Vermicomposting: A Solution to Noxious Emissions in the South Asian Subcontinent

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Abstract— *One of the most significant threats to the environment is posed by the ever-increasing generation of waste. This has resulted in an urgent need for global waste management techniques that integrate the ideas of recycling and reusing of the essential components of waste. The current technologies of waste management including incineration, landfills, and material recovery have not proven as useful as intended. These mostly outdated methods have resulted in generation of toxic fumes, health hazards, and high energy and operation costs. Thus, a unique, safe, hygienic, and sustainable method of waste management is essential.*

Vermicomposting is a low-cost, eco-biotechnological process of waste treatment in which earthworms are used to biodegrade the organic waste into useful nutrient-rich vermicast. The products of this waste treatment process are disinfected, detoxified and nutrient-rich bio-organic fertilizers. The process not only recycles organic wastes, but also helps improve soil structure and contents. This review provides an insight into the design, operation, commercialization, and factors affecting the vermicompost reactors.

Keywords— Biofertilizers, crop-burning, Emissions, Rice husk, Vermicomposting.

I. INTRODUCTION

According to the UN World Population Prospects, it is predicted that the world population will reach 9.74 billion by 2050. (United Nations, 2019) The ever-increasing human population has resulted in a significant increase in global waste generation and pollution. Approximately 1300 million tons (MT) of solid waste is generated annually in the major cities of the world, an amount projected to rise to 2200 MT by 2025. (Hoornweg & Bhada-Tata, 2012) Solid waste generation is positively related to the level of income and urbanization. On an average, developing countries including India, Pakistan, and Bangladesh, generate over 0.70 kg of solid waste per individual per day. (Troschinetz et al, 2009) It is estimated that 1.8 MT of solid waste per day will be generated in Asia alone by 2025. (Dasgupta, 2014; Yoshizawa et al., 2004) Table 1 compares the waste generation in Asia during the year 1995 and 2025 (projected values) (Hoornweg, 1999).

Waste disposal is a pressing issue, as the existence of widely spread waste imperils the environment in general and soil health in particular. The rapid development of human society creates imbalances in nature through rapid urbanization, industrialization, and infrastructure development, all of which cause deterioration of soil health. As the overall environmental milieu is polluted, humans are also affected.

When disposing waste, system complexities and the integrated nature of materials and pollution are quickly apparent. For example, waste incineration is expensive and poses challenges of air pollution and ash disposal. Incineration requires waste placed outside for collection to be containerized to stay dry, and much of the waste stream is not combustible. Landfills require land availability, and siting is often opposed by potential neighboring residents. Solving one problem often introduces a new one, and if not well executed, the new problem is often of greater cost and complexity. Most approaches to waste disposal lead to soil deterioration, toxic effects, and increased pollution of the land, air, and water and have an adverse impact on living beings in addition to the expense involved. To address this issue, we need an eco-friendly, one-step solution for managing wastes that also provides a beneficial end-product.

TABLE 1
1995 AND 2025 MUNICIPAL SOLID WASTE GENERATION IN ASIA[4]

	GNP per Capita (USS)		Urban Population (% of Total)		MSW generation (kg day^{-1} per capita)	
Country	1995	2025	1995	2025	1995	2025
Low Income	490	1050	27.8	48.8	0.64	0.6-1.0
Nepal	200	360	13.7	34.3	0.5	0.6
Bangladesh	240	440	18.3	34.3	0.49	0.6
Myanmar	240	580	26.2	47.3	0.45	0.6
Vietnam	240	580	20.8	39	0.55	0.7
Mongolia	310	560	60.9	76.5	0.6	0.9
India	340	620	26.8	45.2	0.46	0.7
Laos	350	850	21.7	44.5	0.69	0.8
China	620	1500	30.3	54.5	0.79	0.9
Sri Lanka	700	1300	22.4	42.6	0.89	1
Middle Income	1410	3390	37.6	61.1	0.73	0/8-1.5
Indonesia	980	2400	35.4	60.7	0.76	1
Philippines	1050	2500	54.2	74.3	0.52	0.8
Thailand	2740	6650	20	39.1	1.1	1.5
Malaysia	3890	9400	53.7	72.7	0.81	1.4
High income	30990	41140	79.5	88.2	1.64	1.1-4.5
Republic of Korea	9700	17600	81.3	93.7	1.59	1.4
Hong Kong	22990	31000	95	97.3	5.07	4.5
Singapore	26730	36000	100	100	1.1	1.1
Japan	39640	53500	77.6	84.9	1.47	1.3

Widely regarded safe and sustainable strategies to treat organic wastes include best-known practices of composting and vermicomposting for biological stabilization of solid organic wastes by transforming them into a safer and more stabilized material that can be used as a source of nutrients and soil conditioner in agricultural applications (Lazcano et al, 2008; Bernal et al, 2009). Vermicomposting is one of the most efficient means to mitigate and manage environmental pollution problems. It is the process in which earthworms are used to convert organic materials (usually wastes) into a humus-like material known as vermicompost. The goal is to process the material as quickly and efficiently as possible.

II. VERMICOMPOSTING: BASIC PROCESS

Vermicomposting is defined as a bio-oxidative process in which earthworms interact with microorganisms and other fauna within the decomposer community, accelerating the stabilization of organic matter and greatly modifying its physical and biochemical properties. (Gomez-Brandon et al, 2014) Vermicomposting is a bio-conversion process whereby organic waste is turned into vermicasts by the action of epigeic earthworms (Jadia et al 2008). The earthworms eat up the organic waste (feed) and expel it as vermicasts (product), which are dark brown solid particles in nature (M. M. Manyuchi, 2012). These vermicasts are rich in the primary nutrients of a fertilizer i.e. nitrogen (N), phosphorous (P) and potassium (K) (Jadia et al 2008; M. M. Manyuchi et al. 2012; A. A. Ansari et al. 2010). Furthermore, a leachate called vermiwash is produced alongside the vermicasts and is also rich in NPK (M. Gopal et al. 2010; V. Palanichamy et al. 2011; C. Sundaravadivelan et al. 2011; G. Nath et al. 2012).

Vermicomposting has a unique position in environmental and chemical engineering as it is the only pollution control process that uses multicellular animal as a bioagent. (Abbasi et al 2009) It is a process of stabilization of organic material through the joint action of earthworms and micro-organisms. Microbes are responsible for the biochemical degradation of organic matter, while earthworms are important drivers to condition the substrate and alter the biological activity. (Suthar 2009) This joint action of earthworms and microbes results in a higher-quality end product compared to conventional composting process.

Vermicomposting is carried out in different vermireactors such as the windrows, bins, and flow-through systems (G. Munroe, Year unknown). Vermireactors are biological reactors where earthworms' activities take place. Windrows and bins are batch vermireactors whereby the earthworms, bedding and feed are put initially and the vermicomposting process is allowed to take place until all the vermicasts are obtained at a given retention time (G. Munroe, Year unknown).

III. ROLE OF EARTHWORM IN VERMICOMPOSTING

Earthworms are invertebrates belonging to the phylum Annelida, class Oligochaeta and family Lumbricidae. The earthworms are long, elongated, cylindrical, soft bodied animals with uniform ring like structures consisting of segments along the length of their body outwardly highlighted by circular grooves. There are about 3320 species of earthworms all over the world (Bhatnagar et al 1996), but hardly 8–10 species are suitable for vermicompost preparation. Earthworms have been extensively utilized for the recycling of a variety of organic wastes like municipal solid wastes (Ciavatta et al 1993) wheat straw, sewage sludge, forestry waste, vegetable waste (Vallini et al. 1989), farmyard manure etc. Epigeic (Greek word "upon the earth") worms live on the surface litter and feed on decaying organic matter. They do not have any permanent burrows and are the type of worm widely used in vermicomposting.

Earthworms act as grinder, crusher, chemical degrader, and a biological stimulator of waste material. (Binet et al 1998) Earthworm hosts millions of biodegrading microbes, hydrolytic enzymes and hormones that help in rapid decomposition of complex organic matter into vermicompost in a relatively smaller duration of time. The mechanism of formation of vermicompost by earthworms occurs in following steps; organic material consumed by earthworm is softened by the saliva in the mouth of the earthworms. Food in esophagus is further softened and neutralized by calcium resulting in particles of size less than < 2µm, thereby giving an enhanced surface area for microbial processing. This finally ground material is exposed to various enzymes such as protease, amylase, lipase, cellulase and chitinase secreted in lumen by stomach and small intestine (Dominguez et al 2010). Moreover, microbes associated with intestine facilitate breaking down of complex biomolecules into simple compounds. Only 5–10% of the ingested material is absorbed into the tissues of worms for its growth and the rest is excreted as vermicast. The vermicast is a good organic fertilizer and soil conditioner. High-quality vermicast can be produced by worms such as the red wrigglers (E. fetida) as it contains humus with high levels of nutrients that has good potential to produce organic fertilizer. Figure 1 gives a detailed breakdown of the role of each part of an earthworm in the vermicompost production process. (Lemtiri et al. (2014).

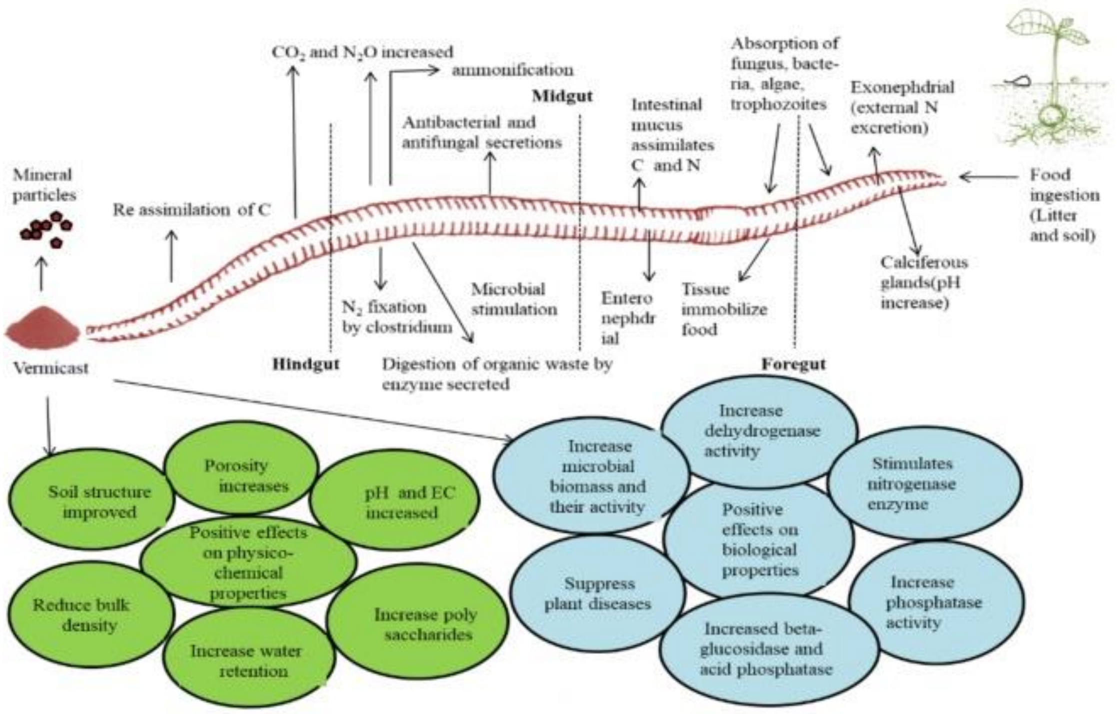


FIGURE 1: Process of vermicomposting in an earthworm and its consequences (Lemtiri et al. (2014)

IV. REACTOR DESIGN

The vermicomposting process is designed to ensure optimum processing of the organic waste. The organic waste is first shredded to reduce the particle size. The organic waste is then pre-composted for a short period of time usually a week while the pH and moisture content in the feed is monitored. Earthworms function well in a pH range of 5.0-9.0, temperatures below 45°C and moisture content of 45-75% (M. M. Manyuchi, 2012). Pre-composting facilitates in making available the other organisms that can aid the vermicompost process and by reducing the organic waste surface area the earthworms will act on. The feed is then introduced into a flow-through vermireactor whereby the vermicomposting process is initiated by adding the earthworms. pH, temperature, and moisture content are continually monitored whilst the vermicasts and vermiwash produced are collected at the bottom of the vermireactor for storage. Figure 2 shows a process flow diagram for a simple flow-through vermicompost production.

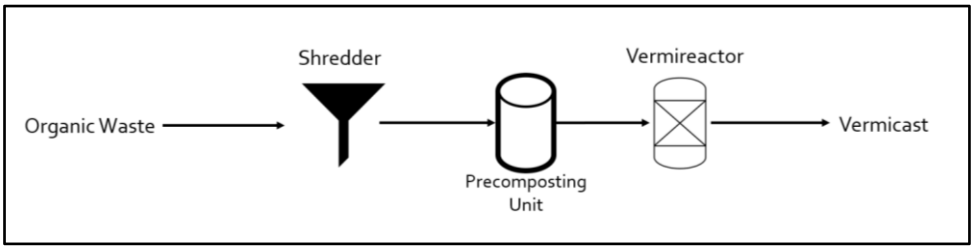


FIGURE 2: Process flow diagram showing each component of vermicomposting.

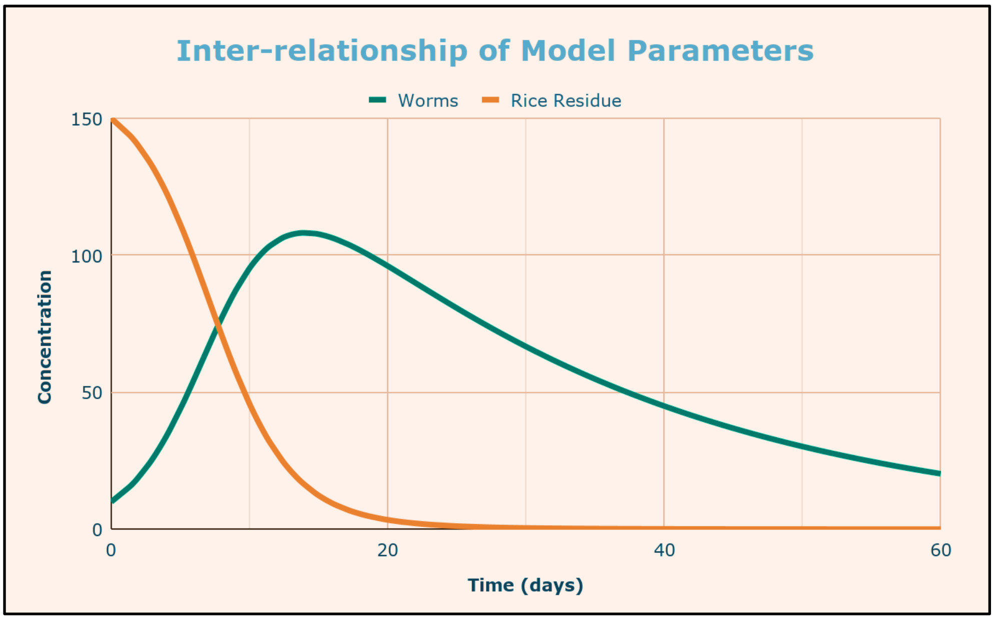
The vermicomposting process has certain parameters that need to be considered in deriving a simple kinetic model. The vermireactor can be seen as a system consisting of two main parameters which are Earthworms and organic wastes (for purpose of this example we will be considering rice residue as the organic wastes). Using these parameters, a model can be proposed for their inter-relationship.

Once the two components of the reaction are mixed, the earthworms will use the rice residue to metabolize and increase in population, shown in Equation 1. After a certain time, when there is no more rice residue to be bio-degraded, there will be an unavailability of sufficient nutrients in the system and the earthworms will eventually die off, as shown in Equation 2.

Worms + Rice Residue → 2 Worms

Worms → Death of Worms

To further analyze the inter-relationship of the parameters present in the system, a graph can be generated to visually see the relationship. As shown in the graph below, as the Rice Residue concentrations decrease exponentially, the earthworm concentration present increases exponentially. Once the rice residue concentration tapers off and reaches approximately zero within 25 days, the earthworm concentration begins to decrease over the time. It is imperative to note that the earthworm concentration is assumed to be one-tenth (1/10) of the concentration of rice residue at the start.



GRAPH 1: Inter-relationship of the Model Parameters.

Although vermicomposting approximates as a continuously stirred tank reactor (CSTR) in which the contents are mixed and aerated, the reactor is unique in design and operation. The earthworms in the vermireactors function as ‘reactors within reactors’ in the sense that the entire processing of the substrate from the reactant to the product occurs within each worm. Thus, an integral part of the reactor design is to understand and model the earthworms as a separate reactor units inside the vermireactor. (Abbasi et al 2008)

The digestive tract of the earthworm extends the whole length of its body as a long tube, which starts from the mouth and ends at the anus (Edwards and Bohlen 1996). The tubular gut of earthworm is assumed to be a plug flow reactor (PFR) possessing an input and output (Figure 3). The entering food particles via mouth move at a constant rate (steady state) with perfect radial mixing and the digestion proceeds according to first-order kinetics (Levenspiel 1999).

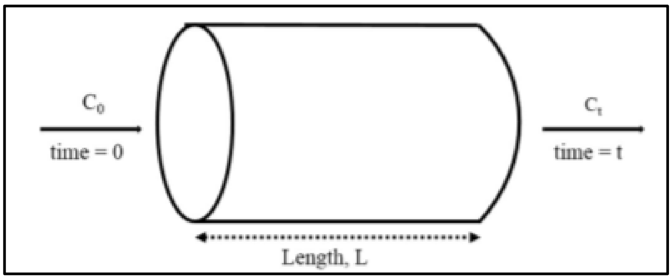


FIGURE 3: Diagrammatic representation of a plug-flow reactor showing an input and output

Considering each earthworm as a PFR, we can express the first order kinetics based on the following general-mass balance equation,

Accumulation = Input − Output + Generation – Consumption

The general equation expressing rate (r) at which mass or volume of a material C changes with time along the gut of earthworm can be given as below:

$$\textbf{Rate} = \frac{dC}{dt} = -\textbf{kt}$$

where C is the concentration of the reacting substance, per unit time t and k is the first-order rate constant. This general equation can be integrated within the limits of concentration C_0 and C_t at the time t=0 and t, respectively, to give:

$$\int_{C0}^{Ct} \frac{dC}{C} = -k \int_{0}^{t} dt$$

Upon integration,

$$\ln[C]t - \ln[C]0 = -k\,t$$

From the laws of algorithm, equation 3:

$$\ln\frac{[C]0}{[C]t} = -k\,t$$

The linear pattern of digestion kinetics observed by Kiyasudeen et. al 2018 (figure 4) provides ample evidence that the earthworm gut can be modeled as a PFR. The kinetic result demonstrated that the gut sections expressed a linear pattern of digestion, thus, supporting PFR behavior. However, an evident deviation in the foregut region was also identified. The deviation could be due to the activity of digestive organs such as gizzard and crop in the pre-intestine region, which are known to enhance the surface area for the microbes apart from their role of enzymatic secretions (Hickman 2005).

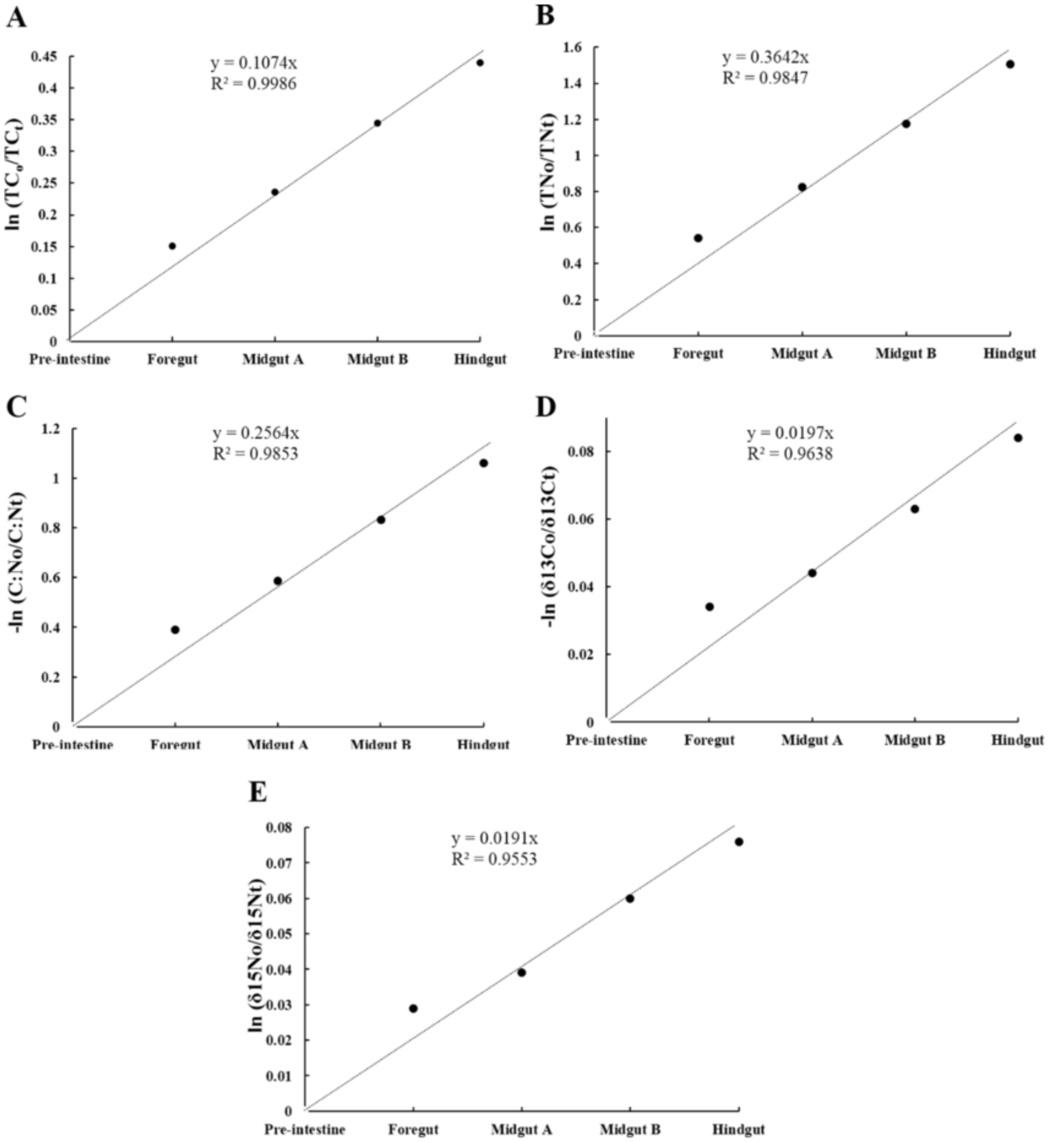


FIGURE 4: Digestion kinetics (first-order) of total carbon (a), total nitrogen (b), C/N (c), δC^{13} (d), and δN^{15} (e) during gut transit in earthworms calculated using equation 3.

V. FACTORS AFFECTING VERMICOMPOSTING

The most important factors which affect vermicomposting process include moisture, pH, temperature, aeration, pH value, ammonia and salt content.

5.1 Moisture

A strong relationship exists between the moisture content of organic wastes and the growth rate of earthworms. A study on vermicomposting process and earthworm’s growth at different temperature and moisture ranges showed that 65–75% is most suitable range of moisture at all ranges of vermicomposting temperature (Suthar S. 2007). The bedding material for vermicomposting must be able to hold enough moisture as earthworms respire through their skins and moisture content less than of 45% can be fatal to the worms.

Although epigenic species, E. fetida and E. andrei can survive moisture ranges between 50% and 90%, they grow most rapidly between 80% and 90% (Edwards et al 1988). The bacteria also plays vital role in vermicomposting. Its activity decreases in moisture content lower than 40% and it almost stops in lower than 10% (Tchobanoglous et al 1993)

5.2 Temperature

Earthworm activity, metabolism, growth, respiration, and reproduction are greatly influenced by temperature (Edwards et al 1996). The temperature for the stable development of earthworm population should not exceed 25°C (Sinha et al 2008). Although E. fetida cocoons survive extended periods of deep freezing and remain viable, they do not reproduce and do not consume sufficient food at single digit temperatures. It is generally considered necessary to keep the temperatures preferably 15°C for vermicomposting efficiency and 20°C for effective reproductive vermiculture operations. Temperatures above 35°C will cause the worms to leave the area or if they cannot leave, they will quickly die. Bacterial activity is also greatly depended on temperature as it multiplies by two per each 10°C increase in temperature and is quite active around 15–30°C.

5.3 Aeration

Earthworms are oxygen breathers and cannot survive in anaerobic conditions. They operate best when compost material is porous and well aerated. Earthworms also help themselves by aerating their bedding by their movement through it. E. fetida have been reported to migrate in high numbers from oxygen depleted water saturated substrate, or in which carbon dioxide or hydrogen sulfide has accumulated.

5.4 pH value

The pH value is also one of the important factors affecting the vermicomposting process (Gajalakshmi et al 2004). Epigenic worms can survive in a pH range of 5–9 (Edwards, 1998). The pH of worm beds tends to drop over time. If the food source/ bedding is alkaline, than pH of bed drop to neutral or slightly alkaline and if the food source is acidic than the pH of the beds can drop well below 7. The pH can be adjusted upwards by adding calcium carbonate or peat moss for adjusting pH downward can be introduced into the mix. Although microorganisms which are active in vermicomposting which can maintain their activity even in lower pH of around 4 but recommended pH range for compost is around 6.5–7.5.

5.5 Ammonia and salt content

Earthworms cannot survive in organic wastes containing high levels of ammonia. Worms are also very sensitive to salts and they prefer salt contents less than 0.5% (Edwards et al 2002). However, many types of manures have high salt contents and if they are to be used as bedding, they should be leached first to reduce the salt content, it is done by simply running water through the material for a period of time.

VI. COMMERCIALIZING VERMICOMPOSTING

In light of the pollution issues, government agencies and farmers are seeking new ways to manage and utilize agricultural wastes to beneficial use. Despite claims that rice residues are agricultural wastes, they are rich in silica plant material and are potential sources of plant nutrients (Mandal et al. 2004; Kadam et al. 2000)

As compared to utilizing rice residues as fuel for energy generation through burning, vermicomposting promotes reuse and bio-transformation of organic waste into organic fertilizer, which helps contribute significantly towards sustainable agricultural practices (Yan et al. 2012)

The vermicomposting process has emerged as an environmentally friendly waste management method as well as an attractive alternative to chemical fertilizers by converting organic detritus into high-quality organic fertilizers. Generally, vermicomposting can accelerate the stabilization process of organic materials through the joint action of earthworms and microorganisms (Sim and Wu 2010).

The proposed system can be divided into four main categories and follows the flow diagram as shown below.

1. Collection of Rice Residue
2. Transport
3. Vermicomposting
4. Packing

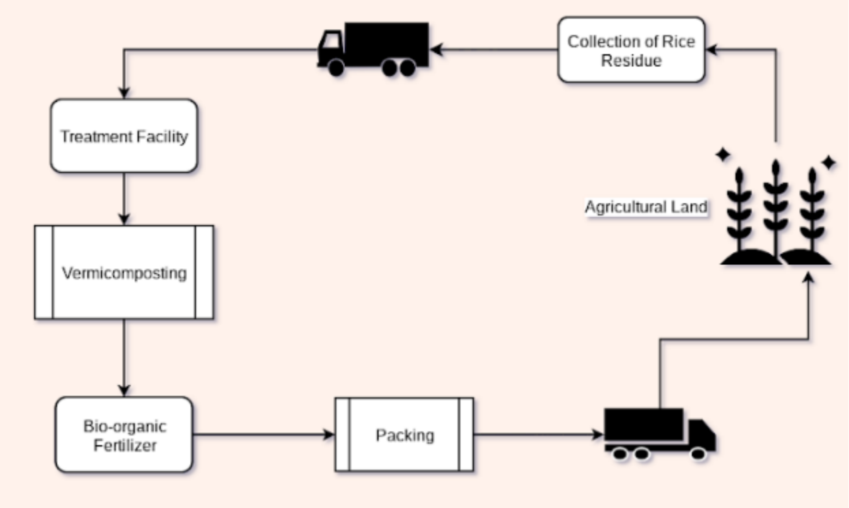


FIGURE 5: Process Flow diagram showing the schematics of the proposed solution.

VII. DISCUSSION AND RECOMMENDATIONS

Increasing generation of solid waste, whether from domestic, agricultural, or industrial sources, has created serious environmental threats. This excessive waste must be recycled and re-incorporated into production processes by using vermicomposting technology. Vermicomposting can transform waste into a form of biofertilizer, which is easily stored, handled, and used in agriculture, providing a vital step toward sustainable organic farming. Vermicomposting is an integrated approach that can be used effectively to improve soil health and crop productivity, to treat wastewater, and to produce energy. It provides favorable conditions for microbes and earthworms to interact and convert waste into biofertilizer. It is suggested as a sustainable technology for waste management, and it can lead to zero waste production. It can also reduce groundwater contamination and the toxicity of soils and plants by removing harmful chemicals.

As a non-homogenous and multiphase reaction system, vermicomposting can not be mathematically modeled. Modeling the vermireactor as a simple CSTR based on assumptions of a homogenous reaction is theoretically incorrect, however it does provide a simple insight into the operation of the reactor as a whole. Earthworm's gut has been modeled as a PFR successfully based on the experimental data by Kiyasudeen et al. Essentially one can argue that the vermireactor is a combination of multiple small PFR systems operating in series. It is recommended that with further research and experimentation, a more practical model for the system can be developed.

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