



Vermicomposting Technology as an Environmental Preservation Strategy in Sub-Saharan Africa [†]

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Abstract

In the urban and peri-urban areas across Sub-Saharan Africa, rapid urbanization, population growth and changes in consumer behavior have resulted in large volumes of biodegradable waste, most of which is disposed of through open dumping and land-filling. These practices contribute to greenhouse gas emissions, contamination of water bodies and declining soil productivity. This research assesses the impact of vermicomposting technology for the production of biofertilizers on the environment in Sub-Saharan Africa, with a focus on its role in sustainable waste management, soil health restoration and environmental resilience. Vermicomposting is the biological conversion of organic waste into nutrient-rich vermicompost and vermiwash using earthworms as catalysts. The process is low-cost, decentralized and appropriate for rural and urban setups. This research embraces a mixed methods approach, based on field observations, compost and soil analysis, structured interviews with farmers and waste managers and policy document reviews from case studies in South Africa, Kenya and Ghana. The results showed that vermicomposting reduced organic waste volumes by 50–60%, decreased manure pH from 8.5 to 7.0 and increased NPK concentrations by 50%, demonstrating its effectiveness as a waste stabilization technology. Regardless of ecological advantages, implementation is still minimal owing to policy gaps, limited technical skills and inadequate institutional backing. This study shows how waste can be turned into useful resources, supports efforts to restore damaged land and points out policy issues that slow down progress. It concludes that vermicomposting technology holds significant potential to improve environmental quality and promote sustainability in Sub-Saharan Africa. Scaling its impact will require integration into national policies, investment in education and community engagement and incentives for decentralized implementation. This approach can foster greener and more resilient communities across the region.

Keywords: biofertilizers; climate change; environment; vermicomposting technology



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1. Introduction

Sub-Saharan Africa faces severe environmental degradation due to rapid urbanization, agricultural intensification and poor waste management practices leading to environmental deterioration such as soil degradation, water pollution and increased greenhouse gas emissions. Conventional waste management systems remain inadequate, allowing organic

waste to accumulate in landfills where it generates methane (CH₄) emissions, which pose serious public health risks [1]. Vermicomposting is a process that uses earthworms and microorganisms to convert organic waste into nutrient-rich vermicompost and vermiwash. This technology represents a sustainable and eco-friendly solution to these challenges in Sub-Saharan Africa. The adoption of vermicomposting technology promotes circular economy principles by closing the nutrient loop between waste and agriculture. Reference [2] expressed that vermicomposting aligns with multiple global sustainability goals, including climate action, soil conservation and poverty reduction through green job creation.

Although vermicomposting has been extensively studied in Asia, Europe and North America, research in Sub-Saharan Africa remains comparatively limited. Existing studies have primarily been conducted in South Africa, Kenya, Ghana and Zimbabwe. In South Africa, vermicomposting has been investigated for municipal organic waste management, sewage sludge stabilization and soil fertility enhancement [3]. Kenyan studies have focused on market waste recycling and livestock manure valorization [4], while Ghanaian researchers have evaluated vermicomposting as a strategy for converting agricultural residues and food waste into organic fertilizers [5]. Zimbabwean studies have largely concentrated on livestock manure management and sustainable agriculture [6]. Despite these advances, most African studies have focused on agronomic benefits, with limited attention given to environmental impact assessment indicators, such as waste reduction, pollution control and climate change mitigation.

An environmental impact assessment (EIA) provides a framework to assess the environmental benefits of waste management technologies, including waste reduction, resource recovery, pollution prevention and climate change mitigation [7]. However, there remains a significant knowledge gap regarding the broader role of vermicomposting as an environmental preservation strategy in Sub-Saharan Africa. The novelty of this study lies in its environmental impact assessment perspective, which evaluates vermicomposting as an environmental preservation strategy rather than solely a biofertilizer production technology. It was hypothesized that vermicomposting significantly reduces organic waste volumes, improves soil quality and contributes to environmental sustainability. Therefore, this study assesses the impact of vermicomposting technology on environmental preservation in Sub-Saharan Africa by addressing the following questions: (i) How effective is vermicomposting in reducing organic waste and environmental pollution? (ii) What environmental and soil health benefits are associated with vermicompost application? and (iii) What barriers and opportunities influence the adoption of vermicomposting technology in Sub-Saharan Africa?

2. Literature Review

2.1. Vermicompost Characteristics

Vermicompost is a dark, granular and odorless organic fertilizer produced through the breakdown of organic matter by earthworms. Vermicompost contains rich essential nutrients such as nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and micronutrients, which makes it an excellent soil conditioner [8]. Vermicompost enhances the soil structure by improving soil aeration, water retention and microbial activity and also boosts plant growth by providing slow-release nutrients, which promotes healthier and resilient crops. Vermicompost contains beneficial microbes that help suppress soil-borne diseases whilst lowering the need for synthetic fertilizers, thereby reducing environmental pollution [9]. Vermicompost is essential in Sub-Saharan Africa where soil depletion and low agricultural outputs are key challenges, and its application assists small-scale farmers in improving yields sustainably, hence lessening the reliance on ex-

pensive chemical inputs [10]. Table 1 shows the vermicompost characteristics and process conditions from various studies.

Table 1. Vermicompost characteristics and process conditions.

Organic Waste Used	Loading Rate (kg/m ² /day)	Earthworm Species	Earthworm Quantity (kg/m ³)	Vermicomposting Period (Days)	pH Range	Temp Range	NPK Content	References
Cow dung + vegetable waste	3–5	<i>Eisenia fetida</i>	0.5–1.0	60–90	7.0–8.0	18–25	1.8–2.5 N; 0.5–1.2 P; 1.0–1.8 K	[9]
Food waste + paper sludge	5–7	<i>Eisenia andrei</i>	0.8–1.2	30–50	6.8–7.5	20–28	2.0–2.8 N; 0.9–1.5 P; 1.5–2.0 K	[8]
Municipal waste + cow dung	6–8	<i>Eisenia fetida</i>	1.5–2.0	60–80	7.2–8.5	24–35	1.3–1.7 N; 0.5–0.9 P; 1.0–1.4 K	[10]
Fruit waste + garden waste	5–7	<i>Dendrobaena veneta</i>	1.0–1.5	60–80	6.5–8.0	20–28	1.2–1.8 N; 0.5–1.0 P; 1.1–1.5 K	[11]
Sugarcane bagasse + cow dung	4–6	<i>Eudrilus eugeniae</i>	1.0–1.5	45–60	6.5–7.5	25–32	1.5–2.0 N; 0.7–1.0 P; 0.4–1.4 K	[7]

2.2. Vermiwash Characteristics

Vermiwash is a liquid biofertilizer, brown in color and odorless, produced during the vermicomposting process where it is leached through earthworm castings and their habitat. Vermiwash is a collection of soluble nutrients, enzymes, hormones and essential microorganisms that enhance plant growth and protect against pests and diseases [12]. As a foliar spray, it acts as a liquid fertilizer that provides an immediate nutrient boost to plants [12]. Vermiwash's natural pesticide properties help to inhibit pests and fungal infections; hence, it is cost effective and easy to use, making it accessible to small-scale farmers. Vermiwash offers a low-cost organic alternative in Sub-Saharan Africa, where access to agrochemicals is often limited.

2.3. Earthworm Characteristics

Vermicomposting earthworms vary in their average length, color and markings, feed consumption, ideal habitat, temperature tolerances and reproduction rates. Reference [10] explained that during vermicomposting, common earthworm species, such as *Eisenia fetida*, *Eisenia andrei*, *Eudrilus eugeniae* and *Eudrilus perionix*, are the driving force. They consume organic waste, digest it and excrete nutrient-rich castings. As soil engineers, earthworms enhance the soil structure through burrowing, improving aeration and water infiltration. They can also be used as a protein supplement for livestock and fish feed, whilst farmers can sell excess earthworms for breeding and fishing bait, creating additional revenue streams.

2.4. Vermicomposting Reactor Selection

When choosing vermicomposting reactors, it is important to choose a system that creates the right conditions for worms and microbes to thrive. These conditions include proper aeration, moisture, and a dark protective environment, and the system should work as a temperature insulator. Vermicomposting reactors range from simple trench systems and wooden boxes for small-scale operations to continuous flow reactors and cement beds for commercial applications [7].

2.5. Key Process Parameters in Vermicomposting

The quality of the vermicompost depends on the maintenance of appropriate operational conditions, including the carbon-to-nitrogen ratio, moisture content, pH and temperature [1]. International quality standards, such as the European Union Fertilizing Products Regulation (EU) 2019/1009 and PAS 100 compost quality standards, recommend stable organic matter levels, low pathogen concentrations and mature compost with acceptable nutrient levels. Optimal vermicomposting conditions generally include moisture contents of 60–80%, a pH of 6.5–8.0, temperatures between 20 °C and 30 °C and C:N ratios ranging from 20:1 to 30:1 [7]. These operational conditions promote earthworm activity, microbial degradation and the production of high-quality vermicompost. Table 2 outlines key process parameters in vermicomposting and their optimal range.

Table 2. Key process parameters in vermicomposting.

Input Parameter	Optimal Value	Measurement Technique	Output Parameter	Monitoring Frequency	Reference
C:N Ratio	20:1–30:1	Chemical analysis	Stable compost C:N ratio	Bi-weekly	[1]
Moisture Content (%)	60–80%	Gravimetric method	Leachate production	Weekly	[12]
pH	6.5–8.0	pH meter	Final compost pH	Weekly	[12]
Temperature	20–30	Thermometer	Microbial activity	Daily	[5]

3. Materials and Methods

A mixed methods research design was adopted between June and December 2025, combining a literature review, policy document analysis, field observations, stakeholder interviews and a pig waste vermicomposting case study conducted in Harare, Zimbabwe. Twenty farmers actively practiced organic agriculture, and five waste management practitioners were purposively selected for structured interviews. Soil and compost samples were collected at the beginning and end of the vermicomposting process using a composite sampling approach. Three replicate samples were collected from each vermibed, and we analyzed their pH, moisture content, organic carbon, total nitrogen, available phosphorus and exchangeable potassium using standard laboratory procedures. This study sought to evaluate the environmental benefits, operational requirements and adoption potential of vermicomposting technologies in Sub-Saharan Africa. Data was analyzed using SPSS Version 29. Descriptive statistics were expressed as the mean $\pm$ standard deviation. Paired sample t-tests were used to compare initial feedstock and final vermicompost physicochemical properties. Statistical significance was accepted at $p < 0.05$.

4. Results and Discussion

4.1. Socio-Economic Benefits for Vermicomposting

Vermicomposting presents several socio-economic benefits. These are well detailed in the sections below.

4.1.1. Waste Reduction and Landfill Diversion

The literature indicates that vermicomposting can reduce the volume of organic waste destined for landfills. In Sub-Saharan Africa, organic waste constitutes approximately 50–60% of municipal solid waste, with urban areas generating between 0.5 and 0.8 kg of waste per capita per day, of which a substantial fraction is biodegradable. This translates to millions of tons of biowaste annually across the region. For example, rapidly urbanizing cities generate over 10 million tons of organic waste per year collectively. Much of this is disposed of through open dumping and uncontrolled landfilling. In conventional landfills, these materials break down anaerobically, releasing CH₄, a powerful greenhouse gas. Studies by [1] indicate that vermicomposting can reduce organic waste by 50–60%, promoting

aerobic decomposition, significantly limiting CH₄ release and lessening the pressure on overburdened waste management systems. This low-tech, scalable method has proved that it reduces waste management costs for municipalities and households alike. Moreover, it can be adaptable at various levels, from small household setups to community-scale systems, encouraging public participation in zero-waste initiatives and supporting national landfill diversion mandates.

4.1.2. Greenhouse Gas Emission Reduction and Pollution Remediation

Although greenhouse gas emissions were not directly measured in this study, previous studies have reported methane emission reductions of up to 90% when organic waste is diverted from landfills to vermicomposting systems [1]. In conventional landfill systems, one ton of organic waste can generate approximately 50–100 kg of CH₄, which has a global warming potential 28–34 times greater than carbon dioxide (CO₂) over a 100-year period. In Sub-Saharan Africa, where waste management systems are often inefficient, methane emissions from landfills contribute significantly to greenhouse gas emissions, accounting for an estimated 5–10% of national emissions in some countries. Vermicomposting, in contrast, promotes aerobic decomposition. This process stabilizes organic matter into humus, effectively locking carbon in the soil instead of allowing it to escape into the atmosphere as CO₂ [13].

4.1.3. Soil Health Improvement and Sustainable Crop Production

Vermicomposting is a most powerful agent for restoring the region's degraded soils. Unlike synthetic fertilizers that only provide short-term nutrients, vermicomposting improves the soil's fundamental physical, chemical and biological properties. Vermicompost is rich in organic matter, which improves the soil structure and increases porosity. This supports healthy root development, better airflow, and efficient water movement and reduces the risks of soil compaction and erosion [14]. Ref. [15] explained that vermicomposting helps buffer the soil pH, bringing overly acidic and alkaline soils closer to a neutral range optimal for crop growth. The high organic content in vermicompost stimulates microbial life, which binds heavy metals and suppress disease-causing organisms through its antibacterial and antifungal compounds. Ultimately, vermicomposting empowers smallholder farmers by increasing farm profitability through higher yields and lower input costs.

4.2. Case Study: Production of Vermicompost from Pig Waste

The management of pig waste continues to pose environmental contamination and health risks due to increasing pig husbandry in Zimbabwe. This case study was conducted in Zimbabwe to assess the feasibility of utilizing pig waste as feedstock for vermicomposting.

4.2.1. Bio Waste Vermicomposting

The feedstock consisted of pig manure, corn stover and sawdust. The experimental design was adapted from similar vermicomposting studies conducted by [6,14,16], which successfully utilized livestock manure and agricultural residues as feedstock for vermicompost production. Prior to vermicomposting, the pig manure exhibited alkaline characteristics with an average pH of approximately 8.5 and elevated ammonia concentrations requiring pre-conditioning. Sawdust was incorporated to improve aeration and adjust the C:N ratio to approximately 25–30:1 [16]. *Eisenia Fetida* earthworms were obtained from an established vermiculture facility in Harare, Zimbabwe. Approximately 1 kg of mature earthworms, equivalent to 800–1000 individuals, was introduced into each vermibed at the commencement of the experiment. *Eisenia Fetida* was selected because of its adaptability, high reproductive rate and proven efficiency in organic waste decomposition. Earthworms were introduced at stocking densities of approximately 500–1000 worms m⁻². Wooden

vermibeds measuring approximately 1.5 m × 1.0 m × 0.5 m were used. The reactors consisted of wooden boxes protected by shade netting and covered to prevent predation as well as excessive moisture loss. Each wooden vermibed had an approximate capacity of 0.75 m³. Construction costs ranged from USD80 to 120 depending on locally available materials. The reactor design was selected because of its affordability and suitability for smallholder farming systems in Zimbabwe. Pig manure and sawdust were mixed at a ratio of 1:1 and pre-composted for 10–14 days to reduce ammonia toxicity and pathogen levels. Following pre-conditioning, the material was transferred into vermibeds and inoculated with *Eisenia fetida*. Operational conditions were maintained at moisture contents of 60–70%, temperatures of 20–30 °C and pH values of 6.5–7.5 for a period of 60–90 days. Vermiwash was collected weekly through drainage outlets positioned at the base of the vermibeds. Approximately 500 mL was collected per sampling event and stored under refrigerated conditions prior to analysis. After the retention period, a mesh sieve was used to separate the majority of the earthworms from the finished vermicompost. Harvested vermicompost was then left to stabilize for two weeks before being applied to crops. Table 3 below shows the physicochemical characteristics of feedstock and final vermicompost.

Table 3. Physicochemical characteristics of feedstock and final vermicompost.

Parameter	Initial Feedstock	Final Vermicompost
pH	8.5 ± 0.2	7.0 ± 0.1
Moisture content (%)	68.4 ± 2.1	55.3 ± 1.8
Organic carbon (%)	42.8 ± 1.5	28.7 ± 1.2
Total nitrogen (%)	0.32 ± 0.03	0.68 ± 0.04
Available phosphorus (%)	0.15 ± 0.02	0.42 ± 0.03
Exchangeable potassium (%)	0.11 ± 0.01	0.37 ± 0.02
C:N ratio	134:1	42:1

Significant reductions in pH, organic carbon and C:N ratio were observed following vermicomposting, while nitrogen, phosphorus and potassium concentrations increased significantly ($p < 0.05$), indicating stabilization and maturation of the compost.

4.2.2. Bio Waste Vermicomposting Results

As ref. [15] claimed, the soil chemistry in this study showed that an initially high alkalinity of the pig manure with a pH of 8.5 decreased to a near-neutral level of around pH 7.0. The C:N ratio declined to below 42:1, which is favorable for plant nutrient absorption. The final vermicompost showed significant increases in essential nutrients, with NPK levels increasing by 50% to 0.4–0.7%, 0.3–0.6% and 0.2–0.4% respectively. This demonstrated that pig waste is a viable feedstock for vermicomposting in Sub-Saharan Africa. Previous studies have reported fecal coliform reductions exceeding 90% during vermicomposting due to enhanced microbial competition and pathogen suppression mechanisms [16]. Similar observations were noted during the present study, although detailed microbiological analyses were beyond the scope of this investigation. High ammonia concentrations in raw pig manure proved toxic to earthworms, underscoring the importance of pre-composting. Effective odor control was dependent on proper aeration and the inclusion of carbon-rich materials. Reference [10] reported that vermicomposting accelerates organic matter breakdown by at least 50% relative to non-biological composting techniques, reinforcing the method's efficiency. This case study confirms that with proper pre-conditioning, pig waste can be effectively converted into a high-quality biofertilizer, offering a viable solution to waste management for smallholder farmers in Zimbabwe.

4.3. Creation of Green Jobs and Circular Economy

The benefits of vermicomposting extend beyond the farm and the environment to create tangible socio-economic opportunities. The production, packaging and sale of

vermicompost, vermiwash and the earthworms themselves created new green jobs and income streams [17]. This is particularly empowering for women and youth in both urban and rural settings. Farmers sell excess worms for use as high-protein feed supplements in livestock and poultry farming and as fishing bait. At a community level, decentralized vermicomposting enterprises can turn waste into a marketable asset, embodying the principles of a circular economy [14]. By closing the nutrient loop, where waste from households and markets is returned to farms as fertilizer [18], vermicomposting builds local economic resilience [19] and reduces dependence on imported agricultural inputs. Figure 1 shows the circular economy potential of vermicomposting.

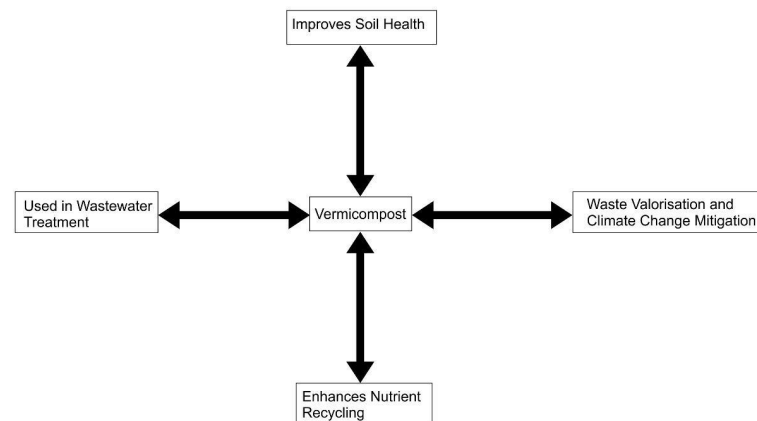


Figure 1. Circular economy potential of vermicomposting.

5. Conclusions

This research confirms that vermicomposting technology is a powerful, practical and environmentally sound response to the intertwined challenges of waste management, soil degradation and climate change facing Sub-Saharan Africa. By converting alkaline pig waste into a neutralized, nutrient-dense organic fertilizer with optimized C:N ratios, the process successfully closes the nutrient loop while diverting biodegradable municipal waste. This study demonstrated that vermicompost directly transforms organic waste, which is an environmental liability, into a valuable resource. Also diverting over 50% of biowaste from landfills, vermicomposting curbs the production of CH₄. However, these baseline findings are limited by a small sample size ($n = 25$) and the reliance on literature estimates rather than direct on-site measurements for methane and pathogen reduction. This process yields high-quality biofertilizers, vermicompost and vermiwash. These products enrich the soil with essential nutrients, organic matter and beneficial microbes, enhancing soil structure, water retention and long-term fertility. This, in turn, supports sustainable agricultural intensification, boosts crop yields and reduces farmers' reliance on expensive and environmentally harmful synthetic fertilizers. Vermicomposting creates tangible socio-economic opportunities, enabling the development of green jobs, the sale of earthworms, biofertilizers and the empowerment of local communities, thereby embodying the principles of a circular economy. Despite these proven advantages, the widespread adoption of vermicomposting in Sub-Saharan Africa remains constrained by several critical barriers, and these include a lack of supportive policy frameworks, limited technical knowledge among potential users, and insufficient institutional and financial backing. By embracing vermicomposting, Sub-Saharan Africa can transform an environmental crisis into a cornerstone of sustainable development. Vermicomposting offers a viable pathway toward building greener, resilient communities, enhancing food security and fostering economic growth, ultimately paving the way for a prosperous and environmentally secure future for the region. To scale this technology, future research

must prioritize direct greenhouse gas flux quantification in field-scale vermibeds, multi-season agronomic crop trials under diverse soil types and the development of localized cost–benefit models to successfully integrate grassroots vermiculture into national waste management and agricultural policies.

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Abbreviations

The following abbreviations are used in this manuscript:

C:N	Carbon to nitrogen ratio
CH ₄	Methane
CO ₂	Carbon dioxide
N	Nitrogen
P	Phosphorus
K	Potassium
Ca	Calcium
Mg	Magnesium
NPK	Nitrogen, phosphorus and potassium

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