Composting as an alternative for final disposal of digested sludge from UASB reactors: a case study in the small municipalities of the state of Bahia, Brazil

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Abstract: This work evaluated the composting process as an alternative for the valorization of anaerobic digested sludge from an upflow anaerobic sludge blanket (UASB) reactor. The process stability and performance were investigated by monitoring physicochemical and microbiological parameters during two distinct and sequential phases. In the first phase, the composting process was evaluated by assembling two composting piles (490 liters each) with anaerobic digested sludge and wood chips as structural material (volumetric ratio 1:1). In the second one, the piles were put together and putrescible food waste was added to form a pile with approximately 523 liters. In addition, a net present value (NPV) calculation was made seeking to investigate the financial viability of the initiative. The results of the first phase showed that the piles did not reach thermophilic temperatures, indicating low microbiological activity. On the other hand, in the second phase, after addition of the food waste as an amendment agent, temperatures above 55°C were registered and maintained for five consecutive days in the pile. The result of the NPV showed that it is necessary to adopt adequate criteria for sampling frequency and number of parameters analyzed, in order to enable the implementation of composting as an alternative to anaerobic sludge valorization in small municipalities of the state of Bahia.
Keywords: amendment agent, composting, food waste, sludge, UASB reactor

1. Introduction

The state of Bahia is located in the northeastern region of Brazil and has a total resident population of just over 15,2 million inhabitants distributed in 417 municipalities, making it the fourth most populous Brazilian state. Despite being the eighth biggest economy in Brazil, with nominal gross domestic product (GDP) higher than $ 50 billion, the GDP per capita is just over $ 3,500 and income is very poorly distributed, which is reflected in the Human Development Index that was equal to 0.66 in 2010, the sixth lowest in Brazil [1].

According to data and information published by the Brazilian Institute of Geography and Statistics, 158 municipalities of Bahia state have a population with less than 15,000 inhabitants and therefore can be considered small municipalities [1-2].The main economic activity in these small towns is the non-mechanized agricultural production of low added value food stuffs in small family farms, also known as family agriculture. Regarding sanitation, 41% of these municipalities have sewage collection (combined or separate) but only 5% have some kind of wastewater treatment, particularly stabilization ponds. In the urban area, septic tanks precariously constructed and without adequate maintenance expose the population to poor health conditions and cause notorious environmental degradation.

However, since the publication of the National Sanitation Policy [3], governmental institutions and non-governmental organizations (NGO) have made efforts to reverse this situation. Regarding specifically the municipal sewage treatment, the construction of facilities that associate the UASB reactor to a post-treatment such as facultative lagoons or constructed wetlands is expected. Due to the Brazilian climatic conditions, this technological lay-out shows good performance and the quality of the final effluent is compatible with the requirements of the current environmental legislation [4-5].

Considering all that was mentioned above, we may say that even in the face of this enormous challenge, there is also an excellent opportunity to plan and implement sanitation services in these municipalities, guided by the concepts of resource-oriented sanitation and agro-sanitation [6]. It seems unwise to send valuable resources out of these communities and then invest in the purchase of chemical fertilizers that will be used in the production of the food consumed by these same people.

The municipal sewage sludge has high concentrations of macro and micronutrients, but before being ready for a use as biosolids or organic fertilizer, this resource certainly requires an important disinfection step, to reduce the concentration of pathogenic microorganisms, as well as to monitor and control the presence of organic and inorganic pollutants. Composting is considered to be one of the most efficient and environmentally friendly ways to stabilize and/or disinfect septic or digested municipal sewage sludge, once that the compost preserves the nutrients and a fraction of the organic matter used by soil microorganisms. Another important aspect is that composting is an activity that promotes income generation, improves standard social interaction, political engagement, and economic empowerment, besides improving leadership qualities in these municipalities of the Bahia state [7].

There are some reports in the scientific literature on the composting of anaerobic digested municipal sewage sludge [8-11], but few studied the composting of the anaerobic sludge from UASB reactors. These studies show that it is possible to reach thermophilic temperatures, starting from carbon:nitrogen (C:N) ratios between 20 and 40 and initial moisture of the sludge mixed with the bulking agent between 60 and 70%. However, sewage sludge from different wastewater treatment plants varies in its composition and physical properties and it is important to find a local solution [12].

Therefore, the main objective of this study was to investigate composting as an alternative for the valorization of municipal sewage sludge from an UASB reactor. In addition to the conventional aspects of the process (C:N ratio, moisture and bulking agent), a study of the financial viability by the net present value method, and a detailed physical-chemical characterization of the compost quality were also carried out.

2. Material and Methods

2.1. Experimental set up

During the first 72 days (phase 1), our composting process as alternative for valorization of anaerobic digested municipal sewage sludge from UASB (ADS) reactor was evaluated with wood chips as a bulking agent in two composting piles (A and B). This experimental procedure followed the methodology proposed by Nikaeen *et al.* [10]. Despite the excellent results obtained by these researchers, our piles did not reach temperatures in the thermophilic range. In the beginning of the second phase, which lasted 64 days, the piles were put together (Pile C) and putrescible food waste (PFW) was added. This type of waste as amendment agent was chosen due to two important characteristics: (i) it is a source of readily biodegradable organic material and (ii) the reality observed in small municipalities in the state of Bahia. As explained previously, the main economic activity of these municipalities is the family agriculture and the production of these medium and small-sized farms is commercialized in a kind of weekly county fair that usually takes place on Saturdays.Therefore, at the end of the day, the generation of some putrescible food waste is unavoidable. On the other hand, by applying the concepts of circular economy, we could say that this waste is actually a resource and thus should be valorized.

The investigation was carried out at the Experimental Laboratory of Sanitation from the Federal University of Bahia located in the northeast region of Brazil (lat. 12° 59’ S, long. 38° 30’ O, alt.58m). Digested municipal sewage sludge from UASB reactor was collected 20 days after the disposal in a drying bed. Donated woodchips composed of a mixture of untreated wood were used as bulking agent. Manually collected putrescible food waste composed by vegetable and fruit leftovers came from one of the weekly county fairs. The main physicochemical characteristics of the materials used in the experiment are listed in Table 1.

Table 1. Characteristics of the materials and composted mass at the beginning of the experiments

	Materials			
Parameter	Phase1		Phase2	
	ADS	Wood Chips	ADS + Wood Chips	PFW
pH value	8.7	5.4	6.1	4.9
Carbon (%)	25.4	38.2	31.4	36.4
Nitrogen (%)	4.1	0.4	3.4	2.0
C:Nratio	6.2	95.5	9.2	18.2
Moisture (%)	84.1	13.5	41.5	90.4
Organic Matter (%)	64.6	99.3	74.7	89.8
Specific Mass (kg.m^{-3})	879.4	119.7	413.9	1021.5
	Composted Mass			
Parameter	Phase1		Phase2	
	Pile A	Pile B	Pile C	
pH value	8.1	7.9	5.4	
Carbon (%)	34.8	32.0	28.1	
Nitrogen (%)	3.0	2.7	4.1	
C:Nratio	11.4	12.1	6.9	
Moisture (%)	75.7	73.2	56.4	
Organic Matter (%)	74.2	79.4	75.2	

2.2. Composting Piles and Physicochemical and microbiological analysis

At the beginning of the first phase, partial thick ADS (≈ 430 kg) was mixed with woodchips (≈ 29 kg) in a volumetric ratio of 1:1 and divided into piles A and B, which had a volume of approximately 490 liters each and were turned manually twice a week. Tap water was added to the piles on days 59 and 65 to adjust moisture content. At the end of the 72 days, piles A and B (≈ 258 kg) were mixed with putrescible food waste (≈ 78 kg) in a volumetric ratio of 5.3:1. They formed pile C that had a volume of approximately 523 liters. During the second phase, pile C was turned manually every day in the first week and twice a week from then. The moisture content of the pile was adjusted on days 85 and 91, with 30 and 25 liters of tap water, respectively.

In each pile, samples were collected from different sites and mixed thoroughly for determination of the physicochemical and microbiological parameters. Fresh samples were used for pH, moisture content, Coliforms and Helminths eggs analysis. The samples were dried for the determination of organic matter, carbon and nitrogen contentsand ground to pass througha 0.4 mm sieve.Temperature was monitored daily, while pH, moisture, organic matter, total carbon and total nitrogen were monitored weekly.

The pH value was determined with a pH meter equipped with electrodes using 1.0 g of the sample immersed in 50 mL of $CaCl_2$ (0.01M) and stirred for 30 minutes. Moisture content, organic matter and nitrogen were analyzed according to the Standard Methods for the Examination of Water and Wastewater (SM) [14]. Nitrogen was determined by an adapted methodology of the 4500-Norg B method: 200 mg of the sample was placed in macro Kjeldahl flasks containing 1.0 mL of commercial H_2O_2, 700 mg of digestion mix (containing 100 g of Na_2SO_4, 10 g of $CuSO_45H_2O$ and 1.0 g of selenium) and 5.0 mL of concentrated H_2SO_4. The digestion was conducted in the speed digester system K-425 model, Büchi. After digestion, 50 mL of deionized water and 35 mL of 10MNaOH were added to the sample, which was then distilled in 50 mL of boric acid, pH 4.65 in distillation unit K355, Büchi. Carbon was determined in a high-temperature solids combustion system (1,200°C) using Analytic Jena multi N/C®2100 analyzer. Total coliforms and *Escherichia coli* were quantified by defined substrate technique using Colilert®, IDEXX. Helminths eggs were quantified by EPA/625/R-92/0 methodology and Termotolerant Coliforms using SM9221.

At the end of the experiment, 550 grams of the sieved compost (mesh opening equal to 5.0 mm) were submitted to physicochemical and microbiological characterization. The concentrations of metals and other chemical elements were determined using inductively coupled plasma-atomic emission spectrometry (USEPA 200.7 Method). The Cation-exchange capacity and Water-exchange capacity were also quantified.

2.3. Financial viability analysis

Aiming to carry out a preliminary analysis of the financial viability of the initiative, the classical Net Present Value (NPV) technique was used (equation 1). For the project to be financially viable, NPV must be greater than or equal to zero.

$$\boldsymbol{NPV} = \sum_{j=o}^{n} \boldsymbol{R_j}(\mathbf{1}+\boldsymbol{i})^{-j} - \sum_{j=0}^{n} \boldsymbol{C_j}\,(\mathbf{1}+\boldsymbol{i})^{-j} \quad \text{(Equation 1)}$$

where

R_j = net cash inflow during the period t

C_j = total initial investment costs

i = discount rate

j = number of time periods

The construction cost, acquisition of a waste disposer and monitoring instruments such as: a set of screens and digital thermometers, were considered. The costs for periodic physicochemical and microbiological analyzes and the manpower required for the management of the composting process were also considered.

The discount rate adopted was that defined by the Special System for Settlement and Custody (Selic). This is the central security depository that makes up the federal domestic debt issued by National Treasury of Brazil and, as such, processes the issue, redemption, interest payments and custody of these securities.The system, which is managed by the Central Bank of Brazil and operated in partnership with Anbima, the Brazil's Financial Market Entities Association, has operational centers located in the city of *Rio de Janeiro*.

3. Results and discussion

3.1 Behavior of the composting process

During the composting process, the increase of the temperature is an indicative of the occurrence of intense microbiological activity. However, during the 72 days of the first phase, the temperature of the piles A and B was very close to the ambient temperature and did not exceed 36°C. This value is not considered adequate to ensure the compost disinfection. The Brazilian legislation classifies the compost derived from sewage sludge into two classes (A and B) and establishes different criteria for the use of this resource according to this classification. For less restricted uses (class B), the Brazilian legislation states that the pile must reach a minimum temperature of 40°C for at least five days, with a peak occurring at 55°C over four successive hours during this period. Additionally, in order to reduce the attractiveness of vectors, whatever the class of the compost, the temperature should be kept above 40°C for at least 14 days and the average temperature during this period should be greater than 45°C. The results shown in Table 2 demonstrate that our piles did not meet the requirements of the Brazilian legislation. We also observed that the process showed no significant variation of the volatile solids or total organic carbon concentrations, which can be interpreted as the absence of intense microbiological activity.

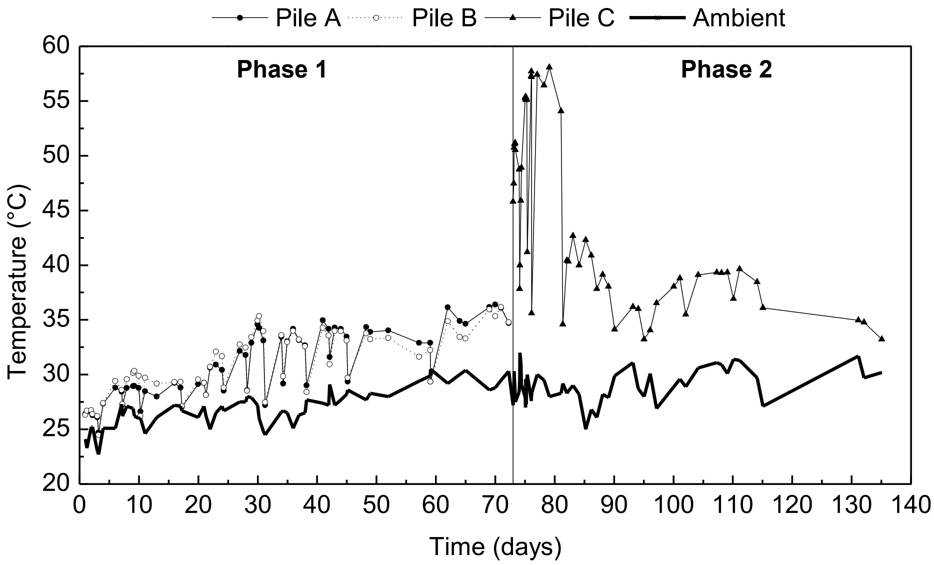
Table 2. Physicochemical parameters monitored during the first phase of the experiment

		pH	TOC (%)	TKN (%)	C:N ratio	Moisture (%)	Volatile solids (%)
LA	A_1	8.2 ± 0.1	26.4 ± 5.5	3.1 ± 0.1	8.7	75.7 ± 0.4	74.2 ± 1.4
	A_2	7.6 ± 0.1	-	3.4 ± 0.1	-	74.0 ± 0.3	75.9 ± 0.9
	A3	6.7 ± 0.1	29.4 ± 1.1	3.6 ± 0.2	8.1	71.7 ± 0.3	75.2 ± 0.5
	A_4	6.0 ± 0.1	-	3.6 ± 0.1	-	67.6 ± 0.9	74.7 ± 0.3
	A_5	5.5 ± 0.3	33.8 ± 1.2	3.6 ± 0.1	9.6	64.1 ± 0.5	74.5 ± 0.4
LB	A_1	7.9 ± 0.1	33.3 ± 0.5	2.6 ± 0.2	12.6	73.2 ± 0.4	79.4 ± 0.6
	A_2	7.5 ± 0.1	-	3.0 ± 0.1	-	71.1 ± 0.4	78.7 ± 0.2
	A_3	6.4 ± 0.2	33.3 ± 1.2	3.4 ± 0.1	9.8	68.3 ± 0.1	77.9 ± 0.4
	A_4	5.8 ± 0.1	-	3.5 ± 0.1	-	64.9 ± 0.4	77.7 ± 0.2
	A_5	5.4 ± 0.3	33.7 ± 0.9	3.6 ± 0.2	9.4	60.8 ± 0.3	77.4 ± 0.2

Legend: A = Aliquot; n = Collection week

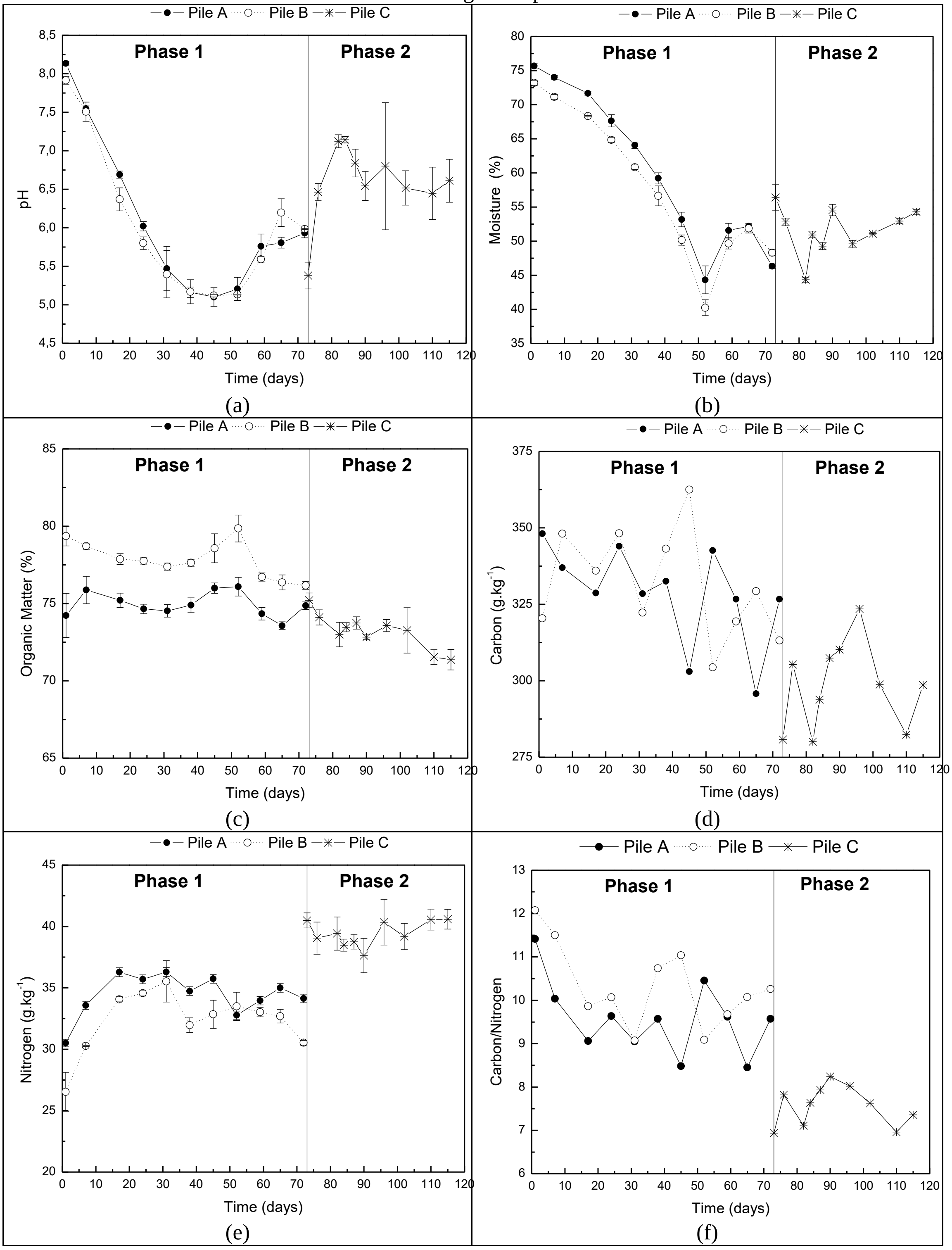
The addition of putrescible food wastes on the 73rd day, which marked the beginning of phase 2, resulted in a significant increase of the temperature as can be seen in Figure 1. The pile C reached temperature values higher than 40°C between days 73 and 87, with peaks higher than 55°C between days 75 and 81.

Fig.1 Evolution of temperature during the composting process



Looking at Figure 1 it is possible to see that for six days the temperature of the pile C was above 55 °C and also for fourteen days above 40 °C. Therefore, considering the criteria of the Brazilian legislation for the time-temperature binomial, it can be stated that the results met the criteria of significant reduction of pathogens microorganism and reduction of the vector attraction (flies, rats and mosquitoes). Figure 2 shows the behavior of the other parameters during the process monitoring time.

Fig. 2 (a) pH, (b) moisture content, (c) organic matter content, (d) carbon, (e) nitrogen and (f) C/N ratio behavior during the experiment



Legend: pile A (●), pile B (○) and pile C (*)

It is well known that the optimal range of the pH value is between 5.5 and 8.0 and, moreover, while the bacteria prefer a pH almost neutral, fungi develop best in a more acidic environment. The reduction in pH value is common at the beginning of the composting process, since organic acids are produced as a consequence of the activity of acidogenic bacteria. When this phase ends, the pH value tends to increase and reaches the alkaline range at the end of the composting process.

During the first phase of our experiment, the pH value did not exactly follow the typical model described in the literature; it decreased its value up to day 46 to values close to 5.0. After day 47, a slow increase was observed, culminating at a pH close to 6.0 on day 72. The initial pH value in pile C was 5.4. In the first 15 days of monitoring (up to the 87th day) the pH varied between 6.8 and 7.1. The pH dropped to values close to 6.5 (Figure 2a) because of the reduction of manual turning frequency, which happened until the end of the experiment.

Regarding the decomposition of organic matter, in our experiment, there was not much variation in the volatile solids concentration, similarly to the experiment by Huang *et al*. [15]. There was a reduction of approximately 5% of the organic matter in the pile C, with contents slowly decreasing from 75% to approximately 70% (Figure 2c). The carbon and nitrogen contents in pile C were always close to 30% and 4%, respectively (Figure 2d-e). These condition made the C:N ratio practically unchanged during the process, with an average value of 7.5 (Figure 2e). Huang *et al* [15] evaluated the composting of pig manure using sawdust as bulking agent and also did not observe a great variation in the volatile solids concentration due to the presence of recalcitrant materials such as cellulose and lignin. Nevertheless, it should be noted that our experiment was conducted with ADS and the initial values of the VS:TS and C:N ratios were already below the values established as typical of mature composts.

Therefore, the main aspect of the composting process as an alternative for final disposal and valorization of digested sludge from UASB reactors in the small municipalities of the Bahia state is to guarantee the occurrence of thermophilic temperatures and ensure the sanitization of the final compost. Care should be taken to avoid directly correlating the occurrence of thermophilic temperatures with the sanitary quality of the compound, that is, the microbiological analyzes are indispensable. Droffner and Brinton [16] reported the difficulty of correlating temperature or time under elevated temperatures with the destruction of pathogens (E. coli and *Salmonella*) during the composting process, which indicates that the mechanism for removal of these microorganisms is complex and not simply dependent on exposure to a certain temperature.

The results also showed that composting allows the preservation of nutrients and organic matter present in the raw material (ADS + putrescible food residues) which is an advantage when comparing this alternative with the application of chemicals such as CaO for sludge disinfection and biosolids production. The Table 3 shows the results of the physicochemical and microbiological characterization of the final compost and the values defined by Brazilian environmental legislation.

Table 3. Characteristics of the compost and limit required in Brazilian legislation

Parameter	Final compost	Resolution Nº 375/2006	Regulation 25/2009 Class D
Viable eggs of helminths (viable egg per g de TS)	< 0.25	< 0,25 (Class A) < 10 (Class B)	< 025
Thermotolerant coliforms (MPN per g de TS)	< 1.1	<10^3 (Class A) < 106 (Class B)	< 1,1
Arsenic** ($mg.kg^{-1}$)	< 0.006	41	<0,006
Barium** ($mg.kg^{-1}$)	-	1300	-
Cadmium** ($mg.kg^{-1}$)	2.4 ± 0.2	39	-
Lead** ($mg.kg^{-1}$)	< 0.005	300	-
Copper** ($mg.kg^{-1}$)	296 ± 24	1500	-
Chrome** ($mg.kg^{-1}$)	18.8 ± 1.2	1000	-
Mercury** ($mg.kg^{-1}$)	< 0.0002	17	-
Molybdenum** ($mg.kg^{-1}$)	23.6 ± 4.0	50	-
Nickel** ($mg.kg^{-1}$)	21.8 ± 3.2	420	-
Selenium** ($mg.kg^{-1}$)	-	100	-
Zinc** ($mg.kg^{-1}$)	809 ± 28	2800	-
Moisture (Max.) (%)	38.6 ± 0.4	-	70
Total Nitrogen (Min.) (%)	4.4 ± 0,1	-	0.5
Organic Carbon (Min.) (%)	32.9 ± 0.3	-	15
Cation ex-change capacity ($mmolc.kg^{-1}$)	620 ± 270	-	-
pH value	6.5	-	6.0
C:N ratio (Max.)	7.4 ± 0.1	-	20
CEC:C ratio	18.9 ± 8.4	-	-

* This Regulation published by the Brazilian Ministry of Agriculture, Livestock and Supply in 2009 classifies as Class "D" the organic fertilizer that, in its production, uses any amount of raw material from the treatment of sewage

**Dry weight basis

3.2 Economic feasibility
In Brazil, Resolution Nº 375 published by the National Environmental Council (Conama) in 2006 [17] regulates quality requirements and defines two classes (A and B) for agricultural use of biosolids from sewage sludge composting. However, the use of any class of biosolids in grassland and cultivation of oilseeds, tubercles, roots or flooded crops, as well as other crops in which the edible part is in contact with the surface of the soil is forbidden. The Brazilian legislation is clearly inspired by the American Resolution [18], but it is even more restrictive than the latter.
It was observed that the impact of the process monitoring, i.e. physicochemical and microbiological analysis to determine the quality of the compost, on total costs was too great and the NPV value was negative (-US$ 6,912.1) which indicates the project's financial unfeasibility. It should be highlighted that, the financial viability was verified by considering the compost as a class A, in which the monitoring of the process is done by performing only microbiological analyzes (thermotolerant Coliforms, viable helminths eggs, *salmonella* and viruses). Another important limitation that should be taken into consideration is that in these small municipalities located in the state of Bahia, there are no highly qualified laboratories to carry out all these physicochemical and microbiological analyzes
Considering the current stage of economic and social development of these small municipalities located in the state of Bahia, it seems reasonable to assume that the sewage generated in these small towns will not present a high degree of chemical contamination and therefore the sludge from the anaerobic treatment should also not generate high chemical risks. Nevertheless, epidemiological research shows that in almost all of these small cities, helminths are prevalent and endemic. Moreover, the compost will be handled by farmers with low formal education level in family farms, which may increase the risks of contamination associated with exposure to pathogenic microorganisms.
From our point of view, it is not acceptable to carry out a mere compilation of parameters and criteria set out in the legislation of other countries. Considering the results obtained, it seems clear to us that the risk assessment approach is the best option to define the required quality criteria of the compost. Local authorities who are responsible for health promotion and environmental quality must have a deep knowledge of the scenario of generation, management and treatment of those wastes through composting, in order to characterize the risk and define the interventions and actions of governance and regulation.
By adopting this protocol, it will certainly be possible to achieve the financial viability, adequate public health conditions and a valorization of ADS and putrescible food waste through a composting process in a sustainable way. In addition, these practices can guarantee the reinsertion of nutrients in the productive cycle and preserve the secular practices of organic and family agriculture that exist in these small localities.

4. Conclusions
The main conclusions of the composting as an alternative to valorization of digested anaerobic sludge from UASB reactors are:
- It is necessary to add a rapidly biodegradable amendment agent so that the process reaches temperature in the thermophilic range. After addition of food residue, the compost pile reached temperatures above 55 ° C sustained for 6 days.
- Microbiological analyzes showed that the concentration of thermotolerant Coliforms and viable helminths eggs in compost were below of the most restrictive limits of Brazilian legislation, which is $<10^3$ MPN per gram of total solids and 0.25 eggs per gram of total solids, respectively.
- The compost presented physicochemical characteristics suitable for agricultural use meeting all the requirements of Brazilian legislation.
- However, the financial analysis using the NPV method showed that the process is not feasible mainly due to the cost of the required microbiological and physicochemical analysis. Considering the results obtained, it seems clear to us that the risk assessment approach is the best option for defining the required quality criteria of the compost.

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