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Agricultural Valorization of Fecal Sludge in the Municipality of Sèmè-Podji, Southeastern Benin

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Abstract

The reuse of fecal sludge in the Municipality of Sèmè-Podji is feasible through compost production that no longer poses a public health risk. The methodological approach combines literature review, field data collection from 302 respondents, and data processing. At Sèmè-Podji, 29% of the surveyed population still use traditional emptying methods, while 71% rely on professional desludging services. The presence of a Fecal Sludge Treatment Plant (FSTP) is crucial for sustainable sludge management. At the plant, raw sludge is discharged into a reception pit where it remains for 15 to 21 days to allow separation of the liquid fraction and obtain dehydrated solids. These solids are stored under controlled conditions. Pre-treatment and co-composting are the main steps in agricultural valorization. Additionally, 73% of farmers apply compost through spreading, while 27% practice burial. These methods improve soil fertility using compost derived from fecal sludge. Due to its richness in nutrients (nitrogen, phosphorus, potassium) and organic matter, treated sludge is used as an agricultural amendment, provided sanitary standards are respected.

Keywords

Sèmè-Podji Municipality, Fecal Sludge, Agricultural Valorization, Compost

1. Introduction

Fecal sludge, composed of excreta, water, and cleansing materials, represents a major public health challenge, requiring rigorous management from collection to treatment in order to eliminate pathogens [1]-[3]. In Sub-Saharan Africa, in the context of rapid population growth and increasing agricultural demands, such sludge should no longer be regarded merely as waste, but rather as a resource for soil amendment [4]. However, current management is largely dominated by the informal sector [3], highlighting urban management challenges, as observed in Lomé [5], and making the use of transfer and treatment facilities indispensable [6].

While compost production from dried sludge constitutes a promising pathway [7] [8], the uncontrolled use of agricultural inputs underscores the need for sustainable nutrient recycling [9]. In Benin, despite the commissioning of the Fecal Sludge Treatment Plant (FSTP) in Sèmè-Podji in 2021 to improve living conditions [10], the effective valorization of the biosolids produced still requires optimization to ensure safe agricultural reuse.

These observations lead to the following research question:

To what extent can the agricultural valorization of fecal sludge treated at the Sèmè-Podji Fecal Sludge Treatment Plant (FSTP) ensure sustainable sanitation management while meeting soil fertility needs?

To address this question, the objective is defined as follows:

To assess the potential and establish the technical conditions for the agricultural valorization of compost derived from fecal sludge at the Sèmè-Podji treatment plant, with a view to sustainable production.

2. Materials and Methods

2.1. Study Area

The Municipality of Sèmè-Podji is located in the Ouémé Department in south-eastern Benin. It lies between latitudes 6˚22'30'' and 6˚27'30'' North, and longitudes 2˚31'30'' and 2˚42'00'' East. It is bounded to the northwest by Lake Nokoué, to the northeast by the Porto-Novo Lagoon, to the south by the Atlantic Ocean, to the east by the Federal Republic of Nigeria, and to the west by the municipality of Cotonou (**Figure 1**).

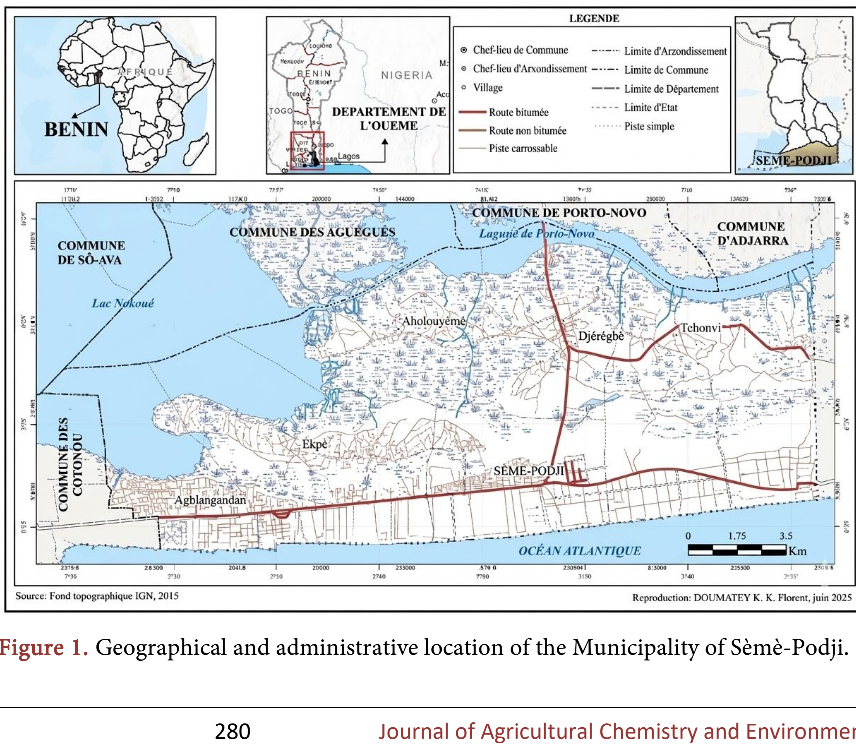


Figure 1. Geographical and administrative location of the Municipality of Sèmè-Podji.

The Municipality of Sèmè-Podji is composed of six (06) administrative districts, namely: Agblangandan, Ekpè, Sèmè-Podji, Djèrègbé, Tohouè, and Aholouyèmè, covering a total area of 250 km^2. This geographical positioning contributes significantly to human settlement patterns and the generation of fecal sludge within the municipality.

2.2. Data and Methods

The socio-anthropological data relate to fecal sludge management practices. These data were complemented by a literature review and socio-health surveys conducted with 302 households selected from a total of 37,249 households in the Municipality of Sèmè-Podji [11], based on the statistical protocol proposed by [12].

The sample was determined using a probabilistic approach, with random selection proportional to household size, based on a set of predefined criteria. A key determinant in selecting surveyed households was their proximity to areas of wastewater and stormwater stagnation, as well as the presence of fecal sludge.

For the target population, the following criteria were applied:

Having at least ten (10) years of experience within a liquid waste management structure, to ensure a solid understanding of the realities of sludge management;

Having resided in the Municipality of Sèmè-Podji for the past ten (10) years, as familiarity with local conditions requires long-term residence.

Thus, for sample size determination in this study, the method proposed by [12] was used. This method relies on the confidence level, estimated prevalence, and margin of error to determine the required sample size for large-scale surveys. It is particularly suitable for rapid implementation over large geographical areas. The formula is as follows:

$$\beta = Z\alpha^2 * \frac{pq}{i^2}$$

With:

β = sample size;

$Z\alpha$ = 1.96: standard normal deviate corresponding to a significance level α of 5%;

$p = n/N$ where p represents the proportion of households in the municipality;

n = number of households in the municipality;

N = total number of households in the department;

i = desired precision set at 5% according to the INStaD and MAEP methodology;

$q = 1 - p$;

The margin of error is set at 5%, which is a commonly accepted standard (A. Durand-Lasserve, 2009, p. 35), indicating that the sample selection is valid at a 95% confidence level.

Thus, the sample size was calculated. The numerical application of the formula proposed by [11] for the Municipality of Sèmè-Podji yields the following expression:

$$\beta = Z\alpha^2 * \frac{pq}{i^2}$$

$i^2 = (1.96)^2 = 3.841$

$P_2 = 49490/232\ 620 = 0.2127504$

$q = 1 - p = 1 - 0.2127504 = 0.7872496$

$e^2 = (5\%)^2 = 0.0025$

$\beta_2 = (1.96)^2 \times 0.2127504 \times (1 - 0.2127504)/0.0025.$

$\beta_1 = 3.84 \times 0.2127504 \times 0.7872496/0.0025$

$\beta_1 = 302$ Household

For this study, statistical analyses were conducted using both descriptive statistics and inferential tests. Specifically, for qualitative variables, response frequencies were calculated, while for quantitative variables, means and standard errors were computed. The resulting datasets were exported into SPSS version 17.0 for tabulation.

Several methods were employed to assess the socio-economic and environmental impacts of liquid waste management in the Commune of Sèmè-Podji. Financial indicators, including total production costs, Gross Product (GP), Net Operating Income (NOI), and financial return were considered to evaluate the financial performance of sludge pre-collection enterprises operating in the commune. To this end, an operating account was developed for each type of enterprise.

The components of this account are as follows:

Total Production Costs (TPC): These represent all expenses incurred in desludging activities over the course of a year. TPC includes both variable costs (VC) and fixed costs (FC).

Variable costs are operational expenses that fluctuate with the level of desludging activity. They include dumping fees, equipment wear and maintenance, truck and equipment depreciation, driver and assistant wages, insurance, licenses and permits, administrative fees, rent, electricity, communication, and preventive maintenance.

Fixed costs are those that remain constant regardless of activity level.

Analytical accounting was used to allocate costs for equipment employed both in desludging and in other activities within the enterprise.

Gross Product (GP): Calculated as the product of the number of desludging operations performed per day and the unit price (P) of desludging, differentiated by category.

Net Operating Income (NOI): Determined as the difference between GP and variable production costs [13].

Financial Profitability (Return Rate, RR): Assessed using the profitability ratio, defined as the percentage relationship between net income and resources invested in the activity [14]:

$$RR = \frac{NOI}{VC} * 100$$

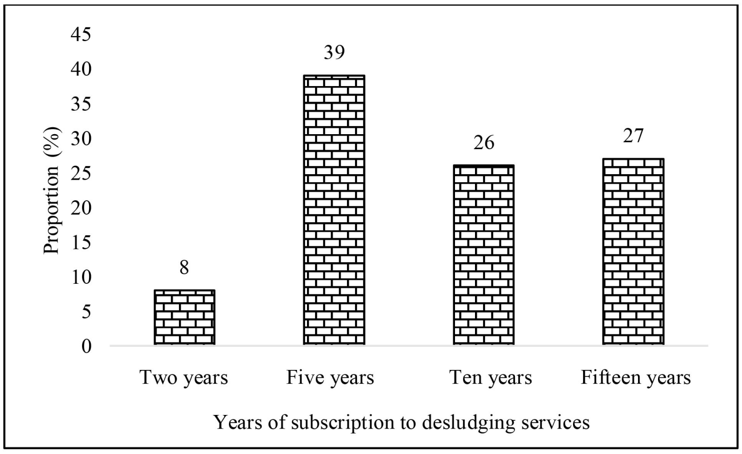
This profitability rate thus indicates the additional value generated by an investment of 100 FCFA in desludging activities over the course of one year.

3. Results and Discussion

3.1. Desludging Practices

In the Municipality of Sèmè-Podji, households adopt both traditional and mechanical desludging methods. Specifically, 29% of the surveyed respondents rely on traditional practices, while 71% use professional desludging services. Analysis of Figure 2 shows that 39% of respondents have been subscribed to desludging services for five years, 27% for fifteen years, 26% for ten years, and 8% for two years.

The cost of desludging varies depending on the capacity of the vacuum truck. For a 6 m^3 truck, the service costs 45,000 FCFA; for a 12 m^3 truck, the cost is 90,000 FCFA; and for an 18 m^3 truck, the cost reaches 135,000 FCFA.



Data source: Fieldwork, May 2025.

Figure 2. Duration of subscription to desludging services in the Commune of Sèmè-Podji.

The Commune of Sèmè-Podji represents a vast and dynamic market that is extensively utilized in terms of sanitation services. Private pre-collection enterprises play a pivotal role by collaborating with the commune to ensure the pre-collection of faecal sludge. The Agblangandan district hosts the largest number of pre-collection enterprises, followed by the districts of Ekpè and Sèmè-Podji. In contrast, the districts of Djèrègbé and Aholouyèmè have fewer such enterprises. This uneven distribution highlights the disparities in the availability of pre-collection services across the commune. Photo 1 illustrates a desludging truck operating at Okun-Sèmè, used for emptying septic tanks and latrines.

The market is open to companies equipped with desludging equipment and pre-collection methods adapted to rural conditions (long distances, housing types, and difficult access). According to 68% of the surveyed respondents, beyond simple collection, there is significant potential for the valorization of fecal sludge (e.g., composting for agriculture, biogas production), which could generate new income streams and enhance the sustainability of business models.

Source: K. K. F. Doumatey, May 2025.

Photo 1. Partial view of a vacuum truck in Okun-Sèmè.

Furthermore, 48% of respondents reported having no fixed desludging schedule, while 26% desludge every two years, 17% every three years, and only 9% carry out desludging annually in the Municipality of Sèmè-Podji. Distances, dispersed settlements, and poor road conditions in rural areas complicate collection and transportation logistics. The lack or remoteness of treatment facilities or appropriate valorization sites in rural areas constitutes a major constraint for fecal sludge management in the Municipality of Sèmè-Podji.

3.2. Financial Performance of Fecal Sludge Pre-Collection Enterprises in the Municipality of Sèmè-Podj

In the Municipality of Sèmè-Podji, desludging companies perform a variable number of operations per day (generally 1 to 3 trips per truck), depending on pit size, distance, pumping time, and discharge conditions. On average, a company operating a single truck carries out two (2) desludging operations per day. Demand fluctuates seasonally, with higher demand during the dry season. The cost of a desludging service ranges between 45,000 and 90,000 FCFA for pits of 6 to 12 m^3. The price charged depends on pit size, accessibility, and negotiation with the client.

Fuel consumption (diesel) per operation varies according to travel distance and truck engine efficiency. In addition, companies are required to pay a discharge fee to dispose of sludge at the Sèmè-Podji Fecal Sludge Treatment Plant (FSTP). This fee is set at 1300 FCFA per cubic meter discharged. The general corporate tax rate is 30%.

Table 1. presents the operating account of desludging.

Désignation	Number of emptying operations	Average unit price (FCFA)	Amount (FCFA)
Gross daily revenue	2	45,000	90,000
Fuel cost	2	12,000	24,000
Dumping fee/discharge charge	2	7800	15,600
Daily gross margin	-	-	50,400
Driver and assistant wages	-	-	10,000
Truck depreciation + insurance + major maintenance	-	-	10,000
Total expenditure	-	-	59,600
Net daily profit before tax	-	-	30,400
Annual net income	-	-	9,636,800
Tax			2,891,040
Total income after tax			6,745,760
ERR (%)/Economic Rate of Return (%)	-	-	30.96

Data source: Fieldwork, May 2025.

An analysis of the data presented in Table 1 shows that desludging service providers incur daily operating costs of 59,600 FCFA. They generate a daily revenue of 90,000 FCFA, resulting in a gross profit of 30,400 FCFA. The annual profitability rate is estimated at 30.96%. Consequently, operators benefit from additional investment returns, as each additional franc invested is not only recovered but also generates an extra return of 0.3096 francs. Thus, desludging activities are financially viable on a daily basis. However, profitability largely depends on the operational efficiency of each enterprise, its ability to control costs, and the level of local demand. The Municipality of Sèmè-Podji is characterized by a shallow groundwater table. As groundwater is close to the surface, desludging activities are more frequent in order to prevent contamination. The desludging rate ranges between 63% and 78% per year. For a household of three permanent occupants, the interval between desludging operations typically ranges from 5 to 8 years. Companies that engage in sludge valorization (e.g., fertilizer production) benefit from additional revenue streams, which significantly enhance their overall profitability.

3.3. Fecal Sludge Treatment and Valorization Facility in the Municipality of Sèmè-Podji

The Government of Benin, through initiatives such as the Government Action Program (PAG) and the Project for the Improvement of Fecal Sludge and Wastewater Management, aims to enhance access to sanitation services. In this context, a Fecal Sludge Treatment Plant (FSTP) was constructed in Sèmè-Podji (Eastern FSTP) as part of a broader sanitation project involving the construction of two treatment plants in the Greater Nokoué area. The Okun-Sèmè treatment site operates under a public-private partnership model. It covers an area of 20 hectares, with a treatment capacity of 502 m^3 of liquid waste, and is located approximately 50 meters from the sea. Partially funded by the World Bank, the facility is designed to treat collected sludge prior to discharge, thereby reducing environmental pollution. Fecal sludge (blackwater) is collected by private desludging operators. Once collected from households, vacuum trucks transport and discharge the waste at the Okun-Sèmè treatment facility.

The main operations carried out at the plant include: discharge (offloading), screening, grit removal, sedimentation, natural lagoon-based treatment, sludge pumping, drying on sludge beds, scraping and recovery of dried sludge, maintenance of equipment, cleaning of installations, discharge of treated effluents, and sludge valorization (Plate 1).

Source: K. K. F. Doumatey, May 2025.

Plate 1. View of a vacuum truck and the separation system for fecal sludge and liquid waste at the fecal sludge treatment plant in Okun-Sèmè.

The observation of Plate 1 shows a vacuum truck and the separation system for sludge and liquid waste within the sludge treatment plant (STBV) at Okun-Sèmè. Access to the site requires wearing a safety vest. The location of the plant was chosen due to its proximity to the sea, which facilitates the discharge of treated effluents. In this regard, regular analyses are carried out to ensure the quality of the water before it is discharged into the sea, so as not to harm the aquatic ecosystem. Once inside the treatment facility, the vacuum truck first passes over a weighbridge to determine its loaded weight before moving to the unloading area. Upon exit, the truck is weighed again empty, allowing the difference in weight to be calculated and used to determine the fee to be paid for treatment services. This weight difference also makes it possible to estimate the quantity of sludge delivered. Each truck is registered and tracked within the system. All vacuum trucks are required to discharge their waste at the sludge treatment plant. The trucks unload raw sludge into a reception pit. This pit is equipped with an agitation system (such as a rake or similar device) to homogenize the sludge and break up aggregates. This facilitates subsequent treatment processes and prevents clogging of equipment. At this stage, a screening system (grit or bar screen) is installed to retain large solid waste (such as wipes, textiles, and plastics) that may have escaped upstream controls. These materials are then transported to a landfill. The STBV in Sèmè-Podji has a daily treatment capacity of 506 m^3/day, expandable to 755 m^3/day, making it a major infrastructure for sanitation in the Greater Nokoué area. However, sludge management is associated with significant environmental pollution risks. The effectiveness of this STBV depends on the level of participation of vacuum trucks and the management model applied to these facilities. The presence of the sludge treatment plant is therefore crucial for the sustainable management of fecal sludge.

3.4. Agricultural Valorization Methods of Fecal Sludge in the Municipality of Sèmè-Podji

The agricultural valorization of fecal sludge (FS) is an ecological and economic recycling practice. It improves soil fertility and provides essential nutrients. The main methods and steps of agricultural valorization of fecal sludge include pre-treatment stages and co-composting processes.

3.4.1. Pre-Treatment Stages

Before any agricultural reuse, fecal sludge (from septic tanks, latrines, etc.) is treated to reduce its volume, stabilize organic matter, and most importantly, hygienize the final product by eliminating pathogens (bacteria, viruses, helminth eggs).

- **Reduction of water content (dewatering)**

This is the first stage, aimed at increasing the dryness of the sludge to facilitate transportation and subsequent treatment. It includes gravity thickening and drying beds. At the plant, drying beds (planted or unplanted) are mainly used for dewatering thickened sludge. The sludge remains on these beds for a period estimated between 15 and 21 days, allowing separation of the liquid fraction and the production of dried solid matter. The sludge is stored in basins where solids settle naturally. In addition, the sludge is spread over filter beds (sand and gravel), often vegetated, where water drains and/or evaporates (Photo 2).

Source: K. K. F. Doumatey, May 2025.

Photo 2. View of a fecal sludge drying bed at Okun-Sèmè.

This is followed by mechanical dewatering, which involves the use of presses or filtration systems to accelerate water removal. The material collected from the drying beds consists of dewatered and partially stabilized sludge, which is suitable for the valorization phase, particularly compost production.

- **Stabilization of organic matter**

This stage aims to reduce odor emissions and to ensure greater biochemical stability of the organic matter. It is commonly achieved through anaerobic or aerobic digestion, i.e., the degradation of organic matter by microorganisms under controlled environmental conditions. Composting is the most widely used method for agricultural valorization (**Photo 3**).

Source: K. K. F. Doumatey, May 2025.

Photo 3. Storage of dewatered fecal sludge at Okun-Sèmè.

The storage of dewatered sludge is essential for several reasons, including continued maturation and hygienization, and preparation for co-composting, while also contributing to overall plant capacity management. Storage allows for additional maturation of the sludge, further reducing pathogenic organisms and stabilizing the organic matter before composting or land application. In Sèmè-Podji municipality, sludge valorization is primarily achieved through compost production for agricultural use. Storage also enables the accumulation of sufficient quantities of dried sludge and ensures the availability of carbon-rich co-substrates (organic wastes) required for mixing and initiating the composting process.

With a treatment capacity of 506 m^3/day (expandable to 755 m^3/day), the plant generates a significant volume of dry matter that requires dedicated storage areas. Dewatered sludge is generally stored under controlled conditions, including covered storage areas and windrows or bins. This helps preserve product quality and prevents rewetting of the dried sludge by rainfall, ensuring a stable material that is easier to handle during co-composting.

The sludge is typically arranged in piles (windrows) or stored in dedicated bins on impermeable concrete slabs to prevent any infiltration of leachate into the soil, thereby protecting groundwater and surrounding ecosystems.

3.4.2. Co-Composting

Co-composting is the most common and efficient method for producing a safe, high-value agronomic product (known as biosolids or organic soil amendment).

1) Principle and role of co-composting

The principle of co-composting consists of mixing dewatered fecal sludge (rich in nitrogen and phosphorus) with bulking agents or carbon-rich organic solid wastes such as agricultural residues, green waste, sawdust, or sorted municipal solid waste. The main roles of co-composting include sanitization (pasteurization), improvement of material structure, and production of a stable organic amendment. During decomposition of organic matter, significant heat is generated. By maintaining the temperature of the compost windrow above 55˚C for several days (thermophilic phase), pathogenic microorganisms and helminth eggs are effectively destroyed, ensuring that the final product is safe for agricultural use.

The addition of carbon-rich materials optimizes the carbon-to-nitrogen (C/N) ratio, promoting efficient decomposition and improving compost porosity and aeration. Mature compost enhances soil structure, water retention capacity, and fertility. According to [7], dewatered fecal sludge—also referred to as treated fecal sludge—represents the biosolid phase obtained after the separation of the liquid and solid fractions using drying beds or sedimentation ponds/lagoon systems. Research on fecal sludge valorization has demonstrated that co-composting dewatered sludge with municipal solid waste improves soil fertility and contributes to higher agricultural yields.

2) Co-composting methods in the municipality of Sèmè-Podji

Co-composting is widely used as the safest and most effective method for valorizing fecal sludge (FS), by mixing it with carbon-rich organic materials. The addition of poultry manure and sorted municipal solid waste is particularly effective, as these materials provide complementary functions in the composting process. Co-composting generally occurs through several successive phases, supported by specific management techniques. These include the preparation of raw materials, formulation of the compost mixture, and construction and management of windrows (compost heaps).

Source: K. K. F. Doumatey, September 2025.

Photo 4. Formation and enrichment of a compost windrow at Okun-Sèmè.

Only the sorted organic fraction (kitchen waste, plant residues) and green waste (branches, leaves) are used. This material is often shredded to accelerate decomposition. Poultry manure and other animal manures are used as they are, since they act as nitrogen-rich activators. The success of composting depends on achieving an optimal initial carbon-to-nitrogen (C/N) ratio, ideally between 25 and 30. The proportion is calculated based on input material analyses, but it is generally close to 1 part dewatered sludge to 1 - 3 parts carbon-rich co-substrates (sorted organic waste/green waste). The addition of manure is adjusted depending on the desired nitrogen content. The most common co-composting technique is the formation of windrows (long compost piles). The homogeneous mixture of the three components is stacked into windrows approximately 1.5 to 2.5 meters high. Under microbial activity, the temperature rapidly rises to 55˚C - 65˚C. This temperature is maintained for at least three consecutive days to ensure the destruction of all pathogenic organisms and helminth eggs, making the final product safe for agricultural use. Windrows are regularly turned (mechanically or manually) to aerate the pile, supply oxygen to microorganisms (aerobic process), and ensure uniform distribution of temperature and moisture throughout the mass. Turning frequency is higher at the beginning (thermophilic phase) and gradually decreases over time. In addition, moisture content is maintained between 40% and 60%. If the pile becomes too dry, it is watered (often using treated liquid effluent from the STBV or clean water). If it becomes too wet, aeration is increased and dry materials are added. According to [15], the pre-treatment of fecal sludge through co-composting, in combination with municipal solid waste or sawdust, can provide added value to workers while reducing the financial burden on low-income populations for purchasing chemical fertilizers or poultry manure. Ultimately, fecal sludge becomes integrated into the production cycle not as waste, but as a resource contributing to improved livelihoods through increased agricultural productivity.

3) Monitoring and quality control (Table 2)

Table 2. Results/summary of sludge analysis.

Parameter	Raw Sludge	MP Outlet*	Standard	Compliance	Required Reduction %	Performance Achieved	Conclusion
pH	7.52	8.07	6 to 9	Compliant	-	-	-
Temperature (˚C)	26.10	25.60	±1˚C	Compliant	-	-	-
Conductivity (ms/cm)	5.67	4.24	-	-	-	-	-
TDS (g/L)	3.79	2.84	-	-	-	-	-
Salinity	3.30	2.30	-	-	-	-	-
TSS (g/L)	4400.00	320.00	85	Non-compliant	90%	92.72	Positive performance
COD (mg/L)	10,475.00	1570.00	250	Non-compliant	75%	85.01	Positive performance
BOD5 (mg/L)	250.00	120.00	50	Non-compliant	70% to 80%	52.00	Negative performance

Continued

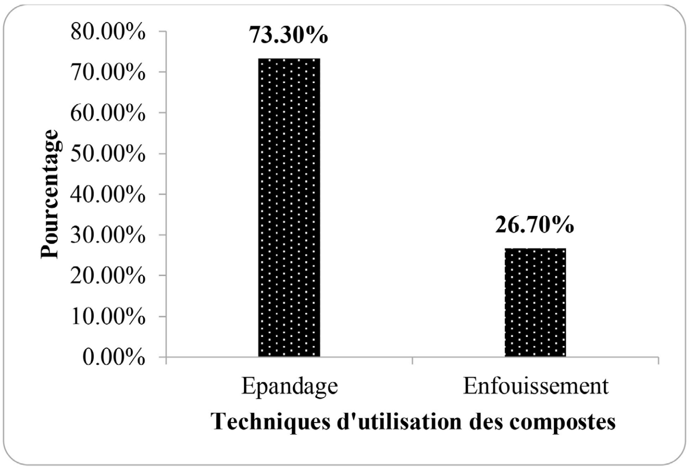
TN (mg/L)	324.17	57.20	15	Non-compliant	70% to 80%	82.35	Positive performance
TP (mg/L)	8.18	1.79	2	Compliant	80%	78.11	Negative performance

Notes: * MP Outlet: Maturation Pond Outlet (Sortie Bassin de Maturation). *c. Decree No. 2001-109 of April 4, 2026. *d. ±1˚C relative to the temperature of the receiving environment. Key Translation Terms Used: TSS (Total Suspended Solids); COD (Chemical Oxygen Demand); BOD (Biochemical Oxygen Demand); TN (Total Nitrogen); TP (Total Phosphorus).

Plant staff carry out strict monitoring throughout the entire process, including surveillance and analysis of the final compost. This is done to assess maturity (C/N ratio, germination index) and hygienic quality (absence of pathogens, especially helminth eggs). Analyses of trace metals (TMEs) are also essential to ensure compliance with regulatory standards for land application. Dewatered sludge (sometimes referred to as dry matter) is mixed with organic waste (green waste, sorted municipal solid waste) to optimize the carbon-to-nitrogen ratio and ensure final hygienization of the product through temperature rise, which ensures the complete destruction of pathogens. Dewatered and stabilized sludge from drying beds is valorized as an agricultural amendment (compost or co-compost with other organic materials) due to its richness in nutrients (nitrogen, phosphorus, potassium) and organic matter, provided that sanitary standards for agricultural use are strictly respected.

3.5. Different Techniques for Using Compost Derived from Fecal Sludge to Improve Agricultural Yields in the Municipality of Sèmè-Podji

Composted fecal sludge, once mature and safe, is used as an organic amendment and fertilizer to improve agricultural productivity. Figure 3 presents the categorization of producers according to the different techniques used for applying fecal sludge compost to enhance crop yields in the Municipality of Sèmè-Podji.



Data source: Field surveys, October 2025.

Figure 3. Categorization of farmers according to the different fecal sludge utilization techniques for improving agricultural yields in the municipality.

The analysis of Figure 3 shows that 73% of farmers practice fertilizer spreading, while 27% use soil incorporation (burial). These techniques enable farmers to enrich soils using compost derived from fecal sludge.

Field application (spreading) is the main method used to incorporate compost into the soil. The compost is distributed over agricultural plots and then incorporated through ploughing before sowing or planting. This technique ensures that the amendment is mixed into the cultivated soil horizon. In some cases, compost is used as mulch or surface application; however, incorporation is generally preferred to maximize soil improvement effects and reduce runoff risks.

Source: K. K. F. Doumatey, September 2025.

Photo 5. Compost application at Okun-Sèmè.

To ensure yield improvement without overloading the soil or harming the environment, proper dosage is essential and must be based on analytical assessments, including dose optimization and compliance with regulatory limits. For soil protection, maximum thresholds are often established (e.g., not exceeding 200 kg of total nitrogen per hectare per year), as well as limits for trace metal elements present in the compost.

Compost adds organic matter, which improves soil structure, enhances water retention capacity, and supplies essential mineral nutrients. Local experiments show that soils amended with fecal sludge compost produce higher yields compared to untreated control soils. The use of compost allows farmers to reduce expenditure on costly chemical fertilizers.

[8] Douanla Maffo (2022) confirms that research on fecal sludge valorization has demonstrated that co-composted sludge improves soil fertility and contributes to higher agricultural productivity. However, limitations related to sanitary safety and the presence of parasites in some composts after three months of maturation highlight the need for further research to confirm the hygienic safety of the process.

3.6. Discussion

The fecal sludge emptying practices identified in Sèmè-Podji—predominantly mechanical but still marked by informal operations—highlight persistent challenges in sludge management in peri-urban areas of Benin. This situation, characterized by illegal dumping, contradicts national sanitation policy goals aimed at environmental sustainability and reflects the lack of adequate collection infrastructure. However, these findings are consistent with the work of [16] S. D. C. Adjei *et al.* (2020, p. 115), who note that in Beninese municipalities, manual emptying persists due to the high cost of mechanical emptying, thereby limiting the efficiency of the sanitation chain. A key limitation in this study is the lack of accurate data on actual sludge volumes generated, which are often underestimated in surveys, leading to poor infrastructure planning, as also highlighted by [17] M. S. E. Dossa *et al.* (2021, p. 45). The financial fragility of pre-collection companies in Sèmè-Podji is explained by low tariffs and an inability to cover operational costs, confirming the weakness of the Public-Private Partnership (PPP) model often promoted in the literature. Contrary to expectations of self-financing systems [18] B. C. A. Houngue *et al.*, 2022, p. 88), companies in Sèmè-Podji struggle to invest in adequate equipment. This structural constraint limits the acquisition of more efficient vacuum trucks, an economic barrier also documented by [19] L. T. K. Agbogu *et al.* (2019, p. 203) in the Greater Nokoué context. The Sèmè-Podji treatment plant, based on a biological process (lagooning), shows variable treatment performance, often below required standards. Although presented as an innovation, uncertainties remain regarding the long-term maintenance of drying beds, particularly the risk of clogging under high loading rates, as noted by [20] A. Y. F. A. D. N'gadi *et al.* (2023, p. 12). Moreover, although the site is operational, the absence of a biogas recovery unit (methanization) limits overall resource recovery potential, as highlighted in studies on the underutilization of treatment by-products in coastal municipalities of Benin. Agricultural valorization through composting offers a sustainable alternative but faces constraints related to compost quality. Levels of contamination, particularly heavy metals and pathogens, are not sufficiently monitored, which challenges the assumption of safe reuse and contrasts with overly optimistic conclusions in some studies.aux conclusions optimistes.

4. Conclusion

Fecal sludge, collected at household level by private operators, is transported to the Okun-Sèmè treatment plant. The technical process includes emptying, screening, grit removal, sedimentation, natural lagoon-based treatment, drying beds, and management of effluents and by-products. In the municipality of Sèmè-Podji, this value chain leads to the production of compost from treated sludge. The compost is then applied to agricultural fields and incorporated into the soil through ploughing, thereby contributing to sustainable agriculture.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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