



PHOSPHORUS AND HEAVY METAL CONTENTS IN SMALL-SCALE COMPOSTING AREAS



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ABSTRACT

Composting is an important tool for recycling and proper disposal of organic waste. However, in small-scale composting, where total soil sealing and leachate collection is not carried out, elements such as P, Cu, Zn, Cd, Cr, Ni and Pb may accumulate in soil. This study aimed to assess phosphorus and heavy metal contents in soils of areas used for small-scale food waste composting. In order to do this, we sampled soil depths of 0-5, 5-10, 10-20, 20-30

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and 30-40 cm of four areas with composting times of 16, 12, 7 and 1 year, in addition to four reference areas. All the study areas are located in the city of Florianópolis, Santa Catarina state, Brazil. We determined available P, Cu and Zn contents and total Cu, Zn, Cd, Cr, Ni and Pb contents in the soil samples. We found that the production of organic compost directly on the soil generally promoted increases in available P contents, which were above acceptable environmental limits, especially at the uppermost soil layers. Still, the presence of Cu, Zn, Cd, Cr, Ni and Pb was not an environmental liability in the composting areas, as the contents found were below those recommended by legislation.

1. INTRODUCTION

Waste production in urban areas has increased significantly in recent decades, with emphasis on food waste, either due to improper handling during processing or wastage in restaurants and households. A suitable alternative for these wastes is composting, which is a biological process of decomposition and stabilization of organic substrates under controlled thermophilic and aerobic conditions (Bernal, 2009; Cadis & Henkes, 2014). Composting promotes oxidation and, consequently, mineralization and partial humification of waste organic matter. This results in a stabilized, pathogen-free, non-toxic product to plants with important chemical properties such as high pH and significant nutrient contents, which can be used for soil conditioning and plant nutrition (Chowdhury et al., 2013; Martínez-Blanco et al., 2013).

There is typically leachate production during the composting process. The amount produced is dependent on the type of material used to make the compost, the size of the pile and the volume of precipitation on the compost pile. The leachate from the pile transports chemical elements from the composting material. The elements and their concentrations vary. P, Cu and Zn contents of 1.2 to 32.7, 0.3 to 3.0 and 1.0 to 5.0 mg L⁻¹ have been found in 100 to 800 L of leachate per m², obtained from piles with 460 kg of dry matter per m³, respectively (Christensen, 1984; Christensen & Tjell, 1984; Chatterjee et al., 2013).

In Brazil, in composting systems classified as small-scale (Brasil et al., 2017), piles are usually made directly on the soil and leachate from the compost pile is not collected. Furthermore, the soil under the pile is not fully sealed. When there is soil sealing, it is done with compacted clay, but it does not prevent leachate percolation into soil. This may result in the accumulation of nutrients and heavy metals in soil. In a literature review, Hargreaves et al. (2008) found an increase in available contents of P, Cu and Zn in soil with the addition of urban solid waste compost. However, these authors also highlighted the increase in total contents of Cd, Cr, Ni and Pb. Still, in a study with annual applications of municipal solid waste compost (40 and 80 t ha⁻¹) in a wheat-growing area for four years, Ayari et al. (2010) found increases in total Cu, Zn, Cd, Cr, Ni and Pb contents at a depth of 0-20 cm.

The increase in available or total contents of P, Cu, Zn, Cd, Cr, Ni and Pb in soil, as observed in several studies using organic sources (Ceretta et al., 2010a; Ayari et al., 2010; Guo & Li, 2012; Lourenzi et al., 2014; Couto et al., 2015ab, Lourenzi et al., 2016), may cause imbalances in the environment such as eutrophication resulting from increased P content in water (Smith et al., 2006). Also, the presence of high Cu, Zn, Ni, Cd, Cr and Pb contents may even result in phytotoxicity and hinder plant growth (Kopittke et al., 2010). In this sense, in a literature review on heavy metal phytotoxicity in plants, Kopittke et al. (2010) observed a general response behavior of plants to the presence of heavy metals in the solution. The degree of toxicity was as follows Pb>Cu>Cd>Ni≈Zn, with average toxic concentrations (in μM) of 0.30 (Pb); 2.0 (Cu); 5.0 (Cd); 19.0 (Ni) and 25.0 (Zn). Cu, Zn and Cr are considered essential elements for humans, while Cd, Ni and Pb are non-essential elements. However, all of these elements can cause toxicity in humans. Some symptoms of heavy metal poisoning are hyperglycemia and liver glucose (Cu); tissue injury and anemia (Zn); pneumonia, gastroenteritis, cardiomyopathy, and cancer (Cd); skin lesion, pulmonary edema, and lung cancer (Cr); neurological effects and lung cancer (Ni); nervous system disorders and intestinal irritation (Pb) (Kabata-Pendias & Mukherjee, 2007). Therefore, it is important to assess the contents of these elements in soil, as they can be absorbed by plants (Ji et al., 2018) or reach water sources (Rajeshkumar et al., 2018), and cause health problems to human beings.

Thus, this study aimed to assess phosphorus and heavy metal contents in soils of areas used for small-scale food waste composting in the city of Florianópolis, Santa Catarina state, Brazil.

2. MATERIAL AND METHODS

2.1. DESCRIPTION OF THE STUDY SITE AND COMPOSTING PROCESS

Eight areas located in the city of Florianópolis, state of Santa Catarina, Brazil, were selected for this study (Table 1). Four of which had a history of small-scale composting (Brasil, 2017) and four areas adjacent to the composting sites used as reference areas (Table 1). However, the composting and reference areas were not set up on natural soils of the region, but rather on landfill sites with soil from other regions or with mixed clayey soil and construction waste. Each area assessed in this study was prepared differently for the making of the compost piles. Areas 1C and 1R were prepared with construction waste (inert material) at deeper layers and material with higher sand content at surface layers. On the other hand, areas 2C and 2R were made up of construction waste and clayey soil. Areas 3C and 3R were located over a dumping ground set up in 1990. Area 3C contained material from construction waste and clayey soil, while 3R was composed of a landfill with soil from adjacent mangrove areas. Lastly, 4C was located in an area previously used for shrimp ponds, which was landfilled with construction waste and clayey soil, while 4R (similar to 3R) was composed of soil from adjacent mangrove areas.

Table 1: Selected areas, location, coordinates and composting time.

Area	Location	Coordinates	Composting time
1C	UFSC	27°35'50.35" S 48°30'55.12" W	12 years
1R	UFSC		Reference
2C	UFSC	27°34'43.20" S 48°30'19.34" W	16 years
2R	UFSC		Reference
3C	COMCAP	27°35'0.13" S 48°30'51.49" W	7 years
3R	COMCAP		Reference
4C	UFSC	27°35'6.20" S 48°30'32.29" W	1 year
4R	UFSC		Reference

UFSC: Universidade Federal de Santa Catarina; COMCAP: Companhia Melhoramentos da Capital; The letters "C" and "R" refer to composting and reference areas, respectively.

All the composting areas were outdoors, with no protection from precipitation and no leachate collection. The compost piles were built with food waste (material with low C/N ratio), including vegetables, fruits, grains, meat and processed products (cooked or fresh) from restaurants, cafeterias, supermarkets, etc., as well as shavings, sawdust or pruned material from urban trees (material with high C/N ratio).

Approximately 700 to 1000 tons of waste per year was added to the composting areas. The waste was arranged in piles of variable length, width of 1.5-2.0 m and height of 1.3-1.5 m when built manually, and 3.0 m wide and tall when built with the help of implements (Inácio & Miller, 2009; Maestri, 2010). Each pile holds approximately 1.33 tons of material per m³. As there is no set position within the area, each new pile was built at a different location, which means that the whole area had a compost pile on its surface at some point.

The composting method used was static piles with passive aeration, known as the UFSC method (Inácio & Miller, 2009). The piles are not turned, and they are built using at least 1/3 of structural material (material with high C/N ratio). Food waste was added to the piles 2 to 3 times a week, until the desired size was reached. Every time new material was added, it was mixed with the material from the upper part of the pile. The piles were built with a 30 to 50 cm layer of structural material (sawdust) followed by a 20 to 25 cm layer of food waste. A layer of grass clippings of approximately 25 cm was added to the sides and surface to protect the piles. The composting process lasted 90 to 180 days from building the piles until the final compost was obtained. This process was carried out similarly in all the composting areas. It is important to note that in areas 1C and 3C, the soil was scraped at a depth of around 10 cm when the compost pile was removed, and a new layer of soil was added to these areas prior to the installation of new piles.

2.2. SOIL COLLECTION

In January 2014 (areas 1C and 1R) and February 2015 (other areas), three trenches of approximately 30 x 30 x 40 cm were opened in each area with a shovel, and the soil was collected at depths of 0-5, 5-10, 10-20, 20-30 and 30-40 cm. Each trench represents a pseudo-replication of the collected area. After collection, the samples were taken to the Laboratório de Análise de Solo, Água e Tecidos Vegetais of the NEPEA-SC (Núcleo de Ensino, Pesquisa e Extensão em Agroecologia) of the Department of Rural Engineering of the Universidade Federal de Santa Catarina (UFSC). Samples were then dried in a forced-air oven at approximately 45°C, manually ground with a wooden rolling pin, passed through a 2 mm sieve and reserved for analysis.

2.3. PHYSICAL AND CHEMICAL ANALYSIS OF THE SOIL

In the soil samples, particle size analysis was performed according to the Pipette method (EMBRAPA, 1997), and the data is shown in Table 2. In addition, available P contents extracted by Mehlich 1 (Tedesco et al., 1995) were determined by colorimetry (Murphy & Riley, 1962). Available Cu and Zn contents extracted by 0.01 mol L⁻¹ EDTA (Chaignon et al., 2009) were determined by atomic absorption spectrophotometer (AAS). Pseudo-total contents of Cu, Zn, Cd, Cr, Ni and Pb were obtained from method 3050B proposed by the Environmental Protection Agency (EPA, 1996), which does not dissolve the elements that make up the mineral structure. To this end, we used 1.0 g of soil from each sample and then added 5 mL of concentrated HNO₃ in digestion tubes, which were placed in a digestion block at 95 °C for 10 min and cooled for 15 min. Then, 5 mL of HNO₃ was added and the tubes were again heated to 95 °C for two more hours. After this period, the samples were cooled for 3 min and 1 mL of distilled water and 1.5 mL of 30% H₂O₂ were added. After effervescence ceased, an additional 5 mL of H₂O₂ was added and the samples were reheated in a digestion block for 2 hours at 95 °C. Finally, the samples were cooled and 10 mL of concentrated HCl and 20 mL of distilled water were added and then heated for 15 min at 95 °C. The aliquots were cooled, filtered and volume adjusted to 50 mL. Cu and Zn contents in extracts were determined by AAS, and Cd, Cr, Ni and Pb contents in extracts were determined by atomic emission spectrometry (AES).

Table 2: Sand, silt and clay contents in soil of the composting areas and corresponding reference areas.

Depth, cm	Sand	Silt	Clay	Sand	Silt	Clay
	g kg ⁻¹			g kg ⁻¹		
	1C			1R		
0-5	805	80	113	651	188	159
5-10	626	155	218	736	167	96
10-20	575	211	213	741	159	99
20-30	591	244	164	638	216	145
30-40	597	179	223	726	117	155
	2C			2R		
0-5	593	193	212	495	246	258
5-10	599	191	209	334	316	349
10-20	619	174	205	225	327	447
20-30	570	206	222	174	433	392
30-40	590	205	204	170	390	438
	3C			3R		
0-5	695	128	175	505	203	291
5-10	638	151	210	469	241	288
10-20	574	208	217	424	279	296
20-30	681	134	183	464	277	257
30-40	654	177	168	549	259	191
	4C			4R		
0-5	482	189	327	638	189	171
5-10	428	211	359	570	238	191

10-20	403	206	390	615	199	185
20-30	495	264	239	693	184	121
30-40	498	57	443		715	150 134

The contaminant potential of Pin the composting areas was assessed through available P contents. In order to do this, we used parameters obtained by Gatiboni et al. (2015) in which the authors assessed the contaminant potential of P and established levels for the Environmental Critical Limit of P (ECL-P) in soil. The following equation was used: $ECL-P = 40 + \% \text{ of soil clay}$. Thus, the ECL-P of each area was established using the data obtained in the composting areas. Samples of the organic compost were characterized, and the values are shown in Table 3.

Table 3: Average chemical characteristics of the organic composts produced in the composting piles.

Parameter	Value	Parameter	Value
pH	8.9	Na, mg kg ⁻¹	532.0
Humidity, %	32.9	Cu, mg kg ⁻¹	28.4
TOC, %	31.7	Zn, mg kg ⁻¹	15.3
P, %	0.86	Cd, mg kg ⁻¹	0.44
K, %	0.9	Cr, mg kg ⁻¹	3.0
Ca, %	3.4	Ni, mg kg ⁻¹	1.3
Mg, %	0.4	Pb, mg kg ⁻¹	5.0

Values of total Cd, Cr, Ni and Pb in the compost were taken from Neto (2017).

2.4. STATISTICAL ANALYSIS

The data was submitted to analysis of variance (F-test, $p < 0.05$) after testing for homogeneity of variance. To compare the composting areas and corresponding reference areas, the data was evaluated by Student's t-test. The means of the depths were compared by the Scott-Knott test ($p < 0.05$) within each area. The variables available P (aP), available Cu (aCu), available Zn (aZn), total Cu (tCu), total Zn (tZn), total Cr (tCr) and total Pb (tPb) of all the areas and depths were subjected to Principal Component Analysis (PCA).

3. RESULTS AND DISCUSSION

Available P contents were higher in all the composting areas compared to their corresponding reference areas (Figure 1). The highest available P contents were found at the 0-5 cm layer. Contents found at this layer were 1200, 8900, 250 and 3400% higher in 1C, 2C, 3C and 4C compared to their reference areas, respectively. These results were expected as the literature supports that compost application to soil increases available P contents. In a study in which three soil types were incubated for 330 days with various sources of organic waste, Carmo et al. (2016) found that the application of 10.8 t ha⁻¹ of urban waste compost promoted an increase in soil available P content compared to the control treatment. In a study carried out in Ireland, Courtney & Mullen (2008) applied doses of 25, 50 and 100 t ha⁻¹ of spent mushroom compost and found an increase in soil available P contents at all doses. The increase in soil available P in the composting areas occurs mainly due to P present in the compost pile that reaches the soil profile, in addition to the presence of organic acids that compete with P for adsorption sites of soil colloids and favor lower P adsorption, increasing the available P content in soil solution (Pavinato & Rosolem, 2008).

When P is added to soil, it tends to accumulate at the surface layers, as it has great affinity with the soil colloids, especially with Fe and Al oxides, hydroxides and oxyhydroxides (Rheinheimer & Anghinoni, 2001). Natural P contents in soils are typically low. Thus, P added to soil is initially adsorbed to functional groups with an affinity for the element. However, after the saturation of these sites, P is adsorbed to the less avid sites and therefore with lower binding energy (Barrow et al., 1998). The saturation of the adsorption sites causes P content in the soil solution to increase and results in the migration of P to deeper layers of the soil profile (Lourenzi et al., 2013; Gatiboni et al., 2015).

High available P contents in soil (especially at surface layers) may cause P to be transferred to water sources. This occurs mainly by surface runoff, where soluble P and soil particles containing P are carried by erosion, but also

Phosphorus and Heavy Metal Contents in Small-Scale Composting Areas

by leaching in the profile (Ceretta et al., 2010b; Lourenzi et al., 2014). Therefore, it is important to understand the ability of soils to adsorb P to colloids without increasing P concentrations in soil solution. Applying the equation established by Gatiboni et al. (2015) for the composting areas, the ECL-P is 58, 61, 59 and 75 mg P dm⁻³ for 1C, 2C, 3C and 4C, respectively. Thus, contents in 1C and 3C at 0-5 cm (Figures 1a, 3c), in 4C up to 10 cm (Figure 1d) and in 2C at all layers (Figure 1b) were above the ECL-P (range 2), which means that these areas can be sources of environmental pollution to waterbodies. This is even more relevant in coastal areas, where the water table is usually near the soil surface.

Several factors influenced the increase in soil P content in the composting areas. Initially, the contact of the compost pile with the soil added readily available P and promoted the addition of organic P. With degradation of soil organic matter, organic P can be released in readily available forms to the soil (Vinhai-Freitas et al., 2010). Furthermore, percolated leachate from compost piles may contain total P contents ranging from 4.0 to 20.0 mg L⁻¹ (Mullane et al., 2015), adding significant amounts of P to soil. Another important factor for the increase in P contents (especially available P) is the increase of pH. As soil pH increases, there is a reduction in pH-dependent positive charges. Consequently, there is decreased P adsorption to colloids and increased concentration in soil solution (Sparks, 2003).

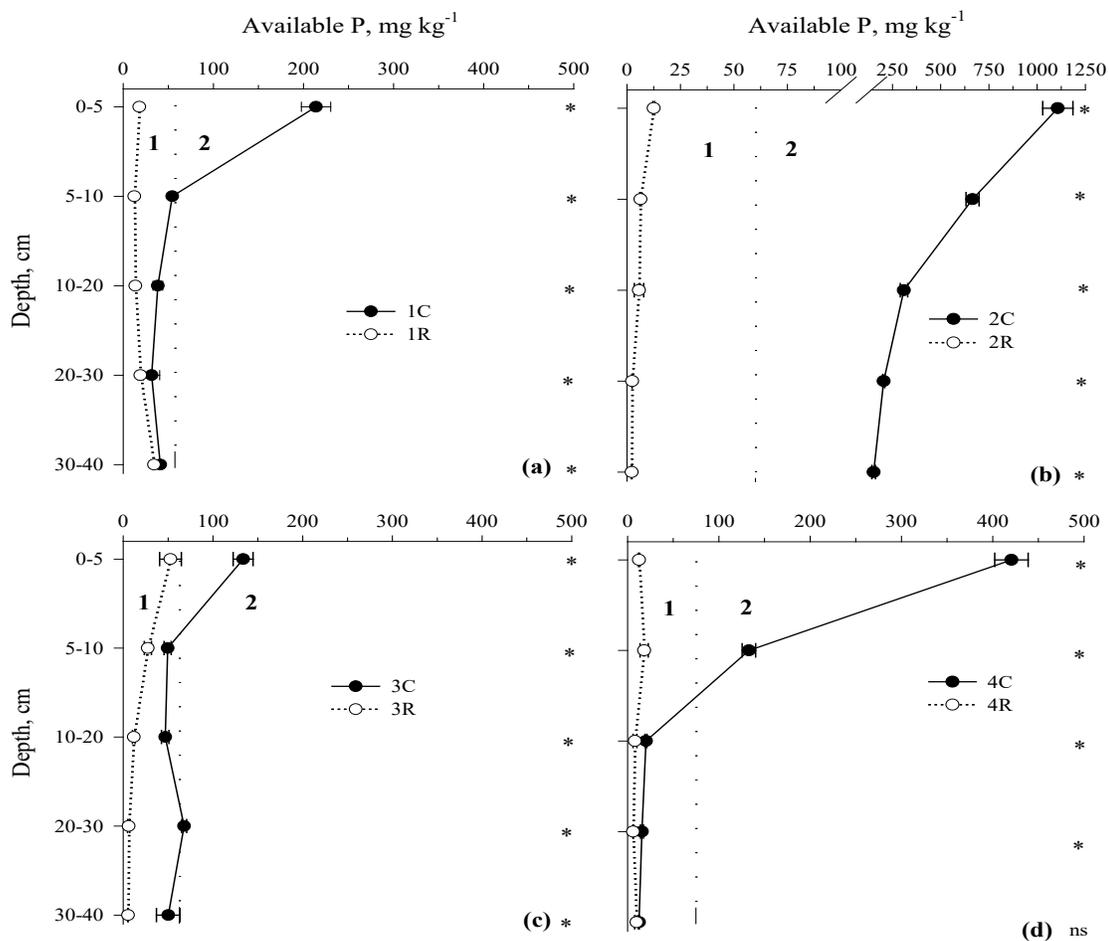


Figure 1: Available phosphorus contents in areas 1C and 1R (a), 2C and 2R (b), 3C and 3R (c), 4C and 4R (d). *Significant difference by Student's t-test at 5%; ns: not significant; 1: Range of soil used as a recycling medium for P; 2: Range of high environmental risk, P content above ECL-P; dashed line represents the ECL-P of each area.

Soil management in the composting areas also favored P increase. Area 2C had the highest P accumulation of all the areas as a result of composting time and because there was no soil scraping in this area. However, soil scraping influenced P accumulation. In comparing P contents of the soil layers of the areas, there were higher P contents in 4C than in 1C and 3C, which are areas with longer composting time and where soil scraping was used. This trend is

found up to a depth of 10 cm, after which the contents stabilized. This means that removing the 0-10 cm layer of topsoil along with the pile also removed the soil that retained most of P lost by the pile via leachate. Thus, the layer that remains after the removal of the pile had P contents below the ECL-P recommended for this soil. As P is an element with low profile mobility, this technique helps prevent uncovered soil (from which the pile was removed) from containing P contents that could cause environmental problems.

Available Cu contents were higher in composting areas than in reference areas, except for 2C, where contents were lower than 2R (Figure 2). In the composting areas, we only found the highest available Cu contents at the surface layer in 4C (Figure 2d), while the highest contents were found at deeper soil layers in the other areas (Figures 2a, 2b, 2c). In comparing total Cu, 1C had higher contents than the reference area at all layers, while 3C showed higher content only at 0-5 cm. Area 4C had similar content at 0-5 cm and higher content up to 20 cm, while 2C showed total Cu contents lower than 2R at all layers (Table 4). Available Zn contents in all composting areas were higher than those found in corresponding reference areas (Figure 3). Similar trend occurred for total Zn contents, except for 1C, which had lower total Zn contents in the reference area up to 10 cm (Table 5).

Total Cu values found in all composting areas, except at 20-30 cm in 1C, were lower than those recommended by CONAMA Resolution 420 (Brasil, 2009), which indicates prevention values for total Cu contents in soil of 60 mg kg⁻¹. This resolution uses USEPA method 3050B to determine existing contents in soil samples. Still, according to the same resolution, none of the areas reached the prevention value for Zn, which is 300 mg kg⁻¹ of total Zn in soil. Composting did not significantly influence Cu and Zn contents in the study areas, because of the low contents found in the compost (Table 3). These contents were lower than those found in other composts in literature (Cravo et al., 1998; Ayari et al., 2010; Lourenzi et al., 2016).

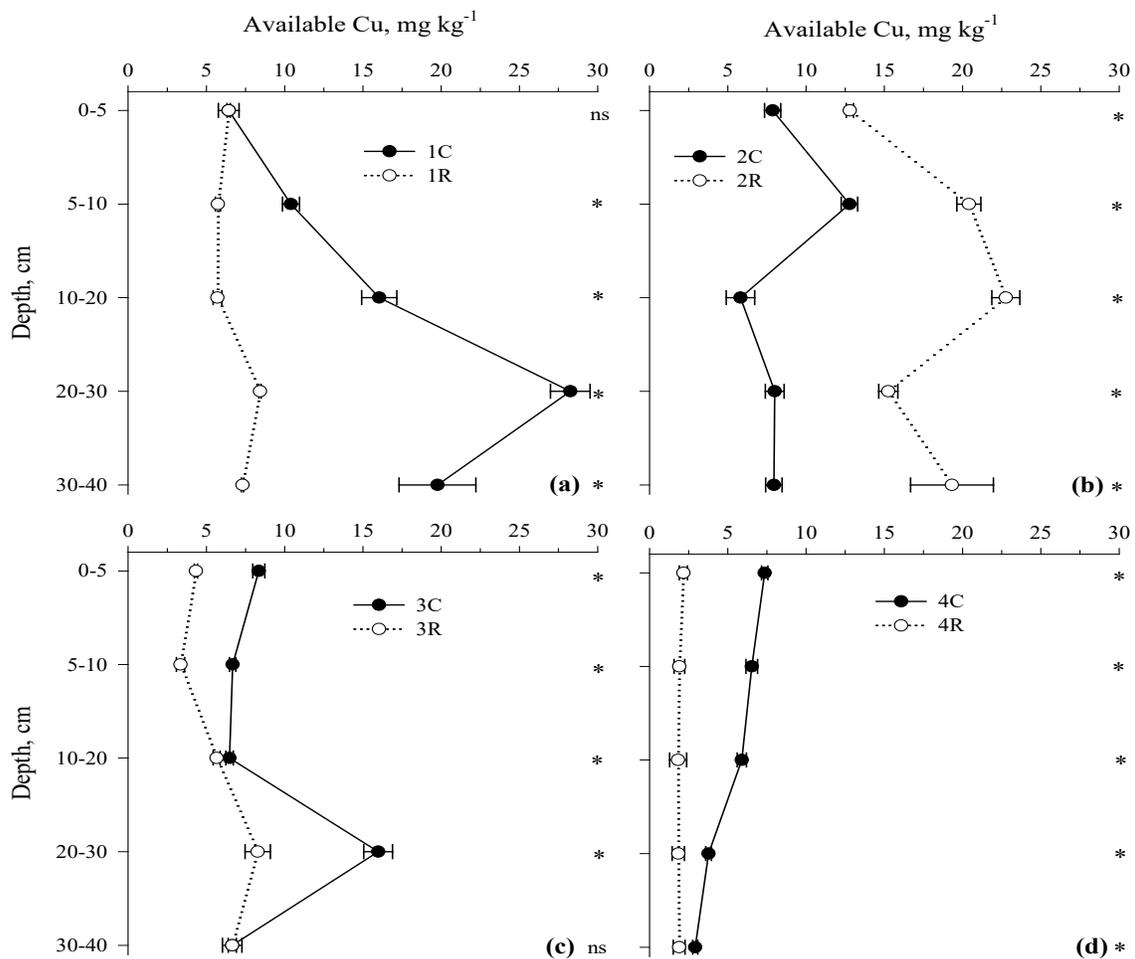


Figure 2: Available Cu contents in 1C and 1R (a), 2C and 2R (b), 3C and 3R (c), 4C and 4R (d). *Significant difference by Student's t-test at 5%; ns: not significant

Table 4: Total Cu contents in soils of the composting and reference areas.

Depth, cm	Total Cu, mg kg ⁻¹					
	1C	1R	CV, %	2C	2R	CV, %
0-5	12.1 c ¹ A ²	11.2 aA	8.39	15.6 aB	37.7 cA	13.50
5-10	15.8 bA	8.3 bB	2.21	13.7 aB	55.9 bA	10.35
10-20	30.3 aA	7.6 bB	6.28	13.5 aB	73.7 aA	5.91
CV, %	3.51	8.02		10.14	9.12	
Depth, cm	3C	3R	CV, %	4C	4R	CV, %
0-5	10.7 aA	6.3 bB	4.66	13.7 cA	5.0 aA	26.47
5-10	7.8 bA	6.7 bA	9.37	20.7 bA	4.6 aB	23.92
10-20	6.8 bB	33.7 aA	12.64	29.8 aA	4.3 aB	4.24
CV, %	13.04	3.85		17.76	16.44	

⁽¹⁾ Means followed by the same lowercase letter in the column show no significant differences by the Tukey test ($p < 0.05$);

⁽²⁾ Means followed by the same uppercase in the row do not show significant differences by Student's t-test ($p < 0.05$).

The presence of Cd and Ni in soils of the study areas was not detected. Total Cr contents in 3C and 4C were higher than those found in the reference areas (3R and 4R) at all layers. Cr contents in 1C were higher than in 1R starting at a depth of 5 cm, while contents in 2C were lower than those found in 2R (Table 6). All composting areas had higher total Pb contents compared to the reference areas at all layers, except for 1C, which presented contents lower than the reference area at 0-5 cm (Table 7).

Total Cr contents in the composting areas were below the prevention value described by CONAMA Resolution 420 of 2009 (Brazil, 2009), which is 75 mg kg⁻¹. However, total Pb contents in 3C and 4C were higher than the recommended prevention values (72 mg kg⁻¹) at all layers, and only at 10-20 cm and 5-10 cm in 1C and 2C, respectively. Prevention values indicate the maximum concentration of a given substance in soil in which the soil is still capable of carrying out its main functions, such as serving as a natural filter, as a means for food production, and maintaining the water and nutrient cycle (Brasil, 2009).

However, Pb contents found may be a result of other factors related to the material deposited in these areas for landfill and not by the compost itself. This is because Pb contents present in the compost produced in these areas are usually low (Neto, 2017) in comparison to those found in other composts in literature (Cravo et al., 1998; Ayari et al., 2010). Classes for construction waste are established by law (CONAMA, 2002). For instance, classes A (such as bricks, blocks, roof tiles) and B (metal, wood, plastic), which can be reused or recycled, are able to release Cr and Pb (De Lima et al., 2008). The use of this type of product mixed with clayey soil (as done in this study) may increase the amount of metals in soil as a result of the release by metals or other debris found in construction waste. Similarly, Baldi et al. (2010) found that there was no significant increase in Cd, Cr, Ni and Pb contents in soil with the application of different doses of domestic organic waste compost for five years.

The contents of these metals in the final compost are low due to the sorting of organic waste from the other wastes at source. By legislation, urban solid waste includes both organic fraction (e.g. food waste) and inorganic fraction (e.g. mixed dry waste) (Brasil, 2010). Depending on how rigorous sorting at source is, different percentages of contaminated wastes may be found in the material used for composting, increasing the contents of Cu, Zn, Cd, Cr, Ni, Pb in the final compost (Richard & Woodbury, 1992). In a study with compost samples of six Brazilian capitals with different selective collection systems, Cravo et al. (1998) found that Cu and Zn contents in Florianópolis, Rio de Janeiro and Brasilia were much lower than those found in the other capitals. The sorting of organic waste at source by the residents of Florianópolis began in 1986, and took greater proportions within the city with the implementation of the Beija-Flor Project in 1987. The low contents of heavy metals found by Cravo et al. (1998) prove the effectiveness of sorting organic waste at source.

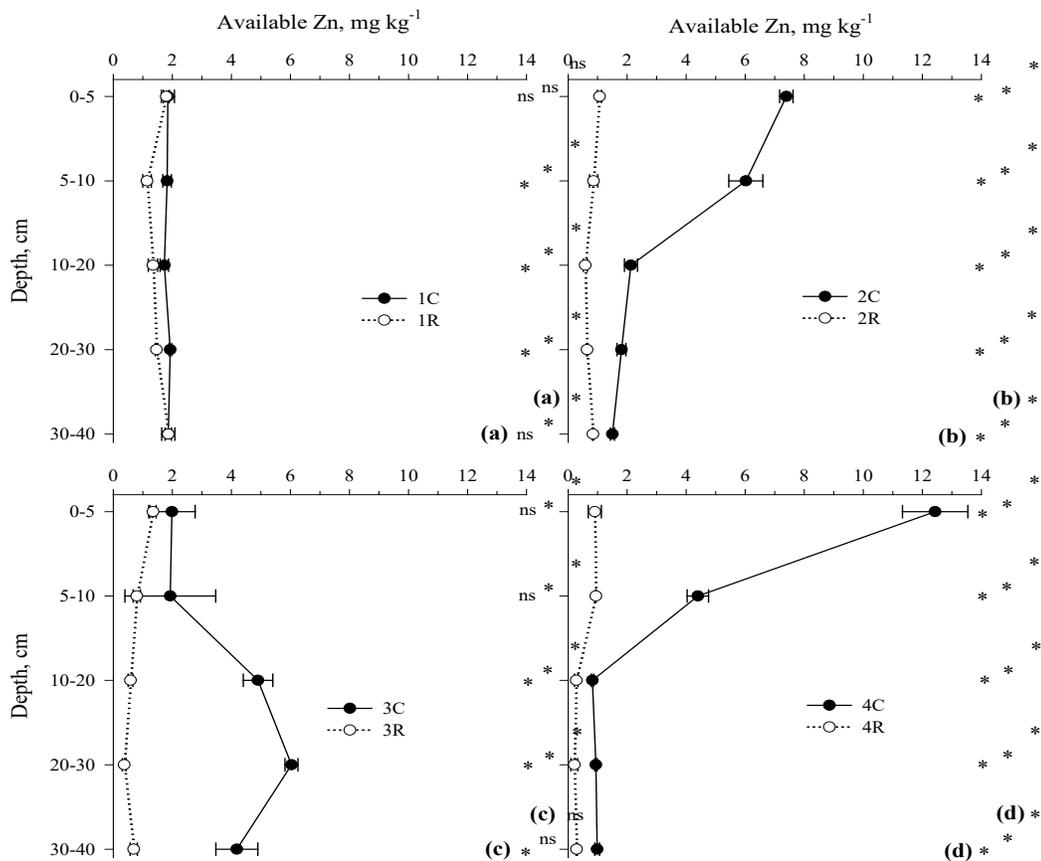


Figure 3: Available Zinc content in 1C and 1R (a), 2C and 2R (b), 3C and 3R (c), 4C and 4R (d). *Significant difference by Student's t-test at 5%; ns: not significant.

Table 5: Total Zn content in soils of the composting and reference areas.

Depth, Cm	Total Zn, mg kg ⁻¹					
	1C	1R	CV, %	2C	2R	CV, %
0-5	13.4 b ¹ B ²	17.9 aA	11.14	38.9 aA	17.7 aB	16.83
5-10	9.6 cB	15.1 bA	5.99	33.6 aA	18.0 aB	6.86
10-20	16.6 aA	13.1 bB	3.47	17.9 bA	17.9 aA	5.56
CV, %	6.53	10.19		15.15	4.14	
Depth, cm	3C	3R	CV, %	4C	4R	CV, %
0-5	90.7 aA	38.4 aB	1.37	38.9 aA	15.1 bB	2.88
5-10	55.6 cA	34.6 bB	6.13	32.1 bA	20.3 aB	6.48
10-20	77.7 bA	33.7 bB	2.25	32.1 bA	12.5 bB	8.16
CV, %	4.96	4.38		5.97	12.51	

⁽¹⁾ Means followed by the same lowercase letter in the column show no significant differences by the Tukey test ($p < 0.05$);
⁽²⁾ Means followed by the same uppercase letter in the row do not show significant differences by Student's t-test ($p < 0.05$).

Table 6: Total Cr contents in soils of the composting and reference areas.

Depth, cm	Total Cr, mg kg ⁻¹					
	1C	1R	CV, %	2C	2R	CV, %
0-5	0.0 c ¹ B ²	6.3 aA	0	24.7 aB	69.7 cA	3.84
5-10	8.5 bA	5.1 aA	13.03	16.2 bB	124.1 bA	11.40
10-20	17.7 aA	0.0 bB	6.80	11.1 cB	176.6 aA	5.72
CV, %	10.82	42.24		7.25	1.89	

Phosphorus and Heavy Metal Contents in Small-Scale Composting Areas

Depth, cm	3C	3R	CV, %	4C	4R	CV, %
0-5	13.8 bA	15.01 cB	18.17	35.3 aA	6.7 cB	7.64
5-10	20.1 aA	4.3 bB	13.11	38.6 aA	10.6 bB	3.16
10-20	8.20 cA	6.8 aA	28.06	37.0 aA	12.6 aB	3.52
CV, %	14.27	16.64		5.06	6.17	

⁽¹⁾ Means followed by the same lowercase letter in the column show no significant differences by the Tukey test ($p < 0.05$);

⁽²⁾ Means followed by the same uppercase letter in the row do not show significant differences by Student's t-test ($p < 0.05$).

Table 7: Total soil Pb contents in soils of the composting and reference areas.

Depth, cm	Total Pb, mg kg ⁻¹					
	1C	1R	CV, %	2C	2R	CV, %
0-5	15.0 c ¹ B ²	81.5 aA	14.48	55.7 aA	10.8 cB	27.26
5-10	71.3 bA	60.7 bB	8.77	77.6 aA	19.7 bB	0.51
10-20	82.6 aA	45.0 bB	6.36	63.6 aA	37.8 aB	9.36
CV, %	3.01	13.49		14.36	4.96	
Depth, cm	3C	3R	CV, %	4C	4R	CV, %
0-5	143.0 aA	62.7 aB	11.93	267.8 aA	88.77 bB	3.74
5-10	89.3 bA	68.0 aB	1.51	220.6 bA	175.2 aA	10.77
10-20	142.0 aA	66.1 aB	0.89	193.2 cA	79.5 bB	5.73
CV, %	8.28	12.08		3.27	3.73	

⁽¹⁾ Means followed by the same lowercase letter in the column show no significant differences by the Tukey test ($p < 0.05$);

⁽²⁾ Means followed by the same uppercase letter in the row do not show significant differences by Student's t-test ($p < 0.05$).

Principal component analysis grouped the variables into 5 components, which explain 97.19% of the variances (Table 8). PC1 explains 36.64% of the variances and consists of variables aCu5, aCu10, aCu20, aCu40, tCu5, tCu10, tCu20, tPb5, tPb10, tCr5, tCr10 and tCr20, with highly significant correlations, as all scores were ≥ 0.5 (Coelho, 2003). PC2 explains 23.86% of the variables and, together with CP1, explains 60.5%. This component consists of variables aP5, aP10, aP20, aP30, aP40, aCu5, aCu10, aZn10 and aZn20. PC3, PC4 and PC5 explain 18.53, 13.64 and 4.52% of the variances, respectively. PC3 is composed of variables aP5, aP10, aZn10, aZn20, aZn30, Zn40, tZn5 and tZn20, while PC4 is composed of aZn5, tPb5, tPb10, tPb20 and tCr5, and CP5 is composed of aCu30.

Through the ordering diagram constructed by PCA (Figure 4), it is possible to notice the formation of 3 distinct groups. One of which is composed by area 2C (related to variables aP), another consists of area 2R (related to variables aCu, tCu and tCr), and the other areas form a third distinct group (Figure 4). Thus, area 2C stood out from the others due to the high contents of available P, indicating that the area with the longest composting time without soil scraping differed from the other areas. The largest group consisting of areas 1C, 1R, 3C, 3R, 4C and 4R were similar in terms of all the variables assessed in the study. This indicates that the composting time of these areas combined with the use or not of the scraping process did not promote significant differences in the variables. This analysis shows that long-term composting in the same area without scraping the topsoil is more likely to accumulate high P contents in soil, increasing the chances of environmental problems. The metals assessed in this study, regardless of the composting time or the use of soil scraping, did not increase to levels considered problematic for the environment.

Table 8: Principal component analysis (PCA) of the variables assessed in soil of the composting and reference areas.

Variance Component	CP1	CP2	CP3	CP4	CP5
Eigenvalue	9.89	6.44	5.00	3.68	1.22
Variability (%)	36.64	23.86	18.52	13.64	4.52
% accumulated	36.64	60.50	79.03	92.67	97.19
Variable	Correlation with principal components				
aP5 ¹	-0.31	0.78*	-0.52*	-0.00	0.09
aP10	-0.29	0.76*	-0.54*	-0.12	-0.06
aP20	-0.28	0.78*	-0.45	-0.27	-0.09

4. CONCLUSION

The production of small-scale organic compost directly on the soil without weather protection and without soil sealing promoted changes in available P, Cu and Zn contents.

All the areas assessed in this study had P contents above the ECL-P in at least one of the layers, which indicates that composting can increase soil P above environmentally sound levels.

The presence of Cu, Zn, Cd, Cr, Ni and Pb did not represent an environmental liability in the composting areas. As the compost did not have high contents of these metals, soil contents were kept below the limits recommended by law.

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CONFLICT OF INTEREST

The author have declared that no competing interests exist.

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