Chapter 19
Potential Transformation of Organic Waste in African Countries by Using Vermicomposting Technology

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Abstract In recent decades rising populations and rapid urbanization have changed the lifestyles of many people. This has resulted in the generation of vast quantities of different types of solid waste. In Africa, the harsh environment (hot weather and acidic soil) and the scant awareness of organic waste recycling have led to a decline in soil quality and to uncollected waste being piled up in streets, public places, and drains. Various studies have revealed that disposal of about 90% of municipal solid waste (MSW) is uncontrolled and that waste is dumped in open areas and landfill sites, creating problems for public health and the environment. This situation has increased the need for long-term green strategies in agricultural engineering and sustainable waste management. Hence, this chapter highlights vermicomposting as a sustainable, economical approach to disposing of the waste generated in African countries and discusses the value of the technology for improving agricultural practices and soil bioremediation. Current vermicomposting scenarios practiced in Africa and their future impact are also considered. The chapter concludes with a suggestion to governmental bodies including authorities and scientists to consider ways of enhancing the practice of vermicomposting in African countries.

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19.1 Introduction

The role of earthworms in breaking down organic matter and thus releasing nutrients has been recognized since the end of the nineteenth century (Edwards 2007). Darwin's book, "Formation of vegetable mould through the action of worms with observations on their habits," published in 1892, was the first research text to mention earthworms (Feller et al. 2003). In the preceding period, i.e., between 1870 and 1889, very few studies concerning earthworms were published. However, to date, there are more than 10,000 publications related to earthworms. Due to the proven success of vermicomposting, this method and other similar treatments using earthworms to break down organic matter to produce valuable soil-like additives and proteins for animal feed have expanded rapidly since 1970. In the 1990s, research focused on the ecology and biology of earthworms and their use to process different types of waste. The increase in researchers' interest in vermicomposting grew alongside the interests of commercial organizations throughout the world, in developed countries such as the USA, Canada, UK, Australia, Russia, and Japan, as well as in developing countries such as India, China, Chile, Brazil, Mexico, Argentina, and the Philippines (Edwards 2007).

The vermicomposting technique has specifically been practiced in countries with high levels of nutrient mining. Sub-Saharan African countries suffer from soil degradation and a significant decline in soil fertility that adversely affects crop yield and food production (Gebrehana et al. 2022). For example, soil nutrient losses from agricultural systems are very high in Ethiopia, accounting for about 30–60 kg ha^{-1} NPK per year (Nguru et al. 2020). Vermicomposting is an environmentally friendly treatment that meets sustainability goal 7 of the UN Millennium Development Goals (MDG7) and is consistent with the concept of natural resource management and sustainability to meet human food requirements. The application of vermicompost to agricultural land has been reported to improve crop production. For instance, plant growth studies on garlic (Gichaba et al. 2020) and maize (Coulibaly 2020) have demonstrated increased growth and crop yields related to the use of vermicompost. Likewise, lettuce yield and total uptake of phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were highest in plants grown in coir-based vermicompost (Schröder et al. (2021). In general, the vermicomposting technique is simple and inexpensive, making it feasible in low-income regions, especially in developing countries with low per capita income such as a many of the African countries classified on the basis of the human development index. This chapter reports important information based on applicability and advances in developing vermicomposting techniques in African countries towards sustainable waste management.

19.1.1 The Role of Earthworms in Breaking Down Organic Matter

The most important role of earthworms in biological processes includes breaking down solid organic matter (Atiyeh et al. 2000), thereby releasing a portion of the organic matter into earthworm biomass and respiration products (Dominguez et al. 2001) and rendering nutrients available to plants (Sun 2003). The role of earthworms in breaking down organic matter is attributed to three processes that occur in the worm gut: interaction with gut microorganisms, digestion of enzymes, and physical grinding.

Earthworm species each have a unique type of digestive system, but the gut structure is similar in all. The digestive system of earthworms consists of the buccal cavity, crop, gizzard, and intestine. Food adheres to mucus extruded by the buccal epithelium. Pressure on the buccal cavity wall is then released, which establishes a partial vacuum whereby materials are transported through the crop, gizzard, and intestine (Sun 2003). The time taken for the food to pass through the worm gut can vary between 3 and 5 h in *E. fetida* and between 12 and 20 h in *Lumbricus terrestris* (Edwards 2007).

Different earthworm species exist in almost all regions except for areas with extreme climates, such as deserts and glaciers. Earthworm species have different life cycles and behavioral and environmental requirements. They are classified into three major ecological categories on the basis of their feeding and burrowing strategies: epigeic, endogeic, and anecic (Ismail 2009; Sun 2003). Only epigeic earthworms are mostly relevant in relation to vermicomposting, though other classes of earthworms like anecic and endogeic have also been used (Edwards 2007). About 8000 species of earthworm have been described as epigeic worldwide, from 800 genera belonging to the order Oligochaeta (Edwards 2004). Among these, seven earthworm species are used in vermicomposting: *Eisenia fetida, Dendrobaena veneta, Dendrobaena rubida, Lumbricus rubellus, Perionyx excavatus, Eudrilus eugeniae,* and *Polypheretima elongata* (Edwards 2007; Sun 2003). These species show positive growth on organic waste and exhibit different life cycles and cocoon production patterns. For example, the growth and life cycle of *Eudrilus eugeniae* was found to vary from between 52 and 60 days in cocoa and cashew residues, with 88% cocoon hatchability (Coulibaly et al. (2019).

19.1.2 Vermicompost, the “Black Gold” in Agriculture

Vermicompost, the end product of vermicomposting, is a homogeneous, odorless compost with high porosity and water-holding capacity. The advantages of using vermicompost in agriculture have been widely demonstrated. Vermicompost is sometimes referred to as “black gold,” because of its extremely valuable properties in relation to plant health and growth. In the last few decades, vermicomposting has been used to convert different bio-waste materials into vermicompost. The process has attracted much interest from researchers, consumers, and producers as it is an inexpensive source of a wide range of bioactive compounds (Fontana et al. 2013; Galanakis 2012). Vermicompost is an excellent plant growth promoter, with demonstrated positive effects on various aspects of agricultural and horticultural development (Gómez-Brandón et al. 2015). Vermicomposting is included among strategies used to produce value-added products for potential agricultural use; Sanchez-Hernandez et al. (2019) reported that the vermicomposting technique plays a dual role in bioremediation and environmental detoxification. For instance, vermicompost can be used for the bioremediation of pesticide-contaminated soils (Sanchez-Hernandez et al. 2019). Gómez-Brandón et al. (2020) studied the effectiveness of vermicomposting for bioconversion of by-products from the wine industry (grape marc) and studied the potential toxicity of the product. These authors concluded that the total polyphenol content of the grape marc decreased significantly to a minimum of 12.8 ± 0.4 mg in 70 days, with no adverse effects on earthworm density, with maximum growth of earthworms being reached within two months. In addition, the aforementioned authors raised safety concerns concerning the use of vermicomposted human waste for agriculture; however, other researchers noted a significant decrease in fecal coliforms and a reduction in mass of about 67% after 4 weeks of vermicomposting with *Eudrilus eugeniae* (Acquah et al. 2021; Nsiah-Gyambibi et al. 2021). Earthworms have been reported to reduce the total abundance of human pathogenic bacteria and modify their diversity, resulting in a higher quantity of Enterobacteriaceae in sludge vermicompost (Huang et al. 2020). Likewise, salmonella has been found to be less abundant than other bacteria in vermicompost, and vermicompost tea samples collected from different farms tested negative for the presence of possible pathogens (Atanda et al. 2018), indicating the safety of vermicompost when produced under hygienic conditions.

19.2 Potential of Vermicomposting in Africa

Agriculture is one of the main economic activities in Africa. Apart from providing more than 60% of food for domestic needs, agriculture is an essential source of income for most of the population, demonstrating the great importance of farming in African countries. Only 6% of all land in Africa is dedicated to agriculture. Therefore, it is vital to improve the soil fertility to enable sustainable production of crops in most African countries. While there is a need to increase food production hugely, to meet the demands of a rapidly growing population remains paramount.

Various types of food are cultivated in countries such as Egypt, Nigeria, and South Africa (Table 19.1). Increasing the volume of cultivated crops will result in massive amounts of agricultural waste generated. By applying the concept of "waste is wealth," these countries could benefit from the amount of waste produced by converting it into value-added products.

Table 19.1 Main crops cultivated in different countries in Africa (Robert K. A. Gardiner 2018)

Corn	Rice	Wheat	Legumes	Root crops	Oil palm	Coconut	Tobacco
Egypt	Egypt	Ethiopia	Egypt	Ethiopia	Congo	Côte d'Ivoire	Nigeria
Mauritius	Senegal	Kenya	South Africa	Kenya	Côte d'Ivoire	Ghana	Tanzania
Reunion	Côte d'Ivoire	Nigeria	Sudan	Madagascar	Nigeria	Nigeria	Zimbabwe
	Guinea	South Africa					
	Madagascar						
	Mali,						
	Nigeria						
	Sierra Leone						
	Tanzania						

The most beneficial approach would be to enhance the use of bioremediation technologies in these countries. Vermicomposting is a well-known cost-effective technology that does not require investment in expensive instruments. However, survival of the earthworms is necessary for success of the process. Earthworm populations depend on both physical (temperature, moisture, aeration, and texture) and chemical (pH) properties of the soil, as well as on food availability, and the ability of the organisms to reproduce and disperse. Hengl et al. (2021) mapped African soil properties and nutrients at 30 m spatial resolution and the results have shown wide variability. Although these researchers faced several problems in gathering the information, the following figure provides an overall picture of soil properties in the African continent.

According to Hengl et al. (2021), diverse soil types are found in Africa, although obtaining data from specific areas such as Congo still remains challenging. Nevertheless, African soils generally have a sandy-loam soil texture with high organic carbon content as indicated in Fig. 19.1 and can provide a niche for some earthworm

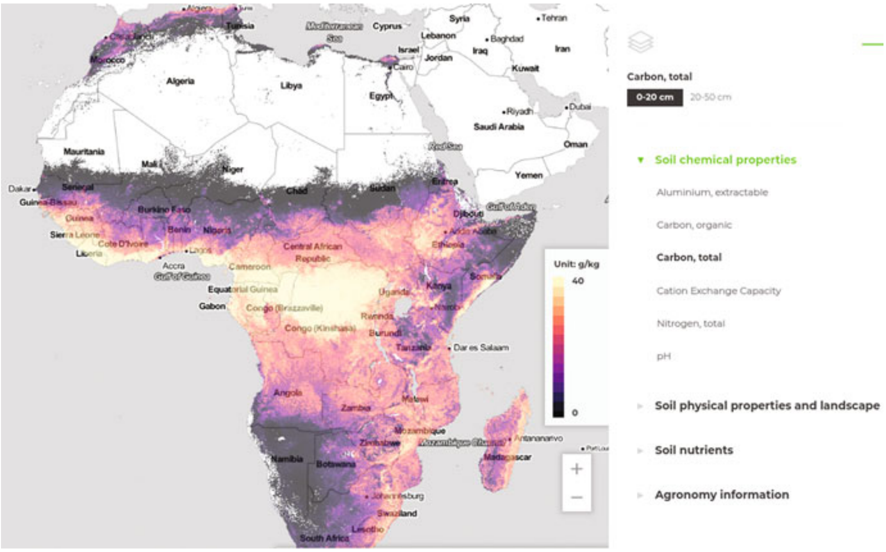

Fig. 19.1 Map showing the soil total carbon for most African countries predicted at 30 m resolution at 0–20 and 20–50 cm depths (source https://zenodo.org/record/4088064#.Yq-OtnZBzIV)

species. For example, *Keffia penetrabilis* n. sp. and *K. proxipora n.* sp. have been described in collections from various localities in Nigeria. Overall, the diverse soil properties and the limited access in some areas (local government security policies) make compiling a database for the whole continent challenging. In addition, the conditions in many African countries are not always favorable to earthworm growth due to the hot climate and dry soil. However, earthworms are highly tolerant and can survive well in slightly acidic environments with adequate moisture levels. Difficulties in maintaining optimal growth conditions to produce high-value fertilizers can discourage smallholders from using the vermicomposting technique to make fertilizers for agricultural purposes. Therefore, there is a need to establish awareness-raising strategies and provide farmers with an in-depth understanding of the concept of soil erosion, degradation, and sustainable farming. This could motivate farmers to develop vermicomposting plants on their farms as a simple, feasible, and economically beneficial strategy for their business.

19.2.1 Vermicomposting Practices in African Countries

Growth of the global population has led to the expansion of agricultural production and industrialization to meet current needs without further damage to the environment. In response, the demand for animal manure and food has led to the inappropriate disposal of waste (Katakula et al. 2021). Declining soil fertility is a challenge to sustainable agricultural production in many parts of the world (Fróna et al. 2019). Seeking eco-friendly ways of replenishing soils has become the main focus of research projects, with composting and vermicomposting gaining momentum due to the limited ecological footprint of these processes (Vyas et al. 2022). These techniques have also been promoted due to increasing awareness that organic nutrient sources play an important role in improving soil quality (Aulakh et al. 2022). Vermicompost can balance the entire soil environment while also providing a desirable habitat for soil microbes (Saha et al. 2022). As an amendment, vermicompost is regarded as an excellent replacement for synthetic fertilizers (Kaur 2020).

Many studies have been conducted in Africa on vermicomposting with various types of substrates, including sludge, paper waste, agricultural waste (rice straw, leaf litter, sawdust, banana peel, etc.) (Mtui 2009), winery solid waste (Masowa 2020), and poultry waste (Adetunji et al. 2021). Researchers observed that using fresh organic substrates results in elevated moisture contents in the mixtures; however, the addition of dry matter such as straw or sawdust can usually restore the moisture content to adequate levels (Al-Assiuty et al. 2021; Mahboub Khomami et al. 2021). Various studies carried out in African cities with different substrates are summarized in Table 19.2. In Kampala, Durban, and Windhoek, similar results were obtained using food waste and animal dung with relatively stable pH or homogenized compost. The findings have been corroborated by studies in other parts of the world (Torrijos et al. 2021; Zhang et al. 2022). Similarly, other research studies have revealed that African night crawlers (*Eudrilus eugeniae*) and tiger worms (*Eisenia fetida*) can digest large volumes of waste, including human excreta (Belmeskine et al. 2020; Watako et al. 2016), food waste and paper waste (Mupondi et al. 2018), producing vermicompost with a high nutrient content (Coulibaly 2020; Jjagwe et al. 2019; Katakula et al. 2021) relative to that produced by other worm species. In study carried out in South Africa, vermicompost addition to contaminated soil yielded a significant reduction in heavy metal concentrations in soils after 8 weeks (Mupondi et al. 2018). Based on the studies conducted by (Wang et al. 2022), bioavailability of Cu/Zn decreases during the vermicomposting process in substrate residue (Wang et al. 2022).

In Nigeria, native plants *Melissa officinalis L* (lemon balm) and *Sida acuta* (stubborn weed) used as additives in vermicomposting showed a high potential for phytoremediation and phytostabilization of contaminated mining soils in Madaka District (Ijah et al. 2021). This was brought about by the need to develop eco-friendly remediation technologies to restore contaminated soils in the country. X-ray fluorescence (XRF) analysis of the remediated soils revealed relatively low levels of elements including Cd, As, and Pb (Kodom et al. 2012). In addition, Lukashe et al. (2020) noted that uptake of Fe, Mn, Zn, and Cr in *Chloris gayana* (Rhodes grass) was significantly reduced by the addition of vermicompost. Similarly, *Vetiveria zizanioides* (vetiver grass) grown with vermicompost amendments displayed a good potential for phytostabilization in semiarid regions (Laxman et al. 2014).

Table 19.2 Vermicomposting scenario of various bio-waste in different African countries

Place, Country	Waste biomass	Time (days/ weeks)	*Earthworms*	Remarks	References
Durban, South Africa	Vegetables, local topsoil, and digested sludge	Two weeks.		The successful vermicomposting results in high organic compounds.	Gårdefors and Mahmoudi (2015)
Kampala, Uganda	Cow manure and food waste	172 days.	*Eudrilus eugeniae*	45.9% reduction in material on total solid basis	Lalander et al. (2015)
Uganda	Cow manure		*Eudrilus eugeniae*	Emission factors found for the vermicompost unit were 10.8, 62.3, and 12.8 g/ Mg bio-waste for methane, nitrous oxide, and ammonia, respectively	Komakech et al. (2016)
Namibia	Goat manure and vegetable food	12 weeks	*Eisenia fetida*	1—Significant difference ($P < 0.05$) in humification parameters across treatments. 2—An average 60% increase in phosphorus content with no significant differences ($P > 0.05$) in nitrate/nitrite concentrations.	Katakula et al. (2021)
Abidjan, Côted'Ivoire	Animal waste (chicken, cow, sheep and pig) waste	90 days	*Eudrilus eugenia Kinberg*	Chicken waste yielded the greatest number of earthworm hatchlings and biomass, followed by cow, sheep, and pig wastes, with the highest rate of cocoons hatching in pig waste.	Coulibaly et al. (2011)

(continued)

Table 19.2 (continued)

Place, Country	Waste biomass	Time (days/ weeks)	*Earthworms*	Remarks	References
Liberia	Toilet waste slurry	50 days	*Eudrilus eugeniae*	Significant digestion of human excreta	Watako et al. (2016)
Uganda	Cattle manure	12 months	*Eudrilus euginea*	–	Jjagwe et al. (2019)
South Africa	Paper waste	8 weeks	*Eisenia Fetida*	Significant reduction of heavy metals to below permissible concentration of potentially toxic elements in soils after.	Mupondi et al. (2018)
Manyatta, Kenya	Goat manure	120 days	*Eisenia Fetida*	–	Gichaba et al. (2020)
South Africa	Jatropha Curcas cake	30 days	*Eisenia Fetida*	Increased NPK content in vermicompost and vermi-wash	Manyuchi et al. (2018)
Chenoua, Algeria	Sewage sludges	21 days	*Eisenia fetida*	The vermicomposting caused a decrease of fecal coliforms number	Belmeskine et al. (2020)
Accra, Ghana	Fresh human excreta and anal cleansing materials	Four weeks	*Eisenia fetida*, *Eudrilus eugeniae.*	The study showed 12.3% and 26.2% reduction in volatile solids and 60% of mass reduction	Acquah et al. (2021)
Tanta University, Egypt	Rice straw, leaf litter, sawdust, kitchen waste, and banana peel) and cow dung.		*Eisenia fetida* and *Aporrectodea caliginosa*	The quality of vermicompost was higher in vermicomposting processed by E. fetida than in case of A. caliginosa.	Al-Assiuty et al. (2021)
Kumasi, Ghana.	Fecal sludge			Low concentration of Fe, Pb, and Al in the vermicompost. Less than 16% earthworm mortality was recorded.	Nsiah-Gyambibi et al. (2021)

(continued)

Table 19.2 (continued)

Place, Country	Waste biomass	Time (days/ weeks)	*Earthworms*	Remarks	References
Holeta, Ethiopia	Manures (cattle manure and donkey manure)	90 days		–	Mnalku and Tamiru (2020)

19.3 Management and Challenges of Vermicomposting in African Countries

Although vermicomposting is promoted as a sustainable solution to soil fertility in Africa, there remain challenges regarding the successful application of this technology. A lack of general knowledge about earthworm biology is the first challenge regarding this technology. Knowledge of earthworm biology is critical for determining the type and quality of food that earthworms require and their temperature, salinity and moisture requirements. In terms of substrate quality, most earthworms used in vermicomposting do not favor organic waste rich in proteins (e.g., meat, fish waste, and dairy products), highly acidic materials (e.g., citrus fruits and onions), and materials with high salt contents (e.g., unwashed seaweed). Earthworms are also very sensitive to pesticide residues, and exposure to pesticide-contaminated soil can lead to their death. However, most smallholders are not aware of these characteristics and often feed earthworms organic materials that are rich in protein or that are acidic or salty, resulting in collapse of the vermicomposting ecosystem.

In addition, most smallholders also find it very difficult to identify the correct earthworm species suitable for vermicomposting. Therefore, using invalidated species in compost heaps has resulted in unsuccessful vermicomposting. This also leads to the production of sub-standard compost, of little value for agricultural purposes. Appropriate conditions are also essential for effective vermicomposting. For example, Dominguez and Edwards (2011)) indicated that *Eisenia fetida* has a temperature requirement of 25 °C, with a tolerance of between 0 °C and 35 °C, while *Dendrobaena veneta* has a rather low-temperature optimum and is less tolerant to extreme temperatures. The optimal temperature for *E. eugeniae* and *P. excavatus* is around 25 °C, and these earthworms die at temperatures below 9 °C. Such information is crucial in vermicompost ecosystem management, and most farmers have a limited understanding of this requirement.

The earthworm species mainly utilized in the vermicomposting process are epigeic earthworms, including *Eisenia fetida*, *Eisenia andrei*, *Eudrilus eugeniae,* and *Perionyx excavatus*. These earthworms can survive by feeding on fresh dead organic material (Gómez-Brandón et al. 2012; Mupambwa et al. 2020). However, anecic and endogeic species that live in soil or deep underground in burrows are prone to being affected by predators, such as birds, rats, ants, centipedes, ants and chickens, or by parasites, such as carabid beetles (Dominguez and Edwards 2011).

Control of these predators is challenging for many smallholders, who typically install vermireactors in open spaces in mixed farming systems where predators like birds and rats eat the earthworms. This is even a challenge in closed container vermi-bins where predators like rats may find their way into the compost.

Within the small-scale farming sector, many farmers practice windrow composting with earthworms; however, as this is done on the ground, there is a loss of vermi-leachate. The leachate contains high levels of nutrients as well as elevated levels of plant growth hormones, and it is very valuable as a liquid fertilizer. Our resource-poor farmers must understand the critical dynamics in effective vermicomposting, which can be a key driver in the adoption of this technology in preference to traditional composting.

19.4 Conclusion

Population growth and industrial expansion may lead to food shortages in Africa, and sustainable food production is therefore vital. Mind-set shifts are required in order to promote sustainable development, which can be done through educational programs. Awareness-raising programs must be directed at professionals, companies, and stakeholders, encouraging them to reduce waste and develop plans to convert different types of waste into valuable products. Vermicomposting technology is a promising approach to achieving sustainable agricultural goals. One of the main reasons for the great potential of vermicomposting is that it is an innovative biotechnology that does not call for expensive laboratories or sophisticated industrial equipment. Moreover, vermicomposting is an environmentally friendly process that meets sustainability goal 7 of the UN Millennium Development Goals (MDG7) and is consistent with the ecological sanitation concept. The simple methodology, together with the low investment required, makes vermicomposting applications possible in low-income areas, mainly tropical countries.

One of the key factors contributing to efficient vermicomposting strategies is the level of satisfaction expressed by communities. There is therefore an excellent opportunity to initiate specific initiatives involving people, private companies, and governments in order to develop solutions for sustainable waste management. Public-private partnerships (PPPs) seem to be the solution to tackling waste management issues (particularly in developing and underdeveloped countries). Other major constraints to efficient, sustainable waste management are the lack of up-to-date information and resources for planning waste treatment infrastructure and the lack of leadership to make projections and estimations for future generations. It is apparent from the existing policy-making strategies in Africa that there is still a large gap between policy-making and implementation. Hence, all stakeholders must adhere to solid regulations to ensure the establishment of efficient waste management systems.

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