Ambiente & Água - An Interdisciplinary Journal of Applied Science
ISSN 1980-993X – doi:10.4136/1980-993X
www.ambi-agua.net
E-mail: ambi.agua@gmail.com

Organic waste management at a food supply center in Maranhão State, Brazil, and proposals for valorization of discarded fruit and vegetables

ARTICLES doi:10.4136/ambi-agua.3132

Received: 27 Oct. 2025; Accepted: 09 Apr. 2026

Jeannye Estephany Keyth da Silva Santos[1]; Paulo Fortes Neto[1,2]; Cecilia Nahomi Kawagoe Suda[1,3*]

[1]Programa de Pós-graduação em Ciências Ambientais. Universidade de Taubaté (UNITAU), Rua Visconde do Rio Branco, n° 210, CEP: 12020-040, Taubaté, SP, Brazil.
E-mail: jeannyestephany@gmail.com, paulo.fortes@unitau.br
[2]Departamento de Ciências Agrárias, Universidade de Taubaté (UNITAU), Estrada Municipal Dr. José Luiz Cembranelli, n° 5000, CEP: 12081-010, Taubaté, SP, Brazil. Email: paulo.fortes@unitau.br
[3]Instituto Básico de Biociências, Universidade de Taubaté (UNITAU), Avenida Tiradentes, n° 500, CEP: 12030-180, Taubaté, SP, Brazil.
[*]Corresponding author. E-mail: cnksuda@hotmail.com

Editor-in-Chief: Nelson Wellausen Dias

ABSTRACT

The improper disposal of organic waste generated in food supply centers significantly contributes to environmental impacts. This study evaluated waste management practices at CEASA-MA, in São Luís, capital of Maranhão, Brazil, through on-site visits, document analysis, and interviews with administrators and merchants. Approximately 245 tons of waste are generated monthly, with incomplete separation and disposal in landfills. In a scenario of adequate segregation, the estimated potential includes 18,468 Nm³ of biogas and 15,100 Nm³ of methane per month, corresponding to approximately 150,000 kWh of energy. Additionally, about 123 tons of compost could be produced monthly. These results highlight the potential for waste valorization through composting and anaerobic digestion, contributing to sustainable waste management and reducing Brazil's dependence on imported fertilizers.

Keywords: biogas, composting, waste management.

Gestão de resíduos orgânicos em uma central de abastecimento no Maranhão, Brasil, e propostas de valorização de frutas e hortaliças descartadas

RESUMO

O descarte inadequado de resíduos orgânicos gerados em centros de abastecimento de alimentos contribui significativamente para os impactos ambientais. Este estudo avaliou as práticas de gestão de resíduos na CEASA-MA, em São Luís, capital do Maranhão, Brasil, por meio de visitas in loco, análise documental e entrevistas com administradores e comerciantes. Aproximadamente 245 toneladas de resíduos são geradas mensalmente, com separação incompleta e descarte em aterros sanitários. Em um cenário de segregação adequada, o potencial estimado inclui 18.468 Nm³ de biogás e 15.100 Nm³ de metano por mês, correspondendo a aproximadamente 150.000 kWh de energia. Adicionalmente, cerca de 123 toneladas de composto poderiam ser produzidas mensalmente. Esses resultados destacam o potencial de valorização de resíduos por meio da compostagem e da digestão anaeróbia, contribuindo para a gestão sustentável de resíduos e a redução da dependência de fertilizantes importados no Brasil.

Palavras-chave: biogás, compostagem, gerenciamento de resíduos.

1. INTRODUCTION

The generation of organic solid waste from the commercialization of fresh food has raised significant environmental concerns, as its inadequate disposal can lead to adverse effects such as unpleasant odors and soil and groundwater contamination (Luo *et al.*, 2019).

In response to growing social pressure regarding environmental issues, Brazil enacted the National Solid Waste Policy (Política Nacional de Resíduos Sólidos – PNRS; Law No. 12,305 of August 2, 2010). The policy aims to reduce the impact on natural resources, promote public health protection, and encourage the adoption of sustainable production and consumption practices. However, the effectiveness of the law in improving municipal solid waste management has yielded limited results (Cetrulo *et al.*, 2018). In 2021, the solid waste collection rate in Brazil's Northeast region was 81.5%; nevertheless, approximately 10,558,666 tons (63.7%) of waste were disposed of in environmentally inappropriate sites (ABRELPE, 2021). The state of Maranhão, located in this region, sent 1,242,559 tons of household and public waste to landfills and open dumping grounds in 2020. São Luís, the capital of Maranhão, was the largest contributor, generating 294,784 tons of waste in that same year (Brasil, 2022b).

According to São Luís Municipal Law No. 6,321 of 2018, establishments that generate more than 200 liters of waste per day are classified as large solid waste generators. The law establishes that such entities share responsibility for the collection, transportation, management, treatment, environmentally appropriate destination, and final disposal of their waste in a legally licensed landfill. They are also held accountable for any damages resulting from improper waste management carried out by contracted service providers.

Food Supply Centers (Centrais de Abastecimento – CEASA) are state-owned or mixed-capital enterprises designed to regulate, promote, and organize the wholesale marketing of vegetables (De Queiroz, 2018). Numerous CEASA facilities operate throughout Brazil, including one in São Luís, Maranhão (CEASA-MA), which commercialized 165,259.36 tons of fresh food in 2021 (CONAB, 2022). In accordance with the aforementioned municipal law, CEASA-MA qualifies as a large solid waste generator and, therefore, is responsible for the management of waste generated by its operations.

Given the concerns surrounding organic waste management and the limited information available on how such waste is handled at CEASA-MA, this study analyzes the quantity and current management practices of solid waste generated during its commercialization activities. Based on the findings, we also propose management strategies and techniques for waste reuse, considering the estimates obtained in this analysis.

2. MATERIAL AND METHODS

2.1. Study area profile

CEASA-MA is in the municipality of São Luís, located on the island of the same name in the Atlantic Ocean. The municipality covers a territorial area of 583,063 km² and had an estimated population of 1,037,775 inhabitants in 2022 (IBGE, 2023). São Luís is the most populous city in the state of Maranhão. CEASA-MA is specifically located at 53 Jerônimo de

Albuquerque Avenue, in the Cohafuma neighborhood (latitude 01°27'21" S, longitude 48°30'16" W).

2.2. Methodological and analytical flowchart

Figure 1 presents the methodological and analytical flowchart of this work.

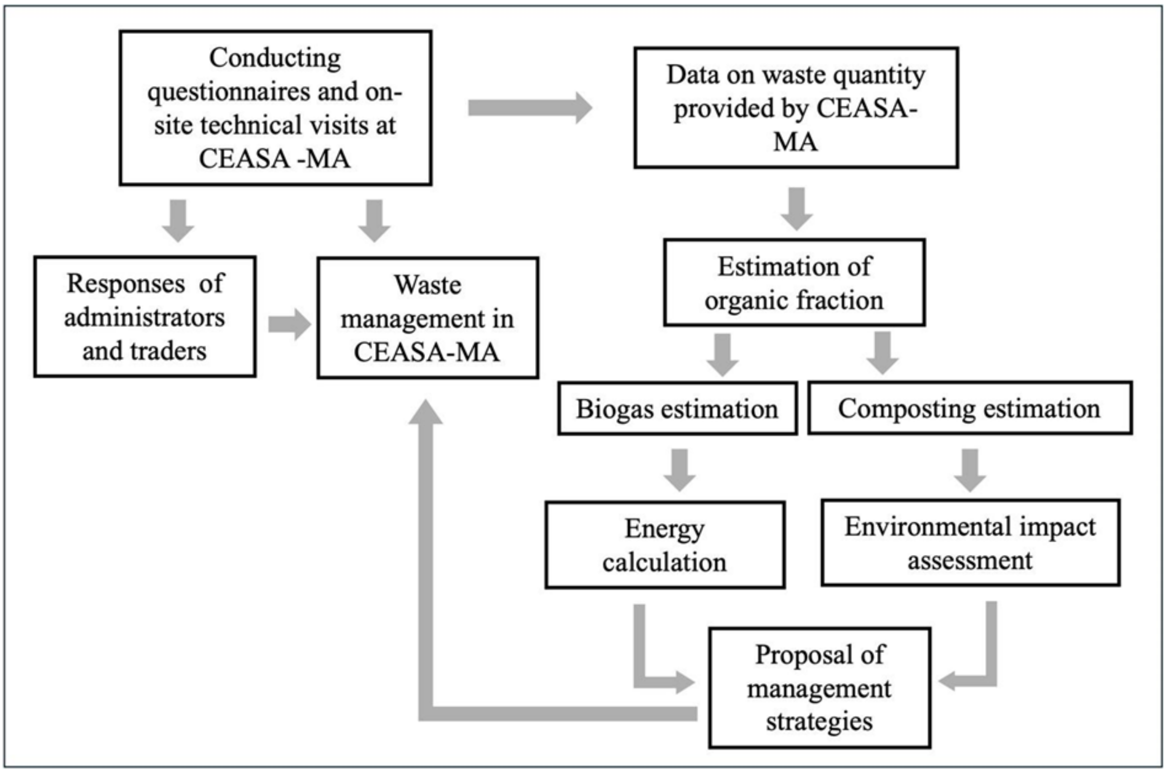

Figure 1. Flowchart of this work.

2.3. Data collection

The data were obtained through on-site technical visits, questionnaires, and documentary research.

2.3.1. Technical visits and questionnaires

The technical visits assessed the organizational practices related to the collection, transportation, and disposal of waste at CEASA-MA.

Two types of questionnaires were administered: one for administrative staff and another for traders operating at CEASA-MA.

The questionnaire for administrative employees included questions regarding respondent demographics (gender, education level, and length of experience), waste collection management at CEASA-MA, the adequacy and availability of waste containers, the existence of a food bank for leftover but still consumable fruits and vegetables, the organization's approach to environmental sustainability practices, and a self-assessment of their knowledge on environmental sustainability.

The questionnaire for traders covered similar demographic information, as well as their perceptions regarding the number and placement of waste containers, the frequency of waste collection, their awareness of selective waste collection, their methods of organic waste disposal, and their interest in environmental issues and participation in environmental education programs.

The questionnaire respondents included two representatives from the administrative sector of CEASA-MA and 103 traders responsible for maintaining their respective sales stalls, or "boxes", which offered products such as fruits, vegetables, fresh meats, cold cuts, dairy products, fish, natural juices, and fruit pulps. At the time of the survey, there were 140 operational boxes, from which 103 were randomly selected to participate in the questionnaire. The sample size was determined using the simple random sampling method via the SurveyMonkey platform (https://pt.surveymonkey.com), establishing 5% error and 95% confidence.

The questionnaire was administered between December 2020 and January 2021, following approval from the Human Research Ethics Committee of the University of Taubaté (CAAE: 37208120.6.0000.5501).

2.3.2. Documentary research

The records on the volume of solid waste collected and sent to the landfill between January 2020 and July 2021 were kindly provided by CEASA-MA.

2.4. Estimates for biogas and compost production

2.4.1. Estimation of organic fraction

Initially, the total amount of solid waste generated at CEASA-MA was determined through an analysis of the company's internal records. Subsequently, the proportion of organic waste was estimated using data from other CEASA facilities (Table 1).

Table 1. Content of organic material contained in solid waste generated in different food supply centers (CEASA) in Brazil.

Name	Localization City, state	Organic residue content (%)	Reference
CEASA - Jaú	Jaú, São Paulo	56	Perim and De Almeida (2013)
CEASA - Paraná	Curitiba, Paraná	80	Silva and Andreoli (2010)
CEASA - Goiás	Goiânia, Goiás	63	Da Costa (2021)
CEASA - Uberlândia	Uberlândia, Minas Gerais	77	Queiroz (2018)
CEASA - Pernambuco	Recife, Pernambuco	90	Dos Santos Filho *et al.* (2020)
CEASA - Rio Grande do Norte	Natal, Rio Grande do Norte	81.6	Da Costa and De Figueiredo (2017)
Mean ± standard deviation		79.3 ± 12.7	

The average percentage of total organic residue was 79.3% across several CEASA facilities. Accordingly, the organic fraction was assumed to represent 79.3% of the total solid waste generated at CEASA-MA.

2.4.2. Estimation of potential biogas production

Biogas production was estimated based on the hypothetical implementation of a horizontal anaerobic reactor, following the methodology proposed by Dos Santos Filho *et al.* (2020). This method was developed using fruit and vegetable waste unfit for human consumption, collected at the CEASA facility in Recife, Pernambuco, Brazil. The inoculum used in the process consisted of domestic sewage sludge, bovine ruminal fluid, and goat manure. After subtracting the biogas generated by the inoculum alone, the authors reported a net biogas yield of 94.83 $Nm^3 \cdot ton^{-1}$ FM (normalized cubic meters per ton of fresh mass), with an average methane concentration of 82%.

Assuming an average organic waste content of 79.3% in the total solid waste generated at

CEASA-MA, biogas production was estimated by multiplying the quantity of organic waste (in tons) by a biogas yield factor of 94.83 $Nm^3 \cdot ton^{-1}$ FM, with methane accounting for 82% of the total biogas produced (Dos Santos Filho *et al.*, 2020).

To estimate the potential energy generation, a conversion factor of 9.9 kWh per Nm^3 of methane was applied (Hernandez *et al.*, 2021).

Therefore, the biogas yield value (94.83 $Nm^3 \cdot ton^{-1}$) was selected based on experimental studies using similar substrates (fruit and vegetable waste), to ensure methodological consistency. The organic fraction (79.3%) was derived from comparable studies conducted at CEASA, while the methane content (82%) and the energy conversion factor (9.9 kWh per Nm^3) were obtained from the cited literature.

2.5. Production estimates of compost and greenhouse gases from composting

Compost production depends on various factors, including the composition of the waste, the composting method employed, and local climatic conditions. In tropical countries, compost yield is typically around 50% of the fresh mass of municipal solid waste (Biddlestone and Gray, 1987). Accordingly, compost production at CEASA-MA was estimated at 50% of the total solid waste generated.

Greenhouse gas (GHG) and ammonia (NH_3) emissions from composting were estimated using average emission factors reported in the literature, which were 0.4, 0.14 and 0.12 kg per ton of fresh mass, for methane (CH_4), NH_3 and nitrous oxide (N_2O), respectively (Pergola *et al.*, 2020). These values were multiplied by the total quantity of organic waste (in tons) to estimate the respective emissions.

3. RESULTS AND DISCUSSION

3.1. Profile of CEASA-MA workers

Regarding the traders, 63% were male and 37% were female. The predominance of male workers is likely associated with the physical demands of the job, which often requires manual strength and skill for loading, unloading, and transporting goods. Female workers at CEASA-MA were primarily engaged in administrative or customer service roles. A similar gender distribution was observed among traders at CEASA in Salvador, Bahia (Brazil), where males accounted for 61% of the workforce (Ferreira dos Santos *et al.*, 2020).

In terms of educational attainment, 56% of CEASA-MA traders had completed high school, 22% had completed elementary school, 20% held higher education degrees, and 2% had completed postgraduate studies. These figures reflect a higher overall level of education compared to traders at CEASA in Salvador, where only 33.3% had completed high school and 30.6% had not completed elementary education (Ferreira dos Santos *et al.*, 2020). Regarding length of employment, 49% of the CEASA-MA traders had been employed for over ten years, 18% for one year or less, 17% for five to ten years, and 16% for one to five years.

Two administrators were interviewed – one female and one male. Both individuals had completed higher education, with one attending graduate school. Their tenure at CEASA ranged from five to ten years.

3.2. Waste management at CEASA-MA

The administrative employees interviewed reported that CEASA-MA has not yet implemented a selective collection system for all solid residues. However, materials such as cardboard, wooden crates, and other high-volume recyclable items can be voluntarily deposited at a designated collection point within CEASA-MA (Figures 2a and 2b). These materials are subsequently transferred to specialized recycling companies.

The interviewees also stated that fruits and vegetables rejected by customers due to their poor visual appearance – but still suitable for human consumption – are donated to a food bank located within CEASA-MA (Figure 3a). The food bank of São Luís was implemented by the Government of Maranhão in June 2019 and has distributed about 1,600,000 tons of food among 50 registered philanthropic institutions. The entire process of collection, selection, sorting, processing, and distribution is managed by the food bank's staff, which includes nutritionists and technical personnel (Maranhão, 2024).

Figure 2. Collection shed for recyclable material at CEASA-MA. External (a) and internal (b) views. Photo by author.

Figure 3. Food bank of São Luís (a), common trash bin (b), makeshift trash bin (c) and disposal shed for solid waste at CEASA-MA. Photo by author.

Other organic and inorganic solid wastes were disposed of in common trash bins (Figure 3b) or in improvised containers (Figure 3c). These bins were placed in the sales pavilion, and the waste was collected by CEASA-MA's cleaning staff and temporarily stored in a disposal shed (Figure 3d) until it was collected by an outsourced company. This waste was managed by Titara Corporation (Central de Gerenciamento Ambiental Titara S/A), which transported the material to a sanitary landfill in the municipality of Rosário, located 65 km from São Luís (São Luís, 2025). At the landfill, the solid waste was mixed with other urban solid waste.

The perception of traders regarding the waste collection system at CEASA-MA was assessed by asking them to rate four specific aspects—namely, the number and placement of trash bins, the number of sweepers, and the frequency of garbage collection—using a three-point scale: good, average, or poor. A majority of respondents considered the number of trash bins to be insufficient (55.3%) and also judged their placement to be inadequate (54.4%). In contrast, approximately 60% of traders rated both the number of sweepers and the frequency of garbage collection as satisfactory (Table 2).

Table 2. Evaluation of the waste collection system of CEASA-MA by traders that worked there. The data are presented as frequency (freq) and percentage (%).

Classification level	Quantity of trash bins		Location of trash bins		Quantity of sweepers		Frequency of garbage collection	
	freq	%	freq	%	freq	%	freq	%
Good	24	23.3	20	19.4	62	60.2	61	59.2
Average	22	21.4	27	26.2	30	29.1	25	24.3
Poor	57	55.3	56	54.4	11	10.7	17	16.5
Total	103	100	103	100	103	100	103	100

Traders were asked whether they engage in any form of waste separation. The majority (77.7%) reported that they did not separate their waste, while 18.4% indicated that they separated organic from recyclable waste. Only 3.9% practiced more comprehensive segregation, distinguishing between organic waste, paper, plastic, glass, and metals.

Regarding the disposal methods for organic solid waste, 64% stated that they discarded it in regular trash bins, 23% claimed to use bins designated for organic waste, 14% reported delivering it to the food bank, and 2% disposed of it elsewhere. However, given that no bins specifically designated for organic waste were observed at CEASA-MA, it is likely that these 23% of respondents misunderstood the question or lacked accurate information on proper disposal methods.

Although 81% of traders reported knowing how to identify the types of waste generated by their commercial activities, 19% admitted being unable to do so, indicating that roughly one-fifth of traders require guidance on waste classification.

Despite the general lack of proper waste separation practices, 73% of traders expressed a willingness to separate recyclable from non-recyclable waste. In contrast, 12.6% were unwilling, and 14.4% were uncertain.

When asked about their environmental concerns, 86% of respondents stated that they were worried about the increase in environmental pollution, while 6.8% were not, and approximately 8% reported being unaware of the issue.

Finally, 62% of traders indicated a willingness to participate in initiatives organized by CEASA-MA to reduce waste generation, such as environmental education programs. Meanwhile, 29% were not interested, and 11% responded that they might participate.

3.3. Estimates of biogas, methane, and electric power

Table 3 presents the monthly quantities of organic solid waste generated between January

2020 and July 2021, with the exception of September and November 2020, when waste measurements were not recorded. During the analyzed period, a total of 4,174.99 tons of solid waste was generated. The highest quantity was recorded in July 2020, whereas the lowest was observed in June 2020.

Table 3. Quantity of solid waste generated at CEASA-MA, and estimates of production of biogas, methane, and energy.

Month/Year	Solid waste (ton)	Organic waste (ton)[a]	Biogas production[b] (Nm^3)	Methane production[c] (Nm^3)	Energy production[d] (kWh)
January/2020	185.62	147.20	13.958.66	11.446.10	113.316.40
February/2020	272.50	216.09	20.492.05	16.803.48	166.354.48
March/2020	199.11	157.89	14.973.11	12.277.95	121.551.71
April/2020	202.85	160.86	15.254.36	12.508.57	123.834.88
May/2020	174.87	138.67	13.150.26	10.783.21	106.753.79
June/2020	170.63	135.31	12.831.41	10.521.75	104.165.37
July/2020	387.34	307.16	29.128.04	23.884.99	236.461.44
August/2020	175.36	139.06	13.187.11	10.813.43	107.052.92
October/2020	229.30	181.83	17.243.40	14.139.59	139.981.95
December/2020	324.09	257.00	24.371.63	19.984.74	197.848.89
January/2021	321.73	255.13	24.194.16	19.839.21	196.408.17
February/2021	305.18	242.01	22.949.59	18.818.67	186.304.80
March/2021	179.80	142.58	13.520.99	11.087.22	109.763.43
April/2021	294.80	233.78	22.169.02	18.178.59	179.968.07
May/2021	304.04	241.10	22.863.87	18.748.37	185.608.86
June/2021	181.10	143.61	13.618.75	11.167.38	110.557.05
July/2021	266.67	211.47	20.053.63	16.443.98	162.795.41
Total 2020+2021:	**4,174.99**	**3,310.77**	**313,960.04**	**257,447.23**	**2,548,727.61**
Monthly average/2020:	232.17	184.11	17,459.00	14,316.38	141,732.18
Monthly average/2021:	264.76	209.95	19,910.00	16,326.20	161,629.40
Mean[e] ± standard dev.	**245.6 ± 68.2**	**194.8 ± 54.1**	**18,468.2 ± 5,131.4**	**15,144.0 ± 4,207.7**	**149,925.2 ± 41,656.5**

[a] Solid organic waste corresponds to 79.3% of the total solid waste.
[b] One ton of organic solid waste produces 94.83 Nm^3 of biogas.
[c] Methane gas corresponds to about 82% of biogas.
[d] One Nm^3 of methane produces 9.9 kWh of energy.
[e] Mean = 17-month average.

Based on the estimates of biogas and methane production (Table 3), the average energy generation is projected to be approximately 149,925.2 kWh per month, which could supply around 1,170 households, considering the average residential consumption in the Northeast region of Brazil is 128 kWh per month (Brasil, 2021).

Organic solid waste can generate valuable products for society when utilized for biogas or compost production. Biogas is a biofuel that produces renewable energy and is considered carbon neutral, as its carbon content originates from organic matter synthesized from CO_2 absorbed from the atmosphere. The applications of biogas include domestic heating, vehicle fuel, electricity generation, heat cogeneration, and use in chemical industries (Silva dos Santos *et al.*, 2018).

In Brazil, approximately 80% of the solid waste generated in food supply centers consists of organic matter. The organic waste produced monthly at CEASA-MA has the potential to generate significant amounts of biogas and electricity. However, biogas energy production in Brazil is not currently considered economically viable, as its cost can reach 105 USD/MWh, compared to 87 USD/MWh for thermoelectric power plants (Silva dos Santos *et al.*, 2018). Additionally, several technological, commercial, political, and regulatory challenges must be addressed for biogas to achieve a greater share in the Brazilian energy matrix (Mathias and Mathias, 2015).

Our energy production estimate was based on the hypothetical implementation of a horizontal anaerobic reactor (Dos Santos Filho *et al.*, 2020). Although anaerobic digestion results in low CO_2 emissions, its energy generation potential is generally lower than that of other technologies, particularly the incineration of organic waste from sanitary landfills (Salah *et al.*, 2022). These authors reported that incineration leads to lower emissions than landfilling and suggested that, in Palestine, anaerobic digestion and incineration should be combined to achieve higher energy production efficiency and lower greenhouse gas emissions.

Therefore, considering the high costs of biogas generation in Brazil, other alternatives should also be considered. Organic waste from CEASA-MA could be directed to biorefineries that convert plant biomass into energy and other products, using renewable resources to reduce carbon emissions. Economic feasibility and environmental sustainability studies of biorefineries, including analyses of the distance between the material source and the biorefinery, and waste composition have been conducted (Clasen *et al.*, 2026).

Composting converts organic waste into compost, which can be used as fertilizer and for soil restoration in degraded areas (Hettiarachchi *et al.*, 2020). The addition of compost improves soil properties by reducing surface sealing, minimizing soil erosion, and enhancing water infiltration and retention. Moreover, increasing soil organic matter contributes to carbon sequestration, thereby reducing greenhouse gas emissions. Soil biodiversity is also enhanced, potentially leading to a more robust microbiome around plant roots, which can improve plant mineral nutrition and inhibit soilborne diseases (Hettiarachchi *et al.*, 2020).

The estimated total compost production from CEASA-MA's organic waste during the analyzed period was 2,087.50 tons, with a monthly average of 122.8 tons (Table 4).

Organic fertilizers produced through the composting of municipal solid waste can increase soil pH and, therefore, may be useful as amendments for acidic soils (Domínguez *et al.*, 2019; Hargreaves *et al.*, 2008). However, their electrical conductivity may exceed the recommended levels for seed germination, potentially inhibiting plant growth. Additionally, the nitrogen content in compost may be insufficient for certain plants during the first year of application, requiring higher compost inputs. The phosphorus content, on the other hand, is generally adequate to support plant growth, but excessive compost application can lead to phosphorus leaching into water bodies, contributing to eutrophication. Approximately 36–40% of the potassium in organic compost is readily available to plants, and even low compost application rates can significantly increase soil potassium concentrations (Hargreaves *et al.*, 2008; Manea *et al.*, 2024).

Metals may also be present in compost, increasing the bioavailability of elements such as Cu, Pb, and Ni, which could be harmful to soil microbiota and the food chain (Manea *et al.*, 2024). However, metal accumulation levels in soils are often within permitted limits, although some crops may moderately or strongly bioaccumulate specific metals (Abd-Elhalim *et al.*, 2025). Furthermore, pesticides and herbicides can be detected in composts when the feedstock is contaminated. Some herbicides are resistant to degradation and can harm growing plants, whereas others degrade during the composting process and pose no significant risk (Manea *et* *al.*, 2024). Recently, composting has been explored as a strategy for pesticide bioremediation in contaminated soils by promoting their stabilization and degradation. The process involves amending polluted soils with non-hazardous organic materials to stimulate microbial activity, thereby enhancing physicochemical and biological transformations of the contaminants (Lau *et al.*, 2023).

Table 4. Production estimates of compost, greenhouse gases and ammonia from CEASA-MA organic waste.

Month/Year	Compost (ton) [a]	Organic waste (ton)	CH_4 [b] (kg)	NH_3 [c] (kg)	N_2O[d] (kg)
January/2020	92.81	147.20	58.88	20.61	17.66
February/2020	136.25	216.09	86.44	30.25	25.93
March/2020	99.56	157.89	63.16	22.11	18.95
April/2020	101.43	160.86	64.34	22.52	19.30
May/2020	87.44	138.67	55.47	19.41	16.64
June/2020	85.32	135.31	54.12	18.94	16.24
July/2020	193.67	307.16	122.86	43.00	36.86
August/2020	87.68	139.06	55.62	19.47	16.69
October/2020	114.65	181.83	72.73	25.46	21.82
December/2020	162.05	257.00	102.80	35.98	30.84
January/2021	160.87	255.13	102.05	35.72	30.62
February/2021	152.59	242.01	96.80	33.88	29.04
March/2021	89.90	142.58	57.03	19.96	17.11
April/2021	147.40	233.78	93.51	32.73	28.05
May/2021	152.02	241.10	96.44	33.75	28.93
June/2021	90.55	143.61	57.44	20.11	17.23
July/2021	133.34	211.47	84.59	29.61	25.38
Total 2020+2021:	**2,087.50**	**3,310.77**	**1,324.31**	**463.51**	**397.29**
Monthly average/2020:	**116.08**	**184.11**	**73.64**	**25.78**	**22.09**
Monthly average/2021:	**132.38**	**209.95**	**83.98**	**29.39**	**25.19**
Mean [e] ± standard dev.	**122.8 ± 34.1**	**194.8 ± 54.1**	**77.9 ± 21.6**	**27.3 ± 7.6**	**23.4 ± 6.5**

[a] Compost corresponds to 50% of the total solid waste (Table 3).
[b] One ton of organic waste produces 0.4 kg of CH_4.
[c] One ton of organic waste produces 0.14 kg of NH_3.
[d] One ton of organic waste produces 0.12 kg of N_2O.
[e] Mean = 17-month average.

The quality of compost depends on the origin of the composted material. According to new Brazilian legislation (Normative Instruction No. 61, July 8, 2020), organic fertilizers are classified into classes A and B. Class A fertilizers are produced from segregated organic matter collected separately at the source. However, at CEASA-MA, organic waste is not separated and is instead mixed with other waste materials before being discarded in a landfill. This represents a missed opportunity, as high-quality compost could be produced and enriched with mineral additives, such as rock powder, to enhance its composition and generate an organo-mineral fertilizer. Consequently, CEASA-MA may be foregoing a valuable opportunity to commercialize its organic waste with minimal sanitary contamination by supplying it to a composting or organic fertilizer production facility.

According to Farias *et al.* (2020), Brazil imported 78% of the NPK fertilizers consumed in 2018. The majority (70%) of these fertilizers were used for the cultivation of soybeans, corn, and sugarcane crops that serve as raw materials for biofuel production. In 2019, biofuels supplied approximately 25% of Brazil's fuel demand, and the country aims to increase this share to 28.6% by 2028 in alignment with the Paris Agreement.

The debate surrounding Brazil's dependence on imported fertilizers intensified following the outbreak of the Russia-Ukraine war in 2022, as Brazil had imported approximately 22% of its NPK fertilizers from Russia in 2020 (Brasil, 2022a). To reduce this external dependence, Brazil launched the National Fertilizer Plan (Decree No. 10,991 of March 11, 2022), which includes the objective of increasing the production and supply of organic and organo-mineral fertilizers.

In this context, an organo-mineral fertilizer known as BIOFOM was developed in Brazil using waste from the sugar and ethanol industries. This fertilizer incorporates vinasse, filter cake, ash, soot, and a mineral source of nitrogen (N), phosphorus (P), and potassium (K). This initiative not only provided an environmentally sustainable solution for vinasse disposal, but also demonstrated economic viability (Olivério *et al.*, 2011).

To ensure high-quality organic waste, CEASA-MA should implement a selective collection system. The majority of CEASA-MA traders (73%) indicated that they are willing to separate recyclable and non-recyclable waste, and 86% expressed concerns about increasing environmental pollution. These findings suggest that the implementation of selective organic waste collection at CEASA-MA has a high potential for success. Additionally, approximately 66% of the interviewed traders expressed willingness to participate in environmental education programs.

Environmental sustainability attitudes are often correlated with educational levels, as understanding environmental issues requires a certain degree of ecological and environmental knowledge (Liu *et al.*, 2012). At CEASA-MA, most traders (56%) have completed high school, while 22% have attained some level of higher education. Therefore, implementing environmental education programs among CEASA-MA workers is both feasible and beneficial for the effective separation of organic waste.

However, the location and quantity of trash bins were deemed inadequate by most traders. Addressing this issue is crucial for the successful implementation of selective waste collection. Trash bins must be clearly labeled to facilitate the proper disposal of vegetable and fruit waste. Non-organic waste, including unsanitary materials that are not of fruit or vegetable origin, must also be separated and transported to a landfill to prevent contamination of organic materials intended for composting.

Furthermore, if organic waste were separated from other residues at the source, the pretreatment costs for removing plastic, metal, and other impurities could be significantly reduced for biogas production and high-quality compost production. This pretreatment is essential for preventing mechanical failures in biogas plants (Hansen *et al.*, 2007).

Despite its benefits, the expansion of compost use has been limited by the lack of integrated management between agricultural sectors that could utilize compost and the waste management sector. Additionally, composting has not yet generated strong commercial interest (Hettiarachchi *et al.*, 2020). In Brazil, only 1.9% of municipalities had composting facilities as of the most recent assessment (Lima *et al.*, 2018). These challenges were also highlighted by two interviewed employees from the CEASA-MA administrative sector, who reported that environmental sustainability practices are perceived primarily as operational costs for the company, despite CEASA-MA's compliance with legal environmental policy requirements. According to Kharola *et al.* (2022), the main barrier to organic waste management is the lack of valorization of these residues, identified as the most significant causal factor. Additional causal barriers include financial constraints. The resulting effects are predominantly operational, behavioral, and informational, manifesting as inadequate collection and separation infrastructure, inappropriate disposal practices, low public awareness, and negative attitudes toward the waste management system.

Although composting is an environmentally sustainable alternative for managing organic waste, it can also contribute to global warming. The composting process releases greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), while ammonia (NH_3) emissions can lead to unpleasant odors (Pergola *et al.*, 2020).

During the analyzed period, CH_4 emissions were estimated to reach 1,324.31 kg, with a monthly average of 77.9 kg. The estimated monthly emissions of NH_3 and N_2O were 27.3 kg and 23.4 kg, respectively (Table 4). CO_2 emissions were not calculated, as the CO_2 released from composting processes is biogenic and, therefore, not classified as a greenhouse gas emission (Pergola *et al.*, 2020).

The global warming potential (GWP) of CH_4 and N_2O is 25 and 298, respectively (IPCC, 2007). Accordingly, the estimated CO_2 equivalent (CO_2e) emissions from these gases are 1,947.5 kg per month for CH_4 and 6,973.2 kg per month for N_2O.

The global warming potential (GWP) of sanitary landfills in Brazil can reach 256 kg CO_2e per ton of waste (Lima *et al.*, 2018). If the monthly solid waste production at CEASA-MA (245.6 tons) were disposed of in a landfill, the estimated GWP would be 62,873.6 kg CO_2e. However, if the organic fraction were composted, the GWP of the process could be reduced to 8,920.7 kg CO_2e, representing a lower environmental impact compared to landfill disposal. Nevertheless, this study did not account for GWP contributions from electricity consumption during composting, transportation of waste to composting facilities (e.g., diesel usage), and other direct emissions. As a result, the actual GWP of composting CEASA-MA's organic waste may be higher than the estimated value.

Ammonia (NH_3) is a compound with a strong odor that is released during protein degradation, and its concentration can exceed threshold limits during food waste composting (Wei *et al.*, 2017). However, the composting of fruit and vegetable waste releases relatively low amounts of NH_3 (Pergola *et al.*, 2020). Therefore, composting organic waste from CEASA-MA is expected to result in minimal NH_3 emissions with limited odor-related impacts.

Recent studies indicate that integrated waste valorization systems can substantially reduce environmental impacts while simultaneously generating economic benefits (Kharola *et al.*, 2022; Salah *et al.*, 2022; Clasen *et al.*, 2025). The implementation of selective collection systems at CEASA-MA could enhance the valorization of organic residues, improve compliance with the National Solid Waste Policy (PNRS), and support circular economy initiatives based on waste recovery. Furthermore, the use of compost may contribute to reducing Brazil's dependence on imported fertilizers.

This study presents some limitations. First, the estimates were based on secondary data and parameters reported in the literature. Second, no economic feasibility analysis was conducted. Third, life cycle assessment (LCA) was not performed. Finally, the absence of experimental validation introduces uncertainty in projections.

4. CONCLUSION

This study demonstrates that CEASA-MA has significant potential to improve organic waste management through the implementation of selective collection systems and waste valorization strategies. The high proportion of organic waste indicates strong viability for biogas production and composting, offering relevant environmental and economic benefits. However, the current lack of selective collection practices at CEASA-MA limits the realization of this potential. The implementation of structured waste management practices, aligned with public policies, could improve sustainability, reduce unregulated landfill disposal, and contribute to circular economy initiatives in Brazil.

5. DATA AVAILABILITY STATEMENT

Data availability not informed.

6. ACKNOWLEDGMENTS

The authors thank CEASA-MA for all information provided, J.E.K. da Silva Santos received a masters scholarship from the Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão (BM 02233/20).

7. REFERENCES

ABD-ELHALIM, B. T.; GIDEON, M.; ANTON, K.; BOYI, M. O. Impact of dumpsite compost on heavy metal accumulation in some cultivated plants. **BMC Research Notes**, v. 18, n. 1, p. 20, 2025. https://doi.org/10.1186/s13104-025-07083-9

ABRELPE. **Panorama dos resíduos sólidos no Brasil 2021**. São Paulo, 2021.

BIDDLESTONE, A.; GRAY, K. *Production of organic fertilizers by composting*. *In*: DETRITUS AND MICROBIAL ECOLOGY IN AQUACULTURE: ICLARM CONFERENCE, 14, 26-31 August, 1985, Bellagio. **Proceedings[…]** Manila: International Centre for Living Aquatic Resources Management, 1987. p. 151-180.

BRASIL. Ministério da Agricultura e Pecuária. **Governo Federal lança Plano Nacional de Fertilizantes para reduzir importação dos insumos**. 2022a. Available: https://www.gov.br/agricultura/pt-br/assuntos/noticias/governo-federal-lanca-plano-nacional-de-fertilizantes-para-reduzir-importacao-dos-insumos Access: March 2022.

BRASIL. Ministério das Cidades. **SNIS - Série Histórica**. 2022b. Available: https://app4.cidades.gov.br/serieHistorica/ Access: Feb. 2022.

BRASIL. Ministério de Minas e Energia. **Anuário estatístico de energia elétrica 2021: ano base 2020**. Brasília, 2021.

CETRULO, T. B.; MARQUES, R. C.; CETRULO, N. M.; PINTO, F. S.; MOREIRA, R. M.; MENDIZÁBAL-CORTÉS, A. D. *et al.* Effectiveness of solid waste policies in developing countries: A case study in Brazil. **Journal of Cleaner Production**, v. 205, p. 179-187, 2018. https://doi.org/10.1016/j.jclepro.2018.09.094

CLASEN, A. P.; AGOSTINO, F.; ALMEIDA, C. M. V. B.; GIANNETTI. B. F. A decision-making model for more sustainable municipal solid waste management. **Environmental Impact Assessment Review**, 2026. https://doi.org/10.1016/j.eiar.2025.108258

CONAB. **Centrais de Abastecimento: comercialização total de frutas e hortaliças**. Brasília, DF, 2022. v. 5

DA COSTA, L.; DE FIGUEIREDO, F. Panorama dos resíduos sólidos gerados na central de abastecimento do Rio Grande Do Norte (CEASA/RN). *In*: INOVAGRI INTERNATIONAL MEETING, 4., 2-6 Oct. 2017, Fortaleza. **Proceedings[…]** Available: https://icolibri.com.br/public/anais/TC4730838.pdf. Access: October 2025.

DA COSTA, W. M. **Análise da gestão de resíduos sólidos nas Centrais de Abastecimento de Goiás S. A. (CEASA-GO).** 2021. 106f. Dissertação (Mestrado em Agronegócio) - Universidade Federal de Goiás, Goiânia, 2021.

DE QUEIROZ, T. A. N. As Ceasas no contexto da reestruturação do território brasileiro. **Geotemas,** v. 8, n. 2, p. 59-78, 2018.

DOS SANTOS FILHO, D. A.; OLIVEIRA, L. R. G.; FRAGA, T. J. M.; DA MOTTA SOBRINHO, M. A.; JUCÁ, J. F. T. Development of a horizontal reactor with radial agitation to synthesize bio-methane from biomass waste and domestic sewage sludge. **Journal of Cleaner Production**, v. 257, p. 120616, 2020. https://doi.org/10.1016/j.jclepro.2020.120616

DOMÍNGUEZ, M.; PARADELO NÚÑEZ, R.; PIÑEIRO, J.; BARRAL, M. T. Physicochemical and biochemical properties of an acid soil under potato culture amended with municipal solid waste compost. **International Journal of Recycling of Organic Waste in Agriculture**, v. 8, n. 2, p. 171-178, 2019. https://doi.org/10.1007/s40093-019-0246-x

FARIAS, P. I. V.; FREIRE, E.; DA CUNHA, A. L. C.; GRUMBACH, R. J. S.; ANTUNES, A. M. S. The fertilizer industry in Brazil and the assurance of inputs for biofuels production: prospective scenarios after COVID-19. **Sustainability**, v. 12, n. 21, p. 8889, 2020. https://doi.org/10.3390/su12218889

FERREIRA DOS SANTOS, S.; CARDOSO, R. C. V.; BORGES, Í. M. P.; ALMEIDA, A. C.; ANDRADE, E. S.; FERREIRA, I. O. *et al.* Post-harvest losses of fruits and vegetables in supply centers in Salvador, Brazil: Analysis of determinants, volumes and reduction strategies. **Waste Management**, v. 101, p. 161-170, 2020. https://doi.org/10.1016/j.wasman.2019.10.007

HANSEN, T. L.; JANSEN, J. L. C.; DAVIDSSON, Å.; CHRISTENSEN, T. H. Effects of pre-treatment technologies on quantity and quality of source-sorted municipal organic waste for biogas recovery. **Waste Management**, v. 27, n. 3, p. 398-405, 2007. https://doi.org/10.1016/j.wasman.2006.02.014

HARGREAVES, J. C.; ADL, M. S.; WARMAN, P. R. A review of the use of composted municipal solid waste in agriculture. **Agriculture, Ecosystems & Environment**, v. 123, n. 1, p. 1-14, 2008. https://doi.org/10.1016/j.agee.2007.07.004

HERNANDEZ, O. A. D.; PAULA, A. C.; POSSETTI, G. R. C.; CANTÃO, M. P.; AISSE, M. M. Quali-quantitative characterization of biogas with the temporal behavior of organic load on wastewater treatment plant with upflow anaerobic sludge blanket reactors through measurement in full-scale systems. **Brazilian Journal of Environmental Sciences (Online)**, v. 56, n. 4, p. 621-629, 2021. https://doi.org/10.5327/Z217694781059

HETTIARACHCHI, H.; CAUCCI, S.; SCHWÄRZEL, K. **Organic waste composting through nexus thinking: practices, policies, and trends**. Cham: Springer Nature, 2020. 232 p. https://doi.org/10.1007/978-3-030-36283-6

IBGE. **Brasil / Maranhão / São Luís**. 2023. Available: https://cidades.ibge.gov.br/brasil/ma/sao-luis/panorama Access: March 2025.

IPCC. **Climate Change 2007**. Cambridge: Cambridge University Press, 2007. Available: https://www.ipcc.ch/report/ar4/wg1/. Access: October, 2025.

KHAROLA, S.; RAM, M.; GOYAL, N.; MANGLA, S. K.; NAUTIYAL, O. P.; RAWAT, A. *et al.* Barriers to organic waste management in a circular economy. **Journal of Cleaner Production**, v. 362, p. 132282, 2022. https://doi.org/10.1016/j.jclepro.2022.132282

LAU, Y. Y.; HERNANDES, E.; KRISTANTI, R. A.; WIJAYANTI, Y.; EMRE, M. Exploring the potential of composting for bioremediation of pesticides in agricultural sector. **Industrial and Domestic Waste Management**, v. 3, n. 1, p. 47-66, 2023. https://doi.org/10.53623/idwm.v3i1.245

LIMA, P. D. M.; COLVERO, D. A.; GOMES, A. P.; WENZEL, H.; SCHALCH, V.; CIMPAN, C. Environmental assessment of existing and alternative options for management of municipal solid waste in Brazil. **Waste Management**, v. 78, p. 857-870, 2018. https://doi.org/10.1016/j.wasman.2018.07.007

LIU, X.; WANG, C.; SHISHIME, T.; FUJITSUKA, T. Sustainable consumption: Green purchasing behaviours of urban residents in China. **Sustainable Development**, v. 20, n. 4, p. 293-308, 2012. https://doi.org/10.1002/sd.484

LUO, H.; CHENG, Y.; HE, D.; YANG, E.-H. Review of leaching behavior of municipal solid waste incineration (MSWI) ash. **Science of The Total Environment**, v. 668, p. 90-103, 2019. https://doi.org/10.1016/j.scitotenv.2019.03.004

MANEA, E. E.; BUMBAC, C.; DINU, L. R.; BUMBAC, M.; NICOLESCU, C. M. Composting as a sustainable solution for organic solid waste management: Current practices and potential improvements. **Sustainability**, v. 16, n. 15, p. 6329, 2024. https://doi.org/10.3390/su16156329

MARANHÃO. **Banco de Alimentos completa cinco anos e comemoração acontece nesta quinta-feira (06), na sede do equipamento**. 2024. Available: https://www.ma.gov.br/noticias/banco-de-alimentos-completa-cinco-anos-e-comemoracao-acontece-nesta-quinta-feira-06-na-sede-do-equipamento Access: March 2025.

MATHIAS, M.; MATHIAS, J. Biogas in Brazil: a governmental agenda. **Journal of Energy and Power Engineering**, v. 9, p. 1–15, 2015. https://doi.org/10.17265/1934-8975/2015.01.001

OLIVÉRIO, J. L.; BOSCARIOL, F. C.; MANTELATTO, P. E.; CÉSAR, A. R. P.; CIAMBELLI, J. R. P.; DO AMARAL GURGEL, M. N. *et al.* Integrated production of organomineral biofertiliser (BIOFOM®) using by-products from the sugar and ethanol agro-industry, associated with the cogeneration of energy. **Sugar Tech**, v. 13, n. 1, p. 17-22, 2011. https://doi.org/10.1007/s12355-011-0069-1

PERGOLA, M.; PERSIANI, A.; PASTORE, V.; PALESE, A. M.; D'ADAMO, C.; DE FALCO, E. *et al.* Sustainability assessment of the green compost production chain from agricultural waste: A case study in southern Italy. **Agronomy**, v,10, n. 2, p. 230, 2020. https://doi.org/10.3390/agronomy10020230

PERIM, J. M.; DE ALMEIDA, T. L. Diagnóstico de Resíduos Sólidos da CEASA–JAÚ. *In*: SIMPÓSIO DE TECNOLOGIA EM MEIO AMBIENTE, 5., 12-14 Jun. 2013, Jahu. **Proceedings[...]** São Carlos: Rima, 2013. p. 231-241.

QUEIROZ, A. L. A. **Resíduos sólidos na central de abastecimento de Minas Gerais – unidade de Uberlândia**. 2018. 44f. Trabalho de Conclusão de Curso (Bacharel em Engenharia Ambiental) - Universidade Federal de Uberlândia, Uberlândia, 2018.

SALAH, W. A.; ABUHELWA, M.; ABUSAFA, A.; BASHIR, M. J. K. The feasibility of renewable energy recovery from municipal solid wastes in Palestine based on different scenarios. **Biofuels**, 2022. https://doi.org/10.1080/17597269.2022.2151428

SÃO LUÍS (Maranhão). **Para onde vai o lixo recolhido diariamente em São Luís?** 2025. Available: https://www.saoluis.ma.gov.br/para-onde-vai-o-lixo-recolhido-diariamente-em-sao-luis---sulip/#:~:text=Desde%20a%20desativação%20do%20Aterro,resíduos%20até%20o%20aterro%20sanitário. Access: October 2025.

SILVA, C. A.; ANDREOLI, C. V. Compostagem como alternativa a disposição final dos resíduos sólidos gerados na CEASA Curitiba/PR. **Revista Engenharia Ambiental**, v. 7, n. 2, p. 27-40, 2010.

SILVA DOS SANTOS, I. F.; VIEIRA, N. D. B.; DE NÓBREGA, L. G. B.; BARROS, R. M.; TIAGO FILHO, G. L. Assessment of potential biogas production from multiple organic wastes in Brazil: impact on energy generation, use, and emissions abatement. **Resources, Conservation & Recycling**, v. 131, p. 54–63, 2018. https://doi.org/10.1016/j.resconrec.2017.12.012

WEI, Y.; LI, J.; SHI, D.; LIU, G.; ZHAO, Y.; SHIMAOKA, T. Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. **Resources, Conservation and Recycling**, v. 122, p. 51-65, 2017. https://doi.org/10.1016/j.resconrec.2017.01.024