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Production of organic compost from different plant waste generated in the management of a green urban space[1]

Produção de composto orgânico com diferentes resíduos vegetais gerados no manejo de área verde urbana

Carlos Henrique Corrêa da Silva[2]*, Fernanda Cipriano Rocha[3] and Lusimar Lamarte Gonzaga Galindo da Silva[2]

ABSTRACT - Plant waste generated in a properly treated arboretum promotes nutrient cycling, reducing the volume of the residue. The aim of this study was to evaluate the potential of plant waste generated in the management of the Botanical Gardens of Rio de Janeiro, Brazil, for the production of organic composts. An experiment was carried out over 110 days to compost leaves, shredded twigs and leaves, shredded twigs and leaves plus manure, blades of grass, and aquatic plants, to determine influence factors and the levels of N, P and K. The experimental design was completely randomised with five treatments and four replications. The manure had an influence on the decomposition of the shredded plant waste. The shredded waste plus manure, blades of grass and aquatic plants resulted in composts that were more stable as regards temperature, while the shredded waste and leaves required more time for the biomass to decompose. The grass and aquatic-plant material displayed higher levels of N and greater reductions in volume. The P and K content was maintained where losses occurred from leaching, due to the process being carried out in an open system.

Key words: Composting. Green waste. Nutrient cycling.

RESUMO - Resíduos vegetais gerados em espaços de arboretos tratados de forma adequada promovem a ciclagem de nutrientes reduzindo o volume de biomassa de resíduos. O objetivo deste trabalho foi avaliar o potencial dos resíduos vegetais gerados no manejo da área verde do Jardim Botânico do Rio de Janeiro para produção de compostos orgânicos. Durante 110 dias foi conduzido experimento de compostagem de folhas, galhos e folhas triturados, galhos e folhas triturados e esterco, folhas de grama e plantas aquáticas para determinação de fatores de influência e teores de N, P e K. O delineamento experimental utilizado foi o inteiramente casualizado com cinco tratamentos e quatro repetições. Houve influência do esterco sobre a decomposição dos resíduos vegetais triturados. O material triturado mais esterco, folhas de grama e plantas aquáticas resultaram em compostos mais estáveis quanto ao fator temperatura, enquanto o material triturado e de folhas necessitaram de maior tempo para decompor da biomassa. Materiais de folhas de grama e plantas aquáticas mostraram maiores teores de N e maiores reduções de volume. Observou-se manutenção dos teores de P e K, onde ocorreram perdas por lixiviação devido ao processo ser realizado em um sistema aberto.

Palavras-chave: Compostagem. Resíduos verdes. Ciclagem de nutrientes.

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*Author for correspondence
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[2]Instituto de Pesquisas Jardim Botânico do Rio de Janeiro/JBRJ, Rua Jardim Botânico, 1008, Rio de Janeiro-RJ, Brasil, 22.470-180, carlohjb@gmail.com, llggalindo@gmail.com
[3]Programa de Pós-Graduação em Engenharia de Biossistemas, Universidade Federal Fluminense/UFF, Rua Passo da Pátria, 156 - Bloco D, Sala 236, Niterói-RJ, Brasil, 24.210-240, fecipri@hotmail.com

INTRODUCTION

Anthropogenic activity has steadily increased the production of organic waste; this has become a major concern for society, especially in urban centres, where the model for economic development is based on unrestrained consumerism associated with waste. The fate of organic waste therefore demands solutions, to minimise or avoid negative impacts on the environment (PEIXOTO, 2011). Properly managed plant waste can have positive effects on agroecosystems, improving the parameters of soil quality (ALTIERI *et al*., 2012), in addition to removing pathogens and reducing the use of ecologically harmful products (ST. MARTIN, 2014).

Recycling waste through a process of composting imparts sustainability to the urban environment and meets the prime action of the National Solid Waste Policy (ALVAREZ; MOTA, 2012). According to Souza and Resende (2014), composting is the use of organic waste as raw material on matter that can be used in agriculture, transforming organic matter through the action of microorganisms.

Composting has been established as an efficient way of minimising environmental problems and reducing the volume of discarded solid organic waste (PEDROSA *et al*., 2013). Development of the composting process is directly related to factors that provide adequate conditions for the microbial biomass to develop and act in transforming the organic matter (VALENTE *et al*., 2009).

Temperature is an important factor and indicates the biological balance that reflects the efficiency of the process (FERNANDES; SILVA, 1999). Another indispensable factor is water, essential to the physiological needs and survival of organisms (KIEHL, 2004). The aeration factor provides oxygen for microbial activity, and removes carbon dioxide, water and heat (FERNANDES; SILVA, 1999). Microorganisms require carbon as a source of energy, and nitrogen for protein synthesis, in the right proportion for the correct process of decomposition (SOUZA; RESENDE, 2014). The decomposition of plant waste is an important variable in nutrient cycling, with the dynamics of this decomposition depending on the make-up of the plant material (TEIXEIRA *et al*., 2012). The main advantages of the technique of composting are a reduction in the mass and volume, and in pathogenic microorganisms, giving a final product with excellent fertilising characteristics (ORRICO JUNIOR, 2012).

The 54 hectares of the Botanical Gardens of Rio de Janeiro (JBRJ) include an arboretum with a living collection comprising around 9,000 specimens, with 1,500 species grouped in themed beds, alleys and other landscaping treatments, in addition to the species grown in greenhouses (JARDIM BOTÂNICO DO RIO DE JANEIRO, 2010). During conservation, about 500 m³ of green waste is generated monthly, 60% of which is destined for composting. Located within the urban centre, there is a lack of space for treating and disposing of the generated volume of plant biomass; this results in the high cost of contracting a company specialised in the collection, transport and final disposal of such waste. The aim of this study was to evaluate the potential of the different plant waste generated in the management of the Botanical Gardens of Rio de Janeiro, for the production of organic composts.

MATERIAL AND METHODS

The experiment was carried out between February and June of 2013, at the Botanical Gardens of Rio de Janeiro (JBRJ), in the city of Rio de Janeiro, Brazil. The climate, according to Köppen, is type Aw, characterised by a rainy season with heavy rainfall in the summer and a dry season in the winter, w ith an average annual rainfall of around 2,000 mm. The average annual temperature is 23.8 °C, with a maximum of 30.3 ºC registered in February and a minimum of 16 ºC in June (INSTITUTO NACIONAL DE METEOROLOGIA, 1990).

The experimental design was completely randomised with five treatments and four replications, using the green waste generated in the management of the arboretum of the Botanical Garden of Rio de Janeiro, and consisted of the following treatments: leaves; shredded branches; grass clippings; aquatic plants; and a mixture of shredded branches (85%) and (15%) rotten cattle manure, both materials naturally moist. The cattle manure was acquired commercially and had the following chemical composition: 7.6 $g.kg^{-1}$ N; 2.2 $g.kg^{-1}$ P; 20.35 $g.kg^{-1}$ K; C/N = 3.5 and a pH of 8.8), the aim being to provide a source of inoculant rich in nutrients and microorganisms. The shredded plant waste was obtained using a Menxon Charger 5.0 electric shredder, which reduced the material to particles of approximately 1.5 cm. The waste was selectively collected while still naturally moist, homogenised and packed according to treatment in cylindrical containers with a volume of 1 m³ (1.13 m Ø x 1 m H), made of wire screen lined internally with plastic nursery sheeting with a mesh of 1 cm^2. The containers were distributed in static piles over an area of compacted earth with a slope of 2%, in partial shade in the open air.

After filling the containers, water was added to homogenise the moisture in the treatments, as per the methodology described by Peixoto (2011). The samples were collected manually from the centre of each cell at three different times: the first was on the third day after constructing the piles, the second at 50 days and the third at 110 days. The collected material was packaged, identified, weighed and dried in a forced-ventilation oven at 65 °C for 72 hours, following the method described by Carmo (2000), and then sent to the Soil and Plant Tissue Analysis Laboratory to determine the levels of total nitrogen, phosphorus, potassium, organic carbon and pH. The concentrations of C and N were determined by the CHN method in an elemental analyser, and of the other elements by the method of acid digestion (SILVA, 1999). Following collection of the samples for laboratory analysis, they were weighed to determine the fresh weight. After drying, the dry matter was obtained, and the percentage of moisture calculated.

The density was measured using the self-compacting method, by filling a container of known volume and allowing this container to fall under its own weight from a height of 10 cm; the container was then weighed and the wet density calculated. The reduction in volume was measured by reducing the height occupied in the container and then calculating the remaining volume and percentage reduction. The temperature at the centre of the piles was measured on two alternate days each week using a digital penetration-probe thermometer; the ambient temperature and rainfall were also recorded, using data from weather station 16 of the National Meteorological Institute (INMET), located at 22°58’22” S and 43°13’26” W. The procedures followed the recommendations of Peixoto (2011) and Normative Instruction 17 of the Ministry of Agriculture, Brazil (2007).

The results were submitted to statistical analysis using the SISVAR® software developed by Ferreira (2011). This was followed by an analysis of variance, with the mean values submitted to Tukey’s test at 5% to evaluate the interaction between the treatments and periods. The collected temperature data were further adjusted by regression analysis, employing the linear and polynomial models with the highest coefficient of determination (R^2) and significance by F-test ($p>0.05$), using the graph tools of the Microsoft® Office Excel software (2007).

RESULTS AND DISCUSSION

The data showed significant variation ($p>0.05$) in the values obtained for biomass temperature in the different treatments as a function of time, with the rise and fall related to microbial activity. An interaction between periods was seen for density, moisture and volume reduction. In evaluating the pH, C to N ratio and levels of N, P and K for the different types of waste, significant variations were seen for the same period under study, except for the values of pH, P and K at 110 days, which did not differ significantly between treatments. There was also an interaction between the mean values obtained for any one variable in the periods under study. The shredded waste plus manure, blades of grass and aquatic plants reached temperatures of 53 °C, 43 °C and 58 °C respectively during the first three days, the thermophilic phase, when microorganisms that survive high temperatures are active and decomposition is at maximum, indicating biodegradability and full microbiological activity, with energy released in the form of heat. However, leaves and shredded plant material without the addition of manure used as inoculant, displayed lower initial temperatures (Figure 1).

Primo *et al*. (2010) emphasise the importance of temperature, especially with regard to the speed of biodegradation and the elimination of pathogens; it is in addition an indicator of biological action, reflecting the efficiency of this process. The microbiological activity seen in the waste can be explained by the cell structure of the material. While leaves and shredded waste have a cell structure formed over a longer period, composed of cellulose fibres, lignin, waxes and oils, the waste from grass and aquatic plants has cell walls that are thinner and less lignified, which facilitates the decomposition of less-complex carbohydrate structures by the microorganisms. In the treatments with shredded waste plus manure, grass clippings and aquatic plants, temperatures quickly reached the thermophilic phase, receding as the biomass matured to the mesophilic phase, when the temperatures are milder, and certain microorganisms survive to act on the initial breakdown of less-complex organic matter. Similar behaviour was seen by Heck (2013), Orrico Junior (2012) and Pedrosa *et al*. (2013), when analysing the temperature in a compost of plant waste. During the study period, leaf waste and shredded-material without the addition of manure recorded milder temperatures of between 23 °C and 38 °C in the mesophilic phase, when the recalcitrant characteristics of the waste may have limited an increase in microbial activity and consequently the high temperatures required to sanitise the compost (BRITO *et al*., 2014), which only occurs with implantation of the thermophilic microbial community able to degrade more complex molecules. The densities of the leaf waste and grass clippings in the initial period were the same, with values of 0.04 $g.cm^{-3}$, similar to the treatments with shredded waste plus manure, and aquatic plants, which had values of 26 and 22 $g.cm^{-3}$ respectively. However, the mean values between treatments for the density of the moist biomass were found to have increased 461%, from 0.13 $g.cm^{-3}$ in the initial period, to 0.60 $g.cm^{-3}$ at 110 days, with a significant variation ($p>0.05$) between periods (Figure 2A). This behaviour can be attributed to consumption of the carbon in the raw material by microorganisms during the biological activity, which results in an increase in humification. This consumption of biomass reduces the volume and aeration spaces due to microbial attack and the agglutination of particles, causing lodging and an increase in density. In studies on the physical parameters of composting, Ahn, Richard and Glanville (2008) concluded that increased density is associated with increases in the moisture and absorption capacity of the material.

Due to their nature and composition, the initial moisture content of the aquatic plants was 69%, differing (p>0.05) from the other treatments, which at 50 days increased from the initial levels of 16 to 31% to the higher values of 58 to 72% (Figure 2B). This increase may have been the result of water produced during the decomposition process, and considering the open system, of rainfall during the period, which compensated for any evaporated water (BRITO *et al*., 2014). At 110 days, the moisture content in all treatments was around 50%, equivalent to a semi-cured or biostabilised compost according to Kiehl (2004), and similar to levels seen by Brito *et al.* (2014) for the same period in composting plant waste.

With the aquatic plants, despite the high initial moisture, there was intense microbial activity at high temperatures, possibly due to oxygen penetrating into the aeration spaces. Ivan, Almir and Indira (2009), studying initial moisture in composting, found that a high water content can influence gas exchange, limiting its diffusion and restricting the use of oxygen by the microorganisms; they concluded however, that the initial mositure of 69% did not inhibit the start of the composting process, corroborating the results seen in the treatment with aquatic plants.

Figure 1 - Temperature variation (y axis) due to time (x axis) in the treatments with leaves (A), shredded waste (B), shredded waste with manure (C), grass clippings (D), aquatic plants (E) and the ambient temperature and rainfall (F). * - Significant by F-test (p>0.05)

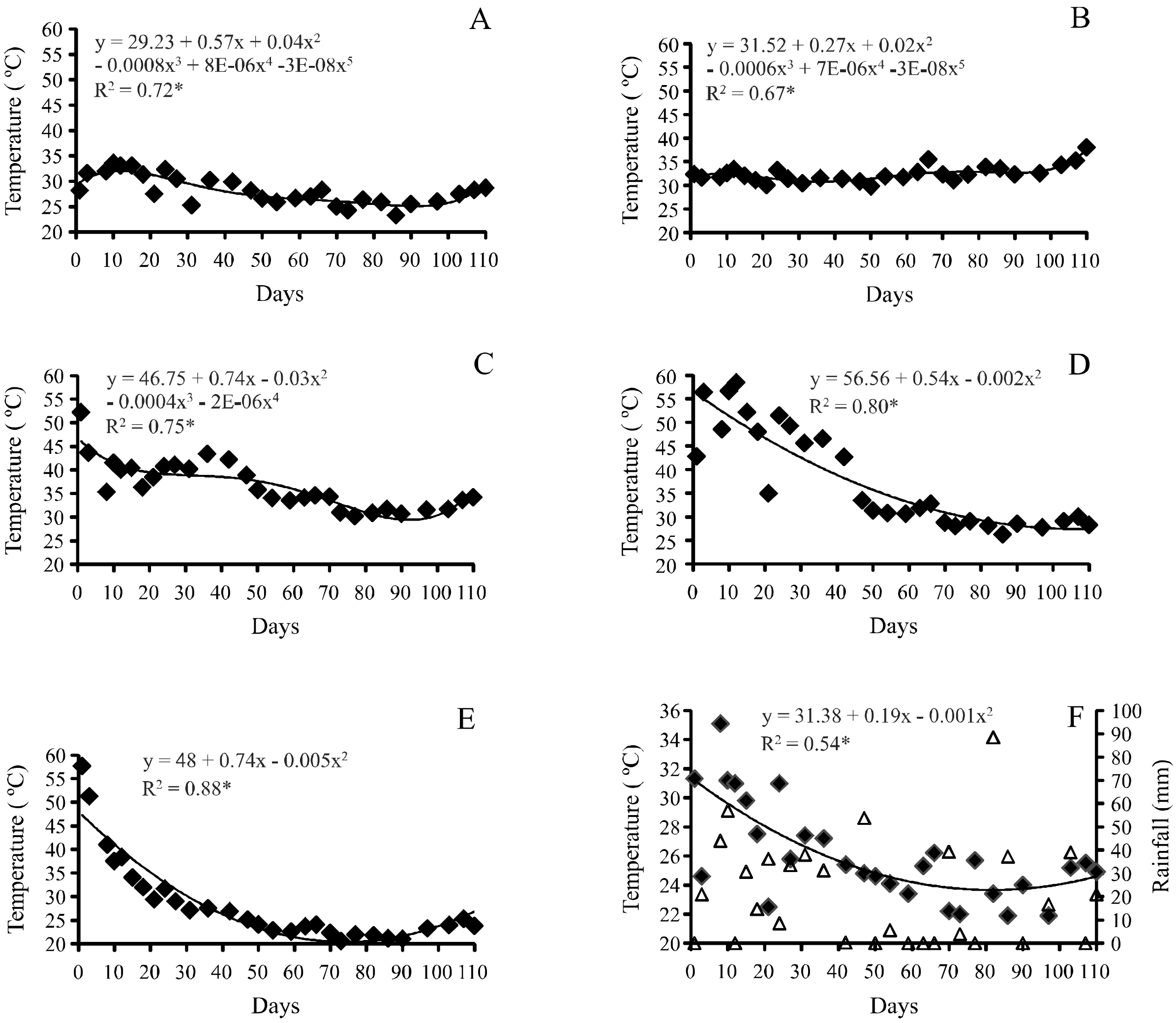
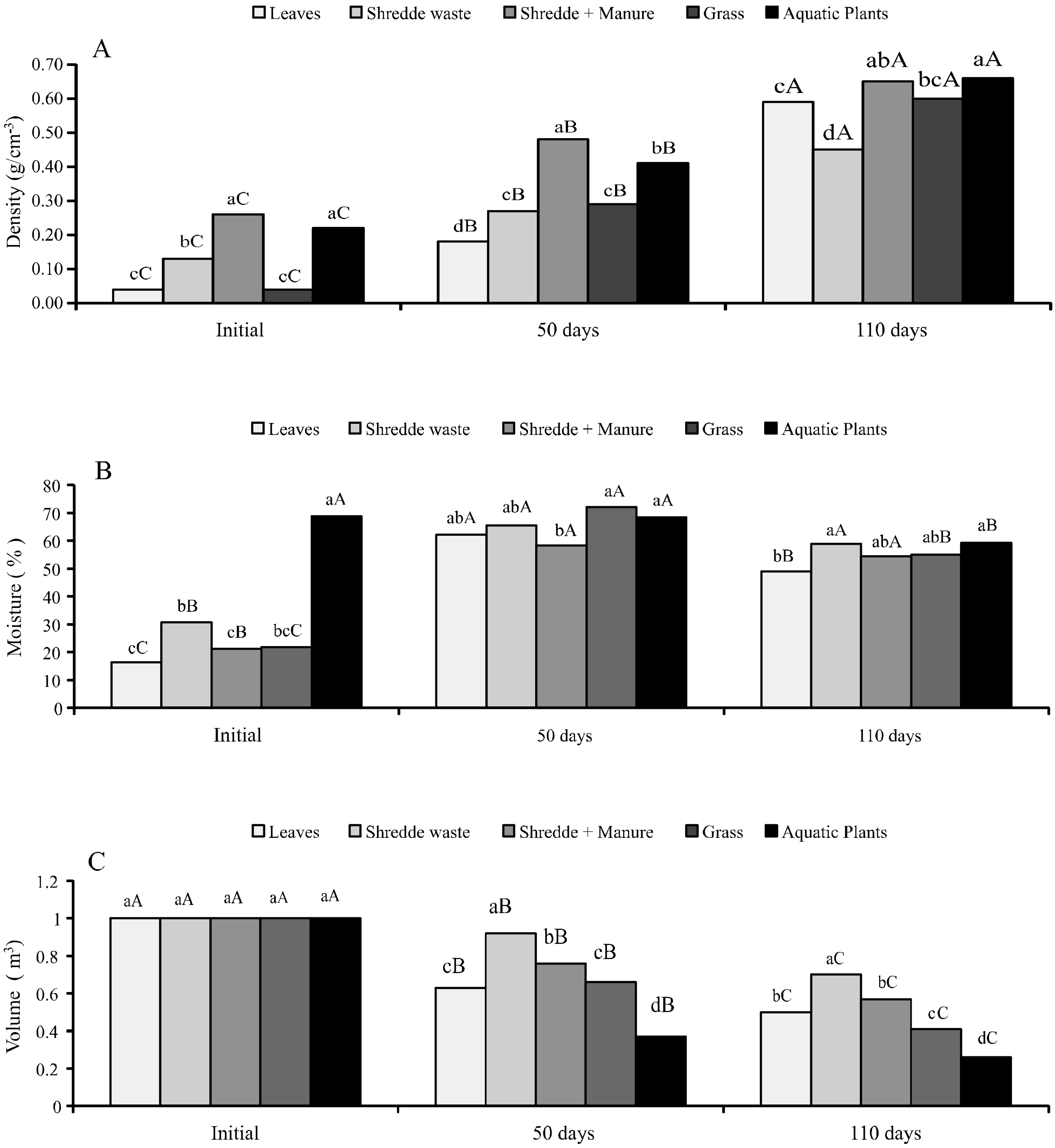


Figure 2 - Values per treatment for Density (A), Moisture (B) and Volume Reduction (C) in the initial period, and at 50 and 110 days



Mean values for the same period with the same lowercase letter do not differ, and mean values for different periods and the same treatment with the same uppercase letter do not differ by Tukey's test at 5%

Volume reductions in the treatments differed ($p>0.05$) for the periods under study, with the largest reductions of 60 and 75% seen in the treatments with grass clippings and aquatic plants respectively. The lowest reduction of 30% was seen in the treatment with shredded waste without the addition of manure, followed by the shredded treatment plus manure, with 43%, and the treatment with leaves, with a reduction of 45% (Figure 2C), consistent with the C to N ratio at 110 days. High levels of organic matter resistant to composting reduce the capacity of the microorganisms to oxidise the material, and consequently reduced the volume (SUNADA *et al*., 2015).

The pH and C to N ratio varied according to the type of waste (Table 1), with a significant effect ($p<0.05$) from the period being seen for each treatment. In the initial period, the plant waste from leaves, the shredded waste and the grass clippings had a slightly acidic pH with levels of 6.1, 6.5 and 5.9 respectively, differing significantly ($p<0.05$) from the shredded waste plus manure, where the pH was 7.4, and the aquatic-plant waste with a pH of 7.8, both levels slightly alkaline.

At 50 days, the waste showed a rise in pH, possibly due to the formation of organic compounds in the reaction with the bases released from the organic matter during decomposition, where the microbial attack in the organic waste promoted an increase in pH through the decarboxylation of organic anions that consume protons (PAVINATO; ROSOLEM, 2008). Whereas at 110 days, the pH levels underwent a reduction in relation to the levels at 50 days, differing (p <0.05) between the types of waste, but compatible with stabilised organic composts. Similar results were seen by Heck *et al*. (2013), investigating the composting process in household organic waste and green waste, and also by St. Martin *et al*. (2014), who reported a tendency for the pH to increase during the initial phase of composting, with a gradual reduction during the later phase. With a high C to N ratio of 49:1, the shredded plant waste differed significantly from the other waste in the initial period, however at 110 days, there was no significant difference in the C to N ratio between the treatments with different types of waste (Table 1). This can be attributed to an intense reduction in the organic C consumed by the microorganisms, resulting in the release of CO_2 during the process of microbial respiration, while maintaining the levels of N, which is a part of the cellular content of microorganisms, and consequently reducing the C to N ratio. Brito *et al*. (2014) investigated the shredded waste of *Acacia longifolia* (Andrews) Willd. mixed with pine bark (*P. pinaster*) at an initial C to N ratio of 56:1, and found a greater resistance to biodegradation due to the more woody characteristics. There is a tendency for a lower C to N ratio to favour the decomposition process

Table 1 - Mean values for pH, Carbon to Nitrogen Ratio (C:N), and levels of Nitrogen (N), Phosphorus (P) and Potassium (K) in the collected samples during composting, in the initial period, and at 50 and 110 days after constructing the piles

Initial period						
Treatment/Variable	Leaves	Shredded material	Shredded + manure	Grass clippings	Aquatic plants	Mean
pH water (1:2.5)	6.1 b	6.5 b	7.4 a	5.9 b	7.8 a	6.8 C
C:N Ratio	28.2 b	49.0 a	28.1 b	26.6 b	17.3 b	29.8 A
N (g kg^{-1})	7.7 b	6.5 b	8.8 b	12.6 a	13.6 a	9.9 B
P (g kg^{-1})	0.5 b	0.8 b	3.6 a	1.6 b	2.0 ab	1.7 A
K (g kg^{-1})	9.3 b	8.0 b	16.6 a	16.1 a	21.0 a	14.2 A
50 days						
Treatment/Variable	Leaves	Shredded material	Shredded + manure	Grass clippings	Aquatic plants	Mean
pH water (1:2.5)	7.5 b	7.4 b	8.3 a	7.4 b	8.6 a	7.8 A
C:N Ratio	32.1 b	62.9 a	22.3 bc	19.8 bc	13.5 c	30.1 A
N (g kg^{-1})	8.1 b	6.3 b	9.2 b	18.3 a	15.3 a	11.4 A
P (g kg^{-1})	NT	NT	NT	NT	NT	-
K (g kg^{-1})	5.9 ab	3.0 c	10.5 b	7.4 ab	19.3 a	9.2 B
110 days						
Treatment/Variable	Leaves	Shredded material	Shredded + manure	Grass clippings	Aquatic plants	Mean
pH water (1:2.5)	7.0 ab	7.3 ab	7.6 a	6.7 b	7.3 ab	7.2 B
C:N Ratio	27.7 a	28.6 a	18.9 a	18.6 a	16.0 a	21.8 B
N (g kg^{-1})	5.0 b	7.7 ab	7.9 ab	9.9 a	9.4 a	8.0 C
P (g kg^{-1})	0.8 a	0.7 a	0.8 a	0.6 a	0.7 a	0.7 B
K (g kg^{-1})	1.7 a	2.3 a	4.5 a	2.5 a	2.2 a	2.7 C

Mean values on the same line in each period followed by the same lowercase letter do not differ by Tukey's test ($p>0.05$). Mean values in different periods for the same variable followed by the same lowercase letter do not differ by Tukey's test ($p>0.05$). NT: not tested of plant waste (ALTIERI *et al*., 2012; TEIXEIRA *et al*., 2012).

The levels of N, P and K underwent a significant effect from the treatment x period interaction (Table 1). The blades of grass and aquatic plants displayed higher levels of N for the first two periods, tending to equalise in the final period, due to their similar physicochemical characteristics, with young tissue and less-complex carbohydrates resulting in faster stabilisation. However, they differed significantly from the other waste in the initial period and at 50 days, when they registered an increase in N content, the probable cause being the intensity of the process of N mineralisation and immobilisation in the microbial biomass, which was regulated by the C to N ratio (ACOSTA *et al*., 2014); whereas the loss of N at 110 days may have occurred due to the volume of organic matter consumed. Primo *et al*. supposed the reduction in N at the end of composting to be the result of the temperature during the process, volatilising N in the form of ammonia (BRITO *et al*., 2014) through the reaction: $N\text{-}NH_4^+ + OH^-$ (aqueous)$\rightarrow H_2O + N\text{-}NH_3$ (gas). In all treatments, a final N content of from 5.0 g kg^{-1} was seen in the biomass, in accordance with IN 25 of the Ministry of Agriculture, Brazil (2009), with losses of less than 40% of the initial levels. Leal *et al*. (2013) evaluated the process of composting waste with different initial C to N ratios, and found that the smaller the C to N ratio, the greater the loss of N relative to the initial value. Phosphorus levels differed significantly during the initial period, with the highest levels seen in the shredded waste plus manure, followed by aquatic plants (Table 1). The increase in P in the shredded waste plus manure was possibly caused by the inoculant source (PRIMO *et al*., 2010), with its origin in the digestive tract where a part of the ingested nutrients is excreted in the faeces and urine. At 110 days, there was no difference between the levels of P, which registered a reduction in concentration (Table 1). Reductions in the remaining P were also reported by Heinz *et al*. (2011) when studying the decomposition of plant waste. However, even with a reduction in the loss of P during the decomposition process, there is a rapid release of water-soluble P at the start of the decomposition period (HEINZ *et al*., 2011). Nevertheless, as a result of the death of the microbial mass, immobilised organic P may have been released and leached by the action of rainfall during the final period (Figure 1F).

In the initial period, the highest levels of K were seen in the shredded waste plus manure, blades of grass and aquatic plants, differing significantly from the leaves and shredded waste. The marked loss of K at 110 days is attributed to the dynamics of this element, which are influenced by the water regime, and is related to K not being a part of any organic structure or molecule; it is also found as a free or adsorbed cation, which, due to its high mobility, makes it easily exchangeable in cells or tissue (TORRES; PEREIRA, 2008). Heinz *et al*. (2011), evaluating the release of nutrients during the decomposition of crop waste under a no-till system, found that K presented a near-zero content in the final evaluation. In linear regression models adjusted to the data, Kolling *et al*. (2013) found signs of a positive correlation between potassium loss during the process of composting and different plant waste. Loss through leaching was favoured, as the experiment was conducted in the open air, and the accumulated rainfall during the second half of the experiment was 230 mm, with 88.4 mm occurring in only one day. According to Orrico Junior *et al*. (2012), the leaching of nutrients occurs mainly at the end of the composting process, when a great part of the nutrients is in soluble form, increasing the chance of loss.

CONCLUSIONS

1. The increase in the temperature, density and humidity of the plant waste under test was consistent with full microbiological activity, with the release of organic C and retention of N, resulting in a reduction in the C to N ratio, and producing a biostabilised organic compost;
2. Shredded waste mixed with manure at a proportion of 15% by volume, results in a reduction of 13% in the total volume of the mixture at 110 days composting, compared to shredded waste with no manure.
3. Grass clippings and aquatic plants yielded composts with a higher concentration of nitrogen, and a greater reduction in volume and the speed of stabilisation;
4. P and K loss due to leaching occurs in an open system where the piles have no protection from excessive rainfall.

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