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Harmonizing procedures for the evaluation of compost maturity in two compost types in Ghana

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ABSTRACT

Composting is one of the most favoured options for municipal solid waste recycling for waste streams with high content of biodegradable materials. Compost has many uses including its use in agriculture for soil structure and fertility improvement. However, non-mature composts when applied to soils could present inimical phytotoxic problems to crops. Despite this reality, many developing countries including Ghana, lack simple and reliable compost maturity tests, and run the risk of producing and/or using composts that have not reached maturation stage. This study was conducted to validate some chemical and biological procedures for testing the maturity of composts prepared from agricultural residues (AR) and municipal solid wastes (MSW) in Ghana. Three maturity indices – humus colour, CO_2 respirometry, and germination index – were considered for this validation study. For composts produced from crop residues, the optimal values for humus colour test, CO_2 evolution test, and germination index were 0.36–0.59, 1.24–1.80 gCO_2 kg^{-1} day^{-1}, 159.5–259.4, respectively. Similarly for the MSW composts the optimal maturity index ranges were 0.41–0.51 for humus colour test, 0.43–0.56 g CO_2 kg^{-1} day^{-1} for CO_2 evolution test and 0–59.1 for germination index. The MSW composts appeared mature under humus colour and CO_2 evolution tests, but inhibited germination. Agricultural residue composts on the other hand were found to be mature when subjected to all three maturity tests. This is indicative that composts may pass certain maturity parameters, yet fail germination test. It is therefore concluded that the germination test index is able to discriminate better between mature and non-mature composts.

1. Introduction

As commercial and community based composting projects are beginning to take root in Ghana, one area of concern is lack of reliable methods based on compost maturity indices that compost producers and users alike can use to assess the maturity of their products. This is important because in the absence of simple and reliable compost maturity indices there is a risk of producing and using composts that might possibly not have attained full maturation. The soil-application of non-stabilized organic materials could affect both crops and the environment because of the presence of phytotoxic compounds (Alburquerque et al., 2006; Butler et al., 2001; Chen et al., 2007; Fernandez et al., 2007; Moore et al., 2007). Unstable or immature compost may cause poor plant growth and damage crops by competing for oxygen or causing phytotoxicity to plants due to insufficient biodegradation of organic matter (Alidadi et al., 2008). In addition immature compost typically immobilizes nitrogen instead of releasing it for plant growth (Blanco, 1996). This is because immature composts continue to decompose even after application to soil, in which case, soil microbes scavenge for the nutrients that should have been made available to plants.

Various methods have been used to determine maturity of composts (Claudio et al., 2003; Garcia et al., 1992; Lasasidi and Stentiford, 1998; Ouatmane et al., 2000; Paletski and Young, 1995; Penninck and Verdonck, 1987; Roletto et al., 1985; Saviozzi et al., 1988; Zucconi et al., 1981a,b). These can be broadly categorised into different groups as physical (odour, temperature), chemical (C/N ratio, cation exchange capacity, nitrification), biological (plant bioassay–germination test), microbiological (respiration analysis), spectroscopic (NMR and infrared methods), humification (humic/fulvic acid content) and chromatographic (sephadex fractionation) (Chukwujindu et al., 2006). These methods differ in

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simplicity, duration and approach. Although there is a wide range of literature on this subject, there is still controversy as to the parameters that can be used for defining the maturity of the composted product. For most developing countries, methods based on spectroscopy and chromatography are quite complex and expensive for local compost producer to utilise (Alburquerque et al., 2006; Butler et al., 2001; Moore et al., 2007; Husted et al., 2004). Furthermore, many of these studies were based on organic wastes of sewage origin and/or typical waste streams in the industrialised countries (Butler et al., 2001; Li et al., 2005). There are few reports on compost maturity analyses using solid waste composts in developing countries, and for sub-Sahara Africa specific region, there are no standard procedures for determining compost maturity. In Ghana, agricultural practices which rely upon compost application for soil fertility improvement are common (Drechsel and Kunze, 2001; Danso et al., 2002). However without reliable methods for determining compost maturity, there are serious concerns about the use of composts with unknown maturation state (Moore et al., 2007; Tiquia, 2005; Meunchang et al., 2005; Abdelhamid et al., 2004).

The use of composts in urban and peri-urban agriculture is very common in Ghana for several reasons. These include guaranteeing urban food security and at the same time providing an opportunity for recycling biodegradable materials in the municipal waste stream (Moore et al., 2007). But this can only be possible if composts achieve maturation to avoid phytotoxic effects on crops (Alburquerque et al., 2006; Garcia et al., 1992; Ranalli et al., 2001). In this study, compost maturity methods – CO_2 respirometry, humus colour and germination index – selected based on their comparative ease of execution and availability of the necessary facilities to conduct such tests regularly, were evaluated to validate such procedures for local application. Using these parameters, the maturity of the two most commonly applied composts in Ghana, municipal solid waste and agricultural waste composts were investigated. The suitability and optimization range of these procedures in determining compost maturity in Ghana were assessed.

2. Methods and materials

2.1. Experimental design

Municipal solid waste (MSW) composts that were considered mature by local producers, based on dark brownish compost colour and absence of odour, were sampled from two composting sites in Accra, The MSW composts were prepared using two methods, namely: (i) large-scale mechanized composting from the Teshie-Nungua composting plant and (ii) local community level composting technique (the Asiedu-Keteke mini-composting unit) both being suburbs of Accra. The feedstock for both composting methods was mixed-waste materials from the municipality. The second compost type (compost prepared from crop residue) was sampled from the University of Ghana Agricultural Research Station (ARS) at Kade. This was prepared from a mixture of cocoa husk, rice straw, saw dust and chicken manure (Table 1). Compost that was similarly produced from agricultural residue but curated for a year at the ARS served as a reference compost for validation of the procedures.

2.2. Sampling procedure

Three different batches of compost were sampled from two sites, one in Accra and other in Kade, a big city and a small town respectively. From the sites, newly prepared composts were sampled at the points that compost producers considered them mature. The length of composting process was approximately 6–8 months.

Table 1
Materials used to prepare agricultural residue and MSW composts.

Agricultural Residue Composts (Relative amounts of raw materials used (v/v))	
S_1	1:1:1 (SD, PD, CH)
S_2	1:2:2 (SD, PD, CH)
S_3	1:2:1 (SD, PD, CH)
R_1	1:1:1 (RS, PD, CH)
R_2	1:2:2 (RS, PD, CH)
MSW Composts	
AK	Prepared from mixed solid waste stream
TN	Prepared from mixed solid waste stream

SD = Sawdust, PD = Poultry Droppings, CH = Cocoa Pod Husk, RS = rice straw; S_1, S_2 and S_3 are sawdustt based composts; R_1 and R_2 are rice straw based composts; AK = Asiedu-Keteke; TN = Teshie-Nungua.

Composts were presumed to have reached maturity by producers based on compost characteristics such as appearance of dark brown compost colour and absence of odour. Ten replicate samples were collected randomly from ten different points and layers in the compost heaps from each sampling site. These were thoroughly mixed in a plastic container to obtain composite samples. The composite samples were collected into sampling bags and taken to the laboratory. Triplicate samples, each weighing about 20 g, from each bag were air-dried, ground and sieved (particle size <0.5 mm) for analyses. The compost materials were evaluated in the laboratory using chemical and biological compost maturity procedures.

2.3. Chemical analyses

Chemical analyses of the materials were conducted as follows: pH and electrical conductivity (EC) were measured for 1/10 (compost/water) extract using pH and EC meters respectively. Humus colour was determined from alkali extracts of the compost and the absorbance was measured at 400 and 600 nm using spectrometric technique. The change in absorbance (log K value) was calculated as $\log K\,400 - \log K\,600 = \log(K400/K600)$, where $K400$ and $K600$ were the absorbance at 400 and 600 nm respectively (Morel, 1982). Basal respiration was determined by incubating compost samples for 24 h in gas-tight vessels. Carbon dioxide was trapped in a 2 M NaOH solution and determined by titration after precipitating with $BaCl_2$.

2.4. Biomaturity assay

Twenty seeds each, of (i) two carrot varieties (*Little* and *Kuroda*), (ii) cabbage from Sakata Seed Company, Japan, and (iii) tomato (*cv. Wosowoso*, local variety) were obtained. The seeds were placed on a filter paper in a petri-dish. Water extracts of each of the composts were prepared by weighing 20 g of the compost and dissolving it in 40 ml of distilled water. Twenty millilitres of the water extracts was used to soak the seeds and kept in the dark at ambient room temperature (27 °C). Distilled water was then used to soak seeds as control treatment. Seeds were monitored over 5 days until there was adequate germination in the control plates. Germination was then stopped by adding 1 ml 50% (v/v) ethanol to each petri-dish. Un-germinated seeds were defined as being zero (0) cm long. The germination indices which combined seed germination and root growth were both expressed relative to the control (Shashi et al., 1998). Ten replicates were conducted. Germination index (GI) was calculated as follows:

$$\text{Germination Index} = (\%\,\text{Germination}) \times (\%\,\text{Radicle Length})$$

$$\text{Where, } \%\,\text{Germination} = \frac{\text{Mean germination in compost extract}}{\text{Mean germination in water}} \times 100$$

Table 2
pH, CO_2 evolution and EC of AR and MSW composts.

Sample	pH H_2O	CO_2 emission ($g\ CO_2\ kg^{-1}\ day^{-1}$)		EC ($dS\ m^{-1}$)
		a*	b*	
S_1	7.4	7.86	1.24	5.68
S_2	7.7	7.93	1.57	9.63
S_3	7.9	6.60	1.80	4.25
R_1	7.9	12.01	1.65	6.03
R_2	7.7	16.42	1.30	10.60
AK	6.0	ND	0.56	3.86
TN	7.3	ND	0.43	1.50
RMC	7.4	ND	ND	5.65

*The CO_2 emission rate at the beginning of the experiment (a) and at the end (b).
RMC = Reference matured compost, was aged over 10 months.
ND = No Data.

$$\text{and \% Radicle Length} = \frac{\text{Mean radicle length in compost extract}}{\text{Mean radicle length in water}} \times 100$$

A compost extract producing a germination index greater than 100 was judged as growth stimulating, while one producing less than 100 was judged phytotoxic.

3. Results and discussion

The pH is a good indicator of the development of composting. During the early stages of composting, the pH decreases slightly to values of about 5, and later rises as materials gradually decompose and stabilise. The pH finally stays at values between 6 and 8 (Fernandez et al., 2007; Brandli et al., 2007; Cardenas and Wang, 1980; Chiang et al., 2001; Gray et al., 1971).

The pH values of the composts in this study were within acceptable limits (Table 2). For the agricultural residue compost, there were notable differences in EC for a change in raw material base from sawdust to rice straw. Generally, the use of rice straw increased the EC compared to the corresponding sawdust ratio (Table 2). The agricultural residue composts had high EC compared to the MSW composts, indicating higher total soluble ions in the water extract of agricultural residue composts compared to MSW composts. The release of easily decomposable compounds into the solution has been implicated in previous studies to account for the total soluble ions in water extracts from composts (Fernandez et al., 2007; Moore et al., 2007; Saviozzi et al., 1988; Brandli et al., 2007; Tiquia, 2005; Cardenas and Wang, 1980; Chiang et al., 2001; Gray et al., 1971; Saviozzi et al., 1987).

The CO_2 evolution during the initial stages of the composting process was very high indicating a probable high microbial activity (a* column in Table 2). The evolution rate however decreased significantly after six months of composting (b* column in Table 2), suggesting a low microbial activity. The fact that the CO_2 evolution in the agricultural residue composts was greater than that of the MSW composts (b* column of Table 2) suggests lower microbial activity in the latter. This probably meant greater stabilization (an indicator of maturation) in the MSW composts than in the agricultural residue composts. But on the whole, the CO_2 evolution for both the agricultural residue and MSW composts was well within the range of values reported in previous studies for composts that were up to 6 months old (Iannotti et al., 1994).

It has previously been reported that mature compost had a likely humus colour, described in terms of optical density of its water extract, of less than 0.7 (Domeizel et al., 2004; Morel, 1982).

Table 3
Humus colour determined at 400 and 600 nm.

Code	Abs 400 nm	Abs 600 nm	Optical Density*
S_1	0.43	1.28	0.48
S_2	0.43	0.99	0.36
S_3	0.88	0.26	0.53
R_1	0.93	0.36	0.41
R_2	0.86	0.22	0.59
AK	0.81	0.25	0.51
TN	0.94	0.37	0.41
RMC	0.83	0.21	0.61

* Organic matter determination of Abs 400/Abs 600 ratio. Values less than 0.7 indicates maturity of compost.

In this study, irrespective of the raw material (whether agricultural residue or MSW) and the relative proportions (feedstock materials), the optical density was less than 0.7 (Table 3), indicating that the humus colour was independent of the compost source. The reference compost sample produced similar optical density results as the experimental composts which meant there was strong agreement among the test procedures or optimization for compost maturity determination.

This study tested the suitability of carrot, cabbage and tomato seeds for biomaturity determination, as they were easily attainable in Ghana than cress or ryegrass, routinely used for such maturity determinations. Among the three seeds: carrot, cabbage and tomato, the tomato seed was most responsive to the bioassay test for estimating compost maturity, which meant that it was better estimator of compost maturity locally in Ghana. Key characteristics making it the most suitable candidate for germination index assays were early germination properties and easy attainability, which were important requirements for biomaturity measurements. For any of the three seeds to be considered suitable for biomaturity determination; it should have proven responsive to bioassays in the reference compost sample, in which case the tomato seed was found to be most suitable candidate (Table 4). Generally, the agricultural residue compost extracts (S_1, S_2, S_3, R_1 and R_2) stimulated germination and growth of tomato seeds, which indicated that the maturation point for the composts was reached. On the other hand, there were inhibitory effects on tomato seeds by MSW compost extracts, which probably meant that the composts were not mature and might have introduced phytotoxins in the composts.

The agricultural waste composts had EC ranging between 4.25 and 10.60 $dS\ m^{-1}$. It was observed that at this EC range, the agricultural waste composts did not inhibit germination of tomato seeds. However, the MSW composts, which had lower EC ranging between 1.5 and 3.86 $dS\ m^{-1}$, rather generally inhibited seed germination. Thus, the MSW compost though with low EC, its application during the testing period produced adverse germination effects compared to the more positive germination index observed when compost from agricultural wastes was tested. This observation appeared to contradict finding from other studies on compost application to

Table 4
Germination indices of the different composts using carrot, cabbage and tomato seeds.

Code	Kuroda carrot	Little carrot	Cabbage	Tomato
S_1	73.1	72.4	81.1	251.4
S_2	85.7	68.1	97.3	159.5
S_3	91.6	106.1	110.8	202.7
R_1	87.4	86.2	64.9	224.3
R_2	95.8	86.2	86.5	164.9
AK	0.03	ND	55.9	0.0
TN	14.7	ND	115.6	59.1
RMC	95.8	90.5	73	224.3

cress, which found that high EC contributed to phytotoxicity of composts, with cress germination being inhibited at EC threshold of 2.45 dS m^{-1} (He et al., 1992a; Sessay et al., 1997). Perhaps, tomato seed had much higher EC threshold tolerance for inhibition of germination than that for watercress. This probably meant that the inhibitory effects of the MSW composts on tomato seeds at relatively lower EC range, might not be a direct effect of EC, but might be reflecting the effect of other factors in the composts such as low molecular weight organic acids, which were noted to be very phytotoxic.

This study found considerable positive association among the three maturity test parameters when applied to the agricultural residue composts but not for MSW composts; possibly implicating some endogenous factors in the feedstock to be playing a role in compost response to maturity assays. It was demonstrated that, whilst the optical density and CO_2 evolution tests showed that the MSW composts were mature, the germination index test indicated otherwise, showing strong disagreement between the two procedures with respect to compost maturity determination. This could reasonably be explained by the fact that the biomaturity test was able to detect the effects of phytotoxins, whilst the optical density and CO_2 evolution tests did not.

Indeed, biomaturity assay was expressed to present an enhanced system for assessing compost maturity, in view of the fact that it was able to give an indication regarding the presence of phytotoxins in composts. When compost did not pass the biomaturity test, it could suggest the presence of phytotoxic compounds often associated with inhibition of germination and subsequent plant growth. Such inhibitory effects had been attributed to the presence of some low molecular weight organic acids in composts (Tiquia, 2005; Wolkowski, 2003; Zucconi et al., 1981b). These organic acids were widely reported in the process of composting and their phytotoxic effects were well known. They appeared in composts during the early stages of decomposition of the waste but became destroyed as the compost reached maturation (Fernandez et al., 2007; Garcia et al., 1992; Li et al., 2005; Manachini et al., 2005; Meunchang et al., 2005). Perhaps, organic acids still prevailed in the MSW composts after 6–8 months of composting, hence the indication of non-maturation. This was not inconceivable given the observations made by Iannotti et al. that 164-day-old MSW composts still inhibited cress seed germination well after the composts were probably mature (Ranalli et al., 2001; Iannotti et al., 1994; Wolkowski, 2003).

Generally, MSW composts tended to have characteristic chemical properties such as high EC and high NaCl content, as well as high metal content, which might all contribute to phytotoxicity in composts (Hargreaves et al., 2008; He et al., 1995, 1992b). The EC of MSW composts in this study, though lower than that of the agricultural waste composts, it was still generally high compared to EC values of MSW composts reported in literature (Hargreaves et al., 2008; He et al., 1995, 1992b; Aslam et al., 2008; Wu et al., 2000; Zmora-Nahuma et al., 2007) Accumulation of nitrate in some instances had been associated with increases in EC (Smith and Doran, 1996). Although nitrate was not measured in this study, it might have been responsible for the high EC observed in the agricultural waste composts. Differences in the quality of the MSW and agricultural waste composts suggested that the ultimate quality of the compost product was dependent on the type of feedstock materials used in its production (Diaz et al., 1994; Tomati et al., 2002; Zbytniewski et al., 2002). Both, the type of organic waste used and its subsequent treatment might have influenced the content of phytotoxic substances. Depending on the chemical composition of the raw materials and the composting process, phytotoxic effects could still prevail after composting.

4. Conclusions

Commercially produced MSW composts in Ghana that were investigated in this study appeared mature when they were analysed for humus content and CO_2 evolution, but inhibited germination. The agricultural residue composts on the other hand responded to both the chemical and biomaturity assays. Using rice straw or sawdust as the base feedstock material for the agricultural residue composts did not affect germination index. Among the three seeds – cabbage, tomato and carrot – the tomato seeds provided most definitive response to the germination index (biomaturity) test and could probably be used in biomaturity determination in the absence of ryegrass or watercress. Finally, the germination test index was found to be a better discriminatory test-tool for determining compost maturity. Chemical maturity parameters alone were insufficient to serve as compost maturity indicators.

References

Abdelhamid MT, Horiuchi T, Oba S. Composting of rice straw with oilseed rape cake and poultry manure and its effects on faba bean (Vicia faba L.) growth and soil properties. Bioresour Technol 2004;93(2):183–9.

Alburquerque JA, et al. Measuring detoxification and maturity in compost made from “alperujo”, the solid by-product of extracting olive oil by the two-phase centrifugation system. Chemosphere 2006;64(3):470–7.

Alidadi H, et al. Evaluation of biosolids compost maturity in South Isfahan wastewater treatment plant. Iran J Environ Health Sci Eng 2008;5(2):137–40.

Aslam DN, Horwath W, VanderGheynst JS. Comparison of several maturity indicators for estimating phytotoxicity in compost-amended soil. Waste Manage 2008;28:2070–6.

Blanco MJ. Evaluation of parameters related to chemical and agrobiological qualities of wheat-straw composts including different additives. Bioresour Technol 1996;51:125–34.

Brandli RC, et al. Organic pollutants in compost and digestate. Part 1. Polychlorinated biphenyls, polycyclic aromatic hydrocarbons and molecular markers. J Environ Monit 2007;9(5):456–64.

Butler TA, et al. Compost age and sample storage effects on maturity indicators of biosolids compost. J Environ Qual 2001;30(6):2141–8.

Cardenas RR, Wang LK. Composting process. Handbook of environmental engineering, vol. II. New York: Human Press; 1980.

Chen KS, Lin YS, Yang SS. Application of thermotolerant microorganisms for biofertilizer preparation. J Microbiol Immunol Infect 2007;40(6):462–73.

Chiang KY, et al. Stabilization of heavy metals in sewage sludge composting process. Water Sci Technol 2001;44(10):95–100.

Chukwujindu MAI, et al. Compost maturity evaluation and its significance to agriculture. Pakistan J Biol Sci 2006;9(15):2933–44.

Claudio M, et al. An integrated chemical, thermal, and microbiological approach to compost stability evaluation. J Environ Qual 2003;32:2379–86.

Danso G, Fialor SC, Drechsel P. Farmers' perception and willingness-to-pay for urban waste compost in Ghana. In: Almorza D, Brebbia CA, Sales D, Popov V, editors. Waste Management and the Environment. WIT Press; 2002. pp. 231–241.

Diaz LF, Savage GM, Golueke CG. Composting of municipal solid wastes. In: Kreith F, editor. Handbook of solid waste management. NY: McGraw-Hill, Inc.; 1994.

Domeizel M, Khalil A, Prudent P. UV spectroscopy: a tool for monitoring humification and proposing an index of maturity of compost. Bioresour Technol 2004;94:177–84.

Drechsel P, Kunze D, editors. Waste Composting for Urban and Peri-urban Agriculture – Closing the rural-urban nutrient cycle in sub-Saharan Africa. Wallingford: IWMI/FAO/CABI; 2001. p. 229.

Fernandez JM, et al. Organic matter in degraded agricultural soils amended with composted and thermally-dried sewage sludges. Sci Total Environ 2007;378(1–2):75–80.

Garcia C, et al. Phytotoxicity due to the agricultural use of urban wastes. Germination experiments. J Sci Food Agric 1992;59:313–9.

Gray KR, Sherman K, Biddlestone AJ. A review of composting. Part 1: microbiology and biochemistry. Process Biochem 1971;6:32–6.

Hargreaves JC, Adl MS, Warman PR. A review of the use of composted municipal solid waste in agriculture. Agric Ecosys Environ 2008;123:1–14.

He X-T, Traina SJ, Logan TJ. Chemical properties of municipal solid waste composts. J Environ Qual 1992a;21:318–29.

He X-T, Traina SJ, Logan TJ. Chemical properties of municipal solid waste composts. J Environ Qual 1992b;21(3):318–29.

He X-T, Logan TJ, Traina SJ. Physical and chemical characteristics of selected US municipal solid waste composts. J Environ Qual 1995;24(3):543–52.

Husted S, et al. Elemental fingerprint analysis of barley (Hordeum vulgare) using inductively coupled plasma mass spectrometry, isotope-ratio mass spectrometry, and multivariate statistics. Anal Bioanal Chem 2004;378(1):171–82.

Iannotti DA, et al. Waste management: oxygen respirometry to assess stability and maturity of composted municipal solid waste. J Environ Qual 1994;23:1177–83.

Lasasidi KE, Stentiford EI. A simple respirometric technique for assessing compost stability. Water Res 1998;32(12):3717–23.
Li Y, et al. Nematodes as bioindicator of soil health: methods and applications. Ying Yong Sheng Tai Xue Bao 2005;16(8):1541–6.
Manachini B, Landi S, Tomasini V. Biodiversity of nematofauna of oilseed rape (Brassica napus L.). Commun Agric Appl Biol Sci 2005;70(4):927–35.
Meunchang S, Panichsakpatana S, Weaver RW. Co-composting of filter cake and bagasse; by-products from a sugar mill. Bioresour Technol 2005;96(4):437–42.
Moore JE, et al. A novel challenge test incorporating irradiation ((60)Co) of compost sub-samples to validate thermal lethality towards pathogenic bacteria. Ecotoxicol Environ Saf 2007.
Morel JL. L'évaluation de la maturité des compost urbains par une méthode colorimétrique. Compost Inform 1982;10:4–8.
Ouatmane A, et al. Compost maturity assessment using calorimetry, spectroscopy and chemical analysis. Compost Sci Util 2000;8(2):124–34.
Paletski WT, Young JC. Stability measurement of biosolids compost by aerobic respirometry. Compost Sci Util 1995;3(2):16–24.
Penninck R, Verdonck O. A few additional parameters for a better determination of the compost quality. In: De Bertoldi M, et al., editors. Compost: production, quality and use. London: Eslvier Applied Science; 1987. p. 809–14.
Ranalli G, et al. Composting of solid and sludge residues from agricultural and food industries. Bioindicators of monitoring and compost maturity. J Environ Sci Health A Tox Hazard Subst Environ Eng 2001;36(4):415–36.
Roletto E, et al. Chemical parameters for evaluating compost maturity. BioCycle 1985:46–8, March.
Saviozzi A, Riffaldi R, Levi-Minzi R. Compost maturity by extract analysis. In: De Bertoldi M, et al., editors. Compost: production quality and use. London: Elsevier Appl. Sci.; 1987. p. 359–67.
Saviozzi A, Levi-Minzi R, Riffaldi R. Maturity evaluation of organic wastes. BioCycle 1988;29(3):54–6.
Sessay AA, et al. Controlled composting of paper pulp sludge using the aerated static pile method. Compost Sci Util 1997;5(1):82–96.
Shashi SR, et al. Stabilization of chemical and biochemical characteristics of grass straw and leaf mix during in-vessel composting with and without seeding material. Soil Sci Plant Nutr 1998;44(4):485–95.
Smith JL, Doran JW. Measurement and use of pH and electrical conductivity for soil quality analysis. Methods for assessing soil quality. Madison: SSSA Special Publication; 1996. p. 169–85.
Tiquia SM. Microbiological parameters as indicators of compost maturity. J Appl Microbiol 2005;99(4):816–28.
Tomati U, et al. Evaluation of commercial compost quality. Waste Manage Res 2002;20(5):389–97.
Wolkowski RP. Nitrogen management considerations for landspreading municipal solid waste compost. J Environ Qual 2003;32(5):1844–50.
Wu L, Ma LQ, Martinez GA. Comparison of methods for evaluating stability and maturity of biosolids compost. J Environ Qual 2000;29:424–9.
Zbytniewski R, et al. The comparison study of compost and natural organic matter samples. Environ Sci Pollut Res Int 2002:68–74, Spec No 1.
Zmora-Nahuma S, Hadar Y, Chena Y. Physico-chemical properties of commercial composts varying in their source materials and country of origin. Soil Biol Biochem 2007;39:1263–76.
Zucconi F, et al. Biological evaluation of compost maturity. BioCycle 1981a;22(4):27–9.
Zucconi F, et al. Evaluating toxicity of immature compost. BioCycle 1981b;22(2):54–7.