Composting of solid waste from the coffee milling process using trench composting and a bioreactor with the help of efficient microorganisms in the Libre University, Socorro headquarters

Compostaje de residuos sólidos del proceso de molienda de café utilizando compostaje en zanja y bioreactor con la ayuda de microorganismos eficientes en la sede de Libre Universidad Socorro

Compostação de resíduos sólidos do processo de moagem de café utilizando a compostação de trench e um bioreator com ajuda de microrganismos eficientes na Universidade Libre, sede Socorro

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Abstract

Introduction: The present article is the product of the research "Use and management of organic waste from the Majavita farm, Universidad Libre, Socorro Headquarters (Santander)" carried out during 2017 and 2018 in Socorro, Santander.

Problem: Currently, the Libre University possesses a trench compost management system to prevent contamination that can be caused by a poor disposal of the solid waste coming from the milling of coffee; this does not imply the production of an optimum product that shall have the quality standards of a suitable compost.

Objective: Propose an alternative to operate the compost process under suitable process variable conditions; The hope is to provide a more efficient compost process.

Methodology: This article compares the effectiveness of composting production in a traditional trench system against a semi-closed bioreactor system, and the cost-benefit of implementing this proposed system.

Results: To guarantee the result by showing the improvement of the process; it is necessary to follow and compare the behavior of the process variables in each kind of composter, such as temperature, moisture, and ph.

Conclusion: This project seeks to propose a viable alternative for the treatment of the solid waste of the milling process of coffee.

Originality: This research seeks to improve the process of composting in the Majavita Farm.

Limitations: The time used by the farm to compost the solid waste using a traditional system.

Keywords: Composting, Coffee, Solid Waste, Bioreactor, efficient microorganisms.

Resumen

Introducción: el presente artículo es producto de la investigación "Uso y manejo de residuos orgánicos de la finca Majavita, Universidad Libre, Sede Socorro (Santander)" realizada durante 2017 y 2018 en Socorro, Santander.

Problema: actualmente la Universidad Libre, ofrece un sistema de manejo de compostaje tipo zanja para prevenir la contaminación que se ocasiona por la mala disposición de los desechos sólidos provenientes del beneficio del café; pero esto no implica la producción de un producto óptimo que tenga los estándares de calidad de un compost adecuado.

Objetivo: proponer una alternativa para operar el proceso de compostaje bajo condiciones adecuadas de las variables del proceso; esperando que esto permita que los desechos se transformen en abono de manera más eficiente y en menos tiempo.

Metodología: este artículo compara la efectividad de la producción de abono en un sistema de zanja tradicional contra un sistema de biorreactor semicerrado, así como el costo-beneficio de implementar este sistema propuesto.

Resultados: para garantizar el resultado de una mejora del proceso; Es necesario seguir y comparar el comportamiento de las variables del proceso en cada tipo de sistema de compostaje, como temperatura, humedad y ph.

Conclusión: este proyecto busca proponer una alternativa viable para el tratamiento de los residuos sólidos del proceso productivo del café.

Originalidad: esta investigación, busca mejorar el proceso de compostaje en la Finca Majavita.

Limitaciones: el tiempo que emplea la finca para compostar los residuos sólidos mediante un sistema tradicional.

Palabras clave: compostaje, café, residuos sólidos, biorreactor, microorganismos eficientes.

Resumo

Introdução: este artigo é o produto da pesquisa "Aproveitamento e gestão de resíduos orgânicos da Fazenda Majavita, Universidade Livre, Sede Socorro (Santander)" realizada durante 2017 e 2018 em Socorro, Santander.

Problema: atualmente a Universidade Livre oferece um sistema de gerenciamento de compostagem tipo trincheira para evitar a contaminação causada pelo descarte inadequado de resíduos sólidos do processamento do café; mas isso não implica a produção de um produto ideal que atenda aos padrões de qualidade de um composto adequado.

Objetivo: propor uma alternativa para operar o processo de compostagem em condições adequadas às variáveis do processo; esperando que isso permita que os resíduos sejam compostados de forma mais eficiente e em menos tempo.

Metodologia: Este artigo compara a eficácia da produção de composto em um sistema de trincheira tradicional com um sistema de biorreator semifechado, bem como o custo-benefício da implementação do sistema proposto.

Resultados: garantir o resultado de uma melhoria de processo; É necessário acompanhar e comparar o comportamento das variáveis do processo em cada tipo de sistema de compostagem, como temperatura, umidade e pH.

Conclusão: este projeto busca propor uma alternativa viável para o tratamento de resíduos sólidos do processo de produção do café.

Originalidade: esta pesquisa visa aprimorar o processo de compostagem na Finca Majavita.

Limitações: o tempo que a fazenda leva para fazer a compostagem dos resíduos sólidos em um sistema tradicional.

Palavras-chave: Compostagem, café, resíduos sólidos, biorreator, microorganismos eficientes.

1. Introduction

Composting is an environmentally sustainable alternative to the treatment of organic waste, which has a positive environmental and economic impact, and improves the soil through the application of the product obtained [1]. Coffee is one of the most popular beverages in the world [2]. Colombian coffee is recognized for its special characteristic and nutritive value [3] and is an important product for the country's economy [4]. In the coffee productive process, several kinds of waste are generated. This waste is principally the parchment of the coffee, the mucilage and the cherry [5].

It is a potential pollution source for nearby soils and the watershed to harvest fields [6]. The present study was done in the Majavita Farm, in Socorro, Santander where the Socorro headquarters of the Universidad Libre is located. Here, different kinds of agricultural products are harvested, one being coffee, which is harvested once a year in the second semester.

Currently, the research center of the Universidad Libre in Socorro is making advances in processes to avoid the pollution caused by this waste, both liquid and solid. In the case of the cherry, it is mainly the high concentration of sugars [7] as well as with the mucilage [8]. The mucilage is treated after the pulping process in the residual water treatment plant of the farm [9] and thanks to the properties of the fruit - like in other agricultural products [10] - this can be used to transform it to produce economically useful products [11]. One of these is through an optimum compost process, generating soil fertilizer. The transformation is usually done in trench composters, like in the rest of the region [12] and requires a manual and non-automatized process, similar to other regions in the country [13].

In this article, the intention is to show how to improve this process to get optimum results, through the control and tracking of the several variables associated to the process, for the specific case of the husk or fruit of the coffee, by-product of the milling process. The analysis is done for the traditional compost system as well as the prototype designed for the project. Both used the coffee pulp by-product of the harvest of 2017 and the behavior of the different variables was observed. At the end, the proposed system performed better and, from this, a system for the management of the total coffee husk production in the farm was designed, establishing the cost/benefit of its implementation from the results.

2. Research background

As was shown in some applied studies, using the coffee waste generated a benefit [14]. This can become an excellent source of compost for the soil that can decrease the inherent environmental impact of the coffee production process [15]. Using several waste concentrations, searching for the optimum combination, Betancurt et al. [14] showed that "complying with the nitrogen and potassium requirements established in the NTC 5167 was T1 (95% of coffee pulp and 5% organic lime), while not complying with the minimum level of P" generating an acceptable compost to improve the soils.

In addition, Sánchez, Galán, Mercado and Olguín [16] compared the performance of a compost process of coffee pulp without any additional substratum, with a composting process in a similar pile, in which sheep excreta was added to the mucilage generated by the milling. The addition of this organic matter sped up the process, improving the quality of the obtained compost in terms of nitrogen, potassium, and humid acids content. Like this, some studies emphasize the importance of the Microbes as a vital additive for solid waste compost [17] and even the benefit of applying biochar [18].

Another important antecedent was studied in the same Universidad Libre. The principal goal was to build an experimental horizontal bioreactor of fixed bed and rotating drum, fed by photovoltaic energy, for the production of compost coming from the *Azolla filiculoides* and *TypHa latifolia* from the Chocolate lagoon in the Une municipality in Cundinamarca [19]. Throughout the compost process, the temperature is a fundamental variable to allow for degradation, microbial growth and vector inhibition [20]; Thanks to the coffee pulp properties, it is an excellent source for the cultivation of mushrooms [21]. Being outdoors, the variations of the temperature between the day and the night, as in each shoveling, affect the substrate and do not allow for keeping an optimum temperature range for the development of the microbial population. Some studies regarding the compost process model [22] show how the environmental temperature can slightly affect the temperature in the substrate even in closed conditions and how the degradation kinetics vary notably with the temperature variation. For this reason, it is supposed that there are high variations of temperature in outdoor conditions, resulting in a part microbial population inhibition in each variation with decreased kinetic factors. This causes the molecules of the degradable lignin and holocellulose [23] to not completely degrade into assailable monomers, ending in the result of not producing a quality compost and not being assimilated completely by the plants. For this reason, some authors position bioreactors as the most efficient technology for the compost process [24].

In the Table 1, the moisture percentage in the coffee husk and the chemical composition of the dry substrate can be appreciated. Arias & Meneses [25] show similar results to Hernandez et al. Some authors like Alonso [26] focus on the chemical composition in the volatile organic material, registering this as 73.2%, although it should be noted that the study was done with the *Arábica-Robusta* population and not pure *Arábica*. Other authors like Shemekite [27] investigated the chemical composition focus in the produced compost from this waste.

Table I. Dry coffee husk composition.

Moisture	Crude fiber		
	Holocellulose		Lignin
	Cellulose	Hemicellulose	
11.6 ± 1.8	32.56 ± 2.00	28.66 ± 2.30	26.40 ± 1.10
	61.22%		
	87.62%		
99.22%			

Source: Adapted to Londoño et al. [23]

In the Majavita farm, the composting was performed in little trenches; the artisanal way. This process is inefficient because it does not supply the production of solid waste; the complete process of degradation lasts about 2 months and is usually not completed. These problems of efficiency in volume and time in the treatment process make it necessary to design an alternative process; one that offers an efficient degradation of the substrate, in short periods of time, to provide the maximum exploitation of the volume of total waste generated and in a process that is automated as much as possible. This will allow for an optimal performance of the several variables in the compost stages, to ensure the production of a high-quality compost in a short time. Therefore, the design of a compost process bioreactor and the use of efficient microorganisms (EM) is proposed, to modify the substrate microbial population into one that produces beneficial substances for the soil [28].

3. Materials and methods

The investigation project has been in the compost zone of the Majavita farm, property of the Universidad Libre, located in Socorro, Santander in the harvest season of 2017. It lies at an elevation of 1350 meters above sea level, a 7° north latitude and 73 ° west longitude, with an average temperature of 24°C. The investigation is quantitative and qualitative; the variables to analyze in the project are the compost process variables (pH, temperature, moisture) in each system.

Collection of the data during the investigation was performed through fieldwork, with analysis in situ and sampling and laboratory analysis. Sampling of the coffee husk solid waste was made across the stages of the process in both systems. The

average, maximum and minimum value, trend line and the standard deviation of each variable to both systems was calculated. The process is detailed below:

- Visit to the farm to evaluate the volume of waste produced, the compost process and the climate and topographic variables of the zone. Then the necessary volume to keep the variables substrate in the desired range in the bioreactor compost system and the materials to build it was calculated.
- According to the calculations, a semi closed prototype of a bioreactor compost system was designed and built.
- After, the substrate was added to this along with the efficient microorganisms.
- The moisture, pH and temperature were recorded in both the bioreactor system and in the trench system.
- The generated data in both systems was compared, providing technical criteria to contrast the efficiency in each one and establish the financial benefit of the bioreactor compost system.

3.1. Bioreactor system

Using a semi-open compost system, as expected, the variables behaved better, accelerating the process as well as not evidencing the proliferation of vectors. A polyethylene plastic trash can of 80 liters was used. It was chosen for its market availability, low cost, physical resistance and low thermal conductivity; 0.42 to 0.51 W/mK (Watt per meter Kelvin).

Figure 1. Profile and plan view of bioreactor compost system prototype in meters.

Source: own work

Figure 1 shows the design of the modified trash can; approximately 40 holes were made in the bottom with a $\frac{1}{4}$ inch drill to allow for the flow of process leachate and retain the moisture stored in a 50-liters trashcan that was installed below the base. Equally, to allow for the correct air rate for the substrate and ensure the minimum of oxygen, as well as the gas exchange with the outside and keep the temperature; a one meter PVC tube of 1- inch diameter was installed perpendicularly to the surface at the top center. This came down near to the bottom and protruded 0.3 meters above the top so that it could be removed to feed in the substrate and take out the compost. It was also drilled with some $\frac{1}{4}$ inch holes. 5 plastic blades were also installed across the PCV tube; at 20 cm in each side and located every 8 cm of distance. These were used to turn them and ensure the homogeneous aeration of the substrate. For the addition of the efficient microorganism, a local product called Sabia was used, due to its availability in the area. According to the indications of use, one glass was diluted in 1 liter of water and was added to the substrate.

Figure 2. Bioreactor compost system for solid coffee waste treatment.
Source: own work

3.2. Trench compost system.

The Universidad Libre has 9 trenches for the treatment of this type of waste, as can be seen in Figure 3. They are formed of 3 groups of 3 trenches. Each trench has an approximate length of 3.7 meters, are an average of 1 meter in width and 0.8-meters deep. The trenches are parallel to each other and the trench groups are placed alongside each other. Lime is added to regulate the pH and two people flip the contents with a shovel two times a week to ensure the aeration, rotating the compost from one ditch to another as per the development of the process; each trench corresponds to one stage of the process and ensures continued entry space for new waste.

Figure 3. Profile and plan view of the traditional trench compost system in meters.

Source: own work

This generated considerable temperature loss and is also very laborious work. When the collection and the processing of the coffee starts, the waste is put in the first trench until it is full. When new waste arrives, the old waste goes to the next trench and the new waste is put in the first trench. This continues until the waste passes through every trench to the last. This process takes around 30 days; not enough to ensure a total degradation of the substrate. The study monitors the full waste trench system, from the first trench through to the last.

Figure 4. Presence of larvae in trench system for the treatment of solid coffee waste.

Source: own work

3.3. Measurements

55kg of waste was passed through the Bioreactor system and 2 tonnes of waste passed through the trench system. Both systems were in the same place in the farm and the process was started at same time for both systems as well as the monitoring of moisture, pH, and temperature. According to this, the sampling period in the trench was for 30 days, corresponding to the average of time used to do the process across the 9 trenches. The sampling in the bioreactor system was done until the variables attained the same values as those reached by the trench system in the 30 days; this resulted in a monitoring time of 15 days in the bioreactor system.

Due to the lack of a guide for sampling the compost process, the sampling was done following Resolution No. 0062 of the IDEAM [29], "By which the methods of sampling and laboratory analysis are adopted for the physicochemical characterization of waste or hazardous waste in the country". Although this is not hazardous waste, the sampling methods proposed in these guidelines are statistically ideal, due to how these wastes are stored; in piles and tanks.

Temperature sampling was carried out in situ, twice or thrice a week through 2 thermometers, one analog and the other digital. A systematic sampling was carried out taking 5 sampling points along both systems, each point was at the same distance, the process was carried out as follows:

1. Checking for normality and non-disturbance in the systems.
2. Calibration and verification in the 2 thermometers, ensuring that the measurement was always similar (+ - 10 degrees).
3. Identification of the points and taking of temperature with each thermometer at a depth of 0.30 meters; the average of both was the value of the temperature in each point, and then, the final temperature of the system was the average of the temperature value in the different points.
4. Tabulation, graphing and analysis of the data collected.

For the sampling of moisture and pH, stratified and composite random sampling for each system was performed, to allow for a subsequent ex situ analysis. 15 representative samples in relation to the volume of each system were taken, taking samples of approximately 20-grams in the bioreactor system and of approximately

50-grams in the trench system. 3 random samples were taken in the area around each one of the 5 points, measuring the temperature. In each area, the samples were taken at the same depth but each area had a different sampling depth, one deeper than the last, from a depth close to the surface to a depth close to the bottom of each system. At the end, the 15 samples have been collected and mixed with a final sample of approximately 300-grams for the bioreactor system and 750-grams for the trench system. The respective laboratory tests performed for the result of these mixed samples, were collected on the same day in the installations of the Universidad Libre. The pH test was done via the potentiometric method, following NTC 5264:2018 [30], taking 20 grams of each final sample and diluting in 20-mL of distilled water. After the respective calibration, the readings were taken with a multi-parameter water meter. The gravimetric technique was used for the moisture test following NTC 6230:2017 [31]. 80 grams of each sample was taken and dried in the muffle oven at 105 °C for 24 hours, the difference between the initial and final mass in the process corresponds to the moisture percentage in each system. Figure 5 and Figure 6 show the sampling technique used in both systems; the points of the temperature sampling are in green and the areas around this denote the different sampling locations for the pH and moisture tests:

Figure 5. Methodology of sampling in bioreactor system.

Source: Authors of the project (2017).

Figure 6. Methodology of sampling in system.
Source: own work

4. Results

After the tracking of both systems, with their respective measurements and laboratory tests, the collected data was presented in graphic form to contrast the behavior of the variables during the compost process in both systems:

4.1. Temperature

In Figure 7, the tendency of the two graphs to form the typical curve of a composting process [20] can be seen. Both processes start at 20 °C. The trench system reaches a peak of 54 °C at 15 days and it remains at this level for 5 more days until day 21 and then enters the stabilization stage. In the bioreactor system, the peak is reached in a period of 10 days, with 44 °C, 10 °C less than in the trench system, possibly because the volume of the substrate is not as large, thereby generating less heat in the decomposition process. Besides, because the little size and the geometry of the bioreactor system generated that more percentage of the substrate was in thermal exchange with the exterior and inclusive with a material with little thermal exchange like the polyethylene, this ends in peak of 10 °C less than in the trench system. Next, the temperature behavior during the compost process in both systems is shown:

Figure 7. Temperature curve in the bioreactor and trench compost system.
Source: own work

Followed by its stabilization period, the process in the trench system after 30 days dropped to 34 °C. It did not drop below 30 °C, indicating that the process was not completed. Although the appointed time to the process had already concluded, the temperature in the bioreactor system reached a similar value after only 15 days. However, the process in both was rapid and the peaks of thermophilic temperature was reached in less than a month, compared to other studies in similar geographical conditions, in which the peak was reached near the fifth week [32]. Nevertheless, between them, the bioreactor system turned out to be more efficient with regards to the time necessary to complete the thermophilic phase and start the second mesophilic phase. That can be evidenced with the time that was necessary to increase the temperatures until reaching the peak, and equally the time necessary to complete the thermophilic phase and start the descent of the temperature, as an indicator of the change of phase. However, because the measurements were done each 5 days and the process in the bioreactor system was faster, the graphic looks like it only reaches the maximum point and starts to decrease, but the process could stay in this phase for a few days before decreasing, and could have even reached a higher temperature and have a higher peak. For this, the temperature curve probably was as expected, but for the fast process and the frequency of the measurements it could not be appreciated. This shows that the shovelling performed in the trench system and maybe also the loss of temperature at night affect the process, and the degradation is faster with a low but continuous temperature rather than with a higher initial temperature followed by a decrease of it. In addition, the standard deviation is closer to the one in the bioreactor system; this shows a lower dispersion of the data, which shows a more stable behavior in the process.

4.2. Moisture percentage:

The moisture behavior in both systems is shown in Figure 8:

Figure 8. Comparative Graph moisture percent in both composting systems.

Source: own work

Analyzing Figure 8, it is evident that both processes began with a moisture of 80%; quite high for the process. This then diminishes throughout the process in the two systems indicating that the composting process is occurring in both systems [20]. However, if the number of days is detailed and contrasted with the decrease in the percentage of moisture, it can be seen that the bioreactor system reached a moisture of 70% at 10 ten days, compared to the 22 days it took for the trench system to achieve the same percentage. The moisture behavior again demonstrates that the degradation process has occurred faster in the bioreactor system, and again the standard deviation is closer to one in the bioreactor system, showing a more stable behavior in this process.

4.3. pH behavior:

Below in Figure 9 is the behavior of the pH throughout the process for the two systems. Both show the typical behavior of the expected pH in the composting process [20], where it starts acidic, decreases a little more and then increases in scale until normalizing and reaching a neutral pH. This, like the previous items reflects that in the two systems the composting processes were carried out and although the total composting process did not end, it reaches the point that provides consistent data for an analysis. As can be seen in both, the pH starts at 5.5. For the bioreactor system, the pH continued to drop to 4.7 and then increases to the expected stabilization pH, that is, 7, over a period of 10 days. For the trench system, this drops a little more to 4.5 and begins to increase, but it takes the pH 30 days to reach the pH of 7. The pH is an indicator of process maturity; this shows us that in the bioreactor system this

occurs at a faster rate. For this specific parameter, the standard deviation has been shown to be less in the bioreactor system; although it should be considered that the pH decreased more before beginning to increase.

Figure 9. pH graph in the bioreactor and trench system.

Source: own work

4.4. Cost benefit relation:

The annual cherry and parchment coffee production of the years 2014-2018 in the Majavita farm are presented in Table II. On average 65.2 Tonnes of cherry coffee by year were processed, in which were obtained on average 13.39 Tonnes of parchment coffee. This gives a relation of 20.48% in weight; that is in the expected range [30].

Table II. Coffee production 2014-2018.

Year	Tonnes Cherry Coffee	Tonnes parchment Coffee	Parchment / Cherry relation	Tonnes Of Husk
2014	82.25	17.71	21.53%	35.36
2015	55.68	11.56	20.76%	23.94
2016	72.64	14.63	20.14%	31.23
2017	66.71	13.20	19.79%	28.68
2018	48.71	9.84	20.20%	20.94
Average	65.20	13.39	20.48%	28.03

Source: Universidad Libre (2019).

According to the conversion coffee factors IN the milling process accepted by Cenicafé [30], the fresh pulp corresponds to the 43% in weight, for the coffee cherry for the Colombia variety. In the same table, the theoretical annual production of this waste can be seen, because measurements are only performed on the cherry and parchment coffee generation. This results in a maximum waste production of 35.36 Tonnes.

Figure 10. Weekly annual waste production per last five years.

Source: Universidad Libre (2019)

Likewise, from the historical data of the weekly coffee cherry collection, the weekly waste generation for each year was estimated, as can be seen in Figure 6. Each year has a peak approximately in the middle of the collection. For the selected year, this means a peak of 19 083.1 Kg in one month. Some studies show the Arabica coffee husk has an approximate moisture of 86% [34]; others put this at 75% [35]. In the

specific case of this study, a moisture of 80% was recorded. That is the same before and after the pulping process in the belcosub module as water is not used in this part of the process [36].

For the compost process, several authors recommend [35] that the maximum moisture reached should be 70%. For this moisture, this means a proportion in weight of 3.816 Tonnes of dry waste for 8.905 Tonnes of water, for a total of 12.722 Tonnes of residue. The apparent density of the coffee fruit is 299.74 kg/m³ [33] and for the water is 997kg/m³. Dividing each weight with its respective density, gives us the occupied volume for each one; this being 8.93 m³ for the water and 12.73 m³ for the dry waste. It means a total of 21.66 m³ wet waste. The free air space that is needed to ensure the correct aeration in the compost process is 30% [20]. In this way, for the monthly compost process of 12 722 kg of waste with moisture of 70%, a total volume of 30.95 m³ is needed.

Table III. Bioreactor proportion.

Mass and volumetric proportion in the reactor for a 70% moisture		
Variable	Mass (kg)	Volume (m³)
Dry waste	246.0	0.821
Water	574.0	0.576
Waste	820.0	1.396
Free Air Space	0.72	0.598
PVC	1.6	0.004
Total	1642.32	1.999

Source: own work

To carry out the project, 2000L Polyethylene bins were selected, each 1.55 meters high and 1.52 meters in diameter at the widest part, to allow enough waste to be stored to reach the desired temperatures. In this way taking the 30.95 m³ of the necessary space, divided by the net volume of the tank that would be 2 cubic meters less than the volume that would occupy the PVC pipe of two inch in diameter, that would be 0.004 m³, gives us 30.95 m³ divided into 1.994 m³.

$$\frac{30.95 \text{ m}^3}{1.994 \text{ m}^3} = 15.52$$

This gives us 15.52 containers; this mean 16 containers are required to meet the maximum demand and there would be plenty of space in case of any eventuality. These can be arranged in two groups with two rows of 8 containers. In Figure 11, the profile and plan view of the bioreactor compost system in meters for the whole waste production are detailed. In the middle of the two rows is located a structure of 1.2 meters of elevation, to supply the substrate in the top of the system with a wheelbarrow. In the bottom of each dustbin is located a gutter to evacuate the leachate product of the compost process to a central gutter. Just as in the prototype system, the dustbin bottom must have holes around the PCV tube to allow for the flow of this fluid. Those central gutters are to the sides of the central structure and ends in a PVC plastic tube to avoid the rainwater getting in. After this, the leachate can be stored or gravity driven to the residual water treatment plant of the farm. Likewise, the dustbins have a bypass valve at 0.05 meters high, to evacuate the substrate in the ground to be placed in the wheelbarrow after.

Figure 11. Profile and plan view of bioreactor compost system.

Source: own work

In orange, is the occupied area for the traditional system. The occupied space for this is 48m² in comparison with the 71 m² of the bioreactor system; this provides 47.91% more space. Nevertheless because of the elevation necessary to feed the system, a ramp is necessary to elevate this from the ground. For a flat surface, this means more 26.5m² to build this, as can be seen in Figure 6.

Table IV. Initial Project Cost.

Input	Quantity	Unit price	Total
2 m ³ eternit plastic dustbin	16	\$355 491	\$ 5 687 856
Pvc Soldamax 1/16 Gallon	1	\$19 040	\$19 040
3-inch neoprene packing	32	\$6 900	\$220 800
50 meters Teflon tape	1	\$8 300	\$8 300
Meter of 2-inch pvc tube	32	\$7 483	\$239 456
3-inch diameter smooth bypass valve	16	\$85 000	\$1 360 000
3-inch pvc flanges	32	\$47 863	\$1 531 616
½ x 3-inch hexagon screw with nut	64	\$4 900	\$313 600
Meter of 3-inch pvc tube	10	\$17 000	\$170 000
3-inch pvc elbow	2	\$4 700	\$9 400
m2 Roof tiles	85	\$21 267	\$1 807 695
Meter of 3/8-inch zinc threaded rod.	32	\$6 900	\$220 800
12 units of 3/8-inch zinc hex nuts.	11	\$4 312	\$47 432
Workday to assemble the system.	2	\$29 260	\$58 520
Civil work of the soil	1	\$6 500 000	\$6 500 000
TOTAL			\$18´194.515

Source: own work

Finally, four 0.5-meter Zinc Threaded Rods of 3/8 inch were selected for the blades of the dustbin and for the soil an underlayment plate with bait filler is necessary to support the weight of the waste and avoid the soil sinking; other more environmentally sustainable materials can also be considered [37]. In this way, in Table IV, the initial project cost can be seen to be \$18´194.515 COP. The cost of the project does not include the cost of the ramp, the support structure in the middle and the roof tiles. This is because, firstly the coffee harvest it is located in mountainous areas and the structure can be built in an area that takes advantage of the natural slope of the area thereby avoiding the need to build a ramp. Secondly, because the structure can be built with materials such as concrete, metal and even in wood, these could make variations in the cost. The price of the civil work of the soil in the table, is the price that usually has this the type of projects in the market.

For the use of efficient microorganisms, the dilution must be made at a ratio of one liter of SAVIA, (which is the name of the product) for 20 liters of water to degrade a ton of waste; that is, 12 722 liters of SAVIA are required to degrade the 12 722 Tonnes of

waste. Considering that the product is sold per Gallon, and that one Gallon is equivalent to 3.78541 Liters, making the relationship between the elements gives us a total of 3.3 Gallons to degrade the waste corresponding to a month, leaving 19.01% extra product for eventualities.

Table V. Monthly maintenance project cost.

Input	Quantity	Unit price	Total
Hour Work	2	\$3 658	\$7 316
Gallon of Efficient Microorganisms	4	\$45 000	\$180 000
TOTAL			\$187 316

Source: own work

Since the beginning, the effort required of two people to deposit the material in the bioreactor system requires less work than in the trench system; this also applies to its extraction this. This equates to approximately one hour per person at the beginning and at the end of the process. In addition, the time required to turn the blades of the system and adapt each reactor weekly is approximately 1 minute per reactor. Using two people a week would need 8 minutes for both, compared to the two hours currently taken by these two people to adapt the substrate twice a week. Thus, the work needed in a month would be approximately an hour per person compared to the 16 currently required. This would result in a saving of 15 hours per month per person. The monthly maintenance project cost is show in the Table VI.

Regarding the process variables, the temperature decreased after reaching the thermophilic peak in the trench system in 21 days while in the bioreactor system it was after 10. As for the pH, the expected level was reached in 30 days for the trench system and 10 for the bioreactor system, and finally in terms of moisture, the trench system reached the minimum value in 22 days while the bioreactor only took 10. Thus, it is clear to see that the variables in the bioreactor system reach the expected behavior in less time that it takes for the trench system to reach the same values, that shows that in the bioreactor system the degradation process is faster. In this way, the cost benefit would be an initial cost of \$18'194.515 COP and a monthly maintenance would cost \$187 316, with a benefit of less time needed to compost the substrate and reach the desired value for the several variables. Taking the last value reach in each variable in the trench compost system after the 30 days, and through the linear regression of the trend line of the several variables in the bioreactor system, the exact time needed to reach these same values could be found; as it can result in non-integers numbers of

days, the time is displayed in relation to the percentage of time required in the trench system. In this order; the bioreactor system reaches the 34.5 °C in 49.45% of the time, the pH of 7.03 in 38.78% of the time, and the moisture of 63.23% in 55.93% of the time. On average the three variables reach the values reached by the trench system after the 30 days in 50.59% of time; this means on average a 49.41% faster process compared to the time required in the traditional system.

5. Discussion and conclusions

Through the analysis of the two composting systems, it was possible to demonstrate a more stable behavior of the variables in the bioreactor system when compared to the trench system. The measurement has been made in days; unfortunately this could not be performed in hours so as to see the day versus night behavior. The time in which the typical curve of the composting process was produced for each variable was shorter in all in the bioreactor system. Is important to mention that the addition of only efficient microorganisms in the bioreactor system produced great benefits in improving the decomposition time of organic matter compared to the traditional additives handled and coordinated by the Universidad Libre for the trench system, such as caldolomite, ashes or lime, to maintain the ideal pH behavior.

As it can be seen in the graphs, the composting process in trench system lasts more than a month to reach a final maturation. In the farm not one procedure is carried out to ensure that the process has already reached its end. Therefore, this shows that in a month period, the produced compost is not completely ready, and this can affect the quality of the soil that is fertilized with it. On the contrary, in 15 days the bioreactor system process shows a remarkable progress over half of the time and the final maturation is expected to have been reached within the 30 day period. Even so, in both systems a normal behavior was observed regarding expected common composting process. However, as could be seen, the proposed reactor system was more efficient, thus presenting a viable alternative for composting the solid waste (fruit) of coffee coming from the milling process. It therefore serves as a point of reference about how to improve a traditional composting process, increasing the speed and effectiveness and this respective cost. As this is one of the main agricultural production products in the country, it would improve the soils with which it is cultivated and the product generated in the coffee farms, giving a value added to the coffee and in case of mass

production, a potential green bond. Finally, thanks to the obtained results and, in the search, to optimize the process, the following bullet points have been recommended:

- The incorporation of other improved techniques that have not been considered in this investigation and could be beneficial for the process, such as the use of forced convection air flow [36] to increase the effectiveness and oxidation level of the efficient microorganisms existing in the system and even the reflow of the product gas of the process [39].
- In the thermophilic phase of the bioreactor process, the highest temperature reached was 60 °C and not 70 °C. This is necessary to ensure a complete sanitation of the substrate. If reviewed by the literature, it is recommended for a compost pile to have a height of not less than one meter to maintain the appropriate temperature, therefore it will be taken as a reference point to a prototype bioreactor system because the proposed bioreactor meets this value.
- The moisture of the substrate after the process can be reduced by adding dry materials that allow for stabilization or another process that allows the substrate to dry before starting the process.
- In the framework of the waste recovery process, other by-products of the coffee production process, such as honey waters, could not only have been treated to avoid contamination, but also it could be used to generate added value. Even, in its absence, sludge from the treatment system also could have been analyzed to include them in an integrated composting system of the by-products of the coffee benefit in the farm.

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