Community environmental management of household and agricultural waste promoting productive sustainability in Ecuador

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Abstract

Composting is an important sustainable waste management strategy because it transforms waste into resources and improves soil fertility. However, implementing it in rural communities presents logistical, technical, and regulatory challenges. This study examined how the community of San José del Cantón Portoviejo in the province of Manabí, Ecuador, manages household and agricultural waste. The field study was exploratory, not experimental. Two systems, Open Pit and Static Reactor with Aeration, were evaluated without experimental replications. A comparison of the systems was carried out using controlled indicators of physicochemical and biological processes. Initially, a descriptive survey was conducted to understand how household and agricultural waste was managed. Based on the obtained information and quantities collected, two composting systems were designed: an open-air pile and a static reactor with aeration. For four months, indicators such as humidity, oxygenation, and temperature were monitored to ensure optimal biodegradation conditions and minimize the impact of external factors on the process. At the end of the process, the physicochemical and biological parameters of the compost obtained from both systems were analyzed and compared with the standards established by Ecuadorian regulations. The results showed adequate levels of humidity (38%-42%), bulk density (0.35%-0.36 g/cm³), porosity (82.06%-83.33%), organic matter (18.82%-20.16%), and pH (6.94%-6.98%). However, the electrical conductivity (5.61–5.74 dS/m), calcium content (0.98–1.2%), and nitrogen content (2.49–2.63%) exceeded the national limits, though they complied with international standards. Additionally, total coliform levels (30,000-35,000 u.f.c./g) exceeded permitted values (<1,000 u.f.c./g), suggesting the need for additional treatments to ensure safety. Both systems produced compost with favorable characteristics, though adjustments to some parameters are needed to comply with local regulations. Community participation was essential for implementing composting, and the return of biofertilizer was a key incentive for its adoption and continued use.

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1. Introduction

Soil health is defined as the inherent and sustained ability to function as a living, dynamic ecosystem that is essential for supporting the vital functions of plants, animals, and humans (Wenzel et al., 2024). However, the integrity and functionality of soil are threatened by processes such as sealing, salinization, desertification, pollution, compaction, acidification, and erosion. These alterations compromise biodiversity and affect soil functions such as agricultural production and water quality regulation (Cano-Díaz et al., 2023).

Given its massive generation at a global level and predominantly plant composition, agricultural waste management emerges as a fundamental strategy to mitigate environmental problems. Reincorporating it into the soil promotes sustainable circular economy practices, favoring the conservation of soil resources and minimizing adverse environmental impacts (Paradelo et al., 2024).

Composting organic waste provides substantial environmental advantages over traditional landfill disposal (Manea et al., 2024). Organic amendments, derived from the decomposition and mineralization of plant, animal, and industrial waste, are an effective waste management strategy. Incorporating them into the soil promotes the circular economy and optimizes its physical, chemical, and biological properties, thereby promoting microbial activity and agricultural sustainability (Lin et al., 2022).

Using organic amendments is a fundamental agricultural practice that increases and maintains organic carbon in the soil. This practice favors microbial activity, prevents degradation, and promotes the sustainability of soil resources (Koushika et al., 2024).

In recent years, using organic waste has become increasingly relevant due to its ability to mitigate greenhouse gas emissions and its potential as a renewable energy source. This contributes to developing more sustainable and efficient systems (Dhar et al., 2017; Haider et al., 2022).

Composting systems include methods such as bioreactors, static piles (with and without oxygen), mechanical turning, and open swaths (Aranguren & Hinojosa, 2018). To function optimally, they must guarantee ventilation, access to microorganisms, protection against rain, and ease of handling the material (Benítez, 2020).

2. Methodology

2.1. Location of the study area

The community of San José is located in the Picoazá parish of the Portoviejo canton in the province of Manabí in Ecuador. It has a population of 556 people organized into 158 families. The community's main economic activity is agriculture. Geographically, San José is located at the UTM coordinates 17S: 557376.25 E; 9888673 S. The area has an average annual temperature ranging from 24 °C to 26.7 °C.

2.2. Survey carried out

A survey and a review of secondary information were used to characterize waste management in the community. Following the methodological criteria of Otzen & Manterola (2017) and Baptista et al. (2014), 48 heads of household were selected, representing 30% of the total number of families. The structured survey took a descriptive approach and addressed aspects related to the management of household and agricultural waste. It was reviewed and applied in a pilot test to verify adequate understanding, as was previously done.

2.3. Collection and characterisation of the waste used.

Agricultural residues, such as cocoa, peanuts, and poultry litter composed of rice husks and manure, as well as household residues, including banana peels, cassava, eggs, beans, and carrots, were collected from the farms of the surveyed families in the community. A sample of each type of waste was taken and crushed in a Wiley TE-680 mill. Then, the samples were sent to a specialized commercial laboratory for analytical characterization.

2.4. Design of composting systems

2.4.1. Open pile

It was carried out on a plastic sheet in order to minimize the generation of leachate, following the methodology proposed by Isaza-Arias et al.,(2009) and the recommendations of Álvarez-Sánchez et al. (2021). The structure adopted a trapezoidal shape, according to what was proposed by Qarani Aziz et al. (2018) which allowed better control in the evolution of the process.

2.4.2. Aeration reactor

An artisanal aeration reactor was designed using a PVC tank with a capacity of 1.3 m^3 (1300 L). The system included an opening at the top with hinges, which allowed efficient removal of materials, in addition to facilitating the monitoring of quality indicators and preventing the accumulation of rainwater, according to (Stipniece et al., 2022).

2.5. Installation of composting systems and process control.

The waste was applied in layers of 15 cm thick, in the two systems, adjusting the carbon-nitrogen ratio (C/N) to 30.1 (Ayilara et al., 2020) and maintaining a controlled moisture content between 50 and 60%. The transformation process was controlled by periodic monitoring of temperature (25–60 °C), humidity and oxygenation parameters, ensuring optimal conditions for microbial activity (Liang et al., 2003).

Oxygenation.

In both systems, turning was an essential technique to guarantee the oxygenation and homogenization of the material, which favored aerobic microbial activity and the efficient degradation of organic waste. In the pile, turning was carried out manually with a shovel and rake to homogenize the waste. In the aeration reactor, a one-meter-long stainless steel aerator cane was slowly inserted and removed to prevent material compaction and allow air circulation, in accordance with recommendations of Apaza et al. (2015).

2.5.2. Humidity control

Humidity control was carried out on a scheduled basis in both systems (every 15 days depending on weather conditions). To determine if the humidity was within the optimal range (45–60%), the "clenched fist" technique indicated by (Moncks et al., 2022) This consists of taking a handful of composted material, squeezing it with the hand and observing its behavior, if when you open the hand the material falls apart without maintaining its shape, indicates insufficient moisture and water is added by direct irrigation; if it keeps water droplets, the material is too wet; and if it maintains its shape without draining water, the humidity is adequate.

2.5.3. Temperature control

The temperature was recorded using a T-100 probe thermometer made of stainless steel for compost, with a measurement range of 0 to 120°C and capacity to measure up to 50 cm deep. The measurements were carried out daily in the morning, specifically at 11:00 a.m

2.5.4. Evaluation of the final product

To carry out the analyses, a representative sample of the materials was obtained using the quartering technique. This technique involved dividing the material into four equal parts in both the pile and the reactor. Then, several points were selected from which portions were obtained to form a composite sample. This guaranteed a homogeneous and representative sample. The sample was then sent to a certified commercial laboratory, AGROLAB, where the physical, chemical, and biological analyses of the compost were carried out. The Ministry of Environment and Water of

Ecuador (2020) and the Instructions for the General Regulations to Promote and Regulate Organic-Ecological-Biological Production of the Ecuadorian Agency for Agricultural Quality Assurance (2020) recommended these analyses.

3. Results and discussion

3.1. Survey carried out

3.1.1. Socioeconomic and agricultural characteristics of respondents

The data obtained from the survey are presented in Table 1, which details the characteristics of the population and participation in the study.

Table 1. Respondents' characteristics and cropping systems.

Features	Description	Number of members (% of total sample)
Members per family	1–2 / 3 / 4–5 / 6–8	11 (24) / 14 (30) / 19 (40) / 3 (6)
Gender of respondents	Male / Female	38 (79) / 10 (21)
Land Use	Exclusively agricultural	48 (100)
Crop systems	Associated with perennials/rotation	41 (85) / 7 (15)

Most of the families surveyed are small (2–5 members), in line with the national average, which could limit labor in agricultural activities. With a predominantly male population, reflecting gender roles in agricultural decision-making, although women also play important roles that are not always visible. In terms of agricultural activity, 100% of those surveyed allocate their land to agriculture, which shows that the sample corresponds to active farmers with 85% of them cultivating in association with perennial crops. These systems require sustained management and conservation practices.

3.1.2. Destinations of the production and management of agricultural inputs and residues

Results related to the destination of production, inputs used and waste management in the community, Table 2

Variable	Description	Number of members (% of total sample)
Destination of production market	*M1 / M2 / M1+M2 / M3 / Intermediates	14 (29) / 10 (21) / 9 (19) / 6 (13) / 9 (18)
Agricultural inputs used	Inorganic / Mixed / Organic only	25 (52) / 14 (29) / 9 (19)
Agricultural waste management	Soil Incorporation / Burning	34 (71) / 14 (29)
Domestic animals (birds)	Present / Absent	37 (77) / 11 (23)

Table 2. Production destination *M = Market; M1 = Portoviejo; M2 = Maquita; M3 = Portoviejo and Maquita; M4 = Picoazá; intermediaries.

Production is sold to markets such as: Portoviejo (M1), the main market (29%), followed by Maquita Cushunchic (21%) and mixed channels (19%). This shows varied commercial strategies that allow producers to reduce risks of dependence on a single market, as has also been described in studies on short agricultural marketing chains in Ecuador.

The use of inorganic fertilizers and the reincorporation of waste into the soil predominate, with poultry breeding in most homes.

3.1.3. Household waste management and knowledge.

56% do not separate waste properly and most kitchen waste is thrown away. Although 92% know about recycling, only 19% have received education on waste management and 58% are unaware of environmental damage.

Table 3. Waste management and knowledge.

N°	**Identification**	**Quantity harvested (kg)**
1	Cocoa waste	3. 947
2	Peanut Waste	162
3	C. rice chicken manure	852
4	Domestic (legume scraps)	300
	Total	**5.261**

The baseline survey made it possible to determine the amount and destination of organic waste in the community, showing that 65% of household waste is discarded, while agricultural waste is incorporated into the soil without a prior transformation process. Through the survey, the causes and effects of the inadequate management and final disposal of this waste were identified, highlighting the lack of knowledge and training as the main factors.

3.1.4. Amount of waste collected.

The amount of waste collected is displayed. Plastic bags, drawers, shovels, biosafety equipment, scales and transport were used (Table 4).

Table 4. Amount of waste collected in the community.

N°	**Identification**	**Quantity harvested (kg)**
1	Cocoa waste	3. 947
2	Peanut Waste	162
3	C. rice chicken manure	852
4	Domestic (legume scraps)	300
	Total	**5.261**

Table 1. Characterization of the waste used

Parameter		**Type of waste**		
	Poultry manure + *c. rice	**Domestic**	**Tamo de Peanuts**	**Cocoa**
M.S. %	70.50	38.20	69.60	55.50
C %	32,27	46,71	40,00	50,00
N %	2,60	1,70	2,00	1,20

C/N	12,41	27,47	20,00	41,60
H %	29,50	61,80	31,40	44,50
pH	8,00	7,50	7,70	9,20
Ce (d/Sm	27,70	24,50	17,60	21,40
M.O%	15,00	16,10	28,40	30,00

Note. M.S = Dry matter; C = Total carbon; N = Total nitrogen; C/N = Carbon/nitrogen ratio; H = Moisture; pH = Hydrogen potential; EC (dS/m) = Electrical conductivity; M.O. = Organic matter. *Husk

3.2. Design and installation of composting systems.

An open-air pile with a plastic base was installed to prevent leachate infiltration. Its dimensions were 1.10 m × 1.80 m × 1.90 m (height, width, length), located according to Salina et al. (2018) with an initial temperature of 32 °C and addition of irrigation for 36 min.

The study was field, exploratory and not experimental. Two systems (Open Pit) and Static Reactor with Aeration were evaluated without experimental replications. The comparison between systems was carried out using physicochemical and biological indicators.

3.2.2. Artisanal reactor

It was built with a 1.3 m³ PVC tank, located horizontally on a wooden base. An opening was made in the upper part of 79 cm × 97 cm (length and width) with a hinged lid for the incorporation of waste and the base was perforated to facilitate the drainage of leachate. The system allowed a more efficient control of aeration and excess humidity, reducing the effect of rainfall, As in the pile, the same raw material was used, registering an initial temperature of 32 °C and the same irrigation time was equivalent to that of the pile.

C/N Adjustment

The results of the initial balance (Table 5), established to guarantee the balance of the materials, with a C/N ratio of 30 in both systems, a condition considered adequate for microbial activity, are presented. The materials were adjusted to 60% humidity, within the optimal range (50–65%) for the development of microorganisms, and controlled irrigation was applied when the temperature exceeded the limit values, ensuring favorable conditions for the process.

Table 5. C/N ratio adjustment for both systems

N°	Identification	Battery	Reactor	H. %	C. %	N %	C/N
		Kg	kg				
1	Poultry manure + c. rice	426,00	240,00	29,50	32,27	2,60	
2	Household waste	150,00	120,00	61,80	46,71	1,70	30,00
3	Peanut Plant	80,00	80,00	31,40	40,00	2,00	
4	Cocoa Total	1974,00 2628,00	1000.00 1440,00	44,50 -	50,00 -	1,20 -	

Note. H = Moisture; C = Total carbon; N = Total nitrogen; C/N = Carbon/nitrogen ratio; *Husk

Table 6 shows the adjustment of the C/N ratio in the reactor, which obtained the same value as that of the pile (C/N = 30.1).

3.2.4. Oxygenation in the stack system.

From the oxygenation provided by periodic turning, irrigation was applied in a controlled manner. Table 6 details the number of turnings carried out, as well as the amount of water added in each one, in order to guarantee adequate oxygenation in the compost systems during the process.

Table 6. Numbers of turns and irrigations in the two systems during the process.

Systems	**Turning/watering number**	**Watering (min)**	**H2O Volume (l)**
	1	36,00	468,00
	2	25,00	325,00
	3	40,00	520,00
Battery	4	10,00	130,00
	5	5,00	65,00
	6	5,00	65,00
	1	20,00	260,00
	2	15,00	195,00
	3	3,00	39,00
Reactor	4	3,00	39,00
	5	2,00	26,00
	6	1,00	13,00

3.2.5. Temperature evolution

During composting, the temperature reached its highest point in the first and second week (62°C in the reactor and 60°C in the pile), then decreases significantly in the third week (46°C in the reactor) and gradually decreases in the pile until the sixth week (49°C). The temperature then fluctuates to around 30 °C at the end of the process in both systems.

Figure 3 Temperature evolution. Source: Authors.

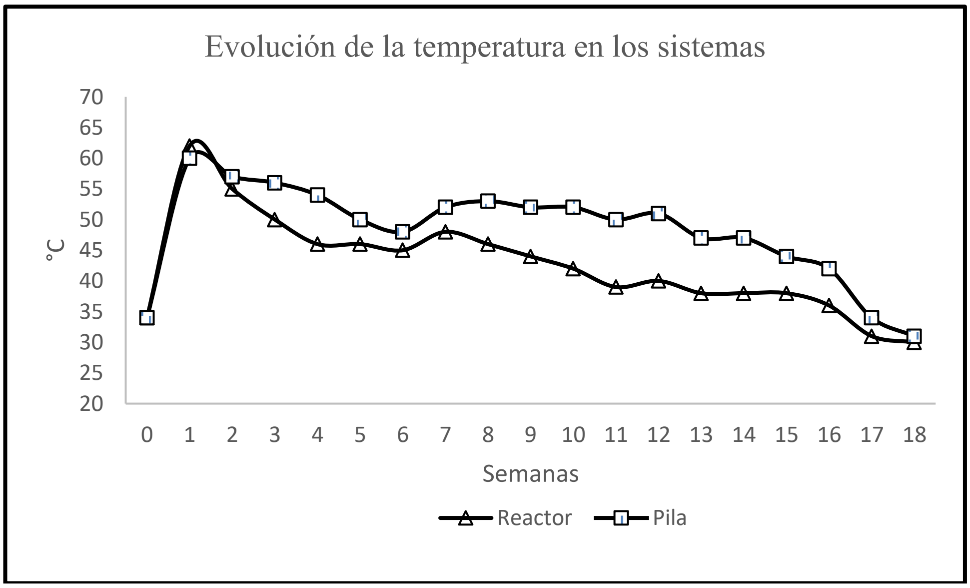

Table 7 shows the average temperatures in both composting systems, showing significantly different values, with the pile system having an average of 48.15° C compared to 42.50° C in the artisanal reactor.

Table 7 Comparison of mean temperatures with Tukey's method with a significance level of 0.05.

e			
Error: 21.2324 gl: 222			
System	Tights	n	Lyrics*
Reactor	42,50	112	To
Battery	48,15	112	B

*Tights with different fonts are significantly different.

3.2.6. Weight of product obtained

The weight of the final product obtained was 660 kg in the reactor system and 950 kg for the open-pit pile, with a dry matter of 382 kg and 589 kg respectively (Table 10).

The transformation and reduction of domestic and agricultural waste through the two composting techniques designed achieved the expected results, in accordance with previous research (Al-Khadher et al., 2021; Chen et al., 2020; Roy et al., 2018; Silvosa-Millado et al., 2021; Zhan et al., 2021). This confirms the viability of the process in the area, considering the available environmental and economic conditions.

3.3. Product evaluation

3.3.1. Evaluation of the final product according to Ecuadorian regulations

The final product obtained in both the open-pit pile and the reactor was evaluated according to the physical, chemical and microbiological parameters established in Ecuadorian regulations (Ecuadorian Agency for Agricultural Quality Assurance, 2020). Although there are no fixed values in the guidelines, the ranges indicated in the Manual for the Use of Municipal Organic Solid Waste of the Ministry of Environment and Water of Ecuador, (2020) to analyze the results obtained in commercial laboratory analyses (Table 11).

Table 8. Physical, chemical and reactor analyses of the product obtained.

Indicators	**Unity**	**Battery**	**Reactor**	**Recommended**
Physical				
Humidity	%	38,00	42,00	35,00 – 50,00
D.a.	(g/cm)	0,35	0,36	0,55 – 0,85
Chemicals				
M.O	%	18,82	20,16	≥20.00
pH	U	6,94	6,98	6,50 – 8,50
Ce	dS/m	5,61	5,74	2,00 – 4,00
N	%	2,59	2,50	0,30 – 1,50
P	%	0,59	0,58	0,10 – 1,00

K	%	2,78	3,19	0,30 – 1,00
Wow	%	1,10	0,98	2,00 – 6,00
Mg	%	0,94	0,98	0,20 – 0,70
Cu	please	111,00	N100.00	< 250.00
Zn	please	113,00	114,00	< 1000.00
Mn	please	370,00	339,00	385,00
CD	mg/kg	0,9	1,20	< 2.5_
Microbiological				
Coliforms t.	u.fc /g	3.0 x104	3.5 x104	<1000 NPM * g /fertilizer
Escherichia coli	u.fc /g	negative	negative	-
Coliforms f.	u.fc /g	negative	negative	<1000 NPM * g /fertilizer
	It is within the range recommended by the instructions of the M.A.E.			
	Not within the recommended negative range			

Regarding the laboratory analyses, both the pile and the reactor had moisture values of 38 % and 42 %, respectively, in the compost, which is within the recommended range (35–50 %), which favors microbial activity and material stability. The bulk density was 0.35 g/cm³ in the pile and 0.36 g/cm³ in the reactor, values below the reference range (0.55–0.85 g/cm³), reflecting a looser structure, with high porosity (83.33% and 82.06%), a desirable characteristic for aeration and field handling.

The organic matter (M.O.) content was 18.82 % in the pile and 20.16 % in the reactor. Although the reactor reached the minimum recommended value (≥20%), the stack was slightly below, which could be associated with differences in the degradation process. The pH values obtained were 6.94 and 6.98, respectively, placing them within the optimal range (6.5–8.5) for mature compost. These results are consistent with what was reported by the Ecuadorian regulations of the Ministry of the Environment, where the pH started at 6.51, rose to values above 8.0 during the thermophilic phase and ended at around 7.0. The similarity in the final values confirms that the composting process tends to stabilize at neutrality.

In the case of electrical conductivity (EC), values of 5.61 dS/m were recorded in the pile and 5.74 dS/m in the reactor, higher than the optimal range (2–4 dS/m), which allows the compost to be classified as intermediate B (4–8 dS/m), with a moderate risk of salinity in sensitive crops.

Regarding macronutrients, nitrogen (N) presented high values (2.63 % and 2.49 %), far exceeding the reference range (0.3–1.5 %), which is an advantage for its use as a soil improver. Phosphorus (P) was 0.59% in both systems, within the appropriate range (0.1–1%), while potassium (K) reached values of 2.79% and 3.18%, well above the reference range (0.3–1%), which increases compost fertility.

For other elements, calcium (Ca) was found to be low (1.2% and 0.98%) from the suggested range (2%–6%), while magnesium (Mg) was slightly above the upper limit (0.93%–0.97% vs. 0.2%–0.7%). Micronutrients were at safe levels: copper (110.5 and 95 ppm), zinc (112.5 and 114 ppm), iron (1061.5 and 1050.5 ppm), and manganese (368.5 and 338.5 ppm), all within permissible limits. The cadmium values (0.96 and 1.2 mg/kg) were well below the maximum established (<2.5 mg/kg), which shows the safety of the material against heavy metals.

Finally, the microbiological indicators confirmed the health safety of the compost: total coliforms (3.0×10^4 and 3.5×10^4 cfu/g) and absence of fecal coliforms and Escherichia coli, results that comply with the regulations (<1000 MPN/g), guaranteeing the safety of the product for agricultural application.

Table 9. List of bases of the biofertilizer obtained.

R. bases (%)	N/K	K/P	Mg/K	Ca/mg	(Ca+Mg) / K	C/N	(K+Ca+Mg)
Battery	0.95	4.77	0.34	1.10	0.70	10.92	4.74
Reactor	0.78	5.44	0.31	1.01	0.61	11.69	5,11

The biofertilizer obtained shows a higher ratio of bases in the reactor, with a favorable balance between Ca, Mg and K. The Ca/Mg and (Ca+Mg)/K ratio indicates good availability of essential cations for the soil. The C/N index suggests a stable compost suitable for soil improvement.

Conclusions

1. The two composting techniques designed in the San José community made it possible to transform and significantly reduce domestic and agricultural waste. This demonstrates the process's feasibility in the area given the available environmental and economic factors.

2. We drew up a baseline that allowed us to determine the amount and management of organic waste in the community. We observed that most household organic waste is discarded, while agricultural waste is largely incorporated into the soil. However, this occurs without any prior stabilization process due to a lack of knowledge and training.

3. The bio-composting systems were highly efficient because they prevented leachate from filtering into the soil and, consequently, prevented these fluids from reaching groundwater. Additionally, they allowed us to monitor and control the quality indicators involved in composting and avoid the influence of external factors.

4. Contrary to several deficiencies or excesses of indicators established in the Manual for the Use of Municipal Organic Solid Waste, the final products obtained in open-air piles and composting are within good ranges according to international regulations such as Chilean NCh2880-2004 and Mexican NADF-020-AMBT2011.

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