






Review Article

# Vermicomposting for Sustainable Soil Health in Sub-Saharan Africa Focusing on Ethiopia: Opportunities, Adoption Barriers, and Policy Pathways

Zerihun Getachew Gebrehana <sup>1,\*</sup> , Mesfin T. Gebremikael <sup>2</sup> ,  
Sheleme Beyene <sup>3</sup> , Wim M.L. Wesemael <sup>4,5</sup> , Stefaan De Neve <sup>6</sup> 

<sup>1</sup> Assosa Agricultural Research Center, Ethiopian Institute of Agriculture Research, P.O. Box 2003, Addis Ababa, Ethiopia

<sup>2</sup> Department of food science, Aarhus University, Agro Food Park 48, 8200 Aarhus, Denmark

<sup>3</sup> School of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, Ethiopia

<sup>4</sup> Institute for Agricultural and Fisheries Research (ILVO), Burg Van Gansberghelaan 96, B-9820 Merelbeke, Belgium

<sup>5</sup> Laboratory for Agrozoology, Faculty of Bioscience Engineering, Ghent University, Coupure links 653, B-9000 Ghent, Belgium

<sup>6</sup> Research group Soil Fertility and Nutrient Management, Faculty of Bioscience Engineering, Ghent University, Coupure Links, 653, 9000 Ghent, Belgium

\*Corresponding author: [Zerihun.GetachewGebrehana@UGent.be](mailto:Zerihun.GetachewGebrehana@UGent.be)

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## Abstract

**Purpose:** Soil degradation in sub-Saharan Africa (SSA) threatens smallholder farming sustainability. Vermicomposting, using earthworms to convert agricultural waste into nutrient-rich fertilizer, has emerged as a promising solution.

**Method:** This review synthesizes 86 studies to analyse vermicomposting's impacts on soil and plant health, and alignment with regenerative agriculture and circular economy principles.

**Results:** The bio-conversion process through vermicomposting aligns with principles of regenerative agriculture and the circular economy by recycling agricultural waste into valuable soil improvers, thereby reducing landfill usage and mitigating environmental pollution. The review highlights the role of earthworms and microorganisms in stabilizing organic waste, improving nutrient profiles, and enhancing the biological activity of vermicompost. Additionally, it examines the mechanisms by which vermicompost amendments suppress plant diseases and pests, ultimately supporting sustainable farming practices. While vermicomposting offers substantial environmental and agricultural benefits, these outcomes depend on process optimization and local adaptation. Key knowledge gaps and barriers to adoption in SSA are identified, emphasizing the need for policy interventions.

**Conclusion:** Vermicomposting is a sustainable and practical approach to transforming agricultural waste into high-quality organic manure, with profound implications for improving soil health and fostering smallholder farming resilience in SSA particularly Ethiopia. Integrating vermicomposting into national soil health and waste management strategies, including subsidy programs, can scale its adoption.

**Keywords:** Soil health; Agricultural waste management; Valorization; Earthworms; Regenerative agriculture

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## 1. Introduction

Healthy soils are the foundation of agricultural productivity and ecosystem resilience in sub-Saharan Africa (SSA). However, widespread land degradation, driven by unsustainable farming practices and declining soil fertility (Bado and Bationo, 2018), threatens both food security and environmental sustainability. Approximately 65 % of SSA's agricultural land is degraded, reducing its capacity to deliver critical ecosystem services (Kihara et al., 2023). This degradation undermines the efficacy of chemical fertilizers, which depend on healthy soils for optimal crop performance (Adem et al., 2023). In Ethiopia, for example, nutrient depletion and loss of soil organic matter (SOM) have contributed to a 7 % decline in agricultural GDP (Terefe et al., 2024), disproportionately affecting smallholder farmers. Soil organic matter plays a pivotal role in sustaining soil health by enhancing its biological, physical, and chemical properties (Mutegi et al., 2018). It supports diverse microbial communities that drive nutrient cycling and organic matter decomposition, key processes for maintaining soil fertility. While conventional farming often relies on inorganic fertilizers, their sole use is insufficient to restore degraded soils (Adem et al., 2023). Instead, integrated approaches that combine mineral and organic inputs are essential. Among these, vermicomposting, a low-cost, eco-friendly technology that transforms organic waste into nutrient-rich fertilizer through earthworm activity, has emerged as a promising solution (Raza et al., 2024). Recent studies have shown that vermicomposting is a sustainable management approach to recycle nutrients from various types of waste such as municipal solid waste, agricultural waste and industrial waste (Hajam et al., 2023; Iqbal et al., 2024; Raza et al., 2024). The resulting product, vermicompost, is a nutrient, microbes, and plant growth-promoting rich organic substance that enhances crop yield and maintains soil health (Enebe and Erasmus, 2023; Gebrehana et al., 2023). Vermicomposting offers multiple benefits for SSA's agricultural systems (Lalander et al., 2015). It enhances soil microbial diversity, improves nutrient availability, and suppresses plant diseases (Gebrehana et al., 2023; Oyege and Balaji Bhaskar, 2023). The benefits of products from the vermicomposting process, vermiwash/vermicompost, in disease suppression and pest control have been reviewed in detail by Gudeta et al. (2021). Additionally, vermicomposting aligns with circular economy principles by recycling agricultural, municipal, and industrial waste into valuable soil amendments (Mohite et al., 2024). Compared to synthetic fertilizers, vermicompost reduces greenhouse gas emissions (Raza et al., 2024) and mitigates

toxic metal accumulation in crops (Goswami et al., 2024). Despite its potential advantages, the adoption of vermicomposting in SSA particularly Ethiopia remains limited due to gaps in awareness, high start-up costs, cultural resistance, and technical barriers, and also policy support (Gebrehana et al., 2022).

This review therefore examines the potential of vermicomposting to address soil health challenges in SSA. We highlight its role in enhancing nutrient cycling, suppressing pathogens, and promoting sustainable waste management, while also identifying barriers to its widespread implementation. By synthesizing current research, we aim to provide actionable insights for scaling vermicomposting practices to support resilient and productive agricultural systems across the region.

## 2. Literature search methodology

This review employed a systematic PRISMA approach to identify relevant studies on vermicomposting in Sub-Saharan Africa. Initial searches across Web of Science, Scopus, AGORA, and CAB Abstracts yielded 1,250 records using combined keywords for vermicomposting, soil health, and sub-Saharan African contexts, mainly Ethiopia. After removing 250 duplicates, we screened 1,000 titles/abstracts, excluding 800 publications that lacked SSA focus or agricultural relevance. The remaining 200 full-text articles underwent rigorous evaluation, with 120 excluded due to insufficient primary data (n=45), non-peer-reviewed status (n=32), or irrelevance to smallholder contexts (n=43). The final synthesis incorporated 120 studies, categorized by adoption challenges (n=38), soil impacts (n=45), and policy frameworks (n=37). To ensure methodological rigor, we prioritized peer-reviewed field studies (68 % published since 2015) while selectively including key government reports and FAO bulletins. The selection process specifically emphasized SSA's agro-ecological diversity, with included studies representing 22 countries across all major climatic zones.

## 3. Vermicomposting process and vermicompost

Vermicomposting is a bio-conversion process that involves the degradation and stabilization of organic matter through the combined action of earthworms and microorganisms (Enebe and Erasmus, 2023). Earthworms play a crucial role in this process by ingesting, fragmenting, and digesting organic waste, while microorganisms further decompose the material into nutrient-rich humus (Gómez-Brandón et al., 2021). The process occurs in two phases:

- Active phase: Earthworms ingest organic waste, breaking it down physically and chemically through

gut-associated processes (Gómez-Brandón and Dominguez, 2014). The gut microflora of earthworm plays an important role in the bioconversion process that leads to the stabilization of organic matter and changes in physical and biochemical properties of the resulting humus product, vermicompost (Singh et al., 2016).

- Maturation phase: Microbial activity in the earthworm casts transforms the material into stable vermicompost (Sharma and Garg, 2019). Vermicast consists of a mixture of ingested organic matter, secretions from the gut wall, and microbes it is then transformed into nutrient-rich vermicompost through microbial activity (Gebrehana, 2023).

Overall, vermicomposting results in two useful products: earthworm biomass and the final product, vermicompost (Ndegwa et al., 2000). At the end of this process, a nutrient rich and microbial active humified vermicompost, along with a substantial biomass of earthworms (juveniles and adults) can be harvested (Fig. 1). Vermicomposting induced a significant transformation in the composition of the microbial community present in the waste materials, leading to a diversified and distinct microbial profile compared to the original composition (Parthasarathi et al., 2007). The final product, vermicompost, is a nutrient-rich

organic fertilizer that enhances soil fertility, improves soil structure, and promotes plant growth. It contains higher levels of microbial activity and nutrient availability compared to conventional compost (Arancon et al., 2005; Parthasarathi et al., 2016). However, the nutrient and microbial composition of the final vermicompost is influenced by the initial characteristics of the feedstock (Gebrehana, 2023). Besides earthworm species and substrate used, there are other factors that highly influence the vermicomposting process.

Vermicomposting has emerged as an effective waste management strategy in recent years, primarily due to its cost effectiveness and its ability to process large quantities of organic waste (Gómez-Brandón and Dominguez, 2014). Various types of organic waste, including municipal solid waste, household waste, industrial waste, and agricultural waste such as animal manure and agricultural residues (Hajam et al., 2023), have been successfully managed through vermicomposting. However, knowledge about the influence of different mixed substrates on the growth of different earthworm species and the quality of the resulting vermicompost is still limited. It is crucial to understand the effects of both the earthworm species and feed substrate during the vermicomposting process. Two main vermicomposting systems can be used:

**Earthworm mucus (+)**- stimulate microbes and significantly accelerate decomposition and humification

**Earthworms-** break down and fragment organic substrate (+)

**Eartworm casting activities (+)** microbes disperse through earthworm casts



**Digestion (-)** earthworms modify microbes (gut associated)

**Competition (-)** direct effect of earthworms on microbes

**Figure 1.** Overview of the action of earthworms and microbes during the vermicomposting process. (Earthworms’ positive (+) and negative (-) effects of on microbial biomass and activity)

- Batch systems: Organic waste is added all at once, and the process occurs over a fixed period. This method is simple and cost-effective, making it suitable for smallholder farmers (Zziwa et al., 2021) (Fig. 2).
- Continuous flow systems: Organic waste is added continuously, allowing for ongoing processing and harvesting of vermicompost. This method is more efficient but requires higher initial investment (Enebe and Erasmus, 2023).

Both approaches have their strengths, but the choice between them depends heavily on the scale and resources available for vermicomposting. Recently, Usta and Guven (2024) demonstrated that vermicomposting in a continuous flow-through system reactor would be applicable to different organic waste. However, each technology has advantages and disadvantages that influence the operating system of the reactor and a corresponding effect on earthworm growth and the rate of biomass conversion (Enebe and Erasmus, 2023).

#### 4. Earthworms for vermicomposting

Earthworms are typically classified into three classes, epigeic, anecic and endogeic, based on definite ecological groups and have different effects on trophic functions (Fragoso et al., 1997). Understanding these ecological classifications helps in comprehending the diverse roles and impacts of earthworms in ecosystems. Among mentioned earthworms, *Eisenia fetida*, *Eisenia andrei* and *Eudrilus eugeniae* (African night crawlers) are the most widely used earthworm species for vermicomposting, as illustrated in Fig. 3. These earthworms are used for processing a wide range of substrates (Gebrehana et al., 2023). Their popularity is due to their high reproduction rates, tolerance to a wide range of environmental conditions, rapid bioconversion rate and ability to feed on

a wide range of organic waste (Sharma and Garg, 2019). In addition, *E. fetida* has a wider temperature tolerance than *E. eugeniae* and *P. excavates* which allows it to be cultured at temperatures ranging from 5 to 40°C (Sim and Wu, 2010). This adaptability makes *E. fetida* a preferred choice for vermicomposting practices in various agro-ecological settings.

The survival, growth, mortality, fecundity, and reproduction of earthworm species such as *E. fetida*, *E. andrei*, and *E. eugeniae* have been extensively studied under laboratory and field conditions to optimize vermicomposting performance across different types of organic wastes (Gebrehana et al., 2023). These studies assess how environmental factors and waste composition impact earthworm viability and reproduction potential. These findings guide the selection of earthworm species best suited to local organic wastes and environmental conditions, enhancing vermiculture efficacy and soil enrichment (Table 1). Findings summarized in Table 1 show that combining various organic waste types for vermicomposting is effective with both indigenous and exotic earthworm species, as each species can adapt to specific waste types and environmental conditions to optimize nutrient recycling. To maximize the efficiency of vermicomposting and achieve high-quality vermicompost, it is essential to match each earthworm species with suitable feed substrates, as not all earthworms process every organic material effectively. For example, species like *E. fetida* and *E. eugeniae* may have different requirements and efficiencies depending on the type of waste used, such as agricultural residues, manure, or food waste. Selecting appropriate feed for each species can significantly improve vermicomposting outcomes, enhancing the quality of the final product and promoting sustainable waste management.



**Figure 2.** Vermicomposting bins (batch vermireactors) made by farmers from locally available bamboo wood and plastic sheet in different areas of Assosa, western Ethiopia



**Figure 3.** The most common earthworm species currently used for vermicomposting (Gebrehana et al. 2023)

**Table 1.** Vermicomposting potential of different species of earthworms on various organic wastes

Type of organic waste (substrate)	Earthworm species	Incubation time (days)	Finding remarks	Reference
Nutrient and microbial dynamics during vermicomposting of crop residues (maize, soybean and banana residues) mixed with cow manure	<i>Eisenia fetida</i> , <i>Eisenia andrei</i> , <i>Eudrilus eugeniae</i>	90	Crop residues mixed with cow manure can be used in vermicomposting and better growth and reproduction of worms as well as nutrient-rich and microbially improved vermicompost can be obtained depending on feed substrate and earthworm species used	Gebrehana et al., 2023
Rice straw and paper waste (different ratios)	<i>Eisenia fetida</i>	105	Worm growth and reproduction was significant in different feed stocks except 50 % rice straw showed the ratio is not suitable for the earthworms	Sharma and Garg, 2018
Crop residues (rice, wheat, corn and sugarcane)	<i>Eisenia fetida</i>	90	Crop residues can be an effective substrate for vermicomposting	Ayneband et al., 2017
Vegetable wastes	<i>Eisenia fetida</i> , <i>Perionyx excavatus</i> and <i>Eudrilus eugeniae</i>	70	<i>Eisenia fetida</i> was found better for vermiculture using vegetable wastes than <i>Eudrilus eugeniae</i>	Meghvansi et al., 2016
Cashew leaf litter mixed with various animal dung (cow, sheep and horse)	<i>Perionyx excavatus</i>	-	Cashew can be used as feedstock for earthworm and converted into nutrients and microbial rich organic manure by the action of <i>P. excavatus</i>	Parthasarathi et al., 2016

Type of organic waste (substrate)	Earthworm species	Incubation time (days)	Finding remarks	Reference
Waste paper and chicken manure	<i>Eudrilus eugeniae</i>	51	The results revealed that 20 days of composting considerably degraded the organic waste mixtures from all treatments and a further 7 weeks of vermiculture significantly improved the bioconversion and nutrient value of waste paper and chicken manure with minimum toxicity	Ravindran and Mnkeni, 2016
Vegetable (different botanical families) wastes	<i>Eisenia fetida</i>	-	The substrate combining mixture of non-legume and legume vegetable waste at 2:1 ratio provided the major nutrients and growth of earthworms	Chatterjee et al., 2014
Horse manure, apple pomace, grape pomace, and digestate through a continuous-feeding system	<i>Eisenia andrei</i>	240	After 240 days of vermicomposting, stabilization was evident in all processed materials, as indicated by a reduction in dissolved organic carbon. N-NO <sub>3</sub> <sup>-</sup> levels increased in the processed horse manure and AP materials. This period also showed a decline in earthworm activity, further signifying a high degree of stabilization.	García-Sánchez et al., 2017
Garden waste, kitchen waste and cow dung	<i>Eisenia fetida</i>	-	vermicomposting is a suitable technology for the conversion of wastes into organic fertilizer	Wani and Rao, 2013
Coffee pulp with cow dung slurry	<i>Eudrilus eugeniae</i>	-	Coffee pulp with cow dung can be used as a vermicomposting substrate	Raphael and Velmourouga ne, 2011
Cow dung, poultry droppings and food industry sludge	<i>Eisenia fetida</i>	91	Cow dung alone and 50 % cow dung with the other feeds were better for vermicomposting	Yadav and Garg, 2011
Cow, sheep, pig and chicken manures	<i>Eudrilus eugeniae</i>	147	Sheep, chicken and cow manures were suitable for growth and reproduction of <i>Eudrilus eugeniae</i>	Coulibaly and Bi, 2010
Sewage sludge (SS)	<i>Eisenia fetida</i> , <i>Eudrilus eugeniae</i> , <i>Perionyx excavatus</i>	-	Sewage sludge can be recycled as a good quality fertilizer using the three earthworms studied.	Khwairakpa m and Bhargava, 2009
Vegetable solid waste amended with wheat straw, cow dung and biogas slurry	<i>Eisenia fetida</i>	105	vermicomposting can be an efficient technology to convert negligible vegetable-market solid wastes into nutrient-rich vermicompost	Suthar, 2009
crop residues, farm yard manure, and cattle dung	<i>Eudrilus eugeniae</i> , <i>Perionyx excavatus</i> , and <i>Perionyx sansibaricus</i>	-	biomass production and reproduction performance of tropical earthworms were influenced by quality of the waste material used for vermiculture	Suthar, 2007
Rubber leaf litters	<i>Perionyx excavatus</i> , <i>Eudrilus eugeniae</i> and <i>Eisenia fetida</i>	62	The suitability of rubber leaf litters as a vermiculture substrate was studied and higher growth and reproduction was found in <i>Eudrilus eugeniae</i> followed by <i>Eisenia fetida</i> and <i>Perionyx excavatus</i>	Chaudhuri et al., 2003

## 5. Factors affecting vermicomposting process

Vermicomposting process is affected by several factors including substrate material, various process conditions such as pH, temperature, moisture, and earthworm species used (Sharma and Garg, 2019). Each of these factors plays a crucial role in determining the quality of the final vermicompost prepared from different mixtures of organic waste and in facilitating the growth of earthworms.

### 5.1. Temperature and moisture during vermicomposting

Epigeic earthworms exhibit high tolerance to organic waste conditions, enabling the use of low-management windrow or bed systems (Dominguez and Edwards, 2011). However, optimal vermicomposting occurs within a narrow range of favourable environmental conditions. Temperature and moisture are among the most critical factors affecting process efficiency.

Earthworm growth, reproduction, and vermicompost productivity are highly temperature-dependent. Edwards et al. (1998) observed that earthworms at 15 °C showed no clitellum development (a growth indicator), whereas those at 20–30 °C exhibited clitellum formation and cocoon production. While species-specific tolerances vary, most earthworms thrive between 20–25 °C (Edwards and Arancon, 2006; Dominguez and Edwards, 2011). An optimal moisture range of 60–80 % ensures aerobic conditions and maximizes productivity (Yadav et al., 2022). Excess moisture reduces oxygen availability, while insufficient moisture hinders microbial and earthworm activity.

Overall, several researchers have suggested optimal temperature and moisture conditions for an efficient vermicomposting process, as summarised in Table 2. Additionally, earthworms are highly sensitive to ammonia and inorganic salts, which can be lethal at high concentrations (Edwards and Arancon, 2006). Pre-composting or leaching can mitigate these issues, making combined composting-vermicomposting an effective stabilization method (Lazcano et al., 2008).

### 5.2. Feed substrate quality and stocking density

The decomposition of organic materials follows biochemical pathways influenced by substrate origin (plant, animal, or microbial). Plant-derived substrates dominate, while animal and microbial residues are nutrient-rich but less abundant (Insam and de Bertoldi, 2007). Substrate quality directly affects earthworm growth, reproduction, and compost quality (Singh et al., 2011).

The C:N ratio is a critical factor in vermicomposting, the C:N ratio affects microbial activity and organic matter decomposition (Ravindran and Mkeni, 2016; Lv et al., 2018). The C:N ratio (nutrient balance of organic residues) and the availability of nutrients, as well as lignin and polyphenol contents (Pramanik et al., 2007), are important feedstock components that have a substantial impact on earthworm growth and the quality of compost during vermicomposting. In a recent study, Dominguez (2018) suggested that epigeic earthworms require a substrate with a relatively high moisture content. The C: N ratio of a substrate significantly influences earthworm growth through its impact on moisture and temperature conditions of the substrate during the vermicomposting process. Optimal moisture and temperature conditions are indirectly influenced by C:N balance (Dominguez, 2018). Low C:N ratios promote earthworm growth (Aira et al., 2007), while high ratios reduce biomass (Ndegwa et al., 2000). Therefore, proper balance of the C:N ratio is critical to creating an environment that promotes efficient vermicomposting and yielding high quality vermicompost. Lignin content is also among the most important natural components that have a significant influence on the decomposition of the substrate (Insam and de Bertoldi, 2007). High lignin slows decomposition but can be managed for balanced nutrient cycling (Insam and de Bertoldi, 2007). Stocking density and feeding rate also significantly impact earthworm performance: Higher densities increase total biomass but reduce individual growth (Dominguez and Edwards, 2011). The recommended density is 1.60 kg worms/m<sup>2</sup> with a feeding rate of 1.25 kg feed/kg worms/day (Ndegwa et al., 2000).

**Table 2.** Optimal moisture and temperature conditions during vermicomposting process

Earthworm species	Moisture	Temperature	References
<i>Perionyx excavatus</i>	-	Between 20–30 °C	Edwards et al., 1998
<i>Eisenia fetida</i> and <i>Eudrilus eugeniae</i>	-	Between 15–25 °C	Edwards and Arancon, 2006
-	Between 80–85 % (manually by squeezing)	Between 20–25 °C	Dominguez, 2018
-	Between 50–90 %	-	Dominguez and Edwards, 2011
-	Between 60–80 %	-	Sharma and Garg, 2019
-	Between 60–80 %	< 28 °C	Yadav et al., 2022

### 5.3. Microbial activity and nutrient dynamics during vermicomposting

The vermicomposting process is profoundly influenced by earthworm-mediated biochemical transformations and their symbiotic relationships with microbial communities. As organic substrates pass through the earthworm digestive tract - progressing from the pharynx (where mucin and proteolytic enzymes initiate breakdown) (Konig and Varma, 2006) to the muscular gizzard (for mechanical grinding) and finally the intestine - they undergo both physical and biochemical modification (Kiyasudeen et al., 2016) (Fig. 4). This process generates nutrient-rich casts that stimulate microbial proliferation, particularly bacteria, fungi and actinomycetes, due to enhanced nutrient availability (Brown and Doube, 2004). The gut environment selectively filters pathogens while hosting beneficial symbionts: foregut bacteria aid digestion, midgut actinomycetes suppress pathogens, and hindgut fungi contribute to cast stability (Monroy et al., 2009; Kiyasudeen et al., 2016).

The earthworm-microbe interaction exhibits complex dynamics, with studies reporting both increased microbial activity in casts (Parthasarathi et al., 2007; Singh et al., 2016) and decreased total biomass due to earthworm grazing (Aira et al., 2007; Villar et al., 2017). These apparent contradictions likely reflect variations in substrate composition, earthworm species, and process conditions (Yakkou et al., 2024). Earthworms enhance nutrient cycling through two primary mechanisms: physical mixing of substrates that improves aeration and decomposition (Monroy et al., 2009), and biochemical secretions (mucus and casts) that boost microbial activity and increase nitrogen and phosphorus availability (Chen et al., 2023). Notably, gut-hosted nitrogen-fixing bacteria significantly elevate N content in final vermicompost (Gebrehana, 2023).

### 5.4. Carbon stabilization during vermicomposting

Carbon stabilization represents another crucial aspect of vermicomposting. Earthworms significantly enhance carbon stabilization during vermicomposting through synergistic mechanisms involving digestive enzymes and gut-associated microbial communities (Enebe and Erasmus, 2023). Their intestinal microbiota facilitate aerobic decomposition, transforming organic matter into stable humus that retains soil carbon more effectively than uncomposted material while simultaneously improving soil quality (Gebrehana, 2023). However, the carbon stabilization potential varies considerably depending on waste type (e.g., pineapple peels showing 54-60 % biomass reduction; Zziwa et al., 2021), process conditions, and earthworm species characteristics. The carbon dynamics of

vermicomposting present an interesting paradox. While some studies report higher carbon mineralization and CO<sub>2</sub> emissions compared to thermophilic composting due to accelerated decomposition (Nigussie et al., 2016; Dume et al., 2021), others demonstrate superior carbon retention (Haynes and Zhou, 2016). These apparent contradictions stem from multiple controlling factors: (1) substrate composition (particularly C: N ratio), (2) earthworm species selection, and (3) environmental parameters (moisture, temperature, aeration, and pH). Strategic management can optimize these variables - for instance, high C:N additives like wheat pellets reduce CO<sub>2</sub> emissions by 60-70 % (Dume et al., 2021), while biochar amendments simultaneously enhance carbon sequestration and reduce nitrogen losses (NH<sub>3</sub> by 24.93-66.23 %; N<sub>2</sub>O by 14.91-55.12 %) (Gong et al., 2023). When comparing decomposition pathways, vermicomposting offers distinct advantages over thermophilic composting, including: (1) superior nutrient profiles and enzyme activity (Bellitürk et al., 2023), (2) lower infrastructure and energy requirements (Kumar et al., 2023), and (3) reduced nitrogen losses from leaching - a significant limitation of thermophilic systems (Gebrehana, 2023). The incorporation of recalcitrant carbon sources like bamboo-derived biochar (Nguyen et al., 2022) further enhances long-term carbon storage potential while improving the fertilizer value of the final product (Kumar et al., 2023). These benefits position vermicomposting as a dual-purpose solution for organic waste management and climate-smart agriculture, particularly when process parameters are optimized for humification and nitrogen retention (Gong et al., 2023).

### 5.5. Vermicompost as a dual-function amendment: enhancing plant growth and suppressing diseases

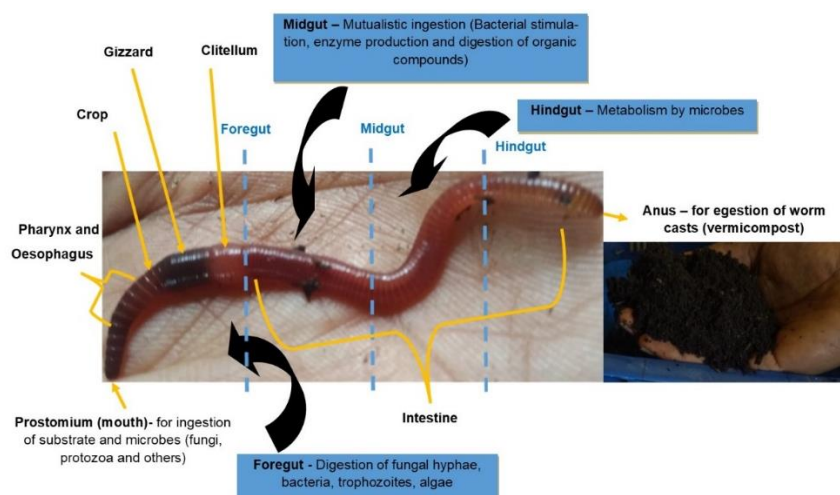
Vermicompost demonstrates remarkable potential as a soil amendment through its dual capacity to enhance plant growth and suppress soil-borne pathogens. The transformation of organic waste via earthworm activity produces nutrient-rich casts that significantly improve soil physicochemical and biological properties (Singh et al., 2016; Poornima et al., 2024). These amendments enhance soil aeration, microbial populations, enzymatic activity, and texture while providing balanced nutrients, vitamins, and plant growth hormones (Edwards and Arancon, 2022). Field studies across various crops including vegetables, fruits, and cereals, confirm that vermicompost application, either alone or combined with inorganic fertilizers, improves yield and nutrient quality while rehabilitating degraded soils (Arancon et al., 2005; Lazcano et al., 2013; Chatterjee et al., 2014). Its superiority to conventional compost lies in higher microbial diversity and enzymatic activity (Parthasarathi et al., 2016), making it particularly

valuable for smallholder farms where soil organic matter restoration is critical (Jouquet et al., 2010; Srivastava et al., 2011). Beyond fertility benefits, vermicompost exhibits strong nematicidal properties against economically significant pests like *Meloidogyne incognita* and *M. javanica* (Godinho-Mendes et al., 2021). Unlike chemical nematicides, which pose environmental and economic challenges (Dong and Zhang, 2006), vermicompost suppresses nematodes through multiple mechanisms (Fig. 5):

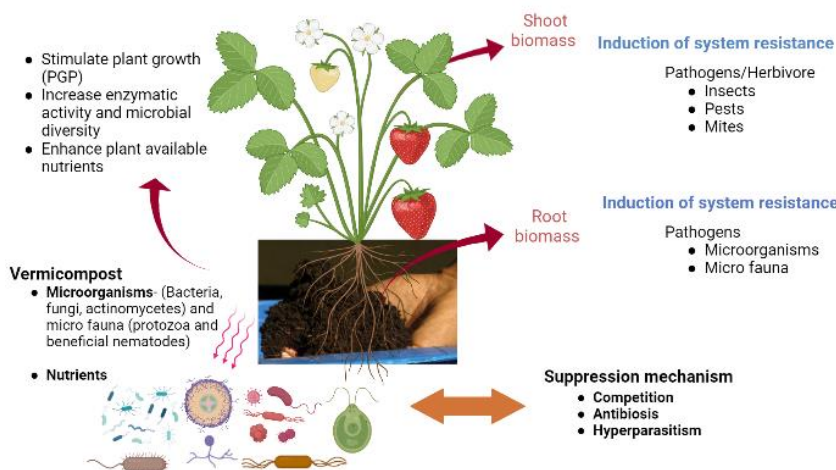
- Enriched beneficial microbes compete for nutrients, produce antibiotics (e.g., hydrogen sulfide, ammonia), and parasitize nematodes (daSilva et al., 2018).
  - Induced Systemic Resistance: Enhanced phenolic and flavonoid production primes plant defenses (Xiao et al., 2016; Edwards et al., 2010).
  - Increases bacterivorous/fungivorous nematodes while reducing parasitic species (Przemieniecki et al., 2021).
- In general, the biological mechanisms through which the microbiome interacts with these soil - borne diseases

include:

- a. Parasitism: beneficial microbes or microbial communities can engage in parasitism against pathogens, essentially acting as predators that consume or disrupt the pathogen's life cycle.
- b. Production of metabolites, toxins, and antibiotics: certain microorganisms in vermicompost produce compounds that are toxic to nematodes and pathogens. They may also secrete antibiotics or metabolites that inhibit the growth and activity of these soil-borne pests.
- c. Competition for nutrients/resources: microbes in vermicompost compete with nematodes and pathogens for essential nutrients and resources in the soil, limiting the growth and proliferation of these pests.
- d. Activation of disease-resistant genes: beneficial microbes may activate disease-resistant genes in host plants, making them more resilient to nematodes and pathogens (Jayaraman et al., 2021).



**Figure 4.** Overview on the activity of earthworms on organic substrate decomposition and microbial activity during the vermicomposting process (developed from Kiyasudeen et al. 2016)



**Figure 5.** Outline on mechanisms of disease suppression by vermicompost (follows competition, antibiosis and hyper-parasitism and also induction of system resistance) (Gómez-Brandón and Domínguez, 2014)

## 6. Vermicomposting impact on regenerative agriculture and circular economy

Vermicomposting has emerged as a transformative technology that bridges regenerative agriculture and circular economy principles, particularly in smallholder farming systems across Sub-Saharan Africa (Fig. 6). This dual benefit system addresses two critical challenges simultaneously: organic waste management and soil fertility restoration. Countries like Ethiopia, Kenya, and South Africa are increasingly adopting vermicomposting to valorize agricultural residues (pineapple waste, crop residues, livestock manure) into nutrient-rich amendments, creating closed-loop systems that reduce external input dependence while improving soil health (Zziwa et al., 2021; Tindwa et al., 2024).

- The technology aligns perfectly with regenerative agriculture's core objectives:
- Soil health restoration: Enhances microbial diversity (Singh et al., 2023) and improves soil structure (Velasco-Muñoz et al., 2022).
- Carbon sequestration: Stabilizes organic matter in soils (Van Hoof et al., 2024).
- Input independence: Reduces synthetic fertilizer use by 30-50 % (Oyege and Balaji-Bhaskar, 2023).
- Economic empowerment: Generates supplemental income through vermicompost and earthworm sales (Raimondo et al., 2023).

From a circular economy perspective, vermicomposting:

- Closes nutrient loops: Transforms waste streams (70-80 % of farm biomass) into valuable inputs (Chojnacka et al., 2020).
- Reduces environmental impact: Diverts organic waste from landfills while lowering GHG emissions by 15-20 % compared to conventional composting (Van Hoof et al., 2024).
- Creates value chains: Premium markets are emerging for "vermicompost-certified" produce in Kenya and Tanzania (Tindwa et al., 2024).

Despite these benefits, scaling challenges persist in low-income regions, including: limited technical knowledge on optimal vermiculture practices, infrastructure gaps for waste collection and processing.

Market barriers for organic inputs. Recent innovations like mobile vermicomposting units in Uganda (Zziwa et al., 2021) and women-led cooperatives in Ethiopia demonstrate promising models for wider adoption. Future research should focus on: optimizing feedstock mixtures for African cropping systems, developing localized earthworm breeding programs, and creating policy frameworks to incentivize circular agriculture. This integrated approach positions vermicomposting as a keystone technology for achieving both agricultural sustainability and circular economy goals in resource-limited settings.



Figure 6. Overview of vermicomposting technology contribution to agricultural productivity and promoting a circular economy

## 7. Challenges and strategic approaches for vermicomposting adoption in SSA

The adoption of vermicomposting in Sub-Saharan Africa faces significant yet addressable challenges that vary across the region's diverse agro-ecological and socioeconomic contexts. Financial constraints represent a primary barrier, with smallholder farmers often unable to afford the initial costs of earthworm procurement and infrastructure setup (Gebrehana et al., 2022). This economic hurdle is compounded by cultural resistance to new agricultural practices and limited technical knowledge about vermicompost management (Sharma and Garg, 2019). Furthermore, the region's climatic variability and inconsistent availability of organic feedstock necessitate localized approaches to system design and implementation (Muluneh et al., 2022).

### Key adoption challenges:

- Economic barriers: High initial costs for materials and earthworms deter smallholders. Micro financing schemes and government subsidies, like Kenya's NARIGP program, have shown promise in overcoming this obstacle.
- Knowledge gaps: Limited understanding of vermicomposting benefits and techniques persists. Rwanda's integration of vermicompost training into existing farmer field schools (Twigire Muhinzi program) provides a replicable model for extension services.
- Feedstock availability: Inconsistent organic waste supply chains hinder production. South Africa's municipal waste segregation policies demonstrate how regulatory approaches can ensure reliable feedstock sources.
- Climate adaptation: Drought-prone regions require modified systems. Research indicates *Eisenia fetida* shows better heat tolerance, making it suitable for arid areas (Mohite et al., 2024).

### Policy frameworks for scaling vermicomposting

Strategic solutions and policy frameworks for scaling up vermicomposting in an auspicious way include three complementary approaches:

#### Community-based models:

- Village vermicompost hubs with shared resources reduce individual costs
- Women-led cooperatives (e.g., Ethiopia's women's development association) improve gender inclusion
- Nigeria's "Vermi-Revolution" reached 5,000 farmers through radio-based training

#### Public-private partnerships:

- Mobile vermicomposting units (Uganda's Waste Ventures Africa) serve remote areas

- Agribusiness collaborations enable large-scale production while maintaining quality

#### Market Incentives:

- Certification systems for quality assurance build consumer trust
- Premium pricing for "vermicompost-grown" produce increases farmer income
- Tanzania's urban-rural circular economy model demonstrates successful market linkages

### Research priorities and future directions:

While vermicomposting demonstrates clear benefits for soil health (Enebe and Erasmus, 2023) and crop resilience (Mohite et al., 2024), several knowledge gaps require attention:

- Cost-benefit analyses specific to smallholder contexts
- Optimization of continuous-flow systems for large-scale waste valorization
- Automated monitoring technologies to reduce labour requirements
- Climate-adaptive earthworm-substrate combinations for different agro-ecological zones

Malawi's successful integration of vermicomposting into climate-smart agriculture subsidies suggests that policy innovation can effectively drive adoption when combined with farmer education and market development. Future efforts should focus on developing circular economy models that simultaneously address waste management and soil fertility challenges while remaining economically viable for resource-limited farmers.

## 8. Conclusion

Vermicomposting presents a transformative solution for sub-Saharan Africa's dual challenges of soil degradation and organic waste accumulation. Our analysis reveals three critical pathways for realizing its full potential: (1) policy incentives to overcome start-up costs, (2) farmer-centric training programs, and (3) research into locally adapted earthworm species. When implemented effectively, vermicomposting can restore SSA's degraded soils by enhancing nutrient availability, boosting microbial activity, and improving soil structure. The technology's circular economy benefits are equally compelling, converting agricultural waste into premium organic fertilizer while sequestering carbon. For smallholders, transitioning from batch systems to continuous-flow vermireactors could increase production efficiency, but requires targeted support through:

- Policy frameworks: subsidized earthworm distribution and infrastructure grants
- Capacity building: hands-on training via farmer field schools

- Market development: certification programs for quality-assured vermicompost

Future implementation should prioritize climate-adapted systems, particularly for drought-prone regions, while research addresses key gaps in long-term soil health impacts, optimal earthworm-substrate combinations, and automated monitoring technologies. With proper quality control and scaling mechanisms, vermicomposting can become a cornerstone of SSA's sustainable agriculture transition simultaneously boosting crop yields, reducing synthetic fertilizer dependence, and restoring degraded ecosystems. Its success will depend on coordinated action between governments, researchers, and farming communities to create an enabling environment for widespread adoption.

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#### Authors Contribution

Zerihun Getachew Gebrehana: Conceptualization, Illustration, Writing – original draft and editing. Mesfin T. Gebremikael: Writing – review and editing. Sheleme Beyene: Writing – review and editing, Supervision. Wim M.L. Wesemael: Writing – review and editing, Supervision. Stefaan De Neve: Writing – review and editing, Supervision.

#### Availability of data and materials:

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

#### Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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