Nutrient recovery from human urine by small scale composting process

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Abstract: Although the report of the International Monetary Fund published in 2018 considers Brazil's economy as the ninth largest in the world, there are still approximately 5 million Brazilians without access to a toilet. The lack of access to basic sanitation is more severe in rural and peripheral urban areas. Waterless toilets may be a suitable technology to reverse this social and environmental situation of vulnerability. However, the direct use of human urine in agriculture presents some practical limitations and faces some cultural constraints in Brazil. Considering this context, it was investigated a small scale composting process of human urine and lignocellulosic residues (coarse sawdust) aiming to design a waterless toilet as a solution for people living in Brazilian rural areas. Two piles (approximately 200 liters each) were prepared and important parameters for process stability such as C:N ratio, moisture, temperature and pH value and further daily operation aspects (piles configuration, turning time and the need for inoculum) were evaluated for 120 consecutive days. The maximum value of C:N ratio was 26:1 and the minimum nitrogen concentration (13.0 $g.kg^{-1}$) was superior to 0.5%, which is the minimum value required by Brazilian legislation. The results showed that in a rural community with 100 inhabitants, it would take about 4 days to produce the volume of urine required for composting. The matured compost can be used as a safe soil conditioner helping to encourage EcoSan practices and initiatives aligned with the concepts of organic agriculture by small and low-income farmers in Brazil.
Keywords: Composting, ecosanitation, human urine, nitrogen

1. Introduction

According to the Brazilian Institute of Geography and Statistics, approximately 31 million inhabitants reside in rural areas and isolated communities [1,2]. Approximately 24 million Brazilians still suffer from the chronic and serious problem of lack of basic sanitation and there are almost 5 million people living in Brazil without access to a toilet. Focusing the analysis only on households located in rural areas, this situation is even more serious. Only 5.1% of the rural households are connected to a sewage collection network and 11.4% (about 3.4 million people) do not have any solution for the environmentally adequate disposal of their excreta.

Another important consideration is the social condition of the Brazilian population that live in rural areas. Approximately 7.5 million people live under conditions of extreme poverty. Family agriculture is the main economic activity, which consists of non-mechanized agricultural production of low added value foodstuffs, produced in small family farms. From this perspective, it is imperative the development of a sustainable model to bring potable water and wastewater treatment to these people. It is a huge challenge, but the use of alternative solutions that lower the financial investment combined with the implementation of public policies with technical feasibility and community participation can be effective measures. All these aspects are covered by the principles and concepts of ecological sanitation (EcoSan).

The EcoSan technologies are not ecological per se, but only in relation to the observed environment [3]. EcoSan practices are also crucial to minimize anthropogenic disturbances in the nutrients cycles and to mitigate environmental impacts. One of the basic principles of EcoSan is to close the gap between sanitation and agriculture in a local level using the macronutrients present in human excreta. From an agronomic point of view, human urine can be a source of essential nutrients, such as nitrogen, phosphorus and potassium (NPK), for the development of plants. In addition, it contributes with a small amount of micronutrients and has a low concentration of heavy metals. It is well established that human urine normally does not contain pathogens responsible for the transmission of enteric diseases to other individuals. Only in special cases, e.g. a systemic infection with fever or faecal cross-contamination, will pathogenic organisms be present in urine [3].

However, the direct use of human urine as a fertilizer is not unrestricted mainly due to the presence of salts. Simha and Ganesapillai [4] warn that human urine is a fast-acting liquid fertilizer that requires careful application and regulation, the absence of which can cause volatilization of intrinsic ammonia. Some limitations such as soil type, evaporation rate, infiltration, and groundwater level need to be carefully evaluated on a case-by-case basis. These aspects become challenges when it is taken into account the current information level of the population residing in rural areas of Latin America. User perceptions, attitudes, experiences and willingness to adopt these new systems are also critical to the success of EcoSan initiatives. Studies on the subject in Mexico and South Africa reported negative user attitudes. Some residents in Ghana accepted that excreta could be used as a fertilizer although they themselves were not willing to do so [4].

The limitations of the direct use of human urine as a fertilizer instigate the search for other valorization approaches that contribute to the full utilization of the nutrients within the EcoSan context. Aggregating human urine during the composting of lignocellulosic waste could be an attempt to overcome these barriers; therefore facilitating a large-scale implementation in a country with severe sanitation deficits in

rural areas, such as Brazil. 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 such countries [5].
There are a few reports on the use of human urine during the composting process [6]. The authors Pinsem and Vinneras [7] carried out experiments aiming at recycling the nitrogen present in human urine mainly as a primary source for organic matter decomposing microorganisms. The authors observed that the extra nitrogen supply stimulates the microbiological activity thus favoring the increase of temperature of the composting piles. It is also worth noting that human urine may favor the development of the actinomycete population, which is responsible for the degradation of residues with high cellulose and lignin content [7].
Waterless toilets and the direct use of human urine in agriculture even in small farms are not widespread practices in Brazil. Considering this context, it was evaluated the composting process of human urine and lignocellulosic residue seeking to design a waterless toilet as a solution for people living in rural areas in Brazil according to the principles of EcoSan. In addition, it was verified if the quality of the final compost meets the requirements of the Directive number 25/2009 published by the Brazilian Ministry of Agriculture, Livestock and Supply.

2. Methods

Urine separating toilets are available in a number of designs depending on the habits of the people. Even so, it is well-known that waterless toilets cannot be compared to the conventional water-flush toilets regarding convenience [3]. Therefore, following the recommendations of Johansson et al. [8], the waterless toilet was designed as a private urinal avoiding mixing of urine with feces. The urine drops down into a recipient that is partially filled with untreated wood residues to absorb the liquid, avoiding nutrient losses and facilitating the handling and transportation. Considering the habits of the population living in rural areas of the northeastern region of Brazil and social-cultural features, the user acceptance, comfort and hygiene, regarding the use of this EcoSan solution, are still being evaluated. During this research, it was investigated the composting process of the sawdust impregnated with urine, i.e. important parameters for process stability (C:N ratio, moisture, temperature and pH value) and further daily operation aspects (configuration of piles, turning time and need for inoculum).
The investigation was carried out at the Experimental Laboratory of Sanitation of the Federal University of Bahia located in the northeast region of Brazil (lat. 12° 59’ S, long. 38° 30’ O, alt.58m). The wood residue did not undergo sieving, since the use of small particles (≤ 0.5 cm) alone could compromise the oxygenation of the composting process by means of compaction. Therefore, it consisted of different particle sizes such as sawdust, chippings and wood chips, referred to as coarse sawdust, what is important for the conical shape pile’s structure and stability. Human urine was stored for 30 days to ensure the inactivation of pathogenic microorganisms. Table 1 shows the main characteristics of these materials. All the physicochemical analyzes were performed in triplicate.

Table 1. Main characteristics of the human urine and coarse sawdust

Parameter	**Coarse sawdust[1]**	**Human urine**
TKN	3.0 ± 0.1 ($g.kg^{-1}$)	10.7 ± 0.1 $g.L^{-1}$
TOC	386.0 ± 0.1 ($g.kg^{-1}$)	2.2 ± 0.2 $g.L^{-1}$
Organic matter	994.8 ± 0.5 ($g.kg^{-1}$)	n.a.
C:N ratio	130:1	4.8:1
pH value	5.6 ± 0.2	9.2 ± 0.2
Moisture (%)	9.6 ± 1.1	n.a

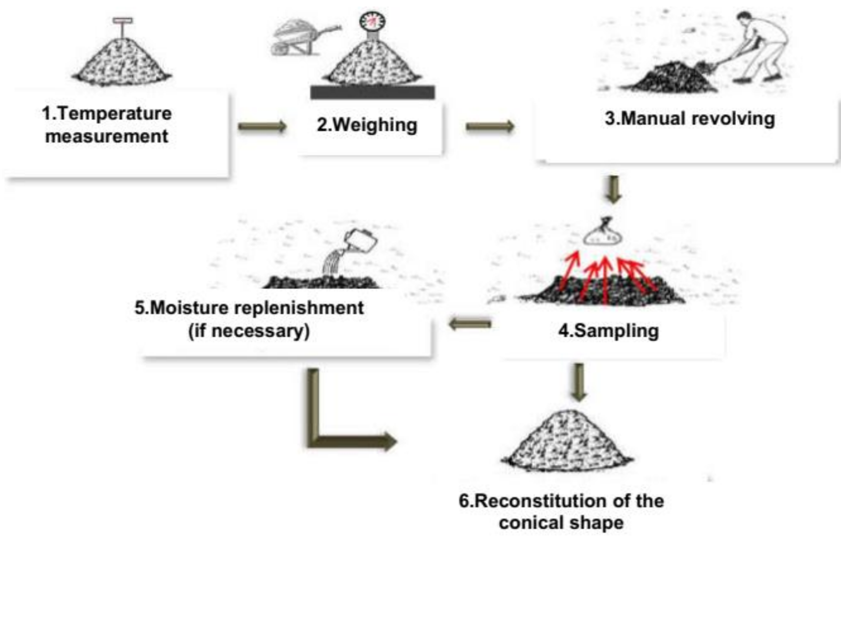
n.a. - not applicable.
1- dry mass

The piles (0.2 m^3) were prepared in duplicate (Figure 1) and inoculated with bovine manure since the occurrence of microorganisms in the stored human urine and coarse sawdust is unlikely. The key parameter chosen for assembling the conical piles was the C:N ratio. Gradually, the initial value (40:1) was adjusted to 30:1 by adding human urine. For practical purposes, this means that every 15 kg of coarse sawdust will absorb 7.0 liters of human urine.

Fig 1. Procedures for assembling conical compost piles (a and b) and piles with addition of human urine (c)

The piles were manually revolved (Figure 2) and the composting process was accompanied by changes in temperature, moisture, pH, organic matter content (O.M.), dry matter, TKN and C:N ratio for 120 consecutive days. The aliquots for physicochemical analyzes were always collected after the manual turning of the piles. 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 and organic matter were analyzed according to the Standard Methods for the Examination of Water and Wastewater [8]. Total 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®. Organic carbon content was determined in a high-temperature solids combustion system (1200°C) using Analytic Jena multi N/C®2100 analyzer. Ambient temperature and relative humidity were monitored daily using a portable thermo hygrometer (model HANNA/HI 9564).

Fig 2. Monitoring the composting process step by step.

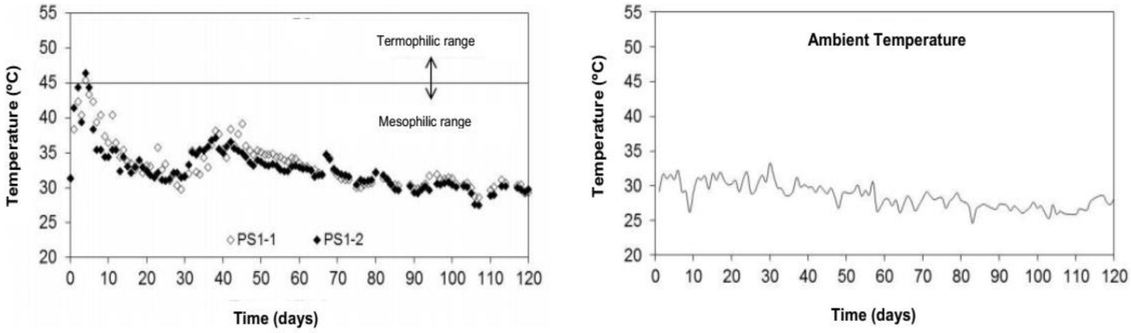


3. Results and Discussion

3.1 Monitoring the composting process

The maximum temperature (51.3ºC) was reached between the third and the fourth day (Figure 3). Probably, the temperature did not remain above 45ºC for a longer time due to the size of the piles (below 1.0 m³). The central part of our piles was located very close to the outer layer, which facilitates the exchange of heat with external medium. It is important to highlight that composting processes subjected to temperatures above 70°C for long periods may lose efficiency. This abiotic condition could reduce the population of microorganisms that decompose organic matter, cause the denaturation of water-soluble proteins and favor ammonia volatilization. However, the inactivation of pathogenic microorganisms and the minimization of the phytotoxicity that inhibit seed germination is directly associated to the maintenance of temperatures in the thermophilic range.

Fig 3. Temperature profile during composting of coarse sawdust impregnated with human urine.



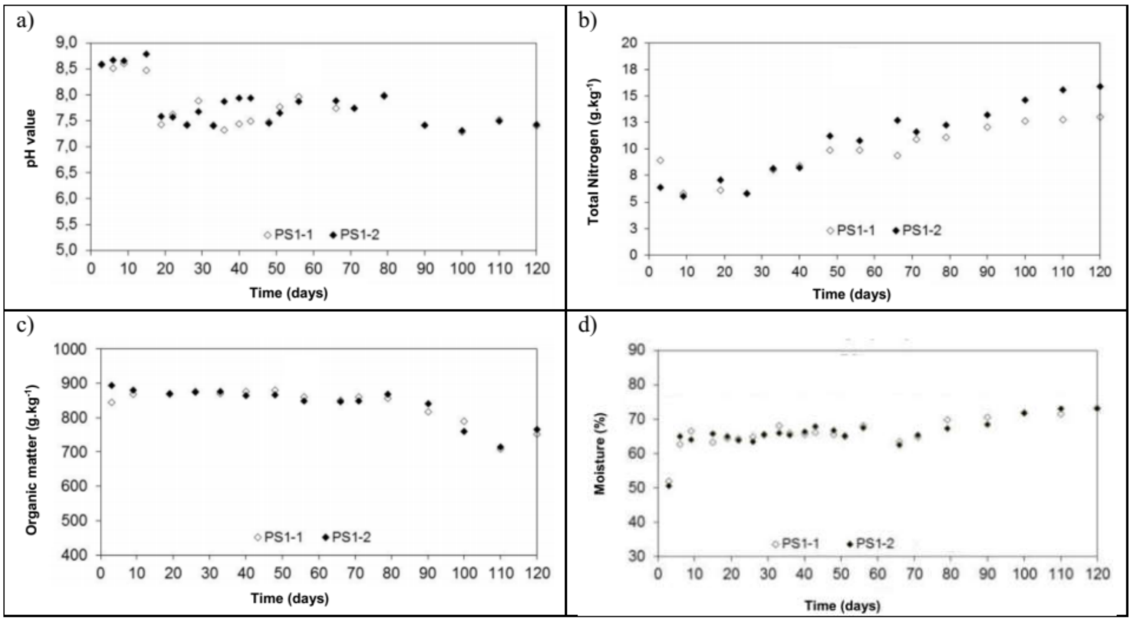
PS1-1 – Pile 1
PS1-2 – Pile 2

Although temperatures above 45ºC occurred for a short period, it should be noted that the composting process was applied to human urine stored for 30 days and the probability of occurrence of pathogens in this case is very low. Therefore, the risk of occurrence of pathogenic microorganisms results mainly from the use of bovine manure as inoculum and could be minimized by adopting a longer compost maturation time. In addition, the use of bovine manure as inoculum is only expected in the first composting cycle. In subsequent cycles, a fraction of the compound itself could be used as an inoculum after a sieving process, for example.

Figure 4 shows the time profile of other important parameters monitored during the composting process. The initial pH value in compost piles could be a problem, once that the storage of human urine for 30 days promotes the hydrolysis of the urea and consequently the elevation of the pH value to ones close to 9.0. Nevertheless, there was a marked reduction of the initial pH value of the piles between the second and fourth week (Figure 4a). It's possible to notice that the composting process with the addition of human urine developed in typical alkaline pH values during the monitored period (lowest registered value being 7.3). From a practical point of view, this aspect can be important for a rapid widespread use and for the transposition of cultural barriers of the composting process with the addition of human urine. Most Brazilian agricultural soils are acidic and often small farmers use chemical pH buffers as lime. Taking, for example, the highly exploited soils of the Brazilian savannah region (*Cerrado*) (about at least 50 x 10^6 ha), where acidity and low native fertility are chemical barriers to root growth, once soil-related constraints are removed by applying lime and chemical fertilizers, high yields can be achieved [9]. Therefore, the use of a final compound with high pH values and nutrient content could be effective as a soil conditioner and an alternative to minimize the use of chemical fertilizers reducing the environmental impacts associated with their production, transport and use.

The initial nitrogen content (dry basis) ranged from 6.3 and 8.9 g.kg^{-1} (Figure 4b). As expected, there was an increase in nitrogen contents as the organic matter was degraded (Figure 4c). However, until the sixth week, all treatments indicated nitrogen losses in relation to the initial concentration. Between the second and the third week the losses reached 36% of the initial content. Nevertheless, at the end of 120 days of composting and maturation, the minimum nitrogen concentration (13.0 g.kg^{-1}) was superior to 0.5%, which is the minimum limit required by the Brazilian Ministry of Agriculture, Livestock and Supply for all classes of mixed organic fertilizers and compounds. Oita et al. [10] defined a country's nitrogen footprint as the quantity of reactive nitrogen emitted during the production, consumption and transportation of commodities consumed within that country. The authors concluded that the consumption of commodities from China, India, the United States and Brazil is responsible for 46% of global emissions. Much of these anthropogenic inputs occur in the Brazilian *Cerrado*, but not exclusively since more urbanized regions such as the state of *São Paulo* also have high rates of nitrogenous fertilizer inputs. In the Amazon region, rates of anthropogenic nitrogen inputs are relatively low, but the continued conversion of natural forests into cattle pasture or secondary forests add a significant amount of new nitrogen to Brazil's share, given the vast area of the region [11].

Fig 4. Monitoring parameters profile during composting of coarse sawdust impregnated with human urine.



PS1-1 – Pile 1
PS1-2 – Pile 2.

Approximately 48 liters of human urine were used during the composting process including the volume required to correct the moisture of the piles. In addition, about 250 liters of water were spared by not being used in flushing toilets. Considering the lack of sanitation services mainly in Brazilian rural areas, it is an important result and may help in encouraging the full-scale adoption of EcoSan practices in Brazil.
The maximum value of C:N ratio was 26:1 at the end of 120 days. The presence of raw materials with high lignin content and, consequently, high value of C:N ratio was also a determining factor in the study by González-Fernández et al. [12]. At the end of 83 days of experiment, these authors produced a final compound that presented a C:N ratio equal to 22:1. For practical purposes, the value of the C:N ratio was slightly higher than that standardized by the Brazilian legislation (20:1) and therefore it is necessary to consider the possibility of extending the maturation time.

3.2 Evaluation of the use of human urine to obtain Brazilian fertilizer class D

Considering the mass of nutrients required to fertilize one hectare of agricultural crops at the time of planting, we attempted to evaluate the volume of human urine needed to obtain Brazilian organic D fertilizer by means of composting process. Initiatives from low-income families whose practices are aligned with the concepts of organic agriculture guided the choice of agricultural crops. Data published by the Brazilian Ministry of Agriculture Livestock and Supply show that vegetables, ornamental plants, medicinal and aromatic herbs are intensively cultivated by these families. The results are shown in Table 2.

Table 2. Volume of human urine required for organic cultivation of some agricultural crops in Brazil.

Crop species	kg N per hectare	Organic fertilizer (Ton per hectare)[1]	Demand for human urine (Liters)
Lettuce (*Lactuca sativa L.*), Sugar-beet (*Beta vulgaris L.*), Carrot (Daucus carota L.), Cauliflower (Brassuca oleracea L. var. botrytis L.), Pepper	40	2.5	$1.5x10^3$

(Capsicum spp.), Green pepper (Capsicum annum L.) Tomato (*Lycopersicum esculentum Mill.*)	60	3.75	$2.2x10^3$

1 – Dry basis

Estimates are necessary in order to have an action plan, but it is important not to forget to take into consideration the availability of organic wastes and urine, besides finding areas that are suitable for the implementation of the composting initiatives. Regarding the results shown in Table 2, it can be stated that even for organic fertilization, large quantities of fertilizers are needed to supply the nutritional nitrogen demand of the species usually cultivated. Admitting a residence inhabited by four adults eliminating between 300 and 400 mL of urine per urination each this dwelling may produce up to 6.0 liters of urine per day [12]. Considering a small rural community with 25 residences and 4 inhabitants in each house, it would take around 4 days to produce the volume of urine required for composting. Fertilizing the same area with chemical fertilizer, such as urea, for example, the amount required would be approximately 91 kg considering that urea contains 44% nitrogen. Comparing chemical and organic fertilizer only in quantitative terms, there is a great disparity between the values. Therefore, the analysis must be carried out in terms of environmental, agronomic, economic and social gains.

Chemical fertilizers, such as urea, provide only a specific nutrient, in this case the nitrogen that is known to have high mobility in the soil and that can contaminate the water table. Organic fertilizers, on the other hand, increase soil productivity because they improve their chemical, physical and microbiological characteristics. In addition to that, composting is recognized as an initiative capable of reducing negative impacts caused by inadequate disposal of organic solid waste. From a social perspective, these activities can generate employment and income, support cooperation initiatives, strengthen political ties in favor of a common interest and empower the rural population.

In Brazil, the quality specifications for organic fertilizers are in the Normative Instruction number 25/2009 published by the Ministry of Agriculture, Livestock and Supply. The legislation states that organic fertilizer class D is the one that uses any amount of raw material derived from the treatment of sanitary waste, resulting in a product of safe use in agriculture. Since human urine was used during composting, the quality of the final compound was evaluated according to the criteria of this class of organic fertilizers. However, the maximum permissible values for the physicochemical and microbiological parameters are quite restrictive due to the initiatives of composting of sewage sludge.

The maximum detected values of C:N ratio (26:1), nitrogen (16 $g.kg^{-1}$) and moisture content (72%) were slightly above the maximum values allowed by the Brazilian legislation. On the other hand, adding human urine did not adversely affect the composting process. Therefore, 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.

Although Simha and Ganesapillai [4] state that in developing countries, the focus of EcoSan action is to reduce health risks in urban, peri-urban and rural areas, recent issues like micropollutants such as medical residues and endocrine disruptors mobility in soil cannot be neglected. Further investigation is needed to describe the fate and removal of these substances before safe use in agriculture can be guaranteed [4].

4. Conclusions

The composting of lignocellulosic residues impregnated with human urine allowed to conclude that:

- The compound presented a minimum nitrogen concentration of 13.0 $g.kg^{-1}$ that increases to 0.5% in dry basis, which is the limit required by the Brazilian Ministry of Agriculture, Livestock and Supply for all classes of mixed organic fertilizers and compounds.
- The pH value of the compound is slightly basic which may be an advantage due to the acidic nature of most Brazilian fertile soils.
- The value of the C:N ratio (26:1) and moisture content (72%) were slightly higher than that standardized by the Brazilian legislation (20:1) and therefore it is necessary to consider the possibility of extending the maturation time.
- The matured compost can be used as a safe soil conditioner helping to encourage EcoSan practices, and initiatives aligned with the concepts of organic agriculture by small and low-income farmers in Brazil.

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