RESEARCH

Effect of adding bulking materials over the composting process of municipal solid biowastes

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Biowastes (BW), the main raw materials for the composting installations in developing countries, are characterized for containing uncooked food wastes (FW), high moisture content, low porosity, acidic pH, and low C/N ratios which affects the overall composting process (CP). In this study, we evaluated the effect of adding sugarcane bagasse (SCB) and star grass (SG) (*Cynodon plectostachyus* (K. Schum.) Pilg.) as bulking materials (BM) over the quality of the substrate, progress of the process, and quality of the obtained product. In this sense, two pilot-scale experiments were performed. The first one contained a substrate formed by 78% BW and 22% SCB (pile A). The second experiment contained a substrate formed by 66% BW and 34% SG (pile B). For each experiment, control treatments (piles A´ and B´ respectively) were performed by using 100% BW without BM. The results showed that in both cases the adding of BM improved substrate quality (pH, moisture, and total organic C content [TOC]), speeding up the starting step (2-3 d) and reducing the duration of the thermophilic phase of CP (3 d). However, the physico-chemical properties of both BM increased cooling and maturation phases duration (between 15 and 20 d). Obtained products quality was improved in terms of higher TOC, cation-exchange capacity, bulk density, and higher water holding capacity. Application of obtained products A and B could improve some soil properties like major nutrient, water retention, and increasing the organic matter.

Key words: Biowastes, bulking materials, composting processes, municipal solid wastes, star grass, sugarcane bagasse.

INTRODUCTION

Biowastes (BW) are the major fraction of municipal solid wastes (MSW) in developing countries being food wastes (FW) like fruits and vegetables their main components (Gustavsson et al., 2011). Composting process (CP) is one of the best-known methods used for BW biological stabilization. For this process, organic components of substrate are transformed in stable materials which could further be used both as organic material source and as organic fertilizers for agricultural applications and soil amendment processes (Haug, 1993; Chiumenti et al., 2005).

The CP effectivity and quality of obtained product depends on initial characteristics of material to be processed (substrates) (*viz*., its biodegradability and nutrient availability) but also of the control of several key factors such as temperature, aeration, pH, and moisture (Zhu, 2007; De Guardia et al., 2010). According to Agnew and Leonard (2003) and Chiumenti et al. (2005), CP might be efficiently developed employing substrates with C/N ratios in range of 25-30, moisture content between 50%-60%, and pH values of 6.5-7.5. However, BW are generally characterized by C/N values lower than 20, moisture higher than 70%, and acidic pH, affecting negatively processing time, transformation efficiency rates and quality of the obtained product (Adhikari et al., 2008; Kumar et al., 2010; Sundberg et al., 2011). Additionally, they could generate environmental secondary contaminant products such as leachates, ammonia, and greenhouse gases (Yang et al., 2013).

Diverse strategies to control moisture and pH dropping have been proposed. Among them, adding bulking material (BM) or increasing aeration rate have widely been used (Sundberg and Jönsson, 2005; Epstein, 2011). Regarding to BM they have been used to modify physical properties of substrates, improving biological activity conditions and biodegradation kinetic (source of C, particle size, volumetric density [VD], porosity, and regulation of moisture) (Haug, 1993; Yang et al., 2013; Li et al., 2013).

Several experiences in which different BM has been applied in order to optimize CP of BW or FW have been documented. For example, wheat residue pellets

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and chopped hay were used by Adhikari et al. (2008), green wastes and cardboard paper by Francou et al. (2008), raked leaves and grass clippings by Kumar et al. (2010). Likewise, Li et al. (2013) reported use of sawdust followed by sugarcane bagasse (SCB), rice husk, and wood shavings. Selection of appropriate BM should be accompanied by not only its physico-chemical characteristics but also its availability and costs related with its raw source.

Regarding to the use of grass residues as BM, they have been identified as additional energy and nutrients (like N) sources, regulates moisture excess proceeding from FW and improve structure and aeration of substrates (López et al., 2010). Other authors (Francou et al., 2008; Kumar et al., 2010) have used this material mixed with FW improving the CP and obtained product quality. From a previous study, Oviedo-Ocaña et al. (2013) demonstrated that adding 17% of star grass (SG, *Cynodon plectostachyus* [K. Schum.] Pilg.) in a CP of BW improved substrate characteristics, degradation rate, hygienization conditions and quality of obtained product. In turn, SCB is a lignocellulosic material composed mainly by 50% cellulose, 25% hemicellulose, and 25% lignin (Balakrishnan and Batra, 2011), which have also been used in different studies as BM (Iqbal et al., 2010). In this sense, it have been reported some CP using SCB mixed with bovine manure and vegetables (Monson and Murugappan, 2010) or with press mud obtained from sugarcane industry (Meunchang et al., 2005).

According to above, there is still a necessity of improving CP and obtained products quality from BW produced in developing countries, as well as, conduct researches aimed to increasing the competitiveness of this option for MSW management. In this sense and continuing with our current program on the identification and evaluation of raw wastes as potential supporting materials (Oviedo-Ocaña et al., 2013), in this study was evaluated the effect of adding SG and SCB as BM in CP of BW obtained from municipal solid wastes over physico-chemical properties of BW and behavior of some variables like temperature, pH, and volatile solids. Furthermore, physico-chemical and microbiological qualities of obtained products were also considered.

MATERIALS AND METHODS

Description of the experiments

This study was carried out at pilot-scale in a locality of the Valle del Cauca Department, Colombia, accounting with a MSW plant were the source separation and the selective collection of the MSW have effectively been implemented. The SCB was supplied by a sugarcane micro-enterprise located in the municipality and SG from grass clipping of surrounding green areas of the locality. The study consisted of two experimental composting installations of BW, in the first one (experiment 1, piles A) it was evaluated the effect of adding SCB to the BW over the CP and the quality of the obtained product, and the second one (experiment 2, piles B) evaluated the effect of adding SG to the BW over the same parameters.

The characteristics of each pile were: Pile A was composed by 78% BW and 22% SCB. This composition was proposed after mass balances supported by physico-chemical characterization of SCB to be used as well as the BW of the locality in order to obtain a final C/N ratio of 25-30 (Haug, 1993). The information employed for calculations was: (i) SCB: total organic C (TOC) = 42.61%; total N by Kjeldahl (N_{Total}) = 0.37%; moisture = 32.5%; C/N ratio = 115.0, and (ii) BW: TOC = 29.76%; N_{Total} = 1.46%; moisture = 76.0%; C/N ratio = 20.79. Pile B, composed by 66% BW and 34% SG. This composition was established after previous results obtained by Oviedo-Ocaña et al. (2013). The compositions of both types of piles are in wet-weight basis; additionally, for each experiment control assays were performed consisting in 100% BW (they will be referred to as Pile A´ and B´, respectively).

Substrate characterization

The BW were generated by the total homes of the municipality, they were source-separated, selectively collected and were stored at homes during 4 d. Before the experiments started, non-biodegradable residues were manually removed from BW. The SCB had 2 wk storage within a covered space while the SG was clipped a previous day before the experiment started and was stored until its use. All substrates (A, B, A´, B´, SCB, and SG) were manually triturated until reaching recommended particle size for the process (5-7 cm) (Agnew and Leonard, 2003). Before the piles were installed, all components were carefully mixed as homogeneous as was possible using the calculated ratios for each component.

Representative samples, 2 kg each one, of the above substrates were processed by following sampling quartering method described by Sakurai (2001) and sample preservation techniques (Sullivan and Miller, 2001). These samples were subjected to measurement of pH, moisture, ashes, total K, total P, and TOC variables by methods described in the Colombian Technical Norm (NTC) 5167 (Icontec, 2003). The N_{Total} was determined by technical norm NTC 370 (Icontec, 1997). Each analysis was carried out by duplicate and when any coefficient of variation was larger than 10%, the measurement was repeated again.

Experimental assembly and monitoring process

Once the materials were mixed, installation of the piles was performed by triplicate for each substrate (piles A´ × 3, A × 3, B´ × 3, and B × 3). The piles had 318 kg for experiment 1 and 258 kg for experiment 2. All piles were conic shaped, 0.6-0.8 m height, and were subjected to the same environmental conditions in a location protected with impermeable roof, flat floor, and 2 m of minimal distance between them. Both experiments were carried out through a completely random design to determine possible differences between products obtained from each treatment.

The recommendations made by Adhikari et al. (2008) and Kumar et al. (2010), parameters like temperature, pH, moisture, volatile solids (VS), electrical conductivity (EC), and germination indices (GI) were chosen as control variables. Temperature was daily measured at the centroid of each pile by using a 30 cm (0-100 °C) thermometer (Compost thermometer, Reotemp, San Diego, California, USA). For pH and moisture measurements, it was taken 200 g sample from each pile, proceeding from four opposite points and mixed together (Sullivan and Miller, 2001). The pH was potentiometrically measured to an aqueous extract obtained from a stirred mixture of the sample and distilled water (1:5 w/w) by using a pHmeter (WTW Model 315i, Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany). To measure water content, a moisture analyzer (Ohaus MB-35 Ohaus Corporation, Pine Brook, New Jersey, USA) was used. All measurements were performed daily during the first 4 wk, and then two times per week until the experiment was completed.

As recommended by Agnew and Leonard (2003), the moisture was kept up to 40% by moisturizing with water. The moisture and pile-weight values were used to determine water volume to be added. A uniform distribution of water was endeavored during the moisturizing process. A turning process was used when the piles reached temperatures of 65 °C or higher and to avoid compacting of the material. The fact that advisable changes in control variables are indicators that CP is in progress and such changes could affect significantly the quality of the obtained products (Li et al., 2013), a continuous monitoring of process was performed until piles reached temperatures nearby to the ambient (± 5 °C) and until the products acquired smell of soil. Both criteria indicated the end of maturation phase. Additionally, in maturation phase, self-heating tests were performed in order to verify if increasing of temperature would not occur during the process.

Quantification of VS was performed by calcination techniques at 550 °C by following recommendations of Ali et al. (2013). Thus, a representative sample of the material, removed from the process, was used to determine its weight at 105 °C during 24 h and at 550 °C during 4 h. The EC was measured through a potentiometric method by using a conductivimeter (model 325, WTW Wissenschaftlich-Technische Werkstätten GmbH, Weilheim, Germany). The GI was measured by determining the sensibility of the radish (*Raphanus sativus* L.) toward the obtained products and following the procedures established by Varnero et al. (2007). Assays to determine VS, EC, and GI, were performed by triplicate and mean values of each measurement for each pile were reported. The obtained information was used to make a descriptive analysis by relating control variables evolution, namely, temperature, pH, VS, GI, and EC with respect to starting substrates quality.

Product quality and statistical analyses

Once the process finished, representative samples for each pile were taken by following the procedure established by Sullivan and Miller (2001). Variables like K (K_2O) (performed by capillary electrophoresis, Standard Methods-SM 3112A), ashes, cation-exchange capacity (CEC), TOC, water holding capacity (WHC), BD, and moisture (according to the norm NTC 5167), EC, and pH (by potentiometric techniques) according to norm NTC 5167 (Icontec, 2003), N_{Total} (by Kjeldahl method) according to the norm NTC 370 (Icontec, 1997), and total P (P_2O_5) (P_{total}) (by spectrophotometry) according to the norm NTC 243 (Icontec, 2001) were measured by duplicate. Microbiologic assays (total coliforms [TC] and total fecal coliforms [TFC]) were performed according to the norm of United States Environmental Protection Agency (US-EPA, 1994). Quality parameters of obtained products were compared with the limit parameters established by the Colombian Norm for the Quality of the Composts – NTC 5167 (Icontec, 2003). In all cases, aleatorization tests were applied to determine if significant differences occurred (5% significance level) between quality parameters of the obtained products (piles A and B) against their corresponding controls A´ and B´. The data processing statistics were performed by using freely available programming software for data analysis and graphics R version 2.12.1 (R Development Core Team, 2008).

RESULTS AND DISCUSSION

Substrate characterization

Table 1 summarizes the initial physico-chemical characteristics of substrates (A, B), controls (A´, B´), as well as BM (SCB and SG) studied. The BW of the locality in study presented high content of uncooked FW (Oviedo-Ocaña et al., 2013). According to literature (Kumar et al., 2010; Li et al., 2013), this type of FW possess special physico-chemical properties such as, organic substances easy-to-degrade, high N_{total} content, and low C/N ratio. In consequence, similar data were obtained for our BW.

Starting BW's (controls A´ and B´) presented acidic pH in the range of 5.67 and 5.39, respectively, which could be associated with low molecular weight fatty acid generated, formed as anaerobic intermediates, during storing period of the BW at homes (Krogmann et al., 2010). This process could increase not only temperature up to thermophilic range (Sundberg et al., 2004) but also mesophilic phase duration (Li et al., 2013). Additionally, starting controls A´ and B´ showed high moisture content (70.8% and

Table 1. Physicochemical characterization of the substrates in experiments 1 and 2.

	Experiment 1			Experiment 2		
Parameters	Pile A´ (control)	SBC	Pile A	Pile B´ (control)	SG	Pile B
pH	5.67	5.12	5.57	5.39	8.30	6.12
Moisture, %	70.8 ± 5.88	41.0 ± 0.66	65.7 ± 1.90	78.99 ± 0.82	74.19 ± 0.32	72.46 ± 1.63
TOC, %	27.26 ± 1.50	43.56 ± 0.83	37.32 ± 2.00	25.94 ± 0.02	40.72 ± 1.17	25.85 ± 0.93
N_{Total}, %	1.27 ± 0.00	0.47 ± 0.00	1.17 ± 0.02	1.08 ± 0.02	1.53 ± 0.04	1.48 ± 0.02
C/N	21.5	91.8	32.0	24.0	26.6	17.5
Ashes, %	34.38 ± 1.03	7.07 ± 0.24	21.87 ± 0.09	31.00 ± 0.90	13.26 ± 0.20	35.54 ± 0.14
K_{Total}, %	1.06 ± 0.01	0.11 ± 0.01	1.33 ± 0.02	1.75 ± 0.03	1.60 ± 0.05	2.05 ± 0.10
P_{Total}, %	0.64 ± 0.05	0.64 ± 0.05	1.06 ± 0.09	0.21 ± 0.01	0.18 ± 0.00	0.59 ± 0.01

Average data ± standard deviation.
SBC: Sugarcane bagasse; SG: star grass; TOC: total organic C; N_{Total}: total N; K_{Total}: total K, P_{Total}: total P.

79.0% respectively) associated with FW (Adhikari et al., 2008; Li et al., 2013), which generally affect the porosity of the material, the oxygen diffusion and progress of the whole process (Krogmann et al., 2010).

Regarding to the TOC, controls A´ and B´ showed values comparable with those reported in other contexts (30.5% by Forster-Carneiro et al., 2008 and 37.8% by Tosun et al., 2008). The N_{Total} parameter had different values for each experiment, which could be associated with previous transformations during the handling and storing of residues before the piles were assembled. Controls A´ and B´ were characterized by an important content of K_{total} (1.06% and 1.75%, respectively), which should be associated with the high presence of plantain peels in them. On the other hand, P_{Total} content was limited (0.64% and 0.21%, respectively), associated with presence of vegetables and legumes as well as a low content of ashes (34.38% and 31.00%, respectively) were attributed to their low content of impurities.

The adding of SCB to the BW (substrate A) had a positive effect over the initiation step of process due to: (i) Moisture was reduced from 70.8% (control A´) to 65.7%, which falls within the recommended range for the initiation step of this type of processes (60%-70%) (Chiumenti et al., 2005); (ii) TOC value increased from 27.26% (Control A´) up to 37.32% as consequence of the high content of C present in this material (43.56%) (Iqbal et al., 2010), as well as (iii) the increasing of C/N ratio from 21.5 (control A´) up to 32.0, which also is nearly to that recommended for the initiation step of this type of processes (25-30) (Agnew and Leonard, 2003). On the other hand, the SCB did not affect the overall pH of substrate A (5.57), due to similar values between control A´ and the SCB (5.67 *vs.* 5.12, respectively). However its addition effectively generated a dilution of the N_{Total} by comparing the control A´ (1.27) with the substrate A (1.17), due to the low content of this element in SCB (0.47), which coincide with data reported elsewhere (0.35% to 0.45%) (Meunchang et al., 2005; Satisha and Devarajan, 2007).

Similarly, adding of SG to the BW (substrate B) had also a positive effect over the pH (it was increased from 5.39 for control B´ to 6.12 for substrate B) in agreement with previous reports which recommend the adding of BM´s to improve the starting pH and hence the CP at all (Smårs et al., 2002). Although SG showed a similar moisture value as substrate B (74.19% and 72.46%, respectively), its presence in substrate B should have increased porosity and aeration of this material, due to its fibrous characteristics (Dormond et al., 1998). In spite that SG had a high TOC value (40.72%) it did not improve TOC value for substrate B (25.85%) respect to its control B´ (25.94%). This finding is in agreement with previous reports Oviedo-Ocaña et al. (2013). Regarding to the N content, the SG reduced the C/N ratio in substrate B (17.47) respect to its control B´ (24.02), but such value is comparable with (19.6) obtained by Kumar et al. (2010), from a substrate formed by a mixture of FW and raked leaves and grass clippings, which resulted completely useful for CP.

Temperature analysis

Figures 1 and 2 represent temperature evolution of piles for the experiments 1 and 2, respectively. In general, this parameter showed similar values in piles for each substrate (A´, A, B´, and B). Except for piles A, in the remaining cases it was observed a typical temperature evolution for a CP, with sequential phases (mesophilic < 45 °C, thermophilic > 45 °C, cooling < 45 °C, and maturation room temperature) (Chiumenti et al., 2005). It was observed that for the control piles (A´ and B´) the thermophilic temperatures were reached about 2 d after they were prepared, however, in cases were BM were used (substrates A and B), this temperature took just 1 d. This finding demonstrates a positive effect of adding BM for the CP of this kind of BW in agreement with previous reports (Francou et al., 2008; Kumar et al., 2010). Lowering of the overall time is a direct consequence of the BM facilitating the operation and monitoring of the CP.

The relative fast increasing of temperature up to thermophilic values in all substrates (A´, A, B´, and B) could be related with transformation of easy-to-degrade fractions proceeding from FW like carbohydrates, proteins and amino acids present in the them (Krogmann et al., 2010). Lower required time to reach thermophilic temperature in piles using BM (A and B) should be associated with better processing conditions like nearly neutral pH (with SG) and major porosity of the material, both improving environment for microbial metabolism (Gajalakshmi and Abbasi, 2008).

In general, piles with BM (A and B) reached faster their maximum temperatures (2-3 d) and had minor lasting of thermophilic phase (9-19 d) than their control piles (A´ and B´) (11-18 d for maximum temperature and 19-25 d for lasting) (Figures 1 and 2). Nevertheless the above differences, in all piles (A´, B´, A, and B) hygienization conditions were reached satisfactorily with thermophilic temperature duration up to 4 d, according to Haug (1993).

As is observed in Figures 1 and 2, control piles (A´ and B´) as well as piles B shows very similar temperature decaying graphics with pronounced decaying during days 20 to 50 for (A´ and B´) and days 15 to 65 for B, followed by extended decaying until their ending, in agreement with (Chiumenti et al., 2005; Gajalakshmi and Abbasi, 2008). In contrast, piles A did not follow a similar evolution presenting continuous temperature oscillations. This fact could be associated with presence of hard-to-degrade compounds in SCB, which slowed and then speeded up the process in an alternate form each time the process was submitted to operation (i.e. turning and moisturizing). After the experiments finished, control piles (A´ and B´) reached almost the ambient temperature while piles (A and B) reached 2 or 3 °C higher.

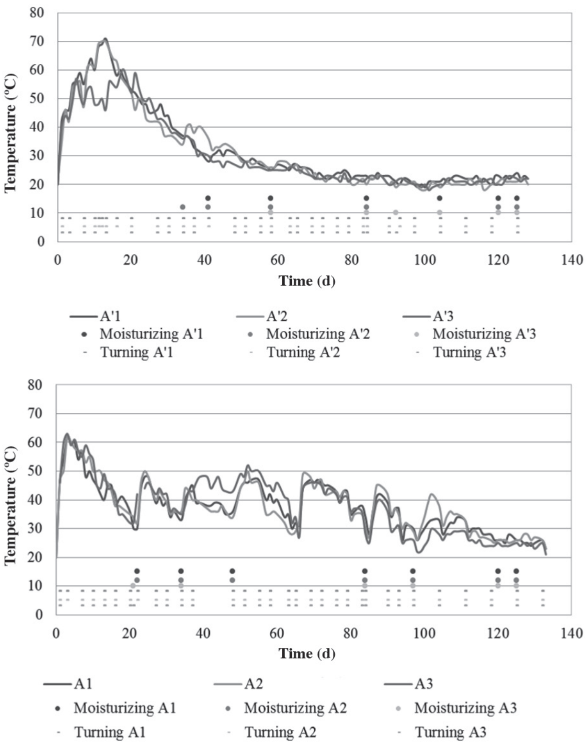


Figure 1. Temperature evolution in piles of the experiment 1.

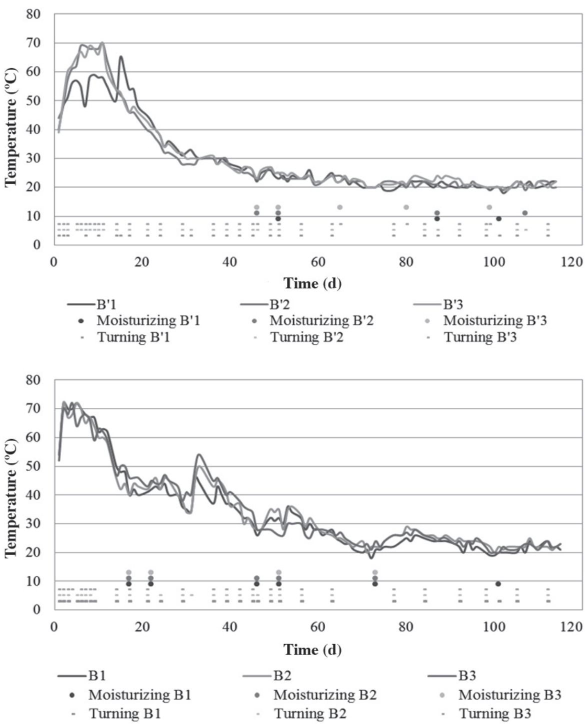


Figure 2. Temperature evolution in piles of the experiment 2.

pH Determination

Figures 3 and 4 show the evolution of the pH both in piles of the experiment 1 (piles A) and experiment 2 (piles B), respectively. Excepting for piles B, all substrates had initial acidic pH values, which could inhibit microorganisms growing as well as determine the relative reactions of some substrate components (Li et al., 2013). However, it was observed that this property was not limiting for processes progress because the easy-to-degrade fractions were fairly

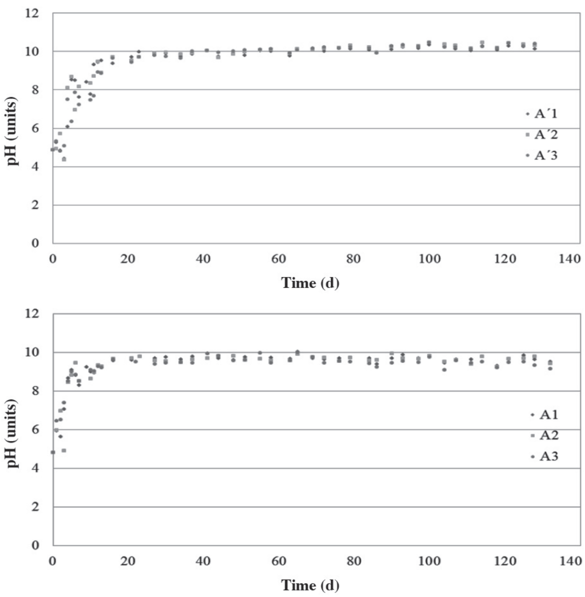


Figure 3. pH evolution in piles of the experiment 1.

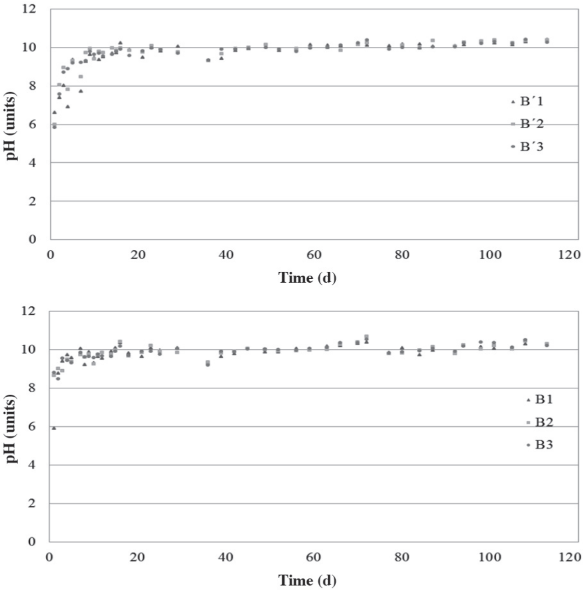
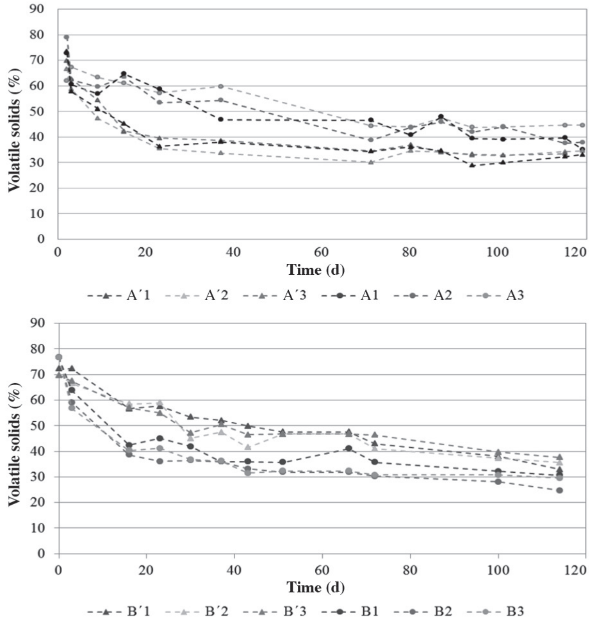


Figure 4. pH evolution in piles of the experiment 2.



Experiment 1: 78% Biowastes (BW) and 22% sugarcane bagasse; Experiment 2: 66% BW and 34% star grass.

Figure 5. Volatile solids (VS) evolution in piles of the experiments 1 and 2.

transformed under controlled conditions (i.e. controlling the aeration and compacting of the materials). Higher value of pH was observed in piles B and it is associated with SG presence, characterized by high basic content (pH = 8.3), which should contribute to reduce the formation of organic acids, typical by-products proceeding from the microbial decomposition of the organic materials (Smårs et al., 2002).

After 1st day (for piles B) and 4th day (for piles A, A´, and B´) alkaline values of pH were observed, which could be associated with the fact that organic acids formed normally are easily biodegraded and consumed by the microorganisms with the subsequent increasing of the pH (Sundberg and Jönsson, 2005). In the same way, the releasing of CO_2 during the aeration process of the experimental unities should not have allowed its accumulation into piles, avoiding subsequent formation of carbonic acid and derivatives (by action of the water and bacteria); in contrary case low pH would be observed (Haug, 1993).

After the processes finished, piles A´, B´, and B showed alkaline pH values in the range of 8-10. This finding could be associated with high (K^+) content in such substrates. This metal, in its water-soluble form, combined with ($HCO_3^=$) ion generated during the organic material mineralization step could form a strong base like KOH responsible of alkaline pH observed (Kalemelawa et al., 2012). In the case of piles A, lower pH values observed could be associated with initial acidic pH of the SCB.

Volatile solids

Figure 5 represents evolution of VS both in experiment 1 (piles A´ and A) and experiment 2 (piles B´ and B). Piles containing BM (A and B) showed higher content of VS, which should be associated with their higher TOC values (Table 1). Pronounced decaying of VS during the first 20 d (i.e. mesophilic and thermophilic phases) in all piles (A´, B´, A, and B) (Figure 5), could be associated to the fact that the easy-to-degrade organic materials are transformed by the microorganisms during the mesophilic and thermophilic phases of the process, releasing CO_2 generated by the microbial breathing (Haug, 1993).

Relative lower decaying slope observed for piles A respect to their control A´ during the first two phases of the process is associated with presence of hard-to-degrade materials like lignin (proceeding form the SCB), which protect the fibrous cells (cellulose and hemicellulose) of microbial attack (Haug, 1993), interestingly, the same evolution was not observed when comparing piles B´ with B (using SC as BM).

After the day 20 (cooling and maturation phases), it was observed a less pronounced slope of decaying of VS in all piles (A´, B´, A, and B), which could be associated with the decomposition of the medium- and hard-to-degrade materials present in the all substrates, as previously have been observed in other studies (Zhu, 2007). Regarding to the decreasing of the VS in experiments 1 and 2, it was observed that piles A´, A, B´, and B showed decreasing percentages of VS of 56.68% ± 1.81%, 47.18% ± 10.88%, 63.04% ± 4.07% and 49.81% ± 4.26%, respectively, by comparing the starting VS values with the final ones at the end of their processes. These relatively high decreasing percentages of VS reflect a significant progress in organic materials transformation in all experiments; although, the major decreasing percentages of VS were observed when the BM were not present (in control piles A´ and B´) (Figure 5).

Products quality

Table 2 shows results related to obtained products quality from each type of pile for each experiment. When comparing control piles A´ with its product A in experiment 1, it is observed that just 4 of 14 evaluated parameters (N_{Total}, C/N ratio, TC, and TFC) did not show significant differences between them (p-value > 0.05). The remaining 10 parameters were significantly different (p-value < 0.05) (Table 2). Regarding to experiment 2, by comparing control piles B´ with products B, significant differences were observed in 6 of 14 parameters (TOC, N_{Total}, ashes, P_{Total}, BD, and WHC). According to the above results, the adding of both BM (SCB and SG) effectively affected composition of starting BW (controls A´ and B´) having the SCB a higher effect than SG.

Both products (A´ and A) of the experiment 1, showed pH values that agrees with the NTC 5167 norm (Icontec, 2003), being the pH of products A the closest to neutrality (7.38). Contrary, for experiment 2, both products (B´ and B) had pH values higher (10.1 and 9.9, respectively) than the limit (9.0), which could restrict continuous applications of these products to alkaline soils (Pigozzo et al., 2006).

Regarding to the moisture, in both experiments the piles using BM required higher moisturizing to keep necessary moisture level for biological activity, than their control piles. Indeed, piles A employed an excess of 24% of water as well as piles B required a 32% of excess, comparing with their controls A´ and B´, respectively. Particularly, products of piles A´ and A had moisture values higher than the maximum recommended by the NTC 5167 norm (Icontec, 2003).

The adding of BM (SCB and SG) favored a major TOC content in both products making them to agree with the minimal value reported by the NTC 5167 norm (Icontec, 2003). This property helps to improve the quality of the product, a critical variable for the composting facilities in the zone of study. Additional to high TOC value, other parameters like high CEC, reduction of BD and increasing of WHC (Table 2), could to improve soils quality after application of these products. Indeed, for a major water and nutrient retention, physical properties improving and soils bacterial activity increasing could be observed (Aggelides and Londra, 2000).

Concerning to N_{Total}, although the main objective of BM is to supply structural support to mixture, the adding of SG also supplied N (N_{Total} value = 1.53% ± 0.04%), allowing products B to agree with the minimal value reported by the NTC 5167 norm (Icontec, 2003). In contrast, when SCB was added a lower N_{Total} value was observed for products A (0.90% ± 0.69%), if it is compared with the value for its starting control A´ (1.54% ± 0.51%); this fact could be associated with decreasing caused by the initial low N_{Total} content (0.47% ± 0.00%) found in BM (SCB).

The C/N ratio of a product should be in the range of 10-15 (Sullivan and Miller, 2001). This situation was observed for products of piles (control B´) (14.77). In the case of products of piles B the low value (9.67) is associated with the high N_{Total} content in SG, while for products of piles A the high C/N ratio is associated with low N_{Total} content and high TOC supplied by the SCB. Aggelides and Londra (2000) argue that use of high C/N ratio materials (like products A) are benefits for recovering and formation of soils, constituting them into an alternative of cover materials for erosion control, due to the their high lignin content, a precursor for humus formation in soils (Amalfitano et al., 2006).

It has been observed that products derivated from composting processes have P and K typical values in ranges of 0.4%-1.1% and 0.6%-1.7%, respectively (Herity, 2003). It is remarkable that in our study, both controls as well as products showed higher P and K values than the required which is in agreement with the NTC 5167 norm (Icontec, 2003).

Table 2. Quality of the obtained products in piles of the experiments 1 and 2.

	Experiment 1			Experiment 2			
Parameters	Pile A´	Pile A	p-value	Pile B´	Pile B	p-value	NTC 5167
pH	8.01 ± 0.13	7.38 ± 0.07	0	10.10 ± 0.28	9.90 ± 0.17	0.318	> 4 and < 9
Moisture, %	39.00 ± 0.87	49.47 ± 11.14	0	32.77 ± 5.62	34.50 ± 3.29	0.714	< 35
TOC, %	12.77 ± 1.97	17.77 ± 1.46	0	13.73 ± 0.40	18.87 ± 2.70	0	> 15
NTotal, %	1.54 ± 0.51	0.90 ± 0.69	0.092	0.90 ± 0.12	2.02 ± 0.50	0	> 1
C/N	9.43 ± 5.37	28.23 ± 18.79	0.122	14.77 ± 1.89	9.67 ± 3.13	0.098	-
Ashes, %	62.63 ± 1.93	57.23 ± 1.00	0	65.67 ± 2.28	61.03 ± 1.33	0	< 60
KTotal, %	3.78 ± 0.37	3.11 ± 0.40	0	3.23 ± 0.38	3.92 ± 0.13	0.293	> 1
PTotal, %	1.45 ± 0.17	1.04 ± 0.08	0	1.32 ± 0.06	1.26 ± 0.10	0	> 1
BD, g cm^{-3}	0.61 ± 0.03	0.44 ± 0.07	0	0.55 ± 0.07	0.34 ± 0.04	0	< 0.6
WHC, %	124.4 ± 7.1	168.83 ± 9.91	0	120.4 ± 6.9	165.6 ± 18.6	0	> 100
EC, dS m^{-1}	0.74 ± 0.23	0.43 ± 0.07	0	0.49 ± 0.07	0.49 ± 0.07	0.907	-
CEC, meq 100 g^{-1}	52.3 ± 0.9	56.2 ± 1.87	0	49.7 ± 1.56	50.0 ± 2.7	0.694	> 30
TFC, NMP g^{-1}	809.3	751.0	0.888	10.0	7.7	0.703	-
TC, NMP g^{-1}	17.0	23.0	0.814	0.0	0.0	0.903	-

Average data ± standard deviation.

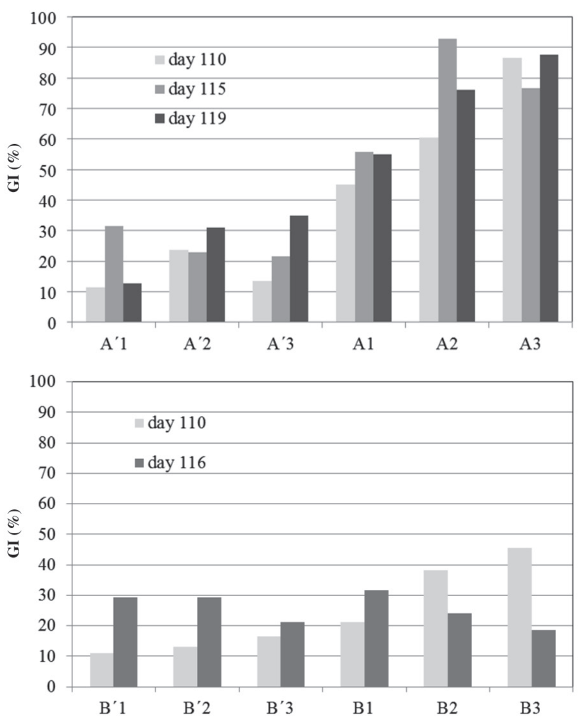
TOC: total organic C; N_{Total}: total N; K_{Total}: total K, P_{Total}: total P; BD: bulk density; WHC: water holding capacity; EC: electric conductivity; CEC: cation-exchange capacity; TFC: total fecal coliforms; TC: total coliforms; NTC 5167: Colombian Technical Norm (Icontec, 2003).

Experiment 1: 78% Biowastes (BW) and 22% sugarcane bagasse; Experiment 2: 66% BW and 34% star grass.

On the other hand, all piles showed low EC values in agreement with the ranges recommended by Getahun et al. (2012) (< 3 dS m^{-1}) for use in agriculture, permitting to suppose that salts content in form of chlorides and sulfates of Na or K would not affect plants growing if these products (A, A´, B´, B) are applied in soils.

Regarding to TC and TFC, it was observed that product of experiments 1 and 2 did not show significant differences between them. Despite that the NTC 5167 norm (Icontec, 2003) does not limit the TFC, the results shows a low content of them in controls (A´ and B´; 17 and 0, respectively) and products (A and B; 23 and 0, respectively) (Table 2), in agreement with the minimal indicated (lower than 1000) by norms like US-EPA (1994). Low content of TFC in both experiments 1 and 2, mainly in products of piles B´ and B indicate the effectiveness of hygienization processes of materials. This fact is associated with keeping thermophilic conditions during periods over than 15 d in all experimental unities.

Figure 6 describe GI values of the experimental units for experiment 1 (piles A´ and A) and experiment 2 (piles B´ and B). It was observed that piles A had high GI values (55%-87%) at the end of the experiments while piles B did not reach at least 50%, although they were higher than those for control piles B´. The high GI values for piles A could be associated to their low EC and almost neutral pH values found for these piles (Table 2), evidencing a minor presence of salts, and for instance, a minimal phytotoxic effect over plants growing (Ali et al., 2013).



Experiment 1: 78% Biowastes (BW) and 22% sugarcane bagasse; Experiment 2: 66% BW and 34% star grass.

Figure 6. Germination index (GI) evolution in piles of the experiments 1 and 2.

Finally, it is worth mention that in the remaining experimental unities (products of piles A´, B´, and B), it was reached high germination percentages (relative germination percentages [RGP] in range of 70%-100%) in all cases, although low roots growing (root growing percentages [rGP] in range of 17%-40%), which could be associated with a possible immature stage of such products (Varnero et al., 2007).

CONCLUSIONS

The effect of adding sugarcane bagasse and star grass as bulking materials over the process and obtained products quality from the composting process of municipal biowastes was evaluated. Bulking materials were effective for speeding up the degradation of the organic materials in starting step of composting process, reducing required time to achieve temperatures for thermophilic phase and lowering the lasting of mesophilic and thermophilic phases. Nevertheless, the presence of hard-to-degrade compounds, like lignin, in both BMs increased cooling and maturation phases duration. Additionally, the presence of these bulking materials improved obtained products quality, in terms of better total organic C, ashes, bulk density, water holding capability, and cation-exchange capacity parameters, permitting anticipate that applying of these products in soils could improve some of their critical properties like macronutrients, water retention, and microbial activity.

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