Implementation of strategies to optimize the co-composting of green waste and food waste in developing countries. A case study: Colombia

A. Hernández-Gómez[1,] *, D. Gordillo[1], F. Gómez[1], A. Calderón[1], C. Medina[1], V. Sanchez-Torres[2], E. R. Oviedo-Ocaña[1]

[1]Escuela de ingeniería civil, Universidad Industrial de Santander, Bucaramanga, Santander, 680002, Colombia
[2]Escuela de ingeniería química, Universidad Industrial de Santander, Bucaramanga, Santander, 680002, Colombia

* Corresponding author at: Escuela de ingeniería civil, Universidad Industrial de Santander, Bucaramanga, Santander, 680002, Colombia.
E-mail address: angelica2188255@correo.uis.edu.co (A. Hernández-Gómez)

1. Abstract

Green waste (GW) management constitutes a problem due to the high generation of waste, heterogeneity in its physicochemical characteristics and occupation of large volumes. The formulation of alternatives for GW management requires the knowledge of its production and physic composition. GW composting is usually used for its recycling. However, the presence of substances of difficult degradation such as lignin and cellulose prolongs composting time. The addition of processed (PF) and unprocessed (UF) foods improve GW degradation and compost quality. A case study was used to estimate the production and composition of the GW; technical standards were applied for the characterization and sampling process. The results show a production of 23.89 m^3 per week; the predominance of materials such as leaves, branches and soil; and a potential fraction for composting. Subsequently, the effectiveness of two optimization strategies was evaluated on a pilot scale: i) Addition of phosphate rock (PR) and ii) Two-stage composting (TSC). Three treatments were conducted: i) TA: (TSC + 15% PR); ii) TB (Traditional Composting-T + 15% PR); and iii) TC (T). The process was conducted for 90 days, where TA decreased the temperature in less time, while TC had a longer duration in the thermophilic phase; the TSC did not show significant differences compared to traditional composting, while the addition of PR increased the phosphorus content of the product. Regarding the quality of the product, it was observed that TC presented a higher level of compliance with standards for soil amendment in accordance with Colombian regulations.

Keywords: green waste, co-composting, phosphate rock, two-stage composting

2. Introduction

The management of solid waste constitutes a major challenge for cities [1]; a most waste is currently disposed in landfills, causing negative environmental and health impacts [1–3]. Municipal solid waste (MSW) consists in all waste produced by households, municipal parks and gardens, offices, public and local institutions [4]. Most of the MSW is constituted by organic waste (i.e. green waste (GW) and food waste (FW)) [5]; in developing countries organic waste constitutes more than 50% of MSW [6].

GW is composed of leaves, branches, flowers, bark of trees, soil, among other materials generated by park and garden maintenance activities [7–9]. Its management is complex because GW occupies large volumes, it is constantly generated, and contains substances of difficult degradation [10, 11]. One of the criteria to determine GW management alternatives is its physical composition; however, this information is generally not reported [10, 12].

Within the framework of new trends in waste management and circular economy, more countries adopt stricter policies to minimize municipal biodegradable waste sent to landfills [4]. Composting of GW is an alternative in agreement with these trends [13]; however, it has limitations regarding the processing time and quality of the product. Several strategies have been used to optimize composting of GW [14], which include: i) operational changes in the process; ii) changes in the oxygen supply; iii) pre-treatments; iv) addition of microbial inoculum; and v) co-composting with different supplementary materials (bulking or amendment).

The two-stage composting (TSC) is an optimization strategy that represents an operational change in the process, according to Zhang *et al.* [15], it has been demonstrated in several studies its benefits in terms of time reduction (i.e. between 73-90%) and product quality, thanks to the two temperature peaks generated by the confinement of the material. On the other hand, the addition of phosphate rock (PR) improved in product quality in terms of phosphorus content [10] and stimulates phosphate solubilizing bacteria. Additionally, others co-substrates obtained from MSW can be used to complement GW composting, such as waste of unprocessed food-UF and processed foods-PF. According to Oviedo-Ocaña *et al.* [2], previous studies show that addition of UF and PF in GW to composting processes improves the degradation rate and increases the amount of nitrogen, which is deficient in GW.

In this study, the physical composition of the GW generated in a case study (i.e. university campus) and its treatment through a co-composting process with UF and PF waste, implementing the TSC and the addition of PR as optimization strategies were evaluated. The research for options to improve GW composting can contribute to a greater implementation of this technology for the urban management of this waste.

3. Materials and Methods

The study was conducted at the central campus of the Universidad Industrial de Santander, located in the city of Bucaramanga (Colombia). Initially, an estimate of GW production on the campus and its physical composition was made, determining the net fraction that can be composted. Subsequently, a co-composting of GW, UF and PF was carried out at pilot scale, implementing the TSC and the addition of PR as complementary strategies.

3.1 Estimation of the production and physical composition of GW

The amount of GW generated on campus was made by adapting procedures related to the estimation and composition of MSW during a study period of eight weeks, applying tests according to Mexican standards: i) NMX-AA-19-1985 [16] for sample quartering and ii) NMX-AA-15-1985 [17] for bulk density. Since there are no standards that fit the classification categories for GW, the following categories will be used for the physical composition: leaves, flowers and fruits, roots, woody material, branches, grass clippings, wood residues, plastic waste, soil extract, others [14].

For the estimation of production, each of the discharges made by the collector truck during the study period were monitored, thus determining patterns of the volumetric amount of GW transported. The total capacity of the truck was 7.4 m^3 (3.7 x 2 x 1 m).

For the estimation of the physical composition, twelve tests were performed during the eight weeks studied. The material was homogenized, then using a volumetric mold of 0.222 m^3 and a balance, the material was weighed and then quartering techniques were applied until reaching a mass of 50 kg. Based on this sample, the GW types were selected according to the previously established classification. Finally, the amount of GW generated in the campus with potential to be transformed by composting was found.

3.2 Co-composting of GW, PF and UF using TSC and Traditional Composting (TC)

- **Experimental area, substrates and composting process**

The experiment was carried out in a pilot composting plant (7° 8' N, 73° 7' W) located at the Universidad Industrial de Santander (Colombia). The plant has an approximately area of 170 m^2 with impermeable roof and floor. GW was collected during a week on campus.; UF and PF were taken from the university dining room three days before the assembly; they were added as amend materials to provide nutrients and organic matter of rapid degradation, necessary for the adequate growth of microorganisms. Both PR and Sawdust (SW), were provided by suppliers of these materials located in the city. The PR was added as support and amend material, providing porosity and phosphorus, the amount added was considered taking into account previous studies [10, 18]. The S was added as a source of carbon and support material. The mixture of all the materials was defined from previous experiments developed at the University [2], trying to have an adequate C/N balance. The mixture consisted of 48% GW + 21% UF + 18% PF + 13% SW (i.e. wet weight).

Conical heaps were made using three treatments of equal composition, varying the process configuration and the addition of PR: i) Treatment A: (TSC + 15% PR); ii) Treatment B (Traditional Composting-T + 15% PR); and iii) Treatment C (T). Table 1 shows the physicochemical characteristics of each of the substrates used and the treatments conformed.

Table 1. Physicochemical characteristics of substrates and treatments

Treatment	pH	Moisture (%)	TOC (%C)	TON (%N)	Ash (%)	Potasium (% K_2O)	TP (% P_2O_5)	EC (mS/cm)	C/N
PR	-	-	-	-	98.28	0.14	5.73	-	-
GW	7.32	59.05	15.34	0.89	31.39	0.37	0.63	0.452	17.23
UF	6.57	86.42	12.44	0.50	1.53	5.08	0.96	1.508	24.89
PF	3.95	67.49	22.82	0.40	1.07	0.80	0.43	1.996	57.06
SW	6.10	11.21	23.64	0.42	3.84	0.28	4.09	0.211	56.29
TA,TB[a]	7.17	42.05	23.68	0.48	22.81	1.40	1.47	0.367	49.32
TC	7.23	60.46	24.41	0.77	11.72	0.38	0.59	0.509	31.70

TOC = Total Organic Carbon; TON = Total Organic Nitrogen; TP = Total Phosphorus; EC = Electrical Conductivity

[a] The characteristics of the whole mixture include PR

The TSC was carried out in the following way: i) in the first stage, wooden containers (0.55 x 1.3 x 1.25 m) were used to confine the mixture, the containers have holes of 5 cm in diameter to maintain the necessary aerobic conditions for the process. This stage ended when the first thermophilic phase was completed. ii) in the second stage, the material was removed from the containers and disposed in conical heaps, in this stage it is expected to obtain the second thermophilic phase and the completion of the process when the material reaches the room temperature [15]. During the process the material was removed from the containers on the eighth day to start the second stage of the process. Traditional composting was carried out disposing the material in conical heaps of 1 m height.

Each treatment was performed in triplicate with 200 kg of material during 90 days. To maintain the aeration of the piles, manual turning and humidification were applied weekly targeting 50 - 60% moisture content [19].

The temperature was monitored daily by inserting a digital thermometer in five characteristic points in the piles and three points in the case of the containers. Twice a week, pH, EC and moisture analysis were conducted. Finally, the stability of the product obtained was evaluated by germination index (Luo *et al.* [20]), and odor and color tests (Oviedo *et al.* [21]).

- **Physicochemical parameters**

In the composting samples, pH and EC were analyzed with a sample solution: distilled water at a radius of 1:10 (w/v) using a sensION ™ + MM374 pH meter. The moisture content was determined with an Ohaus MB-25 moisture meter. The total organic carbon (TOC) was determined by a titulometric technique and the total organic nitrogen (TON) by the Kjeldahl method.

- **Germination index analysis**

The germination index was determined by the methodology of Varnero *et al.* [22] using radish seeds. A fresh sample solution with distilled water was made at a radius of 1:5 (w/v), stirred, allowed to stand for 3 h and then filtered. 10 ml of extract were placed in 9 cm Petri dishes, containing 10 seeds of radish on filter paper. Distilled water was used as control. Finally, the plates were incubated at 25 °C in the dark for 3 days.

- **Statistical analysis**

All the experiments were carried out in triplicate. Data were subjected to ANOVA analysis of variance and the significantly different means were evaluated using Least Significant Difference (LSD) with the software R.

4. Results and Discussion

4.1 Total Production

4.1.1 Total Volume of GW generated

A total of 42 discharges were monitored during the eight-week study period, obtaining an average of five discharges weekly. According to the data obtained, it can be concluded that a total of 191.08 m^3 of GW was discharged on average during this period, corresponding to 4.78 m^3 of GW per day.

4.1.2 Bulk density

Due to the climate variations, bulk density values were obtained for wet and dry conditions. Fig. 1 shows the behavior of the bulk density where the peaks match with wet conditions and the lowest values with dry conditions. On average, the bulk density value obtained was 153.25 kg/m³, with a standard deviation of 37.48 kg/m³, and a coefficient of variation of 0.24. This average density is close to values reported by Epstein *et al.* [23] between 178 - 313 kg/m³ and Soobhany *et al.* [24] between 121-177.7 kg/m³ for grass cutting, dry leaves and small branches.

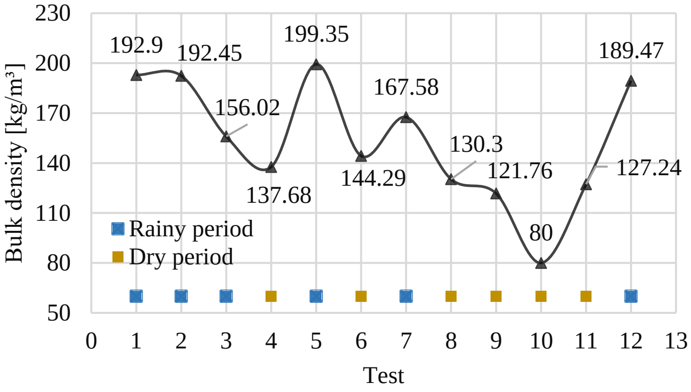


Fig. 1. Behavior of the bulk density

Additionally, a wet bulk density value was obtained taking the highest values, obtaining an average value of 182.96 kg/m³, with a standard deviation of 18.78 kg/m³, and a coefficient of variation of 0.10. On the other hand, the six lowest values were taken to find the dry bulk density, obtaining an average of 123.55 kg/m3 with a standard deviation of 25.36 kg/m3 and a coefficient of variation of 0.21; this average was influenced by maintenance and tree pruning activities carried out on the university campus, therefore, it is observed that these measures had high percentages of medium and large branches.

4.1.3 Estimation of the production of GW

With the obtained information, the estimation of GW production in the university campus was carried out. According to the total volume generated (i.e. 4.78 m³ per day) and an average bulk density of 153.25 kg/m³, estimated an approximate 732.5 kg daily (i.e. values calculated on five-day weeks). Based on the total area of green areas (i.e. 99,981.35 m²) of the university campus it is estimated a production of 73.25 kg/day per hectare of green areas.

4.2 Physical composition of GW

In each of the twelve tests the waste was classified, determining the global physic composition of GW. Overall results of the composition of GW are presented in Fig. 2. Additionally, in Fig. 3 are the results in dry period and rainy period.

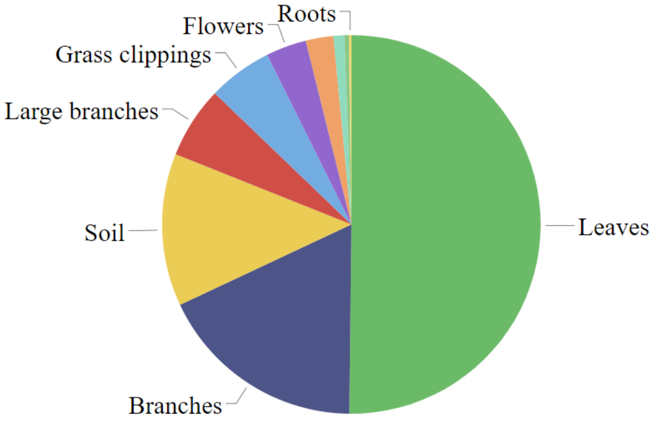
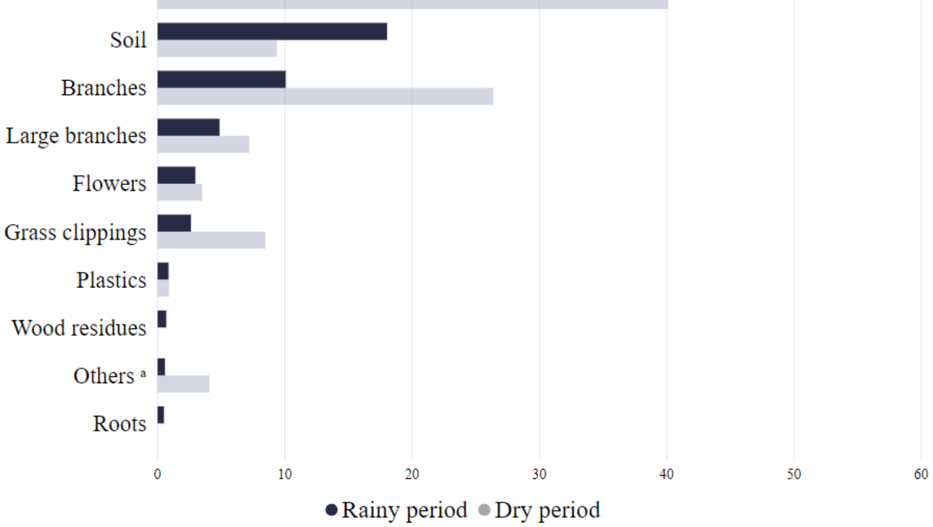


Fig. 2. Global composition of GW



[a] includes cloth, leather, glass, electronic waste, metal and paper.

Fig. 3. Physical Composition of GW in dry and rainy period

According to the results obtained, 74% can be used in GW composting processes. This percentage corresponds to the green fraction (i.e. leaves, branches and grass clippings); according to Reyes *et al.* [14], it is the most used in GW composting processes due to the brown fraction (i.e. woody material) could limit nitrogen mineralization producing an immature compost.

Whit the green fraction, a GW composting process was carried out using two-stage composting and the addition of phosphate rock as optimization strategies.

4.3 Physicochemical changes during the process

The behavior of the temperature indicates the rate of degradation of organic matter [25]. The increase in temperature occurred rapidly, for TA and TC was one day and two days for TB, probably starting the degradation of easily decomposable material from the fraction of UF and PF [26]; however, possibly it was faster in TA due to the confinement of the material, which could influence a greater distribution of the microbiological activity in all the material.

The thermophilic phase starts when the temperature exceeds 45°C [27–29], in this phase are carried out the decomposition and stabilization processes of the initial organic matter content [30]. According to Dulac [31], if thermophilic temperatures are maintained, the elimination of pathogens and parasites will be guaranteed. Additionally, if the temperature is maintained above 55°C for three days, the material will be free of pathogens and weeds [32, 33]. According to the aforementioned, in all treatments the temperature was maintained above 55°C for approximately 7 days, therefore, it can be stated that the material had an adequate sanitization. In Table 2, the maximum temperatures reached are observed, none of the treatments exceed 65 °C, which according to Imbeah [34], higher temperatures would cause the death of almost all microorganisms stopping the process.

Table 2. Summary of the behavior of temperatures

	Water addition (L)	Initial pH	Time when the thermophilic phase began (days)	Maximum temperature (°C)	Time required to obtain the maximum temperature (days)	Duration of the thermophilic phase (days)	Time required to reach RT±3°C (days)
TA	103.3	7.17	1	63,0 ± 1.452	6	24	62
TB	116.2	7.17	2	56.6 ± 1.013	8	25	62
TC	80.0	7.23	1	65.3 ± 1.914	8	30	62

In all treatments, it can be see a typical temperature behavior [35]. However, in terms of the TSC (configuration of TA), it was expected to obtain two temperature peaks according to the methodology described by Zhang *et al.* [15]; it is not possible to appreciate a significant increase in temperature values after day 8, when material was removed from the containers (Fig. 4). Nonetheless, throughout the process it is observed that TA after confinement, maintains lower temperatures than the others, it can be assumed that the confinement of the material helped to degrade in the first stages of the process. In addition, TA reached lower temperatures in less time (day 35); however, at the end of the process there are no significant differences in the degradation of the recalcitrant compounds in the maturation phase. Probably the TSC can be evidenced by providing greater aeration to the material in the first stage (confinement), since the temperatures reached in the first days were high and the manual turns were made every three days, which allows to affirm that containers holes were not enough to supply the oxygen needed in the biomass.

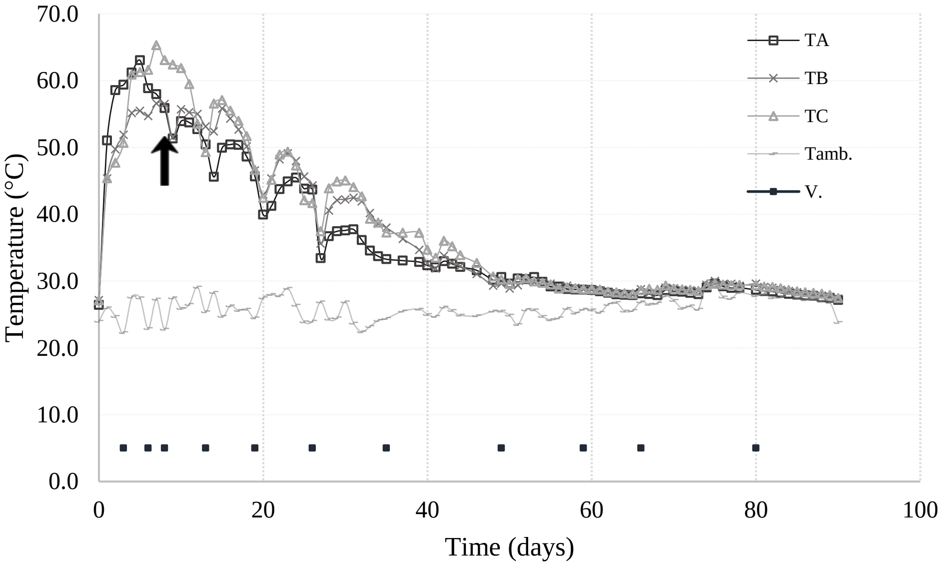


Fig. 4. Behavior of the temperature in all treatments

Additionally, it can be seen that TB did not present thermophilic temperatures as high as the other two treatments, being 56.6 ° C its maximum temperature. Probably an inhibition in the microbial activity as a result of the high added PR content; Sánchez *et al.* [36] argue that the addition of high levels of PR (> 20%), could be toxic to microorganisms, which decreases the rate of decomposition due to presence of traces of elements such as fluorine. Subsequently, the cooling phase begins where the degradation of more resistant polymers such as lignin and cellulose. Finally, the three treatments reached room temperature ± 3 ° C at 62 days, giving rise to the maturation phase where organic matter becomes more stable [37]

pH allow the growth of the microorganisms, bacteria growth in a pH range between 6.0-7.5 while the fungi can be found in a wider range between 5.5-8.0 [38]. TA and TB started with a pH value of 7.17 and TC with 7.23, which are close to the neutral value that are within the suggested range (i.e. 6 - 8) to start composition processes [29, 38]. During the process, there was an increase in the pH values in all treatments, however, in TC this increase was evidenced one day later than in the others (see Fig. 5). The generation of ammonia becomes significant in the rest of the active phase of composting, which causes the pH to remain in the weakly alkaline range [28]. The maximum values of pH were reported by TA and TB with 9.26 and 9.23 respectively, which can be related to the release of NH3 product from the decomposition of proteins and amino acids [27, 29, 39].

Bulk density is related to some parameters such as porosity, particle size and the biological decomposition that occurs during the process. In the composting of materials with high contents of lignin and cellulose, increments in this parameter usually occur due to the fibrous characteristics of these compounds [40]. Fig. 6**Error! Reference source not found.** shows that TA and TB are very similar during the process, differing only in the first days of the process, probably due to the confinement of the TA material. This similarity may be the result of the addition of PR, since these two treatments contained it as a unique difference with TC, which is remarkably different from the others. Also the low values of TC, can be attributed to that they did not have as much humectation as the other two treatments.

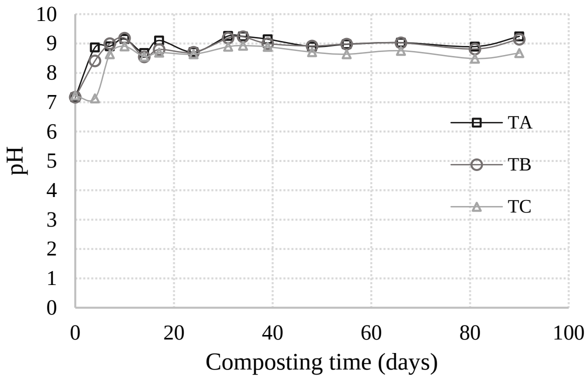


Fig. 5. pH evolution in all treatments

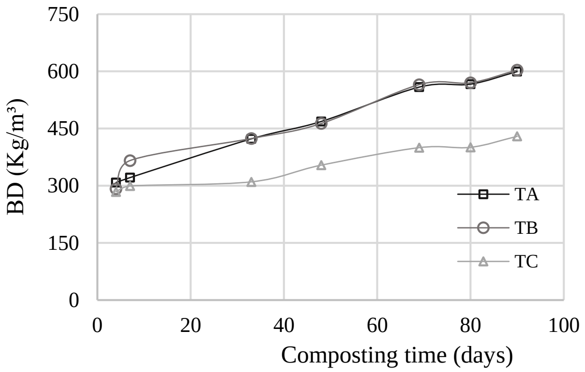


Fig. 6. BD evolution during the process

4.4 Quality of the product

In Table 3 it is observed the physicochemical parameters of the products obtained at the end of the process.

Table 3. Physicochemical parameters of the final compost

Treatment	Ash (%)	CEC (cmol/kg)	TOC (%)	EC (mS/cm)	WRC (%)	PT (%)
TA	74,87(4,04)a	22,00(1,48)b	16,63(6,60)a	0,20(0,15)a	153,73(11,38)b	6,56(1,14)a
TB	74,83(2,95)a	20,43(4,35)b	12,21(3,98)a	0,13(0,02)a	145,60(12,60)b	7,3it 3(0,04)a
TC	51,60(13,55)b	32,77(3,66)a	20,87(7,87)a	0,21(0,01)a	237,47(66,40)a	0,56(0,24)b
NTC 5167	< 60	>30	>15	-	>100	>1
NCh 2880	-	-	-	< 3	-	-

	Moisture (%)	TON (%)	pH	GI (%)	C/N	-
TA	30,37(1,81)ab	0,88(0,15)b	7,72(0,10)a	176a	20,00(11,00)	-
TB	27,97(2,14)b	0,73(0,03)b	7,80(0,04)a	163ab	16,57(4,74)	-
TC	33,87(3,56)a	1,37(0,15)a	7,51(0,07)b	102b	14,93(3,88	-
NTC 5167	<35	>1	>4 - <9	-	-	-
NCh 2880	30 - 45	> 0,5	5 - 8.5	> 80	< 25	-

Means in a column followed by the same letter are not significantly different at $p \leq 0.05$ by LSD

The ash content of TA and TB is significantly higher than in TC, which may indicate high degradation rates of OM in these treatments, because the PR helps to increase the degradation of the material due to the fact that the P provided it can be used as an energy source by the microorganisms [18]; this result is influenced by the addition of PR that has a high percentage of ash; additionally, according to Colombian regulations this parameter must be less than 60%, therefore, only TC complies with the stipulated.

According to the authors Zhang & Sun [18], PR can increase ICC values due to its negative charge, improving the water and the capacity of nutrient retention in the final product. However, an opposite pattern was observed in the products obtained, with better ICC presenting the treatment that did not contain PR. The content of phosphorus in TA and TB is highly influenced by the addition of PR, this allows to affirm that the addition of this substrate is useful to increase the availability of this nutrient, necessary for the growth of the plants; however, Vandeecasteele *et al.* [41] and Belyaeva *et al.* [42] suggest that the amount of phosphorus contained in organic fertilizers does not exceed the limits established for its application in order to prevent infiltration of this nutrient and contamination of groundwater. In addition, it is observed that co-composting of only GW and FW does not provide the necessary amounts and requested by the Colombian norm for organic fertilizers NTC 5167 [43]. Therefore, addition of PR is required, although in proportions lower than those added in this study. The EC reflects the salinity present in the compost, indicating possible phytotoxic effects [44]. In all treatments it is significantly the same and it is found low values due to the substrates used, complying with the Chilean norm Nch 2880 [45] and the recommendation of some authors [46].

GI allows detecting the presence of substances that may have inhibitory effects both on the germination of seeds and on the growth of certain plants [22]. GI of treatments containing PR is greater than GI of TC, possibly because mineral additives such as PR can increase the availability of nutrients in compost [47]; even so, all treatments are above of the recommended value [45] (i.e. 80%). C/N of all treatments decreased throughout the process, knowing the standards and indicating an acceptable degree of maturity [10, 21]. Although TON (%) increased after the process in all treatments, it was expected that in TA and TB these values would be higher because according to some authors [10, 18] PR absorbs NH_3 by minimizing its emission; however, the volatilization of NH_3 can be attributed to the lack of aeration in the initial phase of the process, possibly making it difficult for the process to be carried out.

In general, it is observed that TC complies with most of the conditions established by the Colombian [43] and Chilean [45] regulations, while TA and TB have some deficiencies that must be corrected by decreasing the percentage of addition of PR and improving the aeration conditions during the process.

5. Conclusions

The bulk density of GW varies considerably due to the typical climatic conditions of the context. In the institution of higher education UIS, the production of GW is about 732.5 kg per day, whereof 74% (i.e. leaves, branches and grass clippings) can be recycling by composting processes.

Regarding the composting process, TA and TB did not present significant differences ($p \leq 0.05$) in most of the evaluated parameters, which allows to affirm that the two-stage composting did not represent time optimization or improvements in the quality of the product. Furthermore, the PR achieved increasing the phosphorous content in the product; however, it is necessary to decrease the percentage of PR added, due to the fact that possible inhibitions of the process were presented due to the high content applied. The TC presented better results in terms of product quality; however, it still has deficiencies in phosphorus content.

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