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Article

A Strategic Plan for the Treatment of Organic Waste through Composting by Rural Householders in Santa Elena, Ecuador

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ABSTRACT

Increased levels of organic waste represent a global challenge due to increasing populations and inadequate methods of waste management. Waste treatment methods such as composting help to reduce pollution and improve land use. This study aims to develop a strategic treatment plan involving the classification and management of organic waste. This study also introduced artisanal composting prototypes for use by rural householders in the Ecuadorian province of Santa Elena. The methodological approach had three phases: (i) the identification of inadequate management of organic waste in rural homes; (ii) the design of composting prototypes; and (iii) the design of functionality in the management of the composting process. The results showed the following: In the first phase, a significant relationship between the classification and management of organic waste was established. This phase found that 74% of the people surveyed classified household waste and practiced composting techniques. In the second phase, it was found that Composter Prototype One achieved temperatures of 43 ℃, 52 ℃, and 27 ℃ in the mesophilic, thermophilic, and cooling phases, respectively, and Composter Prototype Two achieved corresponding readings of 42 ℃, 61 ℃, and 27 ℃, indicating increased microbial activity which is ideal for the composting process. Regarding economic analysis, in the third phase, the results obtained a positive net present value (NPV) of USD 22,027.24, an internal rate of return (IRR) of 27.22%, and a profitability index (PI) of 1.83. The composting project is feasible because its circular economy model refers to positive financial returns that drive increased employment opportunities.

KEYWORDS: organic waste; composting; circular economy; rural homes

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ABBREVIATIONS

NPV, net present value; IRR, internal rate of return; PI, profitability index; SDGs, sustainable development goals; pH, potential of hydrogen

INTRODUCTION

In recent years, increased production of solid waste resulting from worldwide economic development and population growth has led to a growing interest in the production, management, and treatment of waste [1]. Today, there is particular interest in the utilization of various productive processes which are suitable for those on low- and middle-level incomes and which offer economic, environmental, and public health benefits by converting waste into hygienic products, thereby diverting it from disposal sites and providing a source of income [2].

Organic wastes are degraded naturally by biotic and abiotic factors, and may be classified as either plant-type or animal-type [3,4]. Organic waste includes green waste, human waste, manure, sewage, and slaughterhouse waste [5,6]. Worldwide, the generation of solid waste of all kinds is increasing, presenting a challenge on a global scale; however, organic waste makes up the greatest proportion of solid waste [7]. In light of this, composting may be regarded as an efficient method for converting organic wastes into fertilizers and thus mitigating pollution [8].

Worldwide, the generation of solid waste of all kinds is increasing, presenting a challenge on a global scale [9]; however, organic waste makes up the greatest proportion of solid waste. In light of this, composting may be regarded as an efficient method for converting organic wastes into fertilizers and thus mitigating pollution.

Solid waste management is, then, a challenge facing the world today. In addition, the mismanagement of solid waste may cause new threats to the environment and to human well-being, especially in rural areas [10,11]. The United Nations (UN) has stated that in Latin America and the Caribbean, solid waste production has now reached almost 540,000 tons per day, due to poor management. The UN has also estimated that this will increase by 25% by the year 2050 [12,13].

Composting is a biological [14] process which develops under aerobic conditions in which organic substrate is stabilized and converted into a product with fertilizer properties [15,16]. Composting organic waste benefits soil fertility and plant growth, helps soil to retain moisture [17], reduces the need for chemical fertilizers, and reduces methane emissions from landfills [18]. There are several types of composting process commonly used today; these include the use of a composter, as well as composting in tunnels, containers, or rows [19].

When using a composter, temperature, aeration, moisture content, particle size, and pH must all be considered. The choice of temperature affects composting efficiency [20,21], influences the evolution of the composting process, and determines the relative advantages enjoyed by microorganisms [22]. Typical composting temperatures range from 40 to 65 °C [23]. Aeration provides oxygen and promotes evaporation of excess moisture from the substrate, increasing microbial activity [24].

More and more municipalities are implementing initiatives to divert food waste through organic waste management programs at both regional and national levels [25]. Home composting has evolved from a hobby to a scientific technology, and differences between rural and urban strategies are now evident. Because waste management programs often require significant investments, home composting may now make an essential contribution to waste management in rural areas [26], if adequate levels of education and infrastructure are provided.

At the international level, the "I National Composting Plan 2020–2050" produced by the National Environmental Council of Costa Rica [27] highlighted the importance of developing a strategic plan to promote jobs through composting. In the Costa Rican canton of Alvarado, in Cartago province, 92% of farmers use compost at least once a year. In addition, the CoopeTarrazú Cooperative processes coffee weeds into compost for its members, and other companies generate compost on a medium or small scale, either for their own consumption or for local sale. Approaches such as these encourage commercial initiatives for the treatment of organic waste, lead to the generation of competitive products, and provide support for community projects such as vegetable gardens and composting centers.

In Colombia, the study by Hernandez [28] on the "Strategic plan for the use of residual compost for the agricultural company del Alto S.A.S." recommended transforming residual compost into organic fertilizer for mushroom crops, guaranteeing viability and technical innovation. Building compost bins on the company's land has reduced costs by eliminating leases and optimizing labor, and has led to the generation of 59 tons of residual compost each month with a profitability value of 2.45.

In Ecuador, the paper "Financial, economic and social evaluation of the project for the creation of the EMAC EP composting plant" by Espinoza and Matamoros [29] showed that the project did not have a distributive effect on income among the population of the canton of Cuenca. However, their risk analysis showed a medium level of risk, with low probabilities of obtaining a negative net present value (NPV), an internal rate of return (IRR) lower than that required by investors, and a profitability index (PI) of 1.05.

According to data from the National Institute of Statistics and Census of Ecuador (INEC, an acronym in Spanish), 96% of waste is deposited in landfills; in addition, 66.5% of waste is organic, the remaining 33.5% being inorganic waste that can mostly be recycled [30]. Moreover, though there are integrated solid waste management processes in Ecuador, these mainly benefit urban, rather than rural areas [31,32].

Another problem in Ecuador today is the high unemployment rate; this has led to migration from the countryside, and even away from the country, as families seek to improve their living conditions. Hundreds of thousands of Ecuadorians have recently left the country [33,34]. In light of this, the present study may be seen as contributing to green employment options in which nature itself grants human beings the ability to remedy environmental damage in economic sectors associated with high levels of pollution; these include agriculture, energy, waste management, public transport, and construction. In addition, the social benefits of green employment options include the creation of quality jobs and greater social inclusion [35].

Ecuador has developed a National Program for the Integral Management of Solid Waste as a strategy to eliminate all open dumps, and thus contribute to the minimization of the environmental impact generated by the mismanagement of urban solid waste while also improving the quality of life of the country's population. The goals of this program include the reduction and reuse of waste [36]; however, the program mainly focuses on balancing environmental effectiveness, social acceptability, and economic affordability, as well as conceptualizing the circular economy to support sustainability, in compliance with the Sustainable Development Goals (SDGs) [37].

According to the Ministry of Environment, Water and Ecological Transition, the generation of solid waste in the province of Santa Elena amounts to 178.91 tons per day; this is classified as 60.8% organic, 14.5% plastics, 4.9% paper, 3.5% cardboard, 3% glass, 1.3% metals, and 12% other waste. The existence of micro dumps should also be noted; these present threats to ecosystems and the health of humans living in them [38], with potentially severe consequences for the quality of life [39,40].

The present study is therefore framed within the 2030 Agenda, with particular emphasis on SDG 11 "Sustainable cities and communities" and SDG 12 "Responsible consumption and production", as well as a desire to address all issues at international, national, and local levels [41].

In this context, the general research question was posed: How does the treatment of organic waste through composting influence the design of the functionality of a circular economy model for a rural housing area in Santa Elena?

In addition, this research aims to develop a strategic treatment plan involving the classification and management of organic waste, and implementation of artisanal composting prototypes for use by rural householders in the San Jose commune, Santa Elena, Ecuador.

MATERIALS AND METHODS

The exploratory character of the present study involved our combining quantitative and qualitative perspectives with an experimental design [42]; this was because we sought to evaluate functionality in the management of a composting process using a handmade prototype composter, while considering its usage in the context of a rural housing project. The methodological approach consisted of three phases, as shown in Figure 1.

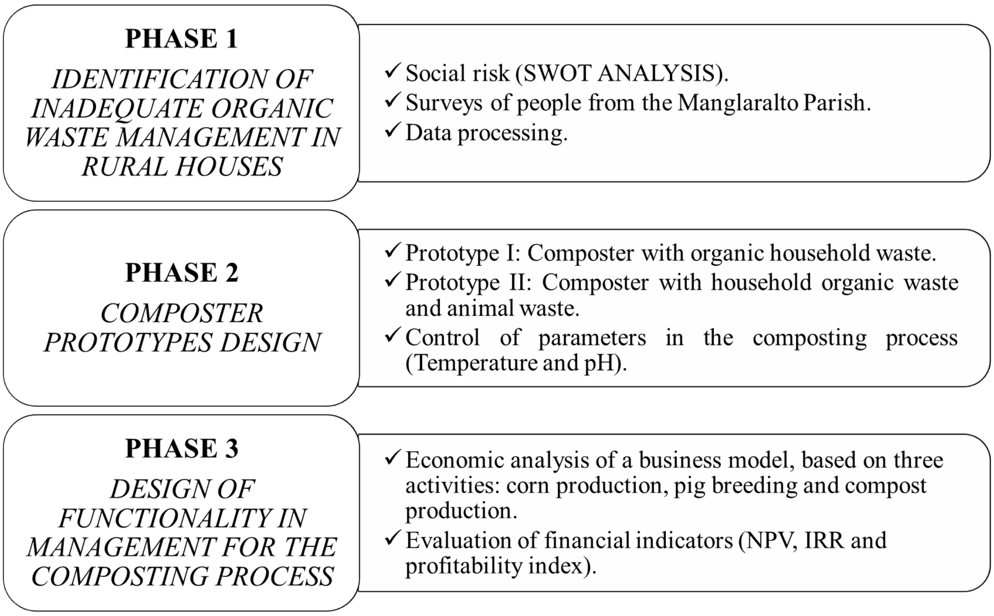

Figure 1. Research flow chart.

Phase 1

The study area was the San Jose commune of the Manglaralto parish, Santa Elena canton, in the province of Santa Elena, Ecuador (Figure 2). Once the study area was delimited, a survey was carried out. Surveys are widely used as a research procedure since they allow for the quick and efficient obtaining and processing of data [43]. Put simply, a series of data are collected and analyzed from a sample group of cases which are representative of a larger population or universe, the characteristics of which are to be explored, describes, predicted, or explained [44].

Figure 2. Study area delimitation.

Statistical analysis

First, the finite population formula (equation (1)) was used to perform the statistical analysis when the total number of observation units was known [45].

$$n = \frac{N\,Z^2\,pq}{e^2(N-1)\, +\, Z^2\,pq} \tag{1}$$

Where: n = sample size sought.
N = population or universe size.
Z^2 = statistical parameter that depends on the level of confidence.
pq = probability of the studied event occurring (success).
e = maximum accepted estimation error.

The study population was selected from among inhabitants of the rural area of the San Jose commune; in total, 40 families were surveyed. The data collected were processed using SPSS statistical software, and the non-parametric chi-square test was used to determine whether or not there was any relationship between the two variables established in the survey (Variable 1: Sorting of organic waste in rural households; and Variable 2: Management of organic waste in rural households). After establishing the variables, two hypotheses were set to be evaluated with a significance level (α = 5%), a null hypothesis (H0) and an alternative hypothesis (H1). These hypotheses were as follows:

H0: Sorting and management of solid waste is not a priority in rural households.

H1: Sorting and management of solid waste is a priority in rural households.

Social risk (SWOT analysis)

SWOT (strengths, opportunities, weaknesses, and threats) analysis is one of a set of tools that can be used to help plan and formulate strategies. It is often used in the form of brainstorming, principally by using each section of the tool to help identify and position the capabilities and environment of the organization, so that the right decisions may then be made [46]. The results of the SWOT analysis are then formalized in the form of a table; this contains four sections, and makes it possible to contrast the strengths and weaknesses identified in the research, as well as any opportunities or threats [47].

Phase 2

The artisanal composter is a device designed to process organic waste; it may also be considered an organic matter reducer oriented to produce agricultural-quality carbon [48]. In open spaces such as gardens, composting can take place directly on the ground, so that the waste forms a pile. However, when low or medium volumes of material are to be composted, an unobtrusive device can be used in spaces such as balconies and terraces, or under stairs [16].

For the design of a composting prototype, the conditions shown in Table 1 should be considered:

Table 1. Conditions for the design of the composter prototype.

Condition	Description
Insulation against rain and direct sun	The composter is open at the top, with a non-airtight lid, as a physical barrier to rainwater and sunlight [49].
Physical barrier to the entry of animals	To prevent the entry of domestic animals, farm animals, rodents or wild animals, plastic or metallic fabric or canvas with an opening of less than 5 mm can be incorporated into the composter [50].
Leachate drainage	The composter allows for the removal of liquids generated as part of the composting process or with excess irrigation water [51].
Aeration	Manual turning with a shovel or hand rake to oxygenate the mixture of decomposing waste [52].
Ventilation	It must allow ventilation to eliminate gases (mainly carbon dioxide and water vapor) and air entry [50].
Separation by modules	This should be done in at least two modules or two piles, to achieve agricultural quality compost and avoid cross-contamination between the compost in process and the mature compost [53].

Disposal of waste in the composter

A manual composter may be used for two types of waste. "Green and wet" waste is typically food scraps from the kitchen, while "dry and brown" waste is typically obtained from the garden (grass, leaves, or pruning waste) [54], as shown in Figure 3.

Figure 3. Organic waste layers (sandwich format).

It is suggested that waste be deposited in alternating sandwich-like layers, starting with “dry and brown” followed by “green and wet” [55]. The first layer of “dry and brown” material should be placed on the base of the composter, followed by the kitchen scraps. It is generally convenient that the last layer of waste is “dry and brown”, to absorb excess moisture [56,57] and mask odors (Figure 3). Depositing a lot of “green and wet” material can compact the waste pile, reducing available oxygen, and potentially causing rotting, while depositing a lot of “dry and brown” waste inhibits the composting process. Depositing waste in “sandwich” form, with alternating thin layers, prevents the material from clumping [58].

Parameter measurement

Composting may be described as the mixing of decomposing organic matter under aerobic conditions to optimize soil structure and provide nutrients [59,60]. It is a controlled natural-transformation process that releases heat and occurs in the presence of oxygen (aerobic) and moisture, so that organic matter is degraded into a stable material with value as a fertilizer or substrate providing nutrients to the soil [61]. In the present study, the two parameters of temperature and pH were measured in our Composter Prototype Two.

The relevant limiting chemical factors for composting are (i) an oxygen supply, which is necessary for the compost transformation bacteria to carry out the process; and (ii) a ratio of carbon to nitrogen in a range from 25:1 to 30:1, this being necessary for the organic matter transformation process.

Temperature

The temperature in the composting process has two distinct thermal zones; i.e., during the composting process, the temperature changes. These two zones are the mesophilic zone (25–38 ℃) and the thermophilic zone (55–70 ℃). The increase in temperature during fermentation is generally the result of exothermic biochemical reactions which are associated with the activity of the microorganisms present [62,63].

Temperature is critical for efficient composting because microbial activity is activated at temperatures above 35 ℃ but slows down significantly below 20 ℃ [64]. Therefore, it is crucial to locate the composter at a location where there are no external factors that lower the temperature [65]. In cold regions, the partitioning process slows down, resulting in compost maturation times of between 5 and 7 months [66]. Temperature influences microbial activity more than other factors such as moisture, pH, or C/N ratio, accelerating waste processing [67]. The Manglaralto’s average annual temperature of 23.1 ℃ favors decomposition and is thus ideal for composting [68].

Hydrogen potential (pH)

pH is another important parameter for assessing process conditions including waste stabilization. As with temperatures, pH values vary with time during the composting process. Initially, the material has a pH value between 6 and 7; however, this value falls in the first days, due to the production of organic acids in the system. Subsequently, pH values increase to between 8 and 8.5 during the thermophilic phase. Finally, after cooling begins, pH values of between 7 and 8 are recorded in mature compost [4].

Phase 3

In this phase, an economic analysis was carried out using a business model based on the circular economy. This model seeks to produce and market products using recovered natural resources, while giving importance to the regeneration of the environment and the achievement of desired production levels without reducing natural resources or causing pollution [69]. The circular economy mainly seeks to offer closed and networked value chains, making the most of resources to reduce the use of raw materials and energy during a production process, and to recover any waste produced during this process, so that it can be used in other processes [70]. This production and consumption model focuses on "sharing, renting, reusing, repairing, renewing and recycling" the materials used in the production processes as much as possible, so that the useful life of products manufactured by the companies can be extended (Figure 4) and value is thereby added [71].

Figure 4. Infographic explaining the circular economy model.

The circular economy has numerous benefits. These include environmental benefits, such as reductions in the use of resources and in energy consumption; and economic benefits, such as a reduction in demand for raw materials resulting from a reduced dependence on imports. Table 2 shows some of the most important financial benefits of the circular economy [69].

Table 2. Economic benefits of the circular economy.

Benefits	Description
Economic growth	Due to the efficient use of inputs, production costs are reduced and include higher economic income [72].
Large net savings on material costs	Due to the reduction of raw material costs in producing food, beverages, and personal care products, net annual savings are achieved, a potential that is highlighted worldwide [69].
Generation of new jobs	The circular economy and the necessary recycling, transportation, processing, and redesigning require hiring additional personnel in the production processes [73].
Innovation	The advantages of a more innovative economy are reflected in higher rates of technological development, better materials, labor and energy efficiency, and more profit opportunities for companies [69].

RESULTS AND DISCUSSIONS

Phase 1 Results

After the statistical analysis was performed using the non-parametric chi-square test, the decision was made to reject the null hypothesis (H0) and accept the alternative hypothesis (H1) because a significant relationship was found between the classification and management of organic waste among the rural households of the San Jose commune ($X^2(2) = 8.921$, p (0.012) < 0.05). Figure 5 shows the chi-square test.

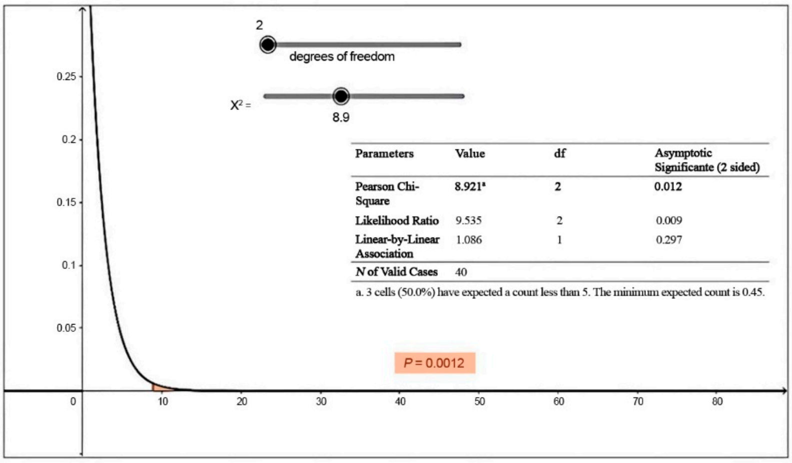

Figure 5. Chi-square test for the variables (V1: Organic waste classification in rural homes and V2: Organic waste management in rural homes).

The sorting and integrated management of organic waste has become a priority for those responsible for environmental management in Santa Elena province, even as they seek to develop and improve the quality of life of inhabitants of the province's rural areas. Integrated waste management involves adopting all necessary measures with respect to waste; these include the responsible consumption, prevention, reduction and separation at source, storage, transportation, use, recovery, treatment, and final disposal of waste in conditions that promote the care of human health and the environment [74].

Among the possible alternatives that seem viable for the use of organic wastes, the production of compost may be seen as one of the best, because organic waste can be used as a primary resource for the formation of life in plants, and may thus be applied to both urban and rural agriculture [16].

In the present study, a SWOT analysis in a context of social risk provided a basis for developing a sound strategic plan to effectively implement the composting of organic waste in rural households in the canton of Santa Elena. Ideally, any such plan should address weaknesses and threats while taking advantage of strengths and opportunities. In the present study, we established a number of strategies for implementation in the project (Table 3) on the basis of our analysis of strengths, weaknesses, opportunities, and threats (Table 3). These strategies may now be described.

Table 3. SWOT analysis.

SWOT	Threats	Opportunities
Strengths	Encourage composting instead of traditional methods such as burning or landfilling, highlighting the environmental and economic benefits.	Take advantage of the considerable quantities of organic waste and the low cost of implementation to seek financing and technical support from government programs.
	Use the flexibility of low implementation cost to adjust compost production according to changes in demand and prices of organic products.	Use the knowledge about waste treatment and the growing demand for organic products to produce and sell compost, generating additional income for rural families.
Weaknesses	Conduct awareness campaigns to change the preference for traditional waste disposal methods, highlighting the benefits of composting.	Seek funding and technical support to develop the necessary infrastructure for handling and processing organic waste.
	Create community networks and partnerships with organizations to maintain ongoing support and training, thus mitigating weaknesses and threats in the long term.	Establish standards and practices to maintain compost quality and consistency, using available technical knowledge and possible external support resources.

Adopting new approaches to waste management faces obstacles in regions where proper separation and treatment of waste are not practiced. In the study area, such a situation was aggravated by the lack of a structured plan as all waste was deposited without sorting. Implementing educational initiatives that promote the benefits of composting is critical to achieving a cultural shift towards better practices in the future.

Phase 2 Results

In light of all the conditions and recommendations stated above, we established two different composting prototypes. Temperature and pH parameters were measured for three months; these measurements allowed us to observe the following: a mesophilic stage that developed during the first four days or so; a thermophilic stage with a duration of roughly 45 days; and finally, a cooling or maturation stage, lasting a further 45 days, during which the composting process was completed.

For the composting process to develop correctly, several conditions must be met. The most important parameter in an adequate composting process is the appearance of the so-called thermophilic phase, i.e., a period of approximately 45 days in which the temperature inside the compost reaches values between 46 °C and 61 °C. However, it should be noted that, under suitable conditions, the composted material can reach a temperature of more than 80 °C [75,76].

Figure 6a shows the Prototype Composter 1. Obtained temperature measurements in the mesophilic phase were in a range from 27 °C to 43 °C; during the thermophilic phase, maximum temperatures between 46 °C and 52 °C were recorded, indicating increase in microbial activity [63]; finally, in the cooling phase, temperature ranged downwards from 38 °C to 27 °C (Figure 6b).

(a)

Figure 6. (**a**) Composter Prototype 1; (**b**) Temperature and pH measurements over 13 weeks.

(**b**)

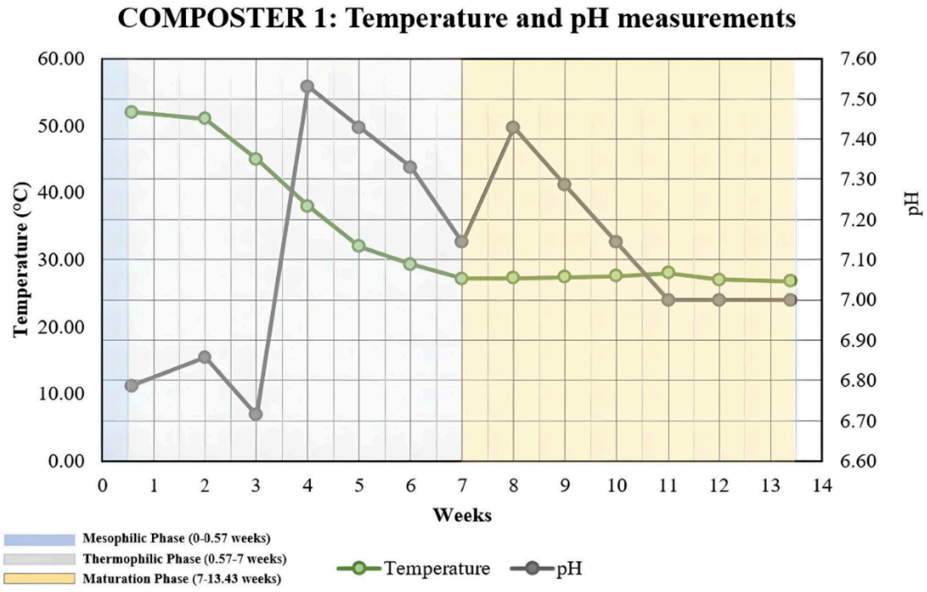

Figure 6. *Cont*.

Figure 7a shows Prototype Composter 2. Figure 7b shows the behavior of Composter 2. It can be seen that, in the mesophilic phase, temperatures between 27 °C and 42.5 °C were recorded. In the thermophilic phase, the temperature increased, ranging between 45 °C and 61 °C, and approaching the optimum values of the process. Finally, in the cooling or maturation stage, temperature values ranging downwards from 41 °C to 27 °C were recorded. In addition, pH values were recorded to evaluate the progression of the decomposition of organic matter; these values were found to range from 6.50 to 7.53 [4].

(**a**)

Figure 7. (**a**) Composter Prototype 2; (**b**) Temperature and pH measurements over 13 weeks.

(b)

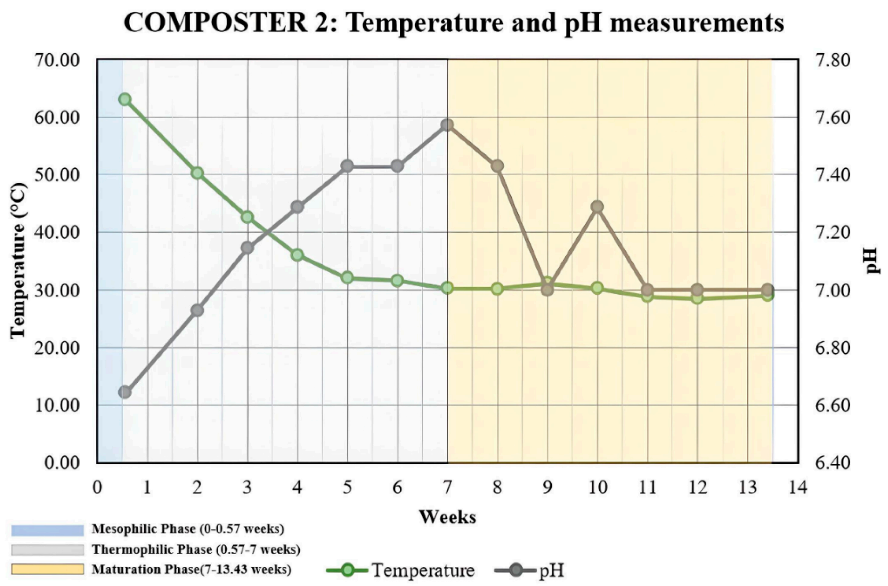

Figure 7. *Cont.*

High temperatures during the thermophilic phase cause the decomposition of difficult-to-decompose materials; high temperatures also result in weight loss, due to the intense emission of water vapor and carbon dioxide (CO_2). It should be noted that high temperatures also have a hygienic effect on composted waste materials, as they promote the breaking down of chemical contaminants such as antibiotics, pesticides, hormones, and pharmaceutical residues [2].

Phase 3 Results

An economic analysis was conducted for an area of rural housing using a business model in which three activities were established; these were corn production, pig raising, and compost production, the latter being the objective of the research. This study sought to establish a circular economy so that the people of the San Jose commune did not have to abandon their land for lack of work, but could generate their source of income, while at the same time avoiding the burning or disposal of organic waste on open dumps.

When defining the budget, net cash flows for the three activities were evaluated. Corn production involved three cycles of corn production per year in an area of 1 hectare, in which 160 sacks of corn were produced for sale in each cycle. Pig raising involved three cycles of a process in which 20 piglets were reared and fattened for breeding and sale. Compost production involved an average monthly generation of 533.33 kilograms (kg) of organic matter, giving a total of 6400 kg per year, using 60% manure waste from pig raising and 40% organic waste recycled from corn crop residues and domestic use, with two yearly productions. This business model had a minimum area of two hectares for the abovementioned activities; therefore, rental costs were included (Figure 8).

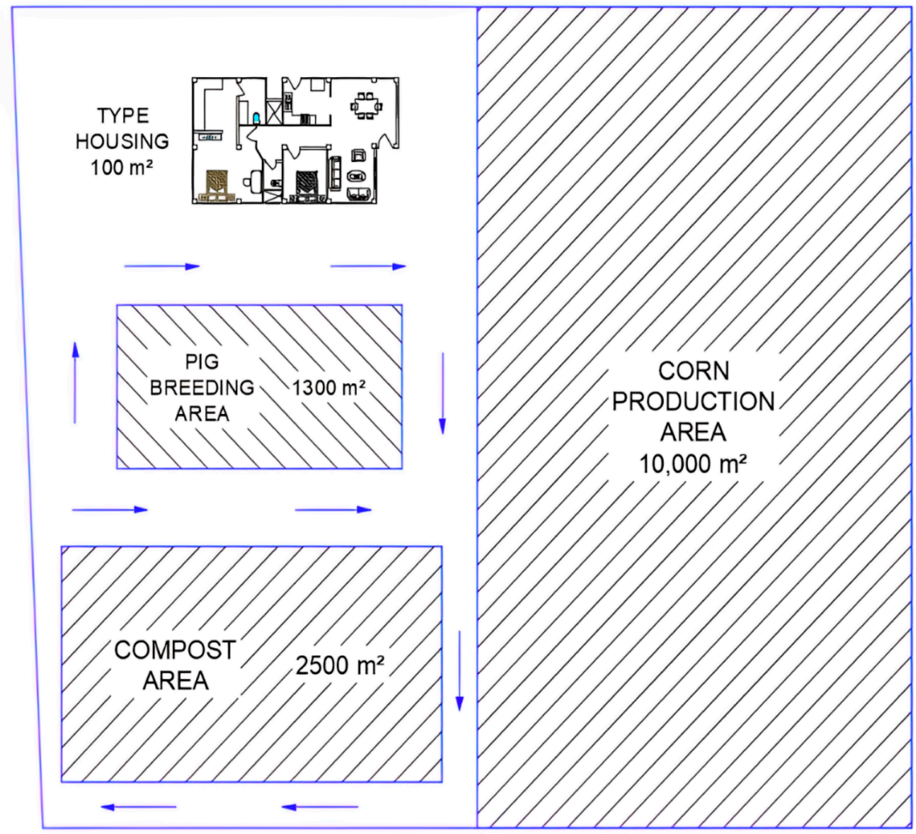

Figure 8. Business model implementation.

A unit price analysis (UPA) of the project budget was performed; this analysis comprehensively included the costs associated with compost production. The following components were specified: (i) Equipment and tools: we considered the costs of acquisition, installation, and maintenance of all equipment necessary for the composting process, such as thermometers, pH meters, and tools for handling material; (ii) Materials: this study considered all materials necessary for composting, such as composter structures, insulation materials, and additional components required to improve the efficiency of the process; (iii) Labor: we considered the labor involved in each phase of composting, including the preparation, handling, monitoring, and collection of the finished compost.

Considering the net cash flow, the project's economic viability was determined according to the NVP, the IRR, and the PI. This business model had an initial investment of USD 26,568.00, which was recovered in the first year. It can be noted from the flow that the income from the sale of the compost starts to be evident from the first year, this being the estimated time in which the composting process was carried out in the pilot tests (6 months per production). According to the market study, an approximate output of 266.66 kg per month was foreseen; this compost could be sold for USD 0.35 per kg. An evaluation of the financial indicators showed that the NPV was USD 22,027.24, the IRR was 27.22%, and the PI was 1.83 (Table 4 and Table 5).

Table 4. Cost-production estimation.

Project periods in years	0	5
Incomes	-	$33,800.00
Expenses	$26,568.00	-
Net cash flow	$−26,568.00	$33,800.00
Current value	$−26,568.00	$24,098.93

Table 5. Evaluation indicators.

Evaluation indicators	
Initial investment	$26,568.00
Interest rate	7%
Present value of the sum of the updated flows	$48,595.24
NPV	$22,027.24
IRR	27.22%
PI	1.83

The discount rate is the financial factor used to determine the time value of money and, in particular, to calculate the present value of future capital or to evaluate investment projects. In the analysis, we used a discount rate of 7.00%, which adequately represents the opportunity cost of capital in Ecuador and the moderate risk associated with the composting project. The evaluation was thus made on this basis.

The circular economy is a notion that supports the responsible circularity of available resources to achieve sustainable development goals [77]. This concept implies a regenerative model in which efforts are made to minimize inputs (resources) and waste in any form of leakage or disposal to close or slow down the material cycle [78]. A circular economy is a production system that aims to increase the use of renewable energy, eliminate toxic chemicals that make it difficult to reuse and return many products to the biosphere, and reduce waste through excellent product designs, systems, and business models.

The results indicate that new personnel are required for production processes due to the circular economy and the necessary recycling work [79].

In the National Composting Plan 2020–2050 of the National Environmental Commission of Costa Rica, published in 2015, the importance of developing strategies to promote employment through composting was highlighted. The aim of the present study was also to help create jobs and avoid forced migration due to a lack of job opportunities. However, in Costa Rica, the main focus was on promoting entrepreneurship and community initiatives; in the present work, we focused on implementation at the level of specific rural households. We therefore present a more customized solution adapted to local needs. The present work focuses on implementation al the level of specific rural households. Therefore, it presents a more customized solution adapted to local needs.

The study conducted by Hernandez [28] in Colombia highlighted the conversion of compost waste into organic fertilizer, and reported PI values of up to 2.45. In the present study, we focused on compost production in terms of its economic viability and its integration into a circular economy combined with agriculture (growing corn) and livestock (raising pigs). We obtained a PI value of approximately (1.83), which suggests that composting can also be carried out profitably in rural Ecuador. The difference between the study of Hernandez and the present work is that we took into consideration the variety of economic activities that enrich and sustain the business model in the San Jose commune, canton Santa Elena, Ecuador.

Revelo [80] provided a detailed analysis of the characteristics of solid waste in Piñas canton, El Oro province. The organic matter content was 68.67%, indicating the enormous potential of composting in urban areas. This study adds to this analysis by providing concrete data on organic matter formation in rural environments, emphasizing the integration of household waste, animal manure, and corn crop residues. In the business model described above, a total of 6400 kg of compost is produced annually, a finding which demonstrates how waste management can be optimized in a rural environment using an integrated approach involving agriculture and livestock.

CONCLUSIONS

In the present study, we surveyed 40 families resident in the rural area of Santa Elena province, Ecuador. The results which we obtained indicated a significant relationship between the classification and management of solid waste in rural homes. Put simply, we found that these families adequately classified and managed their waste for their own benefit. By carrying out composting, they were able to generate economic income.

Two prototypes of handmade composters were designed and made. All organic waste was deposited in a “sandwich-type” manner, and temperature and pH measurements were both taken. By controlling temperature and pH, the composting process was carried out optimally in all its phases.

The project shows solid economic viability. The results indicate that a positive NPV of USD 22,027.00 and an IRR of 27.22% might be obtained. This analysis also suggests that the project will generate positive financial returns. By implementing this composting business model, an increase in employment opportunities can be expected: in compost production; in marketing of the final product; and in roles related to the management and operation of the various project activities. The project contributes to local economic growth by providing employment and generating additional income for the community. In short, the composting project is financially feasible. In addition, it promotes environmental sustainability by reducing the amount of organic waste sent to landfills and producing a valuable and beneficial product for the soil. Furthermore, promoting the circular economy and using renewable resources helps encourage more sustainable and environmentally friendly business practices. In summary, this project not only offers solid economic benefits, but also positively impacts job creation and promotes sustainable business practices, within the framework of a circular economy.

To implement composting as part of a process of organic waste management, improved infrastructure is needed, as well as community education on its economic, environmental and social benefits. We recommend that training programs and awareness campaigns be developed aimed at various sectors, such as rural residents, authorities, and educational centers. Such programs should emphasize waste separation at the source, as well as the proper handling of compost. In addition, partnerships should be established among local governments, non-governmental organizations and community leaders, and composting should be promoted in public policies. The introduction of incentives for those who participate, and sanctions for those who do not comply, will strengthen the adoption of these practices, promoting a cultural change towards more sustainable and effective waste management.

DATA AVAILABILITY

The dataset of the study is available from the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

Conceptualization, LP and GHF; Methodology, LP; Software, LMA; Validation, JGV, GHF and LP; Formal Analysis, GHF; Investigation, LP; Resources, LP and LPP; Data Curation, LP; Writing—Original Draft Preparation, LP, LMA, GHF, JGV and LPP; Writing—Review & Editing, LP and LPP; Visualization, LP and LPP; Supervision, GHF and LMA; Project Administration, LP; Funding Acquisition, GHF.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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