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Evaluation of the Addition of Wood Ash to Control the pH of Substrates in Municipal Biowaste Composting

Evaluación de la incorporación de cenizas de madera para el control del pH de los sustratos en el compostaje de biorresiduos de origen municipal

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Abstract

This study evaluates the addition of wood ashes (WA) for controlling the pH of substrates in municipal biowaste (MBW) composting. Three combinations in wet weight percent (w/w) of MBW and WA were tested: i) BC_1: 2% WA and 98% MBW; ii) BC_2: 4% WA and 96% MBW; and iii) BC_3: 8% WA and 92% MBW. Each combination was compared with a control (100% MBW) called B_1, B_2 and B_3 respectively. The experiment was conducted to pilot scale, with piles of 510 kg. The results indicate that the addition of WA improved the pH level and nutrients for the composting process; however, it had not substantial benefit in the process (start of the thermophilic phase and the behavior of the substrate degradation rate). Furthermore, a higher presence of salts and phytotoxic compounds in the product was observed. This could limit the product use for agricultural activities.

Keywords:

- biowaste
- composting
- amendment materials
- wood ash

Resumen

Este estudio evalúa la incorporación de cenizas de madera (CM) para el control de pH de los sustratos en el compostaje de biorresiduos municipales (BM). Se evaluaron tres combinaciones en porcentaje de peso (base húmeda) de BM y CM: i) BC_1: 2% CM y 98% BM; ii) BC_2: 4% CM y 96% BM; y iii) BC_3: 8% CM and 92% BM. Cada combinación fue comparada con un control conformado por 100% BM, llamados B_1, B_2 y B_3, respectivamente. El experimento se desarrolló a escala piloto con pilas de 510 kg. Los resultados indican que la adición de CM mejoró el nivel de pH y de nutrientes de los sustratos para el proceso de compostaje; sin embargo, no generó beneficios sustanciales en el proceso, tanto en el inicio de la fase termofílica como en el comportamiento de la tasa de degradación del sustrato. Asimismo, los productos de las pilas con CM tuvieron mayor presencia de sales y compuestos fitotóxicos, que pueden limitar el uso del producto en actividades agrícolas.

Descriptores:

- *biorresiduos*
- *compostaje*
- *material de enmienda*
- *ceniza de madera*

Introduction

The composting process effectiveness and product quality are affected by the substrate quality (Chiumenti *et al*., 2005; De Guardia *et al*., 2010). In developing countries, the composting of municipal biowaste (MBW) is characterized by substrates with significant content of raw food and acid pH (Chang and Hsu, 2008; Adhikari *et al*., 2008; Yu and Huang, 2009). The acidity in substrates results from an early production of fatty acids (Smårs *et al*., 2002; Sundberg *et al*., 2004). Similarly, when the decomposition process of acid biowaste begins, the number of mesophilic microorganisms such as lactic-acid bacteria and yeast increases (Kurola *et al*., 2011). This fact can cause a pH drop. The degradation effectiveness of MBW is inhibits with this pH drop, the temperature levels for a hygienization process are not reached and the product quality decreases (Sundberg and Jonsson, 2008).

In the composting process, MBW degradation can be improved by controlling pH levels in the substrate (Sundberg *et al*., 2004; Sundberg and Jönsson, 2008). Alkaline ashes as buffer material for pH reduction during the composting process are suggested by different authors (Koivula *et al*., 2004; Kuba *et al*., 2008; Kurola *et al*., 2011; An *et al*., 2012). Literature suggests that the composting process of sorted kitchen biowaste is enhanced by the addition of ashes from wood combustion (WA). Consequently, the mineralization rate of compost, the formation of humic acid and the O_2 availability increased. Likewise, the formation of acid compounds like H_2S and odors were controlled and minimized (Koivula *et al*., 2004).

In other study (Kuba *et al*., 2008), WA in wet weight percent (wwp) was added to the composting process of sorted household MBW. As a result, the nutrient balance was enhanced, the dynamics of composting process were not negatively affected and the agronomic value of the final product was higher, with the addition of 16% of WA. Kurola *et al*. (2011) reported that with the addition of WA in the range from 4% to 8%, the pH levels, the heat production and the microbial activity in the process increased. Hence, a hygienic and safe final product was obtained. A proper aeration to minimize odors and a severe control in WA quality was also recommended. The influence of carbon ashes addition on food scraps composting was studied by Jian An *et al*. (2012). In this study, higher temperatures during the first eight days, higher O_2 consumption in the first two phases of the process and a lower decay in the pH levels were found.

Due to the scarce documentation and research about the effect of WA in MBW composting in developing countries, and the necessity to identify options to control the acidity of substrates in this context, in the present study we examined the effect of WA incorporation to MBW composting in the context of developing countries and its influence on the Physicochemical quality of the substrates (MBW), the composting process (temperature behavior, pH levels, Electric Conductivity (EC) and Germination Index (GI)), and the Physicochemical quality of the product.

Materials and methods

The study was developed at pilot scale. The substrates were obtained from a location where selective collection of municipal solid waste (MSW) has been successfully implemented. High amounts of raw food scraps were found in the substrates (79.5 to 96.7% wwp). High moisture (70.8 to 84.2% wwp) and acid pH levels (4.6 to 6.7 units) were also characteristics of the substrates (Marmolejo, 2011). The WA was taken from combustion of wood used in the small dairy company in the locality. The pH was 13.4 units and the alkalinity 5.46% (determined as NaOH) (Coefficient of variation-CV: 0.39%). Other variables were: Total Organic Carbon (0.9%), Total Nitrogen (0.27%), Total Phosphorous (0.71%), Total Potassium (9.39%), Calcium (9.5%) and Sodium (5.4%).

Three types of mixture in weight (w/w) of MBW and WA were studied: i) BC_1: 2% WA-98% MBW; ii) BC_2: 4% WA-96% MBW; and iii) BC_3: 8% WA-92% MBW. These proportions were defined according to previous composting experiences with MBW and WA (Koivula *et al*., 2004; Kuba *et al*., 2008; Kurola *et al*., 2011). Control piles with 100% MBW were included in the experiment (B_1, B_2 y B_3). The piles had conic shape, with heights between 0.8 and 1.0 m, with 510 kg weight and were located under equal environmental conditions covered by a waterproof roof. The study involved, mounting pairs of piles (e.g. BC_1 and B_1), starting in three consecutive weeks, according to the MBW availability in the studied locality.

Each substrate was manually crushed, until particle sizes between 5 and 7 cm were achieved. These are the recommended sizes for MBW composting (Agnew and Leonard, 2012) Once the piles were built, representative samples of 2 kg were taken for each pile using the method described by Sakurai (2000). Analyzed parameters included: pH, moisture, Total Oxidizable Organic Carbon (TOC), Potassium and Phosphorous, following the methods specified by the Colombian Technical Norm (NTC) 5167 (ICONTEC, 2003) and Total Nitrogen (N_{total}) according to indications of NTC 370 (ICONTEC, 1997). The physical composition of MBW was determined and classified as: i) processed food, ii) raw food, iii) paper and pasteboard, iv) garden and pruning waste and v) others. These categories were established based on previous research in the study area (Marmolejo, 2011).

The control variables for the composting process were temperature, pH and moisture. Temperature was measured in the centroid of each pile, using a 70 cm length dial thermometer. For pH and moisture determination, four samples 50 g each were taken from different points on each pile. Then an integrated 200 g each sample was composed (Sullivan and Miller, 2001). The pH was measured using a pH-electrode connected to a pH-meter (WTW 315i, Germany). The sample was diluted using distillated water in a 5:1 (V/V) ratio. The moisture was determined with an analyzer Ohaus MB-35. During the first week, pH was measured daily and later on, at least three times per week. Moisture content was kept above 40%, as recommended by Agnew and Leonard (2003), by wetting the sample with tap water. Piles were manually turned over when inner temperatures were equal or above to 65°C.

Due to the importance of studying the evolution of product maturation, EC and GI were monitored after the 90th day. EC was measured using a conductivimeter WTW model 325. GI tests were performed by determining the sensitivity of radish (*Raphanus sativus)* to products, following the procedures established by INN (2004) and Varnero *et al*. (2007). The process was monitored until the temperature of the piles was around room temperatures ±5°C and the product had soil smell. Thus, the maturation process was reached (Dulac, 2001). A descriptive analysis of temperature, pH, EC and GI was carried out.

Once the monitoring period was completed, a representative sample of each pile was taken, as recommended Sullivan and Miller (2001). The same parameters measured in samples were measured in the product. Thus, the substrate quality was determined in pH level, moisture, TOC, K, P, N_{total}. Quality results of the product were compared with the limits establish in NTC 5167 (ICONTEC, 2003).

Results and discussion

Substrate characterization

A predominance of raw food scraps were presented in MBW samples (91.7 to 96,4%), as reported in previous studies (Marmolejo, 2011). Likewise, results were conformed to Parfitt *et al*. (2012), who reported predominance of fresh fruits and vegetables in the composition of food scraps in five countries (United King, Netherland, Austria, United State and Turkey). Other categories showed percentages between 8.3 and 3.6%, integrated by materials such as paper and processed food. Physicochemical analyzes of substrates are presented in Table 1.

Table 1. Physicochemical characterization of substrates of the process

Parameter	Unit	B_1	BC_1	B_2	BC_2	B_3	BC_3
pH	Units	5.85	7.16	5.30	8.02	4.99	9.03
Moisture	%(w/w)	75.24 (CV: 1.74%)	73.30 (CV: 3.06%)	79.77 (CV: 1.82%)	70.73 (CV: 0.58%)	81.11 (CV: 0.16%)	71.74 (CV: 3.94%)
TOC	%(w/w)	28.63 (CV: 6.11%)	27.49 (CV: 9.24%)	32.18 (CV: 2.22%)	17.80 (CV: 1.70%)	23.98 (CV: 0.80%)	21.73 (CV: 2.22%)
N_{total}	%(w/w)	1.41 (CV: 6.22%)	1.16 (CV: 1.90%)	1.24 (CV: 0.14%)	1.13 (CV: 1.02%)	1.22 (CV: 3.14%)	1.13 (CV: 2.20%)
C/N	--	20.25	23.68	26.04	15.79	19.70	19.19
K	%(w/w)	1.54 (CV: 11.80%)	1.27 (CV: 4.10%)	2.42 (CV: 0.76%)	2.84 (CV: 5.30%)	3.18 (CV: 0.10%)	3.26 (CV: 1.70%)
P	%(w/w)	0.36 (CV: 3.60%)	0.19 (CV: 0.70%)	0.15 (CV: 6.42%)	0.17 (CV: 4.80%)	0.21 (CV: 0.40%)	0.39 (CV: 2.20%)

Note: Samples in dry base (d.b.). CV: Coefficient of variation (n:2)

In general, differences in the Physicochemical characteristics among substrates B_1, B_2 and B_3 were observed. These differences can be explained due to temporal variability of substrates quality for the composting of MBW, as reported in other studies (Herity, 2003; Ward *et al*., 2005). The pH levels in MBW were in the acid range and a positive effect was observed by the incorporation of WA, increasing pH values in some cases up to neutral (BC_1) or alkaline ranges (BC_2 y BC_3). However pH values in BC_2 and BC_3 were higher than those recommended by Krogmann *et al*. (2010). Therefore, nitrogen losses as ammonia might be presented when high temperatures are reached in the composting process (de Bertoldi *et al*., 1983).

In all cases, moisture values were higher than the recommended range by different authors for the beginning of the composting process (55 to 65%) (Chiumenti *et al*., 2005; Stentiford, 1996). However, lower moisture values were observed in the samples with the incorporation of WA (BC_1, BC_2 and BC_3). On the other hand, TOC and N_{Total} contents were lower for piles with presence of WA, which means a negligible contribution of those parameters from the WA (Kuba *et al*., 2008). The C/N ratio in substrates BC_2, B_3 and BC_3 was out of the range from 25 to 30%, which is recommended by other authors (Chiumenti *et al*., 2005; Agnew and Leonard, 2001). This might be attributed to the low content of TOC in the MBW. In contrast, increment on K and P concentrations were observed in the in the substrates with 4 and 8% of WA (BC_2 and BC_3, respectively). K and P are essential elements for plants growing (Kuba *et al*., 2008; Kurola *et al*., 2011).

Development of the composting process

Temperature: Figure 1 shows the temperature performance throughout the composting process. A similar tendency was observed in all piles and the typical composting phases were observed (mesophilic, thermophilic, cooling and maturation) (Insam and de Bertoldi, 2007). Thermophilic temperature was reached in all piles during the first and third day of the process. Thus, addition of WA did not accelerate temperature, as reported Koivula *et al*. (2004). However, higher temperatures were reached during the thermophilic phase for piles with WA (73, 70 and 68°C for BC_1, BC_2 and BC_3 respectively). The process had a rapid started due to the presence of easily biodegradable compounds within the food scraps fraction, such as sugars, proteins and amino acids (Krogmann *et al*., 2010; An *et al*., 2012).

A temperature above to 55°C was reached during 7 to 10 days in the piles B_1, B_2 and B_3, and during 9 to 12 days in the piles BC_1, BC_2 and BC_3. Therefore, an enhancement of hygienization process was observed by using WA. However, this temperature level was no possible to keep for more than 14 days, as recommended by Krogmann *et al*. (2010) for a complete hygienization. This might be explained due to the substrate characteristics. The process was in a thermophilic range (T> 45°C) during 18 days in piles B_1 and BC_1, 16 and 15 days in piles B_2 and BC_2, and 24 and 22 days in piles B_3 and BC_3 respectively. Therefore, the gradient temperature was increased by using from 4% to 8% of WA.

Temperature performance during cooling and maturation phases was similar for all piles. First, a sloped decreasing was initially observed (cooling) and then a lower and extended reduction of temperature (maturation). Maturation phase was slower because the more complex molecules are decomposed during this period (Gajalakshmi and Abbasi, 2008). After 136 days of composting process, environment temperatures were reached. A tendency to higher temperatures (+1°C) in piles with WA was observed. It can be attributed to ashes, which increase the thermal capability of the mass, keeping a higher heat in the piles (Koivula *et al*., 2004).

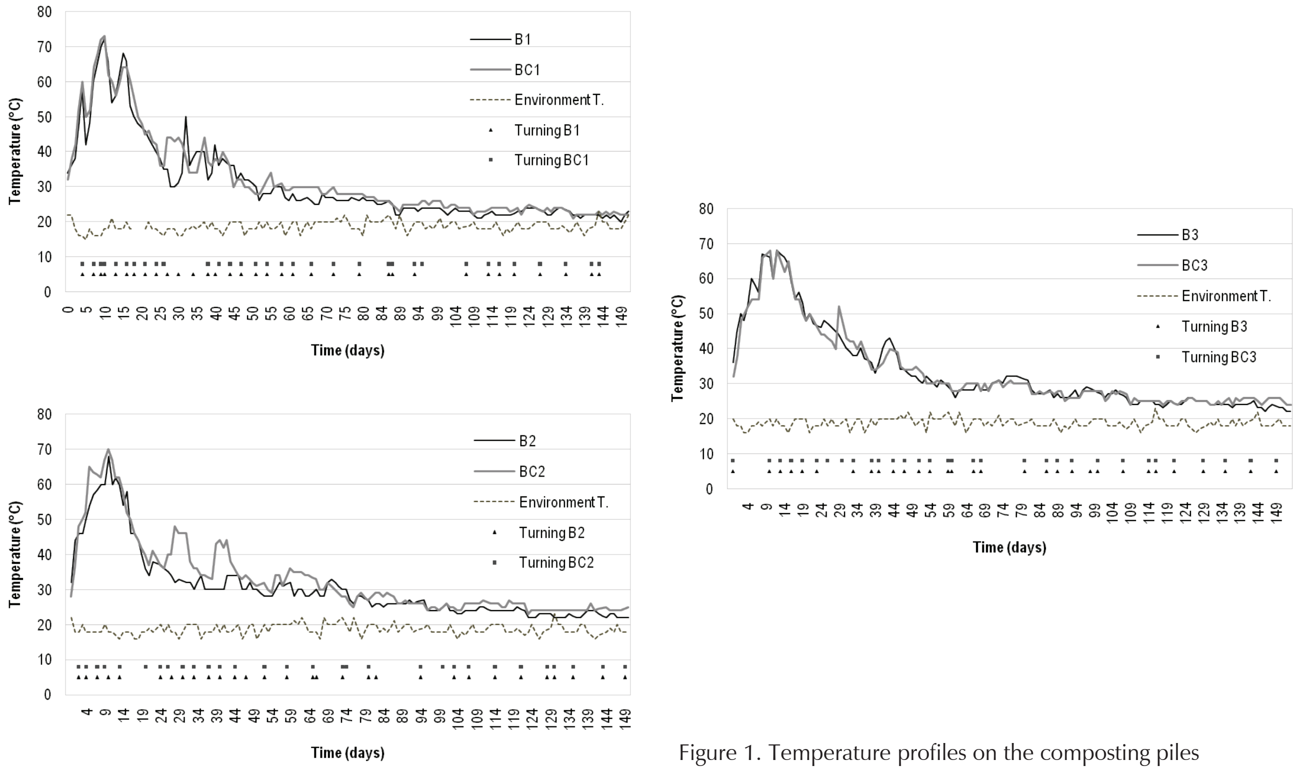


Figure 1. Temperature profiles on the composting piles

pH: As shown before in Table 1, pH levels of substrates were increased by the incorporation of WA (Figure 2). Although an acid level in the pH was observed in the piles without WA, it was not a limitation for the beginning of the composting process and it might be explained due to the presence of easy biodegradable compounds.

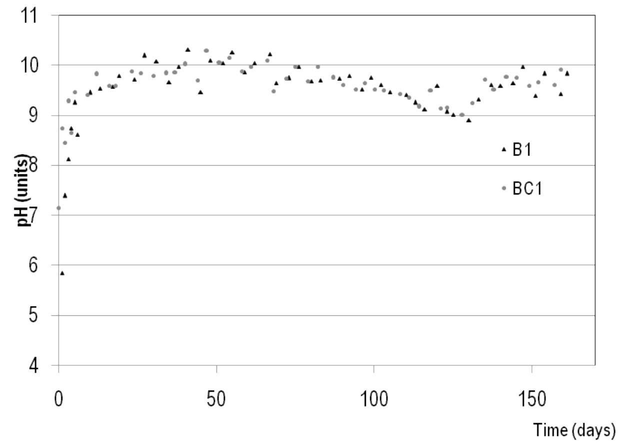
In piles with WA, the acids generated by the organic matter transformation were neutralized and minimal decrease in pH values was observed, due to the alkaline compounds presented in the WA that buffers the acidity (An *et al*., 2012). In the case of control piles, the initial acid values indicate the progress in the degradation of organic matter at the beginning of the process, which is an evidence of the secondary acid metabolites production in the microbial decomposition of easily degradable elements (De Bertoldi *et al*., 1983; An *et al*., 2012).

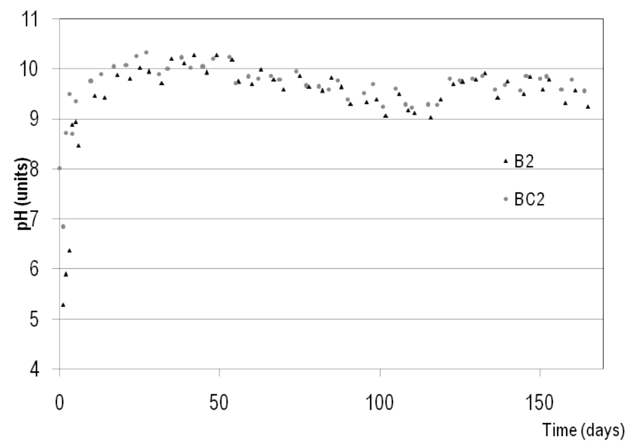
On the other hand, taking into account that temperatures in the thermophilic range occurred between 18 or 24 days, and during this period pH values between 8 and 10 units were kept in all the piles, ammonium can be dissociated easily at these pH and temperatures in H+ y NH_3. That could generate a nitrogen loss by means of ammonia volatilization (Boldrin *et al*., 2010).

The pH value was around 9 and 10 units during thermophilic and maturation phases. This is associated to protein decomposition, ammonification, CO_2 release and biomass aeration (Haug, 1993; An *et al*., 2012). Likewise, due to the increase in concentration of water-soluble base cations arising from organic matter decomposition (Kalemelawa *et al*., 2012). The pH behavior did not present differences between-the piles, as reported Koivula *et al*. (2004).

Electric Conductivity (EC): salt contents associated to the presence of sodium, chloride, potassium, nitrate, sulfate and ammonium salts, is indirectly measured through EC. At high concentrations, these salts are toxic for plants and inhibit their growth (Hargreaves *et al*., 2008; Sullivan and Miller, 2001). EC values were higher in all piles compared to those recommended by different authors: Dinambro *et al*. (2006) (< 2 dS/m), Benito *et al*. (2006) (<0.5 dS/m) or Koivula *et al*. (2004) (4 dS/m) (Figure 3). Phytotoxic compounds were present in all piles and could restrict product use. This situation was more critical in WA piles, due to the high salinity that characterize the WA (Kuba *et al*., 2008).

Germination Index (GI): lower GIs were reached in the piles with WA (Figure 3). This situation shows the phytotoxic compounds in these piles and corroborates





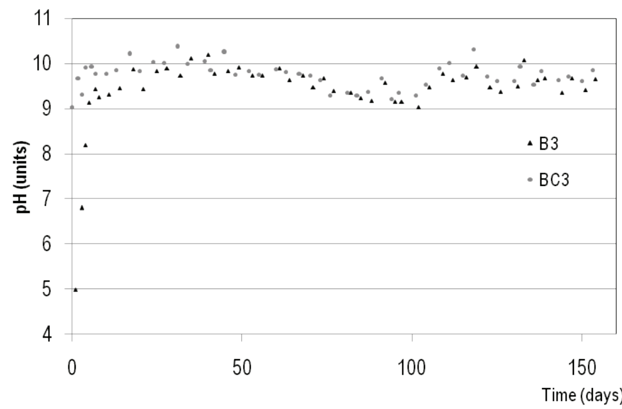


Figure 2. pH profiles on the composting piles

the negative influence of WA (Possibly associated with the presence of salts such as sodium). However, excepting pile B_2, none of the piles reached the 80% value, that indicates product maturity (Varnero *et al*., 2007). This situation shown that is necessary higher time for maturation of material.

Product quality

The product quality is presented in Table 2. High values of pH were found in all piles. These values were reported in previous studies in the locality for the piles with MBW (Marmolejo, 2011). Likewise, they were obtained in experiments with WA and MBW (Kurola *et al*., 2011). The product can have restrictions to its use. The moisture values had minimal differences in piles with incorporation of WA and their controls. In all piles, except B_1 and BC_1, product reached moisture values that fulfill NTC 5167 guidelines.

TOC and N content were lower for piles with presence of WA. This might be attributed to the dilution by mixture with WA and by an improved mineralization (Kuba *et al*., 2008). In all piles, the TOC product breaches with minimal reporting value of NTC 5167 (>15%). N content had typical values for this kind of substrates (0.7-1.7% d.b.) (Kuba *et al*., 2008). Major differences in the N contents were presented in B_3 and BC_3; the last one presented the lowest value of all piles and additionally, was the only one that did not accomplished the minimal value to be reported, as indicated in the NTC 5167 (> 1%).

The C/N ratio in product was in the range 7.6-10.1, which is lower than those recommended by different authors for agricultural use (Barberis and Nappi, 1996; Barrena *et al*., 2006; Sullivan and Miller, 2001). This might be attributed to the low content of TOC found in the products.

Compost coming from MBW has typical P and K content between 0.4 to 1.1% and 0.6 to 1.7% respectively (Herity, 2003). The P and K content in the products were higher in the pile with addition of 8% of WA. This is due to the high content of P and K in the WA (Kuba *et*

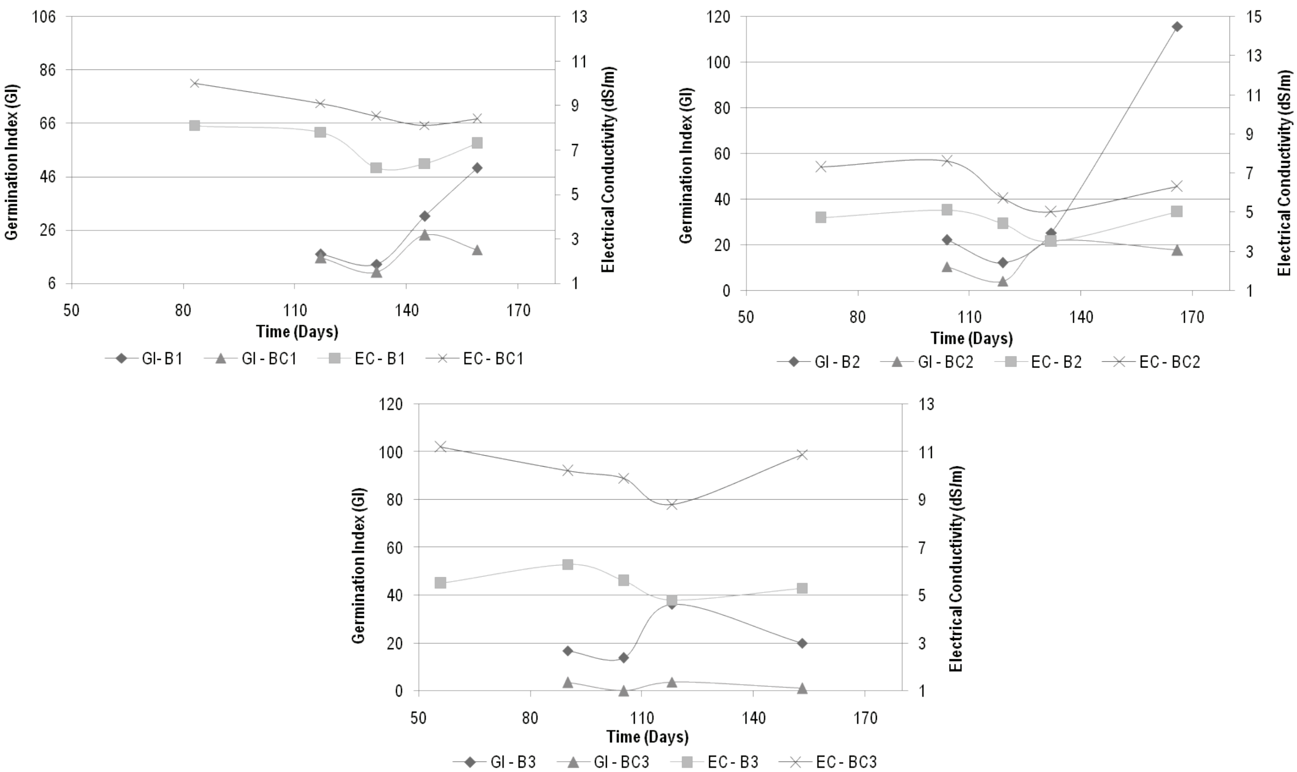


Figure 3. Electric conductivity and germination index profiles on the composting piles

Table 2. Quality product in piles from both substrates

Parameter	Unit	B_1	BC_1	B_2	BC_2	B_3	BC_3
pH	Units	8.94	8.82	8.69	8.87	7.85	9.07
Moisture	%(w/w)	35.20 (CV: 0.58%)	35.40 (CV: 0.12%)	29.80 (CV: 3.20%)	28.70 (CV: 0.60%)	25.30 (CV: 1.00%)	23.90 (CV: 1.39%)
TOC	%(w/w)	11.53 (CV: 3.78%)	11.49 (CV: 7.76%)	11.34 (CV: 5.44%)	9.94 (CV: 3.10%)	12.30 (CV: 0.79%)	8.88 (CV: 7.38%)
N_{total}	%(w/w)	1.44 (CV: 0.93%)	1.52 (CV: 0.94%)	1.35 (CV: 1.34%)	1.30 (CV: 0.74%)	1.45 (CV: 3.08%)	0.88 (CV: 3.55%)
C/N	--	8.03	7.57	8.38	7.62	8.51	10.09
K	%(w/w)	1.05 (CV: 8.32%)	0.79 (CV: 5.50%)	1.62 (CV: 8.68%)	1.28 (CV: 8.59%)	1.43 (CV: 0.14%)	1.48 (CV: 6.91%)
P	%(w/w)	0.66 (CV: 1.66%)	0.56 (CV: 3.93%)	0.64 (CV: 4.77%)	0.63 (CV: 1.59%)	0.60 (CV: 1.59%)	0.80 (CV: 9.27%)

Note: Samples in dry base (d.b.); CV: Coefficient of variation (n:2)

al., 2008). On the other hand, none of the product reached the minimal report value for the P content and except for the BC_1, all piles reached the fulfillment of the NTC 5167 for the K.

Conclusions

A predominance of acid pH values and high moisture were presented in Municipal Biowaste (MBW). The degradation effectiveness of MBW can be inhibited due to these characteristics. Likewise, the product quality is affect due to low TOC, N and P contents. Increments on the initial pH level of substrates were observed with incorporation of wood ashes (WA). A major buffering affect to the acid generated in the first phase of the process and improvement on the nutrient content were presented.

However an excessive increment on the pH level (between 8 and 9 units) associated with thermophilic temperatures, can propitiate losses of N by means of volatilization which demands looking for alternatives to control this issue.

The addition of WA did not accelerate the temperature on thermophilic phase. A similar tendency was observed on the degradation rate of the substrate in all piles. This could be attributed to the content of easily biodegradable organic matter in the substrates. Increments on the presence of salts and phytotoxic elements during the process were observed with addition of WA. This can limit the product use for agricultural activities. The addition of WA improved the pH level for the composting process, however, it had not substantial benefit in the process and the higher presence of phytotoxic compounds in the products could compromise its use.

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