a C-to-N ratio of 25 was composted in vessels for 28 days and then vermicomposted for another 28 days. During vermicomposting, the same stocking density, feeding and feed schedules were adopted as for system I. All the parameters monitored in system I were monitored here in exactly the same way.

2.3. System III: vermicomposting

Again everything here was set as in the systems I and II. The feeding was however done for 56 days instead of 28 days and the material vermicomposted for the entire duration in four replicates. The parameters monitored in systems I and II were also monitored in this system.

2.4. Size characteristics

Determination of size characteristics of the feedstock and products for all the three systems were accomplished using the procedure for the analysis of soil-grain size. This procedure uses a set of sieves and is usually recommended when nearly all the material cannot pass through square openings of a 0.074 mm No. 200 screen (Lambe, 1951). The recommendation further states that, the set of sieves should be selected such that, the sieve above is approximately twice the sieve below. In this work, a set of seven-sieves was selected consisting of numbers 3, 6, 10, 14, 20, 35, and 60, with screen-openings of 6.35, 3.36, 1.68, 1.19, 0.840, 0.420, and 0.250 mm, respectively.

Representative samples of feedstock and products were dried in an oven at 100°C for 24 h. These samples were then broken into individual grains by hand. For each sieve analysis, 100 g of each sample was placed in the top sieve of the stack of seven pre-weighed sieves. The stack was then placed on a Ro-Tap machine and shaken for 5 min. The weight of sample retained in each of the seven sieves was determined. Since 100 g of sample was used each time, this also represented the percentage of total weight of material retained in each respective sieve. Two replicates of each sample were done and the average taken as the representative value.

The size of particles are usually reported in terms of geometric mean (X_{gm}) and geometric standard deviation (S_{gm}) by mass and this standard form (A.S.A.E., 1986) was adopted in the work presented here. Calculated values were obtained as follows:

$$X_{gm} = \log^{-1}\left[\frac{\sum (M_i \log X_{im})}{\sum M_i}\right], \tag{1}$$

$$S_{gm} = \log^{-1}\left[\frac{\left\{\sum M_i\left(\log X_{im} - \log X_{gm}\right)^2\right\}}{\sum M_i}\right]^{1/2}, \tag{2}$$

$$X_{im} = \left[X_i \times X_{(i-1)}\right]^{1/2}, \tag{3}$$

where X_i is the screen opening of the ith screen, $X_{(i-1)}$ the screen opening in the next larger than ith screen, X_{im} the geometric mean of particles on the ith screen, and M_i is the mass on ith screen (actual mass or percent of total).

3. Results and discussion

The parameters (Nutrients N and P, VS, and pH) of the feedstock and the products from all the three systems: vermicomposting (V-system), VC-system and CV-system are presented in Table 1. The respective percentage changes of each parameter after the eight weeks of processing were also calculated and are shown in Table 2. The results of analysis of variance among the three systems, are also given in Table 2 (see the Greek letter-superscripts).

Table 1
Feedstock and final product analysis

Item	N (%)	P (%)	VS (%)	pH
Feedstock	1.71	0.70	82.1	7.55
Vermicompost	1.67	0.81	73.6	6.47
Vermicompost–compost	1.68	0.72	69.6	6.05
Compost–vermicompost	1.70	0.83	71.1	6.10
Feedstock (Water extract)	0.49	0.06		
Vermicompost (Water extract)	0.11	0.05		
Vermicompost–compost (Water extract)	0.14	0.04		
Compost–vermicompost (Water extract)	0.14	0.05		

TS decreased between 35% and 48%. The decrease in TS was significantly different ($\alpha = 0.05$) among the three systems. Higher reductions were observed in the two systems with combined vermicomposting and composting processes than in the lone vermicomposting process. A similar observation was made in the reduction of VS among the three systems. The vermicomposting process by itself resulted in significantly lower reduction in the VS than the other two systems (CV and VC).

Other significant differences were observed in the contents of N and P in both the solid products and in the soluble components of the products (Table 2). Although the concentration of P was observed to increase in all the solid products, the concentration of P in the soluble amounts decreased between 16% and 33%. The highest reduction in the soluble P was observed in the VC-system. This system also displayed the lowest increased concentration of P in the solid. On the other hand, the nitrogen content in the product decreased during the eight weeks of processing time, along with its solubility. The soluble component of nitrogen decreased on average by approximately 73%, which is a significant reduction of its potential impact on the environment.

The temperature profiles during the composting-phase for both the combined systems are presented in Figs. 1 and 2. In the CV-system, all three replicates met the EPAs PFRPs requirement. All three replicates maintained a temperature of at least 40°C for more than five days, and 55°C for at least 3 days. As this product met EPAs requirement, it would be acceptable for general distribution. The MC of the material going into the composting-phase was approximately 75% (Wb). In spite of this high MC, the material reached a temperature of over 40°C in about 13 days. It is likely that this temperature (possibly higher temperatures) would have been achieved much earlier had the material not been so wet initially. On the other hand, the composting-phase in the VC-system (Fig. 2) did not satisfy the EPAs PFRP requirements for class-A compost. For the entire 28 days of composting, the temperatures of only a single replicate reached 40°C, but these peak temperatures could not be sustained for more than two days. It is believed that, the fine nature of this material and its high MC may have curtailed aeration to such an extent that, aerobic composting process could not occur.

The results of the grain-size analysis are given in Tables 3 and 4. The mean (of two samples) percentage of the material retained in each of the sieves, for each system, is presented in Table 3. For the particle sizes, geometric mean size and the geometric standard deviation were calculated and are shown in Table 4. The VC-system and the CV-system, displayed the smallest particle sizes and less heterogeneity (less geometric

Table 2
A comparison of the mean percent changes in the respective responses among the process type[a]

Process	Change (%)[b]						
	pH	TS	VS	N (Product)	N (Soluble)	P (Product)	P (Soluble)
Vermicomposting	−14.3[a]	−35.5[a]	−10.3[a]	−2.3[a]	−77.6[a]	15.7[a]	−16.7[a]
Vermicompost–compost	−19.9[a]	−47.6[b]	−15.2[b]	−1.8[a]	−71.4[a]	2.9[b]	−33.3[b]
Compost–vermicompost	−19.2[a]	−44.6[b]	−13.4[b]	−0.6[a]	−71.4[a]	18.6[a]	−16.7[a]

[a] a,b – Means with the same letter were not significantly different ($\alpha = 0.05$).
[b] Change (%) = [(Original − Final)/Original] × 100.

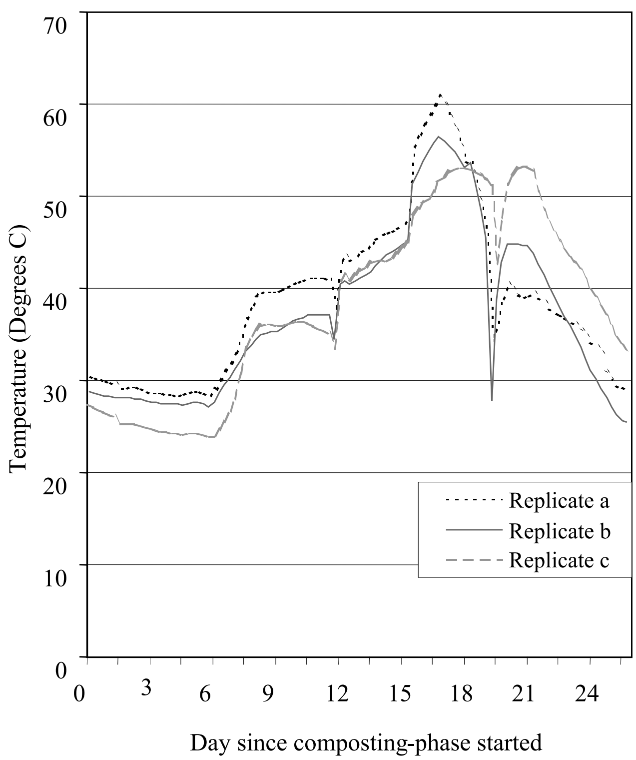

Fig. 1. Temperature profiles of the CV-system during the composting-phase.

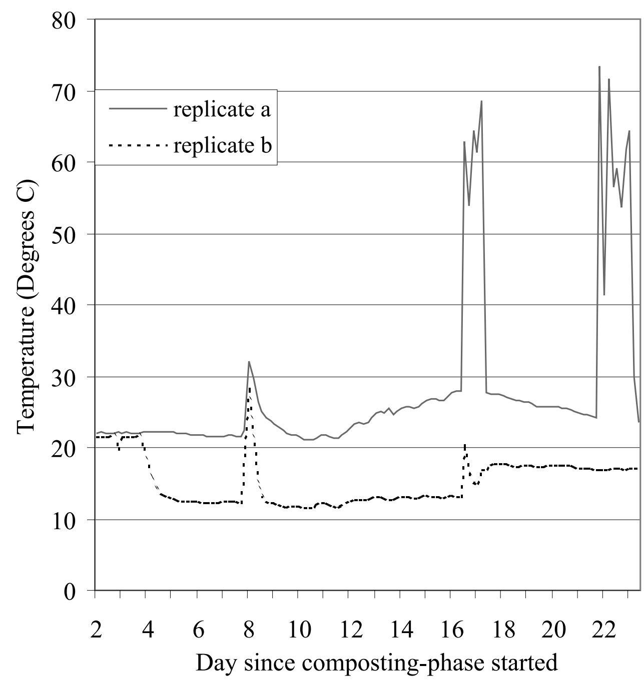

Fig. 2. Temperature profile of the VC-system during the composting-phase.

standard deviation) than the V-system. Compared to the feedstock, size reductions were 6-fold, 5-fold and 2-fold, for the CV-system, VC-system and V-system, respectively. The CV-system was arguably the finest and the most homogenous product.

4. Conclusions

From the waste-treatment point of view, the results presented above suggest that, the combined systems are better treatment options than the vermicomposting system by itself because they resulted in higher reductions of both TS and VS. TS were reduced by approximately 45% in both systems, representing a significant reduction in both the handling and transport costs of the product. The higher reductions in VS suggest that more stable products were obtained from these two integrated systems.

Large reductions in soluble N and a significant reduction in soluble P were also observed in all the products. Although the reduction in soluble N was not significantly different among the three systems, the reduction in soluble P was significant. The VC-system displayed the greatest reduction. This means that, the impact of P on the environment was more mitigated in the VC-system than in the other systems.

The composting-phase in the combined systems was primarily intended to provide the temperature required for pathogen kill to meet the EPAs PFRP requirement for compost. This requirement was met in the CV-system but not in the VC-system. The product coming from the VC-system does not automatically meet the EPAs PFRP temperature criterion and therefore would need to undergo further testing prior to general distribution.

The particle size analysis showed substantial reductions in size in all the systems but more reduction was

Table 3
Percentage retained in each sieve

Sieve number	Sieve size (mm)	Feedstock	Vermicompost compost	Vermicompost	Compost vermicompost
3	6.35	55.40	29.30	9.55	0.15
6	3.36	23.90	15.55	8.20	1.35
10	1.68	12.45	14.45	7.50	4.95
14	1.19	4.40	11.50	6.80	10.60
20	0.84	2.40	15.90	20.40	36.85
35	0.42	0.85	11.10	38.90	40.10
60	0.25	0.30	1.45	6.40	5.25
Pan	–	0.30	0.75	2.25	0.75
Total		100.00	100.00	100.00	100.00

Table 4
Particle size characteristics for the products from respective processes

Source of product	Geometric mean size (mm)	Geometric standard deviation (mm)
Feedstock	5.15	1.94
Vermicompost	2.53	2.72
Vermicompost–compost	1.08	2.57
Compost–vermicompost	0.83	1.67

observed in the combined system. The CV-system was the finest and most homogenous.

The product from the CV-system seems to be better in many ways. It was adequately stable, had less soluble N and P, met the EPAs PFRP criterion and was the most homogenous. Moreover, by regulating the MC content of the feedstock, it would be possible to achieve the required composting within a shorter time, thus effectively reducing the overall processing time for the entire CV-system.

References

APHA, AWWA, WPCF, 1989. Standard Methods for the Examination of Water and Wastewater, 17th ed. Washington DC, American Public Health Association.

ASAE, 1986. Standards: ASAE S424. The Society for Engineering in Agriculture, MI 49085-9659.

DeLuca, T.H., DeLuca, D.K., 1997. Composting for feedlot manure management and soil quality. J. Prod. Agric. 10 (2), 235–241.

Edwards, C.A., 1988. Breakdown of animal, vegetable and industrial organic wastes by earthworms. Earthworms in Waste and in Environment. SPB Academic Publishing, The Netherlands, pp. 21–31.

Edwards, C.A., Bohlen, P.J., 1996. Biology and Ecology of Earthworms. Chapman & Hall, 2-6 Boundary Row, London SE1 8HN, UK.

Erhart, E., Burian, K., 1997. Evaluating quality and suppressiveness of Austrian biowaste composts. Compost. Sci. Utilization 5 (3), 15–24.

Hand, P., Hayes, W.A., Frankland, J.C., Satchell, J.E., 1988. The vermicomposting of cow slurry. Pedobiologia 31, 199–209.

Harris, G.D., Platt, W.L., Price, B.C., 1990. Vermicomposting in a rural community. BioCycle 1990, 48–51.

Hay, C.J., 1996. Pathogen destruction and biosolids composting. BioCycle, June 1996, pp. 67–76.

Lambe, T.W., 1951. Soil Testing for Engineers. Wiley, New York.

Logsdon, G., 1994. Worldwide progress in vermicomposting. BioCycle 35 (10), 63–65.

Ndegwa, P.M., Thompson, S.A., Das, K.C., 1999. Effects of stocking density and feeding rate on vermicomposting of biosolids. Biores. Technol. 71 (1), 5–12.

Ndegwa, P.M., Thompson, S.A., 1999. Effects of C-to-N ratio on vermicomposting of biosolids. Biores. Technol. 75 (2000), 7–12.

Papadimitriou, E.K., Balis, C., 1996. Comparative study of parameters to evaluate and monitor the rate of a composting process. Compost. Sci. Utilization 4 (4), 52–61.

Raymond, C.L., Martin, Jr., J.H., Neuhauser, E.F., 1988. Stabilization of liquid municipal sludge using earthworms. In: Earthworms in Waste and in Environment Management. SPB Academic Publishing, The Hague, The Netherlands, pp. 95–110.