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ORIGINAL RESEARCH

Effect of aeration rate on elimination of coliforms during composting of vegetable–fruit wastes

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Abstract

Purpose In waters and wastes, direct pathogen detection is difficult and time consuming. Therefore, coliforms are used as indicators to measure the presence of pathogens. Composts originated from extrements, sewage sludges and plant wastes those contact with manures may have potential health hazard to human. Therefore, the detection of coliforms both during composting and in the obtained composts is used to investigate the presence of pathogens for determination of the potential health risk.

Methods In this study, the effect of six different aeration rates on elimination of total and faecal coliform bacteria was investigated during in-vessel aerobic composting of vegetable–fruit wastes. Total coliform and faecal coliform numbers in the samples were measured by the most probable number method.

Results Coliforms significantly increased before the thermophilic stage except the faecal coliforms in the reactor which operated with the lowest aeration. The coliforms suddenly decreased after thermophilic stage in all reactors. Total coliforms reduced within the range of 78.2–99.9 % while faecal coliforms reduced within the range of 72.5–99.9 % after the thermophilic stage. At the end of the composting period (day 18), total coliforms and faecal coliforms reduced within the range of 99.9–100 %.

Conclusions Although all the aeration rates used in the present study were effective for the elimination of coliforms, the lowest faecal coliform number was seen in the reactor that had the lowest aeration rate. At the end of the study, the faecal coliform numbers in all reactors confirmed some limits for the application activities of composts.

Keywords Total coliform · Faecal coliform · Aeration · Elimination · Composting · Waste · Vegetable–fruit

Introduction

Organic amendments or fertilisers, including composts, sewage sludge and livestock manures, are valuable sources of nutrients for plants and organic matter, contributing to soil quality and fertility. Recycling of organic waste products to agricultural land is considered as being one of the most economical, practical and environmentally beneficial management options (Nicholson et al. 2005; Brochier et al. 2012).

To protect soil and plant quality, the agronomic efficiency and hygienic safety of such amendments must be demonstrated prior to their application on cultivated fields (Brochier et al. 2012). The application of organic waste products to agricultural land without control of their hygienic safety is one potential route by which pathogens may enter the human food chain (Nicholson et al. 2005; Brochier et al. 2012). There are a number of reports about isolation of *Salmonella*, *Yersinia* and *Escherichia coli* from organic compost (Goldstein et al. 1988). Yun et al. (2007) reported that the total aerobic and coliform bacteria in the 16 commercial composts were ranged from 10^5 to 10^7 CFU/ml and $0–10^3$ CFU/ml, respectively. These results indicate that organic compost may be a potential harbour of food-borne pathogens in vegetables. The

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occurrence of some of the pathogenic microbial organisms in raw vegetables and their implications in causing human health resulting in diarrhoea/dysentery or serious diseases like yersiniosis and listeriosis have been documented (Beuchat 1996; Summer and Peters 1997). In addition to stability and maturity to plant growth (Brewer and Sullivan 2003; Cooperband et al. 2003), the need for control of microorganisms in the organic compost has become paramount (Burge et al. 1978; Yun et al. 2007).

Fermented and/or matured organic compost is a very useful natural fertiliser for organic farming. However, the organic composts pose a microbiological hazard to the farm products because most of the composts are originated from excremental matters of domestic animals (Yun et al. 2007). Various kinds of pathogenic bacteria derived from the intestinal tract of animals exist in compost material like cow dung (Gong 2007). Also some materials used in composting, like sewage treatment sludge and vegetable and fruit wastes, include pathogens.

The hygienic quality of treated organic waste may be assessed using naturally occurring and/or added indicator organisms to model the survival of bacteria, viruses and parasites (Tønner-Klank et al. 2007). Some bacteria like coliforms are used as indicators (Lester and Birkett 1999). The presence of coliform bacteria is often used as an indicator of the overall sanitary quality of soil and water environments. Use of an indicator such as coliforms, as opposed to the actual disease-causing organisms, is advantageous as the indicators generally occur at higher frequencies than the pathogens and are simpler and safer to detect (Hassen et al. 2001).

The aeration rate is considered to be the most important factor influencing successful composting (Diaz et al. 2002). Insufficient aeration can lead to anaerobic conditions due to the lack of oxygen, while excessive aeration can increase costs and slow down the composting process via heat, water and ammonia losses (Guo et al. 2012).

In the literature, there are studies about the indicator microorganisms both in composting materials and during composting (Golueke 1982; Pereira-Neto et al. 1986; Mandelbaum et al. 1988; de Bertoldi et al. 1991; Shuval et al. 1991; Sesay et al. 1997; Tiquia et al. 1998; Shaban 1999; Tiquia and Tam 2000a, b; Ferrer et al. 2001; Hassen et al. 2001; Lin 2008; Rainisalo et al. 2011). Also, there are studies about the effect of aeration rate on some composting parameters (Walker et al. 1999; Lu et al. 2001; Kulcu and Yaldiz 2004; Ahn et al. 2007; Petric and Selimbašic 2008; Guardia et al. 2008a, b; Jiang et al. 2011; Shen et al. 2011; Arslan et al. 2011; Bari and Koenig 2012; de Guardia et al. 2012; Guo et al. 2012). But to our knowledge, there is not any study about the effect of aeration rate on elimination of coliforms during composting. Therefore, in this study, the effect of six different aeration rates on elimination of total and faecal coliform bacteria was investigated during aerobic composting of vegetable–fruit wastes to investigate the presence of pathogens for determination of the potential health risk of composts.

Materials and methods

In the study, six compost reactors which were made of fibreglass and covered with glass wool for insulation were used. The compost reactors had heights of 50 cm and internal diameters of 30 cm (Fig. 1). The air was given to the compost reactors by a compressor. The time of the airflow was 1.5 min in each 8 min period which controlled by timers and solenoid valves. The airflow rates were 0.37, 0.49, 0.62, 0.74, 0.86 and 0.99 L/min kg VS in Reactor 1, 2, 3, 4, 5 and 6, respectively. A flow metre was used to measure airflow rates and pressure regulators were used to control the airflow rates. Except the airflow rates, all of the initial conditions were exactly same in all compost reactors. The initial values of EC, *C*/*N* ratio, pH were 7.93 mS/cm, 25 and 5.52, respectively. Vegetable–fruit wastes were obtained from a marketplace (Elazığ city, Turkey). Biological treatment sludge obtained from activated sludge treatment plant of Elazığ city was used as inoculum. Sawdust obtained from industrial estate of Elazığ city was used as bulking agent. The composting reactors were mixed manually by wearing sterile gloves for obtaining a homogen mass before taking the samples. The samples were taken from the reactors into the sterile vessels at period of 2 days. Temperatures were measured daily by thermometers those mounted in five locations of the six compost reactors. Total coliform and faecal coliform numbers in the samples were measured by the most probable number (MPN) method according to standard methods (APHA et al. 1989).

Fig. 1 Compost reactors

Results and discussion

Temperature variations were given in Fig. 2 temperature values of Reactor 1 and 6 were also given in the other study of us (Arslan et al. 2011). In figures, the mentioned heights of the thermometers are from top to bottom of the reactors. As seen from these figures, the temperatures which measured by the thermometers on the compost reactors increased as a result of the degradation of organic matters by microorganisms in the compost masses as reported in the other study of us (Arslan et al. 2011). The highest temperatures were seen at days 2–3. The thermophilic, mesophilic and cooling phases were begun at days 1–4, 5–8 and 9–12, respectively. In general, the lowest temperatures were between 22 and 25 °C and the highest temperatures were between 58 and 70 °C in the reactors (Arslan et al. 2011). In general, international requirements on compost sanitation are based on a combination of time–temperature conditions that must be guaranteed (Barrena et al. 2006). Usually, time–temperature conditions are given for the destruction of each pathogen. Temperatures within the range of 55–65 °C and times from few to 60 min are usually recommended (Haug 1993; Gea et al. 2007). US EPA regulations for Class A sludges recommend a temperature of 60 °C held for 30 min to provide a $6\log_{10}$ reduction of *Salmonella* (Gea et al. 2007). According to these values, the temperatures reached in our study were proper to eliminate the pathogens.

Total and faecal coliform numbers were given in Figs. 3 and 4, respectively. Coliforms significantly increased before the thermophilic stage, except the faecal coliforms in Reactor 1 which operated with the lowest aeration rate. Faecal coliforms in Reactor 1 did not increase significantly before the thermophilic stage contrary to the other reactors. This situation is probably resulted from the very short time (1 day) of reaching thermophilic temperatures which causing no increase of faecal coliforms. Faecal coliform numbers in the other reactors significantly decreased at day 6. The highest temperature (70 °C) reached in the study was seen in Reactor 1. The reactor reached thermophilic phase earlier than the other reactors (day 1) and stayed at this stage more days (7 days) than the others (Arslan et al. 2011).

The coliforms suddenly decreased after thermophilic stage in all reactors. Total coliform numbers in Reactor 1, 2, 3 and 4 began to decline at day 6. Although total coliforms in Reactor 5 and 6 began to decline at day 4, the numbers significantly decreased at day 6. Total coliforms reduced within the range of 78.2–99.9 % while faecal coliforms reduced within the range of 72.5–99.9 % after the thermophilic stage. Besides the high temperatures, the decrease of organic matters caused decrease of coliforms. Because, coliforms generally use highly degradable matters while they cannot reproduce with complex compounds like lignin and humic materials. The coliforms reproduce at the suitable conditions of enough nutrients. But they are destroyed when the nutrients are consumed and unsuitable conditions are occurred.

Similar to our results, in the study of Hassen et al. (2001), the average number of faecal coliforms at the beginning of the process (2.5×10^7 bacteria/g waste dw) decreased considerably to 7.9×10^7 bacteria/g waste dw during the thermophilic phase. The authors have reported that this decrease was presumably the result of the high temperature (60–65 °C) and of the unfavourable conditions established during the thermophilic phase.

Total coliforms reduced 99.9 % while faecal coliforms reduced within the range of 99.9–100 % at the end of the composting period (day 18). Although the faecal coliform removal percentages after composting were similarly very high, the lowest faecal coliform number was seen in Reactor 1 which had the lowest aeration rate. This situation is positive because of the lowest energy requirement. At the end of the composting study, the faecal coliform numbers in Reactor 1, 2 and 3 are comparable with each other while the numbers in Reactor 4, 5 and 6 are comparable with each other.

Similar to our results, high efficiencies of coliform elimination have reported by some authors. Pereira-Neto et al. (1986) have studied pathogen inactivation in four compost piles, employing the aerated static pile system. They have evaluated pathogen inactivation by means of the commonly used indicator organisms. *E. coli* and faecal streptococci reduced from approximately 10^7 org/g ww to less than 10^2 org/g ww with a removal percentage of 100 similar to our results. Similarly, during open-air windrow composting of beef feedlot manure, Larney et al. (2003) have reported that more than 99.9 % of total coliform and *E. coli* was eliminated in the first 7 days. In the study of Banegas et al. (2007), during the composting process, *Salmonella*, faecal coliforms (*E. coli*), and faecal streptococci were determined in samples taken after 1, 30, 60 and 90 days of composting. Similar to our results, they have reported that at the high temperatures (between 57 and 61 °C) reached during composting most pathogens were destroyed, making resulting composts safer for agricultural use.

Various coliform numbers have reported by various investigators. Laos et al. (2002) have composted biosolids with wood by-products and yard trimmings. In their study faecal coliform content was less than 10 MPN/g dry sample at the end of the process. Lafond et al. (2002) have studied the survival of pathogenic bacteria during in-vessel composting of duck excreta enriched wood shavings in two

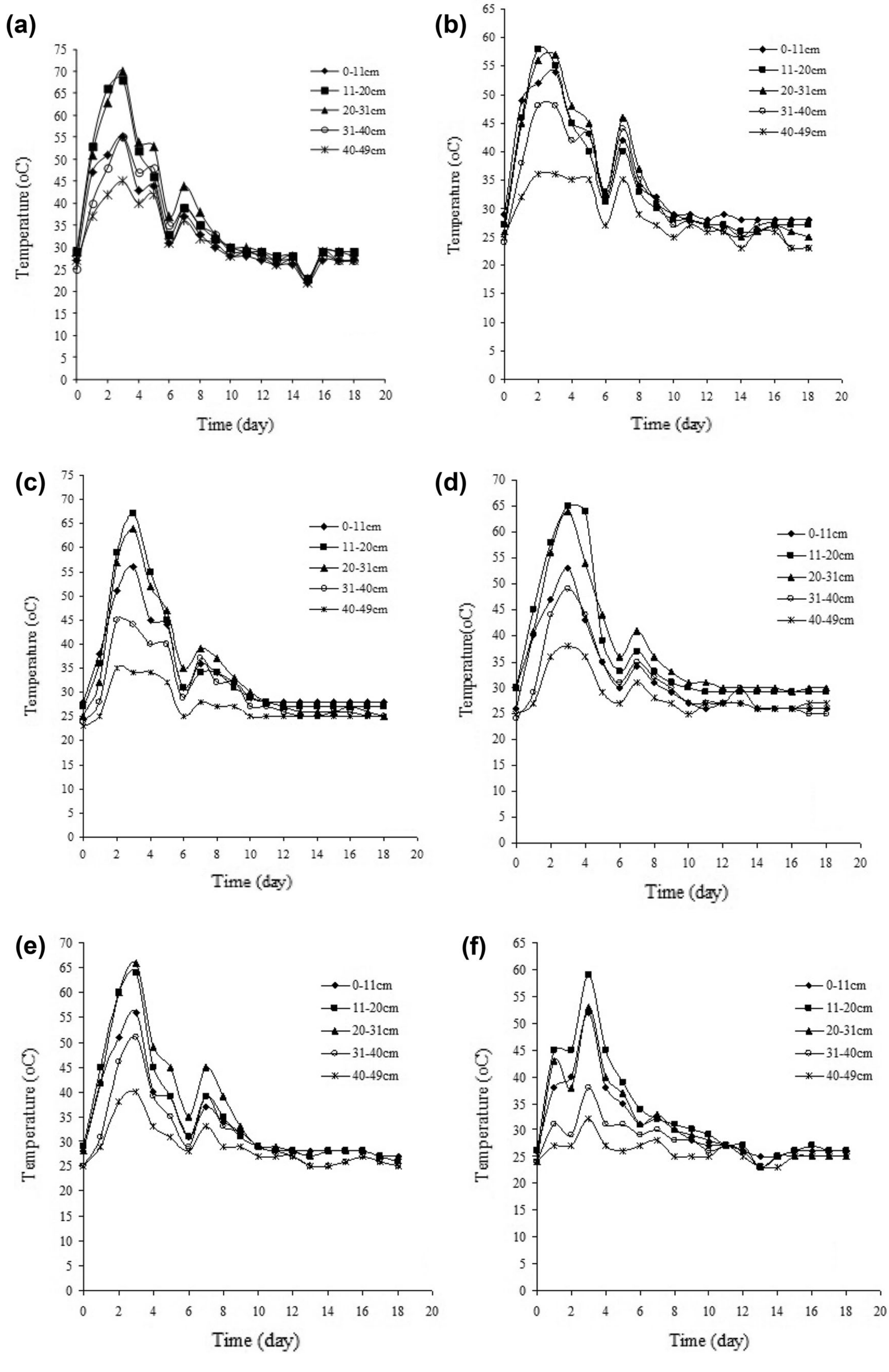

Fig. 2 Temperature variations

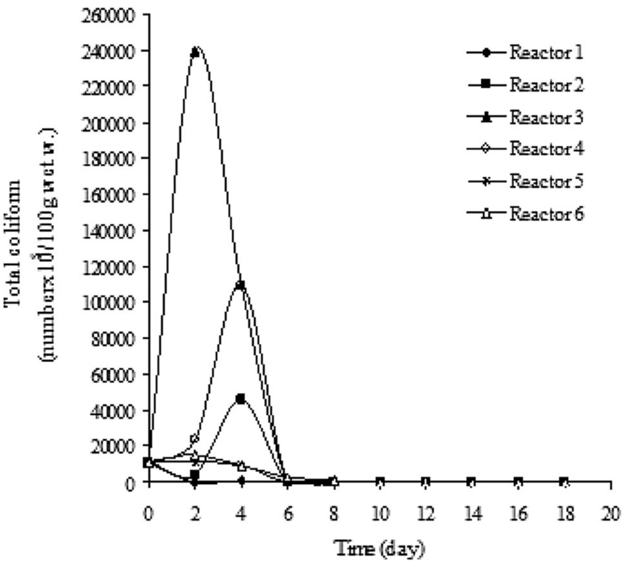

Fig. 3 Total coliform numbers

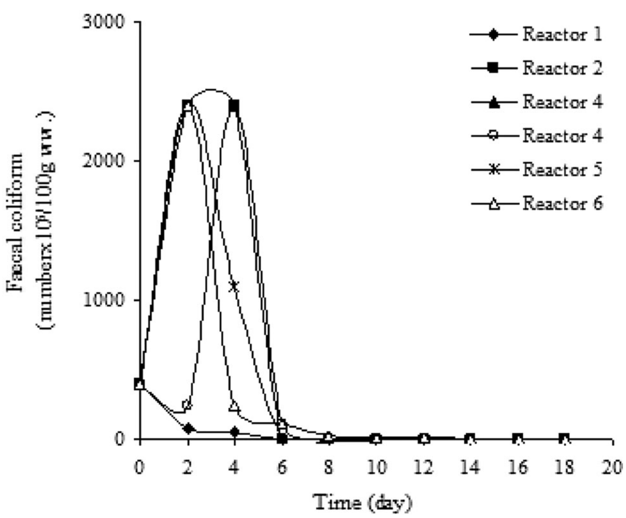

Fig. 4 Faecal coliform numbers

trials. Extremely high initial numbers of total coliforms were not detectable (<10 CFU/g) after 6 days of composting in the trial 1. In trial 2, partial elimination of total coliforms during the thermophilic phase were seen and total coliforms showed regrowth during the mesophilic phase because of the sublethal temperatures attained in the thermophilic phase, contrary to the trial 1. Contreras-Ramos et al. (2004) have composted tannery effluent with cow manure and wheat straw for 90 days, contrary to the period of our study, and less than ten faecal coliforms were detected in the compost while total coliforms decreased by $\log_{10}$ of 2. Cekmecelioglu et al. (2005) have composted food waste with cow manure and bulking materials for 12 day composting period and reported faecal coliform reduction as 59.3 % with a maximum temperature of 56.6 °C, contrary to our results. Bhatia et al. (2013) have reported a decrement with time in the average number of faecal coliforms in full scale rotary drum composter. The reported decrements were from 9.3×10^5 MPN/g to 1.5×10^3 MPN/g and 1.5×10^2 MPN/g, in the middle zone and outlet zone composts. The final value obtained in the middle zone is higher than the value obtained in our study while the value obtained in the outlet zone is similar to the value obtained in our study.

The various standards have faecal coliform number limitations for the application activities of composts. The limit of faecal coliforms given in the local standard of Mexico City (2011), which sets the minimum requirements for composting process of organic waste, is <1000 MPN/g dry basis (Espinosa-Valdemar et al. 2014). In addition, agriculture and agri-food Canada criteria and National Canadian standard have limitations of <1000 MPN/g of TS (oven-dried mass) for faecal coliforms (http://www.ccme.ca/files/Resources/waste/compost_quality/compostgdlns_1340_e.pdf). The faecal coliform numbers in all reactors (between 93–390 MPN/g ww with solid contents of 43.21–59.54 % and 215–752 MPN/g of TS-oven-dried mass) confirmed to this limit at the end of the composting study of us.

Conclusion

According to international requirements on compost sanitation, the temperatures reached in our study were proper to eliminate the pathogens. The coliforms suddenly decreased after thermophilic stage in all reactors within the range of 78.2–99.9 % for total coliforms and 72.5–99.9 % for faecal coliforms. Total coliforms reduced 99.9 % while faecal coliforms reduced within the range of 99.9–100 % at the end of the composting. Although all the aeration rates used in the present study were effective for the elimination of coliforms, the lowest faecal coliform number was seen in Reactor 1 which had the lowest aeration rate. At the end of the study, the faecal coliform numbers in all reactors confirmed some limits for the application activities of composts.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Ahn HK, Richard TL, Choi HL (2007) Mass and thermal balance during composting of a poultry manure-wood shavings mixture at different aeration rates. Process Biochem 42:215–223. doi:10.1016/j.procbio.2006.08.005

APHA, AWWA, WPCF (1989) Standard methods for the examination of water and wastewater. Washington. https://www.standardmethods.org/

Arslan EI, Ünlü A, Topal M (2011) Determination of the effect of aeration rate on composting of vegetable–fruit wastes. CLEAN Soil Air Water 39:1014–1021. doi:10.1002/clen.201000537

Banegas V, Moreno JL, Moreno JI, García C, León G, Hernández T (2007) Composting anaerobic and aerobic sewage sludges using two proportions of sawdust. Waste Manag 27:1317–1327. doi:10.1016/j.wasman.2006.09.008

Bari QH, Koenig A (2012) Application of a simplified mathematical model to estimate the effect of forced aeration on composting in a closed system. Waste Manag 32:2037–2045. doi:10.1016/j.wasman.2006.09.008

Barrena R, Canovas C, Sánchez A (2006) Prediction of temperature and thermal inertia effect in the maturation stage and stockpiling of a large composting mass. Waste Manag 26:953–959. doi:10.1016/j.wasman.2005.07.023

Beuchat LR (1996) Pathogenic microorganisms associated with fresh produce. J Food Prot 59:204–216

Bhatia A, Madan S, Sahoo J, Ali M, Pathania R, Kazmi AA (2013) Diversity of bacterial isolates during full scale rotary drum composting. Waste Manag 33:1595–1601. doi:10.1016/j.wasman.2013.03.019

Brewer LJ, Sullivan DM (2003) Maturity and stability evaluation of composted yard trimmings. Compost Sci Util 11:96–112

Brochier V, Gourland P, Kallassy M, Poitrenaud M, Houot S (2012) Occurrence of pathogens in soils and plants in a long-term field study regularly amended with different composts and manure. Agric Ecosyst Environ 160:91–98. doi:10.1016/j.agee.2011.05.021

Burge WD, Cramer WN, Epstein E (1978) Destruction of pathogens in swage sluge by composting. Trans ASABE 21:510–514. doi:10.13031/2013.35335

Cekmecelioglu D, Demirci A, Graves RE (2005) Feedstock optimization of in-vessel food waste composting systems for inactivation of pathogenic microorganisms. J Food Prot 68:589–596

Contreras-Ramos SM, Alvarez-Bernal D, Trujillo-Tapia N, Dendooven L (2004) Composting of tannery effluent with cow manure and wheat straw. Bioresour Technol 94:223–228. doi:10.1016/j.biortech.2003.12.001

Cooperband LR, Stone AG, Fryda MR, Ravet JL (2003) Relating compost measures of stability and maturity to plant growth. Compost Sci Util 11:113–124

de Bertoldi M, Zucconi F, Civilini M (1991) Temperature, pathogen control and product quality. In: The staff of Biocycle (ed) The Biocycle Guide to the Art and Science of Composting. The JG Press, Emmaus, pp 195–199

de Guardia A, Petiot C, Benoist JC, Druilhe C (2012) Characterization and modelling of the heat transfers in a pilot-scale reactor during composting under forced aeration. Waste Manag 32:1091–1105. doi:10.1016/j.wasman.2011.12.028

Diaz MJ, Madejon E, Lopez F, Lopez R, Cabrera F (2002) Optimization of the rate vinasse/grape marc for co-composting process. Process Biochem 37:1143–1150. doi:10.1016/S0032-9592(01)00327-2

Espinosa-Valdemar RM, Sotelo-Navarro PX, Quecholac-Piña X, García-Rivera MA, Beltrán-Villavicencio M, Ojeda-Benítez S, Vázquez-Morillas A (2014) Biological recycling of used baby diapers in a small-scale composting system. Resour Conserv Recycl 87:153–157. doi:10.1016/j.resconrec.2014.03.015

Ferrer J, Páez G, Mármol Z, Ramones E, Chandler C, Marín M, Ferrer A (2001) Agronomic use of biotechnologically processed grape wastes. Bioresour Technol 76:39–44. doi:10.1016/S0960-8524(00)00076-6

Gea T, Barrena R, Artola A, Sánchez A (2007) Optimal bulking agent particle size and usage for heat retention and disinfection in domestic wastewater sludge composting. Waste Manag 27:1108–1116. doi:10.1016/j.wasman.2006.07.005

Goldstein N, Yanko WA, Walker JM, Jakubowski W (1988) Determining pathogen levels in sluge products. Biocycle 29:44–47

Golueke CG (1982) When is compost ‘safe’? Biocycle 23:28–38

Gong C-M (2007) Microbial safety control of compost material with cow dung by heat treatment. J Environ Sci 19:1014–1019. doi:10.1016/S1001-0742(07)60164-8

Guardia A, Petiot C, Rogeau D (2008a) Influence of aeration rate and biodegradability fractionation on composting kinetics. Waste Manag 28:73–84. doi:10.1016/j.wasman.2006.10.019

Guardia A, Petiot C, Rogeau D (2008b) Influence of aeration rate on nitrogen dynamics during composting. Waste Manag 28:575–587. doi:10.1016/j.wasman.2007.02.007

Guo R, Li G, Jiang T, Schuchardt F, Chen T, Zhao Y, Shen Y (2012) Effect of aeration rate, *C/N* ratio and moisture content on the stability and maturity of compost. Bioresour Technol 112:171–178. doi:10.1016/j.biortech.2012.02.099

Hassen A, Belguith K, Jedid N, Cherif A, Cherif M, Boudabous A (2001) Microbial characterization during composting of municipal solid waste. Bioresour Technol 80:217–225. doi:10.1016/S0960-8524(01)00065-7

Haug RT (1993) The practical handbook of compost engineering. Lewis Publishers, Boca Raton

Jiang T, Schuchardt F, Li G, Guo R, Zhao Y (2011) Effect of *C/N* ratio, aeration rate and moisture content on ammonia and greenhouse gas emission during the composting. J Environ Sci 23:1754–1760. doi:10.1016/S1001-0742(10)60591-8

Kulcu R, Yaldiz O (2004) Determination of aeration rate and kinetics of composting some agricultural wastes. Bioresour Technol 93:49–57. doi:10.1016/j.biortech.2003.10.007

Lafond S, Paré T, Dinel H, Schnitzer M, Chambers JR, Jaouich A (2002) Composting duck excreta enriched wood shavings: C and N transformations and bacterial pathogen reductions. J Environ Sci Health B 37:173–186

Laos F, Mazzarino MJ, Walter I, Roselli L, Satti P, Moyano S (2002) Composting of fish offal and biosolids in northwestern Patagonia. Bioresour Technol 81:179–186. doi:10.1016/S0960-8524(01)00150-X

Larney FJ, Yanke LJ, Miller JJ, McAllister TA (2003) Fate of coliform bacteria in composted beef cattle feedlot manure. J Environ Qual 32:1508–1515

Lester JN, Birkett JW (1999) Microbiology and chemistry for environmental scientists and engineers, 2nd edn. Spon Press, New York

Lin C (2008) A negative-pressure aeration system for composting food wastes Bioresour Technol 99:7651–7656. doi:10.1016/j.biortech.2008.01.078

Lu SG, Imai T, Li HF, Ukita M, Sekine M, Higuchi T (2001) Effect of enforced aeration on in-vessel food waste composting. Environ Technol 22:1177–1182

Mandelbaum R, Hadar Y, Chen Y (1988) Composting of agricultural waste for their use as container media: effect of heat treatments on suppression of *Pythium aphanidermatum* and microbial activities in substrates containing compost. Biol Waste 26:261–274

Nicholson FA, Groves SJ, Chambers BJ (2005) Pathogen survival during livestock manure storage and following land application. Bioresour Technol 96:135–143. doi:10.1016/j.biortech.2004.02.030

Pereira-Neto JT, Stentiford EI, Smith DV (1986) Survival of faecal indicator micro-organisms in refuse/sludge composting using the aerated static pile system. Waste Manag Res 4:397–406

Petric I, Selimbašić V (2008) Development and validation of mathematical model for aerobic composting process. Chem Eng J 139:304–317. doi:10.1016/j.cej.2007.08.017

Rainisalo A, Romantschuk M, Kontro MH (2011) Evolution of clostridia and streptomycetes in full-scale composting facilities and pilot drums equipped with on-line temperature monitoring and aeration. Bioresour Technol 102:7975–7983. doi:10.1016/j.biortech.2011.05.087

Sesay AA, Lasaridi K, Stentiford E, Budd T (1997) Controlled composting of paper pulp sludge using the aerated static pile method. Compost Sci Util 5:82–96

Shaban AM (1999) Bacteriological evaluation of composting systems in sludge treatment. Water Sci Technol 40:165–170. doi:10.1016/S0273-1223(99)00596-X

Shen Y, Ren L, Li G, Chen T, Guo R (2011) Influence of aeration on CH_4, N_2O and NH_3 emissions during aerobic composting of a chicken manure and high C/N waste mixture. Waste Manag 31:33–38. doi:10.1016/j.wasman.2010.08.019

Shuval H, Jodice R, Consiglio M, Spaggiari G, Spigoni C (1991) Control of enteric micro organisms by aerobic-thermophilic composting of waste water sludge and agro-industry wastes. Water Sci Technol 24:401–405

Summer S, Peters DL (1997) Microbiology of vegetables. In: Smith DS (ed) Processing vegetable science and technology. Technomic Publishing Co. Inc., Lancaster, pp 87–106

Tiquia SM, Tam NFY (2000a) Fate of nitrogen during composting of chicken litter. Environ Pollut 110:535–541. doi:10.1016/S0269-7491(99)00319-X

Tiquia SM, Tam NFY (2000b) Co-composting of spent pig litter and sludge with forced-aeration. Bioresour Technol 72:1–7. doi:10.1016/S0960-8524(99)90092-5

Tiquia SM, Tam NFY, Hodgkiss IJ (1998) Salmonella elimination during composting of spent pig litter. Bioresour Technol 63:193–196. doi:10.1016/S0960-8524(97)00113-2

Tønner-Klank L, Møller J, Forslund A, Dalsgaard A (2007) Microbiological assessments of compost toilets: in situ measurements and laboratory studies on the survival of faecal microbial indicators using sentinel chambers. Waste Manag 27:1144–1154

Walker LP, Nock TD, Gossett JM, Vander Gheynst JS (1999) The role of periodic agitation and water addition in managing moisture limitations during high-solids aerobic decomposition. Process Biochem 34:601–612. doi:10.1016/S0032-9592(98)00122-8

Yun H-J, Lim S-Y, Song H-P, Kim B-K, Chung B-Y, Kim D-H (2007) Reduction of pathogenic bacteria in organic compost using gamma irradiation. Radiat Phys Chem 76:1843–1846. doi:10.1016/j.radphyschem.2007.02.093