Comparison of three systems of decomposition of agricultural residues for the production of organic fertilizers

Rocío Sánchez-Rosales[1], Adriana Hernández-Rodríguez[1*], Dámaris Ojeda-Barrios[1], Loreto Robles-Hernández[1], Ana Cecilia González-Franco[1], and Rafael Parra-Quezada[1]

SCIENTIFIC NOTE

ABSTRACT

Organic wastes (OW) of diverse nature must be subjected to controlled decomposition processes to avoid risks of contamination and obtain products useful for agriculture. The objective of the present study was to compare over time physical, chemical and enzymatic parameters of OW transformed as vermicomposting (VC), semicomposting (SC) and composting (CP) for elaboration of organic fertilizers. A mixture of bovine manure and sawdust was subjected to each of three systems for 183 d. Temperature, total N (Nt), organic C (OC), C/N ratio, pH, enzymatic urease activity (EUA), germination index (GI) and electrical conductivity (EC) were measured throughout the time of study. The variables evaluated showed significant differences between time and treatment. The temperature ranged between 20 and 34 °C in VC and SC, while in CP between 20 and 61 °C. All three systems reduced the C/N ratio to less than 15/1. The CP product had higher pH, EC, and EUA values than both VC and SC. The VC product had the highest GI values. All the products obtained at 183 d were within the parameters to be considered as organic fertilizers, but the SC product transformed into an organic fertilizer fastest and had least water usage.

Key words: Compost, semicomposting, vermicomposting.

[1]Universidad Autónoma de Chihuahua, Avenida Universidad y Pascual Orozco s/n, Universidad, 31110 Chihuahua, México.
[*]Corresponding author (aernande@uach.mx).

Received: 31 January 2017.
Accepted: 2 July 2017.
doi:10.4067/S0718-58392017000300287

INTRODUCTION

Agricultural activities generate large amounts of organic waste (OW), which when not properly managed can cause salinization of soils, leaching of nitrates and phosphates to aquifers (Flotats and Solé, 2008), accumulation of lignins, aromatic oils and resins in soil (Achten and Hofmann, 2009), spread pests, weeds, diseases, and phytotoxicity (Fornes et al., 2012). In order to reduce environmental risks, it has been considered that OW must be processed through controlled decomposition techniques (Bernal et al., 2009).

Composting (CP), vermicomposting (VC) and semicomposting (SC) have proved to be useful systems for obtaining products that can be used in agriculture (Fornes et al., 2012). The degradation of OW by these processes allows the formation of stable polymerized molecules (Bernal et al., 2009), but each system of controlled decomposition produces organic fertilizers with profoundly variable characteristics (Fornes et al., 2012).

Composting is the transformation of OW by the action of microorganisms. In the first stage, simple carbon compounds are mineralized and metabolized by thermophilic microorganisms, releasing carbon dioxide, water, ammonia and organic acids, reaching temperatures from 45 to 70 °C (Fornes et al., 2012), which destroys undesirable seeds and pathogenic organisms. In the mesophyll stage, humification of the remaining organic compounds occurs (Fornes et al., 2012). The degree of stability and maturity reached reflects the rate of OW decomposition and phytotoxicity removal (Ocaña et al., 2015).

Vermicomposting is a non-thermophilic process of bio-oxidation and stabilization of organic substrates by the joint action of earthworms and mesophilic microorganisms (Bernal et al., 2009). The metabolism of the annelid generates an organic substrate, in part from the microorganisms of the intestine (Fornes et al., 2012).

Semicomposting is a degradation process that handles volumes of OW lower than that recommended for CP and therefore does not present a thermophilic stage. In this system mesophilic microorganisms are responsible for the degradation of organic matter (OM) (Herrera-Ortíz et al., 2015); however, SC has been poorly documented.

The quality of the final products has been evaluated for safety in agricultural through stability criteria: temperature, C/N ratio, pH, enzymatic activity and phytotoxicity of bio-transformed OM (Bernal et al., 2009). However, the work generated is not conclusive, so it is recommended to evaluate different residues and decomposition systems (Ocaña et al., 2015).

The objective of the present study was to compare, throughout the period of decomposition, physical, chemical and enzymatic parameters of OW subjected to three decomposition systems for the production of organic fertilizers. The results of this study will contribute to the selection of the most suitable OW decomposition system for the producer, according to the availability of resources such as organic material, water or earthworms.

MATERIALS AND METHODS

The study was carried out in the facilities of the Universidad Autónoma de Chihuahua, Chihuahua, México. The duration of the experiment was 183 d, throughout April to October 2014. A mixture of bovine manure and sawdust was subjected to three decomposition systems: Composting (CP), semicomposting (SC) and vermicomposting (VC). For the CP, pallet boxes of a capacity of 1110.9 L, for SC and VC 60 L plastic containers were filled, and for VC, 10 adult Californian red earthworms (*Eisenia fetida* [Savigny, 1826]) were added per liter of substrate at 6 d after the experiment (DAE) (Castillo et al., 2010). Irrigation maintained moisture between 50% and 60% in CP and SC, and between 75% and 85% for VC (Castillo et al., 2010), which was determined by touch test (Soto and Muñoz, 2002). The CP and SC mixtures were manually removed every 28 d.

Temperature of decomposing residues was daily recorded using a maximum and minimum thermometer (Fisher Scientific, Pittsburgh, Pennsylvania, USA). A pistil thermometer with a minimum range of -20 °C and maximum of 110 °C was used. Nine samples were taken at 4, 35, 68, 98, 127, 141, 155, 169 and 183 DAE. A portion of the sample was shade dried at room temperature, sieved in nr 20 mesh (1 mm diameter) for chemical analysis. For the determination of enzymatic urease activity (EUA), fresh samples were reserved at 4 °C. The following analyses were carried out: total nitrogen (Nt) by the Micro-Kjeldahl method (Fernández et al., 2006); organic carbon (OC) with the Walkley-Black dichromate oxidation method (ASTM International, 2010); pH with potentiometer (HI 2210 pH Meter, Hanna Instruments, Woonsocket, Rhode Island, USA) in dilution with 1:10 (w/v) deionized water; EUA was determined using the method of Kandeler et al. (1999). From 141 and up to 183 DAE, electrical conductivity (EC) was evaluated using a conductivity meter (Solubridge Beckman, Cedar Grove, New Jersey, USA) in dilution with 1:10 (w/v) deionized water, and phytotoxicity with the mentioned germination index (GI) by Zucconi et al. (1981).

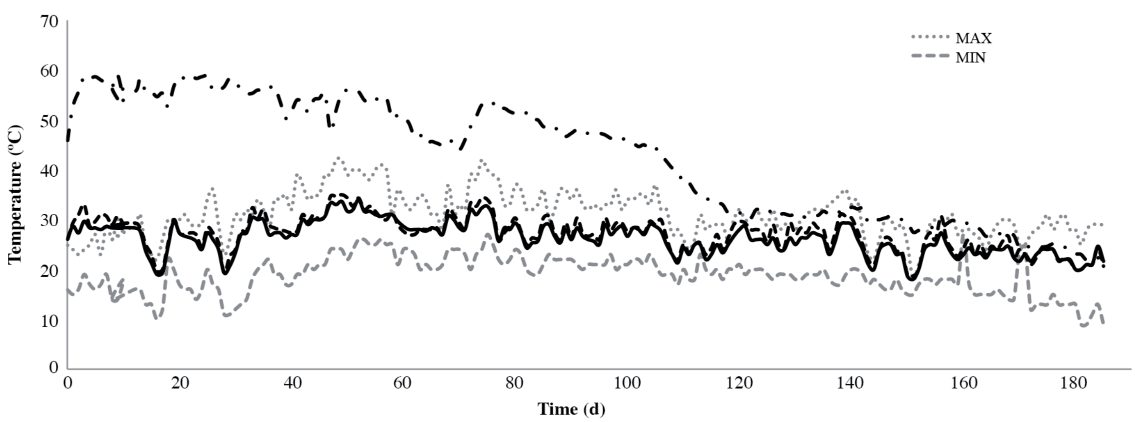
The experiment consisted of three treatments with three replicates and three analytical replicates per sample. A split plot design was used with observations over time, and the main plot effect was defined by OW decomposition system. ANOVA was performed using the statistical software SAS version 9.0 (SAS Institute, Cary, North Carolina, USA; Stokes et al., 2012) and the test of comparison of means implemented in Pro Mixed was used.

RESULTS AND DISCUSSION

Temperature revealed differences ($P < 0.05$) between treatments with time (Figure 1). In CP the thermophilic phase was presented from the fourth DAE to the 85 DAE, at which time the temperature dropped and the cooling and stabilization phase of OW started. The temperature observed in the CP system agree with that found by Ocaña et al. (2015), who evaluated composting with municipal bio-waste and wood ash, finding that the temperature reached 70 °C in the thermophilic phase from days 9 to 12. Likewise Bustamante et al. (2008) reported that in decomposing bovine manure, the thermophilic curve was detected from days 7 to day 84. The rise in temperature per day 100 DAE in this experiment coincided with that reported by Boulter-Bitzer et al. (2006), who at 116 d, after intense work of turning, observed elevation of temperature up to 60 °C.

In SC the influence of the ambient temperature on the temperature of the transformed OW was observed,

Figure 1. Variation over time of the maximum and minimum ambient temperature and temperature of organic waste subjected to three decomposition systems.



Vermicomposting (—), semicomposting (---) and composting (-----). Reference value > 45 °C thermophilic phase and < 45 °C mesophilic phase (Jiménez et al., 2008).

registering in a range of 18 to 34 °C. The thermophilic phase was not presented, which coincides with other studies in which internal temperature was related to the available surface and the total volume of the residues (Herrera-Ortíz et al., 2015). In VC no thermophilic temperatures were present and the recorded temperature ranged from 18 to 34 °C. This coincides with Castillo et al. (2010), who worked with dairy cattle manure and pine sawdust and recorded a range of 20 to 40 °C. In VC systems a controlled temperature interval of 20 and 30 °C is fundamental for the survival of the worm and its efficiency to process the residues (Sinha et al., 2009). In this experiment, an average of 26.3 °C was recorded, the optimal temperature for worm development.

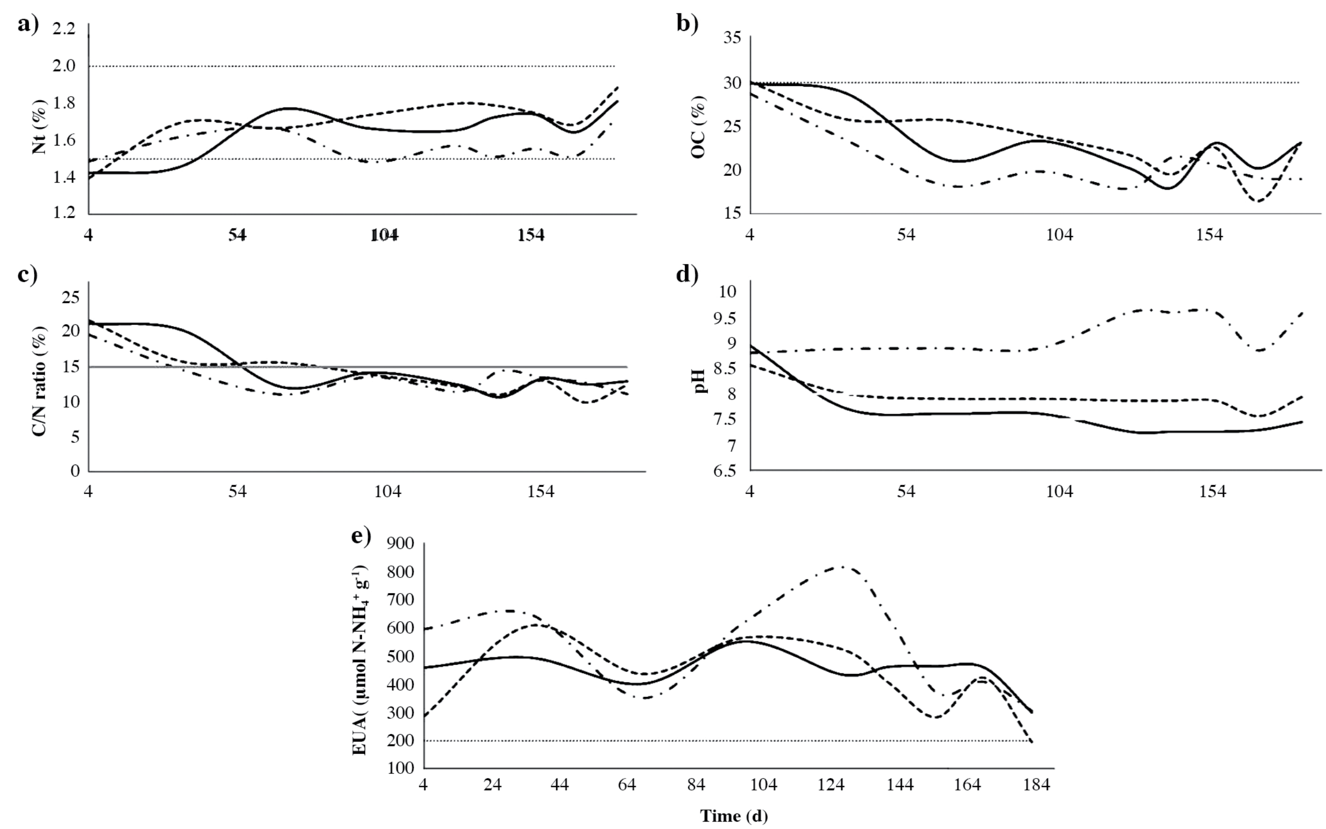
Percentages of Nt showed differences between time and treatments (Figure 2a) with tendency to increase. Differences in Nt during the first stages of the study could be related to the lack of homogeneity of the mixtures. In VC and CP the Nt increased at 68 DAE (1.76 ± 0.05% and 1.71 ± 0.13%, respectively), while in SC an increase in Nt was observed at 35 DAE (1.70 ± 0.02%). In all three treatments Nt had increased by 183 DAE, which coincides with Sangamithirai et al. (2015) who found an increase in Nt at the end of the SC process with OW from garden and tea leaves, as well as with Fornes et al. (2012) who recorded increases of Nt in VC and CP.

Organic C decreased 23.55 ± 0.32% in CP after 35 DAE, while in VC it was 68 DAE (21.24 ± 0.6%) and in SC 23.92 ± 2.41% at 98 DAE. There were increases in OC in VC and SC at 155 and 183 DAE respectively, and in CP 21.55 ± 3.08% at 141 DAE (Figure 2b).

In this study, in CP the largest OC decrease corresponded to 37.3% during the thermophilic phase, which is in agreement with that found by Bustamante et al. (2008). In VC the percentage of OC dropped sharply by 68 DAE and the subsequent decrease was gradual, which coincides with Garg and Gupta (2011) for the transformation of plant residues and cow manure with *E. fetida*. The gradual degradation of OC in SC coincides with that mentioned by Sangamithirai et al. (2015), when studying gardening and paper residues.

Carbon/Nitrogen ratio decreased sharply in all three treatments (Figure 2c), but showed differences between time and treatments. It has been claimed that when OW are transformed, the C/N ratio decreases with time by the C loss as carbon dioxide (De Guardia et al., 2010). In CP and SC the C/N ratio decreased at 35 DAE (14.62 ± 1.32 and 15.68 ± 1.18, respectively). For VC, a significant decrease was observed at 68 DAE (15.56 ± 1.5). A similar result was recorded by Hernández-Rodríguez et al. (2012), when evaluating the decomposition of sheep manure and

Figure 2. Total nitrogen (Nt) organic carbon (OC), C/N ratio, pH and enzymatic urease activity (EUA) with time in organic waste under three decomposition systems.



Vermicomposting (—), semicomposting (---) and composting (-·-·-). Reference value (·····).
a) Nt 1.2 to 2.0%* (Romero, 2004); b) OC < 30%* (Romero, 2004); c) C/N ratio < 15 (Jiménez et al., 2008); (e) EUA < 200 µmol $N\text{-}NH_4^+ \ g^{-1}$* (Liu et al., 2011), (*) based on DM.

sawdust reported an increase in the C/N ratio at 56 d and a steady decline up to 112 d. In this study, the C/N ratio was equal to or less than 15/1 for the three treatments, and there were no differences after 127 DAE in any of the treatments suggesting the stabilization of OM at 68 DAE according to He et al. (2014).

Initial pH values were between 8.57 and 8.94 in all three treatments (Figure 2d). There was a difference between VC (8.94 ± 0.05) and SC (8.57 ± 0.14) at the fourth DAE, and a tendency to acidification to 35 DAE was observed, being greater in VC (7.72 ± 0.15), which coincides with other authors (Garg and Gupta, 2011). In CP the initial pH was 8.9 ± 0.2 and increased to 9.5 ± 0.27 by 127 DAE. Alkalization is a consequence of the mineralization of proteins, amino acids, peptides and their transformation to ammoniacal compounds (Bustamante et al., 2008). In other compost experiments with bovine manure, it was observed that the basic pH could be related to the frequency and type of activities such as churning, humidification and leachate of the material (Gómez-Brandón et al., 2008). López-González et al. (2014) recorded a slightly alkaline final pH when using residues with high levels of cellulose.

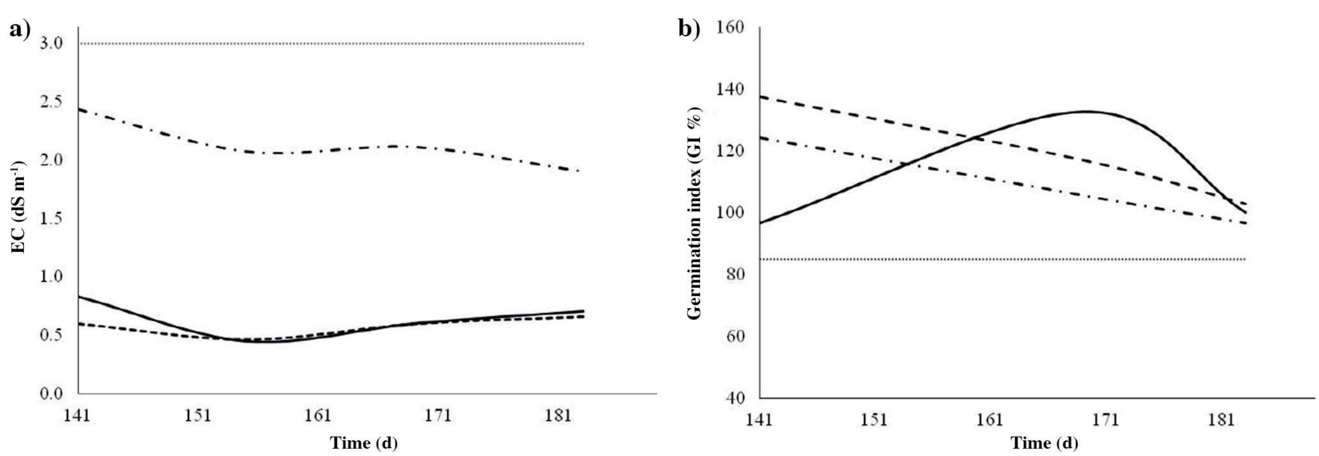
Differences in both time and treatments were observed in the EUA (Figure 2e). In this study, all three treatments observed a peak of EUA at 35 DAE and a decrease at 68 DAE. The VC and SC EUA stability was recorded at 68 DAE (409.32 ± 58.75 and 437.87 ± 36.09 μmol $N\text{-}NH_4^+$ g^{-1}, respectively), whereas CP presented a higher EUA 756.05 ± 270.14 μmol $N\text{-}NH_4^+$ g^{-1} at 127 DAE, coinciding with the establishment of the mesophilic phase. This datum coincides with that mentioned by Castaldi et al. (2008), that during the composting of municipal solid waste, a rise of urease from the first 3 wk and a peak of EUA at day 56 is explained by the presence of nitrates. Liu et al. (2011) when evaluating CP of cow dung and rice stubble concluded that the decrease in EUA may be a good indicator of compost stability.

Germination index has been used as an evaluation of OW maturity and phytotoxicity (Hernández-Rodríguez et al., 2012). The changes recorded in the phytotoxicity test, for all three treatments, showed a GI greater than 96% (Figure 3a). The GI presented a similar gradual decrease for SC and CP; however, for VC an increase of the GI was observed towards 169 DAE (132.78 ± 5.46%), followed by a subsequent decrease at 189 DAE (100.26 ± 9.34%). Sangamithirai et al. (2015) reported that the GI of different mixtures of OW transformed under SC during 90 d was less than 80%, and therefore considered that their direct application to the crops could be phytotoxic.

Electrical conductivity changes in the OW under the three treatments were different (VC, 0.83 ± 0.06; SC, 0.60 ± 0.02; CP, 2.34 ± 0.44 dS m^{-1}) at 141 DAE (Figure 3b). A decrease in EC from 155 DAE was observed for the three decomposition systems. The EC observed in VC coincided with Lazcano et al. (2008) and with Sangamithirai et al. (2015) for SC. This decrease was due to the volatilization of ammoniacal compounds, the fixation by N-assimilating microorganisms or the precipitation of mineral salts, which has been related to degradation of OM and loss of mass (Bustamante et al., 2008).

At 183 DAE the transformed OW presented the characteristics recorded in Table 1. Ranges reported as acceptable for agricultural use are presented in Figures 2 and 3. The three products of the systems studied presented Nt contents within the range suitable for agricultural use according to Romero (2004), however, there was a difference between CP 1.72 ± 0.11% and other systems. The percentage of final OC did not represent difference between VC 23.23 ± 0.59% and SC 23.20 ± 0.54%. The three products reached the recommended range of OC for agricultural use according to Romero (2004). The final C/N ratio in the three treatments was VC, 12.91 ± 1.05; SC, 12.36 ± 0.56 and CP 11.17 ± 1.32, values considered within the range of fertilizers suitable for use according to Jiménez

Figure 3. Germination index (GI) and electrical conductivity (EC) with time in organic waste under three decomposition systems.



Vermicomposting (—), semicomposting (---) and composting (-·-·-). Reference value (·····).
a) GI > 80% (Zucconi et al., 1981), and b) EC < 3.0 dS m^{-1}* (Soumaré et al., 2002), (*) based on DM.

Table 1. Characterization of the products of the three decomposition systems at 183 d.

Treatment	Nt	OC	C/N ratio	pH	EC	EUA	GI
	%*	%*			dS m^{-1}*	µmol N-NH_4^+ g^{-1}*	%
VC	1.81ab	23.23a	12.91ab	7.46a	0.71a	300.77a	100.26a
SC	1.88b	23.20a	12.36ab	7.94b	0.66a	196.57b	102.80a
CP	1.72a	19.10b	11.17a	9.58c	1.90b	307.63a	96.86a

Nt: Total N, OC: organic C, EC: electrical conductivity, EUA: enzymatic urease activity, GI: germination index, VC: vermicomposting, SC: semicomposting, CP: composting, (*) based on DM.
Different letters in the same column indicate significant differences according to test of comparison of means implemented in Pro Mixed ($P < 0.05$).

et al. (2008). In the case of pH there were differences between the three products; OW submitted to VC and SC recorded pH values within the range recommended for agricultural use (7.46 ± 1.01 for VC and 7.94 ± 1.7 for SC) according to Jiménez et al. (2008). The EC at 183 DAE in all three systems was within the range considered non-phytotoxic (0.71 ± 0.10, 0.66 ± 0.11, and 1.9 ± 0.03 dS m^{-1} for VC, SC and CP, respectively) according to Soumaré et al. (2002). EUA values in VC (300.77 ± 47.51 µmol N-NH_4^+ g^{-1}) and CP (307.63 ± 7.73 µmol N-NH_4^+ g^{-1}) showed no difference, while in SC (196.57 ± 7.73 µmol N-NH_4^+ g^{-1}) had lowest value recorded being the closest to what is recommended for agricultural use, with less than 200 µmol N-NH_4^+ g^{-1} according to Liu et al. (2011). For GI, the final values did not present significant differences between treatments, being greater than 80% recommended for agricultural use (Zucconi et al., 1981).

CONCLUSION

Under the conditions of this study, all the products of the three systems obtained at 183 d were within the parameters to be considered as organic fertilizers; however, the semicompost product transformed into an organic fertilizer fastest. All three systems reduced the C/N ratio to less than 15/1. Compost product had higher pH, electric conductivity, and enzymatic urease activity values than both vermicompost and semicompost. Vermicompost product had the highest germination index values, while semicompost showed a lower enzymatic urease activity and higher total N in a shorter time, corresponding to stability indicators. It is suggested to follow up this type of work, since the variables studied may differ by decomposition system and type of organic waste available.

REFERENCES

Achten, C., and Hofmann, T. 2009. Native polycyclic aromatic hydrocarbons (PAH) in coals – A hardly recognized source of environmental contamination. Science of the Total Environment 407:2461-2473.

ASTM International. 2010. Standard test methods for moisture, ash, and organic matter of peat and other organic soils. ASTM International, West Conshohocken, Pennsylvania, USA.

Bernal, M.P., Alburquerque, J.A., and Moral, R. 2009. Composting of animal manures and chemical criteria for compost maturity assessment. A review. Bioresource Technology 100:5444-5453.

Boulter-Bitzer, J.I., Trevors, J.T., and Boland, G.J. 2006. A polyphasic approach for assessing maturity and stability in compost intended for suppression of plant pathogens. Applied Soil Ecology 34:65-81.

Bustamante, M.A., Paredes, C., Marhuenda-Egea, F., Pérez-Espinosa, A., Bernal, M., and Moral, R. 2008. Co-composting of distillery wastes with animal manures: Carbon and nitrogen transformations in the evaluation of compost stability. Chemosphere 72:551-557.

Castaldi, P., Garau, G., and Melis, P. 2008. Maturity assessment of compost from municipal solid waste through the study of enzyme activities and water-soluble fractions. Waste Management 28:534-540.

Castillo, H., Hernández, A., Domínguez, D., and Ojeda, D. 2010. Effect of Californian red worm (*Eisenia foetida*) on the nutrient dynamics of a mixture of semicomposted materials. Chilean Journal of Agricultural Research 70:465-473.

De Guardia, A., Mallard, P., Teglia, C., Marin, A., Le Pape, A., Launay, M., et al. 2010. Comparison of five organic wastes regarding their behaviour during composting. Part 1. Biodegradability, stabilization kinetics and temperature rise. Waste Management 30:402-414.

Fernández, L.C., Rojas, N.G., Roldán, T.G., Ramírez, M.E., Zegarra, H.G., Uribe, R., et al. 2006. Manual de técnicas de análisis de suelos aplicadas a la remediación de sitios contaminados. Instituto Mexicano del Petróleo, Secretaría de Medio Ambiente y Recursos Naturales, Instituto Nacional de Ecología, Distrito Federal, México.

Flotats, J.R., y Solé, F.M. 2008. Situación actual en el tratamiento de los residuos orgánicos: aspectos científicos, económicos y legislativos. p. 44-73. In Moreno, J., y Moral, R. (eds.) Compostaje. Mundiprensa, Madrid, España.

Fornes, F., Mendoza-Hernández, D., García-de-la-Fuente, R., Abad, M., and Belda, R. 2012. Composting versus vermicomposting: a comparative study of organic matter evolution through straight and combined processes. Bioresource Technology 118:296-305.

Garg, V.K., and Gupta, R. 2011. Optimization of cow dung spiked pre-consumer processing vegetable waste for vermicomposting using *Eisenia fetida*. Ecotoxicology and Environmental Safety 74:19-24.

Gómez-Brandón, M., Lazcano, C., and Domínguez, J. 2008. The evaluation of stability and maturity during the composting of cattle manure. Chemosphere 70:436-444.

He, X.S., Xi, B.D., Li, D., Guo, X.J., Cui, D.Y., Pan, H.W., et al. 2014. Influence of the composition and removal characteristics of organic matter on heavy metal distribution in compost leachates. Environmental Science and Pollution Research 21(12):7522-7529.

Hernández-Rodríguez, O.A., López-Díaz, J.C., Arras-Vota, A.M., Quezada-Solís, J., and Ojeda-Barrios, D. 2012. Quality of vermicompost obtained from residues of forestry and livestock. Sustainable Agriculture Research 1:70-76.

Herrera-Ortíz, V., Hernández-Rodríguez, O.A., González-Franco, A.C., Núñez-Barrios, A., Robles-Hernández, L., y Pérez-Leal, R. 2015. Identificación de bacterias cultivables patógenas al humano en semicompostas de residuos agrícolas. Revista Mexicana de Ciencias Agrícolas 6:1189-1201.

Jiménez, E., Barral, M.T., y Marhuenda, F.C. 2008. Indicadores de la estabilidad y madurez del compost. p. 243-284. In Moreno, J., y Moral, R. (eds.) Compostaje. Mundiprensa, Madrid, España.

Kandeler, E., Stemmer, M., and Klimanek, E.M. 1999. Response of soil microbial biomass, urease and xylanase within particle size fractions to long-term soil management. Soil Biology and Biochemistry 31:261-273.

Lazcano, C., Gómez-Brandón, M., and Domínguez, J. 2008. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere 72:1013-1019.

Liu, D., Zhang, R., Wu, H., Xu, D., Tang, Z., Yu, G., et al. 2011. Changes in biochemical and microbiological parameters during the period of rapid composting of dairy manure with rice chaff. Bioresource Technology 102:9040-9049.

López-González, J.A., Vargas-García, M.C., López, M.J., Suárez-Estrella, F., Jurado, M., and Moreno, J. 2014. Enzymatic characterization of microbial isolates from lignocelluloses waste composting: Chronological evolution. Journal of Environmental Management 145:137-146.

Ocaña, É.R.O., Lozada, P.T., Rebellón, L.F.M., Hoyos, L.V., Gonzales, S., Barrena, R., et al. 2015. Stability and maturity of biowaste composts derived by small municipalities: Correlation among physical, chemical and biological indices. Waste Management 10:63-71.

Romero, L.M.R. 2004. Agricultura orgánica. Elaboración y aplicación de abonos orgánicos. In Memorias III. Curso Teórico-práctico. Lombricultura Técnica Mexicana. SOMELAO, Guadalajara, Jalisco, México.

Sangamithirai, K.M., Jayapriya, J., Hema, J., and Manoj, R. 2015. Evaluation of in-vessel co-composting of yard waste and development of kinetic models for co-composting. International Journal of Recycling of Organic Waste in Agriculture 4:157-165.

Sinha, R.K., Herat, S., Valani, D., and Chauhan, K. 2009. Special issue on vermiculture and sustainable agriculture. American-Eurasian Journal of Agricultural and Environmental Sciences 5:01-55.

Soto, G., y Muñoz, C. 2002. Consideraciones teóricas y prácticas sobre el compost, y su empleo en la agricultura orgánica. Manejo Integrado de Plagas y Agroecología. Costa Rica 65:123-125.

Soumaré, M., Demeyer, A., Tack, F.M.G., and Verloo, M.G. 2002. Chemical characteristics of Malian and Belgian solid waste composts. Bioresource Technology 81:97-101.

Stokes, M.E., Davis, C.S., and Koch, G.G. 2012. Categorical data analysis using SAS. 3rd ed. SAS Institute, Cary, North Carolina, USA.

Zucconi, F., Pera, A., Forte, M.M., and De Bertoldi, M. 1981. Evaluating toxicity of immature compost. Biocycle 22:54-57.