XXVI SIMPÓSIO BRASILEIRO DE RECURSOS HIDRÍCOS

URINE-DIVERTING DRY TOILETS PRODUCTS POTENTIAL FOR AGRICULTURE USE IN A VILLAGE OF COTTON PRODUCERS IN MALI

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Abstract: Safe recovery of sanitation-derived resources for soil and plant benefit can enhance soil structure, microbial biodiversity, and nutrient provision. In Bandiagara II, Mali, a village of 630 residents, urine-diverting dry toilets were implemented to face water scarcity. Feces are sanitized using ammonium through a 1:1 mix of lime and ash (130 g/person) with 2% urea to elevate pH, inactivating pathogens for safe soil use. Nutrient content (N, P_2O_5, K_2O, Ca, Mg) was assessed through agrochemicals used for cotton production in the village and a literature review for feces treated by the same method. The nutrient cost was calculated based on the cost of agricultural products in Mali and their constituent percentages. For the treated fecal material, 5% handling losses and an 85% correction factor were applied to account for the inconvenience of using sanitary products in agriculture. Annual treated feces production was estimated at 45,139 kg, yielding 227 kg/year of N, 654 kg/year of P_2O_5, 460 kg/year of K_2O, 7109 kg/year of Ca, and 463 kg/year of Mg, sufficient to meet the nutrient demands for cotton production in 5.23, 24.22, 17.06, 107.72, and 19.23 hectares, respectively. The treatment cost ($3,767/year) was outweighed by the estimated treated material's value ($5,384/year), excluding the carbon benefits on the soil. This approach promotes sanitation, health, waste management, and nutrient cycling. However, pilot studies for field cotton production are required to understand its effects on cultivation.

Keywords – Resource recovery, nutrient cycling, sanitation, financial analysis, water vulnerability; Sub-Saharan Africa

Resumo: A recuperação segura de recursos derivados do saneamento para uso agrícola pode melhorar a estrutura do solo, aumentar a biodiversidade microbiana e a disponibilidade de nutrientes. Em Bandiagara II, Mali, uma vila com 630 habitantes, banheiros secos com separação de urina foram implementados como solução à escassez hídrica. As fezes são higienizadas por meio de tratamento alcalino com uma mistura 1:1 de cal e cinza (130 g/pessoa/dia), acrescida de 2% de ureia, elevando o pH e inativando patógenos, tornando o material seguro para uso no solo. A composição nutricional (N, P_2O_5, K_2O, Ca e Mg) foi avaliada com base em fertilizantes utilizados na cultura do algodão local e literatura científica sobre tratamentos semelhantes. Para estimar o valor econômico, consideraram-

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se os preços dos insumos agrícolas no Mali e seus teores de nutrientes. Aplicou-se uma perda de 5% por manuseio e um fator de correção de 85% pela dificuldade de uso agrícola do material. A produção anual estimada de fezes tratadas foi de 45.139 kg, com valor nutritivo suficiente para suprir de 5 a 108 hectares, dependendo do nutriente. O custo anual do tratamento foi de US$ 3.767, enquanto o valor estimado dos nutrientes recuperados foi de US$ 5.384. Ensaios de campo ainda são necessários para avaliar os impactos agronômicos.

Palavras-Chave – Recuperação de recursos; ciclagem de nutrientes; Saneamento; análise econômica; vulnerabilidade hídrica; África Subsaariana

INTRODUCTION

Globally inadequate sanitation systems constitute a significant health problem, contributing to over 800,000 deaths yearly. Most of these deaths occur in middle and low-income countries and are incredibly challenging in conflict-affected states (UNICEF/WHO JMP, 2017). Additionally, inadequate sanitation can cause long-term negative impacts on health, education, cognition, human capital and lead to risk factors for tropical diseases (Grantham-Mc Gregor *et al.*, 2007; Black *et al.*, 2017). The United Nations (2022) projections estimate that 1.6, 2.8, and 1.9 billion people will lack safely managed drinking water, sanitation, and basic hand hygiene facilities, respectively. That is why the sixth UN SDG aims to 'ensure availability and sustainable management of water and sanitation for all by 2030.

Sanitation problems are further exacerbated in sub-Saharan Africa by the dry climate and the conflict of Islamist insurgency in the Sahel. Mali has a low-income economy, rapid population growth, agriculture, and food insecurity. The extreme poverty rate in 2020 was 47.3% due to health, security, social, and political crises (World Bank, 2022). Over the past decade, the migration of thousands of people led to poor living conditions, such as inadequate water, poor hygiene, and sanitation (Toure *et al.*, 2018). As a result, onsite sanitation systems (OSS), such as pit latrines, are widely used (Capone *et al.*, 2021), as seen in Bandiagara II, a cotton-producing village in Mali.

The use of unimproved latrines can contaminate hand wells' water supply with pathogen microorganisms, and underestimate the potential for water and resource recovery, which can be enhanced by segregating inputs and outputs at the user interface (the toilet). Urine Diverting Dry Toilets (UDDTs) are widely used for this purpose (Tilley *et al.*, 2014). Buckets' containment helps promote on-site ammonium-based sanitization treatment for agricultural use (Magri, 2013) and avoids underground water contamination. Meanwhile, urine usage is easily facilitated by a banana (or other plant) circle, as outlined by Figueiredo *et al.* (2018). However, financial sustainability is crucial for maintaining toilets, justifying investments, and preventing toilet loss.

OBJECTIVE

This study aims to present a Urine Diverting Dry Toilet (UDDT) with feces ammonium-based sanitization, combined with a plant circle for urine treatment and use, adapted by Malian villagers, and to evaluate its financial sustainability in the local context.

MATERIAL AND METHODS

Study area description

Mali is a landlocked country located in the Sahel region of West Africa, with 22,593,590 inhabitants in an area of 1,240,278 km², bordered by Algeria, Niger, Burkina Faso, Mauritania, Guinea, Senegal, and the Ivory Coast. The climate is subtropical in the south, arid in the north, with drought reducing crop revenues by $ 9,5 million annually. The national poverty rate increased from 42.5% in 2019 to 44.4% in 2021 (World Bank, 2023) (Table 1).

Table 1 - Mali's socioeconomic and environmental data (World Bank, 2023)

Aspect	**Indicator**	**Value**	**Year**
Social	Poverty headcount ratio at $2.15 a day (% of the population)	14.8	2018
	Life expectancy at birth, total (years)	59	2021
	Population growth (annual %)	3.1	2022
	Net migration	-22,236	2021
	Human Capital Index (HCI) (scale 0-1)	0.3	2020
Economic	GDP (current billion US$)	18.83	2022
	GDP per capita (current billion US$)	18.83	2022
	GDP growth (annual %)	3.7	2022
	Unemployment, total (% of total labor force)	2.8	2022
	Inflation, consumer prices (annual %)	3.9	2021
	Personal remittances, received (% of GDP)	5.8	2022

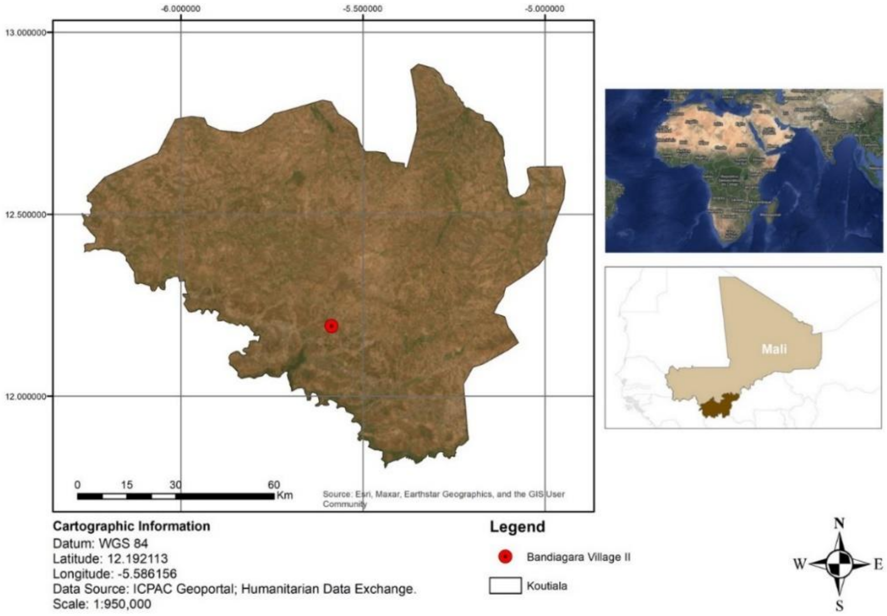
The loss of productive assets and the rise in Jihadist insurgencies since 2017 have increased violence and security incidents and disrupted markets and household livelihoods in the affected areas. As a result, pastoralists have had to search for alternative water sources and pastures, which has contributed to tensions with sedentary farmers. This scenario led to a sanitary crisis in the country (Table 2), which was followed by poor public health, as reported by the Joint Monitoring Program (JMP, 2023).

Table 2 - Access to sanitation services (% population) (JMP, 2023)

Aspect	Water			Sanitation			Hygiene		
	National	Rural	Urbain	National	Rural	Urbain	National	Rural	Urbain
Safely managed	-	-	-	16	23	8	-	-	-
Basic service	84	74	95	34	19	53	17	9	27
Limited Service	5	4	5	17	7	28	53	61	42
Unimproved	11	20	0	28	43	10	-	-	-
No service	1	1	0	5	7	1	30	29	31

The village of Bandiagara II is geographically situated at approximately 12°11'30.06"N and 5°35'15.47"W and had an estimated population of 630 inhabitants in 2024. It lies in a predominantly flat terrain interspersed with small hills, and a semi-arid climate. Annual rainfall ranges between 600 and 900 mm, supporting primarily rainfed cotton as the main crop, followed by cereals and livestock.

Figure 1 – Location of village of Bandiagara II, Koutiala district, southern Mali, Africa.



Existing and proposed sanitation systems.

During a 5-day mission, we characterized the existing sanitation system, including latrines, their operation, faecal sludge (FS) use, and the impact on the hand wells' water supply (Figure 2). The proposed system was presented and discussed with the villagers, aiming to protect the water supply from faecal contamination, reuse water, use the existing superstructure, with locally available additives, and maintain the agriculture FS use. Both systems were analyzed using the templates outlined by Tilley *et al.* (2014).

The proposed system begins with UDDTs for the user interface, where feces are contained in buckets, and treated using ammonium-based sanitization through a 1:1 mix of lime and ash (130 g/person) with 2% urea to elevate the pH, inactivating pathogens for safe soil use. The urine, anal cleansing, and hand washing grey water are conducted through malleable hoses to a banana circle for land-based treatment, and use (Figure 3).

Figure 2 - Existing scenario example at Bandiagara II village.

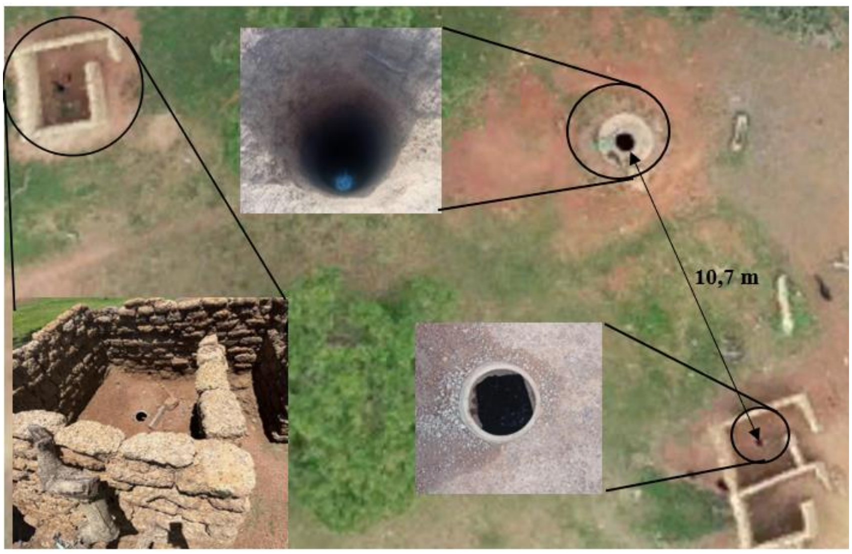
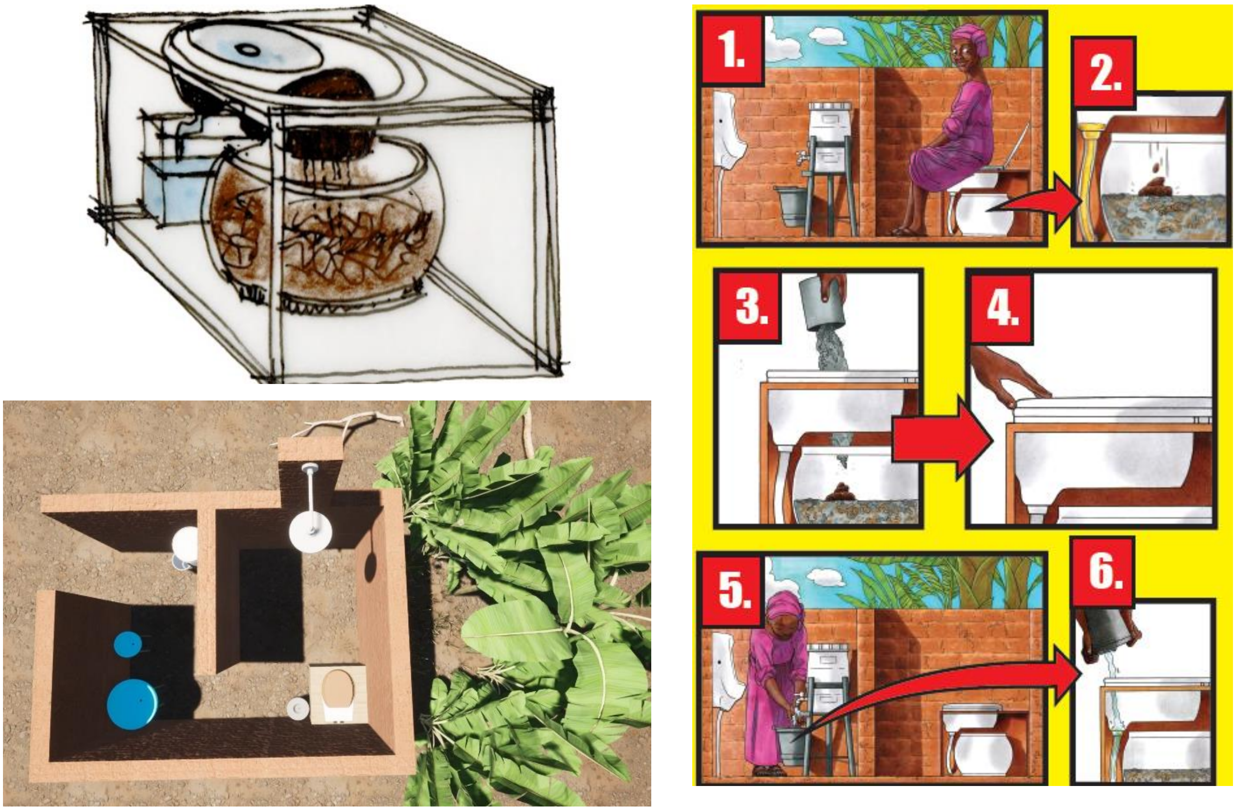


Figure 3 - Proposed UDDT, and on-site treatment.



Financial analysis

Costs were collected at the local market during the materials purchase for installation of UDDTs, and operational costs for both systems were collected from the additive (lime and urea) purchase and operational works from focus discussion groups with the villagers. For revenue, the nutrient content (N, P_2O_5, K_2O, Ca, Mg) of human feces treated by the same method is available at Magri (2014). The nutrient cost was calculated based on the cost of agricultural products in Mali and their constituent percentages, as reported by the Malian Development Textile Company (CMDT). For the treated fecal material price calculation, a 5% handling loss and an 85% correction factor were applied to account for the inconvenience of using sanitary products in agriculture.

A technological and financial plan was developed, utilizing a population growth rate equivalent to that of Mali, for a 20-year period. A life cycle cost assessment was then calculated by evaluating each year's capital expenditure (CAPEX), operating expenditure (OPEX), revenue, and profit or loss, applying the country’s discount rate (r) (Equation 1). The results were then validated by the steering committee, composed of technicians from CMDT and Brazilian researchers.

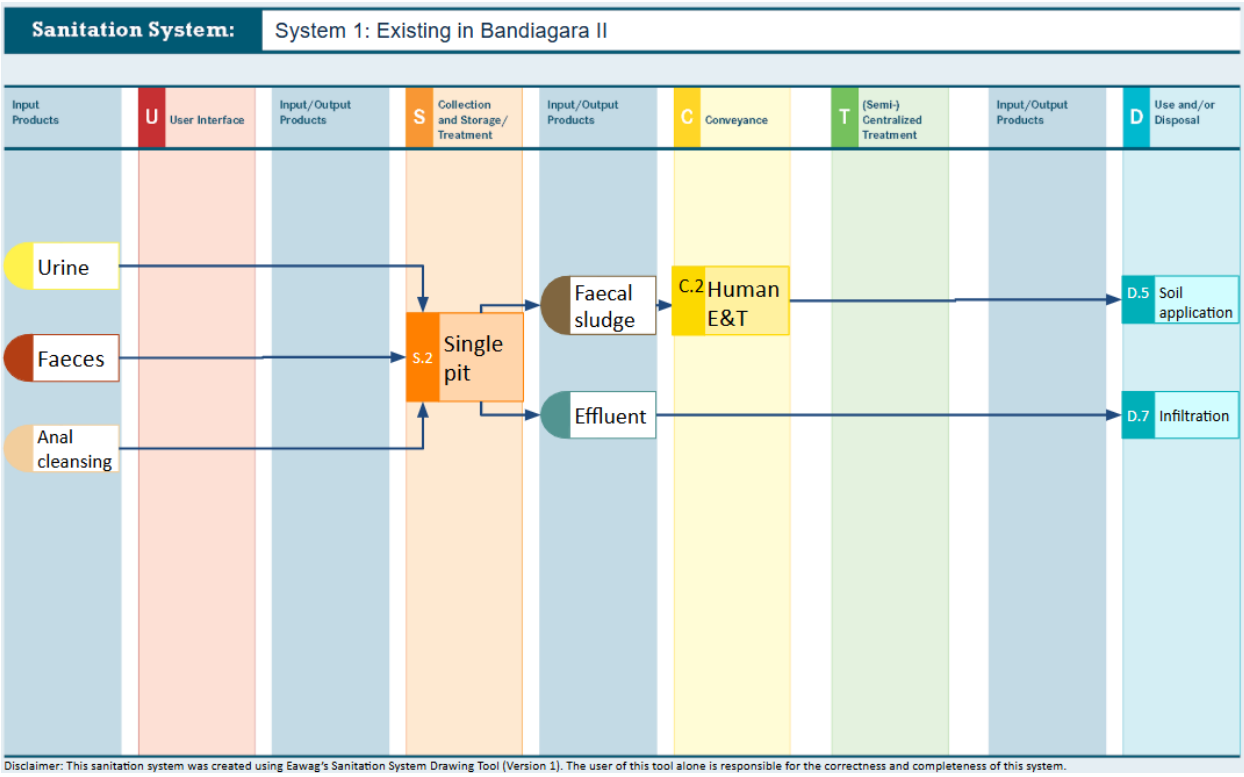
$$Profit\ or\ loss = \sum[Revenue + Budgets - CAPEX - OPEX] \times \frac{r}{1-(1+r)^{-d}} \quad (1)$$

RESULTS AND DISCUSSIONS

Sanitation systems

The existing sanitation system is illustrated in Figure 4, where the current latrines used for defecation are approximately 3 meters deep and are typically in use for 2 years. After that period, they are closed with a piece of wood and kept at rest for another year, after that, the FS is used in agriculture. The urine runs down bathroom walls and remains on the floor surface, posing epidemiological risks and creating an unpleasant odor.

Figure 4 – Existing sanitation system at Bandiagara II village



Estimations of quantities of excreta, toilets, and additives (Table 3) helped design the proposed sanitation system, which utilizes UDDTs, ammonium-based sanitization for treating feces, and a proposed banana circle to treat and use urine and grey water (Figure 5). During the installation, the villagers chose to replace banana plants with papaya (Figure 6). Notably, the successful adaptation of a Brazilian sanitation technique to the realities of a Malian village signifies progress in knowledge through South-South cooperation.

Tabela 3- Excreta generation

Inhabitants	630,0
Family nuclei	47,0
Person/toilet	7,8
Toilet/ family nuclei	2
Total of toilets	94
Feces generation per person per day (g/person.day)*	130
Quantity of additive for ammonium sanitation treatment (g/person.day)*	130
Treated feces (kg/ano)	45,139
Urine generation per day (L/person.day)*	1,5
Urine/toilet.day (L/day)	11,7

*Magri (2013)

Figure 5 – Proposed sanitation system with UDDTs at Bandiagara II village.

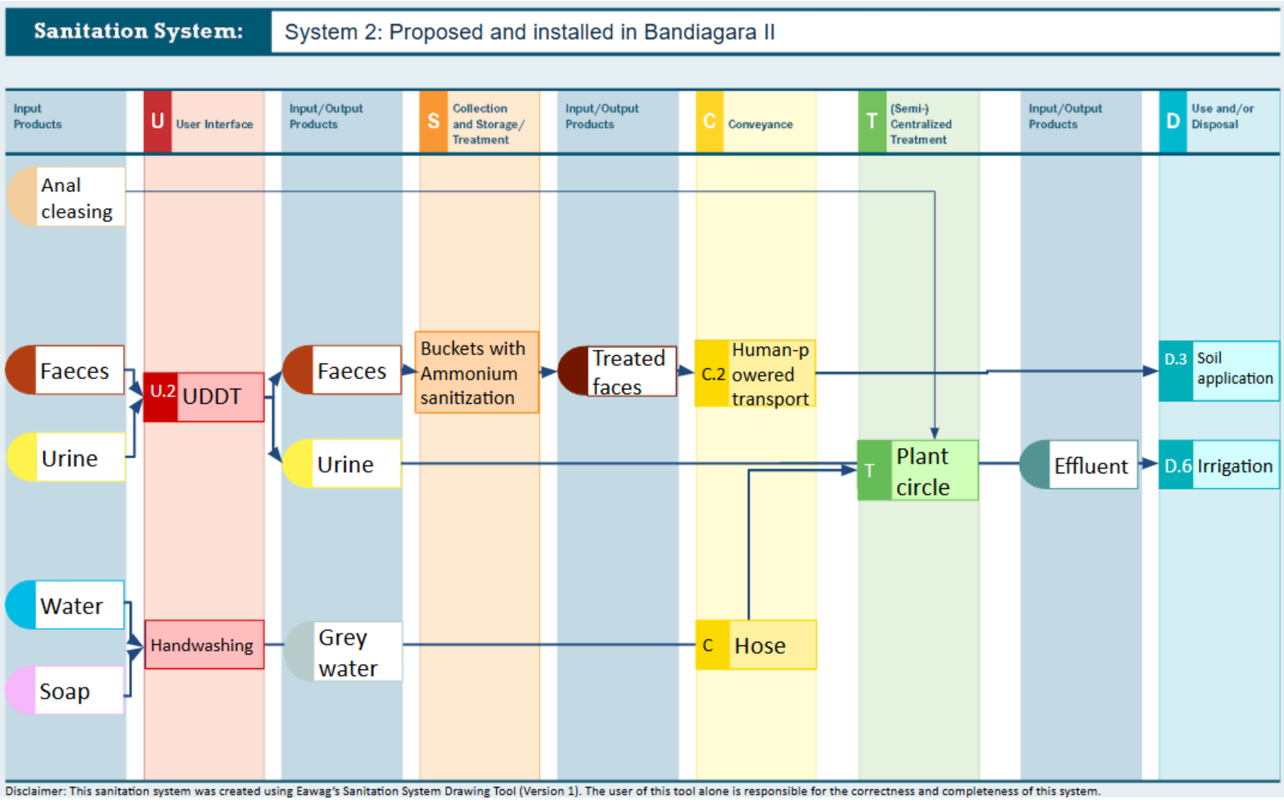


Figure 6 – Urine Diverting Toilets with local adaptation papaya circle installed at Bandiagara II village.

Financial analysis

Annual treated feces production was estimated at 45,139 kg (Table 3), yielding 227 kg/year of N, 654 kg/year of P_2O_5, 460 kg/year of K_2O, 7109 kg/year of Ca, and 463 kg/year of Mg, resulting in an $5,384/year as revenue from the treated feces use on the soil (Table 4). This value still does not include the carbon benefits from organic matter in the soil.

The treatment cost regarding limestone and urea purchase ($3,767/year) for ammonium-based sanitization for the whole village (Table 5), was outweighed by the estimated value of the treated material, and the future projection shows a life cycle revenue (for 20 years) close to $337,000, while the latrines are cheaper to operate, they offer a small revenue and a life cycle loss of $-4,450 (Figure 7).

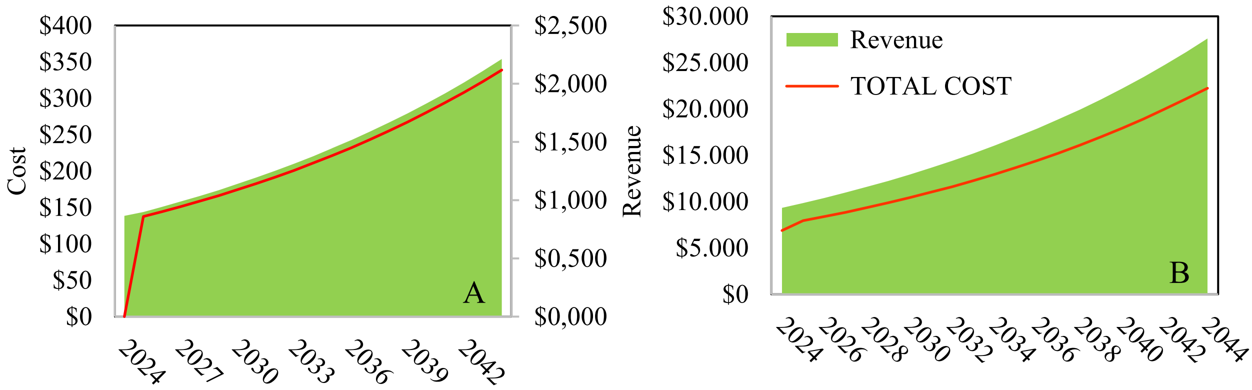
Table 4 – Nutrient contents, price, and production by UDDTs with ammonium-based sanitization in Bandiagara II village.

Material		N	P_2O_5	K_2O	Ca	Mg	Source
Nutrient content (mg/kg)	Feces treated at UDDTs	5,040	14,490	10,206	157,500	10,275	Magri, 2013
	Feces from latrines	5,077	447	-	-	-	
	Cereal complex	170,000	170,000	170,000	-	-	Commercial fertilizers used by the cotton producers
	Cotton complex	140,000	180,000	180,000	-	-	
	Urea	450,000	-	-	-	-	
	Limestone	-	-	-	220,000	120,000	
Nutrient production (kg/year)	Faecal sludge from latrines	228	20,18	-	-	-	**Total (USD)**
	Feces treated at UDDT	227	654	460	7,109	463	
Nutrient costs (USD)	Unit (USD/kg)	$0.95	$0.95	$0.95	$0.71	$0.71	$4.26
	Recovered from latrine faecal sludge use (USD/ano)	$175	$15	-	-	-	-
	Recovered from UDDT feces reuse (USD/ano)	$173	$499	$351	$4.092	$267	$5,385

Table 5 – Additive costs for ammonium-based sanitization in Bandiagara II village.

Additive materials for feces treatment	Quantity needed	Price	
	g/pessoa/dia	USD/kg	USD/ano
Limestone	65	$0,24	$3.623,09
Urea	1,3	$0,48	$144,15

Figure 7 – Latrines (A) and UDDTS (B) financial plans at Bandiagara II village.



Way forward and challenges

Implementation encountered challenges regarding the additive purchase during a financial crisis at CMDT, which would have provided it to the villagers. However, the initial experiences with the possibility of nutrient recovery for agriculture, along with a drop in diarrhea cases, encouraged some families to keep the UDDT operational, using their incomes to support it. Additionally, the local production of the UDDT, particularly regarding the fiberglass-diverted toilet bowl, was cumbersome, despite the mold being suitable for local production. Also, some families reported that children were afraid to use the new toilet.

The villagers suggested replacing the wooden seat with adobe bricks to increase its lifespan and utilizing papaya plants for urine treatment. This demonstrates awareness of treating and reusing excreta safely, built through the process, with potential for technological enhancement through cooperation between Brazil and Mali for simple sanitation solutions, such as composting, biodigesting, evapotranspiration, or others, to be shared.

Therefore, monitoring and adapting the toilets to local needs, along with experimental trials using treated feces in crop production, as well as microbiological tests, will help establish a new feasible solution for rural villages.

CONCLUSIONS

The UDDT with feces ammonium-based sanitization, combined with a papaya circle for urine treatment and use, demonstrated a feasible and safe solution in Bandiagara II village, Mali, as an alternative to the existing unimproved latrines. The estimated profit from using treated feces to improve soil fertility represents its financial sustainability, unlike latrines, which do not generate enough revenue to cover the labor installation costs. This approach promotes sanitation, health, waste management, and nutrient cycling. We suggest conducting experimental pilot studies for the field crop to understand its effects on production, and to conduct nutrient and microbiological tests on the FS and treated faces.

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