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VERMICULTURE AND VERMICOMPOSTING: TWIN EARTHWORM TECHNOLOGIES, SUITABLE FOR HOUSEHOLDS AND SMALLHOLDER FARMERS

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ABSTRACT
Many smallholder farmers in developing countries face interconnected challenges, including poor soil fertilisation, low agricultural output, and inefficient conversion of agricultural wastes into biofertilisers, all of which can be sustainably addressed through vermiculture and vermicomposting—twin earthworm-based technologies. This review aims to explore vermiculture and vermicomposting, their interconnections, and key optimisation factors, while also guiding smallholder farmers on setting up simple vermiculture and vermicomposting units using locally sourced materials. A wide literature search was conducted across databases such as Google Scholar, Scopus, and Web of Science, focusing on vermiculture, vermicomposting and earthworm utilisation in waste management. From an initial pool of articles, 35 studies were selected for their relevance, empirical data, and rigorous methodology. Findings show that earthworms' natural behaviours, such as burrowing, soil ingestion, excretion and rapid reproduction, are exploited by vermiculture and vermicomposting to produce both earthworm mass and vermicompost, a sustainable and efficient biofertilizer. Vermiculture focuses on maximising earthworm harvest, with vermicompost as a secondary product, while vermicomposting aims to maximise vermicompost production, often resulting in increased earthworm mass. Vermicomposting units can be constructed from locally available materials, including wood, organic and agricultural wastes, and earthworm food sources, like fermented cow and sheep dung. The review assesses the potential of these technologies for small-scale farms, emphasising their feasibility and benefits in resource-limited settings. Since low agricultural output by smallholder farmers is partly traceable to unaffordable costs of chemical fertilisers, this review will draw attention to the use of vermicompost as a cheap and sustainable alternative.

Keywords: Epigeic earthworms, Biofertiliser, Burrowing, Vermitechnology, Vermireactor

INTRODUCTION
In spite of efforts aimed at achieving food security globally, cases of hunger and undernourishment still abound, especially in developing countries. The Food and Agriculture Organisation of the United Nations (FAO) reports that an estimated global average of 735 million people faced hunger in 2022, a figure far higher than that of 2019. A much larger proportion of this figure was reportedly in African countries (FAO, 2023). Many smallholder farmers in developing countries are confronted with the interrelated problems of poor soil fertilisation, low agricultural output, and poor waste conversion. Poor soil fertilisation and low agricultural output result partly from the increasing and unaffordable costs of chemical fertilisers and livestock feeds (Ramnarain *et al*., 2019; FAO, 2022). Inadequate conversion of agricultural waste to organic fertilisers is traceable to insufficient access to information on available bioconversion options (Dada and Balogun, 2023).

According to FAO, in some African countries, the cost of chemical fertilisers more than doubled after the COVID-19 pandemic, and such a rate of increase makes chemical fertilisers even more inaccessible and unaffordable to smallholder farmers, who are more vulnerable (FAO, 2022). Since smallholder farmers account for a substantially higher percentage of national food production in African and developing nations (FAO, 2022), information on available alternatives to chemical fertilisers will go a long way in increasing food output in those places. Vermicompost is an organic fertiliser that results from the biodegradation and biostabilisation of organic matter, through the joint actions of earthworms and microorganisms. Vermicompost is rich in Nitrogen, Phosphorus Potassium (NPK), and micronutrients necessary for plant growth. It is useable as an affordable and sustainable alternative to chemical fertilisers, to improve crop productivity (Ramnarain *et al*., 2019).

This review aims to describe vermiculture and vermicomposting, their relationship and the factors necessary for their optimisation. The review also seeks to explain how households and smallholder farmers could set up simple vermiculture and vermicomposting units. The review is expected to draw attention to the opportunity presented by vermicompost for use as a cheap and sustainable alternative to chemical fertilisers, for smallholder farmers.

METHODOLOGY
This review was conducted by searching academic publications across databases such as Google Scholar, PubMed, Scopus, Web of Science, and specialised journals. The search terms employed included "vermicomposting," "earthworms in waste management," "vermitechnology," "vermicomposting of organic waste," "earthworm species identification," and "effects of vermicompost on plant growth." Publications were selected based on their relevance

to vermiculture practices and environmental impacts. The initial search yielded numerous peer-reviewed articles, of which 35 were selected after thoroughly screening their content. Inclusion criteria required relevance to the study, empirical data and clear methodologies, while studies with inconsistencies, unsubstantiated claims, or inadequate data were excluded. The study explores and describes current knowledge on vermicomposting and vermiculture, providing insights into their applications in environmental remediation and sustainable agriculture, particularly for households and smallholder farmers.

DISCUSSION

Earthworms, distribution and ecological classification

Earthworms are metamerically segmented soil invertebrates, with long, narrow, and generally cylindrical soft bodies. They are nocturnal and light sensitive, but some species may be seen in the day roaming about, especially after a heavy rain. Tropical earthworms tend to be generally bigger and more robust (Sinha *et al*., 2010; Munnoli *et al*., 2010). Earthworms harbour millions of nitrogen-fixing and decomposer microorganisms in their gut. They secrete enzymes such as proteases, lipases, amylases, cellulases, and chitinases in their gizzard and intestine, which bring about a rapid biochemical conversion of organic matter. Earthworm casts have higher numbers of microorganisms than the surrounding soil. Casts are usually rich in ammonia and partially digested organic matter (Dada *et al*., 2021). Through their feeding and burrowing habits, earthworms act as aerators, grinders, crushers, chemical degraders, and biological stimulators, wherever they inhabit (Sinha *et al*., 2010; Dada, 2015). These physiological characteristics and habits of earthworms are explored and utilised in vermiculture and vermicomposting.

The distribution of earthworms in soils depends on factors like moisture, availability of organic matter, and pH of the soil. They occur in diverse habitats especially those rich in organic matter. Earthworms are generally absent or rare in soil with a very coarse texture and high clay content or soil with a pH of less than 4. They are very sensitive to light, touch, and dryness. They carry out gaseous exchange through their moist skin. Earthworms are bisexual but reproduction is generally by cross-fertilization, except in a very few species which can also produce cocoons parthenogenetically (Barik *et al*., 2011, Dada, 2015).

Several classifications have been developed for earthworms. Taxonomically, earthworms belong to the Phylum: Annelida, Class: Clitellata, and Order: Oligochaeta. There are several families of earthworms, but the 5 major ones are Lumbricidae, Moniligastridae, Megascolecidae, Eudrilidae, and Glossoscolecidae. There are between 1,800 and 4,200 species, grouped under the phylum, and of course, many genera (Munnoli *et al*., 2010; Ansari and Saywack, 2011). Taxonomic classification of earthworms is beyond the scope of this review and is better handled by earthworm taxonomists. However, earthworms can be ecologically classified into three, and these can be distinguished by colour, pigmentation, and size. They are (1) Epigeics (2) Endogeics (3) Anecics. Epigeics are earthworms that live just beneath the soil surface and feed on surface litter with little ingestion of soil. Endogeics are earthworms that inhabit the top soil mineral layers, feeding on soil rich in organic matter. Anecics are worms that burrow deep into the soil but feed on dead leaves and plant matter which they drag into their burrows, with little ingestion of soil (USDA, 2001; Gajalakshmi and Abbasi, 2004). The distinguishing characteristics of different ecological groups of earthworms are depicted in Table 1.

Table 1: Ecological groups of earthworms and their characteristics

CHARACTERISTICS	ECOLOGICAL GROUPS OF EARTHWORM		
	Epigeics	Endogeics	Anecics
Habitat	Above mineral soil surface	Mineral topsoil layers	Deep soil
Feeding	Surface litter, little ingestion of soil	Soil rich in organic matter	Dead leaves, plant matters, little soil ingestion.
Burrowing	Shallow and horizontal	Moderate, horizontal, branching	Deep, vertical
Body size	Small to moderate	Moderate to large	Moderate to large
Pigmentation	Uniformly pigmented	No pigmentation	Dorsal and anterior pigmentations
Sensitivity to light	Low	Strong	Moderate
Longitudinal contraction	Nil	Least developed	Developed
Skin moistening	Developed	Low	Moderate
Mobility	Rapid	Feeble	Moderate
Fecundity	High	Limited	Moderate
Maturation	Rapid	Slow	Moderate

Sources: modified from USDA (2001), Gajalakshmi and Abbasi (2004) and Dada (2015)

Vermiculture and vermicomposting

Vermiculture and vermicomposting are twin technologies whose products are vermicompost and earthworms. Vermiculture is the culture, breeding, or rearing of earthworms in large numbers for research, livestock, or commercial purposes. The goal of vermiculture is to increase the number or density of worms continually, to optimise sustainable harvests (Munroe, 2012; Dada and Balogun, 2023). Vermiculture is carried out in an organised sequential order. The appropriate starter earthworms (seed stock) are first obtained and put in a vermireactor (culture box or compartment). Optimum food, moisture, air and temperature must be provided to guarantee a good harvest (Munroe, 2012; Dada and Balogun, 2023).

Vermicomposting is the process of biodegradation of organic matter or wastes through the complementary interactions between earthworms and microorganisms, to yield a humus-like product, vermicompost (Dada and Balogun, 2023). Although microorganisms are primarily responsible for the biochemical degradation, earthworms play important complementary roles in the process, by continuously burrowing through the substrate, ingesting and grinding the substrate in their enzyme-rich alimentary canal, and egesting same as a humus-like product. The activities of the earthworms help in optimising biochemical degradation by aerating and fragmenting the organic substrate, and increasing the surface area for enzymatic and microbial activities (Munnoli *et al*., 2010; Dada *et al*., 2021). The goal of vermicomposting is to process the organic material as quickly and efficiently as possible. However, the process of vermicomposting is usually accompanied by the breeding of earthworms.

Hence, vermiculture and vermicomposting are related and overlapping processes, aimed at achieving different primary goals or products. An overview of the relationship and products of vermiculture and vermicomposting is shown in Figure 1.

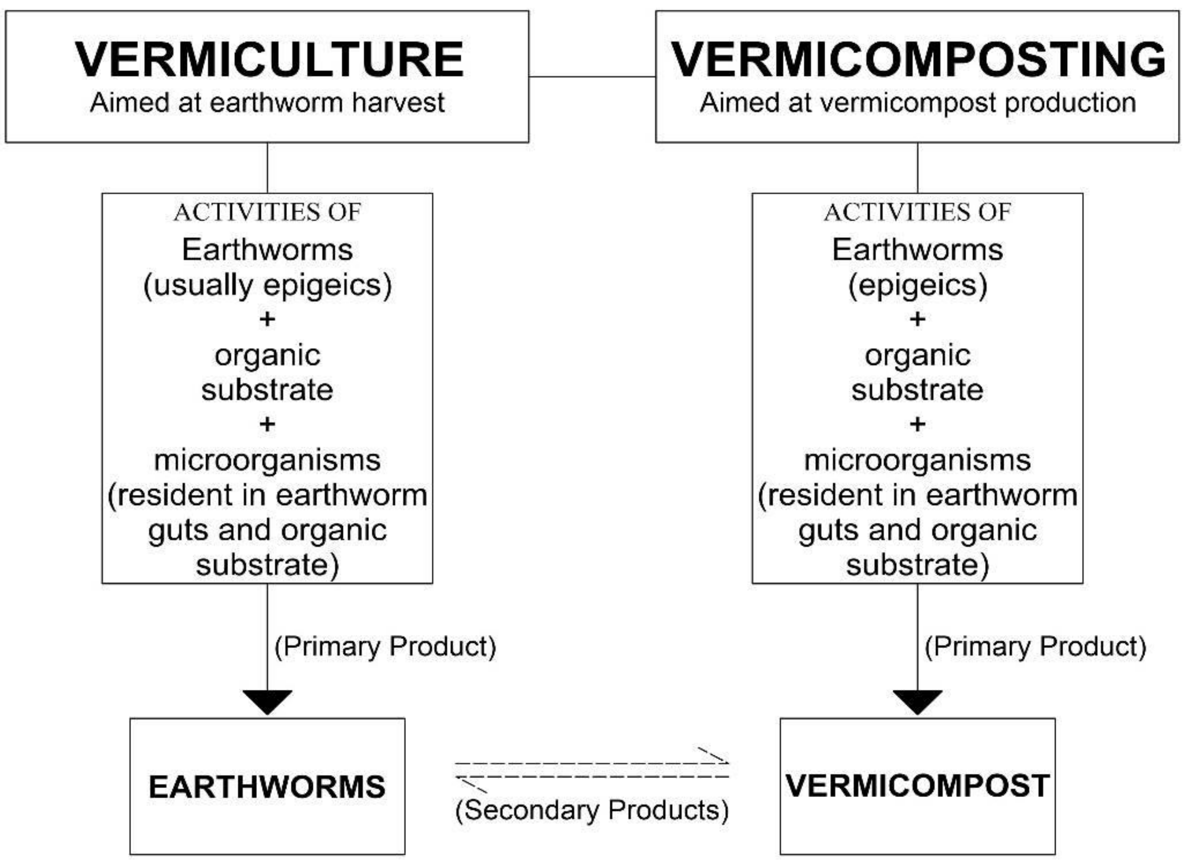

Figure 1: An overview of vermiculture and vermicomposting

Setting up vermiculture and vermicomposting units

To set up a vermiculture or vermicomposting unit, there are three basic requirements, (1) Vermireactor, (2) Bedding materials and organic matter to serve as a food source or composting substrate, (3) Starter earthworms.

Vermireactor

'Vermireactor' is a vermitechnology (earthworm technology) word that describes a compartment where earthworm activities and processes, like breeding and composting, take place. A vermireactor is a biological reactor or unit, where earthworms' activities take place (Manyuchi *et al*., 2013). A vermireactor could be made of wood, plastic, or earthenware (Dada *et al*., 2017). The size of the vermireactor will depend on the size or magnitude of the vermiculture or vermicomposting project. The vermireactor should be constructed in a way that will provide an enabling environment for optimal earthworm and microbial activities, and by extension, optimum earthworm and vermicompost output. The vermireactor should allow for just enough water retention and drainage of excess, optimum temperature and other physical factors that will guarantee increased and sustainable earthworm and vermicompost harvest. Although vermireactors can come in varied designs and shapes, they need not be unnecessarily complex to function as good vermiculture and vermicomposting units.

Different vermireactor designs have been described by several authors, including Chaoui (2010), Manyuchi et al. (2013), Mungruaiklang and Iwai (2021), and Hu et al. (2021). The vermireactor design described below is a modification of these previously described designs, tailored to suit simple households and smallholder farmers. A simple household or smallholder farmer's vermireactor can be a box made of wood, plastic, or earthenware, depending on convenience and availability. The box should have a partition or layer with numerous perforations or holes. This partition divides the box into two chambers: an upper, larger chamber and a lower, smaller one. Beddings, organic composting substrates and earthworm food, like cow dung are laid in the upper chamber. Excess water or vermiwash can drain through the perforated middle layer into the lower chamber, before exiting through the hose, fitted to the bottom hole of the box (Figure 2). The box should bear a top lid or cover, also with numerous perforations, to allow for air ventilation in the upper chamber. However, the box may not be fitted with a lid or cover but left open. In this case, the top should be screened with a fine mesh net, to ward off intruders like predators and ants, and prevent earthworm escape. Importantly, when constructing and designing a vermireactor, there should be two major issues of concern, (1) adequate ventilation, and (2) earthworm safety, in terms of being free from intrusion. In addition to perforations and openings, optimum ventilation is ensured by not filling the composting chamber (upper chamber) beyond ¾ level, during vermicomposting. The sidewalls of the lower chamber should also be perforated, for ventilation. The top lid cover (if present) can be opened to harvest worms and vermicompost at intervals, or when composting is completed. The box may be fitted with roller tyres, to keep it raised from the floor, collect vermiwash, and move it around, if desired. The vermiwash, when collected from the drain hose, is useable as a liquid biofertiliser, for foliar application.

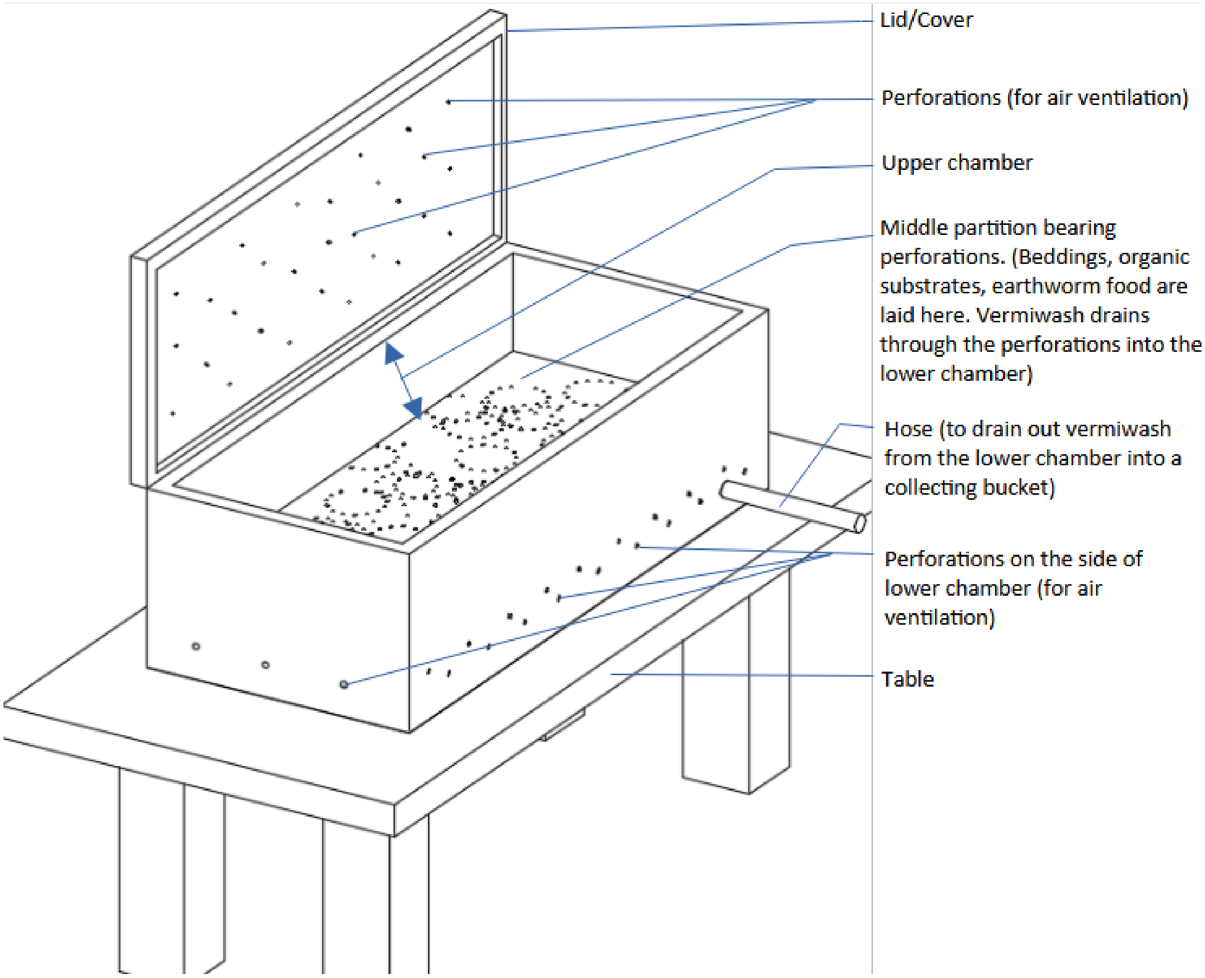

Figure 2: Diagrammatic representation of a simple vermireactor

Bedding materials and organic matter to serve as a food source or composting substrate

After constructing the vermireactor unit as described above, the next step is inputting the bedding materials into it. A good bedding material is one that is able to retain moisture, provide a cushioning effect, and serve as a food source. A typical good bedding is cow or sheep dung mixed with one or more of the following: dry plant leaves, straws, hay, fruit peels, grasses, sawdust, and wood shavings. It is important to add water to the mixture and allow it to precompost for some days (7-14 days) to remove any harmful gases and heat of fermentation, which may kill off the worms or slow down their activities (Munroe, 2012; Dada *et al*., 2016; Katakula *et al*., 2021). Where and when available, wetted cardboard paper without ink or dyes, makes good bedding (Munroe, 2012). The bedding should be rich enough to serve as a starter food source for the breeding or composting of earthworms. If it is a vermiculture project, a fermented or pre-composted mixture of cow dung and agricultural wastes like dry leaves, peels of spinach, Irish potato, sweet potato, pumpkin, and pineapple will be a good food to administer to the earthworms regularly. These can be mixed in a ratio of 1:4 (cow dung: agricultural wastes) (Alshehrei and Ameen, 2021).

For a vermicomposting project, the composting substrate should be fed to the earthworms as required. Suitable kitchen wastes that can be fed to earthworms in home composting include fruits, vegetables, grains, bread, unbleached paper napkins, and coffee filters. Kitchen wastes containing substantial levels of salt, pepper, oil, acids, and onions should be avoided. Meat products, high-fat foods, milk and other dairy products may attract pests, promote excessive fungi growth, and present odour problems; hence they should be avoided, as much as possible (Vasanthi *et al*., 2018). The quantity of food consumed by earthworms varies from 100 to 300 mg/g body weight/day (Kunwar *et al*., 2022). Foods can be spread over the bedding, starting with a small quantity, and increasing it gradually with time. The initial earthworm stocking density may be in the range of 5 g earthworms per kg of composting substrate (Alshehrei and Ameen, 2021).

Starter earthworms

As described above, earthworms are broadly divided into three ecological groups: (1) Anecics, (2) Endogeics, and (3) Epigeics. Epigeic earthworms are the ones we are more familiar with, as they are usually seen crawling around after a rain, or in a wet and cool environment. They tend not to make burrows, but live in the surface litter, feeding on decaying dead organic matter. Of these ecological groups of earthworms, epigiecs are best suited for vermiculture and vermicomposting because of their surface activity, ability to colonise substrate within a short time, and the fast rate of conversion (Suthar, 2007; Munroe, 2012).

Although there are many species of epigeic earthworms, the European species, *Eisenia fetida*, is typically used for vercomposting in the temperate countries. This is obviously due to their high prolificacy, resilience, and ready availability in commercial worm growers' farms and vermiculture shops (Alshehrei and Ameen, 2021). Nevertheless, in tropical countries where *E. fetida* are not available, many more composting earthworm species are available, like *Eudrilus eugeniae* (Hussain *et al*., 2018). Since earthworms are globally distributed, native epigeic species can be randomly sampled, and subjected to a pilot culture or composting study, to determine which one is more suited for vermiculture and vermicomposting.

Harvesting earthworms and vermicompost

To keep vermiculture and vermicomposting units at an optimum level of performance, it is important to harvest the worms and vermicompost as and when due. This will keep the system from becoming unnecessarily congested. Composting worms are efficient digesters of organic matter; hence, vermicompost can be harvested after 3-4 months of composting (Katakula *et al*., 2021). The duration may be longer, depending on some factors as enumerated in the following sections.

Factors influencing earthworm abundance, vermiculture, and vermicomposting

Some factors may affect the success of vermiculture, and vermicomposting; these include substrate type, pH, moisture, and temperature. Each of these factors does not affect earthworms in isolation, but by interacting with other processes and factors.

Composting substrate type and organic matter

The type of substrate and the amount of organic matter available in the substrate influence the rates of growth and fecundity of earthworms (Munnoli *et al*., 2010). It is therefore important to ensure the right mix of substrate as explained above.

pH

Earthworms are very sensitive to pH. From available literature, pH tolerance is to some extent, species-dependent. Munnoli *et al*. (2010) reported that several researchers have indicated that most earthworm species prefer a pH of about 7.0. According to Mason *et al*. (2009), adjusting the substrate's pH to between 6.5 and 6.8 is optimum for vermicomposting.

Temperature

Temperature affects the activities, reproduction, fecundity, and growth of earthworms (Munnoli *et al*., 2010). A temperature range of 18 to 25°C is considered optimal for temperate worms, while the optimal temperature range for tropical earthworms is 25 to 30°C (Barik *et al*., 2011).

Moisture

Substrate moisture content is generally considered a major factor that influences the growth and abundance of earthworms. According to Barik *et al*. (2011), the body of earthworms contains 75 % to 90 % water. Earthworms have mechanisms to replace and conserve water, mostly through the body wall. When the substrate water level is too low, earthworms lose water from their bodies. However, excessively low body water level negatively affects their efficiencies and internal biological processes. Earthworms prefer moist but not saturated conditions. Prolonged water saturation can lead to mortality (Mason *et al*., 2009).

Container or pot-type

Vermiculture and vermicomposting can be done in containers made of different materials, depending on availability and ease of access. Culture containers or pots can be plastic (Munnoli and Bhosle, 2009), wooden (Sogbesan *et al*., 2007), earthen (Ibrahim *et al*., 2010), or concrete (Mason *et al*., 2009). When available, an earthenware container is especially recommended in the tropics, as it tends to provide a constant, cool and localized moisturisation for the earthworms (Ibrahim *et al*. 2010; Kamaldeen *et al*., 2013). However, irrespective of any materials used, the vermicomposting unit should have provisions for the parts described in vermireactors above.

Some successful vermicomposting projects

Many vermicomposting researches and projects have been successfully executed in different places, and at different times, with good results. These speak to the effectiveness, desirability and practicability of vermicomposting for the production of organic fertilisers.

Rogayan *et al*. (2010) was an undergraduate group project carried out in the Phillipines. The project lasted three months. The study found that vermicomposting produced high-quality fertilisers, which are better than the commercial fertilisers sold in open markets. Wang *et al*. (2017) made vermicompost from semi-decomposed cow manure, which they used to grow tomatoes. The vermicompost not only improved soil quality, but also effectively promoted tomato growth and better fruit quality and yield, relative to the conventional fertiliser and chicken manure compost. In the same vein, Rekha *et al*. (2018) vermicomposted cow dung, straw, leaf litter and farm residues for 45 days. Thereafter, they grew crops in soil treated with vermicompost for 5 weeks. Results showed that 50% vermicompost applications significantly improved all the measured growth parameters. In the work of Crutchik *et al*. (2020), vermicompost obtained using digestate from existing vermibeds, vegetable and fruit wastes, including lettuce, tomato, corn stover, chard, lemon and bell pepper significantly promoted seed germination. Details of these and some other vermicomposting works with positive results are summarised in Table 2.

Table 2: Some successful vermicomposting project

Project location	**Materials vermicomposted**	**Duration**	**Findings\ conclusion**	**Reference**
Phillipines	Carabao manure, partially decomposed rice straw and rice hull and shredded moist newspapers.	Three months	Vermicomposting produced high-quality fertilisers, better than conventional chemical fertlisers	Rogayan *et al*. (2010).
Suriname	Cow manure, rice straw and grass clippings.	120 days	Harvested vermicompost had excellent nutrient status and contained all the essential macro- and micronutrients.	Ramnarain *et al*., (2019).
Chile	Digestate from existing vermibeds, vegetable and fruits waste, including lettuce, tomato, corn stover, chard, lemon and bell pepper wastes.	130 days	Final vermicompost was of good quality. Seed germination rate was high in vermicompost.	Crutchik *et al*., (2020).
China	Semi decomposed cow manure.	One full growing period.	Vermicompost improved soil quality. It effectively promoted tomato growth and better fruit quality and yield, relative to conventional fertiliser with urea and chicken manure compost.	Wang *et al*., (2017).
Saudi Arabia	Sugarcane straw, remnants of garden tree leaves, kitchen wastes and cow manure	60 days	Higher N, C and P content in the vermicompost than in the garden soil sample	Bin Dohaish, (2020)
India	Cow dung, straw, leaf litter and farm residue.	Vermicomposting done in 45 days; crop treated with vermicompost for 5 weeks.	50% vermicompost applications significantly improved all the measured growth parameters.	Rekha *et al*., (2018)
India	Cattle dung, plant debris, shredded paper.	Pre-composting: 10 days; Composting: 60 days.	High levels of total nitrogen (0.79%), phosphorus (2.50%) and potassium (1.40%)	Manohar *et al*., (2016)

CONCLUSION

Vermiculture and vermicomposting are twin technologies, which exploit earthworms' natural habits of burrowing, ingesting, excretion, and association with diverse microorganism populations to harvest increased earthworm mass and vermicompost. The earthworms so harvested can be used for fishing baits, animal feed, supplementing natural field density, or sold to make extra income. Vermicompost, being an organic manure, can similarly be used on farms and in gardens to enhance plant growth and increase crop yields. Better still, it can be sold to generate additional profit. Vermiculture and vermicomposting units can be easily set up at home, utilising kitchen and agricultural wastes as composting substrates. Hence, vermiculture and vermicomposting present a reasonable opportunity for households and smallholder farmers to convert waste into wealth.

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