Changes in Soil Acidity Attributes in Areas of Municipal Organic Waste Composting, Santa Catarina, Brazil[1]

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Abstract

Composting is an alternative for treating and recycling municipal solid waste. Composting directly on the soil changes the attributes related to soil acidity. The study aimed to evaluate the influence of municipal solid waste composting in a small scale system on the attributes related to the acidity of soils used for making compost piles. Soil samples were collected at depths of 0-5, 5-10, 10-20, 20-30 and 30-40 cm in four areas under composting (1C, 2C, 3C and 4C) and four adjacent reference areas with no history of composting (1R, 2R, 3R and 4R). The soil was submitted to evaluation of pH in water, total organic carbon (TOC), potential acidity (H+Al), aluminum saturation and base saturation. We found the composting in a small scale system with piles directly on the soil promoted the increase of soil pH values, TOC contents and base saturation up to 40 cm, regardless of the time of use. This shows the potential of the leachate to reduce acidity and aluminum saturation in the subsoil.

Key words: Chemical attributes, organic compost, leachate.

Introduction

A large amount of waste is generated in preparing and consuming food. One way to reuse these wastes, especially in urban areas, is via composting, which is a biological process of decomposition and stabilization of organic substrates (CADIS & HENKES, 2014). Composting produces the organic compost used for soil conditioning and plant nutrition (HARGREAVES et al., 2008; LOURENZI et al., 2016).

The production of leachate (percolated from the compost pile) occurs in municipal solid waste composting. The volume of leachate produced and its chemical characteristics are dependent on the type and diameter of the material used to make the compost, and how the compost pile and rainfall that reaches the compost pile are managed (Chatterjee et al., 2013). A suitable pile should be able to maintain the oxygen content to favor the development of aerobic microorganisms, which are responsible for the decomposition and

humification of organic material (INÁCIO & MILLER, 2009). Thus, the pile should have adequate size and internal structure to allow enough aeration and humidity for the aerobic decomposition process. Pile porosity, which is determined by the particle size of the materials, influences aeration and humidity. Porosity provides drainage of excess water and intake of air. Anaerobic conditions formed when aeration is below 10% and humidity above 65% negatively influence the composting process, in addition to changing the characteristics of the leachate, forming a percolate with acidic pH, known in Brazilian legislation as compost slurry (BILGILI et al., 2007, BRASIL, 2017). The production of compost slurry is a major problem of composting under inadequate conditions, because it lowers soil pH and favors the availability of metals such as Al and Pb, which are toxic to plants.

In small scale composting, the piles are placed directly on the soil, without waterproofing. Aerobic decomposition generates a percolate with pH between 7.0 and 8.0 called leachate (BRASIL, 2017). As CO_2 generated by the decomposition of the organic material is released, there is an increase in the pH of the compost and leachate (SINGH & KALAMDHAD, 2013). Also, studies have found K, Ca and MG concentrations of 40-2000, 70-1100 and 10-400 mg L^{-1} in leachate, respectively (INÁCIO & MILLER, 2009; CHATTERJEE et al., 2013). These concentrations vary in soil, reducing aluminum saturation and increasing base saturation. This favors the use of the area for crops after composting or the use of the topsoil, which can be removed with the compost, as it contains elements leached from the pile.

Composting sites in urban regions are typically located in areas where soils no longer have original characteristics due to human activity (PEDRON et al., 2004; LADEIRA et al., 2012). In fact, the change in urban soils caused by the addition of materials that are not derived from the process of pedogenesis is reported in the literature, and easily observed in practice (LADEIRA et al., 2012). These soils are altered because of the different functions they exert in urban environments, such as support for green areas (parks and gardens), urban agriculture, construction, and waste disposal (PEDRON et al., 2004). Therefore, this study is important because it evaluates the effects of composting in urban areas on soils transformed by human activity (PEDRON et al., 2004; LADEIRA et al., 2012).

The aim of this study was to evaluate the influence of municipal solid waste composting in a small scale system on the attributes related to the acidity of soils used for making compost piles.

Material and Methods

Soil samples were collected in four composting areas/sites located in the city of Florianópolis, Santa Catarina State, Brazil. Soils sampled in the composting sites (C) under piles in a small scale system (BRAZIL, 2017) were 1C, 2C, 3C and 4C. These sites were installed 12, 16, 7 and 1 year(s) ago, respectively. Soils sampled from an area adjacent to the composting sites were used as reference (R - 1R, 2R, 3R and 4R). The locations of the areas are as follows: 1C and 1R (27°35'50'' S and 48°30'55'' W); 2C and 2R (27°34'43'' S and 48°30'19'' W); 3C and 3R (27°35'0" S and 48°30'51" W); 4C and 4R (27°35'6" S and 48°30"32" W).

The areas used in this study are not representative of the natural soils of the region, as they were landfilled. All the sites contain inert construction waste and clay material used for waterproofing was also found in areas 2C, 3C and 4C. Area 1C only contained construction waste. All the composting sites are outdoors

and there is no protection against rainfall and no leachate collection. Sites 1C, 2C, 3C and 4C had an approximate area of 1500, 1200, 5000 and 1800 m^2 respectively. Composting piles were set up with food waste from restaurants, snack bars, supermarkets (low C/N ratio materials), and shavings, sawdust or remains of tree pruning (high C/N ratio materials). Approximately 700 to 1000 tons of waste per year was deposited in the composting areas. These wastes were arranged in piles of different lengths, with 1.5-2.0 m wide and 1.3-1.5 m high when built manually; 3.0 m wide and 3.0 m high when built with tractors (INÁCIO & MILLER, 2009). Each pile contains approximately 1.33 tons of material per m^2 yr^{-1}. Piles were built in different locations so that the entire area had a compost pile on its surface at some point. On average, the organic compost produced in the composting areas had the following characteristics: 8.9 pH; 33% humidity; 31.7% Total Organic Carbon (TOC); 0.86% Total P; 0.9% Total K; 3.4% Total Ca; 0.4% Total Mg; 532 mg kg^{-1} Total Na; 28.4 mg kg^{-1} Total Cu; 15.3 mg kg^{-1} Total Zn.

The composting method used in this study with natural aeration and without turning is known as the UFSC method (INÁCIO & MILLER, 2009). In 1C and 3C, when the compost piles were ripe and removed from the composting sites, the soil below the pile was also removed at a depth of about 10 cm and carried together with the compost. Landfill was added to the surface of the composting areas when necessary, which usually consisted of material from sandy soil nearby.

In January 2014, in 1C and 1R, and in February 2015, in the other areas, three trenches (0.5 x 0.5 x 0.5 m) were opened, and soil samples were collected at depths of 0-5, 5-10, 10-20, 20-30 and 30-40 cm. The samples were air-dried, ground and passed through a 2 mm mesh sieve to obtain fine air-dried soil (FADS), which was reserved for physical and chemical analysis.

We determined the texture of the samples (sand, silt and clay) according to Embrapa (1997), the values of pH in water (ratio 1:1), SMP index, available content of K and Na (extracted by Mehlich-1), and exchangeable Al, Ca and Mg contents (extracted by KCl 1.0 mol L^{-1}) according to Tedesco et al. (1995). These five elements were used to calculate aluminum saturation (m%) and base saturation (V%). Total organic carbon was also determined by the Walkley-Black method (EMBRAPA, 1997). The values of potential acidity (H+Al), m% and V% were calculated according to CQFS-RS/SC (2016).

The data related to soil acidity were submitted to homogeneity of variance test and analysis of variance (F-test, p <0.05). Among the composting areas and corresponding reference areas, the data were evaluated by Student's t-test. Within each area, the layers were compared by the Scott-Knott test (p <0.05). The variables pH, TOC, H+Al, aluminum saturation and base saturation of all the areas were submitted to principal component analysis (PCA).

Results

There was a significant difference in texture among the study areas, especially in soil clay contents (Table 1). These differences were found both within the profile of the same area and at the same layer of different areas. The soil in 1C, 1R, 2C and 3C was classified as loamy sand, in 2R and 3R as clay loam, 4C loam and 4R as sandy loam (SANTOS et al., 2015).

Table 1. Sand, silt and clay contents in soil of the composting areas and corresponding reference areas.

Depth, cm	San	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 soil pH values of the composting areas were between 7.0 and 8.0, which were higher than in corresponding reference areas up to 40 cm. However, 3C had higher pH than 3R up to 10 cm (Figure 1). TOC levels in 1C, 2C and 4C were higher than in reference areas up to 40 cm, while TOC levels in 3C were higher up to 10 cm (Figure 2). In general, the highest TOC contents were found in the surface layers of the evaluated areas, reducing with increasing depth.

The values of H+Al in soil of the composting areas 1C, 2C and 4C were lower than in corresponding reference areas in all the layers evaluated in this study (Table 2). However, H+Al in 3C was lower than in the reference area in the surface layers (0-5 and 5-10 cm). The highest values of H+Al in all the areas were found mainly in the surface layers, except for 1C in which higher values were found from 10-40 cm (Table 2).
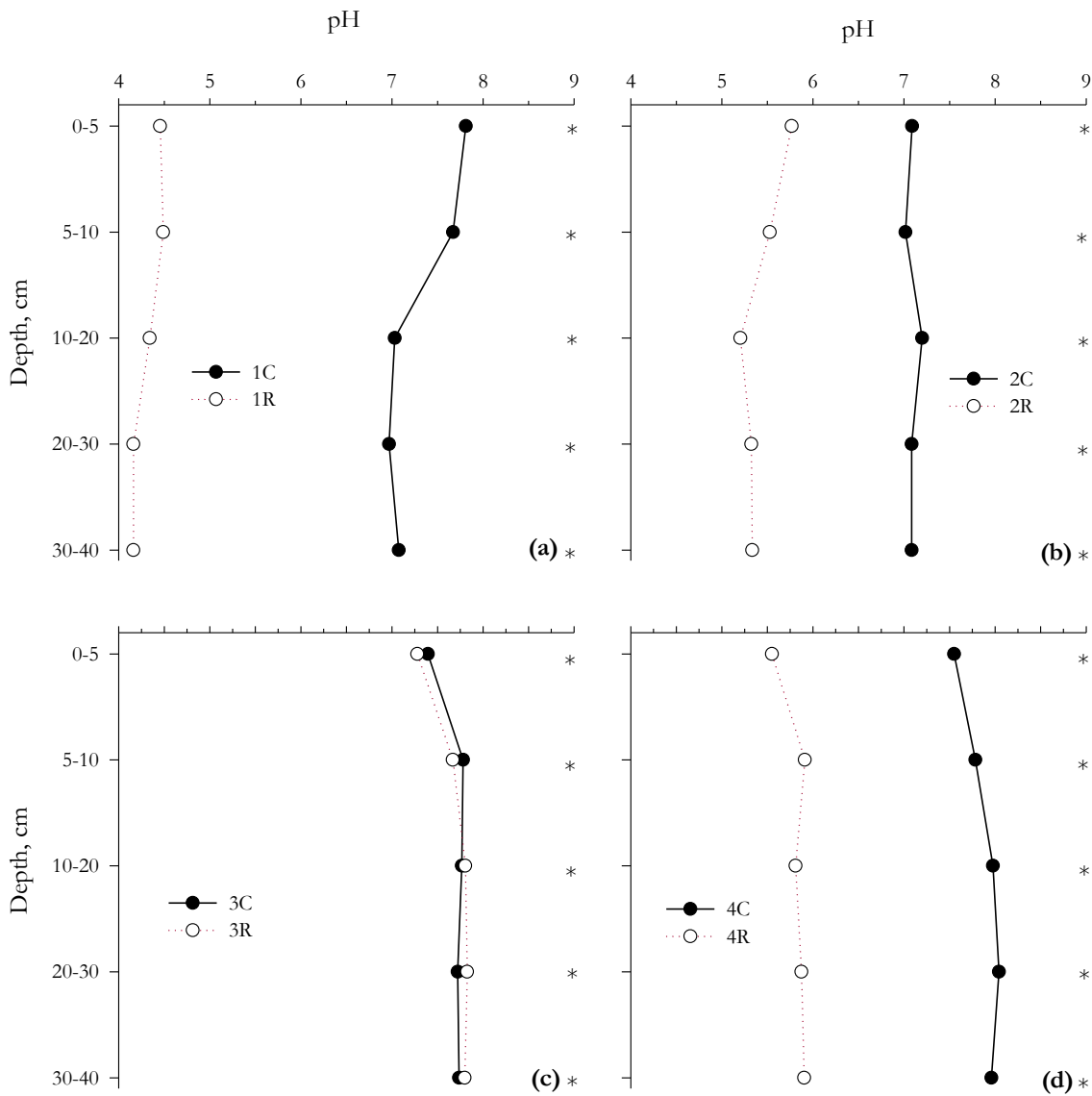
Figure   1.

Soil pH values of 1C and 1R (a), 2C and 2R (b), 3C and 3R (c) and 4C and 4R (d). *Significant difference by Student's t-test (p <0.05); ns: not significant. C: composting area, R: reference area.
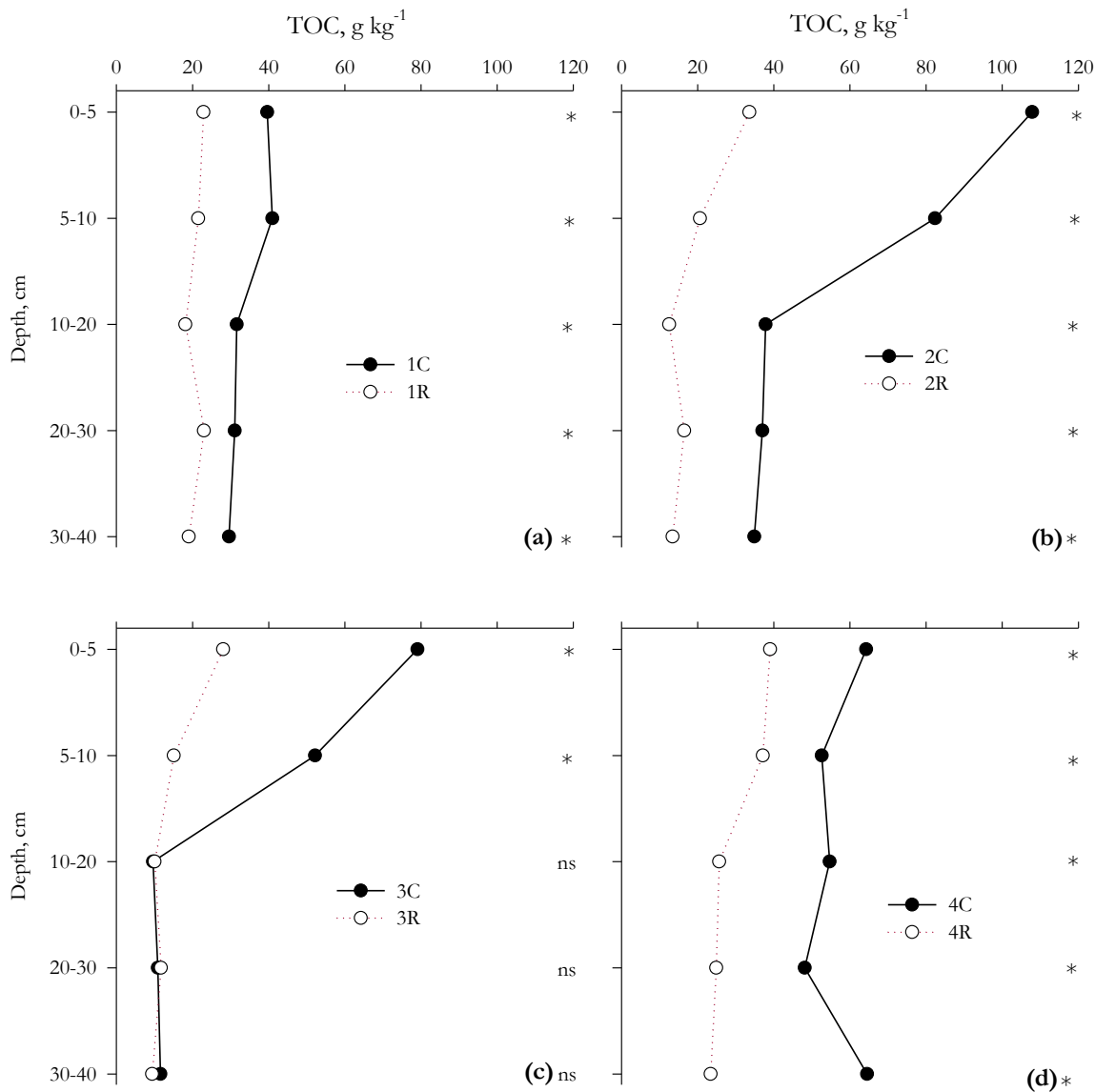
Figure 2.

Total organic carbon (TOC) in 1C and 1R (a), 2C and 2R (b), 3C and 3R (c), and 4C and 4R (d). *Significant difference by Student's t-test (p <0.05); ns: not significant. C: composting area, R: reference area.

Table 2. Potential acidity (H+Al), and percentage aluminum saturation and base saturation in soil of the composting areas and corresponding reference areas.

Depth,	H+Al, $cmol_c kg^{-1}$					
cm	1C	1R	CV, %	2C	2R	CV, %
0-5	1.1 b[(1)]B[(2)]	6.9 aA	22.78	1.8 bB	3.0 bA	3.44
5-10	1.4 bB	4.6 bA	5.57	1.9 aA	3.2 bA	1.74
10-20	1.7 aB	5.8 bA	13.27	1.3 dB	3.9 bA	0.00
20-30	1.6 aB	8.2 aA	4.93	1.4 cB	18.4 aA	0.66
30-40	1.6 aB	4.4 bA	7.47	1.4 cB	2.4 bA	4.10
CV, %	11.41	11.88		2.63	29.31	
Depth	3C	3R	CV. %	4C	4R	CV. %
0-5	1.2 aB	1.3 aA	0.66	0.7 aB	3.4 aA	4.10

5-10	0.9 cB	1.1 bA	5.22	0.6 bB	2.4 bA	5.74
10-20	0.9 cA	1.0 bA	1.97	0.6 bB	2.7 bA	3.52
20-30	1.0 bA	1.0 bA	4.93	0.6 bB	2.5 bA	3.01
30-40	1.0 bA	0.9 cA	1.75	0.5 cB	2.8 bA	3.06
CV, %	3.29	3.49		4.30	11.79	

Depth	Aluminum saturation %					
cm	1C	1R	CV. %	2C	2R	CV. %
0-5	0.0 a[1]B[2]	41.8 cA	0.00	0.0 aB	1.3 eA	0.00
5-10	0.0 aB	73.5 bA	0.00	0.0 aB	15.9 dA	0.00
10-20	0.0 aB	75.8 bA	0.00	0.0 aB	44.0 cA	0.00
20-30	0.0 aB	94.0 aA	0.00	0.0 aB	59.6 bA	0.00
30-40	0.0 aB	93.6 aA	0.00	0.0 aB	82.9 aA	0.00
CV, %	0.00	2.27		0.00	2.92	
Depth	3C	3R	CV. %	4C	4R	CV. %
0-5	0.0 aA	0.0 aA	0.00	0.0 aA	0.0 aA	0.0
5-10	0.0 aA	0.0 aA	0.00	0.0 aA	0.0 aA	0.0
10-20	0.0 aA	0.0 aA	0.00	0.0 aA	0.0 aA	0.0
20-30	0.0 aA	0.0 aA	0.00	0.0 aA	0.0 aA	0.0
30-40	0.0 aA	0.0 aA	0.00	0.0 aA	0.0 aA	0.0
CV, %	0.00	0.00		0.00	0.00	

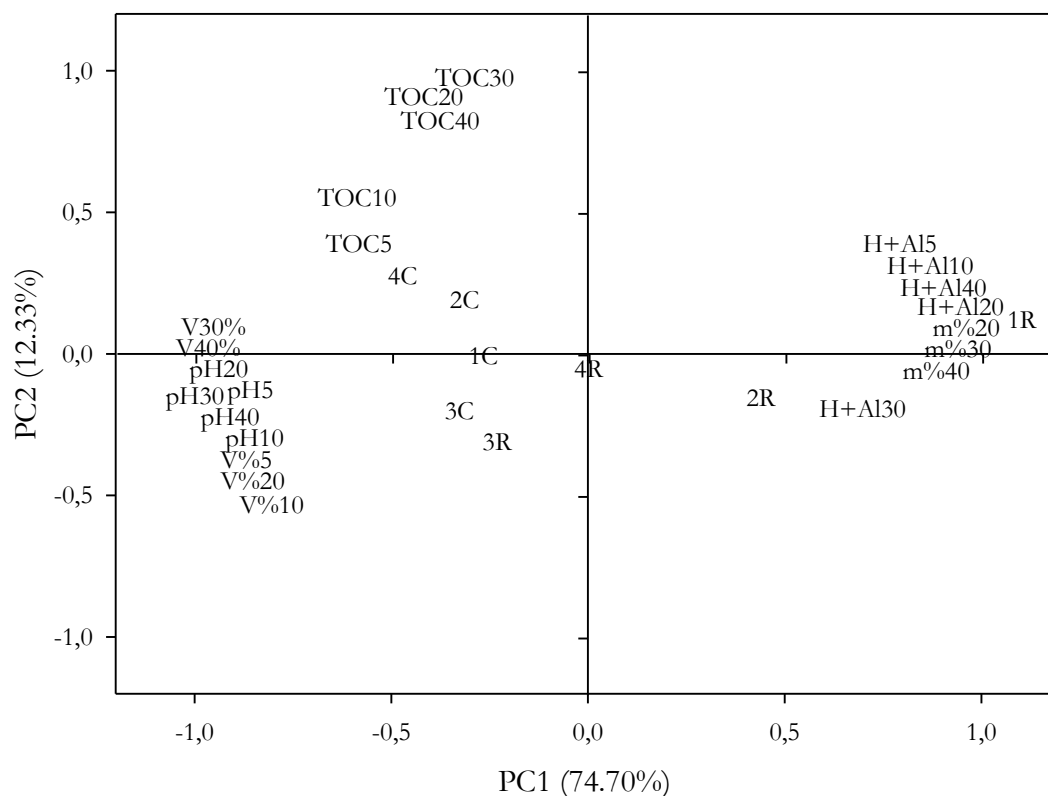| Depth,	Base saturation %					
cm	1C	1R	CV. %	2C	2R	CV. %
0-5	91.9 a[1]A[2]	21.6 aB	1.47	93.1 aA	71.1 aB	0.17
5-10	91.1 aA	13.3 bB	0.99	91.2 bA	65.6 aB	0.10
10-20	89.5 aA	10.6 bB	1.26	90.9 bA	54.1 bB	0.29
20-30	90.7 aA	1.9 cB	0.41	89.7 cA	15.2 dB	0.05
30-40	91.2 aA	3.1 cB	0.46	88.0 dA	23.6 cB	0.46
CV, %	1.01	16.40		0.26	9.26	
Depth	3C	3R	CV. %	4C	4R	CV. %
0-5	93.3 aA	90.8 bB	0.10	93.7 bA	84.9 aB	0.11
5-10	92.3 aA	91.2 aB	0.24	93.2 bA	87.4 aB	0.51
10-20	90.9 aB	91.6 aA	0.35	92.5 cA	84.1 aB	0.31
20-30	88.6 bB	90.6 bA	0.59	92.7 cA	84.4 aB	0.14
30-40	87.7 bA	91.4 aA	3.02	94.8 aA	83.0 aB	0.18
CV, %	1.35	0.30		0.30	1.87	

[1]Means followed by the same lowercase letter in the column did not show significant differences by the Scott Knott test ($p < 0.05$); [2] Means followed by the same uppercase letter in the row did not present significant differences by Student's t-test ($p < 0.05$). C: composting area, R: reference area.

The values of m% in 1C and 2C were lower than in corresponding reference areas up to 40 cm, while there were no differences between composting and reference areas in 3C and 4C (Table 2). However, the m% in all the composting areas was zero up to 40 cm.

Higher values of V% were found in the composting areas than in corresponding reference areas (Table 2). Base saturation above 85% was found up to 40 cm in all the composting areas.

In multivariate analysis, the attributes evaluated were set in two principal components, and the fitting of these data in the model explained 87.02% of the accumulated variability (Figure 3). The first component (PC1) explained 74.69% of the variability of the soil attributes. In PC1, pH, H+Al, m% and V% contributed significantly, as they had scores ≥ 0.5, except TOC in layers 10 to 40 cm (Table 3), which are considered highly significant (Coelho, 2003). As for the contribution of the attributes in the second component (PC2), only TOC stood out, starting at a depth of 5 cm, which showed coefficients with significance above 0.5 (Table 3).

There was separation in two main groups, one group with reference areas 1R and 2R, and another group with the other areas (Figure 3). This can be attributed to the higher values of potential acidity and aluminum saturation in 1R and 2R.

Figure 3. Ordination diagram produced by principal component analysis of the collected data. TOC: Total Organic Carbon, H+Al: potential acidity, m%: aluminum saturation, V%: base saturation. C: composting area, R: reference area. 5 = depth of 0-5 cm, 10 = depth of 5-10 cm, 20 = depth of 10-20 cm, 30 = depth of 20-30 cm, 40 = depth of 30-40 cm.

Table 3. Principal component analysis (PCA) of the variables evaluated in the soil of the composting areas and corresponding reference areas.

Variance component	PC1	PC2	PC3	PC4	PC5
Eigenvalue	18.67	3.08	1.11	1.07	0.89
Variability (%)	74.69	12.32	4.44	4.31	3.57
% accumulation	74.69	87.02	91.47	95.78	99.36
Variable	Correlation with principal components				
TOC 5	-0.57*	0.39	0.34	0.51*	0.34
TOC 10	-0.56*	0.57*	0.28	0.49	0.16
TOC 20	-0.41	0.87*	0.00	-0.23	-0.12
TOC 30	-0.30	0.91*	0.02	-0.21	-0.11
TOC 40	-0.39	0.84*	-0.03	-0.32	-0.02
pH5	-0.92*	-0.05	-0.05	-0.14	0.24
pH10	-0.94*	-0.10	-0.15	-0.09	0.20
pH20	-0.95*	-0.05	-0.17	-0.03	0.24
pH30	-0.95*	-0.07	-0.14	-0.08	0.21
pH40	-0.96*	-0.09	-0.13	-0.07	0.20
H+Al5	0.94*	0.14	-0.13	0.19	-0.12
H+Al10	0.97*	0.09	0.10	0.13	-0.10
H+Al20	0.98*	0.05	0.04	0.02	-0.11
H+Al30	0.71*	-0.18	0.57*	-0.32	0.11
H+Al40	0.93*	0.09	-0.06	0.20	-0.26
m%5	0.84*	0.24	-0.42	0.13	0.17
m%10	0.91*	0.19	-0.28	0.05	0.20
m%20	0.96*	0.08	-0.01	-0.09	0.22
m%30	0.96*	0.06	0.02	-0.11	0.22
m%40	0.93*	0.001	0.17	-0.19	0.23
V%5	-0.95*	-0.14	0.22	-0.03	-0.10
V%10	-0.95*	-0.14	0.19	-0.02	-0.15
V%20	-0.97*	-0.11	0.09	0.02	-0.14
V%30	-0.95*	0.01	-0.16	0.14	-0.18
V%40	-0.97*	-0.01	-0.13	0.08	-0.17

*Characters with higher factor loadings (scores) selected within each component. The criteria for classification were: absolute value <0.30, considered slightly significant; 0.30-0.49, moderately significant; and ≥0.50 highly significant according to Coelho (2003). TOC: Total Organic Carbon, H+Al: potential acidity, m%: aluminum saturation, V%: base saturation. 5 = depth of 0-5 cm, 10 = depth of 5-10 cm, 20 = depth of 10-20 cm, 30 = depth of 20-30 cm, 40 = depth of 30-40 cm.

Discussion

The increase in soil pH of the composting areas is associated to the pH of the compost, which reached an average value of 8.9. Also, the leachate from the piles had a pH of around 7.0 to 8.0, which in contact with the soil, favored the increase in pH to deeper layers. The alkaline pH of the compost and the leachate is the result of a proper composting process in which the aerobic decomposition of the waste and the oxidation of the organic acids produced during the decomposition of the organic material occurred, increasing the pH value (STRAATHOF & COMANS, 2015). As the leachate is in liquid form, it facilitates migration to deeper soil, also changing the pH in depth.

The contact of the compost pile directly on the soil promoted the increase of TOC contents in the surface layers of the composting areas, as there is a large volume of decomposing organic material. The contact of the organic material with the soil promotes the incorporation of carbon into the soil in the form of microbial biomass, non-humic substances and especially humic substances. Similar results were observed by Lourenzi et al. (2016) with the application of 0, 2, 4, 8 and 16 t ha^{-1} of pig slurry with wood shavings on the soil surface. After six years of annual compost applications, an increase in TOC contents was found at a depth of 0-4 cm. We found that the amount of organic material on the soil surface of the composting areas is approximately 1250 times higher than the highest dose applied by Lourenzi et al. (2016). The increase in TOC levels was also found by Brunetto et al. (2012) in evaluating the application of pig slurry and pig deep litter to supply one and two times the need for N in corn/black oat succession. The authors reported an increase in TOC up to 30 cm with the application of a dose of 180 kg ha^{-1} of N via pig slurry. Smaller increases in TOC contents in depths of 20-40 cm are also related to dissolved organic carbon (DOC) of the leachate. It should be noted that the increase found in our study was much higher than that found at the same depths by Brunetto et al. (2012) and Lourenzi et al. (2016), which indicates that it is the organic fraction of the leachate. This organic fraction is the result of thermophilic decomposition, which provides soluble organic carbon. Municipal waste compost has high amounts of DOC (above 4.5 g kg^{-1}), while manures generally have less than 1.0 g kg^{-1} DOC (MELO et al., 2008; STRAATHOF & COMAND, 2015). This organic fraction of the compost leachate has greater mobility than the organic fractions found in other wastes, such as in liquid wastes or stable organic composts, thus increasing TOC up to a depth of 20-40 cm. Similar results were found by Sorrenti & Toselli (2016) with the application of biochar, municipal waste compost, and a mixture of biochar and municipal waste compost in soils stored in lysimeters (considering a depth of 35 cm) in which peach trees were grown under irrigation. The leachate was evaluated for 12 months after the addition of the treatments, with monthly leachate collection. The authors found an increase in DOC content in the leachate, especially in the treatments with the use of the compost (single and mixed). This indicates that the compost (because of higher DOC contents) favors the increase of DOC and TOC in deeper soil depths.

The reduction of H+Al in the soil of the composting areas is a result of the consumption of H$^+$ ions present in the soil solution due to the increase in pH (Figure 2). The Al^{3+} of the soil solution, which is toxic to plants, is also neutralized by OH$^-$ groups, forming Al(OH)$_3$. With the increase in pH, H$^+$ and Al^{3+} are displaced from the CEC to the soil solution and neutralized by OH$^-$, reducing potential soil acidity (BRUNETTO et al., 2012). There is also a decrease in Al saturation in the composting areas due to the

increase in soil pH, which consequently promotes the reduction of H+Al and leads to a reduced amount of binding sites occupied by H^+ and Al^{3+}. With the decrease in Al saturation, there is an increase in base saturation, because with the consumption of H^+ and Al^{3+}, binding sites are available for the adsorption of K^+, Ca^{2+}, Mg^{2+} and Na^+.

Because of the increase in base saturation at all depths, the available sites are mainly occupied by Ca and K, and in smaller proportions by Mg derived from the concentration of these nutrients in the leachate (INÁCIO & MILLER, 2009; CHATTERJEE et al., 2013). The composting process releases Ca from the cell wall and K from the within the cell of plant tissues. Part of these elements (in soluble form in the compost mass) is used by the microorganisms for biological functions, and the other part (in available form) is not used by the bacterial populations. Thus, it may be lost in the water that leaches through the pile, characterizing the leachate.

By means of principal component analysis (PCA), it was possible to identify that the reference areas have higher values of potential acidity and Al saturation (Figure 3), especially 1R and 2R (Table 2). Among the composting areas, 4C and 2C stand out because of the differences in TOC (Figure 3), compared to reference areas 4R and 2R, especially at depths of 10-20, 20-30 and 30-40 cm (Figure 2).

Conclusions

Composting in small scale systems with piles directly on the soil promotes the increase in pH values, TOC contents and base saturation, regardless of the time of use. It also reduces potential acidity and aluminum saturation, providing attributes that favor plant development. A large amount of Ca and K reaches a depth of 20-40 cm, which is highly desirable for removing chemical barriers that prevent root growth in the subsoil. The leachate, therefore, is a valuable agronomic tool for the management of subsurface soil chemistry.

Acknowledgements

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